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Using Imperialist Competitive Algorithm to optimize the Switching Angle of the multilevel Inverter in order to Eliminate Low Order Harmonics Considering the Variation of DC Voltage Sources

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Abstract. This paper investigates the optimum Switching Angle through Imperialist Competitive Algorithm to Eliminate Low Order Harmonics in multilevel Inverter. Variation of DC Voltage Sources is the other parameter that is evaluated. In this regard, a multi level cascaded inverter with 27 different modes of DC voltage Variation is analyzed. The main goal is to achieve fundamental output voltage without low order harmonics. Furthermore, a comparative analysis between particle swarm optimization and Imperialist Competitive Algorithm is done and the optimum switching angles are determined. Simulation results demonstrate the acceptable performance of the approach.

Keywords: Multilevel Inverter, Low Order Harmonics, DC Voltage Variation, Imperialist Competitive Algorithm, Switching Angle Optimization

1-Introduction

Application of Multilevel Inverters in Recent years due to hopeful progress in designing power electronic semiconductor is increasing. A Multilevel Inverter is a power electronic device that delivers AC voltage through different Switching scheme. Quality of the output AC Voltage is related to the number of the Switching level. Batteries, photovoltaic, fuel cells, capacitors and even the rectified output voltage of wind turbines and …are DC input Sources.

Multilevel inverters perform an important role in power system because of their Countless applications. The use of multilevel inverters due to the ability of operating under high voltage and power, improving the quality of the output waveform and their flexibility, is increasing in industry [1].

A theoretical analysis is done about a multilevel Inverter with new PWM method [2]. The main goal of this reference was to develop THD. Soft computing methods and their applications for harmonics elimination with PWM method for inverters in renewable energy conversion systems are discussed in [3]. The matter of eliminating selective harmonics in a Five-Level Inverters through An Analytical Algorithm is also analyzed [4]. In [5] genetic Algorithm has been used for Selective harmonic elimination of a new family of multilevel inverters. Optimal switches of a multilevel inverter to reduce voltage harmonic are determined with particle swarm optimization [6]. In [7] the matter of Harmonic elimination in a cascaded H-bridge multilevel inverter based active power Filter is studied. In this reference, intelligent techniques are used to control the process. The effect of Variable DC Sources and Comprehensive Harmonic Optimization in Cascaded H-bridge Multilevel Inverters is reviewed in [8]. In [9] Fuzzy Logic Controller is hired to eliminate Low Order Harmonics in Multilevel Inverters. In addition, DC Voltage Sources Variations is considered

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in this reference. In [10], different high frequency switching approaches for the multilevel inverters for PV applications is analyzed. In [11], Predictive Control is chosen as a controlling strategy for a Three-Phase Cascaded Multilevel Inverter. Cascaded Multilevel Inverter with Reduced Number of Components based on Fuzzy Logic Controller is studied in [12].

In this paper, elimination of low order harmonics in multi level Inverter with different dc inputs in order to reduce THD is conducted. Imperialist Competitive Algorithm is the heuristic method to determine the optimal switching angle of the inverter while the dc inputs have variation.

2. Cascade Multilevel Inverter

In this paper, a multi level inverter with 10% oscillation in dc voltage is simulated. The simulated model of the cascade multilevel inverter is shown in figure 1.

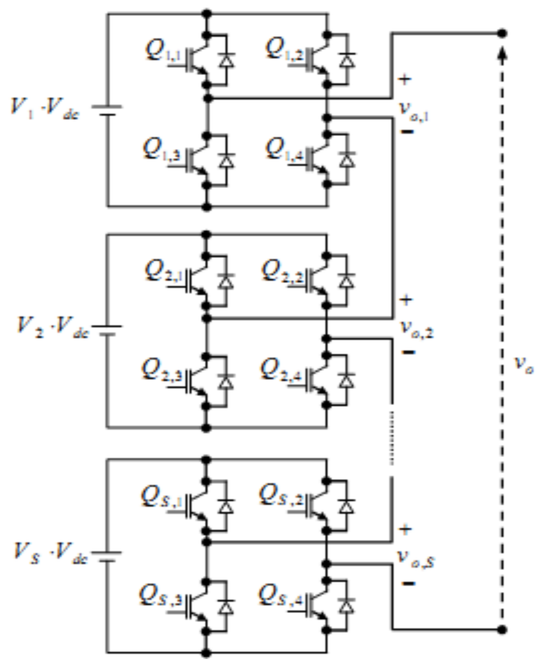

Figure 1. Cascade multilevel inverter.

The pulse generator has applied blew wave form like figure 2 and 3 to the gate of the inverter.

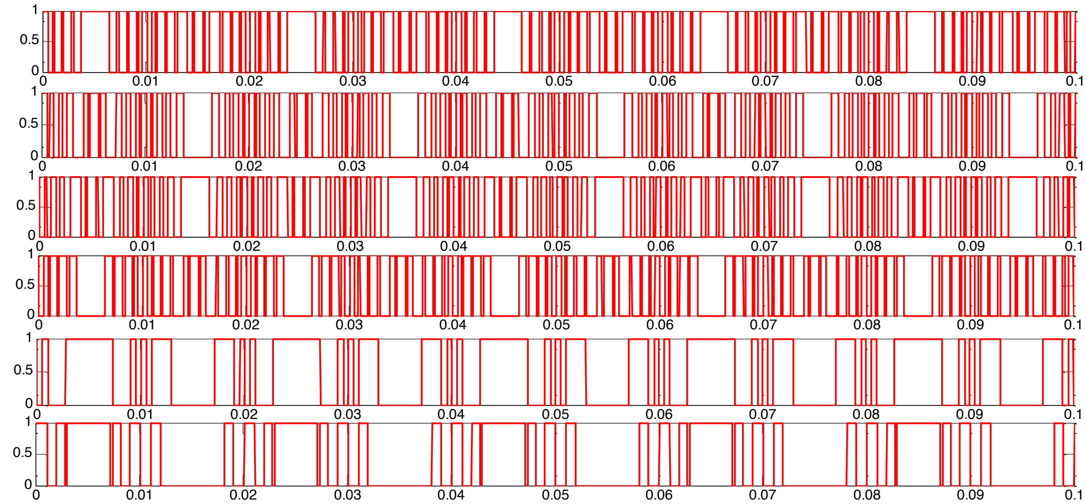

Figure 2. Applied signal to gate 1-6.

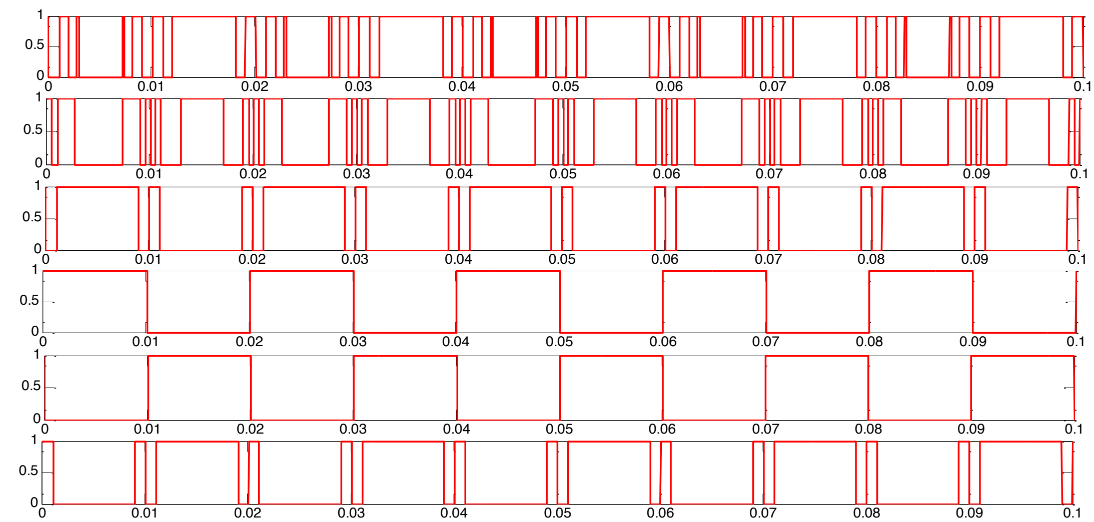

Figure 3. Applied signal to gate 7-12.

3. The proposed controlling method

In this paper, 27 different modes (dc voltage variations), are analyzed and the corresponding angle to eliminate low order harmonics is studied. The inputs are the dc voltage sources V_1, V_2, V_3 and the output signals are θ_1, θ_2, θ_3. This paper analyses ten different modes of dc voltage variation and the output ac waveform. The controlling structure is shown in figure 4.

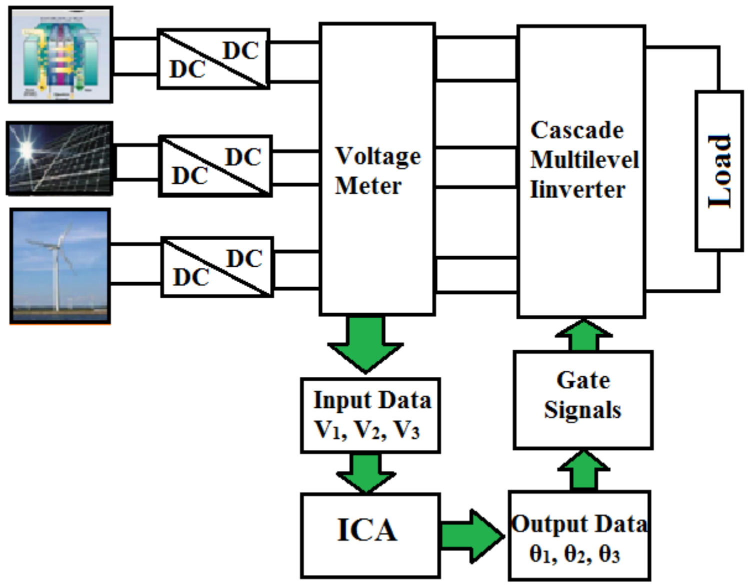

Figure 4. Controlling Structure.

In this regard, ten different modes of voltage source and the proper switching are studied through Imperialist Competetive algorithm.

$$\mathbf{f(\theta_1, \theta_2, \dots, \theta_s) = \left[\sum_{n=1}^{s} V_1 \csc(\theta_S) - \frac{V_f \cdot \pi}{4V_{dc}}\right]^2 + \cdots + \left[\sum_{m=2}^{s}\left(\sum_{n=1}^{s} V_n \csc\big((2m-1)\theta_n\big)\right)^2\right]}$$
(1)

In this paper, $V_1 = 1 \pm 0.1$, $V_2 = 0.9 \pm 0.09$, $V_3 = 0.8 \pm 0.08$ and these dc sources varies Independently. The nominal voltage is $V_1 = 1$, $V_2 = 0.9, V_3 = 0.8$. In addition, M (Modulation Index) is supposed to be M=0.8063, Vdc=1 and Vf=2.49. Finally, Imperialist Competetive algorithm optimizes the switching angle in equation 1.

4. Imperialist Competitive Algorithm

Recently, Evolutional algorithms have been widely used in problem optimization. Among these algorithms, the Imperialist Competitive Algorithm has been inspired by a social phenomenon unlike other optimization algorithms which have been generally adopted from a natural phenomenon. This algorithm was presented in [13]. Considering the historical phenomenon of colonization in order to achieve the social-political development in human societies and consequently, the mathematical modeling of this process, the algorithm has been proposed as a powerful evolutionary approach for the optimization of problems. According to figure 5, a number of random initial populations are called as countries for the algorithm in the first stage. Meanwhile, a number of the most powerful countries (the most cost-effective) are selected as imperialists and the rest as colonies.

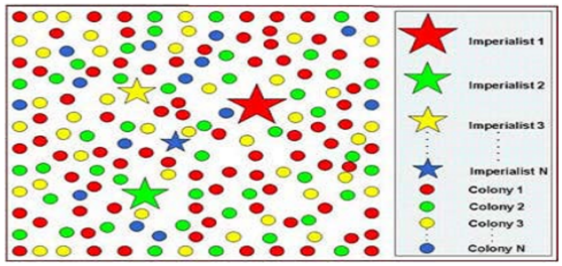

Figure 5. A number of random initial populations[13]

Then, colonies are divided among imperialist countries and enter the related Empire. Finally, according to figure 6, colonies are assimilated to the imperialist of each Empire.

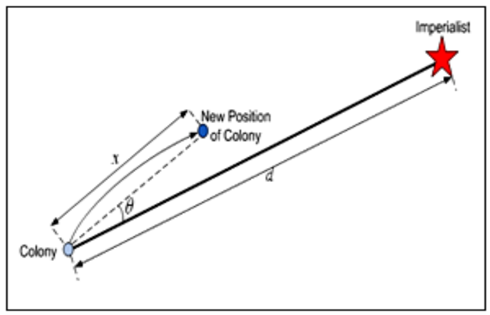

Figure 6. Assimilation Procedure [13]

In figure 6, the distance between the imperialist and the colony has been shown with d. X and Θ are defined as random numbers with uniform distribution according to the following equations.

$$X \sim U(O, \beta \times d) \qquad (2)$$

$$\theta \sim U(-\gamma, \gamma) \qquad (3)$$

In (2), β is a number larger than 1 which enables the colony to approach the imperialist from different directions during its movement. According to (3), γ is a parameter which can have an arbitrary value. If γ is considered to be a small value, the movement of the colony toward the imperialist is a movement near the vector between the imperialist and colony, and if γ is considered to be a large value, the colony moves toward the imperialist with a larger angle compared to the vector between the imperialist and colony. An appropriate selection for these parameters can be β=2 and γ=π/4 (according to radians) [13]. During the movement of colonies toward the imperialist country, some colonies may reach to a better position (positions with less cost) than the Empire. In this case, imperialist and colony countries change their places and the algorithm continues with the imperialist country in a new position; this time, it is the new Empire country which starts to impose the assimilation policy on its colonies. The replacement of the imperialist and colony has been shown in figure 7.

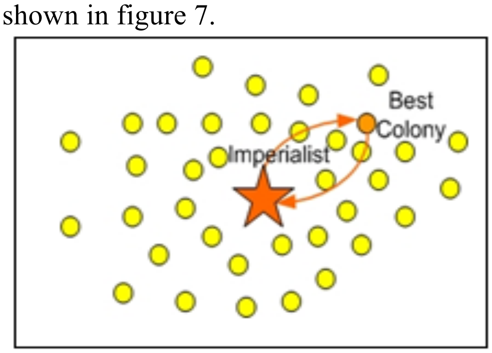

Figure 7. Replacement of the imperialist and colony .[13]

In this figure, the best colony of the Empire which has less cost than the Empire itself has been shown with a darker color. The power of each Empire is determined by the amount of power of the imperialist and its colonies. In order to model mathematical equation for the power of each Empire, it can be said that the power of each Empire is equal to the total power of the imperialist and a percentage of the total power of the colonies. By setting the formation of initial Empires, the imperialist competition begins among Empires. During this process, weak Empires (with high cost) inevitably lose their colonies and these colonies are assimilated by stronger Empires with a random probability. Finally, this process continues until weak Empires lose all of their colonies and are assimilated as a colony by the stronger Empire. Eventually, one strong Empire remains which is consisted of all colonies and the problem is converged.

The main issue in modulation of the cascade multilevel inverter is eliminating harmonics. The switching scheme in fundamental frequency inherently provides the situation to eliminate definite high order harmonics (with different switching angles). So, low order harmonic elimination in multilevel cascade inverter with different dc sources is a very important subject. In this regard, different heuristic approaches for solving the equation are proposed. Unlike the genetic algorithm and other evolutionary algorithms, the ICA is flexible enough for balancing between local and the main results in identification of the search space. This magnificent characteristic prevents soon convergence and cause continuous search.

Low order harmonic elimination in multilevel inverter considering different dc sources with oscillation, is a very important matter in operation of these devices. The results are mentioned in table 1.

Table 1. The simulation result of ICA.

v_1	v_2	v_3	M	Switching angles (degrees)		
				θ_1	θ_2	θ_3
0.9	0.81	0.72	0.8063	21.94434	23.23036	61.87699
0.9	0.81	0.8	0.8063	24.90975	23.40787	66.41318
0.9	0.81	0.88	0.8063	20.72892	20.99412	69.18146
0.9	0.9	0.72	0.8063	21.08526	28.66628	68.88631
0.9	0.9	0.8	0.8063	23.70716	20.755	72.66761
0.9	0.9	0.88	0.8063	21.01224	22.08854	72.02087
0.9	0.99	0.72	0.8063	13.67699	29.46603	75.9806
0.9	0.99	0.8	0.8063	16.09629	29.14079	74.76457
0.9	0.99	0.88	0.8063	19.16304	33.02175	77.65374
1	0.81	0.72	0.8063	21.57933	29.70297	71.59146
1	0.81	0.8	0.8063	20.21168	23.3626	75.10642
1	0.81	0.88	0.8063	26.27556	26.15333	77.01775
1	0.9	0.72	0.8063	18.656	30.65168	75.21029
1	0.9	0.8	0.8063	16.41025	32.48847	74.45975
1	0.9	0.88	0.8063	18.73568	31.70435	75.86176
1	0.99	0.72	0.8063	11.26832	38.8401	77.40605
1	0.99	0.8	0.8063	13.12457	38.8612	82.1003
1	0.99	0.88	0.8063	16.21741	35.09724	79.52669
1.1	0.81	0.72	0.8063	18.53524	34.77159	77.25471
1.1	0.81	0.8	0.8063	19.96295	33.95252	75.47315
1.1	0.81	0.88	0.8063	18.45544	34.74588	80.88258
1.1	0.9	0.72	0.8063	12.12227	39.96919	78.3219
1.1	0.9	0.8	0.8063	17.12578	40.09112	78.55257
1.1	0.9	0.88	0.8063	17.72496	37.11115	79.8025
1.1	0.99	0.72	0.8063	14.39641	42.89122	83.38527
1.1	0.99	0.8	0.8063	14.90244	42.70759	83.28273
1.1	0.99	0.88	0.8063	14.83879	39.72667	83.16496

Simulation Results

Different combinations of dc source variations, is shown in figure 8.

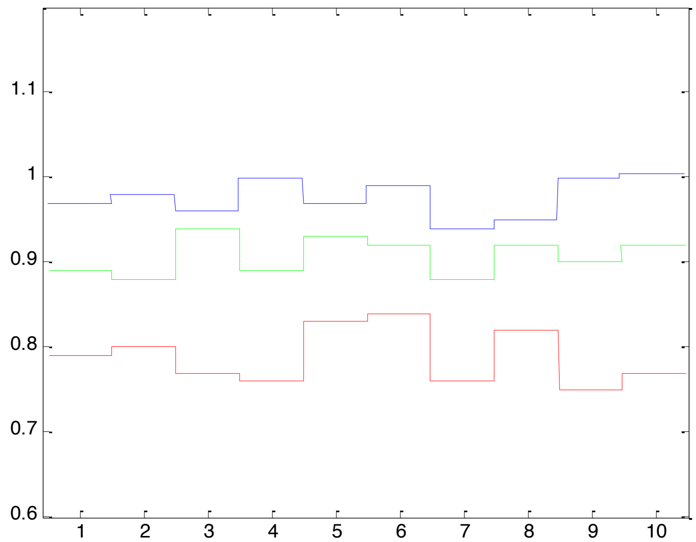

Figure 8. Dc source oscillation.

In figure 9 and 10 the output voltage and current of the inverter, is shown.

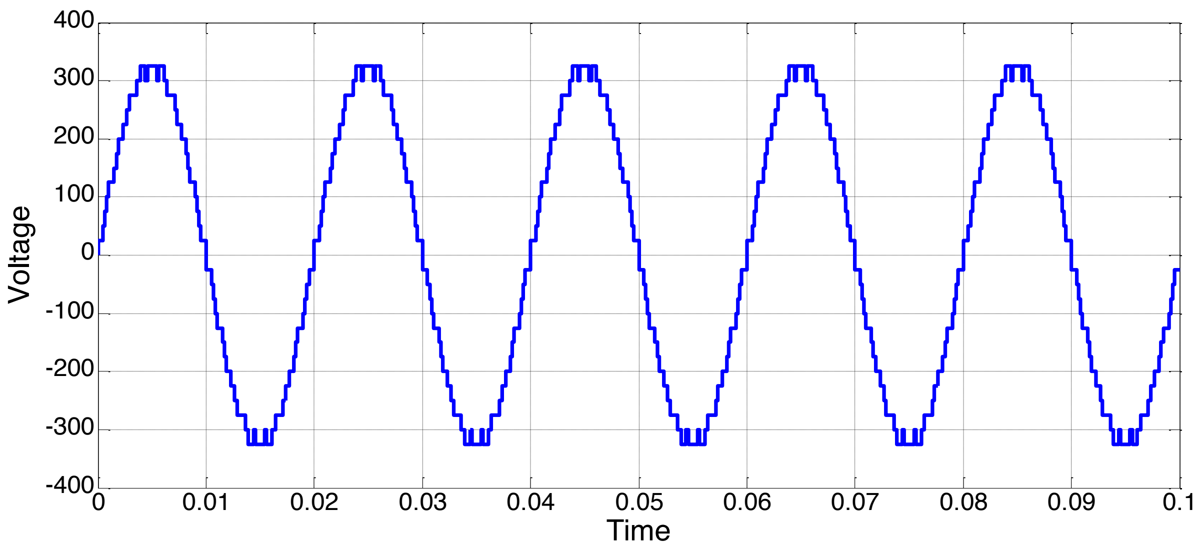

Figure 9. Output voltage of the inverter.

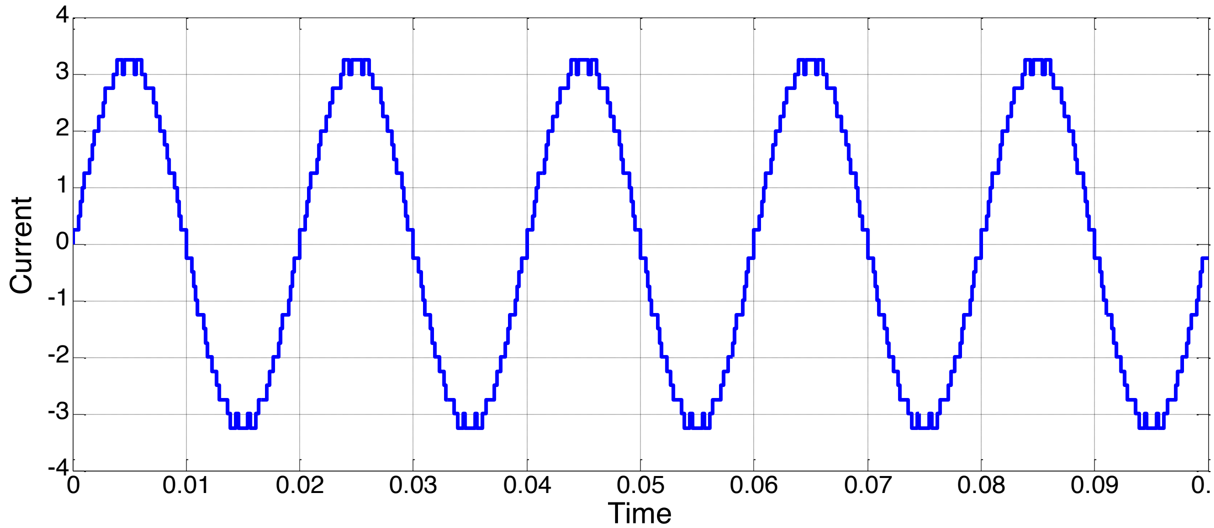

Figure 10. Output current of the inverter.

Figure 11 shows the fundemental output wave form. This figure Suggests that the variation of dc source has not affected the output waveform significantly.

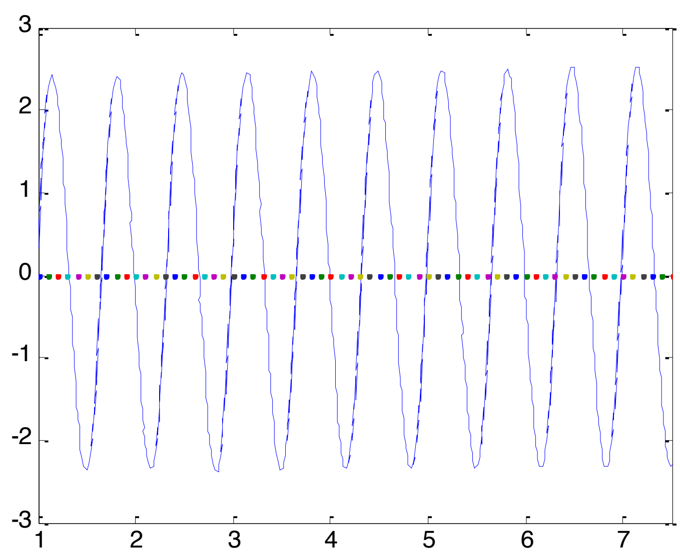

Figure 11. The fundemental wave form without oscillation.

Comparitive analysis with the prier reseaches

Table 2 shows that the optimum angles are close to each other in both particle swarm optimization and Imperialist competitive algorithm.

Table 2. Comparitive analysis between PSO and ICA.

Switching angle (degrees) With PSO			Switching angles (degrees) With ICA		
θ_1	θ_2	θ_3	θ_1	θ_2	θ_3
20.056	23.877	64.163	21.94434	23.23036	61.87699
22.475	22.475	66.423	24.90975	23.40787	66.41318
22.967	22.967	66.423	20.72892	20.99412	69.18146
18.605	27.43	69.844	21.08526	28.66628	68.88631
22.913	23.564	72.156	23.70716	20.755	72.66761
23.427	23.427	73.678	21.01224	22.08854	72.02087
15.006	32.189	74.473	13.67699	29.46603	75.9806
15.815	31.558	76.234	16.09629	29.14079	74.76457
16.418	31.081	77.618	19.16304	33.02175	77.65374
18.79	28.534	70.397	21.57933	29.70297	71.59146
22.266	24.46	72.761	20.21168	23.3626	75.10642
23.452	23.452	74.262	26.27556	26.15333	77.01775
15.913	33.445	74.927	18.656	30.65168	75.21029
16.498	32.856	76.628	16.41025	32.48847	74.45975
16.934	32.415	77.966	18.73568	31.70435	75.86176
13.417	37.247	78.861	11.26832	38.8401	77.40605
13.594	37.09	80.056	13.12457	38.8612	82.1003
13.723	36.976	81.001	16.21741	35.09724	79.52669
16.782	34.833	75.369	18.53524	34.77159	77.25471
17.206	34.279	77.012	19.96295	33.95252	75.47315
17.521	33.868	78.307	18.45544	34.74588	80.88258
14.908	38.713	79.222	12.12227	39.96919	78.3219
15.031	38.563	80.373	17.12578	40.09112	78.55257
15.121	38.455	81.296	17.72496	37.11115	79.8025
13.324	41.813	82.689	14.39641	42.89122	83.38527
13.356	41.777	83.443	14.90244	42.70759	83.28273
13.38	41.751	84.055	14.83879	39.72667	83.16496

The third and fifth harmonic elimination are shown in figure 12 and 13.

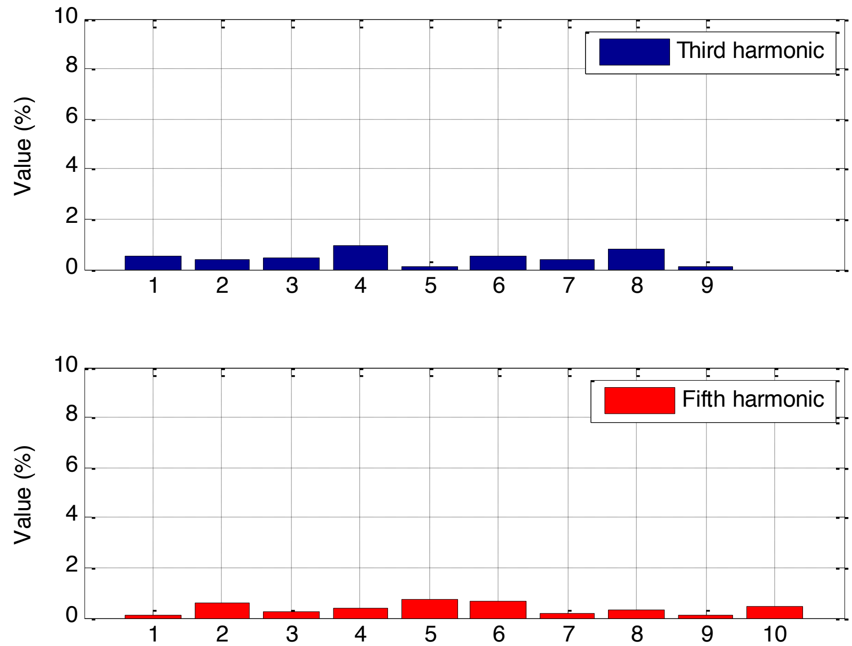

Figure 12. Third and fifth harmonic elimination.

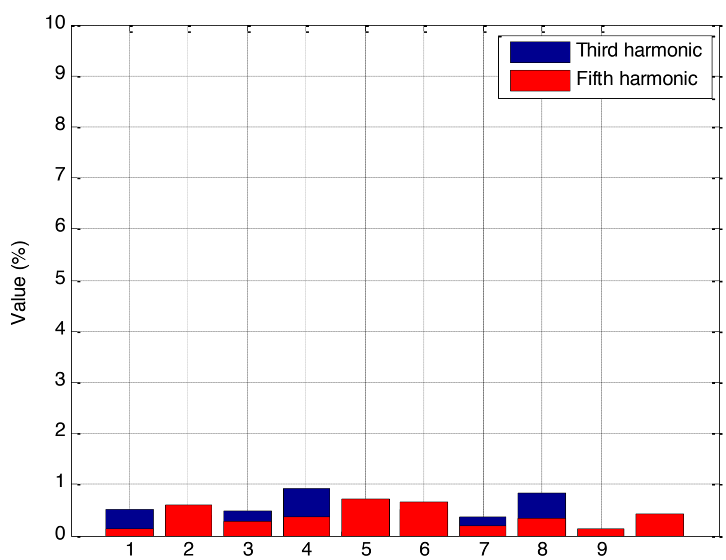

Figure 13. Harmonic elimination

As an example, the frequency spectrum of the output voltage of the inverter in the last state is shown in figure 14. In this figure, the frist harmonic that is the fundemental wave form is quiete complete (100%) and the 3rd and 5th harmonics are also eliminated.

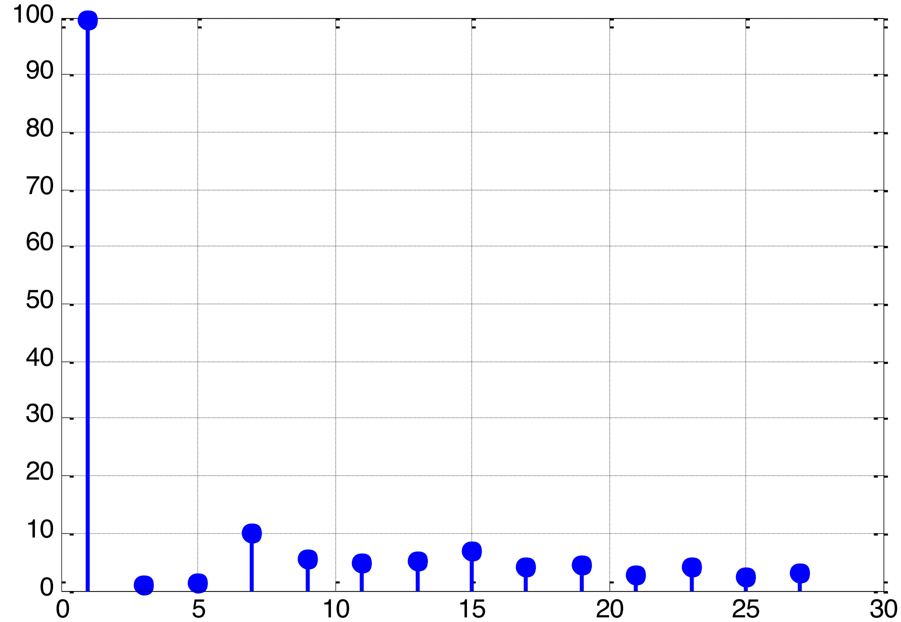

Figure 14. Frequency spectrum of the last state.

Conclusion

Different factors effects on the amplitude of the dc sources in multilevel inverters and usually, a small percentage of this variation is considered in the amplitude of the dc source. In this paper, low order harmonic elimination in multilevel inverters considering dc voltage variation is studied. In this regard, the optimum switching angles in order to eliminate low order harmonics is determined through ICA. Meanwhile, the amplitude of the fundamental wave form with dc voltage oscillation has also been taken into consideration. Simulation is conducted on a multi level inverter and results show complete low order harmonic elimination in fundamental wave form. In addition, there is also a constant value in fundamental wave form with variation of dc source.

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