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A review on various novel and traditional methods for harmonic reduction in various applications

Anuj Rastogi[1], Shashwat Singh[2]
Department of Electrical & Electronics Engineering
Krishna Institute of Engineering & Technology, Ghaziabad, India

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Introduction

The electrical supply voltages and currents are of supreme importance in our diurnal activities. It is thus of supreme importance to maintain the pristine form of this supply. In the pragmatic applications the supply is far from being in the pure form. The supply currents and also the currents in component utility are thus found full of harmonics which actually are induced in the supply currents by a number of non linear devices attached to the supplies. Since the putative working of all the electrical appliances and systems are studied with the pure forms of waves thus with their subjection to the practical harmonic currents yield certain undesirable effects. It is thus a dire need for the electrical engineers to find certain ways in which these harmonics can be separated from the original or ideal waveform whose shape is distorted by the presence of such components.

The review paper thus pays major attention on certain available and effective methods to reduce the presence of such components in the currents and voltages. It discusses certain effective techniques which are available for various applications which reduce the harmonic components in the currents either consumed or produced. Various effective and novel methods available for harmonic reduction in case of Travelling Wave Tubes, Induction Machines, Synchronous Machines, Photo Voltaic systems, wind energy and also in case of inverters are discussed. It is thus being shown that in the quest of harmonic reduction there are separate effective techniques available for different systems which work good for them. The fruitful results obtained, showing the effectiveness, with the application of these techniques in different process are also discussed. The research results concerning their development are also discussed in some reviews. Hence, the paper is an effort to be labour certain novel and traditional methods present to reduce the harmonic contents (present in current and voltage waveforms), in various electrical applications. TWTs are used as amplifiers to amplify signals in communication and counter measure systems. The output is full of harmonic distortions and the second harmonic is majorly present. One way to remove it is the harmonic injection technique but this will require another source to be present near TWT and thus it actually will disturb the working of TWT and will prove to be inconvenient. However a better way can be drawn out by analyzing the hypothesis of Dionne who pointed out that the phase velocity and the coupling impedance of the fundamental wave are associated with the circuit structure. Thus it was concluded that a change in the circuit structure is going to produce salubrious results. Thus in [1]-[5], two novel possible changes that can be made in circuit design of slow wave helix TWT structure were proposed. They were:

a) Changing the helix pitch in the traditional three dielectric support structure.
b) Changing the support dielectric rod shape.

A diamond studded helix TWT with a pitch change scheme was observed and a difference of 9dB in the fundamental and the second harmonic was achieved. This was 5dB more as compared to a normal TWT with no pitch change, no studded structure and having the same specification of bandwidth and power as (6Ghz-18Ghz, 50 W). Thus with the studded and the pitch change structure the second harmonic power can be reduced significantly. The simulation graph with different frequencies was shown and a comparison was drawn with these frequencies transferred through normal TWT and with pitch change and studded Helix.

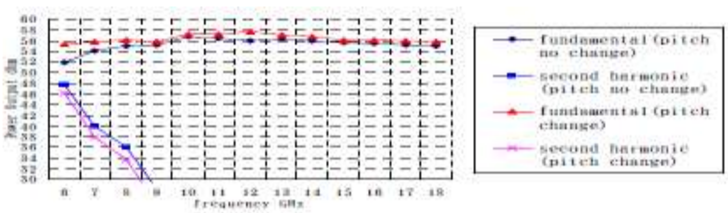

Figure 1: Comparison of power output for normal and pitch change Helix TWT

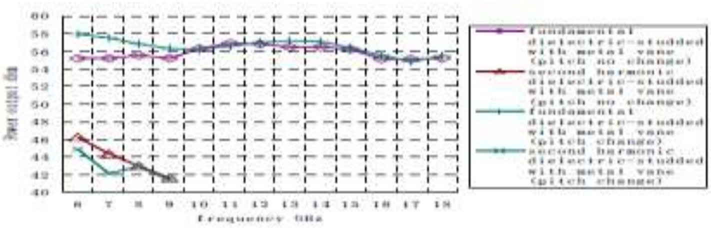

Figure 2: Comparison of power output for normal and dielectric studded Helix TWT

It was thus found that with the changes in the structure that is the changes in the pitch and the changes in the support dielectric rod shape a considerable harmonic reduction was obtained.

The current waveform on the DC winding of the converter is full of harmonics and is far from normal fundamental waveform. Although, a number of methods have been proposed related to the reduction of harmonics but a novel method in [6]-[9] presented an idea which was applicable to any converter (AC-DC). In this method the original current in the DC winding of the transformer of the converter was superimposed by the injecting current in opposite polarity and comprising of the harmonics which were to be removed. Thus the original waveform obtained was found free from harmonics. A figure for this phenomenon is being given as under in which the final current is free from harmonics.

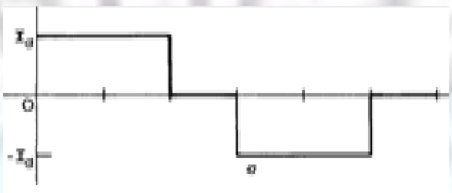

Figure 3: Output of the converter

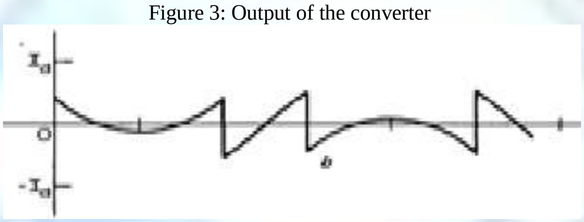

Figure 4: Injected current containing all harmonic component other than fundamental

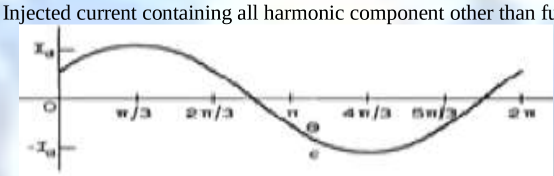

Figure 5: Current obtained after superimposing figure (3) and (4)

The injected current flows through the closed loop which contains the source of its generation and the DC winding of the transformer of the converter.

The results of the method were verified by conducting the experiments for the three phase bridge rectifier where the harmonic reduction was being done with the third harmonic current. In that a power source of 330 kA with an amplifier, an oscillator, a three phase synchronous generator of 2 KVA and180 Hz were used. The oscillator for controlling frequency and amplitude of the injected current and synchronous generator for controlling current were put into practice. Also the experiment on the double star rectifier for the harmonic reduction by injection of the ninth harmonic current was conducted which also showed satisfactory results. It was also analyzed and concluded that for effective reduction of the components greater than the ninth order the value of the harmonic order of the injected current with K=9 was more effective than K=3.

The induction motors are the major cause of disturbing the refined supply of the supply network and introducing harmonics. For the speed control of the induction motor a number of methods are employed but the basic is a rectifier inverter arrangement. The alternating current used by the rectifier contains many harmonics. To remove this, a number of remedies have been suggested. In each of these remedies it was being proposed as to how to reduce the harmonic current of the current obtained by the rectifier. In the induction motor most of the speed control is done by controlling the supply voltage and frequency. Thus a rectifier and inverter arrangement is needed. The input to the rectifier is the supply current full of harmonics from inverter.

Passive tuned filters were widely used for this purpose. They were simple but expensive. Other approaches also used active filters but they made the circuit too complex. Bird introduced a new technique of reducing third harmonic content in the input of the rectifier. Blake first used the harmonic current to static converters in a double star rectifier. But all the injection technique mentioned earlier required an extra source and also the frequency of the injected current needed to be adjusted with the supply current. For fast and active drives both the magnitude and the phase of the injected current needs to be controlled. In the technique proposed by Lawrence and Mielczarski a L-C tuned filter was used to remove the third harmonic from the output of the uncontrolled rectifier and injecting the current into the star point of the DC winding. But in this technique the magnitude of the injecting current needed was controlled manually and thus for active drives it was not an alternative.6

The novel method in [10]-[12], available for reducing the third harmonic in the current fed to the rectifier of the induction motor requires injection of current to the neutral point of the DC winding of the rectifier. Although, the method was applied to the induction motor driven by VSI but the experimental results showed that it was capable of reducing the harmonic content in the line current generated by the drive system. The scheme consisted four switch resistor set. The value of the resistors R1 and R2 were selected following a procedure. A figure to illustrate the implementation of the novel method is as below.

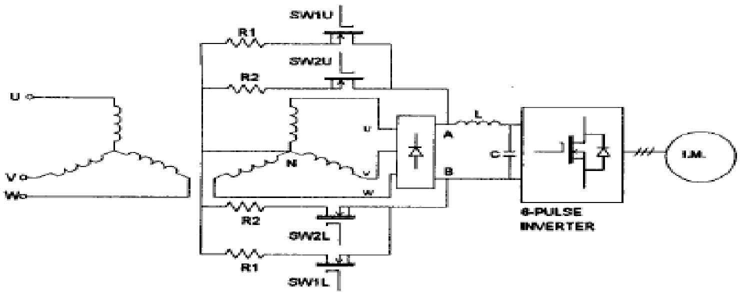

Figure 6: The arrangement of the circuit used in the novel method

The figures presented below show how the injected current in each phase affects the original waveform and achieves the reduction in harmonics.

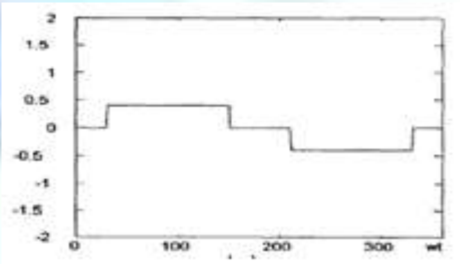

Figure 7.Line current without injected current

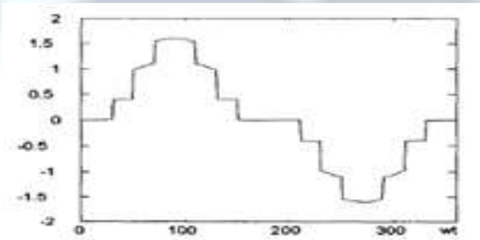

Figure 8.Line current with injected current

The figure for injected current in each of the phases is given below:

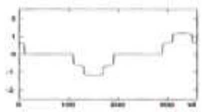

Figure 9.Injected Current in phase A

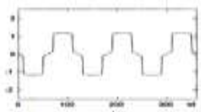

Figure 10.Injected Current in phase B

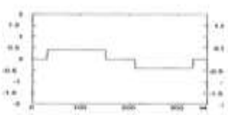

Figure 11.Injected Current in phase C

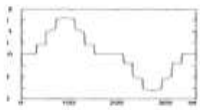

Figure 12.Resultant Injected Current of three phases

Through simulation and experiments it was being shown that the modulation index change, greatly affected the THD (Total Harmonic Distortion). It was deduced that a minimum THD of 1.8% occurs at a modulation index of 0.65. Through the experiments it was found that although the value of the injected current through the two sets of the switch resistor pin needs to be maintained but a general value of 1.2 Ampere for first upper set and 0.75 Ampere for second upper set worked well for almost every case. With these values a minimum THD of 3.6% was obtained at a modulation index of 0.6. A table was deduced at the modulation index of 0.65 and it was thus found that THD in line current by employing the method was reduced from 25% to 3.5%.

The induction machine equipped with Solid State Voltage Controllers (SSVCs) not only suffer from bad power factor, high reactive power, low efficiency but also generate and inject harmonic distortions in the supply line. To reduce the injection of these harmonic current in the supply line a Shunt Harmonic Filter (SHF) was thus used. Its filter was tuned to one or more frequencies and thus was used to remove frequencies close to these frequencies. One of the basic drawbacks SHF faced was in the variable speed induction motor having SSVCs with voltage distortions. When there are voltage distortions a certain harmonic component with high RMS value is present in the distorted current. Moreover, SHFs aggravate the problem by amplifying some of the voltage harmonics. The induction machines with SSVCs especially the group of induction machines, thus suffer from two drawbacks: a High Reactive Power and a Harmonic current injection in the supply line.

Thus the design of the devise, to protect the injection of harmonic current in the supply line, should be a function of the overall reactive power of the drives and also the harmonic currents generated by all the drives. Since this is hard to determine the tuning of the filter in the SHFs is thus a ponderous task.

A study conducted on the induction machine in [13]-[17], showed that with the reduction of the speed of the machine the reactive power as well as the current distortions increase rapidly. Thus this high CHD in SSVCs cause High Voltage Distortions.

In one of the experiments it was shown that if in SHF lowest harmonic is fifth then the frequency will be adjusted between fifth and seventh harmonic. In that, at a slip of 0.13, with low voltage distortion the seventh harmonic has a relatively high RMS value but if the voltage distortions exceeds the acceptable limits then it is the eleventh harmonic along with the fifth harmonic that has a dominant effect and hence the adjustment of the SHF filters to frequencies between fifth and seventh will fail to work.

Thus a new devise for the purpose of removing the CHD came into practice as Harmonic Blocking Compensator (HBC). It is built per phase with the capacitor which reduces reactive power. Thus it resembles Electromagnetic Interference Filters. It has a high impedance path for the high voltage distortions and the low impedance choke shunt path for the load generated current. The following figure shows the circuit structure.

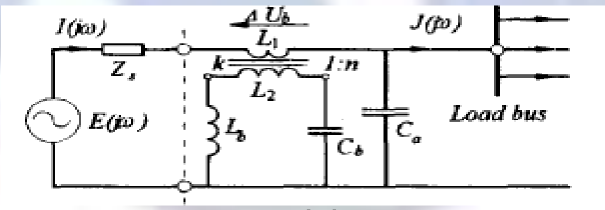

Figure 13.Harmonic Blocking Compensator

It has a disadvantage of suppressing the harmonic content at the cost of fundamental voltage drop across the series impedance which can be improved by adding a series resonance at fundamental frequency. An experiment conducted to compare the performance of SHF and HBC in [13] showed that HBC is capable of removing all harmonics except second. Also, in HBC the power loss in comparison to SHF is quite low. They occur due to the hindrance produced by the series impedance in the flow of fundamental current whereas in SHF they occur due to reactive fundamental component and the current harmonics in the resistance of the filter the sum of which is much higher. Also the power rating of the shunt capacitor in HBC is also quite low. Thus the experimental results verified the supremacy of the new HBC over SHF.

In the Photo Voltaic systems inverters are used to convert the final DC to AC for the commercial use thus the output contains harmonics. One of the most important method to achieve harmonic reduction is by the help of adjusting the SPWM (Sinosodal Pulse Width Modulation). With certain adjustment in the control signal it was found that a very desirable result could be yielded. The international standards set for Total Harmonic Distortion (THD) say that it should be less than 5% and voltage harmonics should be less than 2%. In Photo Voltaic Systems it is highly desirable to have low harmonic content, high power factor and low Electromagnetic Interference (EMI). The output of the inverter is full of harmonics and is highly unacceptable. A recent study in [18]-[20], showed that this can be controlled by controlling the carrier signal. In the most basic SPWM there are two waves one is a Carrier triangular wave and the other is a sinusoidal wave. It was, in the experiment, found that if the peak value of the sine wave was less than half the maximum magnitude of the triangular wave then the harmonics less than 2A are eliminated, where $A=\frac{\text{Sine Wave}}{\text{Triangular Wave}}$ or the number of voltage pulses per half cycle.

It was also found that SPWM reduces further harmonic contents at the inverter if the carrier wave pulses are increased in the half cycle. Thus modulation with the high frequency carrier signal shifts the higher order harmonics to yet higher frequencies which can be removed with the help of LC filter with small sized inductor and capacitor. In the experiment conducted for the same it was proved that if the input voltage to the inverter be 12Volts and the power input is 1Kilo Watt and also the output is also 240Volts, 50 Hz, then by increasing the frequency of the carrier the THD can be reduced from 80.5% to 55.29%. After that AC filters designed with the purpose of removing the frequencies between 150 Hz to 1.5 KHz can reduce THD to 0.41817%.

A TCR (Thyristor control reactor) and TSC (Thyristor Control Switch) set is used now-a-days for reactive power compensation. It is a dire need to ensure that no distortions are injected into the system on their part. The determination of optimum firing angles for the minimization of the THD (Total Harmonic Distortion) caused by TCR and TSC is of utmost importance. For the same reason the neural networks were also introduced so that they can take quick decisions as to what should be the firing angle. A basic circuit for the TSC and TCR is as follows:

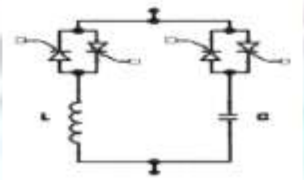

Figure 14.TSC and TCR combination

If the firing angle for TSC and TCR be Ω and θ respectively then it was shown that there are two cases for harmonic reduction in TSC and TCR. These are:
a) A single capacitor and variable firing angle
b) A Capacitor Bank with different firing angle
It was shown in the experiment in [21]-[24], that with one capacitor and different firing angle for positive reactive power the minimum THD occurs at (Ω=0°) and the same occurs for the negative reactive power at (Ω=180°). This was verified by choosing a specific requested power of ±5MVar and the table was thus formed verifying the above result. It was also shown in the experiment that the THD was lowest when maximum capacitors existed in the circuit. For this it was observed that with 0.2MVar power the best results were obtained when 6 capacitors existed with θ=90.5° and with requested power of -2.5MVar the best results come for θ=91.8° with 7 capacitors.

Thus it is a dire need to select the value of θ once this has been proved that what should be the value of Ω for minimum THD. For this an artificial neural network was proposed where for every requested reactive power a data is fed as to at what angle 'θ', the minimum THD will occur. Thus it compares its own produced values with the value of θ as soon as the analytical value matches the theoretical value the firing angle for that reactive powers are obtained. A block scheme for such a neural network was proposed which resembled as follows:

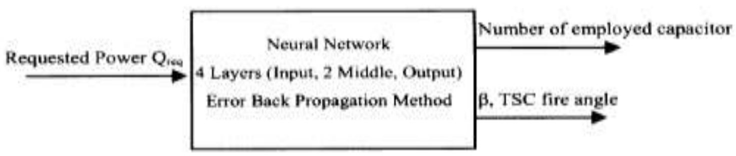

Figure 15.The block diagram of the proposed neural network

Through the experiment it was found to be extremely suitable for fact switching.

In [25]-[27] a new design for the inverter was proposed. This new design was free of the complicated circuitry and the design was such that it would work with 36 pulses and then the motor is fed with a highly sinusoidal current. Furthermore, the same technique was implemented on the rectifier end, so that an effective harmonic reduction would be possible at both the ends of the system i.e., the motor as well as the ac supply system. The analysis and verification of the complete system was done by setting up a 20-kVA laboratory development drive system. The experimental waveforms for the conventional (12-pulse) and proposed (36-pulse) configurations were presented. The display of the waveforms proved the possibility of transforming the operation of variable speed synchronous motor systems from 12 to 36 pulses. The need of the filtering at the rectifier end as well as the reducing considerably problems at the inverter end, namely; a high inverter commutation angle and additional rotor-heating and pulsating electric torque in the motor were eliminated by this higher pulsation. This novel proposition seemed to offer economic and functional benefits to the user and provide opportunities to the system designer to optimize system design and performance.

In [28] the performance of Zig-Zag transformer is analysed by comparing THD of source current. Simulations and laboratory tests helped to understand the performance of the same under unbalanced nonlinear load. Both, simulations and the laboratory tests affirmed that the Zig-Zag transformer is capable of reducing the harmonics in line as well as neutral and attenuating the neutral current in the distribution system. Also, the Zig-Zag transformer is capable of balancing the three- phase currents due to cancelling of the zero sequence current. It is evident from the results that the THD and neutral current of three-phase four-wire distribution system under the unbalanced nonlinear load becomes much reduced after applying the Zig-Zag transformer.

In [29]-[30], an attempt was made to use comb filter for harmonics reduction of the envelope cycloconverter output voltage waveforms. The practicability of using comb filter for selective elimination of harmonic components for the cycloconverter output waveforms was proved by the practical investigations made in the same paper. It was found that the THD was highly reduced and near sinusoidal output voltage and current waveforms were produced. This method also proved to be more effective that the other contemporary methods like increasing the phases of the input or using circulating mode. The described system could be of practical value with a minimum number of components in replacing the conventional phase or envelope cycloconverter circuits for speed control of induction motors.

In [31], synchronized phase shifted parallel PWM inverters with current-sharing reactors were employed for the harmonics reduction. This technique presented inverter output distortion could be reduced significantly, for example total harmonic reduction could be reduced typically in half using just two synchronized phase-shifted parallel inverters (the simulation and experimental studies indicate that even smaller distortion reduction factors can be achieved).

In [32]-[34], a high order harmonic injected PWM is presented to reduce the harmonic content to meet the IEC 555-2(A) standard for a 5-10kW power application without significantly increasing the output. A prototype converter operating at 800V, 6kW with 3x220V input was used to verify the results. By using this method, the THD in single-switch rectifier is improved.

In the application like wind energy where matrix converters are used a large amount of harmonic current is injected into the grid which is highly undesirable. Although, the matrix converters control both the voltage and frequency of generation independently but at the same time in doing so matrix converters operated in PWM switching mode, inject lower order current harmonics and also, switching current harmonics. In an experiment it was shown that if a 5HP, 50Hz, 3-phase, 4 pole induction machine was driven at a speed of 550 RPM and the synchronous speed was maintained at 500 RPM with the converter switching frequency of 2400 Hz, the converter on the grid side injected grid current THD of 200.85% and the grid current harmonics were 33.78%. In order to remove this flaw two novel techniques were verified experimentally in [35] for reducing harmonics from matrix converters. These were different arrangements of the converters:

[1]. Dual configuration
[2]. Quad configuration

- In the dual configuration Induction generator (IG) i.e. the IG-I and the IG-II were connected to the zigzag transformer having $\pm 15°$phase shift to the input voltage. Thus with the voltage shift provided at the grid end current also got shifted and thus certain current harmonics got cancelled. The overall THD was reduced from 200.86% to 191.39%. After this the use of low pass filter reduced THD from 33.78% to 9.66%.

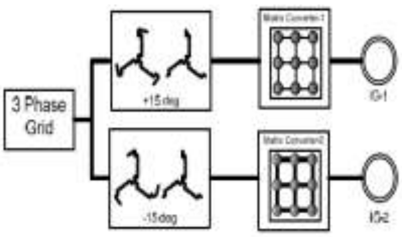

Figure 16.The Dual Configuration

- In the Quad connection there were two pairs of zigzag transformers having $\pm 22.5°\ and\ \pm 7.5°$ phase shifts to the input voltage. Here even better results were obtained and the THD was reduced from 9.66% to 3.63%. Thus the experimental results showed the effectiveness for the novel methods.

In the novel method presented in [36] a new and economical technique was proposed to reduce the harmonics. In this a petrochemical plant was considered with 53-Buses and 7-generators. Also 12-pulse 4 electric drive systems were

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considered with the power rating of 4-5 Mega Watt. The new technique involved the use of nonlinear programming technique. The programming was done on the basis of generalized reduced gradient method to ensure simple software structure. Also, for further harmonic reduction passive filters were used which further minimized the cost of the systems.

In case of High Voltage Booster (HVB) railway line, because of the increasing traffic it is a dire need to reduce the harmonics in the voltages and the currents of the line. To do this a novel method in [37]-[41], was presented wherein an arrangement of the third harmonic filter along with the saturable reactor in series with the Thyristor Controlled Reactor (TCR) was used. It was shown that in order to reduce the harmonics only upto 30 mA in 25 kV, 50 Hz single phase line a multiplying factor of 20 was needed. It was observed that the TCR branch injects a lot of harmonics in the electrical line which can be reduced with the help of saturable reactor and the tuning filter.

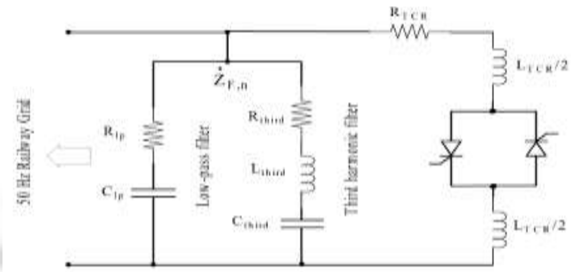

Figure17.The design of the Tuning filter used in the HVB line

It was shown that adjusting the harmonic impedance of the filter reduced the third harmonic. Further, it was shown that still in order to bring the harmonics to the adjustable limits a saturable reactor was used which reduced the harmonic current introduced by TCR switching. In this saturable reactor a harmonic injection scheme was also introduced to further reduce harmonic levels. Thus a highly desirable result was obtained.

Multilevel converters in order to obtain a low THD (Total Harmonic Distortion) have a high switching frequency. The power systems have a limitation on switching frequency. Thus a desirable method would be one in which a low switching frequency could yield the same result. A novel method was thus proposed in [42] where a wide range of modulation index was obtained and a relatively low switching was done. A generalization in the harmonic optimization technique yielded a single switch per cycle for power devices. The basic concept was that in place for switching, a swapping of the voltage levels was done to obtain high range of modulation index. Through an experiment it was shown that in 7-level converter with traditional method a modulation index of 0.5 to 1 was observed and with the new method a variety of modulation index were observed even below 0.5. In order to remove harmonic component it showed that the variable polarities may be connected according to the formulae:

$Yn= \frac{4}{n\pi}[V1\cos(n\alpha1)\pm V2\cos(n\alpha2)....Vm\cos(n\alpha m)]$

Where; m = Number of switching angles;
(2m+1) = levels of the converter; αm= switching angle;
n = harmonic to be reduced

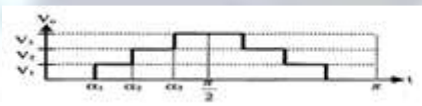

Figure 18.The positive half cycle for seven level stepped waveform with High modulation index

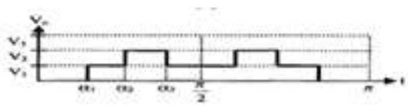

Figure 20.The positive half cycle for seven level stepped waveform with Medium modulation index

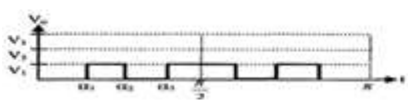

Figure 21.The positive half cycle for seven level stepped waveform with Low modulation index

In the figure the rising edge denoted positive polarity for corresponding cosine terms and accordingly negative was governed. Thus by adjusting positive and negative sign with a low switching wide modulation index was obtained.

References

[1]. Fu Jiang Liao, Ming Hui Hu And Shao Yun Ma, “The Second Harmonic Reduction In Helix Travelling Wave Tubes”, 1-4244-0633-1/07/$20.00@ 2007 IEEE.

[2]. Wohlbier ,John G. Booske ,John H And Dobson Ian. , “On The Physics Of Harmonic Injection In A Traveling Wave Tube” [J].IEEE Transactions On Plasma Science, June 2004, 32(3).

[3]. N. Dionne, “Harmonic Generation In Octave Bandwidth Traveling-Wave Tubes”, IEEE Trans. Electron Devices, Vol. Ed-17, Pp. 365–372, 1970.

[4]. T.A.Brunasso, “A Large Signal Analysis Program For Helix Traveling Wave Tubes”, Ad-A181111 Mf.

[5]. James A.Dayton, Jr., Hsiung Chen, And Carol L.Kory, “Diamondstudded Helical Traveling Wave Tube”IEEE Trans On Electron Devices Vol.52, No.5, Pp.695-700, May 2005.

[6]. A. Ametani, M.Sc, M.I.E.E.J., Mem.I.E.E.E., “Generalised Method Of Harmonic Reduction In A.C.-D.C. Converters By Harmonic Current Injection”, Proc.Iee, Vol.119,No. 7, July 1972, Pp. 857-864.

[7]. Ametani, A.: Japanese Patent Application 46-057215.

[8]. Ametani, A.: Japanese Patent Application 46-066801.

[9]. Bird, B. M., Marsh, J. F., And Mclellan, P. R.: Harmonic Reduction In Multiplex Convertors By Triple Frequency Current Injection', Proc.Iee, 116, (10), Pp.1730-1734.

[10]. Amr M. A. Amin, “Line Current Harmonic Reduction In Adjustable-Speed Induction Motor Drives By Harmonic Current Injection”, IEEE Catalog Number: 97th8280.

[11]. IEEE Guide For Harmonic Control And Reactive Compensation Of Static Power Converters, IEEE Std. 519, 1981 (Updated 1989).

[12]. A. M. A. Amin, J. E. Steelman And L. M. El-Sayed, “Power System Harmonics: Where Do We Stand?”,Ideas In Science And Electronics Proceedings, Albuquerque, New Mexico, April 29-May 30,1986, Pp. 9-16.

[13]. Leszek S. Czamecki, Sm, IEEE Owen T. Tan, Sm, IEEE, “Evaluation And Reduction Of Harmonic Distortion Caused By Solid State Voltage Controllers Of Induction Motors”, IEEE Transactions On Energy Conversion, Vol. 9, No. 3. September 1994.

[14]. W. Mcmurray, "A Comparative Study Of Symmetrical Three Phase Controlled Ac Motor Drives", IEEE Trans. On Ias, Vol.10, 110.3,P P.403411, Mayljune 1974.

[15]. The Emc Handbook Series, "Em Control Methodology And Procedures", Vo1.8, Interference Control Techn., Gainesville, 1992.

[16]. J.C.A. Forest, B.S. Ram, G.W. Swift, "Measurement Of Converter Transformer Loss At Harmonic Frequency", Proceedings Of The 2nd Intern.Conf.On Harmonics In Power Systems, Manitoba, 1986.

[17]. IEEE Std. 519-1981, "IEEE Guide For Harmonic Control And Reactive Compensation Of Static Power Converters".

[18]. A.Z.M.Shahriar Muttalib, S.M.Ferdous, Ahmed Mortuza Saleque, Nawjif Md. Anamul Hasan, “Design And Simulation Of An Inverter With High Frequency Sinusoidal Pwm Switching Technique For Harmonic Reduction In A Standalone/ Utility Grid Synchronized Photovoltaic System”, IEEE/Osa/Iapr International Conference On Informatics, Electronics & Vision.

[19]. Arman Roshan, “A Dq Rotating Frame Controller For Single Phase Full Bridge Inverters Used In Small Distributed Generation System”, M.Sc.

[20]. Thesis, Faculty Of Virginia Polytechnique Institute And State University, Jun., 2006,Patel, Mukund R., “Wind And Solar Power System”, 2nd Ed., Crc Press, Usa, 2008.

[21]. A.H. Gheisari, M.M. Bazratkan, A. Seifi, “Harmonic Reduction In Tcr And Tsc Using Artificial Neural Network”, IEEE.

[22]. Yuanyuan Sun Weijie Zheng Xu, W., "A New Method To Model The Harmonic Generation Characteristics Of The Thyristor Controlled Reactors", Power Tech, 2007 IEEE Lausanne, P.P 1785 - 1790, 1-5 July 2007 .

[23]. Hedayati, M. , "Technical Specification And Requirements Of Static Var Compensation (Svc) Protection Consist Of Tcr, Tsc And Combined Tcr/Tsc", Universities Power Engineering Conference, 2004. Upec 2004. 39th International, P.P 261 - 264 Vol. 1,6-8 Sept. 2004.

[24]. Leonardo T. G. Lima, Adam Semlyen, M. R. Iravani, "Harmonic Domain Periodic Steady State Modeling Of Power Electronics Apparatus: Svc And Tcsc", 2003 IEEE.

[25]. Miguel Villablanca, Wilfredo Ziehlmann, Cristian Flores, Carlos Cuevas, And Patricio Armijo, “Harmonic Reduction In Adjustable-Speed Synchronous Motors”, IEEE Transactions On Energy Conversion, Vol. 16, No. 3, September 2001, Pp. 239-245.

[26]. J. F. Baird And J. Arrillaga, “Harmonic Reduction In Dc-Ripple Reinjection,” Iee Proc.—C, Vol. 127, No. 5, Pp. 294–303, Sept. 1980.

[27]. A. Ametani, “Generalized Method Of Harmonic Reduction In Ac–Dc Converters By Harmonic Current Injection,” Proc. Iee, Vol. 119, No. 7, Pp. 857–864, July 1972.

[28]. S.Ranjith Kumar, S.Surendhar, Ashish Negi And P.Raja, “ Zig Zag Transformer Performance Analysis On Harmonic Reduction In Distribution Load”, International Conference On Electrical, Control And Computer Engineering Pahang, Malaysia, June 21-22, 2011.

[29]. Mohammed S. Mohammed Ali Khesbak, And Mohammed T. Lazim, Mahmoud Zeidan, “Envelope Cycloconverter Harmonic Reduction Using Comb Filter”, 6th International Multi-Conference On Systems, Signals & Devices, 2009.

[30]. C. Lander, "Power Electronics", Second Edition, Mcgraw Hill, England, 1987.

[31]. Nacer Benaifa, Hussain Bierk, Abu Hamed M. A. Rahim And Ed Nowicki, "Analysis Of Harmonic Reduction For Synchronized Phase-Shifted Parallel Pwm Inverters With Current Sharing Reactors", 2007 IEEE Canada Electrical Power Conference.

[32]. Qihong Huang And Fred C. Lee, "Harmonic Reduction In A Single-Switch, Three-Phase Boost Rectifier With High Order Harmonic Injected Pwm", 0-7803-3500-7/96/$ 5.00 0 1996 IEEE.

[33]. Prasad, P. D. Ziogas, And S. Manias, "An Active Power Factor Correction Technique For Three Phase Diode Rectifiers", Conference Record IEEE Pesc 1989, Pp. 58-65.

[34]. L. Simonetti, J. Sebastian And J. Uceda, "Single-Switch Three-Phase Power Factor Preregulator Under Variable Switching Frequency And Discontinuous Input Current", Conference Record IEEE Pesc 1993, Pp. 657-662.

[35]. Shankar Subramanian, Student Member, IEEE, J.K.Chatterjee, Member, IEEE, V. Rajasekhar, Adapa Kondalarao, "Reduction Of Grid Current Harmonic Injection In Matrix Converter Controlled Induction Generator For Wind Applications", 978-1-4577-1510-5/11/$26.00 ©2011 IEEE.

[36]. E. Detuglie, M. Dicorato, M. La Scala, T. Brescia, A Minimal Cost Design For A Harmonic Reduction System: A Petrochemical Plant Example.

[37]. Loris Zanotto, Roberto Piovan, Vanni Toigo, Elena Gaio, P. Bordignon, Tito Consani, And M. Fracchia, "Filter Design For Harmonic Reduction In High-Voltage Booster For Railway Applications", IEEE Transactions On Power Delivery, Vol. 20, No. 1, January 2005, Pp. 259-263.

[38]. M. Fracchia Et Al.. High Voltage Booster For Railway Applications. Presented At The World Congress On Railway Research. [Online]. Available: Http://Www.Sncf.Com/Wcrr/Sp/278.Pdf

[39]. M. Crappe Et Al., "High Voltage Booster For Railways," In Proc. 7th Eur. Conf. Power Electronics Applications, Lausanne, Suisse, 1999.

[40]. S. Bacha Et Al., "Using Svc For Voltage Regulation In Railways Network High Voltage Booster European Project," In Proc. 9th Eur. Conf. Power Electronics Applications, Graz, Austria, August 27–29, 2001.

[41]. Railway Applications—Electromagnetic Compatibility—Part 3-1, Eur. Std. En 50121-3-1, 1996.

[42]. Siriroj Sirisukprasert, Jih-Sheng Lai, Tian-Hua Liu, "Optimum Harmonic Reduction With A Wide Range Of Modulation Indexes For Multilevel Converters", 0-7803-6401 -5/00/$10.00 0 2000 IEEE.