IJAREEIE

e-ISSN: 2278-8875
p-ISSN: 2320-3765

International Journal of Advanced Research

in Electrical, Electronics and Instrumentation Engineering

Volume 10, Issue 12, December 2021

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

Impact Factor: 7.282

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering (IJAREEIE)

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.282|

|| Volume 10, Issue 12, December 2021 ||

DOI:10.15662/IJAREEIE.2021.1012038

Selective Harmonic Elimination of Voltage Source Inverter for Renewable Energy Sources Using Hybrid Salp Swarm-Sine Cosine Algorithm

Ritu Saxena[1], Dr.H.K.Verma[2], Dr.Arun Parakh[3], Rinki Rajpal[4]

PG Student [PE], Dept. of EE, Shri G.S. Institute of Technology & Science, Indore, M.P., India[1]

Professor and Head, Dept. of EE, Shri G.S. Institute of Technology & Science, Indore, M.P., India[2]

Associate Professor, Dept. of EE, Shri G.S. Institute of Technology & Science, Indore, M.P., India[3]

Assistant Professor, Dept. of EE, Shri G.S. Institute of Technology & Science, Indore, M.P., India[4]

ABSTRACT:This paper presents the selective harmonic elimination of voltage source inverter (VSI) which are used for renewable energy sources to eliminate the harmonic distortion in line voltage. This paper proposes a new hybrid Salp Swarm-Sine Cosine Algorithm (HSS-SCA) with a better total harmonic distortion (THD). This is done by optimizing the new exploitation and exploration capability in the Salp Swarm Algorithm (SSA) and Sine Cosine Algorithm (SCA) algorithm. Selective harmonic elimination (SHE) SHE-PWM is implemented by using (HSS-SCA), which provides optimal switching angles and minimizes total harmonic distortion (THD) for the voltage source inverter in order to reduce lower odd order harmonics from the inverter's output voltage, specifically upto 63rd harmonics. The resultsshows that the HSS-SCA algorithm requires the shortest time to compute and outperforms the other two algorithms. The performance of HSS-SCA is more efficient than the SSA and PSO in terms of THD reduction and convergence speed.

KEYWORDS: Particle Swarm Optimization (PSO), Salp Swarm Algorithm(SSA),Sine Cosine Algorithm (SCA), Voltage Source Inverter(VSI), Selective Harmonic Elimination PWM (SHEPWM), Total Harmonic Distortion (THD).

I. INTRODUCTION

VSI can be used to integrate various renewable energy sources(RES) to the AC grid, including solar, fuel cells, and rectified wind energy output. Various types of electrical devices are affected by harmonic distortions in different way[1] . The harmonic reduction problem has grown in importance in order to improve the performance and reliability of the inverter's output voltage waveform. The energy conversion system is required to use energy from renewable energy sources, with the VSI generally injecting power into the grid. To make energy production more environmentally friendly, RES have been introduced into the grid system on a significant scale.The interconnected renewable energy sources minimise the grid's power demand in a typical home application. The grid-connected VSI interface plays a significant role in achieving this goal as a power transfer interface. Variable frequency and variable voltage supplies are required in industrial uses such as single phase and three phase induction motors and other rotating equipment [2]. A voltage source inverter (VSI) is used to change the supply frequency and voltage. Many industrial applications require voltage sources, which are voltage source inverters (VSIs) with an independently controlled AC output that is a voltage waveform. Single-phase VSIs are used for low-power applications, whereas three-phase VSIs are used for medium- to high-power applications.

Due to the rapid growth of controllers for high and medium power converters, modulation techniques can now be used. The four categories of frequency switching systems are fundamental frequency switching, space vector control, classic PWM control and space vector PWM control. The PWM technique is typically used to remove harmonics. Low-order harmonics, on the other hand, cannot be completely eliminated using PWM techniques. Selecting switching angles that suppress specific lower order dominant harmonics is another option. Optimal, programmed, or selective harmonic elimination PWM (SHE-PWM) techniques have been used to eliminate certain low-order harmonics from a

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.282|

|| Volume 10, Issue 12, December 2021 ||

DOI:10.15662/IJAREEIE.2021.1012038

voltage/current waveform generated by a voltage source inverter for a variety of converter topologies, systems and applications. The output voltage waveform is analysed using Fourier theory, which yields a set of non-linear transcendental equations. If these equations find a solution, the switching angles required for a certain fundamental component and harmonic profile are revealed. Iterative techniques such as the Newton-Raphson method were used to solve these sets of equations. Although this method is derivative-dependent and may produce local optima, careful 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 several advantages, including the fact that they do not rely on an initial assumption, that they employ simple algebra, which reduces processing costs, and that they can solve multi-constrained problems. Particle Swarm Optimization (PSO) is a prominent evolutionary method for calculating switching angles PWM VSI inverters in order to reduce low-order voltage harmonics and improve dc-link current harmonics [3].The study's problem can be classified as a single-criteria optimization problem. So that each harmonic value as a function of objective functions can be considered an independent objective function, the SHE issue can be viewed as a multi-objective optimal solution. However, because all evaluated harmonics in the SHE issue must be eliminated for the same objective functions, the desired optimum solution is an idealistic answer from the multi-optimization approach's perspective. As a result of the dedicated connection presented in the article, the optimization functions have been combined to a single optimization variable.HSS-SCA, SSA and PSO are three types of algorithms employed in this paper to solve SHE equations.The major purpose of this research is to explore at how HSS-SCA, SSA and PSO can be used to calculate switching angles for SHE-PWM of VSI.

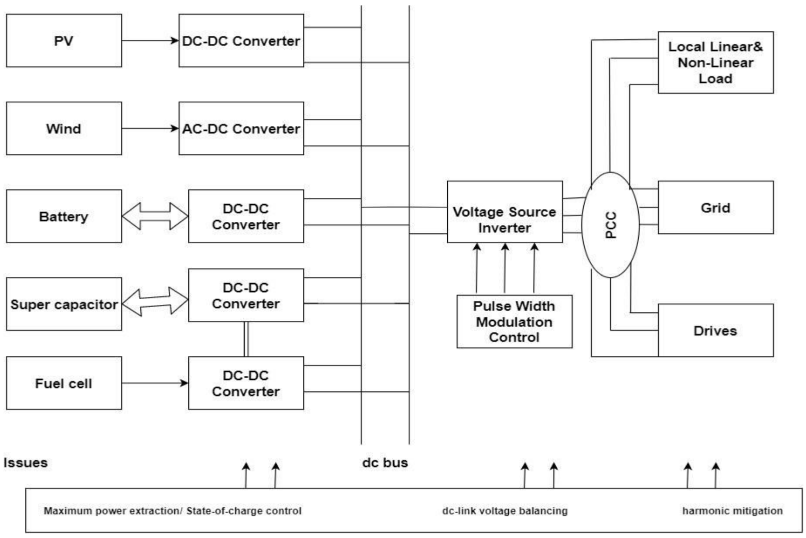


Fig. 1 Block diagram of voltage source inverter with Renewable Energy Sources

II. SELECTIVE HARMONIC ELIMINATION PWM (SHEPWM) PROBLEM

In several cases of SHE-PWM use, it is utilized in electric drives to eliminate low order harmonics, while input filters reduce the amplitudes of high order harmonics. The Fourier series expansion of the inverter output voltage waveform is used in the SHE equations[3].

$f(t) = A_0 + \sum_{n=1}^{\infty}(A_n \cos(n\alpha) + B_n \sin(n\alpha))$ (1)

Where,

$A_0 = \frac{1}{2\Pi}\int_0^{2\Pi} f(t)dt,$

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

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

The dc component $A_0 = 0$ and the Fourier coefficient A_n will both be equal to 0 due to the nature of the waveform and the quarter wave symmetry. As a result, the equation may be written like this:

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.282|

|| Volume 10, Issue 12, December 2021 ||

DOI:10.15662/IJAREEIE.2021.1012038

$f(t) = \sum_{n=1}^{\infty} B_n \sin n\alpha$(2)

$$B_n = \begin{cases} \frac{4*V_{dc}}{n\Pi}[\cos(n\alpha_1) + \cdots + \cos(n\alpha_n) & ;\ for\ odd\ n \\ 0 & ;\ for\ even\ n \end{cases} \quad (3)$$

Where V_{dc} = dc-link voltage, n= no. of switching angles every quarter period

Triple harmonics are eliminated if the inverter's output voltage has an odd quarter-wave symmetry. Even harmonics are also cancelled due to the system's symmetry. A VSI is presented as a case study for analyzing the effects of SHE-PWM on the harmonic spectra. Objective function for VSI is the result of combining nnon linear equations, one of which is for the fundamental component and the others for unwanted harmonics.Therefore, nonlinear transcendental equations can be written as follows:

$$[\cos(\propto_1) + \cos(\propto_2) + \cos(\propto_3) + \cos(\propto_4) + \cos(\propto_5)] = M$$
$$[\cos(5\propto_1) + \cos(5\propto_2) + \cos(5\propto_3) + \cos(5\propto_4) + \cos(5\propto_5)] = 0$$
$$[\cos(7\propto_1) + \cos(7\propto_2) + \cos(7\propto_3) + \cos(7\propto_4) + \cos(7\propto_5)] = 0$$
$$[\cos(11\propto_1) + \cos(11\propto_2) + \cos(11\propto_3) + \cos(11\propto_4) + \cos(11\propto_5)] = 0(4)$$
$$[\cos(13\propto_1) + \cos(13\propto_2) + \cos(13\propto_3) + \cos(13\propto_4) + \cos(13\propto_5)] = 0$$
$$[\cos(n\propto_1) + \cos(n\propto_2) + \cos(n\propto_3) + \cos(n\propto_4) + \cos(n\propto_5)] = 0$$

Where,
M $=(V_1^*)/(4V_{dc}\Pi)$(5)
& the modulation index (m) is $\left(\frac{M}{5}\right)$ for 0≤m≤1
In this study V_1^* is a fundamental voltage component.The primary purpose of this study is to use HSS-SCA to solve Equation (4) and determine switching angles for SHE-PWM, as well as to evaluate its convergence.

III. Problem Formulation

The fitness function must also be defined in resolving SHE Equation (4) using an optimization approach.The fitness function is calculated from the following equation with constraints for n = 5 switching angles and upto 63rd harmonics are eliminated:
Minimize
$\mathbf{fit(\propto_1,\propto_2,\propto_3,\propto_4,\propto_5)=[\sum_{i=1}^{5}\cos(\alpha_i) - M]\hat{}2 + [\sum_{i=1}^{5}\cos(5\alpha_i)]\hat{}2 + \cdots + [\sum_{i=1}^{5}\cos(63\alpha_i)]\hat{}2}$(6)
Subject to: $0<\propto_1<\propto_2<\propto_4<\propto_5<\frac{\pi}{2}$
The main goal is to use an optimization technique to reduce fitness function (6) in order to eliminate the designated fundamental component (V_1^*) and harmonics. The stopping criterion,which is based on the maximum number of iterations and the lowest values of the fitness function.

IV. OVERVIEW

1. Particle Swarm Optimization (PSO)

PSO is a evolutionary computation type approach and one of the optimization strategies. It was discovered to be effective in the solution of non-linear multidimensional problems.James Kennedy and Russel Eberhart created the algorithm and the idea of "Particle Swarm Optimization" (PSO) in 1995[5] .The core concept of swarm optimization is influenced by animal social behaviours in their natural context, such as flock of birds or schools of fish, and hence has its roots in nature.It's also connected to evolutionary computation and genetic algorithms.A population of particles moves through a problem space, evaluating their positions using a fitness function.
After defining a problem space, a collection of particles is created in it, and its positions and velocities are iteratively updated according to the PSO algorithm. Each particle is updated every iteration by using the two best values.
a) pbest b) gbest
The particle's best solution is denoted by the pbest.
Global best refers to the best particle in the entire population (gbest).
After finding the two best values, the particle updates its velocity (7) and position (8) with following equations :

$$V_i(t+1) = wV_i(t) + C_1r_1(pbest_i - x_i(t)) + C_2r_2(gbest - x_i(t))(7)$$

Where i is the particle index, w is the inertia weight factor,C_1, C_2 are acceleration coefficient,r_1, r_2 are random values,V_i(t) is the particle velocity at time t,x_i(t) is the particle position at time t.

$$x_i(t+1) = x_i(t) + V_i(t+1)(8)$$

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.282|

|| Volume 10, Issue 12, December 2021 ||

DOI:10.15662/IJAREEIE.2021.1012038

The stopping process is usually the maximum number of allowed iterations or the minimum error condition for PSO to operate.The PSO's overall performance is influenced by the inertia weight factor w.The following formula is commonly used to reduce inertia linearly:

$w = w_{max} - iter^{*}[(w_{max} - w_{min}) / iter_{max}]$(9)

Where$iter_{max}$ represents the maximum number of iterations, $iter$represents the current number of iterations, w_{max}represents the beginning weight, andw_{min} represents the final weight.

2. Salp Swarm Algorithm (SSA)

SSA is a novel optimization algorithms and it is used to solve the optimization problem with single and multiobjective function. The swarm behaviour of salps when moving and feeding in oceans is the fundamental inspiration for SSA. The algorithm is put to the test on a variety of mathematical optimization functions to see how they perform in terms of finding the best solutions to optimization problems.In the way of mathematical models for salps' swarm behaviour and population. Furthermore, while swarms of bees, ants, and fishes have been thoroughly simulated and used to solve optimization problems, there is no mathematical model of salp swarms [12].The following equation is presented to update the leader's position:

$$X_j^1 = \begin{cases} F_j + c_1\left(\left(ub_j - lb_j\right)c_2 + lb_j\right) c_3 \geq 0 \\ F_j - c_1\left(\left(ub_j - lb_j\right)c_2 + lb_j\right) c_3 < 0 \end{cases} \quad (10)$$

Where X_j^1 represents the position of the first salp(leader) in thej^{th} dimensions,F_j represents the position of the food source in the j^{th} dimension, ub_j represents the upper bound of the j^{th} dimension,lb_j represents the lower bound of the j^{th}dimension,c_1,c_2 and $c_3$represent random numbers. Equation(10) shows that the leader only updates its position with respect to the food source. The coefficient c_1 is the most important parameter in SSA because it balances exploration and exploitation defined as follows:

$c_1 = 2e^{-\left(\frac{4l}{L}\right)^2}$ (11)

Where $l$representsthe current iteration and$L$ represents the maximum number of iterations.The parameters$c_2$and c_3 are uniformly generated random values in the range [0,1]. In fact, they specify whether the next point in the j^{th}dimension should be positive or negative infinity, as well as the step size[13] .

3. Sine Cosine Algorithm (SCA)

SCA is a population-based optimization technique that begins with a set of randomly generated solutions. An objective function evaluates this random set periodically, and a set of rules that is the kernel of an optimization strategy improves it. There is no assurance of finding a solution in a single run because populationbased optimization strategies hunt for the optima of optimization problems probabilistically. The likelihood of obtaining the global optimum improves as the number of random solutions and optimization stages (iterations) grows.In the field of random population-based optimization, the most prevalent distinction is the split of the optimisation problem into two phases: exploration and exploitation. To locate the interesting regions of the search space, an optimization technique combines the random solutions in the number of equations abruptly with a high rate of unpredictability in the first phase. However, there are incremental modifications in the random solutions in the exploitation phase, and random variations are significantly fewer than in the exploration phase.For both phases, the following position updating equations are mentioned below:

$X_i^{t+1} = X_i^t + r_1 * \sin(r_2) * |r_3 P_i^t - X_i^t|$(12)

$X_i^{t+1} = X_i^t + r_1 * \cos(r_2) * |r_3 P_i^t - X_i^t|$(13)

WhereX_i^trepresents the position of the current solution in i^{th} dimension at t-th iteration,r_1, r_2, r_3 represents the random numbers $P_i$represents the position of the destination point ini^{th} dimension and | | represents the absolute value.These two equations are combined to form the following formula:

$$X_i^{t+1} = \begin{cases} X_i^t + r_1 * \sin(r_2) * |r_3 P_i^t - X_i^t| r_4 < 0.5 \\ X_i^t + r_1 * \cos(r_2) * |r_3 P_i^t - X_i^t| r_4 < 0.5 \end{cases} (14)$$

Where,$r_4$represents the random number in[0,1],r_1, r_2, r_3 andr_4 are the four primary parameters of SCA. The $r_1$parameter specifies the next location regions (or motion direction), which may be inside or outside the space between the solution and the destination. Ther_2 parameter specifies how far the movement should be in the direction of the goal or outwards. The r_3 parameter assigns random weights to the destination in order to randomly emphasise (r_3> 1) or deemphasize

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.282|

|| Volume 10, Issue 12, December 2021 ||

DOI:10.15662/IJAREEIE.2021.1012038

(r_3<1) the desalination effect in determining the distance. Finally, in Eq.(14) the parameter $r_4$alternates equally between the sine and cosine components.To locate the promising parts of the search space and eventually converge to the global optimum, an algorithm was able to balance exploration and exploitation. The range of sine and cosine in Eqs. (12) to (14) is modified adaptively using the following equation to balance exploration and exploitation.

$r_1 = a - t\frac{a}{T}$(15)

Where, 't' represents the current iteration, 'T' represents the maximum number of iterations, and 'a' represents the constant[14] .

V. PROPOSED METHODOLOGY

1. HybridSalp Swarm-Sine Cosine Algorithm (HSS-SCA)

HSS-SCA is a novel optimization technique .The proposed optimization technique is a combination of SSA and SCA and it is used for solving non linear and multidimensional problems. This algorithm is applied on a objective functionto see how they perform in terms of finding the best solutions. First the population is separated into two groups: leaders and followers. The salp at the front of the chain is the leader, while the rest of the salps are called followers. The leader of these salps leads the swarm, while the followers follow one another (and leader directly of indirectly). Salps' position is specified in an n-dimensional search space, similar to other swarm-based algorithms, where n is the number of variables in a particular problem. As a result, all salp positions are recorded in a two-dimensional matrix named x. It's also assumed that the swarm's objective is a food source designated F in the search space. The following equation is presented to update the leader's position:

$$X_j^1 = \begin{cases} F_j + c_1((ub_j - lb_j)c_2 + lb_j + rand() * \sin(c_2)) & c_3 \geq 0 \\ F_j - c_1\left((ub_j - lb_j)c_2 + lb_j - rand() * \cos(c_2)\right) & c_3 < 0 \end{cases} \quad (16)$$

Where X_j^1 represents the position of the first salp(leader) in the j^{th} dimensions, F_j represents the position of the food source in the j^{th} dimension ub_jrepresents the upper bound of the j^{th} dimension, lb_jrepresents the lower bound of the j^{th} dimension, andc_1, c_2 and c_3 represent random numbers. Equation(10) shows that the leader only updates its position with respect to the food source. The coefficient$c_1$and $c_2$are the most important parameter in HSS-SCA because it balances exploration and exploitation defined as follows:

$c_1 = 2e^{-\left(\frac{4l}{L}\right)^2}$ (17)

$c_2 = (2pi) * rand()$(18)

Where,l represents the current iteration and L represents the maximum number of iterations.The parameter c_3 is uniformly generated random values in the range [0,1]. In fact, they specify whether the next point in the j^{th} dimension should be positive or negative infinity, as well as the step size. The following equations (Newton's law of motion) are used to update the position of the followers.

$X_j^i = \frac{1}{2}at^2 + V_{0t}$ (19)

Where,i≥ 2, X_j^irepresents the position of i^{th}follower salp in j^{th} dimension, t represents the time,V_0 represents the initial speed, and a= $\frac{V_{final}}{V_0}$where = $\frac{x-x_0}{t}$ .The variance between iterations is equal to 1 because the time in optimization is iteration, and taking $V_0 = 0$, this equation can be stated as follows:

$X_j^i = \frac{1}{2}(X_j^i + X_j - 1^i)$(20)

Where,i≥ 2 andX_j^i represents the position of the ith follower salp inj^{th} dimension.The salp chains can be modelled using Eqs. (16) and (20).

2. Implementation Of HSS-SCA Based SHE Technique

According to HSS-SCA,steps of obtaining switching angle for SHE problem are as follows.

Step 1: Define the input parameters as well as the upper and lower switching angle boundary parameters (x_{min}-x_{max}).

Step 2: Initialization of the salp population in the search space [0,Π/2] radians with N number of search agents having random positions in 5 dimensions.Each search agent's position should be consistent with the parameters of switching angles.

Step 3: Determine the value of each search agent's objective function Eq.6.

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.282|

|| Volume 10, Issue 12, December 2021 ||

DOI:10.15662/IJAREEIE.2021.1012038

Step 4: Choose the most appropriate objective function as a leader and leader position respectively (Food Position).
Step 5: Set iteration=1 as the number of iteration.
Step 6: Update c_1 using Eq.17.
Step 7:Update the salp's position as a leader as shown in Eq.16.
Step 8: Update the salp's position as a follower as shown in Eq. 19
Step 9: Check each search agent's constraint limits. If the constraints limitations are fulfilled, proceed to the next step; otherwise, replace the search agent position with the search space bounds (x_{min}-x_{max}).
Step 10: Determine the value of each search agent's objective function Eq.6.
Step 11: Assign the best objective function as leader and leader position respectively (Food Position).
Step 12: Raise the number of iterations by one, making iter=iter+1.
Step 13: If the maximum number of iterations has been achieved, stop the iterative process and save the food position as the best answer to the optimization problem (switching angles), if not, proceed to step 7.

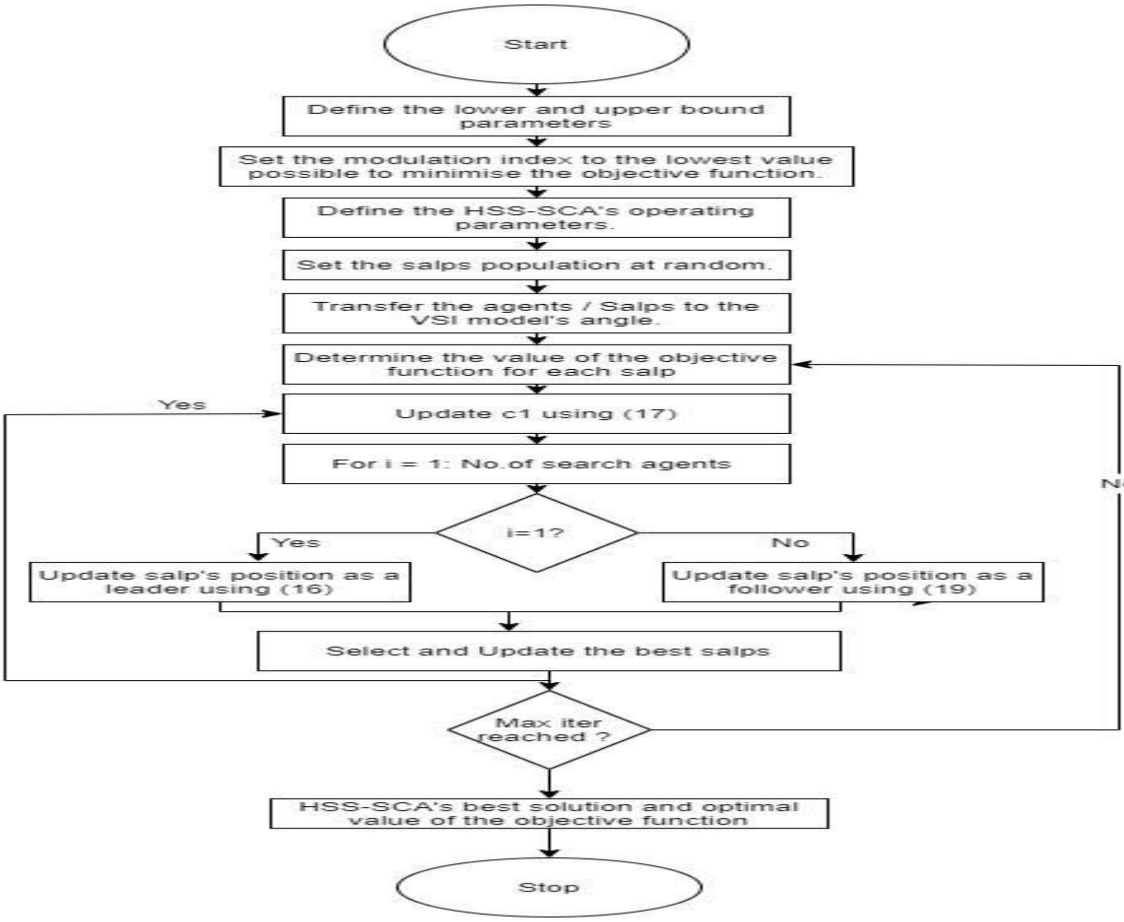


Fig. 2 Flow chart of HSS-SCA algorithm

3. Comparative Study And Simulation Results

In this section, the comparison ofPSO, SSA and HSS-SCA obtained simulated results, are shown. The performance criteria for comparison between these three algorithms are THD percentage and to find the optimal switching angles. The VSI is studied to optimise switching angles $\propto_1$,$\propto_2$,$\propto_3$,$\propto_4$,$\propto_5$ by computing in MATLABprogramme in order to determine the accuracy and performance of the proposed techniques. To reduce THD, the SHE problem is handled using the PSO, SSA and HSS-SCA algorithms.

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.282|

|| Volume 10, Issue 12, December 2021 ||

DOI:10.15662/IJAREEIE.2021.1012038

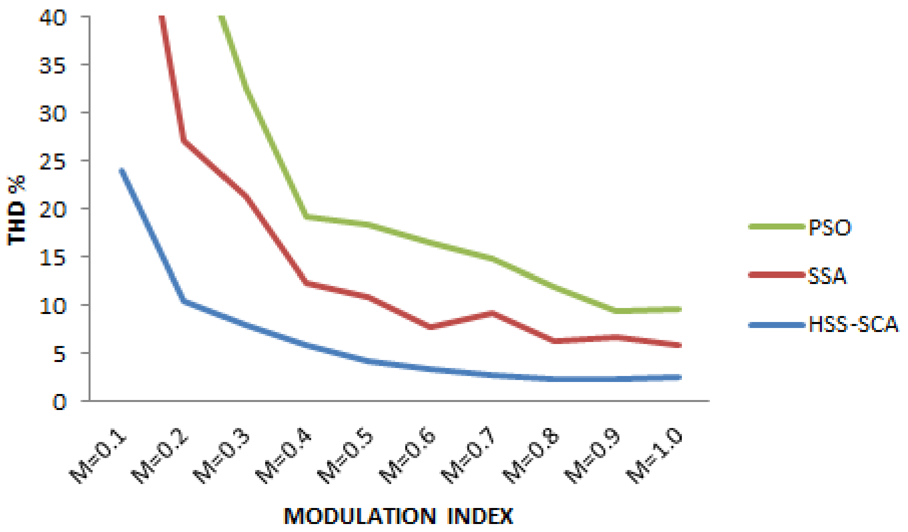


Fig.3. Corresponding values of THD for PSO, SSA and HSS-SCA versus Modulation index

The corresponding values of THD for the three proposed algorithms versus modulation index is shown in Figure 3.The performance of the three THD reduction approaches, which is influenced by the amplitude modulation index (M). For voltage source inverter, the objective function to remove the 63rd order harmonics is given by equation (6). Figure 3 further illustrates that among the proposed methods, the HSS-SCA algorithm has a faster convergence speed.

Table1 Comparsiontable ofSwitching angles,Time, and THD percent forVSI using three algorithms (HSS-SCA, SSA,PSO)

MODULATION INDEX (M)		$\alpha_1(°)$	$\alpha_2(°)$	$\alpha_3(°)$	$\alpha_4(°)$	$\alpha_5(°)$	THD %	TIME (sec)
M=0.1	HSS-SCA	34.2090	44.7313	49.4471	54.3346	58.8129	**23.91**	107.71
	SSA	34.8442	35.2634	42.2390	45.3692	50.7042	39.82	141.19
	PSO	42.4817	51.4626	54.7947	61.2282	65.1193	28.81	113.59
MODULATION INDEX (M)		$\alpha_1(°)$	$\alpha_2(°)$	$\alpha_3(°)$	$\alpha_4(°)$	$\alpha_5(°)$	THD %	TIME (sec)
M=0.2	HSS-SCA	31.0718	35.1422	39.3653	43.5617	47.5367	**10.48**	107.711
	SSA	32.3104	39.2081	40.6420	43.7145	48.0381	16.72	139.44
	PSO	38.2747	52.7670	53.1235	61.9669	62.2410	24.29	110.17
M=0.3	HSS-SCA	34.5719	39.1140	43.6546	72.4233	76.5627	**8.01**	110.38
	SSA	36.3668	39.9725	45.9361	46.3608	54.5904	13.28	138.28
	PSO	21.5732	55.3525	57.9061	59.1946	63.3040	11.29	110.28
M=0.4	HSS-SCA	25.8469	48.6019	53.2547	58.1958	62.8232	**5.92**	110.34

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.282|

|| Volume 10, Issue 12, December 2021 ||

DOI:10.15662/IJAREEIE.2021.1012038

	SSA	47.6843	52.5310	57.6552	61.9621	89.3900	**6.35**	132.29
	PSO	40.9324	46.4725	49.1194	52.4493	56.6068	**6.99**	110.91
M=0.5	HSS-SCA	32.9966	37.4046	41.8957	70.5735	74.7522	**4.09**	102.10
	SSA	35.8184	44.1400	47.2117	49.8423	56.5977	6.76	132.19
	PSO	25.5799	35.2355	36.5209	46.5379	52.0434	7.58	327.36
M=0.6	HSS-SCA	34.0495	38.5687	43.4331	48.2925	52.7829	**3.28**	106.54
	SSA	23.5029	27.9279	39.1012	43.8815	48.5083	4.35	136.17
	PSO	48.3964	49.0752	49.3565	60.194	64.1059	8.75	275.98
M=0.7	HSS-SCA	34.5614	39.1620	44.1050	49.0302	53.5800	**2.79**	131.71
	SSA	30.0783	32.5399	39.0949	47.0036	47.5967	6.32	135.09
	PSO	19.0212	42.8080	57.8476	59.3811	68.6529	5.63	281.98
M=0.8	HSS-SCA	43.6282	48.2181	53.1685	58.1129	62.6921	**2.28**	108.09
	SSA	43.6206	50.9580	54.4350	60.5780	63.3519	3.86	136.17
	PSO	43.3029	45.2824	49.9328	50.6554	73.2508	5.74	277.01
M=0.9	HSS-SCA	39.5938	44.1373	49.0248	53.8977	58.3972	**2.21**	106.86
	SSA	35.0283	35.9593	41.3608	46.0966	48.6804	4.41	132.17
	PSO	29.6576	34.2158	39.1188	43.7152	77.7675	2.67	275.96
M=1.0	HSS-SCA	33.5610	37.8455	48.7300	53.4095	57.9394	**2.65**	108.44
	SSA	50.2412	52.8153	56.7078	63.2364	72.2445	3.21	139.22
	PSO	16.1391	38.9155	45.7540	59.6845	62.5185	3.84	277.18

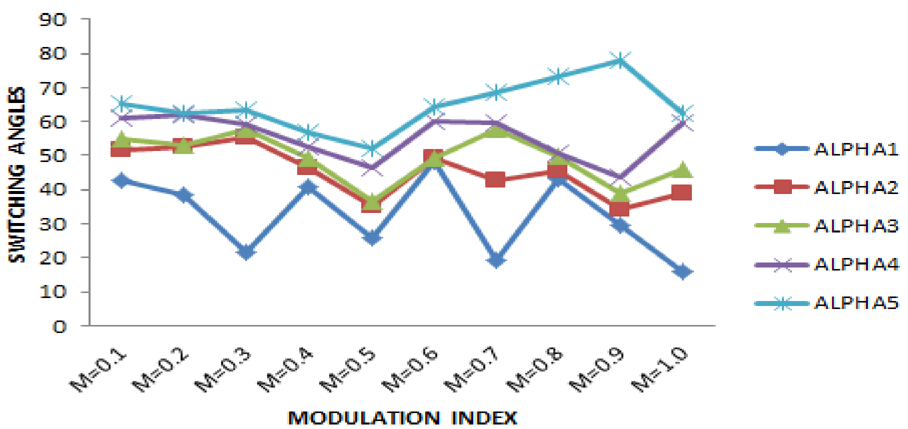


Fig. 4 Switching angles Vs Modulation index with PSO algorithm

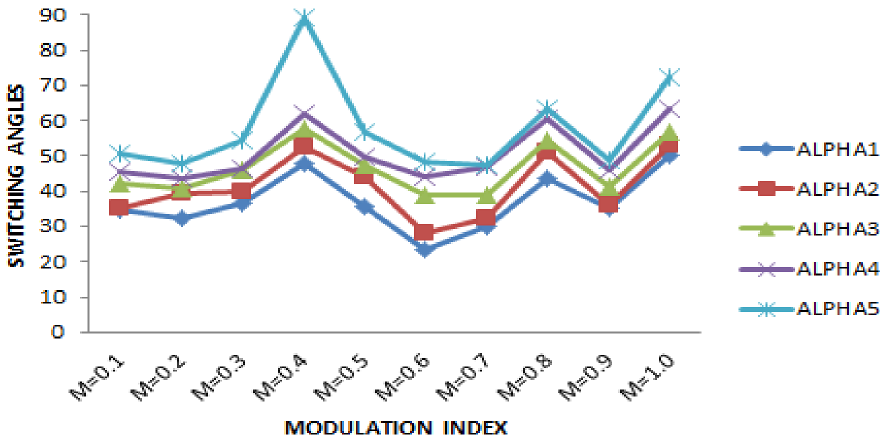


Fig.5 Switching angles Vs Modulation index with SSA algorithm

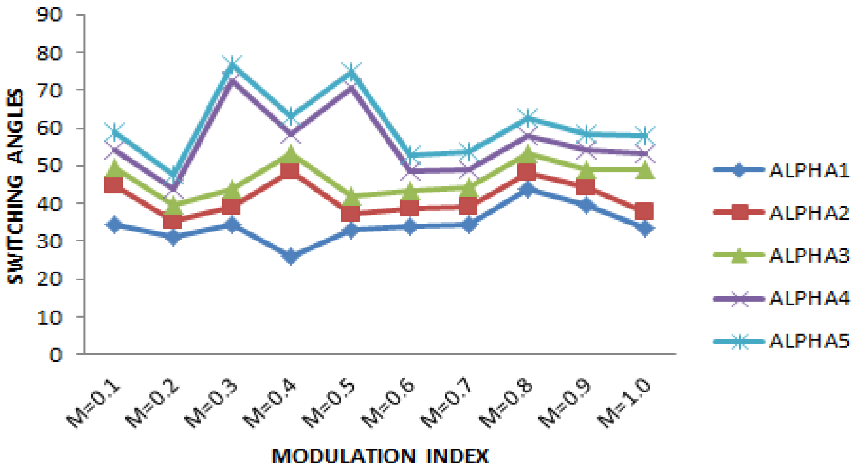


Fig. 6. Switching angles Vs Modulation index with HSS-SCA algorithm

Figures 4-6 illustrate the switching angles for the three methods given (PSO,SSA, and HSS-SCA).The performance of the three THD reduction approaches, which is influenced by the amplitude modulation index (M). Table 1 shows the different values of modulation index between 0.1 to 1.0 which gives different values of THD . In M=0.1 to 1.0, the THD % of HSS-SCA algorithm is lower than SSA algorithm and PSO algorithm. It shows the significant minimization of non triplenodd harmonics of order upto 63rd which provides the optimal switching angles. Hence, it is observed thatthe HSS-SCA algorithm has successfully minimized the objective function. In comparison to SSA andPSO,the HSS-SCA algorithm gives better switching angles,obtains the overall THD is much lower and it takes lesser computational time.

VI. CONCLUSION

The paper presents the Hybrid Salp Swarm-Sine Cosine Algorithm (HSS-SCA) is to reduce total harmonic distortion (THD) by eliminating the selective harmonic in voltage source inverter which are utilized for renewable energy sources. To accomplish this, the PSO, SSA and HSS-SCA algorithms are used to calculate the best switching angles for inverter switches.The target lower order harmonics upto 63rd harmonics have been shown to be well eliminated.The overall THD of the HSS-SCA algorithm is lower than that of SSA and PSO, respectively. While the HSS-SCA algorithm's performance is at par or better than other algorithms. It has lesser computational time, produces lower THD, and faster convergence rate.Hence it is proved that the HSS-SCA algorithm is superior to SSA and PSO algorithm.

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.282|

|| Volume 10, Issue 12, December 2021 ||

DOI:10.15662/IJAREEIE.2021.1012038

REFERENCES

[1] ImanSoltani, Mohammad Sarvi, FatemehSalahian. 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, ISSR Journals, 2013, 2 (4), pp.671-681. ⟨hal-00818066⟩.

[2]Dai N, Lam CS, Zhang W. Multifunctional voltage source inverter for renewable energy integration and power quality conditioning. The Scientific World Journal. 2014 Aug 7;2014.

[3]Peña-Delgado, Adrián F., et al. "A Novel Bio-Inspired Algorithm Applied to Selective Harmonic Elimination in a Three-Phase Eleven-Level Inverter." *Mathematical Problems in Engineering* 2020 (2020).

[4]P. Kala and S. Arora, "Implementation of PSO based Selective Harmonic Elimination Technique in Multilevel Inverters," 2018 2nd IEEE International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES), Delhi, India, 2018, pp. 605-610, doi: 10.1109/ICPEICES.2018.8897309.

[5]Maharana, M. K. (2013) "PSO based Harmonic Reduction Technique for Wind Generated Power System," International Journal of Power SystemOperation and Energy Management:Vol.2:Iss.1,Article8.Available at: https://www.interscience.in/ijpsoem/vol2/iss1/8.

[6]Ray, Rup Narayan, Debashis Chatterjee, and Swapan Kumar Goswami. "An application of PSO technique for harmonic elimination in a PWM inverter." Applied softcomputing 9.4 (2009): 1315-1320.

[7]Ali Ajami, Mohammad Reza JannatiOskuee, Ata OllahMokhberdoran, "Implementation of Novel Technique for Selective Harmonic Elimination in Multilevel Inverters Based on ICA", Advances in Power Electronics, vol. 2013, Article ID 847365, 10 pages, 2013. https://doi.org/10.1155/2013/847365.

[8]Sundari MG, Rajaram M, Balaraman S. Application of improved firefly algorithm for programmed PWM in multilevel inverter with adjustable DC sources. Applied soft computing. 2016 Apr 1;41:169-79.

[9]A. Sadhukhan, S. Ganguly and P. K. Gayen, "Reduction of harmonics at output of three-phase VSI using PSO based PWM technique," 2017 Third International Conference on Research in Computational Intelligence and Communication Networks (ICRCICN), Kolkata, 2017, pp. 104-108, doi: 10.1109/ICRCICN.2017.8234489.

[10]S. M. Sadr, M. Monfared and H. R. Mashhadi, "Application of PSO for selective harmonic elimination in a PWM AC/AC voltage regulator," 2012 2nd International eConference on Computer and Knowledge Engineering (ICCKE), Mashhad, Iran, 2012, pp. 62-65, doi: 10.1109/ICCKE.2012.6395353.

[11] A. Sadhukhan, S. Ganguly and P. K. Gayen, "Reduction of harmonics at output of three-phase VSI using PSO based PWM technique," 2017 Third International Conference on Research in Computational Intelligence and Communication Networks (ICRCICN), Kolkata, 2017, pp. 104-108, doi: 10.1109/ICRCICN.2017.8234489.

[12]Mirjalili S, Gandomi AH, Mirjalili SZ, Saremi S, Faris H, Mirjalili SM. Salp Swarm Algorithm: A bio-inspired optimizer for engineering design problems. Advances in Engineering Software. 2017 Dec 1;114:163-91.

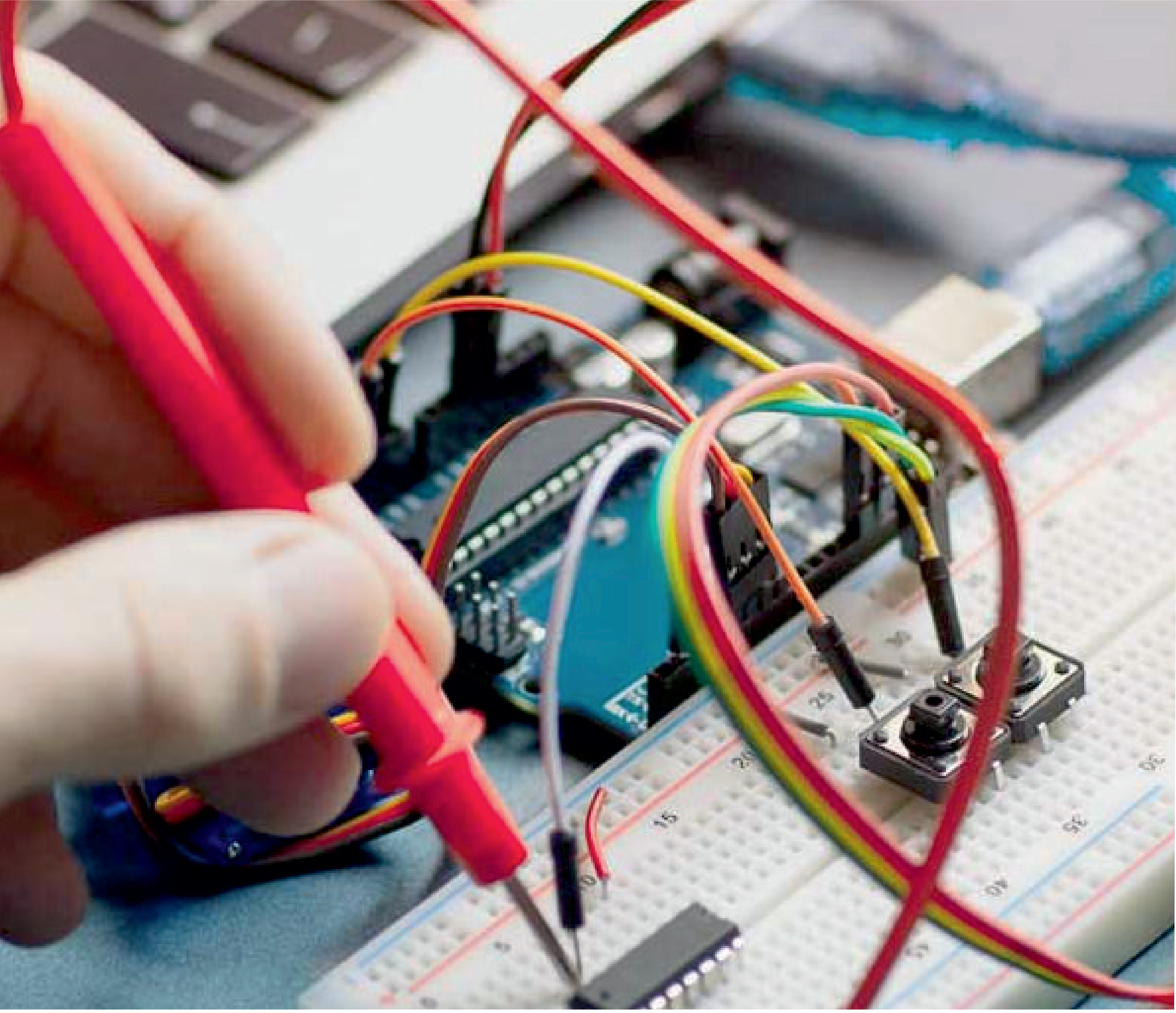
[13]Hosseinpour M, Mansoori S, Shayeghi H. Selective harmonics elimination technique in cascaded h-bridge multi-level inverters using the salp swarm optimization algorithm. Journal of Operation and Automation in Power Engineering. 2020 Feb 1;8(1):32-42.

[14]Mirjalili S. SCA: a sine cosine algorithm for solving optimization problems. Knowledge-based systems. 2016 Mar 15;96:120-33.

[15]Lou, H.; Mao, C.; Lu, J.; Wang, D.; Lee, W.J. Pulse width modulation AC/DC converters with line current harmonics minimization and high power factor using hybrid particle swarm optimization.IET Power Electron.2009.

[16] Patel, H.S.; Hoft, R.G. Generalized Techniques of Harmonic Elimination and Voltage Control in Thyristor Inverters: Part I—Harmonic Elimination. IEEE Trans. Ind. Appl. 1973, IA-9, 310–317.

[17] Patel, H.S.; Hoft, R.G. Generalized techniques of harmonic elimination and voltage control in thyristor inverters: Part II–voltage control techniques. Technology 1974, IA-10, 666–673.



International Journal of Advanced Research

in Electrical, Electronics and Instrumentation Engineering

9940 572 462 6381 907 438 ijareeie@gmail.com

www.ijareeie.com

Scan to save the contact details