Harmonic Reduction of Multilevel Inverters by using Soft Computing Techniques: A Review

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To eliminate harmonics in output voltage, multilevel inverters are used in the utility interface of renewable energy sources and determination of switching angles for removing specific harmonics and lowering THD. Using the SHE-PWM approach, specified harmonics particularly low odd order harmonics, of the inverter's output voltage are eliminated. Because nonlinear transcendental equations contain several local optima, harmonic minimization is a difficult optimization issue. This paper presents that the objective function has alongwith selected harmonic removal restrictions by using various soft computing techniques.

Keywords: Selective Harmonic Elimination (SHE), Multilevel Inverter, Total Harmonic Distortion (THD), Soft Computing Techniques.

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1 Introduction

Various medium voltage & high power conversion applications, multilevel inverters are essential. The use of multilevel inverters in fuel cells, solar cells, and wind turbines is fast expanding these days. Multilevel inverters have a number of advantages over PWM inverters, including reduced dv/dt stress, large operation capabilities, minimal switching losses, excellent efficiency, minimal electromagnetic interference, and the ability to operate at both low and high switching frequencies are now all strengths [9]. In industrial applications, NPC MLI (Neutral Point Clamped MLI), H-bridge MLI (Cascaded H-bridge MLI) and FCMLI (Flying Capacitor MLI) are the most commonly utilized Multilevel Inverter (MLI) topologies. NPC MLI is utilized in a variety of applications that require a single high-voltage dc-bus, such as motor drives, pumps, and mills. In medium traction drives, FC MLI is used. CHB MLI can be used in applications with scattered dc sources, such as fuel cells and solar arrays [1].

When designing an effective multilevel inverter, the output voltage waveform's total harmonic distortion (THD) should be maintained within acceptable limits. For multilevel converters, there are four different sorts of control mechanisms. The basic frequency switching and space vector control methods have a lower switching frequency but greater low-order harmonics at lower modulation indices than the other two control methods. Harmonic removal is generally accomplished using the standard PWM approach. However, low-order harmonics cannot be entirely eliminated using PWM approaches. Another alternative is to select switching angles it will suppress specific lower order prominent harmonics. Harmonic elimination that is optimal, "programmed," or selective. For various converter topologies, systems, and applications, PWM (SHE-PWM) approaches have been employed to remove specialized low-order harmonics from the voltage/current waveform produced by the voltage/current source inverters. Fourier theory is used to analyze voltage waveform, which results in a series of the complex transcendental equations. To solve these sets of equations, iterative approaches such as the Newton-Raphson method were applied. This approach is derivative-dependent & may result in local optima, but smart initial value selection alone ensures conversion.

SHE (selective harmonic elimination) is a well-known modulation technique. Patel and Hoft explained the selective Harmonic Elimination for the first time in the 1960s. In the subject of solving SHE equations, the advent of evolutionary algorithms gives up new possibilities. These algorithms have a number of advantages, including the fact that they are not reliant on an initial assumption, simple algebra is used, resulting in decreased processing costs and the formulation of multi-constrained problems. Particle Swarm Optimization (PSO) is a popular evolutionary approach for determining switching angles for multilevel inverters in order to eliminate the low order voltage harmonics and optimize dc-link harmonics. In the literature, a variety of algorithms for SHE have been proposed: Particle Swarm Optimization (PSO) , Modified Particle Swarm Optimization (MPSO),Grasshopper Optimization algorithm, continuous genetic algorithm, Imperialist competitive algorithm, Weight Improved Particle Swarm Optimization (WIPSO), Modified Species-Based Particle Swarm Optimization (MSPSO) algorithm, Fish Swarm Optimization algorithm (FSO), Flower pollination algorithm (FPA), Modified grey wolf optimization (MGWO), genetic algorithm (GA), improved firefly algorithm (FA),artificial bee colony algorithm (ABCA), Bee algorithm, Nelder Mead Simplex Algorithm, Ant Colony Optimization[2].

2 Cascaded H-Bridge (CHB) Multilevel Inverter

This multilevel inverter's main objective is to generate a desired voltage from a variety of dc sources (SDCSs), such as batteries, or solar cells. Each separate DC sources is equipped with a single-phase full-bridge inverter. By combining the four switches in various ways, $S_1, S_2, S_3 and S_4$, to connect the dc source & the ac output side, each inverter level can output one of three voltages: $+V_{dc}$, 0, or $-V_{dc}$. "s = 2m+1," where "m" is the no. of dc sources. Van denotes the phase voltage of the waveform, and it is defined as $V_{an} = V_{a1} + V_{a2} + V_{a3} + V_{a4} + V_{a5}$. Each bridge unit generates a quasi-square waveform. As a result, switching angles must be computed in order to apply SHE in CHB MLI [3].

3 Fourier Analysis And Expansion

The equation for the staircase output voltage of a cascade multilevel inverter is usually obtained via Fourier series analysis. It's written like this:

$$Vout(\theta) = Ao+\sum_{n=1}^{\infty}(A_n \cos(n\theta) + B_n \sin(n\theta))$$

where

$$A_0 = \frac{1}{2\Pi}\int_0^{2\Pi} f(t)dt,\quad A_n = \frac{1}{\Pi}\int_0^{2\Pi} f(t)\sin(nwt)\,dt, B_n = \frac{1}{\Pi}\int_0^{2} f(t)\cos(nwt)\,dt$$

Because there is no dc output or mean values in all inverter output voltages,$A_0 = 0$. It also contains only odd functions.

$$Vout = \sum_{n=1,3,5....}^{\infty} B_n \sin n\theta$$

The generalized stepwise voltage waveform of a multilevel inverter with non-equal dc voltage sources has theFourier analysis expansion:

$$V(wt) = \sum_{n=1,3,5...}^{\infty} \frac{4V_{dc}}{n\Pi}*(k_1\cos(n\theta_1) + k_2\cos(n\theta_2) + k_3\cos(n\theta_3) + \cdots + k_s\cos(n\theta_s))\sin(nwt)$$

where s denotes the number of H-bridges in a phase's cascade, k denotes the order of harmonic components, Vdc denotes the nominal dc voltage, and switching angles 1-s must satisfy the following requirement.

$$0<\theta_1<\theta_2<\theta_3........\theta_s<\frac{\Pi}{2}$$

4 Selective Harmonic Elimination (SHE) Problem

The determination of switching angles's' for harmonic minimization is the key area of concern in multilevel inverters. The number of the harmonics reduced from the output voltage is "s-1," and a set of 's' transcendental SHE equations is created by giving the fundamental component of voltage, V_1, a specified value.

$$V_1 = [4V_{dc}*(k_1\cos\theta_1 + k_2\cos\theta_2)]/\pi$$

and the equating of "s-1" harmonics is zero. The output voltage of the multilevel inverters is calculated using the calculations below:

$$\frac{\Pi}{2} = k_1\cos\alpha_1 + k_2\cos\alpha_2+.........+k_s\cos\alpha_s$$

$$0 = k_1\cos5\alpha_1+ k_2\cos5\alpha_2+.........+k_s\cos5\alpha_s$$

$$0 = k_1\cos7\alpha_1+ k_2\cos7\alpha_2 +.........+k_s\cos7\alpha_s$$

$$0 = k_1\cos n\alpha_1+ k_2\cos n\alpha_2+.........+k_s\cos n\alpha_s$$

In above SHE equations, Modulation Index 'M' is defined as:

$$M = \frac{V_1}{s\,V_{dc}},\ 0 \leq M \leq 1.$$

5 Comparative Analysis Based on Selective Harmonic Elimination and Its Various Soft Computing Techniques

In 2008, Barkati et al. has discussed that the two evolutionary methods for the best harmonic stepped–waveform approach [4]. In Table I, s.no.1, shows the objective function and constraints mentioned by author. To deliver the requisite fundamental voltage while avoiding specified harmonics, the switching angles of a three-phase, seven-level inverter are estimated utilizing evolutionary algorithms and particle swarm optimization. The PSO method significantly easier to implement than the GA and does not involve the adjustment of various parameters. It may be observed also that the PSO is a potential method for solving the challenge of optimizing power converters. When triggered from a starting position that is closer to the optimal one, Newton's approach tends to yield significantly better results. As a result, the hybrid GA-NR & PSO-NR algorithms were employed to achieve an autonomous and error-free option search. Furthermore, the current research can be simply extended to any variety of levels and used to different multilayer inverter topologies. In 2009, Ray et al. has presented the overall THD of a PWM inverter's output voltage minimized using a PSO-based optimization technique [5]. In Table I, s.no.2, shows the objective function and constraints mentioned by author. The strategy avoids directly solving the SHE problem's nonlinear equations. The suggested PSO algorithm seeks out the widest range of solutions in order to contribute the least amount of THD. For both unipolar & bipolar situations with variable switching angles &varying m_d, the current technique has been demonstrated to be quite effective in lowering total THD. In 2012, Sadret et al. has suggested that simple &computationally tractable solution technique for removing selected harmonics and producing a specified fundamental component. The non-linear transcendental equations resulting from the SHE methodology solved using the particle swarm optimization (PSO) method. For several scenarios, switching angle trajectories has been shown [6] .In Table I, s.no.3, shows the objective function and constraints mentioned by author. In 2013, Maharana has introduced the implement of the PSO technique in an H-bridge cascade multilevel inverter to reduce total harmonics distortion (THD) using the selective harmonics elimination (SHE) procedure with equal dc sources. Their method has been capable of quickly determining the best switching angles. In comparison to other methods, the PSO technique offers a lower computing burden and smoother convergence criteria. A comprehensive analysis of the 11-level inverter has been presented, demonstrating that a significant reduction in THD has been achieved [3]. In Table I, s.no.4, shows the objective function and constraints mentioned by author. In 2014, Soltani et al. has presented the major goal of their research was to reduce total harmonic distortion by eliminating H-bridge cascaded multilevel inverters with identical source have a selected harmonic (THD). To accomplish this, the PSO, WIPSO and MPSO algorithms were used to calculate the best switching angles for converter switches. The amplitude modulation index influences the performance of three approaches for THD reduction (M) for low modulation index (below 0.8) shows that MPSO has smaller THD than PSO and WIPSO, while WIPSO has smaller THD for modulation index 1 and above, and WIPSO has lower THD for other modulation index ranges.. Among the three recommended approaches, PSO has the lowest THD. When compared to the PSO method, the MPSO and WIPSO algorithms obtain reduced iteration counts. In addition, among the proposed approaches, the WIPSO algorithm has the fastest convergence speed. In the optimization problem, the three proposed strategies lower the 5th, 7th, 11th, and 13th order harmonics. Among the presented methods, the WIPSO algorithm obtains the solution with less iterations and faster convergence [1] .In Table I, s.no.5, shows the objective function and constraints mentioned by author. In 2018, Kala et al.

has explained the approach of the PSO-based SHE technique in an 11-level inverter. The computation of optimal switching angles has been done using this method [7]. In Table I, s.no.6, shows the objective function and constraints mentioned by author. When comparing the PSO approach to the CGA approach, it was discovered that the PSO approach has benefits such as a faster response rate and a regarding minimum fitness function value. Their approach has to eliminate the lowers odd order harmonics & THD while also assisting in achieving the target fundamental voltage. Their scheme's superiority was also demonstrated by the fact that it was able to find several solutions for specific modulation indices. As a result, the PSO approach for multilevel inverter (MLI) modulation could be inferred to be a simple, quick, and efficient modulation method. In 2009, Haghet al. has introduced a harmonic minimization solution based on a new species-based particle swarm optimization technique (SPSO) [8]. In Table I, s.no.7, shows the objective function and constraints mentioned by author. To identify the optimum switching angles of multilevel inverters, an MSPSO technique with adaptive niche radius adjustment has been developed. Their approach has been used to SHE-PWM problem, which has a large number of switching angles and cannot be solved using existing methods. The results reveal that at the inverter's output voltage waveform, all unwanted harmonics up to the 50th order have been efficiently eliminated.

In 2009, Kumar al. has introduced the selective harmonic elimination approach was constructed utilizing an optimization methodology that delivers all feasible solution sets when they exist for the fundamental frequency switching scheme. In Table I, s.no.8, shows the objective function and constraints mentioned by author. In compared to other strategies that have been offered, their technique has a number of advantages, including the ability to generate all possible answer sets for any number of multilevel inverters with little computational effort, rapid convergence, and the possibility to develop uninterrupted solutions across the whole modulation index region, allowing for greater control action flexibility. Their method has to calculate the switching angles for 11-level CMLI was successfully implemented. A comprehensive analysis of the 11-level inverter has been published, demonstrating that computing all possible solution sets can result in a significant reduction in THD [9].

In 2013, Ajami et al. have discussed that to calculate the best angles of the 9-level inverter, an ICA technique has been proposed [10]. In Table I, s.no.9, shows the objective function and constraints mentioned by author. Their method has been applied to the Selective Harmonic Elimination (SHE)-PWM problem, which has a larger no. of switching angles and difficult to address using existing methods. To confirm the accuracy of the suggested method for a 9-level inverter were provided. In 2015, M. G. Sundari et al. have presented a new methodology for estimating the switching angles of the 11 level MLI with changeable DC sources, based on a self adaptive enhanced firefly algorithm. Their target was lower order harmonics, namely the 5^{th}, 7^{th}, 11^{th}, & 13^{th}, have been shown to be well eliminated. While the performance of the firefly method was compared to that of other algorithms, it has a few extra benefits, such as a short convergence time [11]. In Table I, s.no.10, shows the objective function and constraints mentioned by author.

In 2017, Sadhukhanet al. has presented the use of the PSO method for finding switching angles in the SHEPWM methodology. At various levels of modulation indices, the switching angles have been determined offline using MATLAB 2014b software. From the computed switching angles, the HEPWM signals were realized in hardware using a PIC microcontroller. In the experimental platform, these PWM signals were used to control the three-phase VSI. It was possible to get a satisfactory improvement in performance. THD was calculated up to the 43rd harmonic in this case. As a result, power electronics inverters were beneficial in a variety of applications, including grid integration of the renewable energy sources and battery energy storaging systems [12]. In Table I, s.no.11, shows the objective function and constraints mentioned by author.

In 2018, Panda et al. has discussed that a new nine-level MLI topology with a reduced switch count and compared with several recently produced MLI topologies in their research. Only three switches were in the current path for the proposed MMLI at any given time, whereas the number of switches in the current path for the other examined topologies increases as the number of the levels increases. This means that the existing MMLI has lower conduction, voltage, and switching losses than the other topologies. In order to determine the best switching angles for selectively reducing voltage harmonics, a novel FPA was implemented. In comparison to PSO, the suggested FPA approach has been successfully obtained a workable solution in the shortest amount of time, according to a delineative study [13]. In Table I, s.no.12, shows the objective function and constraints mentioned by author.In2018, Khattak et al. has explained the unconstrained solver Nelder Mead(NM) was used to compute DC values & switching angles for equal & unequal DC sources in 5 and 7 level inverters. During the operation, both single and three phase output voltages were considered. Their results have been shown that the unconstrained solver NM performs well in the confined issue of THD minimization in CMLI, outperforming both GA & Pattern Search. The range m for which a solution was discovered was larger than that found with GA, indicating that NM has a distinct advantage over GA. Furthermore, if only THD was taken into account. As a result, Symmetric Multilevel Inverter SMLI hardware was less expensive to produce than AMLI gear. In a similar way, the NM approach has been utilized for SHE. NM has a lot of potential when it comes to calculating switching angles in real time [14]. In Table I, s.no.13, shows the objective function and constraints mentioned by author. In 2018, Lodi et al. has presented the goal of their research was to reduce THD for only a modified PUC-5inverter by finding the best switching angles under specified limitations using GA to reduce the nonlinear THD equation. The switching angles obtained by GA were utilized to drive the inverter switching angles. These novel angles have resulted in a low THD that can be achieved without the usage of a large filter [15]. In Table I, s.no.14, shows the objective function and constraints mentioned by author.

In 2019, Routray et al. has introduced the Modified Grey Wolf Optimization (MGWO) optimized eleven-level three-phase HC-MLI employing SHE-PWM has been provided [16]. In Table I, s.no.15, shows the objective function and constraints mentioned by author. When compared to Grey Wolf Optimization (GWO), the employment of an adaptive co-efficient position vector with an exponentially decreasing function yields better results. When compared to GWO, GA, and PSO, the chaotic localized search technique strategy taken care of the local optima, On the other hand, the weighted proposed control strategy improved convergence rate. In comparison to other documented evolutionary intelligence algorithms, MGWO helped to obtain the global optima rapidly and successfully eliminated low harmonics from the output's voltage.

In 2020, Patil et al. has discussed for single phase 7-level CMLI, their hybrid techniques have been used to calculate the optimal switching angles in their research [17]. In Table I, s.no.16, shows the objective function and constraints mentioned by author. All feasible solution sets has been generated by their Hybrid method. In comparison to other methods, the suggested strategy was superior and has numerous advantages, including the ability to generate all potential multilevel inverter solution sets with minimal computational effort and a quick convergence rate. The Concept & physical implementation for a 7-level inverter using the proposed hybrid optimization approach were presented in their work. It has a direct search method for reducing computing load and ensuring the accuracy of calculated switching angle values. The algorithm produces THD levels of 2.66 percent, with a significant reduction in lower order odd harmonics such as the 3^{rd}, 5^{th}, and 7^{th} harmonics. As a result, their method has been proved to be better than others.

In 2020, Steczek et al. has explained the demonstrates how to evaluate the switching angles for SHE - PWM low-frequency, voltage source inverters (VSI) using the newly established GOA (Grasshopper Optimization Algorithm).In Table I , s.no.17, shows the objective function and constraints mentioned by author. GOA algorithm modifications have been performed & compared to the PSO algorithms. As a result, their results shown that the GOA method, like PSO, requires a smaller population sizes to converge with equivalent computational effort. Laboratory measurements proved the efficacy of the GOA algorithm used to solve the SHE problem. GOA outperforms PSO the most. PSO convergences were significantly reduced. According to the findings of the measurement trials, the SHE-PWM optimized by GOA algorithms reduced the selected harmonics in inverter's voltage level [2].

Table I. Comparative Analysis of Objective Function

S. No.	Objective Function	Constraints	Analysis
1.	Fitness($\propto_1, \propto_2, \propto_3$)=$w_1$|3 M − H_1| + w_2|H_5| + w_3|H_7|	Subject to: 0<Θ1<Θ2<Θ3<$\frac{\pi}{2}$ $\frac{3\Pi}{4} = \cos(\theta_1) + \cos(\theta_2) + \cos(\theta_3)$ $0 = \cos(5\theta_1) + \cos(5\theta_2) + \cos(5\theta_3)$ $0 = \cos(7\theta_1) + \cos(7\theta_2) + \cos(7\theta_3)$ M=$\frac{Vref}{3Vdc}$; H1=$\frac{Vref}{Vdc}$	For the optimal harmonic stepped–waveform approach, there are two evolutionary algorithms. Genetic algorithms (GA) and the switching angles are calculated using particle swarm optimization. The diode-clamped multilevel inverter is considered in this study (DCMI). To obtain a high level of precision in harmonic removal, hybrid optimization algorithms which combine with GA or PSO with traditional Newton-Raphson methods (NR) are used [4].
2.	F(α)=F($\propto_1, \propto_2 \ldots . \propto_m$)= $\left[\frac{1}{a_1^2}\sum_{n=5}^{\infty}(an^2)\right]$ ^ $1/2$ a_1=M; M= Amplitude of fundamental Component $a_5 \leq \epsilon 1$; $a_n \leq \epsilon n$;	Subject to: 0<$\propto_1$<$\propto_2$<...<$\propto_m$<$\frac{\pi}{2}$ a_1=$\left(\frac{4}{\Pi}\right)$[1 + $2\sum_{k=1}^{m}(-1)^k\cos(\propto_k)$]=M a_5=$\left(\frac{4}{5\Pi}\right)$[1 + $2\sum_{k=1}^{m}(-1)^k\cos(5\theta_k)$]=0 a_n=$\left(\frac{4}{n\Pi}\right)$[1 + $2\sum_{k=1}^{m}(-1)^k\cos(n\theta_k)$]=0 n=6i±1 ($i = 1,2,3 \ldots$)	Switching angles are employed in PSO approach to reduce the THD of the voltage level. Over a wide range of modulation indexes, the suggested technique has been found to be successful in minimizing THD. The methodology is used to look into unipolar and bipolar switching patterns. In this research, the current strategy is shown to very effectives in lowering total THD for both unipolar & bipolar situations with variable switching angle [5].

3.	Min{ $(g(H))= \|B_1 - m_a V_m\| + \|B_3\| + \cdots \|B_{k-1}\|$}	Subject to: $0<\theta_1 < \theta_2 < \theta_3 < \cdots < \theta_k < \frac{\pi}{2}$ $B_n= \frac{2V_m}{\Pi} \sum_{i=1}^{k} (-1)^i [\frac{\sin(n-1)\theta_i}{n-1} - \frac{\sin(n+1)\theta_i}{n+1}]$ $B_1=V_m(1+\frac{2}{\Pi}\sum_{i=1}^{k}((-1)^i)[\theta_i - \frac{sin2\theta_i}{2}])$ $M_a=B_1/V_m$	The ideal solutions for selective harmonics elimination (SHE) problem in a PWM, AC/AC voltage regulator was calculated using the Particle Swarm Optimization (PSO) technique [6]. This paper works on various switching angle patterns are shown for various circumstances.
4.	For 11-level inverter $f(t)=\sqrt{\sum_{n=3,5,7}^{49} (V_n)^2 / V_1}$	Subject to: $0<\theta_1 < \theta_2 < \theta_3 < \theta_4 < \theta_5 < \frac{\pi}{2}$ $cos\theta_1 + cos\theta_2 + cos\theta_3 + cos\theta_4 + cos\theta_5 = M$ $cos3\theta_1 + cos3\theta_2 + cos3\theta_3 + cos3\theta_4 + cos3\theta_5 = 0$ $cos5\theta_1 + cos5\theta_2 + cos5\theta_3 + cos5\theta_4 + cos5\theta_5 = M0$ $cosn\theta_1 + cos\theta_2 + cos\theta_3 + cos\theta_4 + cos\theta_5 = 0$ $M=\frac{V_1 * \Pi}{4 * V_{dc}}$	The PSO technique was used to reduce THD in a multilevel inverter utilizing the same dc sources. The THD of the inverter circuit voltage up to 49th order harmonics was calculated with modulation index m=0.47 and found to be roughly 6% [3].

5.	For 11-level inverter f(t)=$\sqrt{\sum_{n=3,5,7}^{63}(V_n)^2}/V_1$	Subject to: 0<$\theta_1 < \theta_2 < \theta_3 < \theta_4 < \theta_5 < \frac{\pi}{2}$ $cos\theta_1 + cos\theta_2 + cos\theta_3 + cos\theta_4 + cos\theta_5 = M$ $cos3\theta_1 + cos3\theta_2 + cos3\theta_3 + cos3\theta_4 + cos3\theta_5 = 0$ $cos5\theta_1 + cos5\theta_2 + cos5\theta_3 + cos5\theta_4 + cos5\theta_5 = 0$ $cosn\theta_1 + cos\theta_2 + cos\theta_3 + cos\theta_4 + cos\theta_5 = 0$ M=$\frac{V_1*\Pi}{4*V_{dc}}$	The optimal switching angles were discovered using the Particle Swarm Optimization (PSO), Modified Particle Swarm Optimization (MPSO), & Weight Improved Particle Swarm Optimization (WIPSO) algorithms. Among the presented methods, the WIPSO algorithm obtains the solution with smaller iterations & faster convergences [1].
6.	For 11- level inverter f=min $\propto_i \left[\left(100\frac{V_1^d - V_1}{V_1^d}\right)^4 + \sum_{i=2}^{5}\frac{1}{4h_i}\left(100\frac{Vh_i}{V_1}\right)^2\right]$	Subject to: 0≤θ_i≤$\frac{\pi}{2}$ V_1=$\frac{4V}{\Pi}[cos\theta_1 + cos\theta_2 + cos\theta_3 + cos\theta_4 + cos\theta_5]$ Vh_5=$\frac{4V}{\Pi}[cos\theta_1 + cos\theta_2 + cos\theta_3 + cos\theta_4 + cos\theta_5]$ Vh_7=$\frac{4V}{\Pi}[cos\theta_1 + cos\theta_2 + cos\theta_3 + cos\theta_4 + cos\theta_5]$ Vh_{11}=$\frac{4V}{\Pi}[cos\theta_1 + cos\theta_2 + cos\theta_3 + cos\theta_4 + cos\theta_5]$ Vh_{13}=$\frac{4V}{\Pi}[cos\theta_1 + cos\theta_2 + cos\theta_3 + cos\theta_4 + cos\theta_5]$ M=$\frac{V_1*\Pi}{4*5*V}$, 0≤ $M \leq 1$	SHE techniques based on PSO and SHE based on a continuous genetic algorithm (CGA) were applied [7]. When compared to the CGA-based SHE approach, the PSO approach has advantages such as quicker rates convergence and a substantially lower fitness function value.
S. No.	Objective Function	Constraints	Analysis

7.	F$(\theta_1, \theta_2 \ldots \theta_s)$= $100\left(\left\lvert M - \frac{\lvert V_1\rvert}{sV^{dc}}\right\rvert + \left(\frac{\lvert V_5\rvert+\lvert V_7\rvert+\cdots+\lvert V_{3ks-2\ or 3ks-1}\rvert}{sV^{dc}}\right)\right)$ F$(\theta_1, \theta_2 \ldots \theta_s)$= $100\left(\left\lvert M - \frac{\lvert V1\rvert}{sV^{dc}}\right\rvert + \left(\frac{\lvert V_5\rvert+\lvert V_7\rvert+\cdots+\lvert V_{49}\rvert}{sV^{dc}}\right)\right)$	Subject to: 0<$\theta_1 < \theta_2 < \theta_3 < \cdots < \theta_{ks} < \frac{\pi}{2}$ $(\frac{8\Pi}{4})M = \cos\alpha_1 \pm \cos\alpha_2 \pm \cdots \pm \cos\alpha_{ks-1} + \cos\alpha_{ks}$ $0 = \cos 5\alpha_1 \pm \cos 5\alpha_2 \pm \cdots \pm \cos 5\alpha_{ks-1} + \cos 5\alpha_{ks}$ $0 = \cos 7\alpha_1 \pm \cos 7\alpha_2 \pm \cdots \pm \cos 7\alpha_{ks-1} + \cos 7\alpha_{ks}$ $0 = \cos 3ks - 2\alpha_1 \pm \cos 3ks - 2\alpha_2 \pm \cdots \pm \cos 3ks - 2\alpha_{ks-1} + \cos 3ks - \alpha_{ks}$	The MSPSO (Modified Species-Based Particle Swarm Optimization) algorithm used to determine the optimal big number of switching angles with niche radius adjustment and to minimize a large number of unique harmonics. 50 order harmonics were considered to determine Total Harmonic Distortion (THD) [8].
8.	$\Phi(\theta_1, \theta_2, \theta_3, \theta_4, \theta_5)$= $\sqrt{h_5^2 + h_7^2 + h_{11}^2 + h_{13}^2}$	Subject to: 0<θ_1<θ_2<…<θ_5<$\frac{\pi}{2}$ $h_5 = \cos(5\theta_1) + \cos(5\theta_2) + \cdots + \cos(5\theta_5)$ $h_7 = \cos(7\theta_1) + \cos(7\theta_2) + \cdots + \cos(7\theta_5)$ $h_{11} = \cos(11\theta_1) + \cos(11\theta_2) + \cdots + \cos(11\theta_5)$ $h_{13} = \cos(13\theta_1) + \cos(13\theta_2) + \cdots + \cos(13\theta_5)$	The optimization strategy that yields all potential solution sets was used to build at a fundamental frequency switching scheme, the selective harmonic elimination approach is used. This work proposes sequential quadratic programming (SQP) as a method for solving SHE equations that produces all reasonable solutions [9].
9.	For 9-level cascaded inverter	Subject to: 0≤θ_1≤……..≤θ_{12}≤$\frac{\pi}{2}$	To discover the optimum switching angles and solve the SHE-PWM

	FF=min$\left[(100 * \frac{V_1^*-V_1}{V_1^*})^\wedge 4 + \sum_{i=2}^{ks} \frac{1}{h_i} (50 * \frac{V_{hi}}{V_1})^\wedge 2 \right]$	$(Va_1)=\frac{4}{\Pi}[-1+\cos(\theta_1)-\cos(\theta_2)+\cos(\theta_3)-\cos(\theta_4)+\cdots+\cos(\theta_{12})]$ $(Va_5)=\frac{4}{\Pi}[-1+\cos(5\theta_1)-\cos(5\theta_2)+\cos(5\theta_3)-\cos(5\theta_4)+\cdots+\cos(5\theta_{12})]$. $(Va_{35})=\frac{4}{\Pi}[-1+\cos(35\theta_1)-\cos(35\theta_2)+\cos(35\theta_3)-\cos(35\theta_4)+\cdots+\cos(35\theta_{12})]$	problem with a high number of switching angles, an ICA algorithm was applied [10]. DC-DC converter is used to control the inverter's input Voltage level and ensure that the SHE is met for all modulation index fluctuations, substantially improving the SHE effectively on eliminating undesirable harmonics.
S. No.	Objective Function	Constraints	Analysis
10.	For 11 level cascaded H bridge multilevel inverter FF= $\left[\left(100\frac{V_1^d-V_1}{V_1^d}\right)^4 + \left(\frac{50}{V_1}\right)^2 * \{\left(\frac{V_5}{5}\right)^2 + \left(\frac{V_7}{7}\right)^2 + \left(\frac{V_{11}}{11}\right)^2 + \left(\frac{V_{13}}{13}\right)^2\}\right]$	$\sum_{i=1}^{5} C_i * \cos(\theta_i) = M * S$ $H_5=\left(\frac{4V_{dc}}{5\Pi}\right)[\sum_{k=1}^{5} C_i * \cos(5\theta_i)]=0$ $H_7=\left(\frac{4V_{dc}}{7\Pi}\right)[\sum_{k=1}^{5} C_i * \cos(7\theta_i)]=0$ $H_{11}=\left(\frac{4V_{dc}}{11\Pi}\right)[\sum_{k=1}^{5} C_i * \cos(11\theta_i)]=0$ $H_{13}=\left(\frac{4V_{dc}}{13\Pi}\right)[\sum_{k=1}^{5} C_i * \cos(13\theta_i)]=0$ M=$\frac{\Pi * H_1}{4SV_{dc}}$	Particle swarm optimization (PSO) and to compare the results, the artificial bee colony algorithm was utilized (ABCA) [11]. In this research, the Firefly method applies the shortest time to compute and outperforms another 11 meta optimization algorithm. MATLAB is used to create the method and model, and an experimental procedure using an FPGA Spartan 6A DSP confirms the simulation's correctness.

11.	F(α)=F($\propto_1, \propto_2 \ldots \propto_m$)= $\left[\frac{1}{b_1^2}\sum_{n=5}^{\infty}\left(\frac{b_n}{n}\right)^2\right]^{\wedge}1/_2$ *100	Subject to: 0<$\propto_1$<$\propto_2$<...<$\propto_m$<$\frac{\pi}{2}$ b_1=$\left(\frac{4}{\Pi}\right)[\sum_{k=1}^{m}(-1)^k \cos(\propto_k)]$ =M b_5= $\left(\frac{4}{5\Pi}\right)[\sum_{k=1}^{m}(-1)^k \cos(5 \propto_k)]$ =0 b_n= $\left(\frac{4}{n\Pi}\right)[\sum_{k=1}^{m}(-1)^k \cos(n \propto_k)]$ =0 ; n$\neq$ 1	A three-phase VSI using a PSO-based harmonic elimination pulse width modulation (HEPWM) approach to remove certain low-order harmonics at the output. The PSO techniques were used to compute the switching angles [12].
12.	FF=$\frac{1}{h}\left(\lvert M-\frac{\lvert V_1\rvert}{N^{dc}V^{dc}}\rvert+\left(\frac{\lvert V_3\rvert+\lvert V_5\rvert+\cdots+\lvert V_7\rvert}{N^{dc}V^{dc}}\right)\right)$	Subject to: 0<$\propto_1$<$\propto_2$<...<$\propto_5$<$\frac{\pi}{2}$ V_1=$\frac{4V_{dc}}{\Pi}[\cos\propto_1+\cos\propto_2+\cos\propto_3+\cos\propto_4]=m$ For n=3,5,7 V_n=$\frac{4V_{dc}}{n\Pi}[\cos\propto_1+\cos\propto_2+\cos\propto_3+\cos\propto_4]=0$ m=$\frac{V_1\Pi}{4V_{dc}}$, Modulation index=M=m/Ndc	The flower pollination algorithm (FPA) was compared to the particle swarm optimization (PSO) algorithm in terms of performance [13]. In comparison to PSO, a delineative analysis reveals that the suggested FPA advanced analytics obtains a workable solution in the shortest time. Simulation.
S. No.	Objective Function	Constraints	Analysis
13.	FF=β^γ*$\lvert\sum_{i=1}^{p}\cos(\propto_i)-pm\rvert * THD$	M=$\frac{4V\sum_{i=1}^{p}\cos\propto_i-pm}{\Pi * V_{1max}}$ V_{1max}=$\frac{4V_p}{\Pi}$, V_{1max}=$\frac{4V(k_1+k_2+\cdots+k_p)}{\Pi}$	To obtain the local minimum of a multidimensional THD function, the Nelder Mead (NM) Simplex algorithm, an unconstrained solver, were used [14]. For 5 and 7 level inverter unequal sample DC sources, the Nelder Mead method is used to determine the best DC values and switching angles. During the operation, both single and three phase dc source are considered. The results show that

			the unconstrained solver NM performs well in the restricted issue of THD minimizing in CMLI, outperforming both GA and Pattern Search methods.
14.	THD= $\sqrt{\frac{\sum_{n=3,5,\dots}^{\infty}[\frac{4E(\cos(n\propto_1)+\cos(n\propto_2)-}{n\Pi}}{\frac{4E}{\Pi}[\cos(\propto_1)+\cos(\propto_2)-\cos(}}$	Subject to:0≤ $\alpha \leq \frac{\Pi}{2}$ B_1=$[\cos(\propto_1)+\cos(\propto_2)-\cos(\propto_3)+\cos(\propto_4)]-2m*\frac{\Pi}{4}=0$ G(a)={$\propto_1-\propto_2$<0, $\propto_2-\propto_3$<0, $\propto_3-\propto_4$<0}	Using GA to minimize the nonlinear equation of THD, minimize the THD for modified PUC-5inverter by achieving optimal switching angles under specific limitations [15]. The genetic algorithm improves is with each iteration, yielding better and better outcomes until it converges on the best solution for our needs. This approach is validated experimentally using the TI-28335 DSP and in the MATLAB®/Simulink.
S. No.	Objective Function	Constraints	Analysis
15.	FF=min $\left[\left(100\frac{V_1^d-V_1}{V_1^d}\right)^4+\sum_{s=2}^{S}\frac{1}{hs}\left(50\frac{Vh_s}{V_1}\right)^2\right]$	M=$\frac{1}{3}[\cos(\alpha_1)+\cos(\alpha_2)+\cos(\alpha_3)]$ $\cos(\alpha_1)+\cos(\alpha_2)+\cos(\alpha_3)$=0 $\cos(\alpha_1)+\cos(\alpha_2)+\cos(\alpha_3)$=0 M=$\frac{V_{desired}}{4S(\frac{V_{dc}}{\Pi})}$; 0≤ $M \leq 1$	The suggested algorithm's performance is compared to that of the genetic algorithm, the bee algorithm, and particle swarm optimization [16]. To reduce 5th and 7th harmonics, APSO-NR is applied to the seven-level inverter. The findings demonstrated that the suggested approach is efficient, yielding more precise firing angles in less iteration while confronting local optima. The fitness function value was reduced to less than (10^-25).

16.	THD= $\frac{\sqrt{\sum_{n=2}(\frac{1\sum_{k=1}^{N}(-1)^{k+1})*cos((n\propto_k)^\wedge}{n}}}{\sum_{k=1}^{N}((-1)^{k+1})*cos(\propto_k)}$	Subject to: 0≤ $\alpha \leq \frac{\Pi}{2}$ $-1 + 2\cos(\propto_1) - 2\cos(\propto_2) + 2\cos(\propto_3) - \frac{\Pi M}{4} = 0$ $-1 + 2\cos(5\propto_1) - 2\cos(5\propto_2) + 2\cos(5\propto_3) = 0$ $-1 + 2\cos(7\propto_1) - 2\cos(7\propto_2) + 2\cos(7\propto_3) = 0$	The hybrid algorithm combines the Ant colony optimization & Newton-Raphson algorithms, with the Ant colony optimization algorithm being used for the first 4 cycles and the result of this process being used as a starting point for the Newton-Raphson algorithm [17]. The suggested approach produces THD values of 2.66 percent with a significant decrease in lower order odd harmonics, according to simulation data.
S. No.	Objective Function	Constraints	Analysis
17.	Minimize, fit(θ_1,θ_2,θ_3,θ_4,θ_5)= $\sigma_1(V_1$-$V_1^*)$^2+$\sigma_5(V_5^2)$^2+$\sigma_7(V_7^2)$^2+$\sigma_{11}(V_{11}^2)$+$\sigma_{13}(V_{13}^2)$	Subject to: 0<θ_1<θ_2<...<θ_5<$\frac{\pi}{2}$ $\frac{4}{\Pi}[-1 + \cos(\theta_1) - \cos(\theta_2) + \cos(\theta_3) - \cos(\theta_4) + \cos(\theta_5)]$ $0 = \frac{4}{5\Pi}[-1 + \cos(5\theta_1) - \cos(5\theta_2) + \cos(5\theta_3) - \cos(5\theta_4) + \cos(5\theta_5)]$ $0 = \frac{4}{7\Pi}[-1 + \cos(7\theta_1) - \cos(7\theta_2) + \cos(7\theta_3) - \cos(7\theta_4) + \cos(7\theta_5)]$	The switching angles were determined using the GWO(Grey Wolf Optimization), AGOA (Adaptive Grasshopper Optimization Algorithm), NS (Natural Selection) and Opposite Based Learning (OBL). The results show that, when compared to PSO, the GOA algorithm requiresareduced sizes of the population to convergence with the same amount of compute work [2].

		$0 = \frac{4}{11\Pi}[-1 + \cos(11\theta_1) - \cos(11\theta_2) + \cos(11\theta_3) - \cos(11\theta_4) + \cos(11\theta_5)]$ $0 = \frac{4}{13\Pi}[-1 + \cos(13\theta_1) - \cos(13\theta_2) + \cos(13\theta_3) - \cos(13\theta_4) + \cos(13\theta_5)]$	

This table shows that 17 objective functions that must be reduced with the restrictions of removing specified harmonics utilising a variety of soft computing methods.Specific harmonics of the inverter's output voltage are eliminated using the SHE-PWM technique, especially low odd order harmonics. Various soft computing methods for SHE have been introduced in this analysis: GOA,WIPSO,MPSO,MSPSO,FPA,MGWO,FSO,FA,GA,ABCA, Bee algorithm, Ant Colony Optimization. Soft computing technique are used to determine the appropriate switching angles for selective harmonic elimination (SHE) PWM in multilevel inverter in order to get the lowest total harmonic distortion (THD).The minimizing of non-triplen odd harmonics has been demonstrated in the majority of papers. It also demonstrates that the real peak fundamental voltage is determined as an objective function, showing the efficiency of SHE approaches based on soft computing algorithms. Harmonic minimization is a complex optimization problem in nonlinear transcendental equations because they have numerous local optima. The soft computing techniques presented in this paper have a number of advantages, including the capacity to create all potential solution sets for any number of multilevel inverters with little computation complexity, rapid convergence, and the capability to develop uninterrupted solutions across the whole modulation index ranges, allowing for greater control action flexibility. It can be observed that the majority of the studies compared the PSO to various soft computing strategieswith aquick convergence speed and lowest THD.

6 Conclusion

Various soft computing techniques have been discussed to handle the SHE problem in an H-bridge cascaded multilevel inverter with identical and un-identical dc sources. The majority of papers have proved the reduction of non-triplen odd harmonics to a minimum. It also means that the true maximum essential voltage is computed as an objective function, demonstrating the effectiveness of SHE methods based on soft computing techniques. To determine the switching angles without utilizing a collection of nonlinear equations with many solutions, the objective function resulting from the SHE problem is minimized using soft computing algorithms. Harmonic minimization using multilevel inverters is a difficult optimizing problem involving complex transcendental equations and the use of PSO and other soft computing techniques to identify the most appropriate switching angles. The major goal of this research was to reduce total harmonic distortion by eliminating selective harmonics in cascaded multilevel inverters with equal source. The soft computing-based SHE approach has several advantages, including a faster rate of convergence and a lower fitness function value. Various soft computing techniques have demonstrated their efficacy in determining suitable solutions in a very short space of time for a variety of dc source values, with THD being used as a performance indicator to evaluate the solution's success.

References

[1] Soltani, I., Sarvi, M. and Salahian, F. (2013). Various Types of Particle Swarm Optimization-based Methods for Harmonic Reduction of Cascade Multilevel Inverters for renewable energy sources. *International Journal of Innovation and Applied Studies*, 2(4):671-681.

[2] Steczek, M., Jefimowski, W. and Szeląg, A. (2020). Application of Grasshopper Optimization Algorithm for Selective Harmonics Elimination in Low-Frequency Voltage Source Inverter. *Energies*, 13:6426.

[3] Maharana, M. K. (2013). PSO based Harmonic Reduction Technique for Wind Generated Power System. *International Journal of Power System Operation and Energy Management,* 2(1):8.

[4] Kumar J., Das, B. and Agarwal P. (2009). Harmonic reduction technique for a cascade multilevel inverter. *International Journal of Recent Trends in Engineering*, 1(3):181.

[5] Barkati S. et al. (2008). Harmonic elimination in diode-clamped multilevel inverter using evolutionary algorithms. *Electric Power Systems Research,* 78(10):1736-46.

[6] Ray et al. (2009). An application of PSO technique for harmonic elimination in a PWM inverter. *Applied soft computing,* 9(4):1315-1320.

[7] Sadr, S. M., Monfared, M. and Mashhadi, H. R. (2012). Application of PSO for selective harmonic elimination in a PWM AC/AC voltage regulator. In *2nd International Conference on Computer and Knowledge Engineering,* 62-65.

[8] Kala, P. and Arora, S. (2018). Implementation of PSO based Selective Harmonic Elimination Technique in Multilevel Inverters. In *2nd IEEE International Conference on Power Electronics, Intelligent Control and Energy Systems,* 605-610.

[9] TarafdarHagh, M., Taghizadeh, H. and Razi, K. (2009). Harmonic Minimization in Multilevel Inverters Using Modified Species-Based Particle Swarm Optimization. *IEEE Transactions on Power Electronics*, 24(10):2259-2267.

[10] Ajami, A. et al. (2013). Implementation of Novel Technique for Selective Harmonic Elimination in Multilevel Inverters Based on ICA. *Advances in Power Electronics*, 2013:847365.

[11] Sundari, M.G., Rajaram, M. and Balaraman, S. (2016). Application of improved firefly algorithm for programmed PWM in multilevel inverter with adjustable DC sources. *Applied soft computing*, 1(41):169-79.

[12] Sadhukhan, A., Ganguly, S. and Gayen, P. K. (2017). Reduction of harmonics at output of three-phase VSI using PSO based PWM technique. In *3rd International Conference on Research in Computational Intelligence and Communication Networks*, 104-108.

[13] Panda, K. P., Bana, P. R. and Panda, G. (2018). FPA Optimized Selective Harmonic Elimination PWM Technique Application in Reduced Switch Count Multilevel Inverter. In *IEEE International Conference on Power Electronics, Drives and Energy Systems*, 1-6.

[14] Khattak, F. A. and Khattak, A. A. (2018). Optimal DC Sources and Switching Angles for THD Minimization in MLI using Unconstrained Simplex method. In *International Symposium on Recent Advances in Electrical Engineering*, 1-6.

[15] Lodi, K. A. et al. (2018). Harmonic Minimization in Modified PUC-5 Inverter Using Genetic Algorithm. In *IEEE International Conference on Power Electronics, Drives and Energy Systems*, 1-6.

[16] Routray, A., Singh, R. K. and Mahanty, R. (2020). Harmonic Reduction in Hybrid Cascaded Multilevel Inverter Using Modified Grey Wolf Optimization. *IEEE Transactions on Industry Applications*, 56(2):1827-1838.

[17] Patil, S. D., Kadwane, S. G. and Kadu, A. (2020). Hybrid optimization Approach Applied for Harmonic Reduction in Multilevel Inverter. In *1st International Conference on Power, Control and Computing Technologies*, 79-84.