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Optimization of THD in Single Phase UPS Inverter

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Abstract: **Harmonics is the main issue with UPS inverters. Because of the high switching losses incurred by sinusoidal & space vector type of modulation, selective harmonic elimination is coming up as an alternative for SPWM and SVPWM. In this paper the harmonics can be eliminated by the optimal selection of switching angle by using Selective Harmonics Elimination pulse width modulation (SHE-PWM) and adaptive hybrid technique. The adaptive hybrid technique utilizes Particle Swarm Optimization (PSO) and Artificial Neural Network (ANN). This is tested over a single phase nine level cascaded H bridge inverter with equal DC sources and is simulated under Matlab / Simulink environment. The resultant fundamental and harmonic voltages are analyzed. The results show that there is an effective minimization in harmonics with the switching angles thus obtained by this method. Thus real time switching angle is given by ANN. Hence Total Harmonic Distortion can be minimized**

Keywords: **Harmonics, Multilevel inverter, Artificial Neural network, Particle swarm Optimization, switching angle, UPS.**

I. INTRODUCTION

In today's commercial world high quality power is needed for medical, research and industrial applications to give a good quality results and for accurate evaluation[1]. Critical equipments, such as computers, automated process controllers, and hospital instruments have widespread application for UPS, which serves as emergency power source [2]. An unexpected power disruption could cause injuries, fatalities, serious business disruption or data loss. Since the technology related to power electronics has drastically developed for modern applications like UPS, they use lot of semiconductor devices which draw non sinusoidal current. Non sinusoidal current owing to non linear loads results in non linear voltage which generates harmonics and thereby reduces the power quality. Thus the power quality can be improved by various techniques such as the application of harmonic filters, modification of electric circuit configurations, the choice of transformer connections and the use of higher-pulse converters, have been proposed. Active power filters were developed for harmonic compensation and power factor correction [3]. Although UPS devices are economical, flexible and energy efficient, it may degrade the power quality by creating harmonic currents and excessive reactive power [4].

Harmonics are the undesirable sinusoidal voltages or currents present in the power system which are integer multiples of fundamental frequency. A waveform can be disintegrated to sum of fundamental frequency and harmonics. Total harmonic distortion (THD) is chosen as a criterion to evaluate the harmonic distortion [5]. Harmonics introduced by nonlinear loads can pollute the input supply to the sensitive equipments and cause the connected equipments to malfunction [6]. Current harmonics and Voltage Harmonics are the two types harmonic sources into which nonlinear loads can be categorized [7].

Harmonics is the main issue in UPS inverters. Therefore selective harmonic elimination is coming as an alternative and eliminates lower order harmonics and the higher order frequency is filtered by passive filters. So, selective harmonic elimination can be used to find the appropriate switching instants by solving transcendental trigonometric equations. Some of the related research works are listed in [8]. Some of the related research works are listed in [8]. For three phase UPS inverters a seven level multilevel inverter and nine level multilevel inverter is implemented in [9] and [10]. In this paper, these switching instants can be found using particle swarm optimization (PSO) and the real time switching instants are given by ANN.

II. UPS SYSTEM DESCRIPTION

Uninterruptible Power Supply (UPS) systems are mainly used for supplying emergency power to crucial loads that cannot take up utility failure [11]. The wide spread application of UPS are Critical equipments, such as computers, automated process controllers, and hospital instruments [12]. A high performance UPS should have a clean output voltage with low total harmonic distortion (THD) for linear and non linear loads, high efficiency, great reliability and fast transient response for sudden changes [13]. The main components of UPS are the diode rectifier, pulse width modulation (PWM) inverter, input/output filter, dc-link capacitor, battery charger and battery, battery on/off switch, and load transformer. The two distinct modes of operation possible for the UPS topology are Normal/Charging and Backup mode [14]. In the normal/charging mode, the battery on/off switch is opened. Therefore, the AC mains supply the load power throughout the PWM inverter and charges the battery at constant current as well. In the backup mode, the AC mains are not available and the battery on/off switch is closed. Thus, the battery supplies the load power [15]-[17].

Off-line UPS, Line interactive UPS and Online UPS are three types of UPS topology [18]. In off-line UPS, under normal mode, power is supplied to the load and the battery is charged from the utility line and in case of power failure or low voltage, power is supplied to the load from the battery. Two different possible topologies may be included in a line-interactive UPS. One connects the utility input to the load by means of a series inductor and a bilateral inverter in parallel with the load acts as a backup for the utility line by interacting with the utility line when the energy is reversible [19].In online UPS during normal operation, the utility line supplies power to the load through the rectifier and the inverter and in case of interruption, battery supplies power to the load through the inverter [20].

III. MULTILEVEL INVERTER

Multilevel inverter is used to get a near sinusoidal wave from several levels of DC Sources. As number of levels increases, the output waveform has more steps which provides a staircase wave that approaches a desired waveform. Also, as steps are added to waveform the number of voltage levels increases, thus the harmonic distortion of the output waveform decreases and approaches to zero

1. Cascaded H Bridge Multilevel Inverters

In the family of multilevel inverters, topologies based on series connected H-bridges are particularly attractive because of their modularity and simplicity of control [21]. The concept of this inverter is based on connecting H-bridge inverters in series to get a sinusoidal voltage output. The output voltage is the sum of the voltage that is generated by each cell. The number of output voltage levels are 2n+1, where n is the number of cells. The switching angles can be chosen in such a way that the total harmonic distortion is minimized. One of the advantages of this type of multilevel inverter is that it needs less number of components comparative to the Diode clamped or the flying capacitor, so the price and the weight of the inverter is less than that of the two types. The inverter model of N level is depicted in Fig. 1. In this paper, four single phase H-bridge converters are connected in series for 9 level inverter with equal DC sources.. The output voltage waveform of a 9 level inverter is shown in Fig.2.

The formula for harmonic output voltage of inverter is given as

$$b_n = \frac{4v_{dc}}{n\pi} \sum_{i=1}^{s} cosn\,\alpha_i \qquad (1)$$

Where n=1, 3, 5, 7 and s which represents number of DC sources

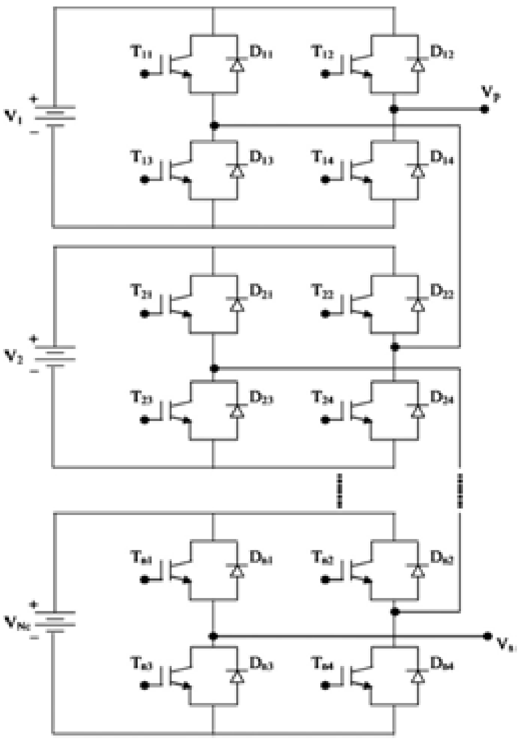

Fig. 1

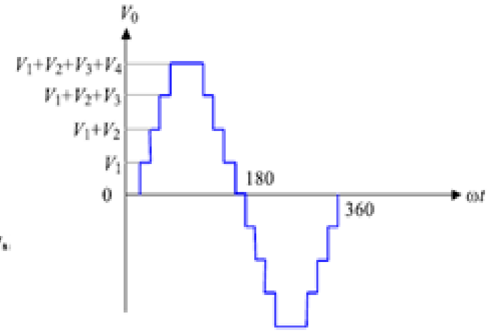

Fig.2

Fig.1 N level cascaded multilevel inverter **Fig.2 Output Voltage waveform of a 9 level inverter**

2. Selective Harmonic Elimination

The Selective Harmonic Elimination PWM technique is based on fundamental frequency switching theory and dependent on the elimination of defined harmonic content orders. SHE method is able to eliminate low order harmonics completely. In the SHE method, mathematical techniques such as iterative methods or mathematical theory of resultant can be applied to calculate the optimum switching angles such that lower order dominant harmonics are eliminated [22]. The main idea of this method is based on defining the switching angles of harmonic orders to eliminate and obtain the Fourier series expansion of output voltage. This allows lower switching frequencies to be used which led to lower losses and higher efficiency.

The objective of SHEPWM is to eliminate lower order harmonics while remaining harmonics can be removed with passive filter. In this the number of harmonics that can be eliminated is equal to s-1 i.e. 3 so third, fifth and seventh harmonics are taken. So, to satisfy the fundamental harmonic component and eliminate the third, fifth and seventh harmonics, four nonlinear equations with four angles are provided. In applications for three phase machine drive, there is no need to cancel the harmonics that are a multiple of three because it is cancelled in the line voltage

The output voltage waveform shown in Fig. 2 can be expressed in the Fourier form as

$$V_{an}(wt) = \sum_{i=1,3,5,7...}^{\infty} \frac{4V_{dc}}{n\pi}\left(\cos(n\alpha_1)+\cos(n\alpha_2)+\cos(n\alpha_3)+\cdots\right).\sin(nwt) \qquad (2)$$

Where

*V*dc………. input dc source;

*α*1, *α2* , *α3*….inverter switching angles;

*V*an ……….. Inverter output voltage

The set of equations for the PSO is

$V_{fund} = \frac{4V_{dc}}{\pi}.(\cos(\alpha 1) + \cos(\alpha 2) + \cos(\alpha 3) + \cos(\alpha 4))$ ..... (3)

$V3th = \frac{4V_{dc}}{3\pi}.(\cos(3\alpha 1) + \cos(3\alpha 2) + \cos(3\alpha 3) + \cos(3\alpha 4))$ .... (4)

$V5th = \frac{4V_{dc}}{5\pi}.(\cos(5\alpha 1) + \cos(5\alpha 2) + \cos(5\alpha 3) + \cos(5\alpha 4))$ ...... (5)

$V7th = \frac{4V_{dc}}{7\pi}.(\cos(7\alpha 1) + \cos(7\alpha 2) + \cos(7\alpha 3) + \cos(7\alpha 4))$ ...... (6)

The objective function is formulated as

$f(V_{fund}, V3, V5, V7) = (Vfund–230) + V3+V5+V7$ ….. (7)

To eliminate fifth, seventh and eleventh harmonics V5, V7 and V11 are set to zero in the above equations. To determine the switching angles the following equations must be solved,

$\cos(\alpha 1)+\cos(\alpha 2)+\cos(\alpha 3)+\cos(\alpha 4) = 4M$ · · · (8)

$\cos(3\alpha 1)+\cos(3\alpha 2)+\cos(3\alpha 3)+\cos(3\alpha 4) = 0$ · · · (9)

$\cos(5\alpha 1)+\cos(5\alpha 2)+\cos(5\alpha 3)+\cos(5\alpha 4) = 0$ · · · (10)

$\cos(7\alpha 1)+\cos(7\alpha 2)+\cos(7\alpha 3)+\cos(7\alpha 4) = 0$ · · · (11)

Here M represents modulation index which varies from 0 to 1.The switching angles α1, α2, α3 and α4 must be less than π/2. The equations are solved by Newton Raphson (NR) method and resultant theory in the literature. But it is time consuming and needs initial guess for solving the equations. Hence evolutionary algorithms are used for solving these types of nonlinear equations. The PSO is programmed to obtain the optimum set of angles to control the multilevel inverter for each value of modulation index.

IV. PROPOSED METHODOLOGY

1. Particle Swarm Optimization:

Particle Swarm Optimization (PSO) is mainly inspired by social behaviours observed in flocks of birds, schools of fish, or swarms of bees, colonies of ants, and even human social behaviour, from which the intelligence is emerged. PSO, proposed by Kennedy and Eberhart (1995) uses a number of particles that constitute a swarm moving around in an N-dimensional search space looking for the best solution[23],[24],[25],[26]. Each particle in PSO keeps track of its coordinates in the problem which are associated with the best solution (best fitness) it has achieved so far. This value is called “P_{best}”. Another ‘‘best’’ value that is tracked by the global version of the particle swarm optimizer is the overall best value and its location obtained so far by any particle in the swarm. This location is called “g_{best}”. Let X and V denote the particle’s position and its corresponding velocity in search space, respectively. At iteration K, each particle i has its position defined by Xi = [xi1, xi2. . . xiN] and velocity is defined as Vi= [vi1, vi2, . . ., viN] in the search space N.

2. Artificial Neural Network:

ANNs are computational models that were inspired by the biological neurons. It has a series of nodes with interconnections where mathematical functions are applied to do an input/output (I/O) mapping. An important feature of an ANN that made it suitable for this problem is its flexibility to lead in its domain and outside it, as well as work with the nonlinear nature of the problem [27]–[31]. Although the data set presented to the ANN is not complete and not all combinations were obtained by the PSO, the ANN has flexibility enough to interpolate and extrapolate the results. These features make ANNs suitable for problems commonly encountered in power electronics such as fault detection [30 and harmonic diagnostic [33]. ANNs are generally time consuming to train but fast to run and can be easily parallelized, once it is accordingly trained. Comparatively, lookup tables increase exponentially as the number of DC sources increases and it needs to deal with extrapolation leading to time-consuming algorithms, and also, analytical approaches have to deal with the computational time required for the task. In both cases, a methodology has to be found to handle the no solution range [34].

V. SHE USING PSO

PSO algorithm is applied to minimize the harmonics in a nine level multilevel inverter with equal voltage sources. The optimum switching angles are obtained from PSO. To validate the results of PSO, MLI is simulated in Matlab/Simulink and the harmonic spectrum is analyzed.

The step by step procedure for implementing PSO is as follows:

1. First the parameters like population size and maximum number of iterations are initialized.
2. Each particle in the population is randomly initialized between 0 and $\pi/2$.
3. The velocity, personal best, global best and iteration count are initialized.
4. The fitness value at each particle position should be evaluated.
5. The velocities for each particle should be calculated based on the personal best and global best position
6. The particle position must be updated.
7. The iterations must be repeated until it satisfies the constraints eqn.(7)-(9).

VI. ADAPTIVE SHE

The data set was used to train the neural network. The ANN topology proposed is shown in Fig. 3. It is a feed forward ANN with a tangent-sigmoid function activation hidden layer and a linear activation function output layer. This ANN takes the modulation index ranging from 0 to 1 and gives the switching angles for the control system.

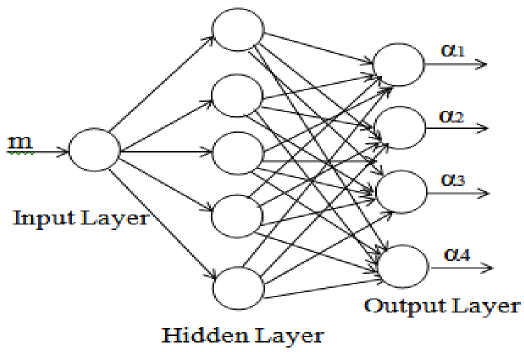

Fig. 3 ANN topology

VII. RESULTS AND DISCUSSION

The proposed technique is of a cascaded multilevel inverter prototype, used in a single phase 9-level, 4H-bridge UPS inverter, that is implemented in the working platform of MATLAB (versionR2011A)/Simulink. In this implementation, harmonics affected voltage waveforms are generated from a H-bridge type of UPS inverter. There are four levels of H-bridge inverter. So, selecting four optimum switching angles α1, α2 , α3 and α4 are essential. The technique is implemented to eliminate the third, fifth and seventh order harmonics. Thus, the THD is minimised in the UPS inverter. The output waveform of different switching pulses are shown in Fig. 4

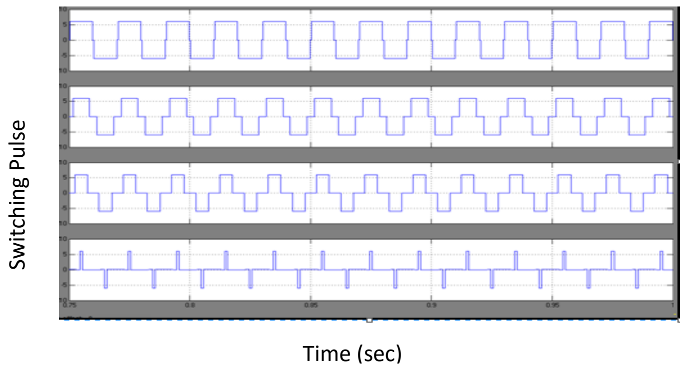

Fig. 4 Output waveform switching angle of bridge 4
Output waveform switching angle of bridge 3
Output waveform switching angle of bridge 2
Output waveform switching angle of bridge 1

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The output voltage of the single phase 9-level cascaded multilevel inverter is shown in Fig.5. The output voltage is four times the input voltage. The nine levels of the output are obtained, which are both positive and negative polarity.

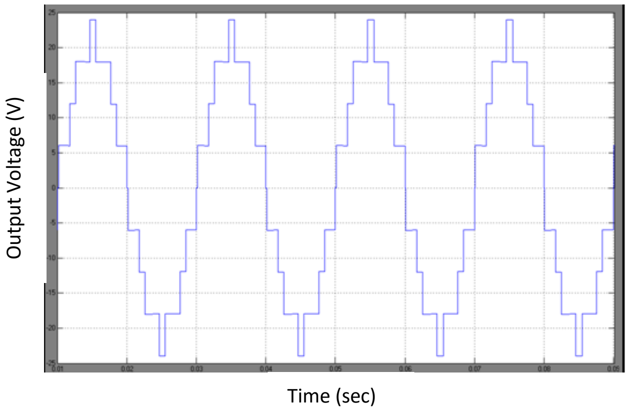

Fig. 5 Output voltage waveform of 9 level UPS inverter

The output current waveform is shown in Fig, 6 for single phase nine level inverter. As RL load is connected, it synthesizes a near sinusoidal waveform

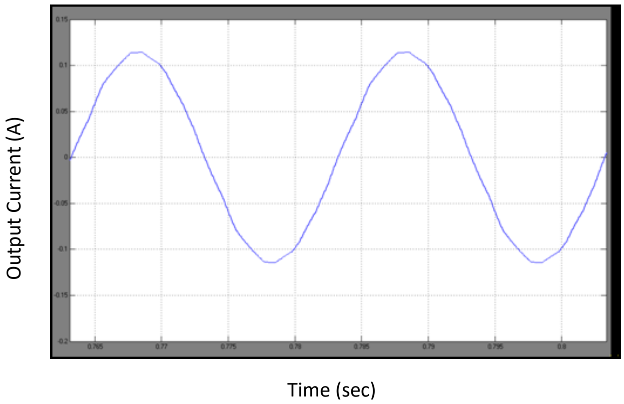

Fig. 6 Output current waveform of 9 level UPS inverter

The FFT analysis is done to estimate the THD value. Fig.7 and Fig. 8 show the FFT analysis for the output voltage and current waveform obtained from PSO. It displays the harmonic spectrum of the output voltage. The objective in this work is to minimize low-order harmonics.

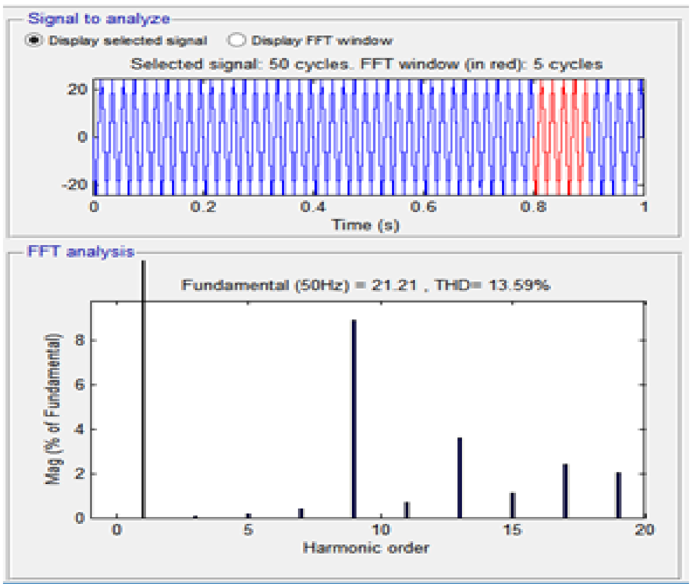

Fig.7 FFT Analysis of output voltage waveform of 9 level UPS inverter.

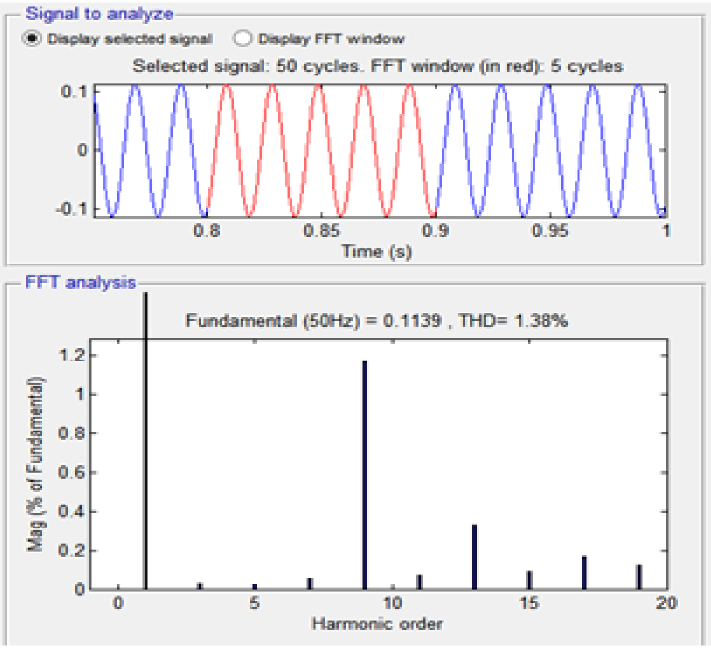

Fig.8 FFT Analysis of output current waveform of 9 level UPS inverter

VIII. CONCLUSION

In this paper, an adaptive hybrid technique was proposed to select an optimal switching angle for eliminating the odd harmonic voltages in a single phase UPS 9-level inverter. The hybrid technique is the combination of a particle swarm optimization and neural network. The proposed technique was implemented and its performance in eliminating the 3^{rd}, $5^{th}$and 7^{th} order harmonic voltages was tested in a 9-level 4-H bridge UPS inverter. Here particle swarm optimization algorithm is used to solve the non linear transcendental equations obtained from SHEPWM strategy. These equations determine the switching angles which are used to minimize the THD. The THD value obtained from PSO is 1.38% .The solution obtained using PSO is used for training the neural network. The trained network is used for online determination of switching angles to minimize the harmonics. A new approach for real-time computation of switching angles using ANNs has been presented. This work can be extended further for experimental verification.

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