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THD Minimization in Multilevel Inverter Using Optimization Approach

Ms. Madhuri Mali
Department of Electronics Engineering
Walchand College of Engineering
Sangli, India

Dr. B.G.Patil
Department of Electronics Engineering
Walchand College of Engineering
Sangli, India

Abstract-— **Harmonic minimization in multilevel inverters is a complex optimization problem that involves nonlinear transcendental equations having multiple local minima. The non linear equations are obtained from the programmed PWM technique which characterizes the low order harmonics to be eliminated. The main challenge of programmed PWM or Selective Harmonic Elimination PWM technique is to solve the equations whose solutions produce improved harmonic reduction. In this paper, optimization algorithm based on natural selection is proposed to solve the non linear equations which are more effective and time consuming than the conventional algorithm. This paper states constrained genetic algorithm to seven-level cascaded multilevel inverter.**

Keywords— Cascaded Multilevel Inverter, Genetic Algorithm, Harmonics, Optimization, Programmed PWM, Seven-level, Total Harmonic Distortion

I. INTRODUCTION

Generally the output voltage of the inverters must be sinusoidal. However the waveforms of practical inverters are non sinusoidal and contain certain harmonics. For low and medium power applications, square wave or quasi square wave may be acceptable but for high power applications, low distorted sinusoidal waveforms are required. By increasing number of levels in inverter the output voltage have more steps generating a staircase waveform, which has reduced harmonic distortion. There emerges need of multilevel inverter. In recent years, multilevel inverters have received more attention in industrial applications, such as motor drives, Static VAR Compensators (STATCOMs), Flexible AC Transmission System (FACTS), high voltage direct current lines, electrical drives and renewable energy systems. The most attractive features of multilevel inverters are they can generate output voltages with extremely low distortion and lower dv/dt, they draw input current with very low distortion, they generate smaller Common Mode (CM) voltage thus reducing the stress in the motor bearings. In addition, using sophisticated modulation methods, CM voltages can be eliminated. They can operate with a lower switching frequency.

There exist three commercial topologies of multilevel voltage source inverters: Neutral Point Clamped (NPC), Cascaded H-Bridge (CHB), and Flying Capacitors (FCs). Cascaded multilevel inverters are based on a series connection of several single phase inverters. This structure is capable of reaching medium output voltage levels using only standard low-voltage technology components. Typically, it is necessary to connect three to ten inverters in series to reach the required output voltage. These converters also feature a high modularity degree because each inverter can be seen as a module with similar circuit topology, control structure, and modulation. Therefore, in the case of a fault in one of these modules, it is possible to replace it quickly and easily. Moreover, with an appropriated control strategy, it is possible to bypass the faulty module without stopping the load, bringing an almost continuous overall availability.

For improving inverter performance and output quality, different methods have been suggested. The first of them is using various switching strategies, such as Sinusoidal Pulse Width Modulation (SPWM), Selective Harmonic Elimination PWM (SHEPWM) or Programmed PWM, Space Vector Modulation (SVM), Optimized Harmonic Stepped Waveform (OHSW) and Optimal Minimization of Total Harmonic Distortion (OMTHD). In this, Selective Harmonic Elimination PWM has been a research topic since the early 1960's, first examined in and developed into a mature form during the 1970's.SHE offers several advantages compared to traditional modulation methods including acceptable performance with low switching frequency to fundamental frequency ratios, direct control over output waveform harmonics, and the ability to leave triple harmonics uncontrolled to take advantage of circuit topology in three phase systems. These key advantages make SHE a viable alternative to other methods of modulation in applications such as ground power units, variable speed drives, or dual-frequency induction heating. Sinusoidal Pulse Width Modulation (PWM), selective harmonic elimination, and Space Vector Modulation (SVM), however, PWM techniques are not able to eliminate low order harmonics completely. Another approach is to choose switching angles so that specific lower order dominant harmonics are suppressed. This method is known as Selective Harmonic Elimination (SHE) or programmed PWM technique in technical literatures.

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SHE-PWM techniques offer several advantages over other modulation methods, including acceptable performance with low switching frequency to fundamental frequency ratios, direct control over output waveform harmonics, and the ability to leave triple harmonics uncontrolled to take advantage of circuit topology in three phase systems, and therefore have drawn great attention in recent years. A systematic approach to solve the SHE problem based on resultant theory method is proposed, where transcendental equations that describe the SHE problem are converted into an equivalent set of polynomial equations, and then, resultant theory method is utilized to find all possible sets of solutions for this equivalent problem. A cascaded multilevel inverter consists of a series of single phase full bridge inverter units. To obtain a 7-level multilevel inverter, three full bridge inverters are connected in series. Each full bridge inverter can generate three different voltage outputs: +Vdc, 0, and –Vdc. The phase output voltage is synthesized by sum of three inverter outputs,

$$V_{an} = V_{a1} + V_{a2} + V_{a3} \quad .... (1)$$

II. OBJECTIVES

The objective is elimination of low order harmonics, while the fundamental harmonic is satisfied. If this goal cannot be obtained, the highest possible harmonics optimization is desired.

III. LITERATURE SURVEY

M. Mythili. In this paper, Genetic algorithm is applied to minimize the low order harmonics, as well as to satisfy the desired fundamental component. The algorithm is proposed here is used to find the optimized switching angles than the conventional one and thus reduced THD is obtained. [1]

B. Ashok and A. Rajendran The emergence of multilevel inverters has been in increase since the last decade. These new types of converters are suitable for high voltage and high power application due to their ability to synthesize waveforms with better harmonic spectrum. Numerous topologies have been introduced and widely studied for utility and drive applications. Amongst these topologies, the multilevel cascaded inverter was introduced in Static VAR compensation and drive systems. This project presents a new technique for getting an effective multilevel SHEPWM control techniques is used to reduce odd harmonics. Selective harmonic elimination Technique in Seven Level Multilevel inverter with SRM is used in MATLAB Simulink environment is used to simulate the results. [2].

Prakruthi Vasanth and Gowtham N. The dc sources that feed the multilevel inverter are varying in time, and the switching angles should adapt to the dc source variations. Any variations in the input will result in harmonics at the output. To mitigate the harmonics in the inverter output, GA is used. A genetic algorithm optimization technique is applied to determine the switching angles for a cascaded multilevel inverter. Then, artificial neural networks are used to determine the switching angles for real time application. This eliminates specified order harmonics while maintaining the required fundamental output constant [3].

Baharuddin Ismail et.al This paper presents an efficient selective harmonics elimination method for a cascaded five level inverter by using Particle Swarm Optimization (PSO) method. The aim of this research is to eliminate selected low-order harmonics by solving non-linear equations using the developed PSO algorithm, while at the same time the fundamental component is retained efficiently. In order to find the efficient switching angles of a five- level cascaded inverter, a PSO algorithm has been developed to solve the non-linear equations. Instead of single switching, multiple switching in a quarter cycles has been introduced to increase the number of harmonic orders that should be eliminated. With the proposed method, the required switching angles are computed efficiently by PSO in order to eliminate low-order harmonics up to the 17th order from the inverter voltage waveform. The entire system has been simulated using PSIM software and a prototype of five -level cascaded inverter with Field Programmable Gate Array (FPGA) has been built in the laboratory. Performance of the proposed method for a five-level cascaded H-bridge inverter, based on simulation studies, is evaluated and experimentally verified. [4].

M. Suresh Kumar, K. Ramani This paper proposed the comparison made between Multi-Carrier Pulse Width Modulation, Sinusoidal Pulse Width Modulation and Selective Harmonic Elimination Pulse Width Modulation technique for minimization of Total Harmonic Distortion in Cascaded H-Bridge Multi-Level Inverter. In Multicarrier Pulse Width Modulation method by using Alternate Position of Disposition scheme for switching pulse generation to Multi-Level Inverter. Another carrier based approach; Sinusoidal Pulse Width Modulation method is also implemented to define the switching pulse generation system in the multi-level inverter. In Selective Harmonic Elimination method using Genetic Algorithm and Particle Swarm Optimization algorithm for define the required switching angles to eliminate low order harmonics from the inverter output voltage waveform and reduce the total harmonic distortion value. So, the results validate that the Selective Harmonic Elimination Pulse Width Modulation method does capably eliminate a great number of precise harmonics and minimize the Total Harmonic Distortion value in output voltage waveform in compared with Multi-Carrier Pulse Width Modulation method, Sinusoidal Pulse Width Modulation method. In this paper, comparison of simulation results shows that the Selective Harmonic Elimination method can attain optimal harmonic minimization solution better than Multi-Carrier Pulse Width Modulation method, Sinusoidal Pulse Width Modulation method. [5]

Teena Jacob Multilevel inverters are highly capable of achieving higher quality output voltage waveforms and higher power ratings with the help of their multilevel structure. They have been of great interest in the field of power industry and are best suited for reactive power compensation. Multilevel voltage source inverters are capable of operating at high voltage with less electromagnetic interference and results in higher efficiency. The harmonic elimination in a multilevel voltage source inverter is of almost importance and different types of modulation strategies can be applied to the inverters to eliminate these harmonics. Among these modulation techniques, Selective harmonic elimination PWM is A significant switching strategy that can be applied to the output voltage waveform of multilevel inverters for lower order harmonic elimination. This paper gives a review on the various optimization algorithms that is been used for the SHEPWM technique. Performance comparisons of these optimization algorithms in SHEPWM are discussed. [6].

IV. MULTILEVEL INVERTER:

The Inverter is an electrical device which converts direct current (DC) to alternate current (AC). The inverter is used for emergency backup power in a home. The inverter is used in some aircraft systems to convert a portion of the aircraft DC power to AC. The AC power is used mainly for electrical devices like lights, radar, radio, motor, and other devices.

Now a day's many industrial applications have begun to require high power. Some appliances in the industries however require medium or low power for their operation. Using a high power source for all industrial loads may prove beneficial to some motors requiring high power, while it may damage the other loads. Some medium voltage motor drives and utility applications require medium voltage. The multi level inverter has been introduced since 1975 as alternative in high power and medium voltage situations. The Multi level inverter is like an inverter and it is used for industrial applications as alternative in high power and medium voltage situations.

The need of multilevel converter is to give a high output power from medium voltage source. Sources like batteries, super capacitors, solar panel are medium voltage sources. The multi level inverter consists of several switches. In the multi level inverter the arrangement switches' angles are very important.

A. *Types of Multilevel Inverter*

a. *Diode clamped multilevel inverter*

The main concept of this inverter is to use diodes and provides the multiple voltage levels through the different phases to the capacitor banks which are in series. A diode transfers a limited amount of voltage, thereby reducing the stress on other electrical devices. The maximum output voltage is half of the input DC voltage. It is the main drawback of the diode clamped multilevel inverter. This problem can be solved by increasing the switches, diodes, capacitors. Due to the capacitor balancing issues, these are limited to the three levels. This type of inverters provides the high efficiency because the fundamental frequency used for all the switching devices and it is a simple method of the back to back power transfer systems.

b. *Flying capacitors multilevel inverter*

The main concept of this inverter is to use capacitors. It is of series connection of capacitor clamped switching cells. The capacitors transfer the limited amount of voltage to electrical devices. In this inverter switching states are like in the diode clamped inverter. Clamping diodes are not required in this type of multilevel inverters. The output is half of the input DC voltage. It is drawback of the flying capacitors multi level inverter. It also has the switching redundancy within phase to balance the flaying capacitors. It can control both the active and reactive power flow. But due to the high frequency switching, switching losses will takes place.

c. *Cascaded H- bridge multilevel inverter*

The cascaded H-bride multi level inverter is to use capacitors and switches and requires less number of components in each level. This topology consists of series of power conversion cells and power can be easily scaled. The combination of capacitors and switches pair is called an H-bridge and gives the separate input DC voltage for each H-bridge. It consists of H-bridge cells and each cell can provide the three different voltages like zero, positive DC and negative DC voltages. One of the advantages of this type of multi level inverter is that it needs less number of components compared with diode clamped and flying capacitor inverters. The price and weight of the inverter are less than those of the two inverters. Soft-switching is possible by the some of the new switching methods.

Multilevel cascade inverters are used to eliminate the bulky transformer required in case of conventional multi phase inverters, clamping diodes required in case of diode clamped inverters and flying capacitors required in case of flying capacitor inverters. But these require large number of isolated voltages to supply the each cell.

B. *Advantages of Multilevel Inverter:*

The multilevel converter has a several advantages, that is:

1. Common Mode Voltage: The multilevel inverters produce common mode voltage, reducing the stress of the motor and don't damage the motor.
2. Input Current: Multilevel inverters can draw input current with low distortion
3. Switching Frequency: The multilevel inverter can operate at both fundamental switching frequencies that are higher switching frequency and lower switching frequency. It should be noted that the lower switching frequency means lower switching loss and higher efficiency is achieved.
4. Reduced harmonic distortion: Selective harmonic elimination technique along with the multi level topology results the total harmonic distortion becomes low in the output waveform without using any filter circuit.

V. PROPOSED SYSTEM

The Selective Harmonic Elimination PWM or Programmed PWM technique is based on fundamental frequency switching theory and dependent on the elimination of defined harmonic content orders. The main idea of this method is based on defining the switching angles of harmonic orders to eliminate and obtaining the Fourier series expansion of output voltage. This allows lower switching frequencies to be used which led to lower losses and higher efficiency. In general Fourier series is given by,

$V(\omega t) = a_0 + \sum_{n=1}^{\infty}(a_n \cos n\omega t + b_n \sin n\omega t)$... (2)

In this case Fourier series expansion of output voltage waveform is given by,

$$V(\omega t) = \sum_{n=1}^{\infty} b_n \sin n\omega t \quad .... (3)$$

Where $a_0 = a_n = 0$ (due to quarter wave symmetry)

$$b_n = \frac{1}{\pi}\int_0^{2\pi} V_{dc} \sin n\omega t \; d\omega t \quad ..... (4)$$

for quasi square wave equation (3) becomes

$$b_n = \frac{2}{\pi}\int_0^{\pi-\alpha} V_{dc} \sin n\omega t \; d\omega t \quad ..... (5)$$

On solving equation (4) we get,

$$b_n = \frac{4V_{dc}}{n\pi} \cos n\alpha \quad .... (6)$$

For 7-level cascaded multilevel inverter for three dc sources it is given as,

$$b_n = \frac{4V_{dc}}{n\pi} \sum_{i=1}^{s} \cos n\alpha_i \quad ..... (7)$$

Where n=1, 5, 7 and s=3 which represents number of DC sources. The objective of SHEPWM is to eliminate lower order harmonics while remaining harmonics can be removed with filter. In this number of harmonics that can be eliminated is equal to s-1 i.e., 2 so fifth and seventh harmonics are taken. So, to satisfy the fundamental harmonic component and eliminate the fifth and seventh harmonics, three nonlinear equations with three angles are provided in,

$$b_1 = V_1 = \frac{4V_{dc}}{\pi}[\cos(\alpha_1) + \cos(\alpha_2) + \cos(\alpha_3)] \quad .... (8)$$

$$b_5 = V_5 = \frac{4V_{dc}}{\pi}[\cos(5\alpha_1) + \cos(5\alpha_2) + \cos(5\alpha_3)] \quad ... (9)$$

$$b_7 = V_7 = \frac{4V_{dc}}{\pi}[\cos(7\alpha_1) + \cos(7\alpha_2) + \cos(7\alpha_3)] \quad ...(10)$$

To eliminate fifth and seventh harmonic V5 and V7 are set to zero in the equation (8) and (9). To determine the switching angles the following equations must be solved,

$$\cos(\alpha_1) + \cos(\alpha_2) + \cos(\alpha_3) = 3M \quad .... (11)$$

$$\cos(5\alpha_1) + \cos(5\alpha_2) + \cos(5\alpha_3) = 0 \quad .... (12)$$

$$\cos(7\alpha_1) + \cos(7\alpha_2) + \cos(7\alpha_3) = 0 \quad .... (13)$$

Here M represents modulation index varies from 0 to 1.M is given by,

$$M = \frac{\pi V_1}{12 V_{dc}} \quad .... (14)$$

The switching angles α_1, α_2 and α_3 must be less than $\pi/2$. 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 this type of non linear equations. Here genetic algorithm is proposed to solve these equations.

VI. GENETIC ALGORITHM

Genetic Algorithm is a method used for solving both constrained and unconstrained optimization problems based on natural selection. It imitates biological evolution by using genetic operators referred to as reproduction, crossover, mutation etc. The genetic algorithm is simple and applicable to problems with any number of levels, without the extensive derivation of analytical expressions, for both eliminating and minimizing harmonics. This algorithm is used for optimizing switching angles. The structure of a simple GA consists mainly of three operators. A selection operator, a crossover operator acts on a population of strings to perform the required reproduction and recombination, and a mutation operator which randomly alters character values, usually with a very low probability. GA technique is used for its ability to deal with complicated problems where analytical formula is not yet possible. In the multi-objective SHE problem, if there is no set of angles that will satisfy the SHE will not return an answer. The GA, on the other hand, will always return an answer that will not exactly solve all equations but instead will give answers that are very close to the solutions. Thus instead of eliminating harmonics it minimizes them.

The steps followed in the proposed genetic algorithm are as follows:

Step 1. Select the population type

Step 2. Initialize the population

Step 3. Evaluate the fitness function of each individual

Step 4. Minimize the fitness function that satisfies the constraints (10)-(12).

Step 5. Pick the best individuals

Step 6. Create a new offspring using crossover and mutation operations

Step 7. If number of iterations is less than 100, repeat the process otherwise terminate the process.

VII. CONCLUSION

In this paper a method based on genetic algorithm is used to solve the non linear transcendental equations. These equations determine the switching angles which are used to minimize the THD. The effectiveness of the applied method is verified using the simulation results. This work can be extended to multilevel inverters with reduced number of switches for further enhancement of output waveform.

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