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Performing of the MPPSO Optimization Algorithm to Minimize Line Voltage THD of 3-Level Inverter

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Abstract: *Different modulation methods have been proposed to control the multilevel inverters. This paper focuses on the staircase waveform modulation for 3-level inverters with low switching frequencies. In this paper a novel solution along with a new robustness optimization algorithm is presented to minimization of Total Harmonic Distortion (THD) of the output line voltage of the inverter based on the Multi Population Particle Swarm Optimization (MPPSO). The MPPSO algorithm has a lot of advantages compared with a general optimization algorithm such as Genetic algorithm (GA). A comparison has been drawn between aforementioned techniques related to optimization. A new expression of fitness function is presented to optimization of Line Voltage THD (LVTHD) of 3-level Inverter. The advantages of fundamental frequency harmonic minimization and swarm intelligence are combined to improve the quality of output line voltage. The validity of the proposed method is proved through various simulation results by MATLAB software.*
Keywords - *3-Level Inverter, Harmonic Minimization, Total Harmonic Distortion (THD), Optimization Algorithm, Multi Population PSO (MPPSO).*

I. INTRODUCTION

The current needs in power electronics topology are focused on reliability, availability and power quality [1]. Nowadays, grids are restricting the harmonic content to guarantee the quality of power supply [2, 3]. The most common topologies which are used in the prior article for three-level inverter are included neutral point clamped [4-7], the diode clamped structure [8] and full-bridge structure [9-11]. The full-bridge structure needs fewer components to produce the same output waveform. In this paper, the full bridge structure is used, Because the most used topologies in industry is full bridge structure, due to require a small number of components compared to other structures, also show lower harmonic distortion [12].

The THD is a parameter that defines the quality of output voltage of the inverter (THD is evaluated with the distortion, this parameter is the difference between the output and input signal in the system). For producing a waveform in output with minimum harmonic, near to sinusoidal waveform, many modulation techniques have been used. Modulation methods which can be used for 3-Level Inverter can be classified according to switching frequencies [13], low switching methods and high switching methods are two general types of switching methods. The famous high switching techniques that have been used up to now are included SPWM [14], SVPWM [7], and the low switching techniques are SHEPWM [15, 16] and OMTHD [17].

In OMTHD technique, THD is minimized. In this paper, the new modulation technique called THDM based on OMTHD technique is presented. When the exact amount of THD is used, exact optimal angles are extracted. Also, the analytical approaches can be elicited to a valid expression, so extracting the precise formula of LVTHD is necessary. In literature [18] the precise formula of LVTHD is extracted for 3-Level inverter with infinite number of switching degrees, So, in this paper the precise formula of LVTHD is applied as a novel fitness function to minimize LVTHD. This novel LVTHD formula is a transcendental equation via switching angles. The Newton-Raphson method has been used to solve transcendental equation in the literature [19] but this method has some drawbacks like divergence problems, require precise initial guess and gives no optimum solution [20]. Hence the heuristic algorithms such as common Particle Swarm Optimization (PSO) [21] have the ability to combat the drawbacks like divergence problem. As an optimization technique, PSO is much less dependent on the start values of the variables in the optimization problem when compared with the widely used Newton–Raphson or mathematical programming techniques such as Sequential Quadratic Programming (SQP). Moreover, in this paper the new optimization algorithm called Multi Population Particle Swarm Optimization (MPPSO) is used to minimize the new transcendental LVTHD formula in order to extract the precise switching angles. The MPPSO optimization algorithm has more advantages compared with a general optimization algorithm such as Genetic Algorithm (GA) or common PSO.

The THD Minimization (THDM) [22, 23], is a switching strategy can clearly show the importance of an analytical formula for THD, because this technique tries to find those angles which leads to generate minimum THD. If there is no formula for finding angles as analytically, then analytical methods such as resultant theory [24] can no longer be used. Instead, heuristic methods like Genetic Algorithm (GA) [25] and

Particle Swarm Optimization (PSO) [26, 27] should be utilized that lead to the local minimum instead of the global minimum. Moreover, proposed methods can be used for the three-level inverter with each switching angles.

In this paper, two novel solutions have been presented, to minimize the LVTHD, The first new solution is applying the LVTHD precise formula as a fitness function, and the next one novel solution is implementing the MPPSO optimization algorithm to minimize LVTHD precise formula. In the next part, the full bridge 3-phase structure and precise formula of LVTHD for three-level inverter is explained. In the third part, the MPPSO is explained. Simulation results in MATLAB software are offered in order to validity of the new methods which are presented in forth section. Finally, in the fifth section, the complete conclusion is presented.

II. FULL BRIDGE INVERTER STRUCTURE AND PRECISE LVTHD FORMULA

A. Three phases Three Level Structures

The Fig. 1 shows a basic circuit configuration of a three-phase full bridge inverter. The three-phase loads can be connected either Y or Delta type to the Inverter's output. The output voltages of this inverter, shown in Fig. 2, are included phase voltage of phase a, phase b and line to line voltage ab, respectively. Generally, the output voltage with half-wave symmetry is assumed to have S switching angles in each quarter of the cycle. Here, S is an odd number that may be three, five, seven or more.

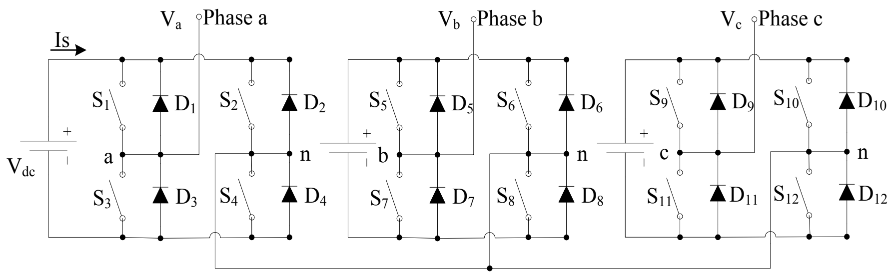

Fig. 1 Single phase full bridge inverter

Fourier series for all n is achieved from the following equation.

$$f(\omega t) = \sum_{n=1}^{\infty} a_n \sin(n\omega t) \tag{1}$$

Assuming odd quarter-wave symmetry of the unit height waveform of Fig. 2, the Fourier series coefficients are given by Eq. (2) For odd n with the assumption that V_{dc} = 1p.u. For even n, a_n =0 and for all n, b_n =0. a_n for odd n is calculated by Eq. (2).

$$a_n = \frac{4V_{dc}}{n\pi} \sum_{k=1}^{M} (-1)^{k+1} \cos n\alpha_k \tag{2}$$

Switching angles should respect the following constraint.

$$0<\alpha 1<\alpha 2<\ldots<\alpha M<\pi/2 \tag{3}$$

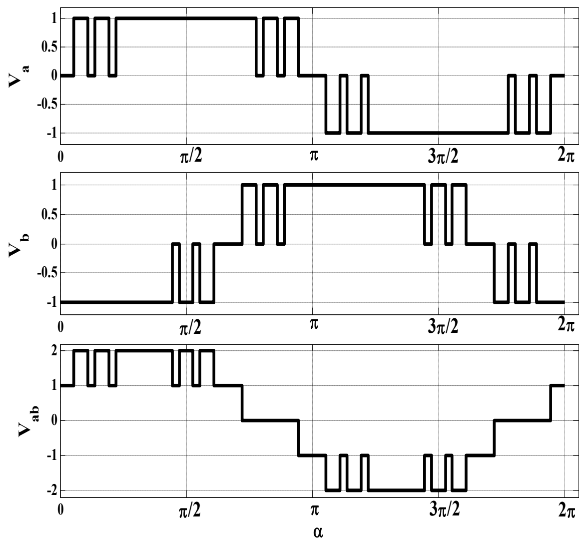

Fig. 2. Output voltage of a three-phase three-level inverter

B. Precise Line Voltage THD Formulation

In the literature [18] the precise LVTHD formulas for a three-level inverter with infinite number of switching degree is extracted. As a case study in [18] this aforementioned precise LVTHD formula with two switching angles are obtained, which are shown in (4) to (12).

$F1: 0 < \alpha_1 \le 30 \quad \& \quad 0 < \alpha_2 \le 30$

$$THD_{Line} = \sqrt{\frac{-\pi(\alpha_1 - \alpha_2)}{6(\cos\alpha_1 - \cos\alpha_2)^2} - 1} \tag{4}$$

$F2: 0 < \alpha_1 \le 30 \ \& \ 30 < \alpha_2 \le 60 \ \& \ 30 < \alpha_1 + \alpha_2 \le 60$

$$THD_{Line} = \sqrt{\frac{\pi^2\left(\frac{1}{4} - \frac{3}{2\pi}\alpha_1\right)}{9(\cos\alpha_1 - \cos\alpha_2)^2} - 1} \tag{5}$$

$F3: 0 < \alpha_1 \le 30 \ \& \ 30 < \alpha_2 \le 60 \ \& \ 60 < \alpha_1 + \alpha_2 \le 90$

$$THD_{Line} = \sqrt{\frac{\pi^2(-\frac{1}{4} + \frac{3}{2\pi}\alpha_2)}{9(\cos\alpha_1 - \cos\alpha_2)^2} - 1} \tag{6}$$

$F4: 0 < \alpha_1 \le 30 \ \& \ 60 < \alpha_2 \le 90 \ \& \ 30 < \alpha_2 - \alpha_1 \le 60$

$$THD_{Line} = \sqrt{\frac{\pi^2(-\frac{3}{4} + \frac{3}{\pi}\alpha_2)}{9(\cos\alpha_1 - \cos\alpha_2)^2} - 1} \tag{7}$$

$F5: 0 < \alpha_1 \le 30 \ \& \ 60 < \alpha_2 \le 90 \ \& \ 60 < \alpha_2 - \alpha_1 \le 90$

$$THD_{Line} = \sqrt{\frac{\pi^2\left(-\frac{5}{4} - \frac{3}{2\pi}(\alpha_1 - 3\alpha_2)\right)}{9(\cos\alpha_1 - \cos\alpha_2)^2} - 1} \tag{8}$$

$F6: \ 30 < \alpha_1 \le 60 \quad \& \quad 30 < \alpha_2 \le 60$

$$THD_{Line} = \sqrt{\frac{-\pi(\alpha_1 - \alpha_2)}{6(\cos\alpha_1 - \cos\alpha_2)^2} - 1} \tag{9}$$

$F7: 30 < \alpha_1 \le 60 \ \& \ 60 < \alpha_2 \le 90 \ \& \ 90 < \alpha_1 + \alpha_2 \le 120$

$$THD_{Line} = \sqrt{\frac{\pi^2\left(-\frac{1}{2} - \frac{3}{2\pi}(\alpha_1 - 2\alpha_2)\right)}{9(\cos\alpha_1 - \cos\alpha_2)^2} - 1} \tag{10}$$

$F8: 30 < \alpha_1 \le 60 \ \& \ 60 < \alpha_2 \le 90 \ \& \ 120 < \alpha_1 + \alpha_2 \le 150$

$$THD_{Line} = \sqrt{\frac{\pi^2\left(\frac{1}{2} - \frac{3}{2\pi}(2\alpha_1 - \alpha_2)\right)}{9(\cos\alpha_1 - \cos\alpha_2)^2} - 1} \tag{11}$$

$F9: \ 60 < \alpha_1 \le 90 \quad \& \quad 60 < \alpha_2 \le 90$

$$THD_{Line} = \sqrt{\frac{-\pi(\alpha_1 - \alpha_2)}{6(\cos\alpha_1 - \cos\alpha_2)^2} - 1} \tag{12}$$

F1 is equal to F6 and F9, so seven separate equations are totally found for LVTHD (THD_{Line}), therefor the LVTHD is a multi criterion equation. One of the most important application of these formulas is the analytic determination of optimum angles for minimizing line Voltage THD which will be done in the next part. Currently, there is no analytical approach to minimize THD, Now in according to the precise LVTHD formula the analytical approach will be donning. In the next part by using of the Multi Population Particle Swarm Optimization (MPPSO) the precise LVTHD formula is applied as a novel fitness function to minimize the LVTHD in the whole of the modulation index area.

III. MULTI POPULATION PARTICLE SWARM OPTIMIZATION ALGORITHM

The new fitness function is shown in Eq. (13). This new fitness function is applied to minimize LVTHD, In addition in this new fitness function the fundamental component of the output voltage will be adjusted at its desired reference value in the whole of the modulation index area.

$$\textit{fitness function}:\begin{cases}\cos\alpha_1-\cos\alpha_2=M\\ \min\left(THD_{Line}\right)\end{cases}$$
$$0\le M\le 1 \qquad (13)$$
$$0<\alpha_1<\alpha_2<90$$

The multi population method based on PSO algorithm is developed in this paper. The correction motion vector for each particle in PSO method is as follows:

$$v_{i+1}^{k+1}=w_iv_i^k+c_1.rand.(pbest-x_i^k)+c_2.rand(gbest-x_i^k) \qquad (14)$$

In Eq. (14), V_i^k is the motion vector of i^{th} particle in k^{th} repetition. V_i^{k+1} is a correction motion vector for i^{th} particle. *rand* is a random number in [0 1] interval. x_i^k is the current position of i^{th} particle in k^{th} repetition. *pbest* is the best answer of i^{th} particle in all repetition, The index of the best particle among all the particles in the group is represented as *gbest*. w_i is the weight coefficient for speed vector of i^{th} particle and C_i is the weight coefficient for each particle.

In this paper, use of more population in the main PSO algorithm, which can be determined arbitrary value for N_p parameter, the N_p is number of population. Also in (Zhao et al., 2005, Qi et al., 2013) to ensure convergence of the method is used of contraction coefficient *K*, their value is calculated according to the Eq. (15).

$$v_{i+1}^{k+1}=K*(w_iv_i^k+c_1.rand.(pbest-x_i^k)+c_2.rand(gbest-x_i^k))$$
$$K=\frac{2}{\left|2-C-\sqrt{C^2-4C}\right|}\quad \textit{where } C=c_1+c_2 \quad \textit{and} \quad C>4 \qquad (15)$$

In the proposed method multiple populations are used as parallel to optimize the fitness function. In each step of a repeat, the each population will have been optimized the fitness function as separately, which motion vector for each population is modified as follows:

$$v_{i+1}^{k+1}=K*\left(w_iv_i^k+c_1.rand.(pbest-x_i^k)+c_2.rand(gbest-x_i^k)+c_3.rand.(gbest\_total-x_i^k)\right) \qquad (16)$$

In Eq. (16) coefficient C3, is the weight coefficient of third relationship, which can be regulated by trade of technique according to the type of optimization problem. *gbest_total*, is the best value of the *gbest* among all populations in each repetition. In this case, the particles of each population are up to date according to their population and other populations. This new solution increases the scope of the search and the speed of convergence. After repeating process which is considered, the each population will have an optimal result. The ultimate answer, is the best choice from the different population. It is clear that the increasing of the data volume processing by increase the number of populations.

The procedure to implement the proposed MPPSO technique is summarized in the diagram of Fig. 3 (a). And also The flowchart of the basic operation of the MPPSO shown in Fig. 3 (b) is explained as follows:

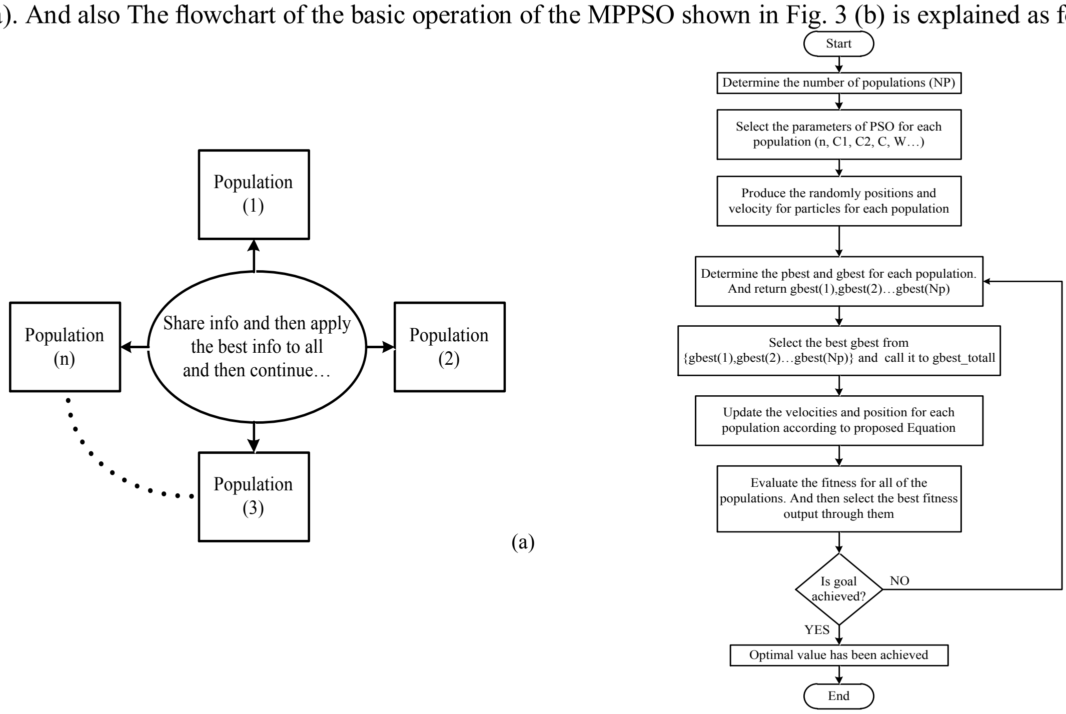

Fig. 3 (a) Block diagram of the implementation of the proposed MPPSO technique (b) Flowchart of MPPSO

IV. SIMULATION RESULTS

In this section, MPPSO is compared with GA method. All possible values of α in a three-level inverter with two switching angles via whole of the modulation index area (α_1 and α_2) are drawn in Fig. 4. It can be seen that the adoptable changes for switching angles in the whole of the modulation index area.

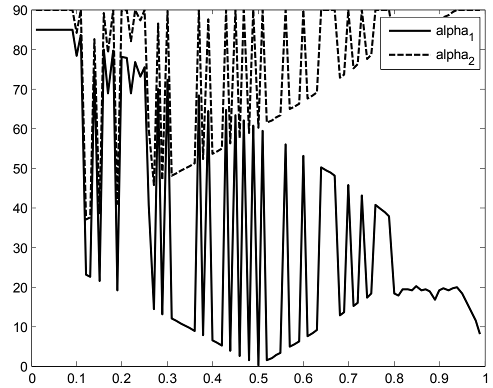

Fig. 4 Switching Angles via Modulation index

There is an acceptable distance between switching angles, So, it is an easy task for applying these switching angles to the hardware controller of three level three phase inverter. But in prior article [17, 28] which have been used of general optimization algorithm such as GA[1] or PSO[2], this distance between switching angles are tiny, therefor the applying of this angle to hardware controller are more difficult than MPPSO elicit angles.

The calculation fundamental component via modulation index is shown in Fig. 5, as can be seen the calculation of fundamental component is equal to the desired reference value in the whole of the modulation index area.

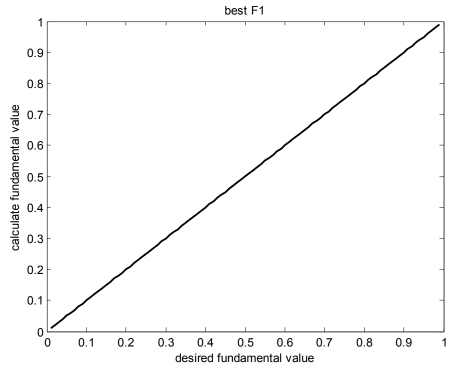

Fig. 5 calculation fundamental components via modulation index

The Line Voltage THD via modulation index is shown in Fig. 6. As can be seen in the majority of the modulation index area, THD is minimized to the best possible value.

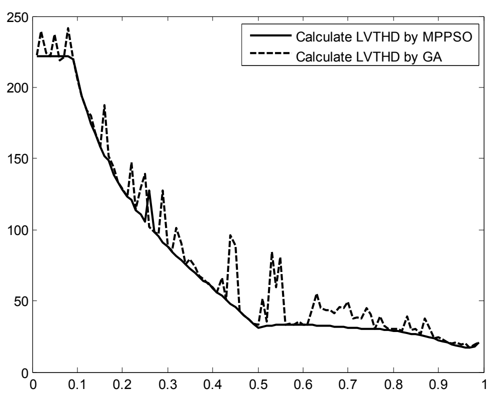

Fig. 6 The Line Voltage THD via modulation index

[1] Genetic Algorithm
[2] Particle Swarm Optimization

The THDM[3] modulation method have been implemented of precise LVTHD formula to minimize THD without any force on the single harmonic order. The THDM method is better than SHEPWM[4] in order to minimize THD in the whole of the modulation index area.

V. CONCLUSION

In this paper, two novel solutions have been presented to minimize the LVTHD in three phase three level inverter with infinite number of switching angles. The first new solution is applying the LVTHD precise formula as a new fitness function for applying them to the optimization algorithm, and the next one novel solution is implementing the MPPSO optimization algorithm to minimize LVTHD. It is shown that all harmonics are taken into account by these methods. In addition, a comprehensive comparison is carried out between these methods and general others methods. These expressions will be used to extract all optimum switching angles for minimizing the THD, analytically. In the simulation results section, the advantages of the MPPSO algorithm compare with GA algorithm has been shown. The MPPSO algorithm is better than GA algorithm in order to minimize THD value.

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