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Harmonic Mitigation Techniques for Non-Linear Loads: An Organized Investigation

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***Abstract*—This paper describes various harmonic mitigation techniques for non-linear loads, which are available to solve harmonic problems in power system. A detailed description with classification of the harmonic mitigation techniques have been made, based on distinguish features like reliability, power factor no/full load, current distortion, load influence, total harmonic distortion (THD), influence variable speed drive (VSD), and cost efficiency. The paper describes banes and boons of harmonic mitigation methods and their mathematical equations. The best mitigation outcome can be achieved by exploiting the methods using its expressions. This paper also helps to decide which harmonic mitigation methods for non-linear load should be used according to the different conditions.**

Keyword-Power quality, Point of common coupling, Non-linear loads, Harmonic filters

I. INTRODUCTION

In recent years both consumers and power engineers have stated concentrating on the '*electrical power quality*' *i.e.* disgrace of current and voltage appropriate to harmonic, low power factor *etc.* [1]. The established electric power distribution system belongs to radial and direction of circulating power is from grid towards consumer. The transmission of power generated from newly set small power station (by using transmission network) is not faceable due to the transition losses, service cost on transmission line and other related issues. This small power station inject active and reactive power to the existing network, badly disturbing the flow of power, hence injecting harmonic in the system at the point of common coupling (PCC) [2].

PCC is the point where two modules or other in one or more direction are coupled at; in unit testing terminology this correction between the modules is called a seam (like a swing). The harmonic injection at PCC due to an undeviating grid link of small power stations to the accessible large electric power system is identified [3]. This paper presents study on harmonic mitigation techniques, which are categorized into three types *i.e.* passive technique, active technique and hybrid harmonic reduction technique using active and passive methods. Fig. 1 shows a succinct explanation of mitigation methods with two typical harmonic mitigation techniques [4-6].

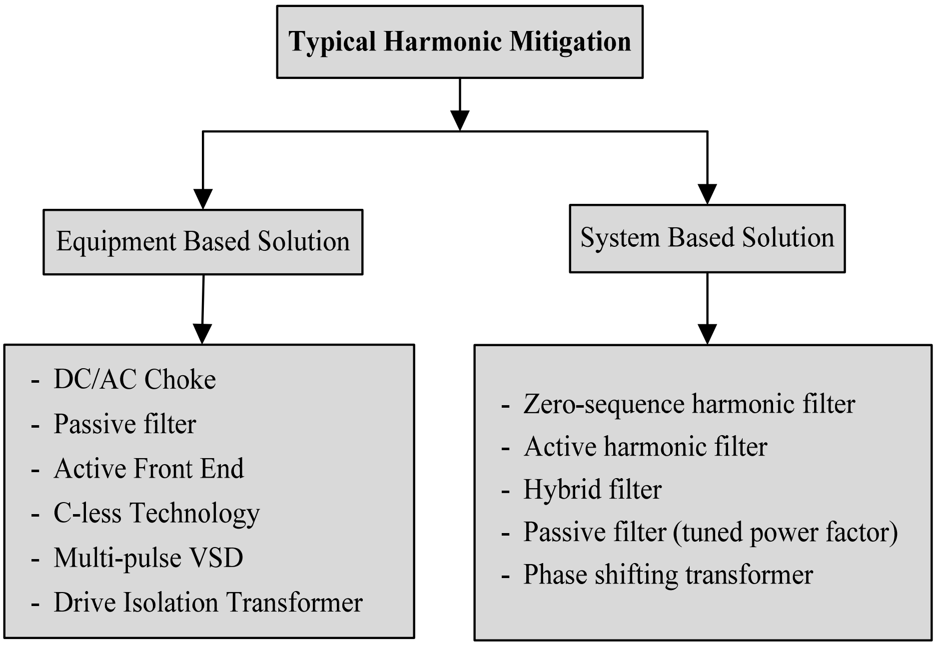

Fig. 1. Types of harmonic mitigation

A detailed description of the electrical characteristics in each method is presented with two typical harmonic mitigation techniques, equipment based solution and system based solution [7].

The Harmonic mitigation methods are explained with their main features including their banes and boons.

II. Impact of PCC Voltage Error of Non-Linear Load

The current harmonic is infrequently, when the 3rd harmonic produces overheating in the three-phase feeder's neutral conductor. The difficulty occurs when a higher-order current harmonic is resonant with capacitors and system reactance generates excessive voltage at the PCC [8]. Significant progress in power electronics had raised the interest in active power filters for harmonic mitigation. Active power filter (APF) performances are self-regulating of the power distribution system properties. Fig. 2 shows the process of harmonic suppression operation in active power filter.

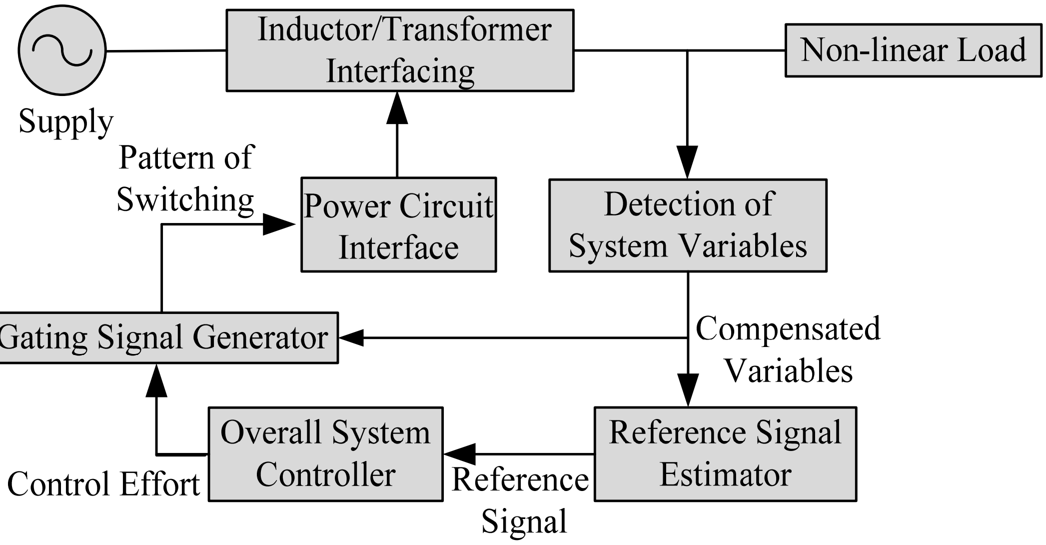

Fig. 2. The process of harmonic suppression operation in active power filter

Signal conditioning refers to the concealment and sensing of harmonic in power distribution line. The reference signal estimation is initiated through the concealment of critical voltage or current signals sensed by potential transformer, current transformer *etc*. The subsequent stage is the source of compensating signal from the disruptive signal consists of both fundamental wave and harmonic content. The third stage is generating of gating signal for harmonic control techniques like space vector pulse width modulation (PWM) repetitive control, fuzzy control *etc*. have been introduced and applied to various configuration of active power filter [9].

A. Harmonic Mitigation filter for Non-linear load

A possible location for a harmonic filter in a typical distribution system is shown in Fig. 3. The service is modeled as a source with impedance consisting of line resistance and line inductance. The resulting voltage (typical 480 volts line-to-line in three-phase system) drives non-linear loads such as motor and other equipments [10]. The system presents high-quality voltage to the load and the load doesn't illustrate excessively high harmonic current from the utility.

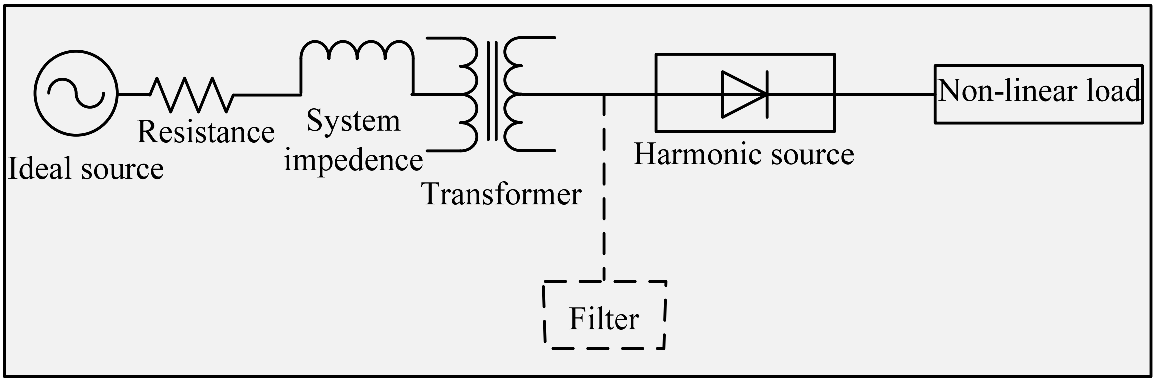

Fig. 3. A possible location for a harmonic filter in a typical distribution system

Several of the goals of IEEE standard 519 are that the utility presents good quality voltage to the load, and the load doesn't draw overly high harmonic currents from the utility. Several methods in the upcoming section by the consequence of harmonic current can be mitigated [11].

B. Methods of Harmonic Mitigation Techniques

Any combination of passive (R, L, C) and active (transistors, op-amps *etc.*) elements designed to select or reject a band of frequencies is called a filter. Filters are used to filter out any unwanted frequencies due to non-linear characteristics of some electronic devices or signals picked up by the surrounding medium. Fig. 4 shows the detailed comparison of harmonic mitigation techniques [12].

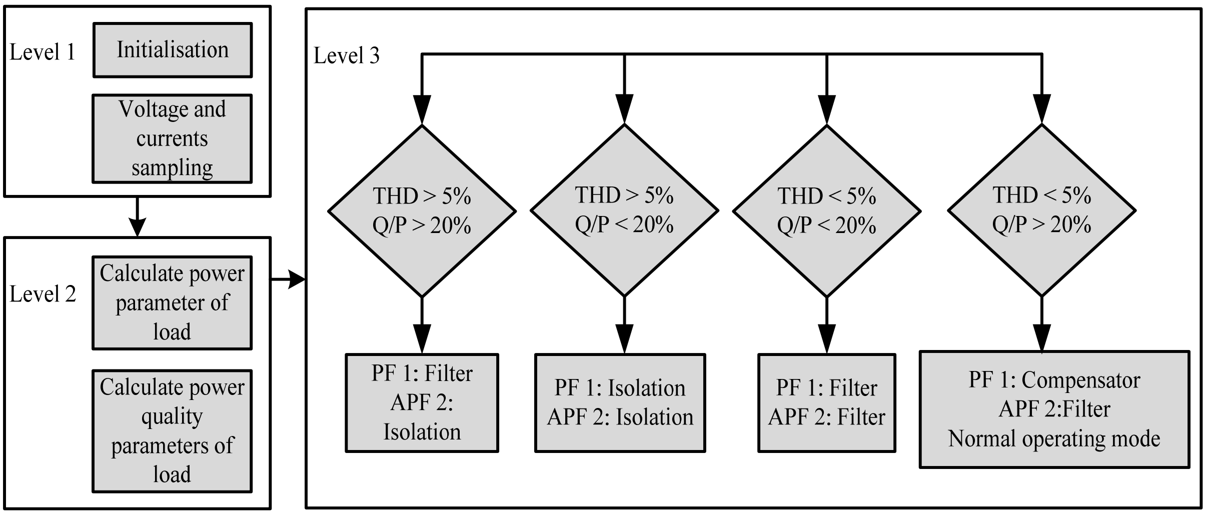

Fig. 4. Flow Chart Compares Mitigation Techniques

APF and PF measuring device provide instantaneous and average information concerning harmonic. Instantaneous values are used for investigation of instability linked to harmonic [13-15].

C. Methods of Harmonic Mitigation

There are many ways to reduce harmonics ranging from variable frequency drive designs to the addition of auxiliary equipment. This paper describes harmonic mitigation methods for non-linear load used according to the different conditions, THD reduction expressions and applications as shows in Table I.

TABLE I

Methods of Harmonic Mitigation

Methods	Harmonic mitigation techniques	Description	Applications	THD Reduction Expressions
A	DC/AC choke	AC/DC choke is transition state from initial position to final position *i.e.* zero to *V* (volt) or *V* or *vice versa*	A choke is an inductor used to obstruct higher frequency alternating current (AC) in an electrical circuit, while transient lower frequency or direct current (DC) [16]	$L=\frac{d_0}{d_i}$
B	C-less	C-less is filters resonance angular frequency, which is inversely proportional to the inductance capacitance [17]	This branch is tuned to the fundamental harmonic frequency [18]	$\omega_r = n_r\omega = \frac{1}{\sqrt{L\frac{C_1C_2}{C_1+C_2}}}$
C	Passive filter (tuned power factor correction)	Passive filter is based on the assumption that the resonance frequency is directly proportional to the series inductance and a line resistance [25]	Passive tuned filter consist of reactors and resonant circuit arrangement tuned to the frequency of the harmonic order to be eliminated [36]	$F_r = \frac{1}{1+S\frac{L}{R}+LCS^2}$
D	Multi-pulse transformer	A 12-pulse rectifier system, annulment of the 5th and 7th harmonic can be achieved on the primary side of the transformers to the degree that these currents are balanced in each of the transformer secondary windings [19]	Multi-pulse transformer methods have also been used to decrease facility harmonic distortion [39]	$h = 12n * p \pm 1$
E	Active front end	Active front end filter is the filters supply current is propositional to the input filter inductance and resistances [26]	The Active front end, regenerative braking technology helps reduce operating costs by reusing motor braking energy rather than wasting it as heat	$\frac{di_s}{dt} = \frac{1}{L_f}\left(\vec{V_s} - \vec{V_R} - R_f i\right.$

F		Zero-sequence harmonic	Zero-sequence harmonics reduces neutral current and neutral-to-ground voltage as well as both current and voltage triple harmonic alteration [27]	Reduces neutral current and neutral-to-ground voltage as well as both current and voltage triplen harmonic distortion [37]	$\left(Z_1 = R, Z_2 = R, Z_0 = \infty\right.$
G		Phase shifting transformer	Phase shifting transformer is the mitigating transformers require equal and opposite magnitudes of harmonic for complete cancellation [23]	Reduce 5th and 7th or 11th and 13th harmonic currents at point of common coupling which, in turn, reduces voltage distortion as well [38]	$PF_{tot} = F_d * F_{dist}$
H		Drive isolation transformer	Drive isolation transformer which is based the electrical system requires a drive transformer to determine the KVA rating [24]	Use of delta-wye transformers for half of the drives to provides 30^0 phase shift can provide substantial reduction in THD isolation transformer can also provide isolation of ground faults if delta-wye unit is used	$KVA = \frac{1.732 \times V_{L-L} \times V}{1000}$
I		Passive filter	Passive filter is the resonance frequency of passive filter which is inversely propositional to inductance and capacitance [20]	Passive filters are series capacitor and reactor resonant circuits 'tuned' to present a high impedance path to the fundamental frequency and low impedance path to higher particular frequency (*i.e.* 5th - 250Hz, 7th - 350Hz)	$F_r = \frac{1}{2\pi \sqrt{LC}}$
J		Active filter	Shunt-connected active filters (*i.e.* parallel with the non-linear load) as shown in figure (5) given the process of harmonics suppression operation in active power filter [21]	Active filter is relatively common in industrial applications for both harmonic mitigation and reactive power compensation (*i.e.*, electronic power factor correction) [27]	$A_v = \frac{A_{max}(f / f_c)}{\sqrt{\{1+(f/fc)^2\}}}$
K		Hybrid filter	The best economical and technical solution often is achieved by hybrid solutions.. Harmonic reduction and power compensation is common between a passive filter and a modest active filter [22]	By combining various mitigation methods, improve the overall power quality while controlling costs and reducing the time to payback. Hybrid filter is based on the harmonic reduction and reactive power compensation [28]	$I_{sh} = \frac{Z_{sh}}{(Z_{fh} + Z_{sh})}$

A majority of large power (typically three-phase) electrical non-linear paraphernalia often requires mitigation equipment to attenuate the harmonic currents and associated voltage distortion within necessary limits [29].

D. Hybrid Harmonic filter

With the increasing use of non-linear apparatus either for residential or industrial applications, the power distribution system is contaminated with harmonics. Thus, filters are very much essentials for the harmonic compensation and improving the power quality and hence increase the consistency of the distribution system [30-31]. The common Hybrid active power filter (HAPF) is obtained by connecting PF and APF as shown in Fig. 5.

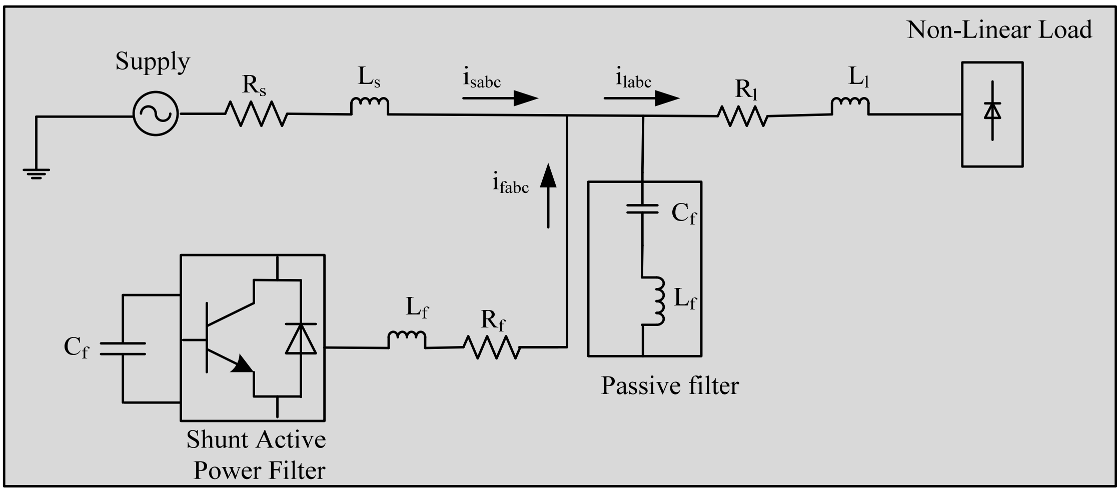

Fig. 5. Hybrid active power filter topology

HAPF topology is the connection between passive filters and active power filter. HAPF consist of resistance, inductance in series connected with non-linear load. It consists of shunt active power filters and a passive filter through which current in flowing in the direction of non-linear load. The proposed hybrid passive harmonic filter (HPHF) overcomes shortcomings of conventional SPF techniques by analysis of SPF under different filter concert parameters such as quality factor, tuning factor, current absorption factor and key performance factors are the total voltage and current harmonic distortion for scrutiny [32-35].

III. Comparison of Harmonic Mitigation Techniques

With the increasing use of non-linear loads in the power systems, harmonic mitigation techniques become even more important. Harmonic mitigation techniques are compares at different parameters like approximate costs, current distortion, efficiency, reliability, power factor no/full load, current distortion, load influence THD, influence VSD and typical performance of various solutions for harmonic mitigation as presented in Table II [40-43].

TABLE II
Comparison of Harmonic Mitigation Alternatives

Mitigation Solution	Standard parameter value	Choke	C-Less	Passive filter (TPFC)	Multi Pulse	Active Front End	Active Filter	Drive Isolation Transformer	Zero Sequence Harmonic	Phase Shifting Transformer	Passive Filter	Hybrid Filter
Current Distortion (%)	>80	<48	<30	<(5-16)	<(5-10)	<5	<5	-	<173	-	<5	<(3-5)
Drop Voltage	N	Y	N	N	N	N	N	Y	Y	Y	N	N
PF No/Full Load	<0.8	<0.75-0.95	0.95	0.75-1	0.90	1	1	1	-	-	1	1
Load Influence THD	N	Y	N	Y	N	N	N	Y	Y	Y	N	N
Efficiency	100	97	100	98	96	96	96	35	50-100	80-100	96	96
Reliability	H	H	M	M	M	M	M	M	M	M	M	H
EMC	S	S	M	S	S	M	M	S	S	S	M	M
Influence VSD	N	N	N	N	N	N	N	Y	Y	Y	N	N
Resonance Risk	N	N	N	Y	N	N	N	N	Y	Y	N	N
Cost Efficiency	H	S	M	M	H	M	S	M	H	M	M	M
Price Ratio Drive Cost (%)	100	110-120	150-200	95	200-250	250	250	75+	100	100	250	250
Foot Print Ratio On/Drive (%)	100	120	200	100	350	150-200	300-500	100-118	-	-	300-500	300-500

Here N, Y, H, M, S belongs to no, yes, high, medium, and small respectively. Hybrid solution is the best option; *i.e.* combining filters with other technologies. In this paper, passive, active and hybrid solutions are presented, showing banes and boons.

IV. Banes and boons of Different Techniques in Harmonic Mitigation

Mitigating the power system harmonic represents a great importance in the non-linear loads applications in order to enhance system reliability, enhance THD, avoid unwanted paraphernalia breakdown and cost efficiency. Table III shows banes and boons of harmonic mitigation techniques [44-48].

TABLE III
Banes and boons of various techniques of harmonic mitigation

S. No.	Filters	Banes	Boons
1	DC/AC Chokes	• Most cost effective solution (0-20) % of drive cost • Reduce THD around (30-50) % • Line chokes protects the drive front end, limits voltages spikes and short circuit current	• Bulky and heavy • Proper ventilation • Depending on load condition, might not be able to meet standard requirements • Voltage drop (>5%) can affect low line supply conditions. Lower torque performance at full speed when voltage drop is higher
2	C-Less	• Reduces THD below 35% without added filter • Lowest cost for harmonic mitigation	• Only for fan, pump and non demanding applications (HVAC) high voltage alternative current • More DC bus ripples so more torque ripple • More sensitive to network voltages drop and perturbation
3	Passive Filter (Tuned power factor correction)	• Able to reduce THD to around 5% • Line chokes protects the drive front end, limits voltages spikes and short circuit current	• Bulky and heavy • Expensive [(50-80) % drive cost] • Designed to full load capacity to obtain effective impedance • Filter capacitor (passive filter) must be disconnected when VSD operates at no load or low load condition (causing leading PF and voltages regulation concern is remain connected)
4	Multi-Pulse	• Reduces THD down to (10-15) % (12 Pulse), (5-3) % (18 Pulse) • Suppresses line voltage transients • Efficient on the all load range	• Very bulky and heavy • Expensive (100 % drive cost) • Needs 2 or 3 diodes bridge rectifier • Needs specific transformer windings • More cost effective for high power VSD (>100kW)
5	Active Front End	• Nearly sinus supply (THD <5%) • Reversible, allow to feedback energy onto the network • Can be embedded in the drive	• Very expensive if reversibility not needed (150% drive cost) • Need addition EMC filter • Reliability (IGBT, more components)
6	Zero Sequence Harmonic	• Installed close to the non-linear current	• Proper ventilation and bulky
7	Phase Shifting Transformer	• Protects the drive front end, limits voltage spikes and short circuit current • Trap triplen harmonic order in delta windings • Attenuation of 5th and 7th harmonic current with an angular displacement of 30°	• Bulky, heavy • Expensive (100% drive cost) • Both transformers (same rating) have to be loaded equally to achieve optimum harmonic attenuation • Transformer must be able to withstand excessive heat due to harmonic current
8	Drive Isolation Transformer	• Trap triplen harmonic order in delta windings (zero-sequence network) • Protects the drive front end, limits voltage spikes and short circuit current • Reduce common-mode noise, induced ground current, impulse from either both sides	• Bulky and heavy • Expensive (50-80% drive cost) • Cannot completely isolate the harmonics (positive-sequence network)
9	Active Filter	• Reduces THD Below 5% • Several units can be installed on the same supply • Global solutions • Resonance elimination • Corrects displacement power factor	• Expensive (150% drive cost) • Reliability (more components) • CT direction and location must be correct
10	Hybrid Filter	• Reduces THD Below (3-5) % • Almost every working occasion can be comfortable • Give more flexibility and reliability to power device	• Reduced power factor and reduced system capacity • Random tripping of circuit breakers

V. CONCLUSION

This paper analyzed and summarized the banes and boons of harmonic mitigation methods. In this manner, the greatest mitigation outcome can be achieved by exploiting the merits of each method. Hybrid filters are proficient at sufficient amount to confiscate harmonic content of non-linear loads, it was proven beyond doubt by many researches in their footsteps, and further extension of filtering process is done using new topology of harmonic mitigation techniques. The aim of this paper is to study recent developments in these areas and present a systematic review on harmonic mitigation technologies and strategies that could be used to develop the power quality in non-linear load.

NOMENCLATURE

P	Number of pulse per cycle	Z_1	Positive sequence
n	Integer 1, 2, 3…..	Z_2	Negative sequence
ω	Angular frequency	Z_0	Zero sequence impedance
ω_r	Resonance angular frequency	R_S	Source resistance,
n_r	Resonance number	R_f	Filter resistance
F_r	Resonance frequency	C_f	Filter capacitance
A_v	Voltage gain	L_S	Source inductance
$Amax$	Maximum gain	R_l	load resistance
F	Frequency	L_l	load inductance
f_c	Carrier frequency	L	Inductance
I_{sh}	Source harmonic current	do/di	Variation of flux with current
Z_{fh}	Filter harmonic impedance	$\overrightarrow{v_S}$	Source voltage vector
Z_{sh}	Source harmonic impedance	$\vec{i_s}$	Input currents of space vector
PF_{tot}	Total power factor	H	Order of generated harmonics
F_d	Displacement factor	C_1 and C_2	Capacitance in series and parallel
F_{dist}	Distortion factor	$VFDi$-	Variable frequency drive of current ampere
V_{L-L}	Line to line voltage	dis/dt	Rate of change of source current
L_f	Input filter inductance	KVA	Kilovolt-ampere
R_f	Filter resistance	$HVAC$	High voltage alternative current

REFERENCES

[1] H. A. Kazem, "*Harmonic mitigation techniques applied to power distribution networks*," Advances in Power Electronics, vol. 7, no. 8, pp. 1-10, 2013.

[2] M. Bollen, H. Amaris, A. M. Blanco, A. G. De Castro, J. Desmet, M. Klatt, L. Kocewiak, S. Rönnberg and K. Yang, "*Future work on harmonics – some expert opinions part i – wind and solar power*," 16th International Conference on Harmonics and Quality of Power, vol. 7, no. 4, pp. 904-908, 2013.

[3] R. Zahira and A. P. Fathima, "*A technical survey on control strategies of active filter for harmonic suppression*," International Conference on Communication Technology and System Design, Chennai, vol. 3, no. 2, pp. 686-693, 2011.

[4] T. Lee and S. Hu, "*An active filter with resonant current control to suppress harmonic resonance in a distribution power system*," IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 4, no. 6, pp. 198-209, 2015.

[5] L. H. Tey, "*Improvement of power quality using adaptive shunt active filter*," IEEE Transaction on Power Delivery, vol. 20, no. 2, pp. 482-490, 2005.

[6] A. Memon, "*Harmonics mitigation of industrial power system using passive filters*," Mehran University Research Journal of Engineering & Technology, vol. 31, no. 2, pp. 355-360, 2016.

[7] B. Singh, K. Al-Haddad and A. Chandra, "*A review of active filters for power quality improvement*," IEEE Transaction Industry Electronic, vol. 46, no. 5, pp. 960-971, 2012.

[8] Y. S. Cho and H. Cha, "*Single-tuned passive harmonic filter design considering variances of tuning and quality factor*," Journal of International Council on Electrical Engineering, vol. 1, no. 1, pp. 7-13, 2011.

[9] P. Salmeron and S. P. Litran, "*Improvement of the electric power quality using series active and shunt passive filters*," IEEE Transactions on Power Delivery, vo1. 25, no. 2, pp. 1058-1067, 2010.

[10] S. Bai and S. M. Lukic, "*Unified active filter and energy storage system for an mw electric vehicle charging station*," IEEE Transactions on Power Electronics, vol. 28, no. 12, pp. 5793-5803, 2013.

[11] L. Ciufu and M. O. Popescu, "*Experimental stand for studying the impact of modern electrical drives on asynchronous motors*," Electrotehnica Electronica Automatica, vol. 64, no. 4, pp. 59-65, 2016.

[12] A. A. M. Zin, A. Naderipour and J. Tavalaei, "*Control active power filter for improving power quality in the micro-grid*," International Journal of Engineering research and technology vol. 2, no. 8, pp. 2249-2253, 2013.

[13] K. P. Panda and S. K. Mohapatra, "*Anti-predatory PSO technique-based solutions for selected harmonic elimination in cascaded multilevel inverters*," International Journal of Industrial Electronics and Drives, vol. 3, no. 2, pp.78–88, 2016

[14] S. Bai and S. M. Lukic, "*Unified active filter and energy storage system for an mw electric vehicle charging station*," IEEE Transactions on Power Electronics, vol. 28, no. 12, pp. 5793-5803, 2013.

[15] S. Bai and S. M. Lukic, "*New method to achieve ac harmonic elimination and energy storage integration for 12-pulse diode rectifiers*," IEEE Transactions on Industrial Electronics, vol. 60, no. 7, pp. 2547-2554, 2013.

[16] A. K. Khan, "*Monitoring power for the future*," IEE Power Engineering Journal, vol. 15, no. 2, pp. 81–85, 2001.

[17] F. Zhao, L. Wang, X. M. Zhou, T. Suo and S. N. Luo, "*Novel injection type hybrid active power filter and its energy saving application*," Third International Conference on Measuring Technology & Mechatronics Automation, vol. 2, no. 3, pp. 694-700, 2011.

[18] A. F. Zobaa, M. M. A. Aziz and S. H. E. A. Aleem, "*Comparison of shunt-passive and series-passive filters for dc drive loads*," Electric Power Components and Systems, vol. 38, no. 3, pp. 275-291, 2010.

[19] A. Hamadi, S. Rahmani, and K. Al-Haddad, "*A hybrid passive filter configuration for var control and harmonic compensation*," IEEE Transaction on Industrial Electronics, vol. 57, no. 7, pp. 2419-2434, 2010.

[20] Z. A. Memon, M. A. Uqaili and M. A. Soomro, "*Experimental analysis of harmonic mittigation efforts of three-phase six- pulse controller by using passive filters*," Mehran University Research Journal of Engineering & Technology, vol. 30, no. 4, pp. 653-656, 2011.

[21] S. Khalid and B. Dwivedi, "A Review of State of Art Techniques in Active Power Filters and Reactive Power Compensation," National Journal of Technology, vol. 3, no. 1, pp.10-18, 2007.

[22] J. C. Das, "*Passive filters-potentialities and limitations*," IEEE Transactions on Industry Applications, vol. 40, no.1, pp. 232-241, 2004.

[23] G. W. Chang, H. L. Wang and S.Y. Chou, "Strategic Placement and Sizing of Passive Filters in a Power System for Controlling Voltage Distortion," IEEE Transactions on Power Delivery, vol. 19, no. 3, pp. 1204-1211, 2004.

[24] G. Carpinelli, F. Iacovone, P. Varilone and P. Verde, "*Single phase voltage source converters: analytical modelling for harmonic analysis in continuous and discontinuous current conditions*," International Journal of Power and Energy Systems, vol. 23, no. 1, pp. 37-48, 2003.

[25] B. Singh, B. N. Singh, A. Chandra, K. Al-Haddad, A. Pandey, and D. P. Kothari, "*A review of three-phase improved power quality AC-DC converters*," IEEE Transactions on Industrial Electronics, vol. 51, no. 3, pp. 641-660, 2004.

[26] S. Peeran, T. Barclay, K. Sanborn, R. S. Carolsfeld, and M. Shields, "Fault analysis through power quality metering," *IEEE Industry Applications Magazine*, vol. 5, no. 2, pp. 28–31, 1999.

[27] V. G. Agelidis, "*A five-level symmetrically defined selective harmonic elimination PWM strategy: Analysis and experimental validation*," IEEE Transactions on Power Electronics, vol 23, no. 1, pp 19–26, 2008.

[28] I. Hunter, "*Power quality issues-a distribution company perspective*," IEEE Power Engineering Journal, vol. 15, no. 2, pp. 75-80, 2001.

[29] V. F. Corasaniti, M. B. Barbieri, P. B. Arnera and M. I. Valla, "*Hybrid power filter to enhance power quality in a medium voltage distribution network*," IEEE Transaction on Industrial Electronics, vol. 56, no. 8, pp. 2885-2893, 2009.

[30] C. Sharmeela, M. R. Mohan, G. Uma, and J. Baskarane, "*Fuzzy Logic Controller Based Three-Phase Shunt Active Filter for Line Harmonics Reduction*," Anna University, vol. 3, no. 2, pp. 76- 80, 2007.

[31] D. Alexa, A. Sirbu, and D. M. Dobrea, "*An analysis of three-phase rectifiers with near-sinusoidal input currents*," IEEE Transactions on Industrial Electronics, vol. 51, no. 4, pp. 884-891, 2004.

[32] J. R. Johnson, "*Proper use of active harmonics filters to benefit pulp and paper mills*," IEEE Transactions on Industry Applications, vol. 38, no. 3, pp. 719-725, 2002.

[33] D. Li, Q. Chen, Z. Jia, and J. Ke, "*A novel active power filter with fundamental magnetic flux compensation*," IEEE Transactions on Power Delivery, vol. 19, no. 2, pp. 799–805, 2004.

[34] Z. Du, L. M. Tolbert, and J. N. Chiasson, "*Active harmonic elimination for multilevel converters*," IEEE Transactions on Power Electronics, vol. 21, no. 2, pp. 459-469, 2006.

[35] G. W. Chang and T. C. Shee, "*A novel reference compensation current strategy for shunt active power filter control*," IEEE Transactions on Power Delivery, vol. 19, no. 4, pp. 1751-1758, 2004.

[36] D. Basic, V. S. Ramsden, and P. K. Muttik, "*Hybrid filter control system with adaptive filters for selective elimination of harmonics and interharmonics*," IEEE Proceedings: Electric Power Applications, vol. 147, no. 4, pp. 295-303, 2000.

[37] S. Senini and P. J. Wolfs, "*Hybrid active filter for harmonically unbalanced three phase three wire railway traction loads*," IEEE Transactions on Power Electronics, vol. 15, no. 4, pp. 702-710, 2000.

[38] P. Salmeron, J. C. Montano, J. R. Vazquez, J. Prieto, and A. Perez, "*Compensation in non sinusoidal, unbalanced three-phase four-wire systems with active power-line conditioner*," IEEE Transactions on Power Delivery, vol. 19, no. 4, pp. 1968-1974, 2004.

[39] X. Zha and Y. Chen, "*The iterative learning control strategy for hybrid active filter to dampen harmonic resonance in industrial power system*," Proceedings of the IEEE International Symposium on Industrial Electronics, vol. 2, no. 3, pp. 848-853, 2003.

[40] A. Choudhary and P. Gaur, "*Current control strategies for active filter for harmonics mitigation*," International Journal of Innovation and Scientific Research. vol. 10, no.1, pp. 27-34, 2014.

[41] Z. Salam, T. P. Cheng and A. Jusoh, "*Harmonics mitigation using active power filter: a technological review*," Elektrika Journal of Electrical Engineering, vol. 8, no. 2, pp. 17-26, 2006.

[42] X. Peng, K. A. Corzine, and G. K. Venayagamoorthy, "*Multiple reference frame-based control of three-phase pwm boost rectifiers under unbalanced and distorted input conditions*," IEEE Transactions on Power Electronics, vol. 23, no. 4, pp. 1-13, 2008.

[43] F. Blaabjerg, R. Teodorescu, M. Liserre and A.V. Timbus, "*Overview of control and grid synchronization for distributed power generation systems*," IEEE Transactions on Industrial Electronics, vol. 53, no. 5, pp. 1398-1409, 2006.

[44] P. Kumar and A. Mahajan, "*Soft computing techniques for the control of an active power filter*," IEEE Transactions on Power Delivery, vol. 24, no. 1, pp. 452-461, 2009.

[45] P. K. Sadhu, G. Sarkar and A. Rakshit, "*A microcontroller based variable voltage variable frequency sinusoidal power source with a novel pwm generation strategy,*" Measurement – Elsevier, vol. 45, no. 1, pp. 59-67, 2012.

[46] I. Colak and E. Kabalci, "*Developing a novel sinusoidal pulse width modulation (spwm) technique to eliminate side band harmonics*," International Journal of Electrical Power & Energy System- Elsevier, vol. 44, no. 3, pp. 861-871, 2013.

[47] A. M. Al-Zamil and David A. Torrey, "*A passive series, active shunt filter for high power applications*," IEEE Transactions on Power Electronics, vol. 16, no. 1, 2001.

[48] O. Fatih Kececioglu1 , Hakan Acikgoz2 and Mustafa Sekkeli1, "*Advanced configuration of hybrid passive filter for reactive power and harmonic compensation*," SpringerPlus, vol. 5, pp. 1-20, 2016.