PERFORMANCE ESTIMATION OF CHAOS EMBEDDED GRAVITATIONAL SEARCH ALGORITHM FOR POWER CONVERTER APPLICATIONS

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Abstract : *In this paper, Selective Harmonic Elimination (SHE) technique is utilized to reduce the dominant lower order frequencies present in the output voltage waveform of cascaded H-Bridge Multilevel Inverter (CHBMLI). Chaotic Gravitational Search Algorithm (CGSA) is applied to obtain the optimal switching angles, modulation index and input voltage values of seven level and eleven level cascaded multilevel inverter. The results obtained from various chaotic maps are compared with the already reported firefly and differential search algorithm based MLI for fixed input voltages and modulation index. From the simulation results, it is found that the Tent chaotic map (CGSA10) of CGSA provides better performance with minimum lower order harmonics and Total Harmonic Distortion (THD). The statistical performance analysis also confirms that the Tent chaotic map of CGSA provides consistent solutions with minimum standard deviation values as compared with other chaotic maps embedded in GSA.*

Keywords: *Multilevel inverters, Selective Harmonic Elimination, CGSA, Harmonics, THD*

1. Introduction

In recent years, renewable energy resources plays critical role in satisfying the future energy demands without affecting the environment. In renewable energy generation, the contribution of multilevel inverters is unavoidable to integrate the resources with the grid. The usage of power electronic switches in multilevel inverter introduces unwanted harmonic components in the system due to the non sinusoidal nature of the output waveform. This harmonic component affects the quality of the supply and disturbs the performance of the equipments connected in the grid. In addition to this, the multilevel inverters are used in several applications such as industrial drives, power flow control in transmission lines etc., Apart from several multilevel inverter configurations, cascaded multilevel inverters are more popular owing to its low dv/dt, lesser switching stress, higher conversion efficiency and lower electromagnetic interference. Multilevel inverters are becoming popular for high power applications due to its better quality output, minimum stress on switches, appreciable efficiency [1]. The key topologies of multilevel inverters are flying capacitor, diode clamped and cascaded H-bridge type inverters [2]. The flexibility in varying the voltage levels, uncomplicated design and limited components required to generate staircase output voltage waveform makes cascaded H- Bridge MLI most accepted configuration amid of the key topologies. Selective harmonic elimination is one of the switching strategies used in multilevel inverters with reduction of lower order harmonics as goal, maintaining the fundamental component as per the requirement. In SHE, minimization of lower order harmonics is achieved by solving non linear transcendental equations. The major difficulty in SHE PWM is determining the switching angle by solving these non linear transcendental equations. The iterative Newton Raphson method is used to find the switching angles but the trouble in this method is selecting the initial point for solving the equations [3,4]. Resultant theory is utilized by Z.Du et al [5,6] for finding the probable solutions for possible modulation index. This method suffers due to its limitations such as complexity, consumes more time and the expressions will vary with change in DC input voltage. The lower order harmonics are eliminated by estimating the switching angles using Artificial Neural Network (ANN)[7]. But ANN requires knowledge of switching angles for various modulation indices to train the network. To address the shortcomings of conventional methods, evolutionary algorithms are introduced to determine the switching angles for selective harmonic elimination. Ozpineci et al. [8] found optimal switching angles to eliminate lower order harmonics using genetic algorithms. The performance of Bee algorithm in selective harmonic elimination was studied in [9]. Particle swarm optimization algorithm [10], Modified species based particle swarm optimization algorithm [11], memetic algorithm [12], colonial competitive algorithm [13], bacterial foraging algorithm [14, 15] were applied for harmonic elimination of multilevel inverter for the equal voltage sources. Unequal DC voltage concept introduced in selective harmonic elimination along with the determination of firing angle to reduce the prespecified lower order harmonics. Switching angles for selective harmonic elimination of multilevel inverter with equal and unequal sources were calculated using particle swarm optimization [16]. Firefly algorithm was applied for adjustable DC voltage type 11 level multi level inverter to lessen the lower frequency harmonics maintaining the fundamental component [17]. Gravitational search algorithm used to find solution for several engineering optimization problems utilizes law of motion and Newtonian gravity principle [18]. Optimal power flow solution for IEEE 57 bus system [19], multi objective unit commitment with renewable resources [20], photo voltaic excitation control strategy for wind turbine [21], parameter extraction[22] was determined by gravitational search algorithm. Chaotic gravitational search algorithm adds chaotic maps to improve the exploration and exploitation phase of gravitational search algorithm [23]. The proposed chaos based GSA performance was evaluated using unimodal and multimodal bench map functions. Solar photo voltaic cell electric parameter estimation problem was solved using CGSA [24].

In this paper, chaotic GSA is employed to find out the optimal switching angles, input voltage values and modulation index of cascaded H bridge multilevel inverter (MLI), maintaining the fundamental quantity within the limit. The simulation results obtained with chaotic GSA is compared against the reported results of firefly algorithm(FA)[17] for 11 level and differential search algorithm (DSA)[25] for 7 level MLI with fixed input voltage sources. The remaining part of the article is systematized as follows: part 2 explains multilevel inverter topology, part 3 elaborates mathematical formulation of the selective harmonic elimination problem, chaotic GSA is discussed in part 4, part 5 presents the simulation results obtained using CGSA. part 6 narrates the conclusion of the paper.

2. BASIC STRUCTURE OF MULTILEVEL INVERTER

A. Multilevel inverter

Figure 1 illustrates cascaded H bridge inverter with eleven levels in the output voltage. The popularity of Cascaded H Bridge type multilevel inverter (CHB MLI) is due to its merits such as flexibility in modifying the number of output levels, simplicity in fault detection, minimum number of components requirement, low frequency switching and hence less switching loss. In CHBMLI , the output voltage with 'N' ie., (2S+1) levels can be generated by using 'S' number of input voltage sources. Therefore, three H bridge inverters are required to obtain output voltage with seven levels, similarly five inverter units are necessitated for eleven level MLI. Four power electronic switches are connected in bridge pattern to form a CHB single inverter unit.

2.1 Selective Harmonic Elimination PWM :

The stepped output voltage waveform of multilevel inverters is given by the Fourier series expansion is as follows:

$$V(\omega t) = \sum_{n=1,3,5}^{\infty} \frac{4V_{dc}}{n\pi} \left(\sum_{i=1}^{s} k_i * \cos n\theta_i\right) \sin n\omega t \qquad \ldots\ldots(1)$$

For selective harmonic elimination, the simplified non-linear equations for determining the CHB MLI switching angles are given below: with SHE for CHB MLI

$$\left.\begin{aligned}
h_1 &= \sum_{i=1}^{5} c_i * \cos(\theta_i) = M * s \\
h_5 &= \frac{4V_{dc}}{5\pi}\left[\sum_{i=1}^{5} k_i * \cos(5\theta_i)\right] = 0 \\
h_7 &= \frac{4V_{dc}}{7\pi}\left[\sum_{i=1}^{5} k_i * \cos(7\theta_i)\right] = 0 \\
h_{11} &= \frac{4V_{dc}}{11\pi}\left[\sum_{i=1}^{5} k_i * \cos(11\theta_i)\right] = 0 \\
h_{13} &= \frac{4V_{dc}}{13\pi}\left[\sum_{i=1}^{5} k_i * \cos(13\theta_i)\right] = 0
\end{aligned}\right\} \qquad ..(2)$$

where θ_i is the i^{th} switching angle, $k_i = \frac{V_{dci}}{V_{dc,}}$, V_{dci} is the i^{th} unequal DC sources of each H bridge unit, s is the number of DC sources, V_{dc} is the nominal value of DC voltage and i vary from 1 to 5 for eleven level and 1 to 3 for seven level MLI.

The first expression of equation 2 assures the fundamental component required in the output voltage. The remaining expressions of equation 2 is used to mitigate the 5^{th} and 7^{th} order harmonics in seven level in addition to 5^{th},7^{th} , 11th and 13^{th} order harmonics are mitigated in eleven level MLI. The above expression (2) confirms N+1 switching angles are required for removing 'N' harmonics selected. The fundamental component amplitude of the output voltage can be adjusted by varying the modulation index, m and the expression for m is given in equation no.(3)

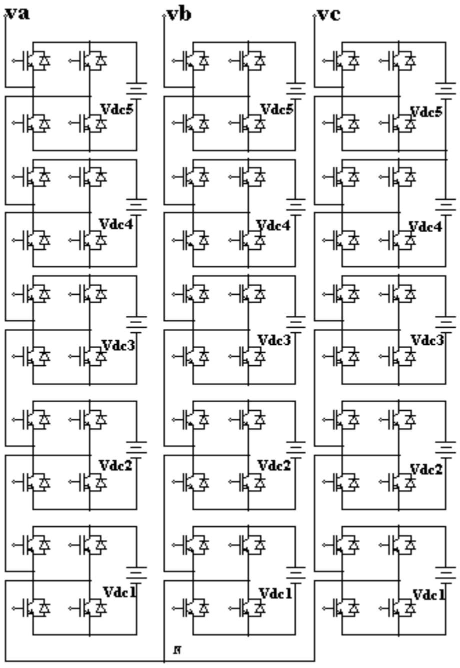


Fig. 1. Three phase five level cascaded Inverter

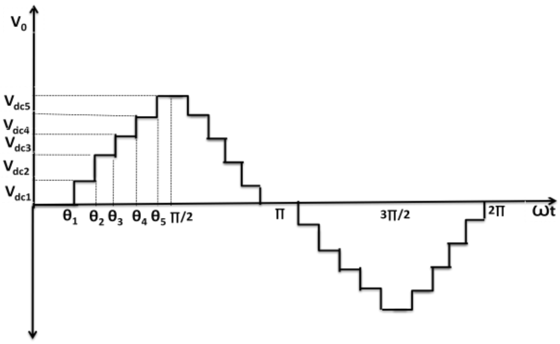


Fig. 2. Output voltage waveform

$$m = \frac{h_1}{4*S*V_{dc}/_{\pi}} \qquad .... (3)$$

The value of m can be varied between 0 and 1 in order to obtain different values of fundamental component, h_1. The output voltage waveform of eleven level MLI with different DC voltages is shown in figure.2

3. PROBLEM FORMULATION

In selective harmonic elimination, the optimal switching angles, input voltages and modulation index of multilevel inverter was determined by considering SHE as an optimization problem. The objective function [25] to be minimized for selective harmonic elimination is given in equation (4):

$$f = \min_{\alpha_i}\left\{\left(100\frac{V_1{}^* - V_1}{V_1}\right)^4 + \sum_{s=2}^{S}\frac{1}{h_s}\left(50 * \frac{V_{h_s}}{V_1}\right)^2\right\}$$

$$i = 1,\ 2,\ ....\ s \qquad ......(4)$$

Equation 5 represents the upper and lower bounds of the variables considered for optimization.

$$0 \le \theta_1 \le \theta_2 \le \theta_3 \le \theta_4 \le \theta_5 \le \frac{\pi}{2} \qquad ......(5)$$

$$0 \le m \le 1$$

$$0 \ge k_1 \ge k_2 \ge k_3 \ge k_4 \ge k_5 \ge 1.1$$

where $V_1{}^*$ is the specified value of fundamental at power frequency, h_s represents the order of the harmonics to be minimized and s denotes the number of switching angles. In the fitness function, the fundamental is controlled by maintaining the error value between the specified value and the actual value within 1 %. The harmonics selected for elimination is mitigated below 2 % of its fundamental. The harmonic limit of 2% is taken in the objective function is based on the IEEE519 standards for harmonics [32].

4. Algorithm considered for Optimization

Chaos embedded Gravitational search algorithm is used to optimize the variables such as firing angles of the switches, modulation index and the input DC sources.

4.1 Gravitational search algorithm

Gravitational search algorithm (GSA) is based on population to determine the global optimal solution for an optimization problem having more than one solution. GSA differs from other algorithms based on the method used for the solution while updating the positions. Every solution of the problem is assumed as mass and the interaction between the masses(X_i) is carried out with the help of gravitational forces.

$$X_i = \left(x_i^1, \dots, x_i^d, \dots, x_i^n\right) \qquad (6)$$

for $i = 1,2, \dots .. N$

In the above equation, N, n represents the number of $i^{\,th}$ solutions and variables respectively.

$$F_{ij}^d\,(t) = G(t)\frac{M_{gpi}\,(t)\ x\ M_{gaj}\ (t)}{R_{ij}\,(t) + \varepsilon}(x_j^d\ \ (t) - \ x_i^d(\mathrm{t})) \quad (7)$$

The equation (7) is used to determine the gravitational force that exists among the masses. M_{gpi} , M_{gaj} are the masses of $i^{\,th}$and $j^{\,th}$solution. $G(t)$ denotes the gravitational constant and the expression to calculate $G(t)$ is given in equation(8)

$$G(t) = G_o e^{-\alpha\frac{t}{T}} \qquad (8)$$

$$R_{ij}\,(t) = \ ||\ x_i(t), x_j(t)\ ||_2 \qquad (9)$$

The equation (9) is used to find the Euclidean distance, $R_{ij}(t)$ between i and j solutions. G_o is the initial value taken for gravitational constant, α and t represents the coefficient and current iteration respectively.
The net gravitational force between the i^{th} solution and the rest of the solution is found by the equation

$$F_i^d(t) = \sum_{j=1, j\neq i}^{N} rand_j\, F_{ij}^d(t) \quad (10)$$

The velocities and acceleration of the agents are calculated after determining net gravitational force.

$$a_i^d(t) = \frac{F_i^d(t)}{M_{ii}(t)} \quad (11)$$

$$v_i^d(t+1) = rand_i\ x\ v_i^d(t) + a_i^d(t) \quad (12)$$

The expressions (11) and (12) are used to find the acceleration and velocities, where d is the total number of variables considered in the optimization problem. 'M_{ii}' is the inertial mass of the agent.
The updation of the solution's position is carried out after determining the velocity and acceleration. The equation (13) is used to update the solution's position.

$$x_i^d(t+1) = x_i^d(t) + v_i^d(t+1) \quad (13)$$

The fitness value determined by the fitness equation is the mass of the solution. A normalization technique must be used due to the correlation among the fitness function and the mass. The normalization technique integrated with GSA is as given below:

$$m_i(t) = \frac{fit_i(t) - weak\ (t)}{strong\ (t) - weak\ (t)} \quad (14)$$

$$M_i(t) = \frac{m_i(t)}{\sum_{j=1}^{N} m_j\ (t)} \quad (15)$$

The efficiency of the gravitational search algorithm is more when compared with genetic algorithm and particle swarm optimization [19]. The fitness function has direct impact on the determination of mass of agents. Due to this, agents become heavier with increase in iterations leads GSA to lock in local optima and the speed of convergence get reduces. Several literatures show the slower convergence and falling in local minima of GSA. To overcome these problems, chaotic method is used in CGSA.

The systems which are nonlinear and dynamic in nature are termed as chaotic systems. The solutions of the chaotic systems are greatly dependant to the initial conditions considered. Chaotic maps are reported in literature to improve the performance of algorithms such as PSO [26], artificial bee colony algorithm [27], harmony search algorithms [28]. In addition to this, chaos concept is used to modify the performance of meta-heuristic algorithms namely chaotic genetic algorithms [29], chaotic differential evolution [30], chaotic firefly algorithm [31]. The conclusions of chaos incorporated with meta-heuristic algorithms improves the efficiency. In CGSA, ten chaotic maps [23] are embedded with GSA to overcome the drawbacks of GSA discussed.

4.2 GSA embedded with chaotic maps

In GSA, gravitational constant value determines the search agent motion. Therefore, it is necessary to control the value to avoid the solutions trapped into non-global optima. Mirjilali et al.[23] incorporated chaotic maps into the GSA gravitational constants which inturn adjust the net gravitational force between the agents in every iteration. The expression for modified gravitational constant is given as

$$G(t) = C^{norm}(t) + G_o e^{-\alpha\frac{t}{T}} \quad (16)$$

$$C^{norm}(t) = \frac{(C(t) - a)V(t)}{(b-a)} \quad (17)$$

where $C^{norm}(t)$ given in equation (17) indicates the normalized chaotic map function.

$C(t)$ represents the value of chaotic map at time 't', $[a, b]$ indicates the interval of the chaotic function considered. For every iteration, the range of normalization is proportionally decreased as follows:

$$V(t) = \max - \frac{t}{T}(max - \min) \quad (18)$$

The addition of chaotic concept in GSA highly enhances the stability among the exploration and exploitation of solutions results in better improvement in the performance of CGSA in contrast with GSA algorithm.

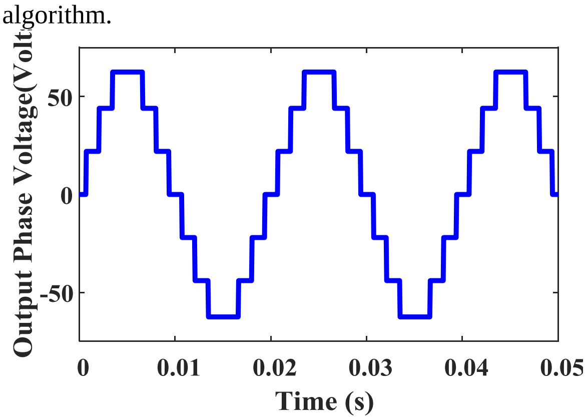
5. Results and discussion

Selective harmonic elimination is applied for seven level and eleven level CHBMLI in order to minimize the lower order harmonics present in the output of inverter, thereby the overall THD is reduced. The optimal values of control variables such as modulation index, input voltages and switching angles are calculated by using Chaotic GSA. Firefly algorithm [17] and DSA [25] based multilevel inverter are considered to compare the performance of CGSA based MLI. The coding and simulations are performed in MATLAB2018a version. The simulations are carried out for 100 runs by considering the population size as 100 and functional evaluation as 4000. The DC source voltage ranges between 10 to 110% of 20V and the assumed load considered is R = 14.4 Ω and L = 12 mH.

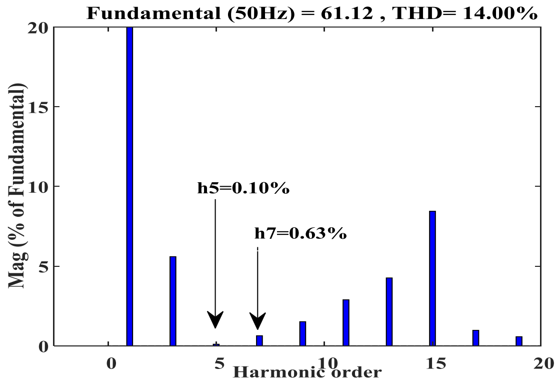
5.1 Simulation results of CGSA based MLI

The simulation results of selective harmonic elimination for various chaotic maps selected in CGSA are discussed in this section. The best solutions of Switching angles, modulation index and input variables and output voltage values of seven level MLI for different chaotic maps are displayed in the table 1. From the table, it is identified that the CGSA10 chaotic map (Tent) provides better results with minimum objective function values, minimum lower order harmonics and total harmonic distortion of phase voltage as 14 % and line voltage as 8.89 % as compared with DSA based MLI. Even though, some other maps give lower fitness function values and THD, their performances are not consistent as per the statistical results given in table 7. The statistical performance of CGSA10 chaotic map (Tent) is also better with lower standard deviation values of fitness function over the 100 runs considered along with better fitness function value and total harmonic distortion. The harmonic spectrum, phase voltage and line voltage waveforms of seven level CGSA embedded with tent map tuned MLI is shown in figure 3 and 4.

The proposed CGSA based multilevel inverter efficiency is also investigated also using eleven level MLI. The input and output parameters for various chaotic maps of eleven level CGSA based inverter is given in the table 2 and 3. As like seven level, the CGSA10 chaotic map offers outstanding performance with reasonable value of fitness function and minimum THD of 8.83% for phase voltage and 5.83% for line voltage. The THD of CGSA based eleven level inverter is very low as compared with firefly based multilevel inverter. The statistical performance of CGSA10 map given in table 8 also proves that it gives reliable performance with very low standard deviation value as compared with other maps. The harmonic spectrum, phase voltage and line voltage waveforms of eleven level CGSA embedded with CGSA10 map tuned MLI is shown in figure 5 and 6. Table 4, 5 and 6 shows the comparison results of CGSA with firefly and DSA algorithm.

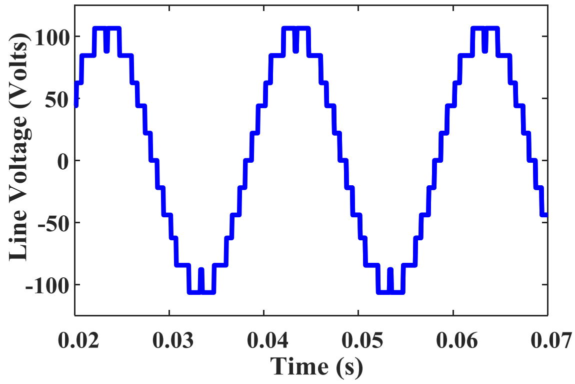


(a)

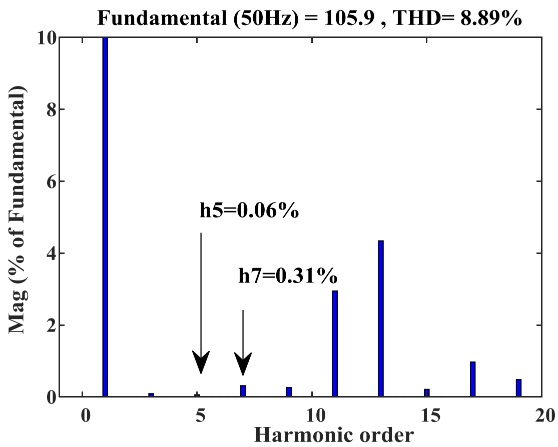


(b)

Fig(3) Simulation results for CGSA 10 at modulation index = 0.8002 (a) Waveform of output phase voltage (b) Harmonic Spectrum of output phase voltage

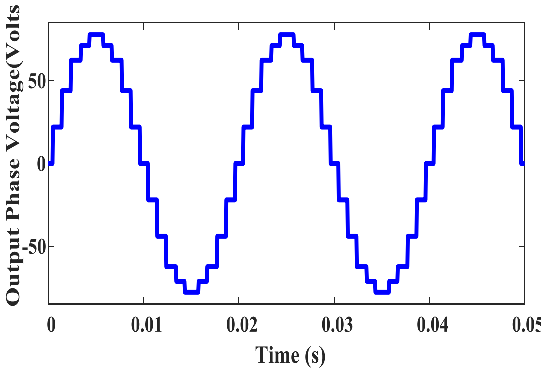


(a)

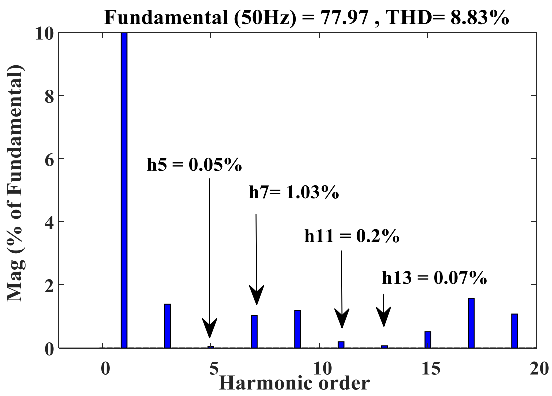


(b)

Fig(4) Simulation results for CGSA 10 at modulation index = 0.8002 (a) Waveform of output Line voltage (b) Harmonic Spectrum of output Line voltage

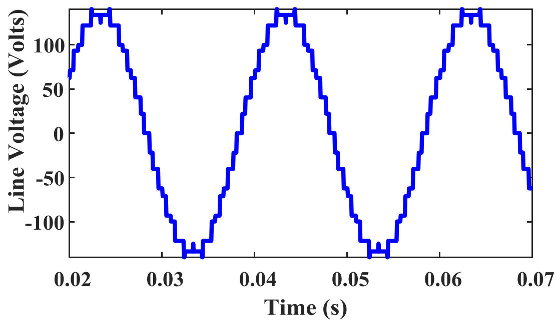


(a)

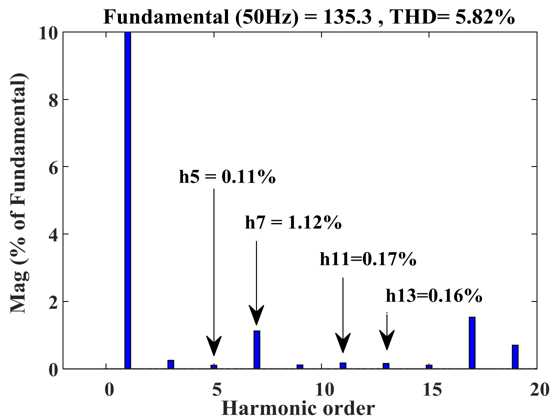


(b)

Fig(5) Simulation results for CGSA 10 at modulation index = 0.6142 (a) Waveform of output phase voltage (b) Harmonic Spectrum of output phase voltage

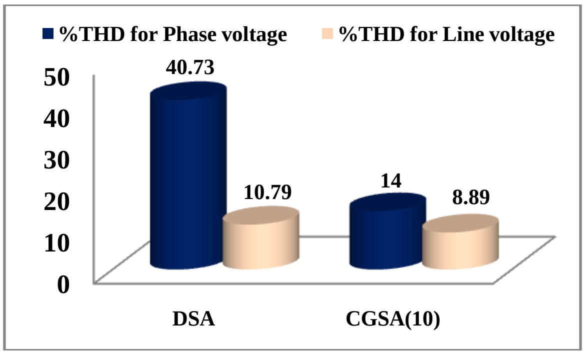


(a)

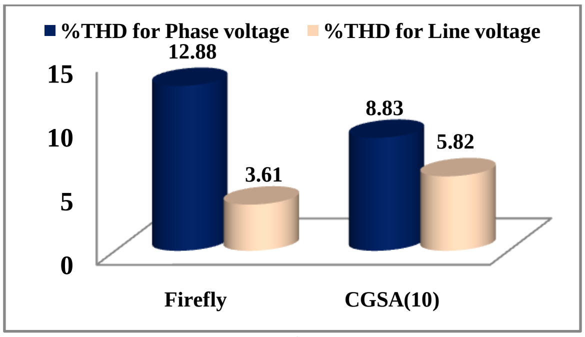


(b)

Fig(6) Simulation results for CGSA 10 at modulation index = 0.6142 (a) Waveform of output Line voltage (b) Harmonic Spectrum of output Line voltage



Fig(7) THD Values of Seven level Inverter



Fig(8) THD Values of Eleven level Inverter

The total harmonic distortion values of DSA based MLI and CGSA based seven level MLI are compared in figure 7. Similarly, the THD comparison of eleven level CGSA based MLI with firefly algorithm based MLI is displayed in figure 8. From the both comparison graphs, it is evident that CGSA based MLI gives better performance with minimum THD.

The statistical performance of seven level and eleven level MLI is given in the table 7 and 8. For 100 runs, the least, the maximum, the mean and the standard deviation of fitness values attained for CGSA are reported in tables. It is noticeable that better performance is offered by CGSA10 chaotic map with least average and standard deviation values. The proximity of the results attained in all the 100 runs reveals that CGSA is better than DSA and firefly algorithm to compute optimal solution for SHE.

Algorithm	*Best Optimal*	θ_1	θ_2	θ_3	*Mod. Index*	*K1*	*K2*	*K3*	*THD(%)*	*V1*	*V5(%)*	*V7(%)*
CGSA1	0.0013	12.6450	42.5808	82.1533	0.6621	1.1000	1.1000	0.6859	**16.66**	50.3560	0.0428	0.0679
CGSA2	2.8204e-05	13.9777	43.8327	79.4569	0.6045	1.1000	0.9069	0.4141	**15.46**	45.8084	0.0057	0.0059
CGSA3	1.8038e-04	11.1068	38.9099	79.7803	0.5768	1.0600	0.8411	0.2668	**15.82**	44.3516	0.0156	0.0130
CGSA4	1.9331e-06	14.9285	45.2919	77.6860	0.6506	1.1000	1.1000	0.5266	**16.85**	49.6500	0.0018	0.0030
CGSA5	1.0617e-07	12.2418	33.9023	60.2082	0.8387	1.1000	1.1000	1.0660	**13.81**	64.1612	4.8933e-04	4.6226e-04
CGSA6	6.6646e-06	10.3769	38.6139	74.0534	0.6654	1.0975	1.0586	0.3613	**14.52**	51.1630	0.0034	0.0033
CGSA7	4.8297e-04	14.5313	44.2737	74.4716	0.6189	1.0672	0.9873	0.4380	**15.56**	47.4261	0.0295	0.0041
CGSA8	4.7974e-08	16.0630	46.9841	78.1407	0.6322	1.1000	1.0706	0.5026	**17.58**	48.1224	1.1525e-04	3.5438e-04
CGSA9	1.9163e-04	14.0177	42.9866	71.7063	0.6776	1.1000	1.1000	0.5320	**15.43**	51.9041	0.0135	0.0283
CGSA10	**6.7702e-08**	**12.4979**	**36.1919**	**61.9013**	**0.8002**	**1.1000**	**1.1000**	**0.9265**	**14.00**	**61.12**	**0.1000**	**0.6300**

Table.1. Seven level inverter input variables and output parameters for unequal Voltage Sources

Algorithm		*Best Optimal*	θ_1	θ_2	θ_3	θ_4	θ_5	*Mod. Index*	*K1*	*K2*	*K3*	*K4*	*K5*
CGSA1	***Chebyshev map***	0.0091	8.0852	27.6759	44.5980	64.7379	81.3186	0.5235	1.0988	0.8553	0.8414	0.3135	0.2752
CGSA2	***Circle map***	0.0504	9.6306	27.2461	44.7070	62.5141	80.3537	0.5421	1.0999	1.0068	0.6803	0.4962	0.1010
CGSA3	***Gaussimouse map***	0.9413	9.0355	23.6400	40.1456	64.0672	80.9663	0.4569	0.9576	0.8025	0.5482	0.3460	0.2163
CGSA4	***Iterative map***	3.8359e-7	10.5839	31.1441	50.2451	64.3603	81.9659	0.4562	1.1000	0.8729	0.4967	0.2707	0.1236
CGSA5	***Logistic map***	0.0151	8.3698	22.2488	38.9455	59.5768	82.9238	0.7128	1.1000	1.1000	1.1000	1.1000	0.3341
CGSA6	***Piecewise map***	0.0023	8.6891	27.9206	45.2982	64.5124	81.3525	0.5137	1.1000	0.9038	0.7388	0.3141	0.1948
CGSA7	***Sine map***	0.0182	8.0849	25.7389	43.7245	64.2582	84.8633	0.6109	1.1000	1.0908	0.9739	0.5656	0.3939
CGSA8	***Singer map***	0.0010	9.8317	28.5906	46.8219	62.9119	79.5607	0.4826	1.0943	0.8826	0.5564	0.3546	0.1000
CGSA9	***Sinusoidal map***	1.9052e-7	8.6134	20.7281	37.1833	58.7918	86.1316	0.7169	1.1000	1.1000	1.1000	1.1000	0.3116
CGSA10	***Tent map***	**0.0516**	**7.7467**	**24.5939**	**41.7045**	**60.4387**	**76.6180**	**0.6142**	**1.1000**	**1.0964**	**0.9220**	**0.4398**	**0.3284**

Table.2. Eleven level inverter input variables and output parameters for unequal Voltage Sources

Algorithm	*THD(%)*	*V1(%)*	*V5(%)*	*V7(%)*	*V11(%)*	*V13(%)*
CGSA1	**9.56**	66.7119	0.1189	0.2970	0.0155	0.0227
CGSA2	**9.12**	68.9823	0.3841	0.3275	0.1525	0.1669
CGSA3	**10.81**	58.1921	1.0330	1.5459	0.2190	0.8201
CGSA4	**10.21**	58.0706	7.3069e-04	4.0364e-04	8.9655e-05	2.1379e-04
CGSA5	**9.35**	90.6568	0.3303	0.1273	0.0927	0.1281
CGSA6	**9.52**	65.4472	0.0788	0.1014	0.0048	0.0334
CGSA7	**9.25**	77.8297	0.0338	0.5134	0.0247	0.0744
CGSA8	**9.68**	61.4599	0.0654	0.0030	0.0099	0.0246
CGSA9	**9.05**	91.2596	2.3578e-04	0.0015	6.5908e-05	1.3739e-04
CGSA10	**8.83**	**77.97**	**0.0500**	**1.0300**	**0.2000**	**0.0700**

Table.3. Eleven level inverter output parameters

Technique	*Best Optimal*	θ_1	θ_2	θ_3	*M*	*K1*	*K2*	*K3*	*THD*	*V1*	*V5*	*V7*
CGSA	**6.7702e-08**	**12.4979**	**36.1919**	**61.9013**	**0.8002**	**1.1000**	**1.1000**	**0.9265**	**14.00%**	**61.12**	**0.10%**	**0.63 %**
DSA[25] *(for fixed M and voltage source)*	-	33.498	54.759	67.103	0.60	1	1	1	40.73%	45.81	0	0

Table 4. Comparison of output parameters for Seven level MLI for different algorithms

Technique	***Best Optimal***	θ_1	θ_2	θ_3	θ_4	θ_5	***M***	***K1***	***K2***	***K3***	***K4***	***K5***
GSA	**0.0516**	**7.7467**	**24.5939**	**41.7045**	**60.4387**	**76.6180**	**0.6142**	**1.1000**	**1.0964**	**0.9220**	**0.4398**	**0.3284**
Firefly[17] *(for fixed M and voltage source)*	-	3.08	15.33	33.74	41.47	84.4	0.7	1.08	0.98	0.9	0.86	0.8

Table 5. Eleven level inverter input variables for different algorithms

Algorithm	THD	V1	V5	V7	V11	V13
CGSA11	**8.83%**	**77.97**	**0.05%**	**1.03%**	**0.2%**	**0.07%**
Firefly[17] (fixed M & fixed voltage source)	12.88%	88.2	0.05%	0.1%	0.2%	0.04%

Table 6. Comparison of output parameters for Eleven level MLI for different algorithms

Algorithm	Mean optimal	Std optimal	Worst Optimal	Best Optimal
CGSA1	22.7476	65.2618	327.6225	0.0013
CGSA2	12.6704	54.2914	391.4249	2.820e-5
CGSA3	46.3677	136.2298	932.7847	1.803e-4
CGSA4	14.2308	61.3258	421.9399	1.933e-6
CGSA5	16.2713	85.6543	732.9288	1.061e-7
CGSA6	7.0303	24.4389	204.9597	6.664e-6
CGSA7	3.5187	14.9171	143.2510	4.829e-4
CGSA8	14.0584	77.7183	726.7629	4.797e-8
CGSA9	12.7962	53.9076	475.9082	2.218e-8
CGSA10	**4.9849**	**16.7108**	**157.6333**	**6.770e-8**

Table 7. Statistical evaluation values for Seven Level MLI

Algorithm	Mean optimal	Std optimal	Worst Optimal	Best Optimal
CGSA1	39.8980	130.3116	847.6891	0.0091
CGSA2	42.1321	118.8801	613.4524	0.0504
CGSA3	24.7707	43.2300	189.6950	0.9413
CGSA4	29.4039	107.1363	700.1192	3.835e-7
CGSA5	29.4698	125.1928	886.2549	0.0151
CGSA6	21.0139	69.1437	463.5694	0.0023
CGSA7	32.9136	109.9013	633.5894	0.0182
CGSA8	39.2718	122.9031	846.6665	0.0010
CGSA9	35.7513	70.6090	410.1193	1.905e-7
CGSA10	**7.3059**	**13.1040**	**67.9533**	**0.0516**

Table 8. Statistical evaluation values for eleven Level MLI

Conclusion

In this paper, chaotic gravitational search algorithm is utilized for finding the optimal switching angle, modulation index and input DC voltage values of selective harmonic elimination applied for seven level and eleven level three phase cascaded H- Bridge multilevel inverter maintaining the prespecified fundamental component. The simulation results of seven level and eleven level MLI using MATLAB confirms that CGSA10 chaotic (Tent) map of the various chaotic maps considered determines best possible control parameter values that minimizes the objective function considered and total harmonic distortion. The results are compared with the reported results of DSA for seven level and firefly algorithm based for eleven level MLI. The statistical performance of various chaotic maps indicates the CGSA10 chaotic (Tent) map provide reliable performance compared with other chaotic maps. The selective harmonic elimination with variable voltage and variable modulation index based MLI gives improved performance than fixed voltage, fixed modulation index based MLI.

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