ISSN (Online) : 2319 – 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization, Volume 3, Special Issue 1, February 2014

International Conference on Engineering Technology and Science-(ICETS'14)

On 10th & 11th February Organized by

Department of CIVIL, CSE, ECE, EEE, MECHNICAL Engg. and S&H of Muthayammal College of Engineering, Rasipuram, Tamilnadu, India

Harmonic Minimization for Cascade Multilevel Inverter based on Genetic Algorithm

Ranjhitha.G[1], Padmanaban.K[2]

PG Scholar, Department of EEE, Gnanamani College of Engineering, Namakkal, India [1]
Assistant Professor, Department of EEE, Gnanamani College of Engineering, Namakkal, India[2]

Abstract— Multilevel inverter have been attracting increasing interest recently due to the increased power rating, improving harmonic performance, and reduced electromagnetic inference (EMI) emission. In this project, a genetic algorithm (GA) optimization technique is applied to 7-level cascaded multilevel inverter which determines optimum switching angles to eliminate 5th and 7th order harmonics. Genetic Algorithm is developed as the preferred solution algorithm of specific harmonic elimination (PWM-SHE) switching pattern. This project describes an efficient genetic algorithm that reduces significantly the computational burden resulting in fast convergence. The output voltage contains harmonics the different type of harmonics elimination methods are available. But all the method having some limitations. This project deals with how to reduce the particular harmonics in the output voltage of inverter. The concept of the harmonic stepped waveform technique for the multilevel inverter to be presented. By applying this concept, selected harmonic can be eliminated, and the output voltage THD can be improved. A procedure to achieve the appropriate switching angle is to be proposed. The proposed project is to be simulated by using MATLAB.

Keywords— Multi level inverter, Selective harmonic elimination, Genetic algorithm, Total harmonic distortion

I. INTRODUCTION

Nowadays high quality power is needed for medical, research and industrial applications to bring into being good quality results and for accurate evaluation. In this project, an attempt has been made to improve the quality of power. A seven level cascaded multi level inverter with identical dc supply is designed to reduce the harmonic components of the output voltage. Multilevel inverters continue to receive more and more attention because of their high voltage operation capability, low switching losses, high efficiency and low output of electromagnetic interference (EMI). The preferred output of a multilevel inverter is synthesized by several sources of dc voltages. With an increasing number of dc voltage sources, the inverter voltage waveform approaches a nearly sinusoidal waveform while using a low switching frequency scheme. This results in low switching losses, and because several dc sources are used to synthesize the total output voltage, each experiences a lower dv/dt compared to a single level inverter. Consequently, the multilevel inverter technology is a promising technology for high power electric devices such as utility applications. Selective Harmonic Elimination Pulse Width Modulation (SHE-PWM) has been intensively studied in order to achieve low THD. The common characteristic of the SHE-PWM method is that the waveform analysis is performed using Fourier theory.

The main objective of this project is to introduce a minimization technique assisted with Genetic Algorithm (GA) in order to reduce the computational burden associated with the solution of the nonlinear transcendental equations of the selective harmonic elimination method. An accurate solution is guaranteed even for a number of switching angles that is higher than other techniques would be able to calculate for a given computational effort.

The proposed system uses adaptive selective harmonic minimization method to minimize the harmonics in the case of cascade multilevel inverters. The cascaded multilevel inverter consists of a series of H-bridge inverter units. It consists of three H-bridges, each bridge module comprises of four Gate turn-offs Thyristor (GTO). Multilevel inverters offers several advantages such as, its capabilities to operate at high voltage, high efficiency, and low electromagnetic interference (EMI). Cascade Multilevel Inverter (CMLI) requires least number of components with compare to diode-clamped and flying capacitors type multilevel inverters and no specially designed transformer is needed as compared to multi pulse inverter. It has modular structure with simple switching strategy and occupies less space.

Selective Harmonic Elimination Pulse Width Modulation (SHE-PWM) has been intensively studied in order to achieve low THD. This method is to minimize the harmonics by determine the optimum switching angles for equal dc sources. Sets of non-linear transcendental equations are then derived using Fourier theory. The proposed approach is to choose the switching angles of both lower and higher order harmonics such as the 5th, 7th, 11th, and 13th are suppressed in the output voltage of the inverter.

A GA will be implemented to find the switching angles (offline) for a set of predetermined input voltages for a 7-level cascade inverter. We can avoid overhead and no-solution conditions by using the generalization shown in Fig. 2.ability of Genetic algorithm. Since GA runs fast, it is possible to quickly determine the switching angles to realize real-time control. The output of the multilevel inverter is fed to the second order low pass filter in order to reduce harmonic level and to get sinusoidal waveform.

II. SEVEN LEVEL CASCADED H-BRIDGE INVERTER

The Cascade Multilevel Inverter (CMLI) is one of the most important topology in the family of multilevel and multi pulse inverters. It requires least number of components with compare to diode-clamped and flying capacitors type multilevel inverters and no specially designed transformer is needed as compared to multi pulse inverter. It has modular structure with simple switching strategy and occupies less space.

The cascaded H-bridges multilevel inverter is a relatively new inverter structure. It is proposed here to solve all the problems of the multilevel inverters as well as conventional multi pulse (PWM) inverters. This new multilevel inverter eliminates the excessively large number of

1) Bulky transformers required by conventional multi pulse inverters.
2) Clamping diodes required by multilevel diode clamped inverters.
3) Flying capacitors required by multilevel flying capacitor inverters.

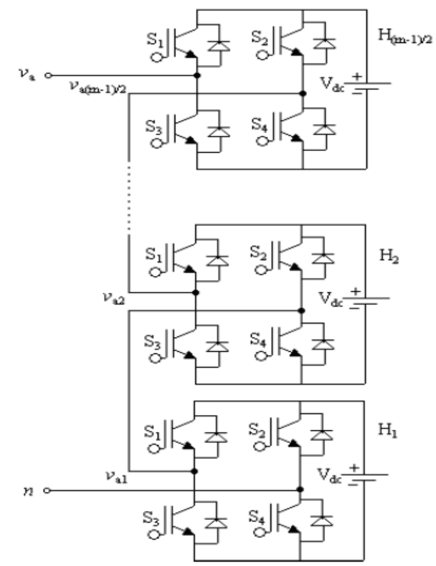

Fig. 1 Configuration of single-phase cascade multilevel inverter

The cascaded H-bridges multilevel inverter is simply a series connection of multiple H-bridge inverters. The Configuration of single-phase cascade multilevel inverter shown in Fig. 1.Each H-bridge inverter has the same configuration as a typical single-phase full-bridge inverter. The CMLI consists of a number of H-bridge inverter units with separate dc source for each unit and is connected in cascade or series as shown in Fig. 2. Each H-bridge can produce three different voltage levels: +Vdc, 0, and –Vdc by connecting the dc source to ac output side by different combinations of the four switches S1, S2, S3, and S4. The ac output of each H-bridge is connected in series such that the synthesized output voltage waveform is the sum of all of the individual H-bridge outputs. By connecting the sufficient number of H-bridges in cascade and using proper modulation scheme, a nearly sinusoidal output voltage waveform can be synthesized. The number of levels in the output phase voltage is 2s+1, where s is the number of H-bridges used per phase. Fig. 3 shows a 7-level output phase voltage waveform using three H-bridges. The magnitude of the ac output phase voltage is given by

$$Van = Va1+Va2+Va3.$$

ISSN (Online) : 2319 – 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization, *Volume 3, Special Issue 1, February 2014*

International Conference on Engineering Technology and Science-(ICETS'14)

On 10th & 11th February Organized by

Department of CIVIL, CSE, ECE, EEE, MECHNICAL Engg. and S&H of Muthayammal College of Engineering, Rasipuram, Tamilnadu, India

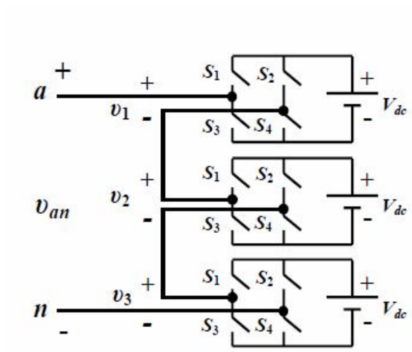

Fig. 2 Configuration of 7Level Cascade H-bridge inverter

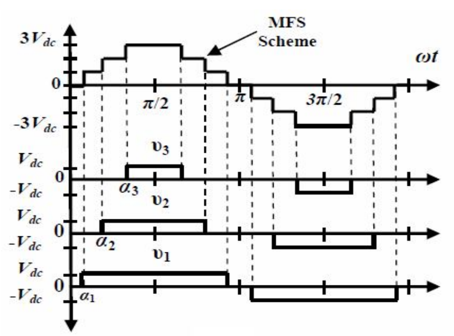

Fig. 3 7-level cascaded inverter output phase voltage waveform

TABLE I
7-LEVEL CASCADED INVERTER OUTPUT SWITCHING STATES

	Cell 1			Cell 2			Total
n	S1	S2	Va1	S3	S4	Va2	VaN
1	1	0	3Vdc	0	0	0	3Vdc
2	1	0	3Vdc	0	1	-Vdc	2Vdc
3	0	0	0	1	0	Vdc	Vdc
4	0	0	0	0	0	0	0
5	0	0	0	0	1	-Vdc	-Vdc
6	0	1	-3Vdc	1	0	Vdc	-2Vdc
7	0	1	-3Vdc	0	0	0	-3Vdc

Table I shows the switching states of H-Bridge circuit which consist of four switches such as s1, s2, s3&s4.

III. MATHEMATICAL MODELS OF SWITCHING ANGLES AND SHE EQUATIONS FOR A CASCADE MULTILEVEL INVERTER

This chapter shows how harmonic elimination is done in Inverter by Pulse Width Modulation technique by solving the non linear equations. Equations are used to determine switching angles of an Inverter. Switching angles play an important role to produce the desired output by eliminating selected harmonics. In order to form the equation set, fundamental component is given desired output value and all other harmonics are equated to zero. In my simulation I find the switching angles for the 5^{th} and 7^{th} harmonics.

In general, the Fourier series expansion of the staircase output voltage waveform as shown in Fig. 3 is given by

$$V_{an}(\omega t)= \sum 4V_{dc}/k\pi(\cos(k\alpha_1)+\cos(k\alpha_2)+..+\cos(k\alpha_s))\sin(k\omega t)$$
where k=1,3,5.. to œ
(1)

where s is the number of H-bridges connected in cascade per phase. For a given desired fundamental peak voltage V1, it is required to determine the switching angles such that

$$0 \leq \alpha_1 < \alpha_2 < \ldots < \alpha_s \leq \pi/2$$

and some predominant lower order harmonics of phase voltage are zero. Among s number of switching angles, generally one switching angle is used for fundamental voltage selection and the remaining (s-1) switching angles are used to eliminate certain predominating lower order harmonics. In three-phase power system, triplet harmonics are cancel out automatically in line-to-line voltage as a result only non-triplet odd harmonics are present in line to- line voltages.

From (1), the expression for the fundamental voltage in terms of switching angles is given by

$$4V_{dc}/\pi\,(\cos(\alpha_1)+ \cos(\alpha_2)+\ldots+ \cos(\alpha_s)) = V_1 \quad (2)$$

Moreover, the relation between the fundamental voltage and the maximum obtainable voltage is given by modulation index. The modulation index, m1, is defined as the ratio of the fundamental output voltage V1 to the maximum obtainable fundamental voltage V1max. The maximum fundamental voltage is obtained when all the switching angles are zero i.e.

$$V_{1max} = {}^{4sV_{dc}}/_{\pi}.$$

Therefore the expression for m1 is

ISSN (Online) : 2319 – 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization, Volume 3, Special Issue 1, February 2014

International Conference on Engineering Technology and Science-(ICETS'14)

On 10th & 11th February Organized by

Department of CIVIL, CSE, ECE, EEE, MECHNICAL Engg. and S&H of Muthayammal College of Engineering, Rasipuram, Tamilnadu, India

$$m_I = {\pi V_1}/{4sV_{dc}}$$

For an 7-level cascade inverter, there are three H-bridges per phase i.e. s = 3 or three degrees of freedom are available; one degree of freedom is used to control the magnitude of the fundamental voltage and the remaining two degrees of freedom are used to eliminate 5th, and 7th order harmonic components as they dominate the total harmonic distortion. The above stated conditions can be written in following way by combining (1) and (3);

$$\cos(\alpha_1) + \cos(\alpha_2) + \cdots + \cos(\alpha_5) = 5m_I$$
$$\cos(5\alpha_1) + \cos(5\alpha_2) + \cdots + \cos(5\alpha_5) = 0$$
$$\cos(7\alpha_1) + \cos(7\alpha_2) + \cdots + \cos(7\alpha_5) = 0 \quad (4)$$

In general, (4) can be written as

$$F(\alpha) = B(m_I) \quad (5)$$

The (4) is a system of two transcendental equations, known as selective harmonic elimination (SHE) equations, in terms of three unknowns' α1, α2 and α3. For the given values of m1 (from 0 to1), it is required to get complete and all possible solutions of (4) when they exist with minimum computational burden and complexity.

Here it is shown that all possible solutions for any number of levels can be computed by proper implementation of the Genetic Algorithm without knowing any specific initial guess and range of modulation index for which solutions exist.

IV. GENETIC ALGORITHM TO CALCULATE OPTIMUM SWITCHING ANGLES

The limitations of the Newton Raphson method is eliminated by using genetic algorithm based optimization technique. The switching angles are determined using GA.The steps for formulating a problem and applying a GA are as follows:

1. Select binary or floating point strings.
2. Find the number of variables specific to the problem; this number will be the number of genes in a chromosome. In this application the number of variables is the number of controllable switching angles which is the number of H-bridges in a cascaded multilevel inverter. A seven-level inverter requires three H-bridges; thus, each chromosome for this application will have three switching angles, i.e., (ϴ1, ϴ 2, ϴ 3).
3. Set a population size and initialize the population. Higher population might increase the rate of convergence but it also increases the execution time. The selection of an optimum-sized population requires some experience in GA. The population in this project has 20 chromosomes, each containing three switching angles. The population is initialized with random angles between 0 degree and 90 degree taking into consideration the quarter-wave symmetry of the output voltage waveform.
4. The most important item for the GA to evaluate the fitness of each chromosome is the cost function. The objective of this study is to minimize specified harmonics; therefore the cost function has to be related to these harmonics.

In this work the fifth and seventh harmonics at the output of a seven-level inverter are to be minimized. Then the cost function (f) can be selected as the sum of these two harmonics normalized to the fundamental,

$$f(ϴ1, ϴ2, ϴ3) = 100(|V5| + |V7|)/V1$$

For each chromosome a multilevel output voltage waveform is created using the switching angles in the chromosome and the required harmonic magnitudes are calculated using FFT techniques.

The fitness value (FV) is calculated for each chromosome inserting. In this case,

$$FV(ϴ1, ϴ2, ϴ3) = 100(|V5| + |V7|)/V1$$

The switching angle set producing the maximum FV is the best solution of the first iteration.

5. The GA is usually set to run for a certain number of iterations (100 in this case) to find an answer. After the first iteration, FVs are used to determine new offspring. These go through crossover and mutation operations and a new population is created which goes through the same cycle starting from FV evaluation. Sometimes, the GA can converge to a solution well before 100 iterations are completed. To save time, in this project, the iterations have been stopped when the absolute value of the cost function goes below 1, in which case the sum of the fifth and the seventh harmonics is negligible compared to the fundamental. Note that after these iterations, the GA finds one solution; therefore, it has to be run as many times as the number of solutions required to cover the whole modulation index range. The algorithm to find the optimum switching angles is described through the flow chart shown in Fig. 4.

ISSN (Online) : 2319 – 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization, Volume 3, Special Issue 1, February 2014

International Conference on Engineering Technology and Science-(ICETS'14)

On 10th & 11th February Organized by

Department of CIVIL, CSE, ECE, EEE, MECHNICAL Engg. and S&H of Muthayammal College of Engineering, Rasipuram, Tamilnadu, India

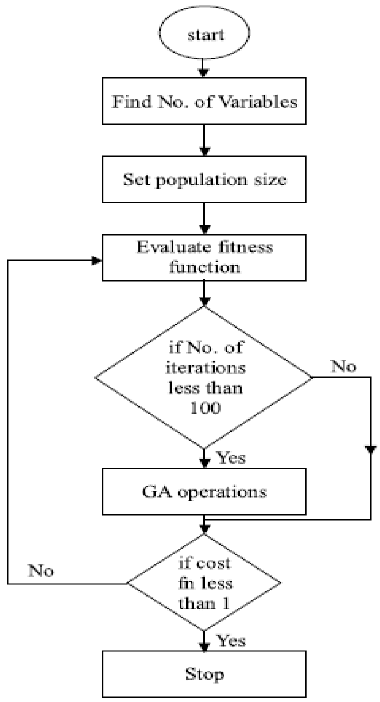

Fig. 4 Genetic algorithm flow chart

V. SIMULATION AND RESULTS

The single phase cascaded seven level inverter using PWM technique and switching angle variation technique are simulated with the use of MATLAB R2007b.For seven level inverter three H-bridges are needed for simulation. GTO switches are used as power switches. Figure 5 shows the simulation circuit for seven level inverter using PWM technique

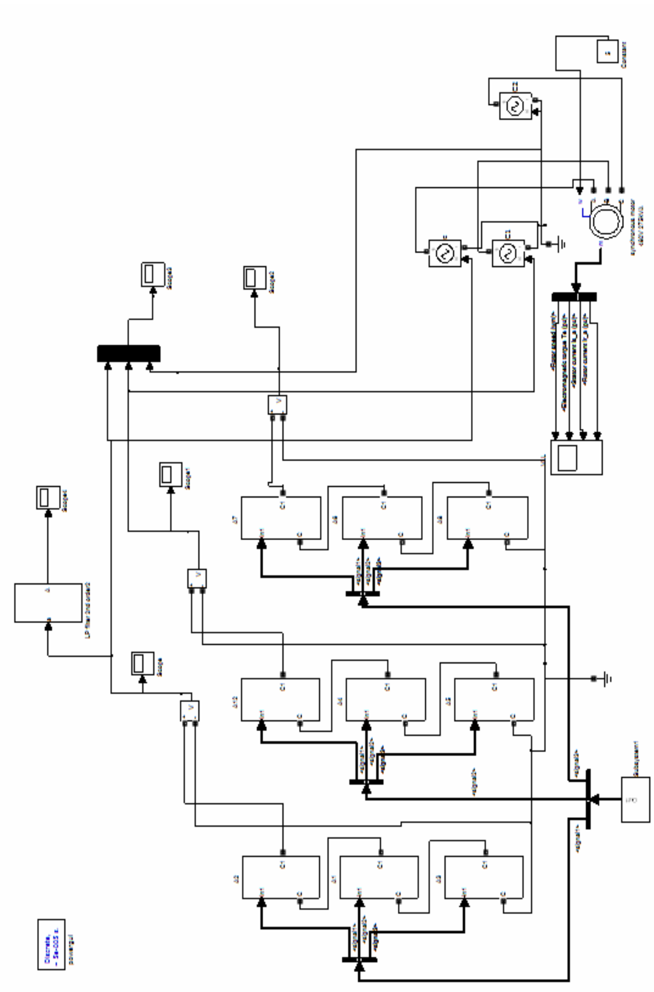

Fig. 5 Simulation diagram of proposed system

The proposed simulation diagram consists of three phase multilevel inverter and each phase contains three subsystems. The subsystem diagram is shown in the Fig. 6. Each subsystem contains H-Bridge units in which GTOs act as a switch.

ISSN (Online) : 2319 – 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization, Volume 3, Special Issue 1, February 2014

International Conference on Engineering Technology and Science-(ICETS'14)

On 10th & 11th February Organized by

Department of CIVIL, CSE, ECE, EEE, MECHNICAL Engg. and S&H of Muthayammal College of Engineering, Rasipuram, Tamilnadu, India

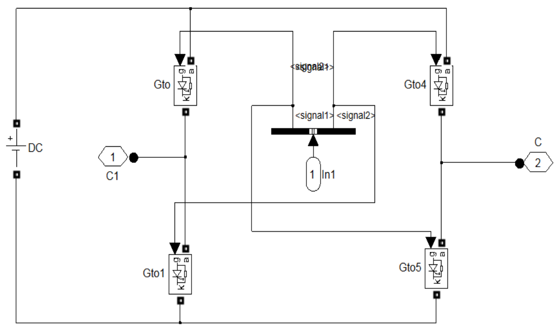

Fig. 6 Circuit diagram of sub system (H-Bridge)

In order to validate the computational results as well as the simulations results are presented for a three phase 7-level cascaded H-bridge inverter. The circuit configuration is shown in the Fig. 6 the inverter uses GTOs as the switching devices, and the nominal dc-link voltage for each H-bridge is considered to be 12 V. The gate control signals are generated by a dedicated unit is provided to the each H-bridge.

The Fig. 7 shows the single phase output waveforms of seven level cascaded inverter,

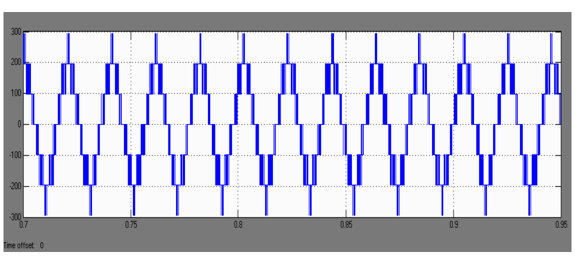

Fig. 7 Single phase output waveform of seven level cascaded inverter

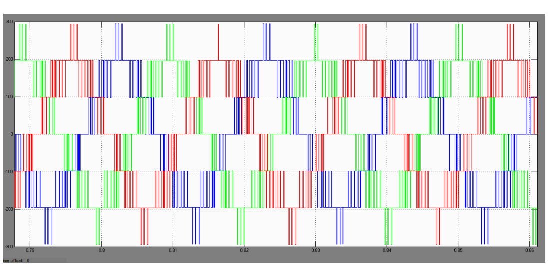

Fig. 8 Three phase output waveform of seven level cascaded inverter

TABLE II
OPTIMUM SWITCHING ANGLES FOR 3 PHASE 7-LEVEL INVERTER

θ1	0.5789 + 0.4765i
θ2	0.5781 + 0.4765i
θ3	0.3812 - 0.4631i
THD	4.28 %
Modulation index (m)	0.8

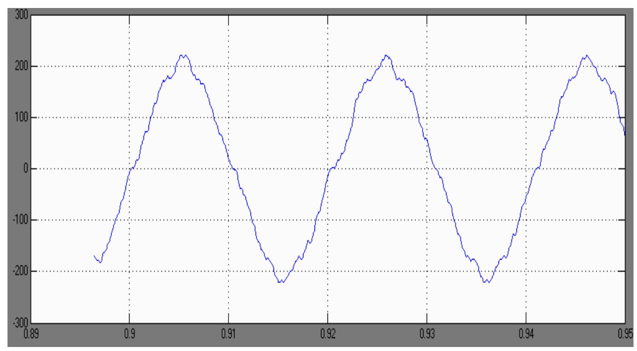

Fig. 9 Second order low pass filter output waveform

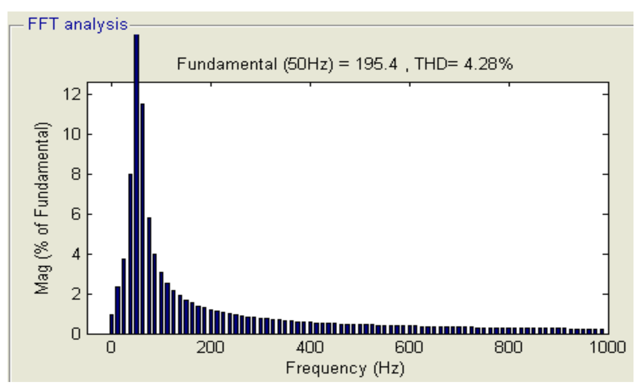

Fig. 10 FFT analysis with THD Value

VI. Conclusions

The selective harmonic elimination method at fundamental frequency switching scheme has been implemented using the Genetic Algorithm that produces all possible solution sets when they exist. In comparison with other suggested methods, the proposed technique has many advantages such as: it can produce all possible solution sets for any numbers of multilevel inverter without much computational burden; speed of convergence is fast etc. The proposed technique was

ISSN (Online) : 2319 – 8753
ISSN (Print) : 2347 - 6710

International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization, Volume 3, Special Issue 1, February 2014

International Conference on Engineering Technology and Science-(ICETS'14)

On 10th & 11th February Organized by

Department of CIVIL, CSE, ECE, EEE, MECHNICAL Engg. and S&H of Muthayammal College of Engineering, Rasipuram, Tamilnadu, India

successfully implemented for computing the optimum switching angles for 7-level CMLI. A complete analysis for 7- level inverter has been presented and it is shown that a significant amount of THD reduction can be attained if all possible solution sets are computed.

REFERENCES

[1] Adaptive Selective Harmonic Minimization Based on ANNs for Cascade Multilevel Inverters With Varying DC Sources, IEEE transactions on industrial electronics, vol. 60, no. 5, may 2013, Faete Filho, Member, IEEE, Helder Zandonadi Maia, Tiago H. A. Mateus, Burak Ozpineci, Senior Member, IEEE, Leon M. Tolbert, Senior Member, IEEE, and João O. P. Pinto, Member, IEEE

[2] J. R.Wells, B.M. Nee, and P. L. Chapman, "Selective harmonic control: A general problem formulation and selected solutions," IEEE Trans. Power Electron., vol. 20, no. 6, pp. 1337–1345, Nov. 2005.

[3] W. Lenwari, M. Sumner, and P. Zanchetta, "The use of genetic algorithms for the design of resonant compensators for active filters," IEEE Trans.Ind. Electron., vol. 56, no. 8, pp. 2852–2861, Aug. 2009.

[4] M. S. A. Dahidah and V. G. Agelidis, "Selective harmonic elimination PWM control for cascaded multilevel voltage source converters: A generalized formula," IEEE Trans. Power Electron., vol. 23, no. 4, pp. 1620–1630, Jul. 2008.

[5] Y. Liu, H. Hong, and A. Q. Huang, "Real-time calculation of switching angles minimizing THD for multilevel inverters with step modulation,"IEEE Trans. Ind. Electron., vol. 56, no. 2, pp. 285–293, Feb. 2009.

[6] Z. Du, L. M. Tolbert, and J. N. Chiasson, "Active harmonic elimination for multilevel converters," IEEE Trans. Power Electron., vol. 21, no. 2,pp. 459–469, Mar. 2006.

[7] H. Taghizadeh and M. T. Hagh, "Harmonic elimination of cascade multilevel inverters with nonequal DC sources using particle swarm optimization,"IEEE Trans. Ind. Electron., vol. 57, no. 11, pp. 3678–3684,Nov. 2010

[8] Roger C. Dugan, Mark F. McGranaghan, H. Wayne Beaty : Electrical Power Systems quality. New York : McGraw Hill, c1996

[9] Wilson E. Kazibwe and Mucoke H. Senduala : Electric Power Quality Control Techniques. New York: Van Nostrand Reinhold, c1993

[10] Issa Batarseh : Power Electronic Circuits. New York : John Wiley, c2004

[11] An application of PSO technique for harmonic elimination in a PWM inverter from World Wide Web

[12] Z. Du, L. M. Tolbert, J. N. Chiasson, and H. Li, "Low switching frequency active harmonic elimination in multilevel converters with unequal DC voltages," in Conf. Rec. IEEE IAS Annu. Meeting, Oct. 2005, vol. 1,pp. 92–98.