Harmonics Elimination in Cascade Multilevel Inverters Using Newton-Raphson and Genetic Algorithm

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Abstract—This paper represents the reduction of harmonics in a cascade H-bridge multilevel inverter using iterative newton-raphson (NR) and genetic algorithm (GA) techniques. The proposed optimization techniques are used to solve the set of non-linear transcendental trigonometrical equations. The controlling pulses are obtained by harmonic elimination pulse width modulation (SHE-PWM) switching method. The set of non-linear transcendental equation is minimized by proposed iterative newton-raphson (NR) and genetic algorithm (GA) techniques, and also have been analysed and compared the harmonics.

Key words: Multilevel inverter, SHE-PWM, newton-raphson (NR), genetic algorithm (GA).

I. INTRODUCTION

The multilevel inverters are suitable configuration to reach in the area of high power rating and medium voltage applications. The multilevel inverter has overcome the limitations of conventional two voltage level converters. The advantages of multilevel inverter are low electromagnetic interference, higher power quality, lower switching losses and higher voltage capability [1]. Mostly, three types of topologies for multilevel inverter used are cascade H-bridge multilevel inverter with separate dc sources [2], [3], diode clamp multilevel inverter, and flying capacitor multilevel inverter. The cascade H-bridge multilevel inverters has received important attention due to its circuit layout modularity, packaging and simplicity of switching control to avoids bulky and lossy resistor-capacitor-diode snubbers. The separate dc sources either conventional or renewable are used. renewable sources are such as solar cells, wind turbine, etc. Two types of Switching techniques are used in multilevel inverter. The switching techniques are categorized as high frequency switching and low frequencies switching. Low frequency switching includes selective harmonic elimination pulse width modulation (SHE-PWM) [4], [5]. High frequencies switching includes the space vector PWM [6]-[8], [9]-[10], phase shifted PWM (PSPWM) [11], [12], [13], level shifted PWM (LSPWM) [11], [14]-[17], random carrier frequency modulation (RCFM) [19], and switching through FPGA [19]. Some disadvantages of high frequency switching are produces the electromagnetic interferences, switching power losses. Fundamental component utilizes in low frequency switching technique and generate a near sinusoidal staircase voltage waveform.

In this paper, the researchers have performed simulation for seven levels cascade H-bridge multilevel inverter, and used the selective harmonic elimination PWM switching method. PWM [20], [21]. Selective harmonic elimination PWM switching method is utilized for controlling the gate signals of switching device. Switching angles are solved from the non-linear transcendental equations. For generating the optimized staircase voltage waveform, the optimized switching angles are obtained using by newton-raphson technique and genetic algorithm technique (GA). If we know the good initial guesses then the results can be optimized well more.

II. PROBLEM FORMULATION

The fourier series expansion and from Fig.2, the cascade H-bridge multilevel staircase voltage waveform is expanded as below in equation Eq.1.

\[ V_{out}(ωt) = \sum_{n=1,3,5,...}^{N} b_n \sin(nωt) \]  

\[ b_n \] is given by:

Fig. 1: Single phase cascade h-bridge multilevel inverter

Fig. 2: Staircase voltage waveform for single-phase multilevel inverter.
For equal and constant source, \( b_n \) is given by
\[
b_n = \sum_{n=3,5,7,...}^{2N-1} V_{dc1,2} \cos(n\alpha_1) + V_{dc1,2} \cos(n\alpha_2) + \cdots + V_{dcN} \cos(n\alpha_N) + \cos(n\alpha_{N+1})
\]  
(2)

Where, \( V_{dc} = V_{dc1} = V_{dc2} = \cdots = V_{dcN} \).
\( L \) = number of dc sources for each full H-bridge inverter cell, 
\( N \) = number of switching angles,
\( n = 1, 3, 5, \ldots, \) odd harmonics \((2N-1)\).

A set of \( L \times 2 \) harmonics equations and including one fundamental voltages equation for equal and constant source is obtainable from Eq.3. In three-phase power system, triplen harmonics are automatically cancelled from line-to-line voltage. In SHE-PWM, the desired value is assigned for fundamental component and all other harmonics components are equated to zero.

\[
\begin{align*}
\cos(\alpha_1) + \cos(\alpha_2) + \cdots + \cos(\alpha_L) &= m \\
\cos(3\alpha_1) + \cos(3\alpha_2) + \cdots + \cos(3\alpha_L) &= 0 \\
\cos(5\alpha_1) + \cos(5\alpha_2) + \cdots + \cos(5\alpha_L) &= 0 \\
\cos(7\alpha_1) + \cos(7\alpha_2) + \cdots + \cos(7\alpha_L) &= 0 \\
& \vdots \\
\cos(n\alpha_1) + \cos(n\alpha_2) + \cdots + \cos(n\alpha_L) &= 0
\end{align*}
\]

Where, 
\( m = \frac{V_s}{(4V_{dc}/\pi)} \),
Modulation index, \( m_a = m/L \),
\( L \) is the number of dc sources.

The main challenge is that to solve non-linear transcendental Eq.4. Newton-Raphson method [22] and genetic algorithm (GA) technique have been used.

For GA technique, the objective function is important for optimizing the switching angles. Maintaining the fundamental components at pre specified value and eliminating the selected order harmonics. Objective function is minimized with pre defined constraints to obtain the optimized conducting angles as given below:

\[
f(\alpha_1, \alpha_2, \alpha_3, \ldots, \alpha_L) = 100 \times \frac{(|V_s|+|V_{3s}|+\cdots+|V_{3L}|-|3|)+|\alpha_{3L}|+|\alpha_{3L}|+\cdots+|\alpha_{3L}|)}{|V_s|}
\]  
(5)

\[
0 \leq \alpha_1 \leq \alpha_2 \leq \alpha_3 \leq \ldots \leq \alpha_L \leq \pi/2
\]  
(6)

III. NEWTON-RAPHSON TECHNIQUE

The Newton-Raphson method [22], or Newton Method, is a powerful technique for solving equations numerically. Like so much of the differential calculus, it is based on the simple idea of linear approximation. The Newton-Raphson method for computing the roots of an equation is a successive-approximation procedure, which is suitable for implementation in a computer program.

A. Solution Using Newton-Raphson:

Generally, the system of nonlinear equations with \( L \) variables is represented as:

\[
F(\alpha) = B
\]  
(7)

Where:
\[
F = [f_1, f_2, f_3, \ldots, f_L]^T, B = [b_1, b_2, b_3, \ldots, b_L]^T, \quad \text{and} \quad \alpha = [\alpha_1, \alpha_2, \alpha_3, \ldots, \alpha_L]^T.
\]

The main challenge is that to solve non-linear transcendental Eq. 4. Newton-Raphson method [22] and genetic algorithm (GA) technique have been used.

1. Guess a set of initial values for \( \alpha \):
\[
\alpha^m = [\alpha_1, \alpha_2, \alpha_3, \ldots, \alpha_L]^T
\]  
(8)

2. Solve the value of \( F(\alpha^m) = F^m \)
\[
(9)
\]

3. Linearize equation (7) about \( \alpha^m \)
\[
F^m + \left[ \frac{\delta F}{\delta \alpha} \right] \delta \alpha^m = B
\]  
(10)

4. Solve \( \delta \alpha^m \) for \( \delta F \)
\[
(11)
\]

5. Updated the initial values as:
\[
a^{m+1} = a^m + \delta \alpha^m
\]  
(12)

6. Repeat the process from equations (9) to (12) until \( \delta \alpha^m \) becomes lower than a threshold setting to meet the desired degree of accuracy.

7. The condition \( 0 \leq \alpha_1 \leq \alpha_2 \leq \alpha_3 \leq \ldots \leq \alpha_L \leq \pi/2 \) must be satisfied.

IV. GA TECHNIQUE

Genetic algorithm is a directed search algorithms [23]. It was developed by John Holland; University of Michigan in 1970. The basic philosophy of the genetic algorithm theory was inspired by Darwin’s theory of evolution which states that the survival of an organism is affected by rule “the strongest species that survives”. Darwin also stated that the survival of an organism can be maintained through the process of reproduction, crossover and mutation. Darwin’s concept of evolution is then adapted to computational algorithm to find solution to a problem called objective function in natural fashion. A solution generated by genetic algorithm is called a chromosome.

Population: collection of chromosome.
Chromosome: It composed from genes, and its value can be either, binary, numerical symbols or characters.

A. Genetic Algorithm process:

1) Initial population: is generated by many individual solutions randomly.

2) Selection: Individual solutions are selected through a fitness based process. Certain selection methods rate the fitness function of each solution and preferentially select the
best solution. Selected individuals are called the parents that contribute to the population at the next generation.

3) **Crossover**: combination of two parents to form children for the next generation. Crossover is controlled by crossover rate.

4) **Mutation**: Random changes to individual parents to form children. Mutation is controlled by mutation rate.

![Fig. 3: GA process flow chart](image)

**V. SIMULATION RESULTS**

All simulating results and work is done on MATLAB 2012b package. Selective harmonic elimination pulse width modulation (SHE-PWM) switching method is used for controlling the cascade multilevel inverter, and the nonlinear transcendental trigonometric Eq. 4 and objective fitness function are solved and optimized by applying both of proposed newton-raphson (NR) methods and GA techniques respectively. The simulating results are discussed for 7 levels three-phase inverter with separate equal and constant dc sources \( (V_{dc1} = V_{dc2} = \ldots = V_{dcL}) \). Each separate source has 12 volts, and case is studied for modulation index range from 0.4 to 1. Optimized results for 7-level cascade multilevel inverter are obtained at particular modulation indexes where the THD is lowest. Modulation index versus switching angles, THD, and frequency versus are shown in Fig. 4, Fig. 5, Fig. 6, and Fig. 7.

![Fig. 4: Modulation index versus switching angles using newton-raphson](image)

![Fig. 5: Modulation index versus switching angles using GA](image)

![Fig. 6: Modulation index versus thd using GA](image)

![Fig. 7: Frequency versus magnitude](image)

<table>
<thead>
<tr>
<th>Modulating Index</th>
<th>Switching Angles (degree)</th>
<th>THD (%)</th>
<th>Computational Time (secs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha_1 )</td>
<td>29.9</td>
<td>65.8</td>
<td>11.68</td>
</tr>
<tr>
<td>( \alpha_2 )</td>
<td>53.9</td>
<td>4</td>
<td>0.7146</td>
</tr>
<tr>
<td>( \alpha_3 )</td>
<td>65.8</td>
<td>8</td>
<td>0.8082</td>
</tr>
</tbody>
</table>

Table 1: SWITCHING ANGLES, THD AND COMPUTATIONAL TIME FOR 7-LEVEL INVERTER
VI. CONCLUSION

The newton-raphson and GA techniques for harmonics elimination have been compared equal and constant dc source cascade H-bridge inverter. Optimized angles have been obtained by solving the SHE problem. The total harmonic distortion (THD) for line-to-line voltages have been reduced in more amount using GA techniques rather than newton-raphson technique, but newton-raphson takes time lesser than GA.

REFERENCES