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Minimization of Harmonics in Multilevel inverters with Unequal DC sources using Particle Swarm Optimization

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Abstract— Multilevel inverter (MLI) technology has recently emerged as a new kind of power conversion system that offers many benefits for high power applications. This paper focuses on Particle Swarm Optimization (PSO) based method for harmonic elimination in 7 level cascaded MLI. The main objective of this work is to eliminate lower order harmonics by solving non linear equations while satisfying fundamental components. The dc sources feeding the multilevel inverters are considered to be varying, and the switching angles are adapted to the dc source variation. This work focuses on PSO algorithm to obtain switching angles offline for different dc source values to minimize 3rd and 5th harmonic. With the switching angles obtained, Artificial Neural Networks (ANN) is trained such that the network can be used to determine the optimum switching angles corresponding to dc sources in real time .Simulation is done in Matlab/Simulink environment and the results indicate that switching angles obtained using PSO algorithm results in harmonic minimization. The results of PSO are validated using Genetic Algorithm(GA).

Index Terms— Cascaded Multilevel Inverter, Particle swarm optimization, Artificial Neural Network, Selective Harmonic Elimination.

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1 INTRODUCTION

Multilevel inverters (MLI) have been receiving increasing attention in the past few years, due to their ability to synthesize the waveforms with a better harmonic spectrum and attain higher voltage [1]. Multilevel inverters are characterized by the number of different output voltage levels that can be generated by the inverter. As the number of levels increase the synthesized output waveforms have more steps which produce a staircase wave that approaches the desired waveform. Among the different topologies cascaded multilevel inverter with separate DC sources of multilevel converters have many attractive features like high voltage capability, reduced common mode voltages, near sinusoidal outputs, low dv/dt, making them suitable for high power applications [2]. The most familiar power circuit topology for multilevel converters is based on the cascade connection of an *s* number of single-phase full-bridge inverters to generate a $(2s + 1)$ number of levels. To control the output voltage and to eliminate the undesired harmonics in multilevel converters with equal dc voltages, various Pulse Width Modulation (PWM) methods have been proposed. However, the main draw back in PWM techniques is that the lower order harmonics are not eliminated completely [3],[4],[5].In this paper, a selective harmonic elimination technique is introduced to minimize the harmonics. PSO is used to obtain optimum switching angles to minimize the harmonics.

2 MULTILEVEL INVERTER

2.1 Multilevel inverter topology

Cascaded multilevel inverters overcome the disadvantages of diode clamped and flying capacitor multilevel inverters. It requires less number of switches and reduced switching losses. The most familiar power circuit topology for multilevel converters is based on the cascade connection of an *s* number of single-phase full-bridge inverters to generate a $(2s + 1)$ number of levels as shown in the figure 1. These bridges can generate $+V_{dc}$, 0,$-V_{dc}$. The output of the cascaded multilevel inverter produces the staircase waveform shown in the figure 2. The main advantages of MLI are the staircase waveform quality, so it has reduced voltage stress and it can draw input current with low distortion. The MLI can operate at both fundamental and high switching frequency PWM [5].

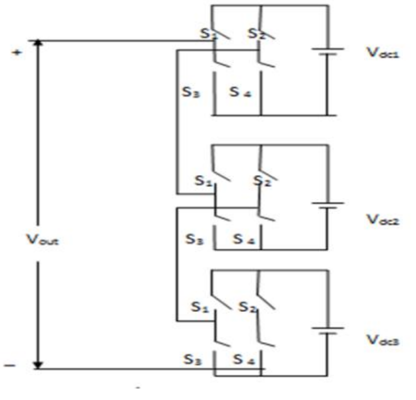

Fig .1. 7 level cascaded multilevel inverter

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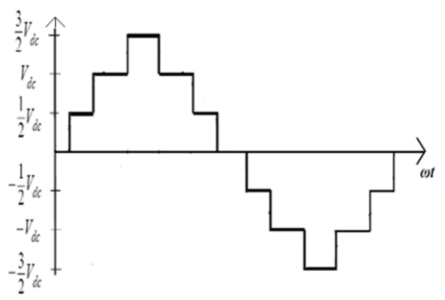


Fig.2. Output voltage waveform of a 7 level inverter

2.2 Selective Harmonic Elimination

The modulation methods with higher switching frequency reduce filter size but increases switching losses. And low switching frequency means low switching losses but it requires large filter size. To reduce the filter size the number of levels of the inverter is increased but it increases the cost of the system [6]. Selective Harmonic Elimination (SHE) modulation method introduces additional notches in the multi-level output voltage. These notches eliminate harmonics at the low order frequency and shifts it a higher order frequency and hence the filter size is reduced without increasing the switching losses and cost of the system. The inverter output voltage is chopped a number of times at certain predetermined angles to eliminate the selected harmonics. This method offer a tight control of the harmonic spectrum of a given voltage waveform generated by a power electronic inverter along with a low number of switching transitions [7].

Using the odd quarter-wave symmetry of the waveform shown in fig 2, the Fourier series coefficients are given below [8]

$$V_{an}(\omega t) = \sum_{n=1,3,5}^{\infty} \frac{4}{\pi}\left(V_{dc1}\cos(n.\theta_1) + V_{dc2}\cos n\,(n.\theta_2) + (V_{dc3}\cos(n.\theta_3)).\sin(n\omega t)\right) \quad ....(1)$$

Where

$V_{dc1}, V_{dc2}, V_{dc3}$	input dc sources
$\theta_1, \theta_2, \theta_3$	inverter switching angles
V_{an}	Inverter output voltage

The equation (1) shows the odd harmonic content of the output voltage waveform. Under variations in the DC input sources, it is desired to maintain the fundamental output voltage and cancel the lowest non triplen harmonics. The set of fundamental component and harmonic components are

$$V_{fund} = \frac{4}{\pi}(V_{dc1}\cos(\theta_1) + V_{dc2}\cos(\theta_2) + V_{dc3}\cos(\theta_3)) \quad ....(2)$$

$$V_3 = \frac{4}{3\pi}(V_{dc1}\cos(3\theta_1) + V_{dc2}\cos(3\theta_2) + V_{dc3}\cos(3\theta_3)) \quad ....(3)$$

$$V_5 = \frac{4}{5\pi}(V_{dc1}\cos(5\theta_1) + V_{dc2}\cos(5\theta_2) + V_{dc3}\cos(5\theta_3)) \quad .....(4)$$

The objective function is formulated as

$$f(V_{fund}, V_3, V_5) = (V_{fund} - 110) + V_3 + V_5 \quad ....(5)$$

The PSO is programmed to obtain the optimum set of angles to control the multilevel inverter for each value of the dc sources.

3 PARTICLE SWARM OPTIMIZATION

Particle swarm optimization (PSO) is mainly inspired by social behaviors observed in flocks of birds, schools of fish, or swarms of bees, colonies of ants, and even human social behavior, from which the intelligence is emerged. PSO, proposed by Kennedy and Eberhart (1995) uses a number of particles that constitute a swarm moving around in an N-dimensional search space looking for the best solution [21],[22],[23],[24]. Each particle in PSO keeps track of its coordinates in the problem which are associated with the best solution (best fitness) it has achieved so far. This value is called "pbest". Another ''best'' value that is tracked by the global version of the particle swarm optimizer is the overall best value and its location obtained so far by any particle in the swarm. This location is called "gbest". Let X and V denote the particle's position and its corresponding velocity in search space, respectively. At iteration K, each particle i has its position defined by $X_i = [x_{i1}, x_{i2}. \,.\, .\, x_{iN}]$ and velocity is defined as $V_i = [v_{i1}, v_{i2}, . . ., v_{iN}]$ in the search space N. Velocity and position of each particle in the next iteration can be calculated as

$$v_{i,n}^{k+1} = wv_{i,n}^{k} + c_1 rand_1\left(pbest_{i,n} - x_{i,n}^{k}\right) + c_2 rand_2\left(gbest_n - x_{i,n}^{k}\right) \quad (6)$$

$$X_{i,n}^{k+1} = X_{i,n}^{k} + V_{i,n}^{k+1} \quad \text{if} \quad X_{min,i,n} \le X_{i,n}^{k+1} \le X_{max,i,n} \quad ..... (7)$$

$$X_{i,n}^{k+1} = X_{min,i,n} \quad \text{if} \quad X_{i,n}^{k+1} > X_{min,i,n} \quad ....(8)$$

$$X_{i,n}^{k+1} = X_{max,i,n} \quad \text{if} \quad X_{i,n}^{k+1} > X_{max,i,n} \quad ....(9)$$

where m is the number of particles in the swarm, N is the number of dimensions in a particle, K is the pointer of iterations (generations), $X_{i,n}^{k}$ is the current position of particle i at iteration k, $V_{i,n}^{k}$ is the velocity of particle i at iteration k, W is the weighting factor, Cj is the acceleration factor and $rand_j$ is the random number between 0 and 1.

The following weighting function is usually used in Equation (6)

$$w = w_{max} - \left(\frac{w_{max} - w_{min}}{iter_{max}}\right) \times iter \quad ...... (10)$$

where W_{max} and W_{min} are the initial and the final weight, respectively, Iter is the current iteration number and $Iter_{max}$ is maximum iteration number. The model using Equation (10) is called the 'inertia weights approach'. The inertia weight is employed to control the impact of the previous history of velocities on the current velocity. Thus, the parameter W regulates the trade-off between the global and the local exploration abilities of the swarm. A large inertia weight facilitates exploration, while a small one tends to facilitate exploitation.

4 SHE USING PSO

PSO algorithm is applied to minimize the harmonics in a seven level multilevel inverter with voltage sources Vdc1=35, Vdc2=35, Vdc3=43. The optimum switching angles are obtained from PSO θ1=5.193, θ2=27.25, θ3=52.346.To validate the results of PSO, MLI is simulated in Matlab/Simulink and the harmonic spectrum is analysed.

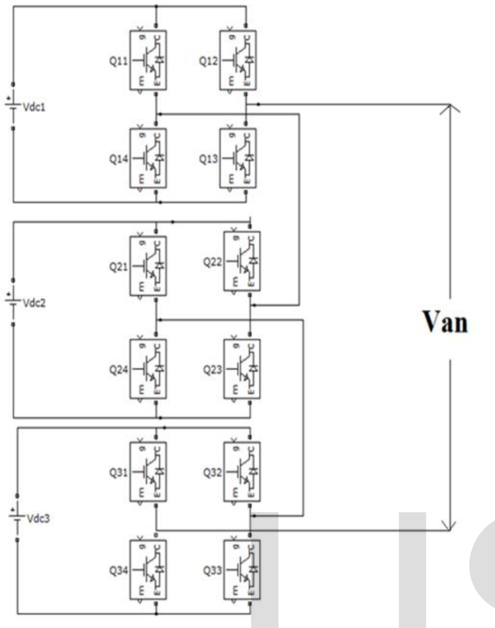


Fig 3. Simulation model of MLI

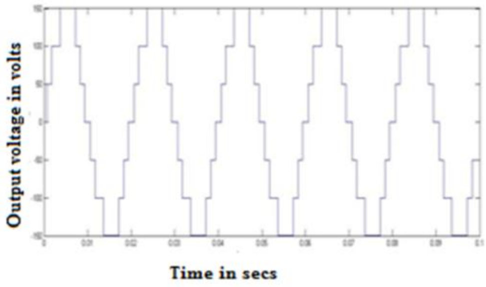
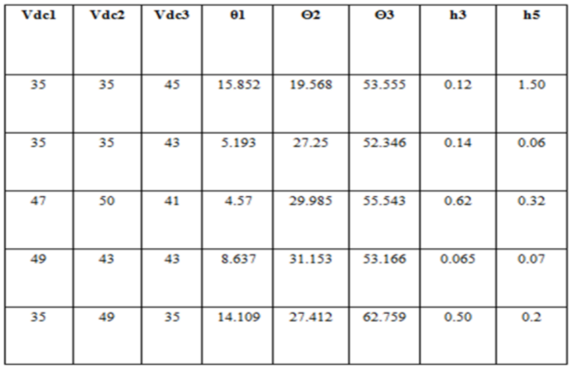


Fig 4. Output voltage waveform of MLI

The simulation circuit of 7 level MLI is shown in figure 3 and the corresponding output waveform for the 7 level MLI is shown in figure4.The harmonic profile is shown in figure 5.From the figure it is evident that there is considerable reduction in 3rd and 5th harmonic.The table.1 shows that the optimum switching angles obtained from PSO for different values of the DC sources.

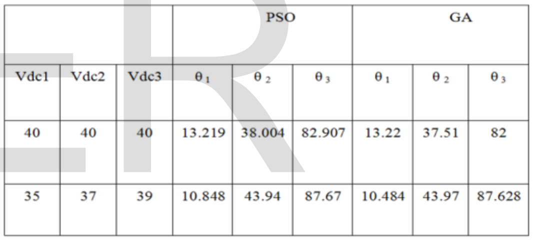
TABLE 1 SWITCHING ANGLES OBTAINED FROM PSO



Vdc1	Vdc2	Vdc3	θ1	Θ2	Θ3	h3	h5
35	35	45	15.852	19.568	53.555	0.12	1.50
35	35	43	5.193	27.25	52.346	0.14	0.06
47	50	41	4.57	29.985	55.543	0.62	0.32
49	43	43	8.637	31.153	53.166	0.065	0.07
35	49	35	14.109	27.412	62.759	0.50	0.2

To validate the results of PSO, SHE is performed using GA. The results are tabulated in Table 2. The closeness of the results validates the PSO based approach.

TABLE 2- OPTIMUM SWITCHING ANGLES PSO VS GA



			PSO			GA		
Vdc1	Vdc2	Vdc3	θ_1	θ_2	θ_3	θ_1	θ_2	θ_3
40	40	40	13.219	38.004	82.907	13.22	37.51	82
35	37	39	10.848	43.94	87.67	10.484	43.97	87.628

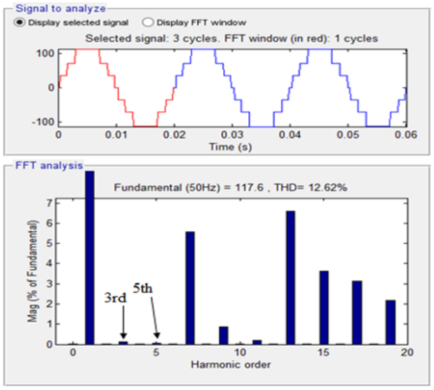


Fig 5.Output voltage and its Harmonic profile

5 ADAPTIVE SHE

For real time implementation the switching angles obtained using PSO are adapted to the DC source variation using ANN. First ANN is trained with the values obtained using PSO algorithm for different value of dc sources. The trained network is used to determine the optimum switching angles in real time. Back propagation algorithm is used for training the neural network.Back propagation algorithm is used to train the neural network [13]. The input vectors Vdc1, Vdc2, Vdc3 are applied to the input layer of the network and output vectors θ1, θ2, θ3 are applied to the output layer of the network as shown in Figure 6.

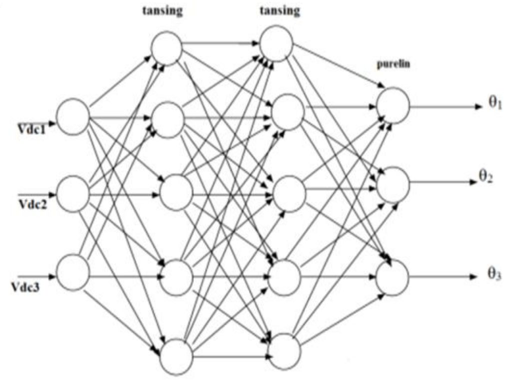


Fig 6.Feed forward Neural Network structure

The training result for ANN is shown in table 3. The accuracy of this trained ANN is verified by considering test points which include both trained and untrained values. The table 3 shows the training results of the ANN. The results of the network are satisfactory when tested with data which were not subjected to training.

TABLE 3- TRAINING RESULT OF ANN

Voltage sources			Actual value			Neural network trained value		
V_{dc1}	V_{dc2}	V_{dc3}	θ_1	θ_2	θ_3	θ_1	θ_2	θ_3
50	43	43	5.152	33.214	54.08	5.237	33.470	53.137
49	41	41	5.696	33.92	54.511	5.766	33.880	53.181
45	45	45	4.63	30.386	53.563	4.620	30.429	53.589
37	37	45	3.297	28.170	51.32	3.124	27.643	51.966
35	35	43	5.193	27.25	52.346	5.36	27.611	52.345

6 CONCLUSION

In this work elimination of lower order harmonics in asymmetric multilevel inverter using SHE is investigated. PSO is applied to solve non linear equations and determine optimum switching angles for different DC sources considered to be varying in time. The results of PSO are verified with Genetic algorithm and the closeness of the results validate the proposed approach. The solutions obtained using PSO is used for training the neural network The trained network is used for online determination of switching angles to minimize the harmonics.

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