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A Novel Method for Reduction of Harmonics with the Incorporation of A DC Choke (L-Filter) – An Experimental Approach

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ABSTRACT: *In this research paper, the design & development of a simulink model for the harmonic elimination using a boost converter type is presented.*
Keywords: *Harmonics, SCR, Experiment, Results, DC Choke filter, Reactor.*

I. INTRODUCTION

The rapid development of renewable generation boosted the need for efficient, cheap, and robust converters that would interface them to the grid, without compromising the quality of supply for the end user. Most renewables provide ADC source of electric power, thus proper interfacing to the grid requires at least an inverter. Often, due to the low voltage acquired from sources such as domestic wind turbines, solar arrays or fuel cells, a boost converter or/and a transformer (if isolation is required) is added at the dc or ac side, respectively, in order to boost the voltage to the appropriate level [99].

Electrical vitality/power is a key element for the modern and all-round advancement of any nation as currently without electricity, the whole world will be in dark & the country's economy falls down drastically as every working device in the universe requires electricity. Hat's off to Thomas Alva Edison, Benjamin Franklin, who invented this great wonder, which is of great importance today. The ideal usage of this type of vitality/energy can be guaranteed by a quality electrical power with no intrusion. The circumstance with power is comparative, the unwavering quality of the supply must be known and the versatility of the procedure to varieties must be caught on [1] – [99].

The most common type of commercial inverter used for this kind of applications is a variation of sinusoidal pulse width modulation full-bridge inverter. The simplicity of the design provides robust operation and simple control, but the harmonic content of the output requires a low-pass filter to comply with the standards. Two disadvantages of this application are the increased size and cost due to the filter and the losses of the semiconducting switches performing the inverting operation at the inverter bridge (four) and the boost converter (one). Several PWM methods have been developed in order to reduce the harmonic content. Selective harmonic elimination solves the transcendental equations characterizing harmonics, so that appropriate switching angles are computed for the elimination of specific harmonics at the output [99].

Theoretically, these methods can provide a satisfying harmonic content. However, the solution of these equations is computationally intensive, thus, quite difficult to be done online. In small-scale applications, where powerful digital signal processors (DSPs) are not currently an option due to their higher cost, either switching angles are calculated offline, or the equations are linearized before they are solved or an approximate solution is sought where the topology permits it [99].

Other methods include modification of the carrier signal or the reference sine wave. All of them though, are open-loop control schemes, which assume a known and perfectly constant dc source (i.e., harmonics induced to the grid by an inductive source are ignored) and ignore the existing harmonic content of the grid voltage or the distortion caused by the load. In simple terms, they aim to reduce the harmonics created by the PWM itself, rather than improve the harmonic content at the terminal bus, which is affected by the PWM only partially [99].

Our innovative world has turned out to be profoundly reliant upon the ceaseless accessibility of electrical force/energy. Business control, i.e., power available commercially is truly empowering the today's

current world to work at its bustling pace. Modern innovation has come too profoundly into our homes and professions, and with the coming of e-trade & commerce is constantly changing the way we interface with whatever is left of world. Electric vitality is a fundamental element for the modern and all-round advancement of any nation. The ideal use of this type of vitality/power can be guaranteed by a quality force/energy/power. The circumstance with power is comparative, the unwavering quality of the supply must be known and the flexibility of the procedure to varieties must be caught on immediately [1]-[10].

As a general rule, obviously, power is altogether different from some other item - it is created a long way from the purpose of utilization and is nourished to the framework together with the yield of numerous different generators and lands at the purpose of utilization through a few transformers and numerous kilometers of overhead and conceivably underground cables. Where the electrical business factories has been privatized, these system resources will be possessed, overseen and kept up by various distinctive associations or companies. Guaranteeing the nature of conveyed force/power at the purpose of utilization is no simple task undertaking and it is extremely unlikely that sub-standard power can be pulled back from the store network or rejected by the client/end-utilizer [11]-[20].

Harmonic spikes have various undesirable consequences for the appropriation framework of the electrical distribution networks. 2 types are there, viz., : short & long term effects. Short impacts are generally the most recognizable and are identified with over the top over voltage mutilation. Then again, long haul (term) impacts frequently go undetected and are normally identified with expanded resistive loss or voltage stress likewise, the consonant streams created by non-straight loads can associate antagonistically with an extensive variety of influence framework gear (electrical power equipments), most strikingly capacitors, transformers, and engines, generators, bringing on extra loss, overheating, and over-burdening. Interference with telephone cables, lines will be caused by the development of these harmonic currents. In light of the antagonistic impacts that these harmonic surges have on P Q, standards have been created to characterize a sensible structure for control of harmonic surges. Its goal is to guarantee consistent state harmonic limits that are worthy considered by both electric utilities and their clients. [21]-[30].

Distortion of harmonics in power/force appropriation system can be stifled utilizing 2 methodologies in particular, latent/passive and dynamic/active fueling. The passive type of sifting/filter is the least difficult traditional answer for alleviate the mutation in harmonics. Even basically, the utilization of detached components does not generally react accurately to the progression of the electrical energy transmission frameworks. Throughout the years, these detached passive channels have created to the abnormal state of modernity. Some even tuned to sidestep or bypass the particular consonant frequencies [31] - [40].

Harmonics are *v* and *i* frequency components which are embedded on the crest level of the normal sine *v*&*i*. The symphonious distortion in waveform issues are for the most part because of the significant increment of non-straight loads because of innovative advances, for example, the utilization of force electronic circuits and gadgets, in air conditioning/dc transmission connections, or burdens in the control of force frameworks utilizing power electronic or microchip controllers. Harmonic sources are categorized into 3 types of loads, viz., [41]-[50]:

- House-hold load
- Industry load
- Controlling device

Any power circulation circuit serving present day electronic gadgets will possess some level of symphonious frequencies. The surge *v*&*i* don't generally bring about issues, yet the more prominent the electrical energy or power is drawn by these advanced gadgets or other non-straight loads, the more prominent is the level of voltage mutilation. There are a number of problems which are related to the harmonic generation, they include the following [51]-[60] :

- Equipment mal-functioning.
- Sudden tripping of the breakers.
- Sudden on & off of the lights.
- Large neutral *i*.
- Conductors in the phase, loads, transformer getting heated,
- U P S suddenly getting failed,
- Transformer suddenly getting failed,
- less power factor.
- Voltage & current surges
- Capacity of the system getting reduced [61]-[70].

How to prevent the harmonics ? The efficient method is to choose a device and have good installation practice which will definitely reduce the overall harmonic contents in the device or circuit or equipment or in a part of the network. On the off chance that the issues can't be illuminated by these basic measures, there are 2

fundamental decisions, viz., to fortify the dissemination framework to withstand *v* or *i* surges or to introduce the gadget to constrict or evacuate the harmonics. Procedures for lessening *v* or *i* surges, from shabby to more costly, incorporate latent symphonious channels, confinement transformers, consonant moderating transformers, the Harmonic Suppression Network (HSN) and dynamic channel filtering mechanisms [71]-[80].

The harmonic effect in the system's *v* or *i* is always decided in terms of the T H D, factor, high & low level harmonic contents. In general, any industry application ask for the load v & I be free of harmonics or at the most < 5 % of harmonics. Majority of the literatures after going through them shows that a number of methodologies have been found out to lessen the T H D [81]-[90].

There are assortments of building arrangements accessible to dispose of or diminish the impact of supply quality issues and it is exceptionally dynamic zone of advancement and improvement. In that capacity, clients should know about scope of arrangements accessible and the relative merits and expenses. A portion of the vital techniques to minimize sounds/surges in *v*&*i*'s are [91]-[99]

- filter which is passive in nature,
- filter which is active nature,
- separation transformer,
- surge reducing transformer,
- surge suppression system, etc…

The flow of the research work is developed one after another as shown below. A background introduction w.r.t. the work done in this paper was presented in the introductory section in sec. 1. Methodology is explained in sec. 2. An overview of the experimental approach developed is given in sec. 3, followed by the description of the circuit in sec. 4 & the process of operation in sec. 5. The sec. 6 gives a photographic view of the experimentation process. Results are presented in sec. 7 followed by the conclusions & the advantages in sec. 8. This is followed by a large number of references used in the development of this paper.

II. METHODOLOGY USED FOR HARMONIC REDUCTIONUSING A LABORATORY HARDWARE SET-UP

In this section, a DC choke (*a combination of small value of R and high value of L, i.e., similar to a tube light choke*) is being used in the circuit for the removal of the harmonics present in the input signal. Also, the hardware implementation of the same is dealt with in this section.

III. OVERVIEW OF THE EXPERIMENTAL SET-UP

In many ways, the DC choke is comparable to an equivalent AC-side line reactor, although the percentage of Total Harmonic Distortion (THD) is somewhat less. The DC choke provides a greater harmonic reduction, primarily uptil the 25^{th} harmonics (in our case considered). On higher order harmonics reduction, the line reactor is superior, so in terms of meeting the IEEE guidelines, the DC choke and line reactors are almost similar, hence a L-filter would suffice our work. If a DC choke (or line reactor) is applied on all AFDs, it is possible to meet IEEE guidelines, where up to 15 - 40 % of the system loads are AFDs, depending on the stiffness of the line, the amount of linear loads, and the value of choke inductance.

IV. CIRCUIT DESCRIPTION

A series inductance (choke) on the later DC side of the semiconductor bridge circuit (6 diodes) on the front end of the AFD can be designed in such a way that majority of the harmonic components can be eliminated. The output of the designed choke circuit is connected to a 3-phase inductive load through a full bidirection bridge switching circuit. Power electronics kits are being used to rig up the designed circuitries and operate it such a way that harmonics are reduced by proper tuning of the respective circuit elements in order to obtain the output supply to be free of harmonic contents. Bread boards / spring boards, resistors, inductors, capacitors, thyristors bridges, diodes, DSO's, sources, oscilloscopes, multimeters, power supplies, connecting wires, etc are being used in this context of conducting the experimentation & observing the results.

V. PROCESS OF OPERATION

The i/p ac waveform is given from the supply (waveform). The diode bridge rectifier is used as a dc link which converts ac to dc. The choke eliminates the harmonics & smoothenes the ripples, whereas the the capacitor stordes DC & converts to AC. The o/p of diode-pure DC (with small ripples). This is given to the bi-directional switches. Then, the bidirectional switches converts the DC to the smooth AC. Note that in this case, when the 3-ϕ inductive load is switched on, harmonics are generated in the output wave form (red color) w/o the choke & with the choke, the harmonics are reduced & we get a smoothened waveform with the help of the bi-directional switches used after the choke.

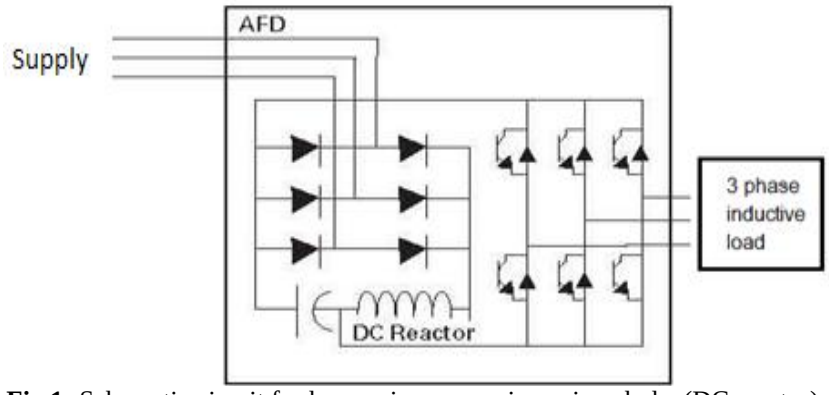

Fig 1: Schematic circuit for harmonic suppression using choke (DC reactor)

VI. PHOTOGRAPHIC VIEW OF THE EXPERIMENTATION

The photographic view of the experimental work done in the laboratory with respect to the works carried out in this paper are shown in this section.

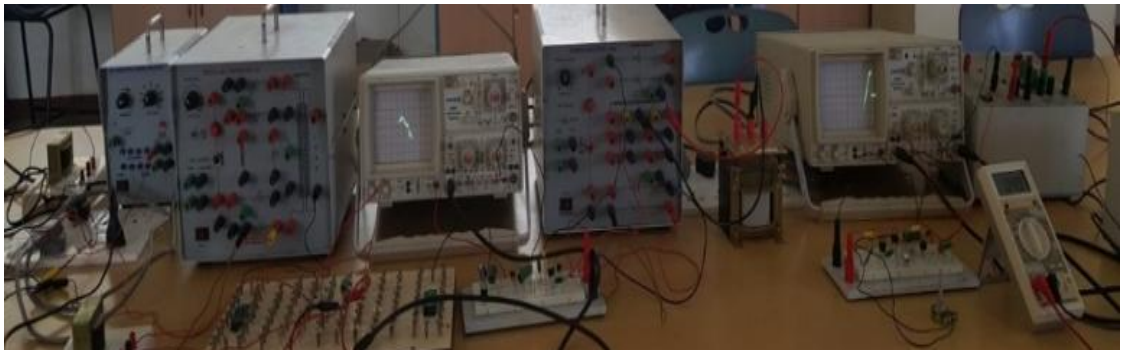

Fig 2: Pictorial view of experimental setup-1

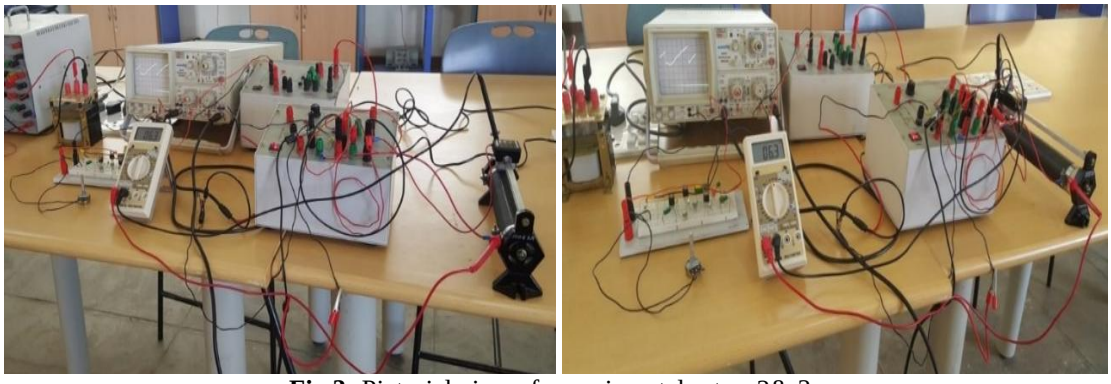

Fig 3: Pictorial view of experimental setup-2& 3

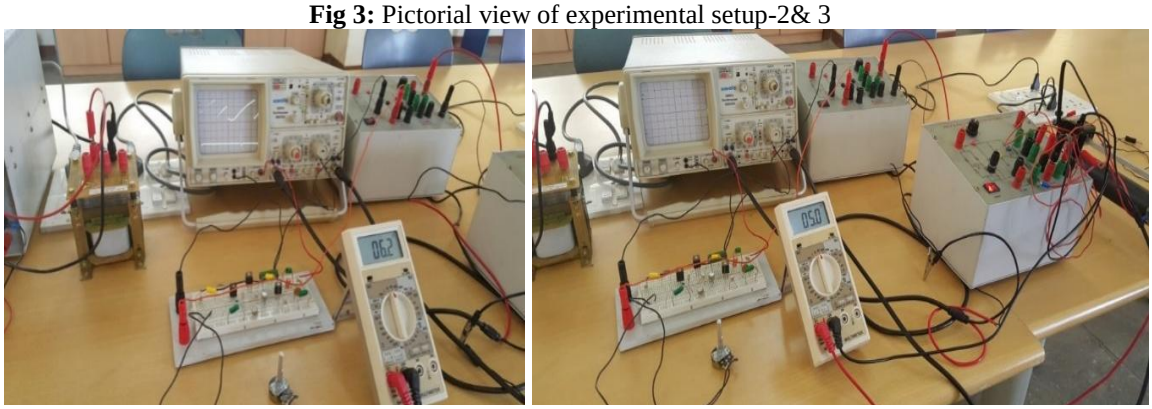

Fig 4: Pictorial view of experimental setup-4& 5

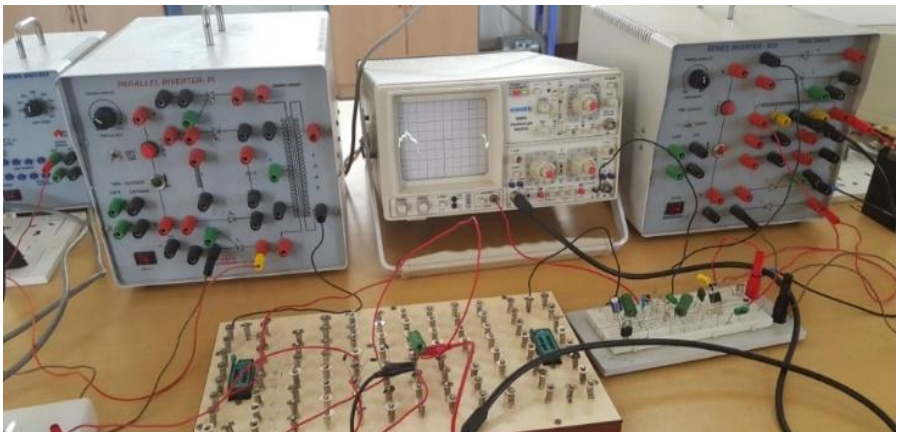

Fig 5: Pictorial view of experimental setup-6

VII. OBSERVATIONS ON THE O/P WAVEFORMS / EXPERIMENTAL RESULTS

The designed circuit was tested in the laboratory and the outputs were observed after the inductive load is switched on & off as a result of which harmonics are generated in the input side of the power supply. Pure sinusoidal waveform after the harmonic removal and the harmonic contents generated in the waveform due to switching could be observed on the scopes. Once the choke is incorporated in line with the output load side, the effects of harmonics are nullified and we get a smooth waveform with less harmonic contents thus maintaining the power quality, safeguarding the equipment from damages. By tuning the choke properly, the designed circuit was able to eliminate harmonics upto the 25th order using the hardware circuitry (maxm. possible), which is shown in the oscilloscope results.

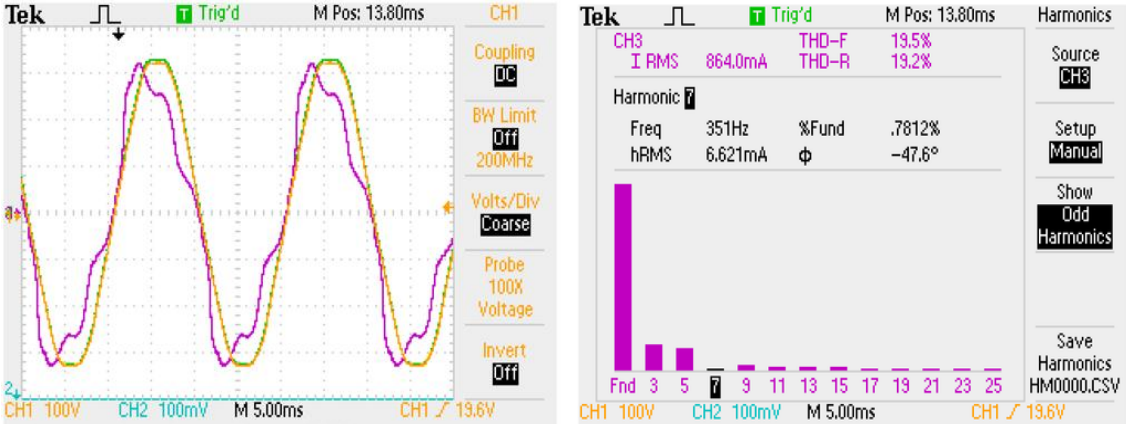

Fig 6: Display of simulated output and distorted waveforms due to switching of the inductive load after the compensation of the 7thharmonic

VIII. CONCLUSION & ADVANTAGES

From this experimental setup and also by the use of a choke filter, harmonics upto the maximum order could be eliminated by proper tuning the circuitries. In this work, it has to be noted that more than 7th harmonic the effect is very less. The main advantages of the DC choke used are ….

- Packaged integrally to the AFD.
- Can provide moderate reduction in voltage and current harmonics.
- Less voltage drop than an equivalent line reactor.

A simple experiment was conducted in the laboratory for the reduction of harmonics and to improve the power quality. It can be observed from the waveforms that w/o the DC-choke filter, the output waveforms are with harmonics & with the incorporation of the DC-choke filter, the output waveforms are free w/o harmonics. The experimental results show the effectiveness of the experimental method done in the laboratory.

REFERENCES

[1]. Zainal Salam, Tan Perng Cheng and Awang Jusoh, "Harmonics mitigation using active power filter : A technical review", Elektrika, Vol. 8, No. 2, pp. 17-26, 2006.

[2]. Fanghua Zhang & Yangguang, "Selective harmonic elimination PWM control scheme on a 3-ϕ 4 – leg voltage source inverter", IEEE Transaction on Power electronics, Vol. 24, No. 7, pp. 1682-1689, Jul. 2009.

[3]. Mahesh A. Patel, Ankit R. Patel, Dhaval R. Vyas & Ketul M. Patel, "Use of PWM techniques for power quality improvement", International Journal of Recent Trends in Engineering, Vol. 1, No. 4, pp. 99 – 102, May 2009.

[4]. Ming-Yin Chan, Ken KF Lee & Michael WK Fung, "A case study survey of harmonic currents generated from a computer center in an office building", Architecture Science Review, Vol. 50, No. 3, pp. 274-280, 2007.

[5]. G.N.C. Fergusson, "Power quality improvement in a harmonic environment", International Electrical Testing Association (NETA) Annual Technical Conference – A reprint version, Mar. 1997.

[6]. Thomas S. Key & Jih-Sheng Lai, "Costs and benefits of harmonic current reduction for switch mode power supply in commercial office building", IEEE Trans. on Industry Applications, Vol. 32, No. 5, Sep.-Oct. 1996.

[7]. V. Suresh Kumar, Ahmed F. Zobaa, R. Dinesh Kannan & K. Kalaiselvi, "Power Quality and Stability Improvement in Wind Power System using STATCOM", International Conference and Exhibition on Green Energy and Sustainability for Aride regions & Mediterranean Countries, 2009.

[8]. Alexander Kusko & Mart C. Thomson, "Power quality in electrical systems", Tata Mc. Graw Hill., New Delhi, 2010.

[9]. Gregory N.C. Ferguson "The cost and benefits of harmonic current reduction in low voltage distribution systems", Int. Jr. of Power Quality, Vol. 3, No. 5, pp. 45-51, May 2013.

[10]. Jonathan K. Piel & Daniel J. Carnovale, "Economic and electrical benefits of harmonic reduction methods in commercial facilities", Proc. Cutler Hammer, USA, Jul. 2004.

[11]. M. Aredes, J. Hafner, and K. Heumann, "3-phase four-wire shunt active filter control strategies," IEEE Trans. Power Electron., Vol. 12, No. 2, pp. 311–318, Mar. 1997.

[12]. C. J. Zhan, A. Arulampalam, and N. Jenkins, "4-wire dynamic voltage restorer based on a 3-dimensional voltage space vector PWM algorithm," IEEE. Trans. Power Electron., Vol. 18, No. 4, pp. 1093–1102, Jul. 2003.

[13]. N.Y. Dai, M.-C.Wong, andY.-D. Han, "A FPGA-based generalized pulse width modulator for 3-leg center-split and 4-leg voltage source inverter," IEEE Trans. Power Electron., Vol. 23, No. 3, pp. 1472–1484, May 2008.

[14]. H.L. Jou, J.C. Wu, K.D. Wu, W.J. Chiang, and Y.H. Chen, "Analysis of zig-zag transformer applying in the three-phase four-wire distribution power system," IEEE Trans. Power Del., Vol. 20, No. 2, pp. 1168–1173, Apr. 2005.

[15]. P. Sanchis, A. Ursua, E. Gubia, J. Lopez, and L. Marroyo, "Control of three-phase stand-alone photovoltaic systems with unbalanced loads," Proc. IEEE ISIE, pp. 633–638, 2005.

[16]. G. Kamath, N. Mohan, and V.D. Albertson, "Hardware implementation of a novel, reduced rating active filter for 3-phase, 4-wire loads," Proc. IEEE APEC, pp. 984–989, 1995.

[17]. S. Choi and M. Jang, "Analysis and control of a 1-ϕ inverter zigzag-transformer hybrid neutral-current suppressor in 3-ϕ 4-wire systems," IEEE Trans. Ind. Electron., Vol. 54, No. 4, pp. 2201–2208, Aug. 2007.

[18]. S. Kim and P.N. Enjeti, "A new hybrid active power filter (APF) topology," IEEE Trans. Power Electron., Vol. 17, No. 1, pp. 48–54, Jan. 2002.

[19]. G. Casaravilla, G. Eirea, G. Barbat, J. Inda & F. Chiaramello, "Selective active filtering for 4-wire loads: Control and balance of split capacitor voltages," Proc. IEEE PESC, pp. 4636–4642, 2008.

[20]. N.Y. Dai, M.C. Wong, and Y.D. Han, "Application of a 3-level NPC inverter as a 3-phase 4-wire power quality compensator by generalized 3D SVM," IEEE Trans. Power Electron., Vol. 21, No. 2, pp. 440–449, Mar. 2006.

[21]. IEEE 100, The Authoritative Dictionary of IEEE Standard Terms, 7th edition, pp. 234, 2000.

[22]. S.Khalid & Bharti Dwivedi, "Power quality issues, problems, standards & their effects in industry with corrective means", Int. Journal of Advances in Engg. & Tech., IJAET, ISSN: 2231-1963, Vol. 1, Issue 2, pp.1-11, May 2011.

[23]. Rajesh Maharudra Patil, Dr. M.S. Nagaraj, Dr. P.S. Venkataramu, "A review of the effect of harmonics due to switching devices in the field of power electronics & its applications", Int. Jr. of Emerging Tech. & Research (IJETR), ISSN (E) : 23475900 ISSN (P) : 23476079,IF : 0.997, Vol. 2, Issue 2, pp. 44 – 50, Mar. – Apr. 2015 http://www.ijetr.org/index.php?p=pi&volume=V2&issue=I2

[24]. Rajesh Maharudra Patil, Dr. M.S. Nagaraj, Dr. P.S. Venkataramu, "Analysis of the effect of harmonics due to switching devices w.r.t. experimental & simulation point of view", Int. Jr. of Innovative Research in Comp. & Communication Engg. (IJIRCCE), IF 4.447, ISSN (Online): 2320-9801, ISSN (Print): 2320-9798, Vol. 3, Issue 3, DOI : 10.15680/ijircce.2015.0303008, pp. 1454 -1461, Mar. 2015 http://ijircce.com/volume-3-issue-3.html

[25]. Rajesh Maharudra Patil, Dr. M.S. Nagaraj, Dr. P.S. Venkataramu, "Harmonic problems in the switching devices w.r.t. electrical power quality point of view", Int. Jr. of Science, Tech. & Mgmt. (IJSTM), ISSN 2394-1537/2394-1529, IF 1.011, Vol. No. 04, Issue No. 03, pp. 17 – 34, Mar. 2015 http://www.ijstm.com/currentissue.php?id=70

[26]. Narain G. Hingorani and Laszlo Gyugyi, "Understanding FACTS : Concepts and technology of flexible AC transmission systems", Wiley-IEEE Press, 452 pages, 1999.

[27]. Suvas Vora, Dipak Bhatt, "A comprehensive review of harmonics effects on electrical power quality", Int. Journal of Engg. Development & Research, Paper id IJEDR1303003, ISSN: 2321-9939, pp. 15-21, 2013.

[28]. Chandrasekar, T., Justus Rabi and A. Kannan, "Harmonics reduction in front end rectifier of uninterruptible power supplies with active current injection", American Journal of Applied Sciences - Science Publication., Vol. 11, No. 4, pp. 564-569, ISSN: 1546-9239, pp. 564 – 569, doi:10.3844/ajassp.2014.564.569, 2014.

[29]. Harish Kumar S., Vengatesh V., Bhuvaneswaran E., "Power quality management in commercial buildings", Int. Journal for Research & Development in Engg. (IJRDE), ISSN: 2279-0500, Special Issue, pp. 157-165, 2014.

[30]. Alireza Hoseinpour and Reza Ghazi, "Modified PWM technique for harmonic reduction", Int. Scholarly Research Network ISRN Electronics, Vol. 2012, Article ID 917897, 8 pages, doi:10.5402/2012/917897.

[31]. K.L. Lian, Brian K. Perkins & P.W. Lehn, "Harmonic analysis of a 3□ diode bridge rectifier based on sampled data", IEEE Transactions on Power Delivery, Vol. 23, No. 2, pp. 1088-96, Apr. 2008.

[32]. M.H. Shwehdi, F.S. AL-Ismail, "Investigating University Personnel Computers (PC) Produced Harmonics Effect on line Currents", Int. Conf. on Renewable Energies & Power Quality (ICREPQ'12), Santiago de Compostela (Spain), 28 - 30 Mar., 2012.

[33]. Sagayaraj R., Thangavel S., "Implementation of intelligent control strategies on current ripple reduction and harmonic analysis at the converter side of the industrial inverters & trade off analysis", Jour. of Theoretical & Applied Info. Tech. (JATIT), ISSN: 1992-8645, Vol. 65 No. 2, pp. 344-351, Jul. 2014.

[34]. Alham, M.H., Hassan M.A.M., El-Zahab, "Control of the shunt active power filter using artificial intelligence techniques", IEEE Int. Conf. on Control, Decision & Info. Tech. (CoDIT), Hammamert, pp. 202 - 207, 2013.

[35]. Sam Abdel-Rahman, Franz Stückler, Ken Siu, "PFC boost converter design guide, Infineon", Application notes.

[36]. Satheeswaran K., Nepolean C., Vikash M., "Harmonic elimination using boost converter", International Journal of Scientific Engineering and Applied Science (IJSEAS), ISSN: 2395-3470, Vol. 1, Issue 9, Dec. 2015, pp. 431 - 434.

[37]. P. Suresh Kumar, S. Sridhar, T. Ravi Kumar, "Design & simulation of boost converter for power factor correction and THD reduction", Int. Jr. of Scientific Engg. & Tech. Res. IJSETR, ISSN 2319-8885 Vol. 3, Issue 42, pp. 8462-8466, Nov. 2014.

[38]. Mohammad Junaid & Bhim Singh "Analysis & design of buck-boost converter for power quality improvement in high frequency on/off-line UPS system", IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES), Mumbai, Print ISBN: 978-1-4799-6372-0, pp. 1 – 7, 16-19 Dec. 2014.

[39]. P. Giroux, G. Sybille, H. Le-Huy, "Modeling & simulation of a distribution STATCOM using Simulink's power system block-set", Industrial Electronics Society, IECON'01, The 27th Annual Conference of the IEEE., Vol. 2, pp. : 990 - 994, Print ISBN : 0-7803-7108-9, Mathsworks Inc., Denver, CO, USA.

[40]. Khaled H. Ahmed, Stephen J. Finney and Barry W. Williams, "Passive filter design for three-phase inverter interfacing in distributed generation", Electrical Power Quality and Utilization Journal, Vol. XIII, No. 2, pp. 49 – 58, 2007.

[41]. Singh B., Al-Haddak, Chandra A., "A review of active filters for power quality improvement", IEEE Transactions on Industry Electronics, Vol. 46, No. 5, pp. 960–971, 1999.

[42]. El-Habrouk M., Darwish M.K., Mehta P., "Active power filters : A review", Electric Power Applications, IEE Proc., Vol.147, Issue 5, pp. 403–413, 2000

[43]. Akagi H., "Active harmonic filters", Proc. of the IEEE, Vol. 93, Issue 12, pp. 2128–2141, Dec. 2005

[44]. Holmes D.G., Lipot A., "Pulse width modulation for power converters: Principles and practice", IEEE Press Series on Power Engineering, Wiley-IEEE Press, Edition 1, Oct. 2003.

[45]. V. Karthikeyan, V.J. Vijayalakshmi, P. Jeyakumar, "Selective Harmonic Elimination (SHE) for 3-Phase Voltage Source Inverter (VSI)", American Journal of Electrical and Electronic Engineering, Science and Education Publishing, DOI:10.12691/ajeee-2-1-4

[46]. Ray R.N., Chatterjee & Goswami S.K, "Reduction of voltage harmonic using optimization – based combined approach", Proc. on IET Power Electronics, Vol. 3, Issue 3, pp. 334 – 344, 2008.

[47]. Mohamed S.A., Dahidah and Vassilios G. Agelidis, "Selective harmonic elimination PWM control for cascaded multilevel voltage source converters: A generalized formula" IEEE Trans on power electronics, Vol. 23, Issue 4, pp. 1620-1630, Jul. 2008.

[48]. Wells, Jason R., Xin Geng, Chapman, Patrick L. & Krein, Philip T. "Modulation based harmonic elimination" IEEE Transactions on Power Electronics, Vol. 22, Issue 1, 2007.

[49]. Javier Napoles, Jose Ignacio Leon, and Aguirre, Miguel A. "A flexible selective harmonic mitigation to meet grid codes in three level PWM converters", IEEE Transactions on Industrial Electronics, Vol. 54, Issue 6, Dec. 2007.

[50]. Hadji S. Touhami O. and C.J. Goodman, "Vector- optimized harmonic elimination for single phase pulse width modulation inverters / converters", IET Electrical Power Appl., Vol. 3, pp. 423-432, 2007.

[51]. Agllidis V.G., Balouktsis A. & Cosar C., "Multiple sets of solutions for harmonic elimination PWM bipolar waveforms: Analysis & experimental verification", IEEE Trans. Power Electron., Vol. 22, No. 1, pp. 491-499. 2007.

[52]. Abd Almula G.M. Gebreel, "Simulation and implementation of 2 level and 3-level inverters by Matlab and RT-lab", M.S. Thesis, Graduate Program in Electrical and Computer Science, The Ohio State University, 2011.

[53]. G. Mahalakshmi, R. Hemavathi, "Comparative analysis of three phase, two level and three level PWM inverter fed induction motor drive using Matlab/Simulink model", International Journal of Emerging Trends in Electrical and Electronics, IJETEE, ISSN: 2320-9569, Vol. 12, Issue 1, Jan. 2016.

[54]. Darshan Prajapati, Vineetha Ravindran, Jil Sutaria, Pratik Patel, "A comparative study of three phase 2-level VSI with 3-Level and 5-Level diode clamped multilevel inverter", International Journal of Emerging Technology and Advanced Engineering, ISSN 2250-2459, Vol. 4, Issue 4, pp. 708 – 713, Apr. 2014.

[55]. Muhammad H. Rashid, "Power Electronics: Circuits, Devices & Applications", Pearson Education, New Delhi, 2013.

[56]. P.S. Bimbhra, "Power Electronics", Edition 4, Khanna Publishers, ISBN 8174092153, 775 pages, 2010.

[57]. B. Kumara Swamy, P. Nageshwar Rao, "Simulation of a space vector PWM controller for a 3-level voltage-fed inverter motor drive", International Journal of Advanced Trends in Computer Science and Engineering, ISSN 2278-3091, Vol. 2 , No. 1, pp. 363 – 372, 2013.

[58]. Veeraiah Kumbha, N. Sumathi, "Power quality improvement of distribution lines using DSTATCOM under various loading conditions", International Journal of Modern Engineering Research (IJMER), Vol. 2, Issue 5, pp. 3451-3457, ISSN: 2249-6645, Sep. – Oct. 2012.

[59]. R. Meinski, R. Pawelek and I. Wasiak, "Shunt compensation for power quality improvement using a STATCOM controller modelling and simulation", IEE Proceedings - Generation, Transmission and Distribution, DOI: 10.1049/ip-gtd : 20040053, pp. 274 – 280, Vol. 151, No. 2, Mar. 2004.

[60]. R. Rajalakshmi, V. Rajasekaran, "Improvement of energy efficiency through power quality by the compensation of harmonics with shunt active power filter", 2011 International Conference on Recent Advancements in Electrical, Electronics and Control Engineering (ICONRAEeCE), pp. 324 - 327, 15-17 Dec. 2011.

[61]. P. Salmerón and S. P. Litrán, "Improvement of the electric power quality using series active and shunt passive filters", IEEE Transactions on Power Delivery, 2015.

[62]. E. Rambabu, E. Praveena, P.V. Kishore, "Mitigation of harmonics in distribution system using D - STATCOM", International Journal of Scientific & Engineering Research IJSER, ISSN 2229-5518, Vol. 2, Issue 11, Nov. 20011.

[63]. Abdelazeem A., Abdelsalam, Mohammed E. Desouki, Adel M. Sharaf, "Power quality improvement using FACTS power filter compensation scheme", J. Electrical Systems, Vol. 9, No. 1, pp. 73-83, 2013.

[64]. J. Arrillaga, D.A. Bradley, P.S. Bodge, "Power System Harmonics", Wiley, 1985.

[65]. M. Rastogi, N. Mohan, and A.-A. Edris, "Hybrid-active filtering of harmonic currents in power systems," IEEE Trans. Power Delivery, Vol. 10, No. 4, pp. 1994–2000, Oct. 1995.

[66]. Yogesh Rathor & Vinay Pathak, "A Review of Reduction of Harmonics with fuzzy logic controller Using Active Filter", Global Jr. of Engg. Design & Tech., ISSN: 2319 – 7293, G.J. E.D.T.,Vol. 4, Issue 3, pp. 13-17, May-June, 2015.

[67]. Shalini Bajpai, "Power quality improvement using AC to AC PWM converter for distribution line", International Journal of Computational Engineering Research IJCER, Vol. 3, Issue 7, Pages 36, Jul. 2013.

[68]. Leszek S. Czarnecki, "An overview of methods of harmonic suppression in distribution systems", IEEE PES Summer Meeting, Seattle, USA, 2000.

[69]. P.W. Hammond, "A harmonic filter installation to reduce voltage distortion from static power converters," IEEE Trans. on Ind. Appl., Vol. 24, No. 1, pp. 53-58, Jan./Feb. 1988.

[70]. Kun-Ping Lin, Ming-Hoon Lin, Tung-Pin Lin, "An advanced computer code for single tuned harmonic filter design," IEEE Trans. on Ind. Appl., Vol. 34, No. 4, pp. 640-648 July/Aug. 1998.

[71]. L.S. Czarnecki, "Effect of minor harmonics on the performance of resonant harmonic filters in distribution systems," Proc. IEE, Electr. Pow. Appl., Vol. 144, No. 5, pp. 349-356, July./Aug. 1995.

[72]. ABS, "Guidance notes on control of harmonics in electrical power systems", American Bureau of Shipping Incorporated by Act of Legislature of the State of New York 1862, Copyright @ 2006, American Bureau of Shipping, ABS Plaza, 16855 Northchase Drive, Houston, TX 77060 USA, May 2006.

[73]. Imtiaz Ahmed, Mir Zayed Shame, Md. Muksudul Alam, "An overview of harmonic sources in power system", IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE), e-ISSN: 2278-1676, p-ISSN: 2320-3331, Vol. 7, Issue 3, pp. 01-03, Sep. - Oct. 2013.

[74]. Ogundana, E.O., "Design and simulation of harmonic filter using Matlab® software", International Journal of Engineering and Mathematical Intelligence, Vol. 2, No. 1 - 3, pp.1 – 8, 2011.

[75]. Mridul Jha, S.P. Dubey, "Neuro-fuzzy based controller for a 3-□ 4wire shunt active power filter", International Journal of Power Electronics and Drive System (IJPEDS), ISSN: 2088-8694, Vol. 1, No. 2, pp. 148~155, Dec. 2011.

[76]. Jyoti Lalotra, Saleem Khan, Shavet Sharma, Parveen Lehana, "Investigation of the effect of inductive load on harmonic distortion of IGBT based power system", International Journal of Engineering and Advanced Technology (IJEAT), ISSN: 2249 – 8958, Volume-2, Issue-5, pp. 423 – 426, Jun. 2013.

[77]. Mukhtiar Ahmed Mahar, Muhammad Aslam Uqaili and Abdul Sattar, Larik, "Harmonic analysis of AC-DC topologies and their impacts on power systems", Mehran University Research Journal of Engineering & Technology, Vol. 30, No. 1, pp. 173-178, Jan. 2011.

[78]. Joy Mazumdar, "System and method for determining harmonic contributions from nonlinear loads in power systems", Ph.D. Dissertation Thesis, Electrical & Computer Engg., Georgia Institute of Tech., Dec. 2006.

[79]. http://www.mathworks.com, Mathworks, Natick, Massachusetts, MA, U.S.A.

[80]. F. Ramirez, A. Suarez, "Harmonic-injection divider based on feedback through a nonlinear transmission line", 2013 IEEE European Microwave Integrated Circuits Conference (EuMIC), Nuremberg, pp. 276 – 279, 6-8 Oct. 2013.

[81]. P. Cheng, S. Bhattacharya & D. Divan, "Experimental verification of dominant harmonic active filter for high power applications," IEEE Transactions on Industry Applications, Vol. 36, pp. 567-577, Mar./Apr. 2000.

[82]. D.D. Sabin, "Analysis of harmonic measurement data," Proc. of the IEEE Power Engineering Society Summer Meeting, Vol. 2, pp. 941 - 945, Jul. 2002.

[83]. John N. Chiasson, Keith J. McKenzie "Elimination of Harmonics in a Multilevel Converter Using the Theory of Symmetric Polynomials and Resultants," IEEE Transaction on Control System Technology, vol. 13, no. 2, pp. 216-223, 2005.

[84]. Biswamoy pal, Reetam Mondal, "Overall THD Analysis of Multicarrier based new Cascaded Multilevel Inverter with reduced switch of Different levels at Different carrier frequency," International Journal of Emerging technologies and Engineering, vol. 1, no. 5, pp. 148 - 156, 2014.

[85]. Rajesh Kumar Ahuja, Amit Kumar, "Analysis and control of Three Phase Multilevel Inverters with Sinusoidal PWM Feeding Balanced Loads using MATLAB," International Journal of Engineering Research and General Science, pp. 93 - 100, 2014.

[86]. José Rodríguez, Jih-Sheng Lai and Fang Zheng Peng, "Multilevel Inverters: A Survey of Topologies, Controls and Applications", IEEE Transaction on Industrial Electronics, vol. 49, no. 2, pp. 724 – 738, 2002.
[87]. M.S. Aspalli, Anil Wamanrao, "Sinusoidal Pulse Width modulation (SPWM) with Variable Carrier Synchronization for Multilevel Inverter Controller", IEEE explore, 2010.
[88]. P. Thirumurugan, R. Preethi, "Comparison of total harmonic distortion in different levels of inverter", Journal of Electrical Engg.
[89]. Muhammed Rashid, "Power electronics handbook", Elsivier Pubs., ISBN 9780123820372, pages 1362, 2011.
[90]. Mehjabeen A. Khan, Akeed A. Pavel, M. Rezwan Khan and M. A. Choudhury, "Design of a single phase rectifier with switching on AC side for high power factor and low total harmonic distortion", IEEE Region 5 Technical Conference, April 20-21, Fayetteville, AR, 2007.
[91]. Shilpa Garg and Ram Avtar Jaswal, "Comparison of Minimising Total Harmonic Distortion with PI Controller, Fuzzy Logic Controller, BFO- fuzzy Logic Controlled Dynamic Voltage Restorer", International Journal of Electronic and Electrical Engineering, ISSN 0974-2174, Volume 7, Number 3, pp. 299-306, 2014.
[92]. H. Anga, S. Gite, S. Bhave, Divya. S, "Power Factor and Harmonic Analysis in Single Phase AC to DC Converter", International Journal of Engineering Research & Technology (IJERT), ISSN: 2278-0181, Vol. 4, Issue 04, April 2015.
[93]. Yew Weng Kean, Pang Siew Yong, Agileswari Ramasamy, V. K. Ramachandaramurthy, "Comparison of the effect of filter designs on the total harmonic distortion in three-phase stand-alone photovoltaic systems", ARPN Journal of Engineering and Applied Sciences, Vol. 10, No. 21, ISSN 1819-6608, ©2006-2015 Asian Research Publishing Network (ARPN), pp. 9919-9925, Nov. 2015.
[94]. Dr. Jagdish Kumar , "THD analysis of different levels of cascade multilevel inverters for industrial applications", International Journal of Emerging Technology and Advanced Engineering, ISSN 2250-2459, Volume 2, Issue 10, pp. 237 – 244, October 2012.
[95]. Y. Sahali, M. K. Fellah, "Comparison between Optimal Minimization of Total Harmonic Distortion and Harmonic Elimination with Voltage Control candidates for Multilevel Inverters", J. Electrical Systems, Vol. 1, Issue 3, pp. 32-46, 2005.
[96]. Avinash Verma, Ruchi Shivhare, Sanjeev Gupta, "Total Harmonics Distortion Investigation in Multilevel Inverters", American Journal of Engineering Research (AJER), e-ISSN : 2320-0847 p-ISSN : 2320-0936 Vol. 02, Issue 07, pp-159-166, 2013.
[97]. P. Vanaja, R. Arun Prasaath, P. Ganesh, "Total Harmonic Distortion Analysis and Comparison of Diode Clamped Multilevel Z-Source Inverter", International Journal of Modern Engineering Research (IJMER), ISSN: 2249-6645, Vol. 3, Issue 2, pp-1000-1005, March-April 2013.
[98]. Chitra Natesan, Senthil Kumar Ajithan, Priyadharshini Palani, Prabaakaran Kandhasamy, "Survey on Microgrid: Power Quality Improvement Techniques", International Scholarly Research Notices, ISRN Renewable Energy, Hindwai Publishing Corporation, Review Article, Vol. 2014, Article ID 342019, 7 pages, 2014.
[99]. Konstantinos G. Georgakas, Panagis N. Vovos, Member, Nicholas A. Vovos, "Harmonic Reduction Method for a Single-Phase DC–AC Converter Without an Output Filter", IEEE Trans on Pwr. Electr., Vol. 29, No. 9, Sept. 2014.
[100]. M.S. Nagaraj, Ananthapadmanabha, "Development of Algorithm for Operational Planning in Power Distribution System using Artificial Neural Network & Fuzzy Logic", Ph.D. Thesis, Visvesvaraya Technological University V.T.U., Belagavi, Karnataka, 2007.

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