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Harmonic elimination in multi level inverter by comparing various soft techniques

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***Abstract*-In this paper, soft computing techniques specially GA, PSO and HSA are applied in multilevel inverter to compute switching angles at fundamental frequency switching scheme by solving non linear transcendental equations (known as selective harmonic elimination equations), thereby keeping certain predominating lower order harmonics within allowable limits, and simultaneously, control over magnitude of output voltage of a multilevel inverter is achieved. Optimization capability of THD minimization, computational time, FFT analysis has been studied for these optimization techniques in MATLAB environment.**

***Index Terms* -Multilevel Inverter; SHE-PWM; Particle Swarm Optimization; Genetic algorithm; Harmony Search algorithm** *(Key words).*

I. INTRODUCTION

Electrical energy is an extremely valuable commodity and many market studies demonstrate that the demand for electrical energy is continually increasing exponentially. In the period from 2001 to 2006, energy consumption increased by 16.1% increase [1]. In 2030, the energy consumption will be increased by 50% [2]. Owing to the limited availability of electrical energy and ever increasing oil prices, however, a new technical age has begun – an age in which the goal is to reduce electrical energy consumption and promote research into alternative sources of energy. As a result, continuous improvements are urgently needed on the efficiency front in all industrial and consumer applications. Inverters are very common application in power electronics. Many researches are going on to improve output voltage with minimum THD [23]. In response to the growing demand for high power inverter units, multilevel inverters have been attracting growing attention from academia as well as industry in the recent decade. Multilevel inversion is a power conversion strategy in which the output voltage is obtained in steps thus bringing the output closer to a sine wave and reduces the total harmonic distortion (THD) [23, 24]. Multilevel converters (MC) are the technology of choice for medium and high voltage application like flexible AC transmission systems (FACTS), laminators, mills, conveyors, compressors, UPS systems, broadcasting amplifier [3], plasma [4], industrial drive [5] as well as STATCOM [6] applications etc.

There are three main types of multilevel inverters: diode-clamped, capacitor clamped, and cascaded H-bridges [7]. Compared with the traditional two-level voltage inverter, the primary advantage of multilevel inverters is their smaller output voltage step, which results in high power quality, lower harmonic components, better electromagnetic compatibility, and lower switching losses [8]. There are several methods used for harmonic elimination in multilevel inverter. Widely used methods for harmonic elimination are sine-triangle PWM (SPWM), Optimal Minimization of Total Harmonic Distortion (OMTHD) and Selective Harmonic Elimination Pulse Width Modulation (SHE-PWM). Sine-triangle PWM method and its variants are very effective for controlling the inverter output voltage but this method is having very high switching frequency which causes switching loss [9].

The existing multilevel carrier-based pulse width modulation (PWM) strategies have no special provisions to offer quality output, besides lower order harmonics are introduced in the spectrum, especially at low switching frequencies [10]. In OMTHD, without any emphasis on special harmonics, all harmonics in the same weight (i.e. THD) are minimized [11, 12]. Selective harmonic elimination PWM (SHE-PWM) is a kind of switching control method benefited from its low switch frequency and high output power quality, and then saved the cost of filter for inverters [13].

There are some other methods like Newton-Raphson (N-R) method [14], Walsh functions [15], Block-pulse functions [16]. N-R methods have some drawbacks like divergence problems, require initial guess and gives no optimum solution. Solving linear equations, instead of non-linear transcendental equations was done in Walsh function and Block-pulse function. Since the harmonic losses in a machine are determined by the ripple currents, a performance index related to undesirable effects of the harmonics should be defined to minimize instead of focusing on individual harmonics. The total energy of harmonics in a PWM waveform is constant; keeping the specific lower-order harmonics in allowable limits, minimizing other harmonics up to certain level will considerably boost the fundamental one.

In this paper, Particle Swarm optimization (PSO) [17], Genetic algorithm (GA) [18, 25] and Harmony Search algorithm (HSA) [19, 20] are used to minimize the overall THD of the output voltage of a 7 level Multilevel Cascaded H-Bridge Inverter with equal dc source. The objective function derived from the SHE problem is minimized, to compute the switching angles while lower order harmonics are controlled within allowable limits. This paper is organized as follows. The proposed scheme is described in Section 2. Simulation results and comparison are presented in Section 3 and finally conclusion in Section 4.

II. PROPOSED SCHEME

A higher level ac voltage can be synthesized by cascading several lower level inverters supplied from equal or unequal dc sources. This configuration is known as multilevel configuration of inverters. A single-phase structure of a cascaded multilevel inverter is shown in Fig. 1. In case of equal dc sources Vdc1 = Vdc2 . . . = Vdcn = Vdc. The synthesized ac output voltage waveform is the sum of all the individual inverter outputs. The number of output phase voltage levels of cascade multilevel inverter is 2N + 1, where N is the number of dc sources. An output voltage waveform of a 7-level cascade multilevel inverter with three dc sources is shown in Fig. 2.

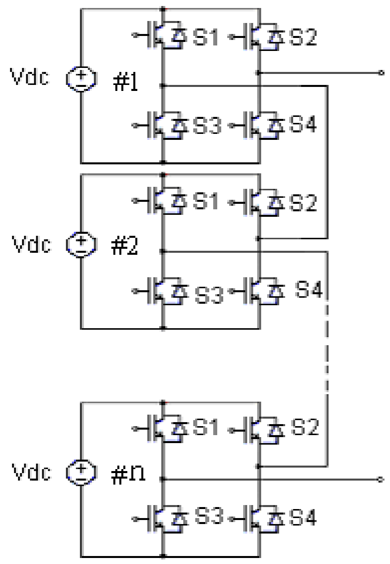

Fig.1 Single-phase configuration of a multilevel inverter

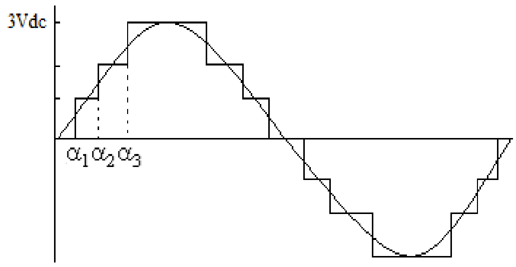

Fig.2 Output voltage waveform of a 7-level multilevel inverter

III. CONVENTIONAL METDOD

The output voltage waveform V(t) of the multilevel inverter as shown in Fig. 2 can be represented by (1)

$$V(t)=\sum_{n=1}^{\infty}(a_n \sin n\alpha_n+b_n \cos n\alpha_n) \qquad (1)$$

The even harmonics are absent (bn = 0) due to quarter wave symmetry of the output voltage [4]. The n-th harmonic an is expressed with the first quadrant switching angles $\alpha_1,\alpha_2,\ldots\alpha_m$.

$$an=(4Vdc/n\pi)\sum_{k=1}^{m}\cos(n\alpha k) \qquad (2) \quad \text{and}$$

$$0<\alpha 1<\alpha 2<\ldots\alpha k<(\pi 2) \qquad (3)$$

For any odd harmonics, (2) can be expanded up to the k-th term where m is the number of variables corresponding to switching angles $\alpha 1$ through αm of the first quadrant. In selected harmonic elimination, an is assigned the desired value for fundamental component and equated to zero for the harmonics to be eliminated [5].

$$a1= 4(Vdc/\pi)\sum_{k=1}^{n}\cos(\alpha k) =M$$

$$a5= 4(Vdc/5\pi))\sum_{k=1}^{n}\cos 5(\alpha k) =0$$

$$an= 4(Vdc/n\pi))\sum_{k=n}^{n}\cos n(\alpha k)=0$$

where M is the amplitude of the fundamental component.

Nonlinear transcendental equations are thus formed and after solving these equations, $\alpha 1$ through αk are computed. Triplen harmonics are eliminated in three-phase balanced system and these are not considered in (4). It is evident that $(m-1)$ harmonics can be eliminated with m number of switching angles. These nonlinear equations show multiple solutions and the main difficulty is its discontinuity at certain points where no set of solution is available [14]. This limitation is addressed in the present method to ease the online application at these points of discontinuity.

IV. PROPOSED METHOD

1. PSO Method

The PSO methodology is a very powerful tool for optimization of nonlinear functions. The method was discovered through simulation of a simplified social model viz. bird flocking, fish schooling, etc. [12] and presently being used in many applications for optimization of nonlinear equations. Physically, this mimics a flock of birds that communicate together as they fly. Each bird looks in a specific direction, and then when communicating together, they identify the bird that is in the best location. Accordingly, each bird speeds towards the best bird using a velocity that depends on its current position. Each bird, then, investigates the search space from its new local position, and the process repeats until the flock reaches a desired destination.

It is important to note that the process involves both social interaction and intelligence so that birds learn from their own experience (local search) and also from the experience of others around them (global search) [22].The conventional SHE technique for multilevel inverter has the disadvantage of complexity to solve the nonlinear transcendental equations that have multiple solutions [15, 16]. Moreover, at certain points, no solutions are available to satisfy these equations. In the proposed PSO method, the complexity of finding the solution of these nonlinear equations is avoided by converting the SHE problem to an optimization problem. The %THD of the output voltage can be computed using (5).

$$\%THD = [(1/a_1^2)\sum_{n=5}^{\infty}(an)^2]^{1/2} * 100$$

Where $n=6i\pm1$ (i=1,2,3,…)
In the developed PSO algorithm, the same expression of the voltage THD is considered as the objective function (α)and minimized with the constraints of individual harmonics limits and minimal variations of switching angles. The formulation of the problem will be as follows:
Minimize

$$(\alpha) = (\alpha_1, \alpha_2, \ldots \alpha_m) \qquad (6)$$

Subjected to:

$$0<\alpha 1<\alpha 2<\ldots\alpha k< \pi 2 \;;$$

$$a1=M$$

$$a5=\varepsilon 1$$

$$a7=\varepsilon 2$$

:

:

$$an\leq\varepsilon n \qquad (7)$$

where $\varepsilon 1$, $\varepsilon 2$,.... εn are the allowable limits of individual harmonics. A flowchart of the PSO algorithm is shown in Fig. 3. With a considerable number of generations and large number of population in each generation, the algorithm searches for all probable set of solutions and finally compute the angles $\alpha 1$ through αm to contribute either the lowest THD or next to the lowest one based on changes in the switching angles, keeping the individual harmonics within the limits as specified by (7). Also at the modulation indices of discontinuity, the switching angles a1 through am are computed based on possible minimum voltage THD optimizing the individual harmonics.

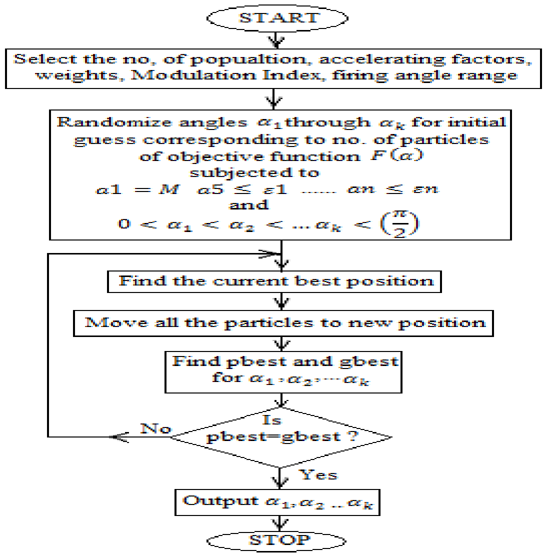

Fig.3 Flowchart of proposed PSO algorithm

2. GA METHOD

Genetic Algorithm (GA) is a method used for solving both constrained and unconstrained optimization problems based on natural selection, the process that drives biological evolution [9, 22]. The GA repeatedly modifies population of individual solutions. At each step, the GA selects individuals at random from the current population to be parents and uses them to produce the children for the next generation. Over successive generations, the population “evolves" towards an optimal solution. A flowchart of the Genetic algorithm is shown in Fig. 4.

GA uses three main rules at each step to create the next generation from the current population:

• *Selection rules* select the individuals, called *parents* that contribute to the population at the next generation.

• *Crossover rules* combine two parents to form children for the next generation.

• *Mutation rules* apply random changes to individual parents to form children.

3. HSA METHOD

Powerful optimization tool namely the music-inspired harmony based optimization algorithm. The algorithm is based on the observation that the aim of music creation is the quest of the perfect state of harmony. Such a quest is relevant to the optimization procedures which also seek the "perfect" solution [17-18]. Harmony Search Algorithm is based on the musical process of searching for the perfect state of harmony.

A flowchart of the Genetic algorithm is shown in Fig. 5. Harmony Search Algorithm (HSA) presents several advantages as the following:

a) HAS imposes fewer mathematical requirements and does not require initial value settings for decision variable
b) As the HAS uses stochastic random searches, derivative information is also unnecessary.
c) The HSA generates a new vector, after considering all of the existing vectors, whereas the method like genetic algorithm (GA) only considers two parent vectors.
d) HAS does not need to encode and decode the decision variables into binary strings.

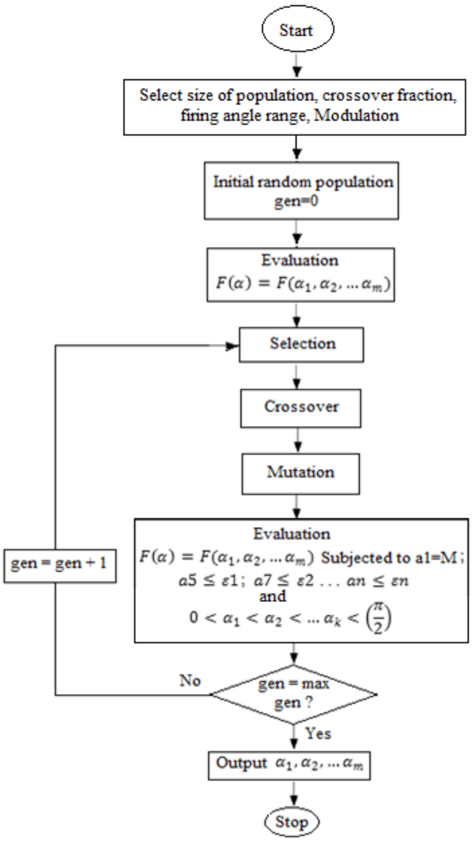

Fig.4 Flowchart of proposed Genetic algorithm

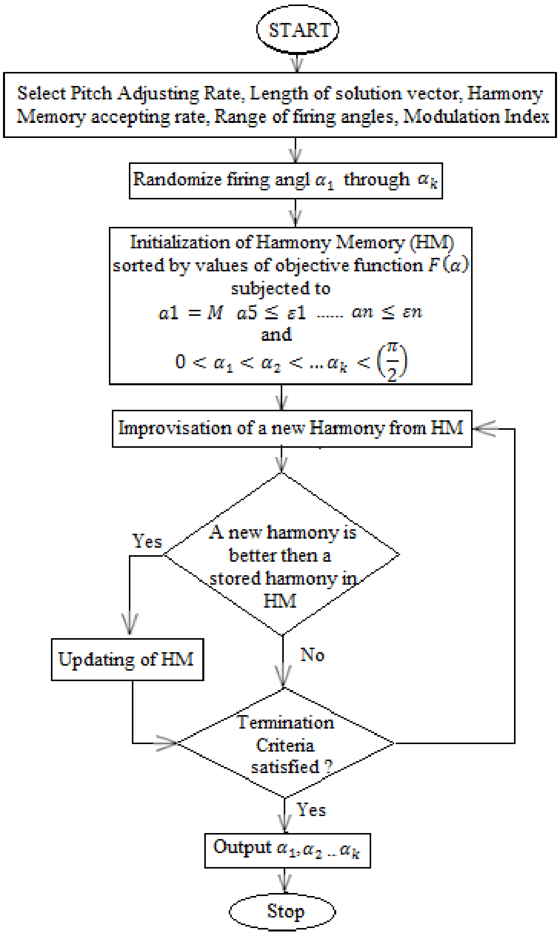

Fig.5 Flowchart of proposed Harmony Search Algorithm

V. SIMULATION RESULTS AND DISCUSSION

The proposed scheme has been simulated in MATLAB/Simulink environment. For three dc sources, the multiple sets of angles present within the modulation index range of 0.20–1.10, eliminating harmonics are computed. The Switching angle against Modulation Index is shown in Fig 6, Fig 7 and Fig 8 using GA, PSO and HSA. The voltage THD against modulation index is shown in Figs. 9 using PSO, GA and HSA as an optimization tool. Harmonic Spectrum for output phase voltage at 1 Modulation Index is shown in Fig 10. For a 7 level inverter, the time taken for particular THD is shown in table I. In PSO algorithm the acceleration factor c1 and c2 is taken as 0.2 and 0.5 for 40 numbers of particles. In GA optimization tool double vector population type is taken for 20 population sizes with 0.8 crossover fraction of scattered function. In Harmony Search Algorithm Pitch adjusting rate is taken as 0.7, Harmony Memory is accepting rate

0.95, Length of solution vector is 20 and switching angle range in between 0 to 90 degree. GA takes 51 generation, PSO takes 51 iteration and HAS takes maximum 500 number of attempts. For 7-Level Multilevel Inverter the THD is being optimized up to 31st order.

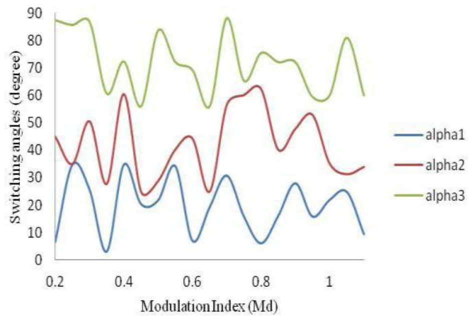

Fig.6 Switching angles versus modulation index for 7-level multilevel inverter using GA

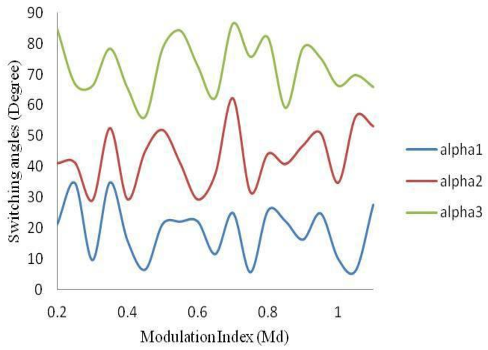

Fig.7 Switching angles versus modulation index for 7-level multilevel inverter using PSO

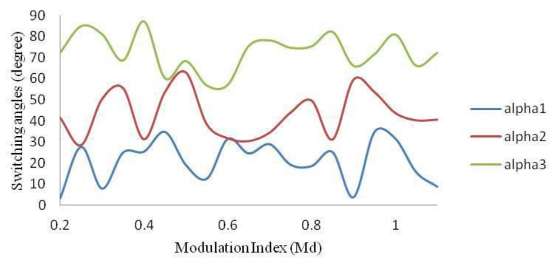

Table I. Comparison between GA, PSO and HSA technique regarding computational time at 0.8 Modulation Index

Optimization technique	Computational technique	%THD
Genetic Algorithm	0.00490 seconds	4.2917
Particle Swarm Optimization	1.88086 seconds	5.7351
Harmony Search Algorithm	0.85458 seconds	5.3954

Fig.8 Switching angles versus modulation index for 7-level multilevel inverter using HSA

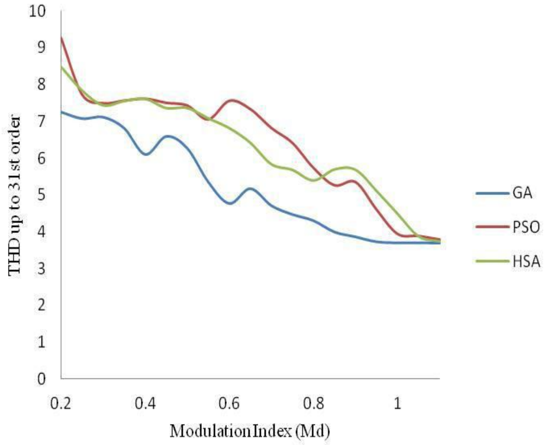

Fig.9 Voltage THD versus modulation index for 7-level multilevel inverter using GA, PSO and HSA considering lowest THD

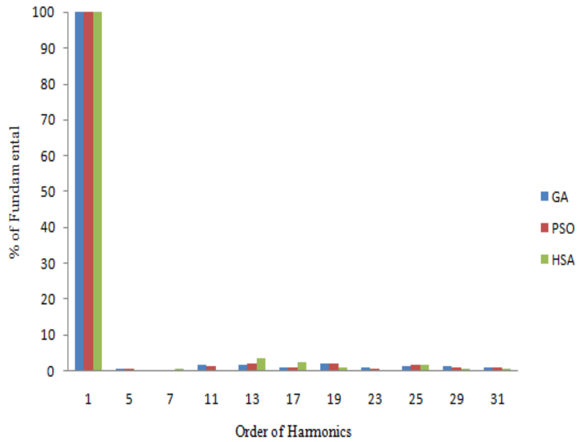

Fig.10 Harmonic Spectrum of output phase voltage for a 7-Level Multilevel inverter at 1 Md up to 31st order having THD 3.6854%, 3.8423% and 4.4878% using GA, PSO and HSA respectively

The results show that proposed approach for the harmonic optimization of multilevel inverters works properly. This method was applied to the seven and eleven levels cascaded multilevel inverters. Then, this method can be extended to more levels inverters. The proposed method is also capable of finding all possible sets of solutions of nonlinear equations. The results show that GA gives better performance in THD minimization and takes less computational time than PSO and HSA. In GA Toolbox all GA codes are in-built. So it is very easy to use GA Toolbox. However, in case of PSO and HSA the algorithm has to be developed either in MATLAB or other higher level languages.

VI. CONCLUSION

Artificial intelligence especially Genetic Algorithm, Particle Swarm Optimization (PSO) and Harmony Search Algorithm are used for THD minimization in Seven Level Cascaded H-Bridge Multilevel Inverter. Selected lower order of harmonics are controlled within allowable limits while the fundamental output voltage is maintained at desired level, thus resulting in the minimum THD and the corresponding switching angles are computed. From the presented case studies it is observed that GA technique provides superior performance compared to PSO and HSA as far as the minimization of THD is concerned.

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