J. Basic. Appl. Sci. Res., 3(9)130-135, 2013
© 2013, TextRoad Publication

ISSN 2090-4304
Journal of Basic and Applied Scientific Research
www.textroad.com

Reduction of Harmonic in Multilevel Inverters using FA and LAFA ALGORITHMS

N. Moshtaghi Yazdani [1] , A. Yazdani.Sequerloo[2], M. Shariat Panahi [3]

University of Tehran

Received: June 10 2013
Accepted: July 9 2013

ABSTRACT

A new method has been proposed in this paper by selection of optimal switching angle based on LAFA and FA optimization algorithms in a multilevel inverter to eliminate selected harmonics and THD for better stabilization of the needed voltage. This technique can be applied for all multilevel inverters with any number of levels. It has been tried in this research to investigate 7 and 11-level inverters, the results of which indicates advantageous performance of the LAFA algorithm in comparison with the classic FA algorithm for elimination of the selected THD harmonics.
KEYWORDS: optimization, reduction of harmonic, inerter, LAFA.

1-INTRODUCTION

High performance electrical drives have recently found extensive applications in various industries taking into account the need to develop electronic power equipments for increasing their efficiency and optimizing their power consumption. Therefore considering the significant role of these industrial equipments, application of power inverters with appropriate performance, cost and efficiency as well as advancement of their technology will be of great importance. Poor quality of the basic inverters may cause harmonics which can make damages to the electrical motor and rather increase its power loss [1]. Numerous approaches have been introduced so far to improve performance of the inverters, for example using a filter at output of the inverter to eliminate some ranges of the harmonics, or using various techniques such as SPWM, SHE PWM, SVM and OHSW [2]. Moreover, wave shape of the output voltage, elimination of the filter, and using multilevel structure transformer were considered in order to reduce the harmonics and THD. The multilevel inverters were introduced for the first time by Nabaei in 1981 to reduce amplitude of the harmonics and switching frequency of the three phase inverters [3]. A multilevel inverter provides a power of different grades, while it is also able to use renewable sources of energy including wind, fuel cells and solar modules [4]. The multilevel inverters are divided into three main groups, namely: cascaded H-bridge, diode clamped (neutral clamped) and flying capacitor. High quality shape of the stepwise wave which can generate an output voltage with little distortion, smaller common-mode voltage, switching frequency and input current with less distortion, are some advantages and characteristics of the multilevel inverters. Numerous advantages of cascade multilevel inverters in comparison with other types of them have been addressed in [5,6]. Meanwhile, disadvantages of using back-to-back inverters in power dissipation applications in comparison with the multilevel inverters in terms of increased size and weight of the inverter, lower efficiency and power factor, poor reliability and existence of a large DC-link capacitor have been studied in [7]. Furthermore, a comparison has been made in [8,9] between different combinations of the multilevel inverters. It indicates several advantages of application of full bridge or half bridge modules for the cascade multilevel inverters in high voltages and powers. Modulation methods of sine PWM and state space PWM in the multilevel inverters have been presented somewhere else [10]. Some other approaches have been suggested in {11,12] for proper selection of the switching time. Thereby, it would be possible to eliminate harmonics of high orders (5^{th}, 7^{th}, 9^{th}, and 11^{th}) in output voltage of the inverter. This method is called programmed PWM or SHE. Simultaneous calculations of the switching angles with analytical proof have been utilized in [13] to minimize the value of THD. This can be used to eliminate all the 3^{rd} order harmonics, but not the harmonics of other orders. PSO and GA algorithms have been utilized by selection of the correct switching angle for reducing THD of the multilevel inverter in [14]. Switching is done by PWM method in it and the harmonics are eliminated in a programmed form. However, optimal switching methods have been discussed in [15] by using genetic algorithm in 7 and 11-level inverters with an equivalent DC source. The obtained results were not satisfactory for the 11-level inverter, which implies that efficiency of the abovementioned method is significantly decreased by increasing the number of levels. Harmonic filtration methods have been introduced in [16] with PSO algorithm for cascade multilevel inverters without an equivalent DC source. Harmonic filtration in a multilevel inverter has been discussed in [17] using PSO

[*] **Corresponding Author:** N. Moshtaghi Yazdani, University of Tehran, Arezoo.Yazdani@ut.ac.ir

algorithm with an equivalent DC source. However, this paper will try to eliminate the selected harmonics using optimization algorithms based on repeating LA and LAFA by choosing the correct switching angle. Then it would be possible to reduce 7 and 11-level voltage THD of the cascade half bridge.

2. Multilevel Inverter of Cascade H-Bridge

A single phase structure of m-level cascade inverter is depicted in Figure 1. Each individual DC source is connected to one half bridge inverter and one full bridge inverter. Each level of the inverter generates three different voltages of $+V_{dc}$, $-V_{dc}$ and 0 by connecting a DC source to an AC source through combination of four switches. AC outputs at each level of the full bridge inverter are connected such that it shapes the voltage wave that is a result of the inverter output. Number of m-levels of the output voltage is given by $2s + 1$ in a cascade inverter, where s is the number of individual DC sources. For a stepwise wave like Figure 2 with s steps, Fourier transform function for the wave shape is calculated as follows:

$$V(\omega t) = \frac{4v_{dc}}{\pi}\sum_n \cos(n\theta_1) + \cos(n\theta_2) + \cdots + \cos(n\theta_s)]\frac{\sin(n\omega t)}{n}, n = 1,2,3, \ldots \quad (1)$$

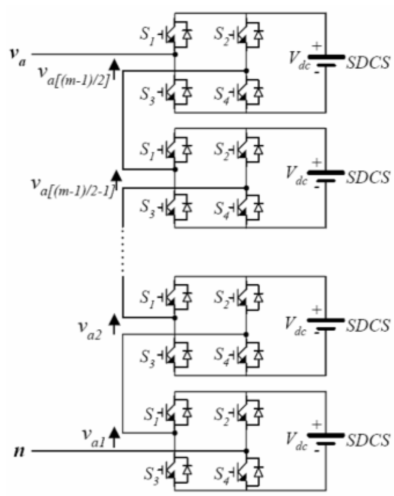

Fig.1. *Single line structure of multilevel cascaded H-bridge inverter*

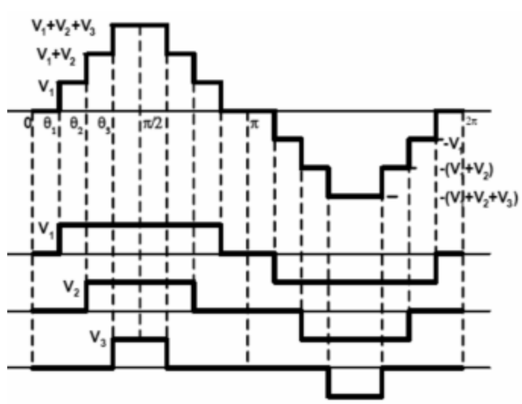

Fig.2. *Wave shape of 7-level cascaded inverter*

Fourier coefficients are calculated using the normalized DC voltage based on Equation (1):

$$H(n) = \frac{4}{n}[\cos(n\theta_1) + \cos(n\theta_2) \ldots \cos(n\theta_s)] \qquad n = 1,3,5, \ldots \quad (2)$$

Where, angles θ_1, θ_2, θ_3 and … θ_n can be chosen in these cases when the harmonic distortion is minimized throughout the voltage. Generally speaking, these angles must be selected such that the dominant frequencies of lower orders (e.g. 5th, 7th, 11th and 13th) could be eliminated. Meanwhile, nominal voltage and switching angles should be defined in the following range:

$$0 < \theta_1 < \theta_2 < \ldots < \theta_s < \frac{\pi}{2} \quad (3)$$

For example, if we want to eliminate the 3rd and 5th harmonics of a 7-level inverter, a set of equations like below will be obtained:

$$\cos(\theta_1) + \cos(\theta_2) + \cos(\theta_3) = m$$
$$\cos(5\theta_1) + \cos(5\theta_2) + \cos(5\theta_3) = 0$$
$$\cos(7\theta_1) + \cos(7\theta_2) + \cos(7\theta_3) = 0 \quad (4)$$

Where, $m = \frac{v_1}{\frac{4v_{dc}}{n}}$ and $m_a = {}^{m}/_{S}$. For demonstration of the output voltage quality, one may define the harmonic distortion of the universal line voltage as below:

$$THD(\%) = 100\frac{\sqrt{\sum_{N=5}^{100} H_n^2}}{H_1} \quad (5)$$

Where, n is an odd number in the form of $n = 6k \pm 1$.

THD is an appropriate tool for measurement of quality of the output signals harmonic. Thus, this function is selected as the objective function for optimization. The optimal value of THD is obtained using LA and LAFA optimization algorithms.

3. Firefly Algorithm

Evolutionary algorithms are random search-based algorithms which are inspired from modeling natural biological evolution. They work on possible answers which have advantages and better survival of generation, so they provide a closer estimation of the optimal answer. A new set of estimations are produced based on choosing members of greater fitness at each generation. Then, they are combined with each other the same as really occurs in the nature. This process will consequently include evolution of individuals who are more compatible with the environment than their parents, exactly consistent with the nature. Firefly algorithm is inspired from the fireflies that use small flashes of light for attracting their victims/couples, or for working as a protective system. Rate of the light, how it is emitted and time intervals between transmitted light signals will contribute to attract the flies of different genders to each other. Intensity of the light (I) is decreased by increasing the distance (R) from the source of light. The transmitted light is used as the formulated objective function.

There are three important properties in a typical FA algorithm:

1) The firefly will become shinier and more attractive when it moves randomly, with all the fireflies being of the same gender in this case.
2) Attractiveness of the firefly is relative to its light brightness and distance. Reduction of the light intensity is calculated by light absorption coefficient (γ). Brightness of the firefly is also determined by the objective function.
3) Distance between every two fireflies is extracted from following equation below:

   $$r_{i,j} = \sqrt{(\boldsymbol{x_i} - \boldsymbol{x_j})^2 + (\boldsymbol{y_i} - \boldsymbol{y_j})^2} \quad (6)$$

   Where, $X_{i,k}$ represents the k^{th} part of the space coordinate for the i^{th} firefly.
4) Movement of the firefly and its attraction toward the firefly that is shinier is given by the following equation:

   $$\boldsymbol{x_i} = \boldsymbol{x_i} + B_0 e^{\gamma r_{ij}^2}\left(x_j - x_i\right) + a(rand - {}^{1}\!/_{2}) \quad (7)$$

   Where, a is the random number generator and $rand$ is a random value between 0 and 1. B denotes the amount of absorption in the light source, while γ is defined considering the variations of absorption and is significantly effective in the value of convergence rate.

Two famous versions of this algorithm which are regularly used in the optimization problems are: (1) discrete firefly algorithm [18], (2) Levy's firefly algorithm in which Levy's random distribution function is applied for optimization of the search [19]. In a recent algorithm which is proposed as the improved firefly algorithm [20], location of each firefly at each step is comprised of two parts for optimization in static environments. The first part is associated to the current location of the firefly and the latter is for following the best personal answer and the best global answer. The algorithm will be transformed to a local search near the best firefly and will fail to reach the remaining space of the search state if the first part does not exist. Moreover, this algorithm will continue a blind search if the second part is not present. Some researchers have tried to solve the problem of local optima of this algorithm via combining FA with algorithms like genetic algorithm. Pseudo code of the firefly algorithm is shown in the figure below.

```
Firefly algorithm
Initialize algorithm parameters:
MaxGen: the maximum number of generations
Objective function of f(x), where x=(x ,........,xd)T
Generate initial population of fireflies or xi (i= , ,..., n)
Define light intensity of Ii at xi via f (xi)
While (t<MaxGen)
For i = to n (all n fireflies);
For j= to n (all n fireflies)
If (Ij > Ii), move firefly i towards j; end if
Attractiveness varies with distance r via Exp [-γr ];
Evaluate new solutions and update light intensity;
End for j;
End for i;
Rank the fireflies and find the current best;
End while;
Post process results and visualization;
End procedure
```

Fig.3. *Pseudocode of firefly algorithm*

4. LAFA Algorithm

Search in Firefly algorithm is such that each firefly is compared with every other firefly. In the problem of finding the maximum point if one firefly emits a smaller light in comparison with the compared firefly, it will move toward the greater light. On the other hand, if there is one particle with a better light in the next run of the algorithm, the particles will approach toward the greater light again. One major disadvantage of this method is that the particles only move based on the number of the fireflies that is the same as local optima. It can thus be said that the global optimum has no effect on the search algorithm and that is why the entire problem environment is not searched optimally. As a result, it seems necessary to have a greater number of repetitions in order to reach the optimal point, which is provided in the improved firefly algorithm for optimization in the static environments [11]. This deficiency was solved to some extent by improvement of the search operation through participation of the other fireflies in the movement process. Their movement and motion has been presented by Equation (4). For this purpose, $B0$ parameter has been introduced in this equation indicating the amount of attractiveness in the light source with the same value for both local and global optimizations. $B0$ is changed here according to the light transmitted from the fireflies in different conditions. The value associated with each firefly in this approach is equal to the difference in its transmitted light in previous repetitions and the best light transmitted by the other fireflies. Thereby, the value of B0 for each firefly at each step is equal to the value of each firefly divided by the average value of each firefly. Much more optimized values will be obtained from the functions by using this approach. Pseudocode of the suggested algorithm is demonstrated below.

```
Initialize the LA
For each fire fly
Initialize fire fly
End For
Do
The LA selects an action ac
For each fire fly
Calculate fitness value of the particle fp
/*updating particle's best fitness value so
far)*/
If fp is better than fBest
set current value as the new fBest
End For
/*updating population's best fitness value
so far)*/
Set gBest to the best fitness value of all
particles
For each pfire fly
if ac is "follow the best"
Calculate fire fly velocity according
equation (7)
Update fire fly position according equation
(2)
End For
While maximum iterations OR
minimum error criteria is not attained
```

Fig.4. *Pseudo code of the suggested firefly algorithm*

5. Comparison of the Optimization Algorithms in Optimizing THD

The proposed algorithms are among the most efficient optimization algorithms. The following steps express how these algorithms are implemented for a cascade H-bridge 11-level inverter.

1)Population of the particles is initiated by random positions between 0 to $\frac{\pi}{2}$ and speed in m-dimensional space of the problem, such that the dimensions of each particle are equal to the controllable switching angles, which is itself similar to the number of cascade half bridge multilevel inverters.

For every particle, the optimal objective is determined for m variables. The main aim is (2 to minimize the specified harmonics. Therefore, a relation must exist between the objective function and these harmonics. THD is considered as the objective function in this problem. The results of simulation are indicative of the better efficiency performance of the LAFA algorithm in comparison with this LA algorithm for cascade single phase half bridge 7 and 11-level inverters. Tables 2 and 3 compares the optimized values of θ in modulation coefficient of 0.9.

Table2. *Comparison between switching angles and THD for the 7-level inverter*

Algorithm	θ_1	θ_2	θ_3	THD
LAFA	29.87	47.29	64.14	4.63
FA	18.73	26.69	49.64	5.34

Table3. *Comparison between switching angles and THD for the 11-level inverter*

Algorithm	θ_1	θ_2	θ_3	θ_4	θ_5	THD
LAFA	16.68	26.41	44.25	58.83	64.35	4.005
FA	18.32	26.59	47.92	62.14	61.27	4.63

6. Conclusion

The purpose of this paper is to eliminate specified harmonics (SHE) for reduction of the output voltage in cascade half bridge 7 and 11-level inverters. Optimization technique of the algorithms is random and comprehensive search based on the number of repetitions in the multilevel inverter. Thereby, the optimal switching angle could be determined in the cascaded inverters for elimination of the high order harmonics, while having an appropriate shape of the voltage wave at the same time. The results of simulation indicate that both algorithms have succeeded to eliminate the selected harmonics in addition to reduce their amplitude. However, as seen from Tables 2 and 3, the LAFA algorithm outperforms the LA algorithm for both of the 7 and 11-level inverters.

REFERENCES

[1] KianiNejad,R.Mobini,A.(2009). Improved utilization of electrical energy by using electro high power multilevel converters. *The first conference, modifying energy intake*,110.

[2] Lai. J, Chair Dusan Borojevic Alex Q.Huang,(1999). Optimized Harmonic Stepped-Waveform For Multilevel Inverter, Msc thesis.

[3] Nabae, A., Takahashi, I., & Akagi, H. (1981). A new neutral-point-clamped PWM inverter. *Industry Applications, IEEE Transactions on*, (5), 518-523.

[4] Du, Z., Tolbert, L. M., & Chiasson, J. N. (2004, October). Harmonic elimination for multilevel converter with programmed PWM method. In *Industry Applications Conference, 2004. 39th IAS Annual Meeting. Conference Record of the 2004 IEEE* (Vol. 4, pp. 2210-2215). IEEE.

[5] Rodriguez, J., Lai, J. S., & Peng, F. Z. (2002). Multilevel inverters: a survey of topologies, controls, and applications. *Industrial Electronics, IEEE Transactions on*, *49*(4), 724-738.

[6] Lai, J. S., & Peng, F. Z. (1996). Multilevel converters-a new breed of power converters. *Industry Applications, IEEE Transactions on*, *32*(3), 509-517.

[7] Soto, D., & Green, T. C. (2002). A comparison of high-power converter topologies for the implementation of FACTS controllers. *Industrial Electronics, IEEE Transactions on*, *49*(5), 1072-1080.

[8] Lesnicar, A., & Marquardt, R. (2003, June). An innovative modular multilevel converter topology suitable for a wide power range. In *Power Tech Conference Proceedings, 2003 IEEE Bologna* (Vol. 3, pp. 6-pp). IEEE.

[9] Marquardt, R. and Lesnicar, A. (2004). “New concept for high voltage – modular multilevel converter.”IEEE PESC.

[10] Kouro, S., Rebolledo, J., & Rodríguez, J. (2007). Reduced switching-frequency-modulation algorithm for high-power multilevel inverters. *Industrial Electronics, IEEE Transactions on*, *54*(5), 2894-2901.

[11] Taghizadeh, H., & Hagh, M. T. (2010). Harmonic elimination of cascade multilevel inverters with nonequal DC sources using particle swarm optimization. *Industrial Electronics, IEEE Transactions on*, *57*(11), 3678-3684.

[12] Lipo, T., & Holmes, G. (2003). Pulse Width Modulation for Power Converters (Principles and Practice), Hoboken.

[13] Liu, Y., Hong, H., & Huang, A. Q. (2009). Real-time calculation of switching angles minimizing THD for multilevel inverters with step modulation. *Industrial Electronics, IEEE Transactions on*, *56*(2), 285-293.

[14] Sarvi, M., & Salimian, M. R. (2010, August). Optimization of specific harmonics in multilevel converters by GA & PSO. In *Universities Power Engineering Conference (UPEC), 2010 45th International* (pp. 1-4). IEEE.

[15] Ozpineci, B., Tolbert, L. M., & Chiasson, J. N. (2005). Harmonic optimization of multilevel converters using genetic algorithms. *Power Electronics Letters, IEEE*,*3*(3), 92-95.

[16] Taghizadeh, H., & Hagh, M. T. (2010). Harmonic elimination of cascade multilevel inverters with nonequal DC sources using particle swarm optimization. *Industrial Electronics, IEEE Transactions on*, *57*(11), 3678-3684.

[17] Taghizadeh, H., & Tarafdar Hagh, M. (2008, June). Harmonic elimination of multilevel inverters using particle swarm optimization. In *Industrial Electronics, 2008. ISIE 2008. IEEE International Symposium on* (pp. 393-396). IEEE.

[18] Hassanzadeh, T. Meybodi,M,R.MahmoudiThe.F ,(2011):An improved Firefly Algorithm for optimization in static environment” Fifth Iran Data Mining Conference / IDMC 2011.

[19] Yang, X. S. (2010). Firefly algorithm, Levy flights and global optimization. In*Research and Development in Intelligent Systems XXVI* (pp. 209-218). Springer London.

[20] Mars, P., Chen, J. R., Nambiar, R., & Fidler, J. K. (1996). *Learning Algorithms: Theory and Applications in Signal Processing*. CRC Press, Inc.