Selective Harmonic Elimination of Five Level Cascaded H-Bridge Inverter Using the Newton-Raphson Technique

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Abstract. Multilevel inverter becomes an alternative for high power and medium voltage applications recently and is more popular in renewable energy. The cascaded H-bridge multilevel inverter is more suitable for the Photovoltaic application because it acts as a separate DC source for each bridge. This paper presents a selective harmonic elimination (SHE) modulation for single-phase cascaded H-bridge (CHB) five level inverter. The optimum angle of the transcendental equations is solved the fundamental and harmonic elements using the Newton-Raphson (NR) process. The proposed selective harmonic elimination (SHE) scheme is tested using MATLAB/Simulink simulation. These simulation results are then verified through experiment using microcontroller. The proposed SHE is efficient in eliminating the 5th order harmonics and producing a higher quality output waveform with a better harmonic profile.

1.0 Introduction

A photovoltaic (PV) system is been widely used in industrial and PV system is easy to find in rural area [1-2]. PV systems are integrated with invert to convert DC power to AC power and have a huge potential to be implemented in the embedded system [3-5]. In the future, PV systems can be used to power up the low power sensors in Wireless Body Area Networks (WBAN) [6] using wearable antennas [7] The inverter in electronic power technologies is an electrical device, which converts DC source to AC load. The multilevel inverter provides the semi-conductor transition with less voltage stress and needs less filter size [8]. Multilevel inverter has three types and cascaded H-bridge multilevel inverter is most application used because it requires fewer component numbers in each bridge. Every different stage multilevel inverter has contained different value of efficiency. Cascaded H-bridge is simpler than other multilevel inverters because of the number of components [9–12], voltage sharing and switching redundancy. Thus, these papers focus to analyse the performance of single phase Cascaded H-Bridge multilevel inverter five level by using 12 V input and each level can generate three voltage outputs +Vdc, -Vdc and zero.

2.0 Methodology

The topology of the five level Cascaded H-Briged multilevel inverter is shown in figure 1. Two input stages generated 24 V output DC voltages and each bridge has four power switches [13]. This multilevel inverter is designed for infrared dryer application.
Figure 1: 5-level Cascaded H-Bridge Multilevel Inverter circuit design

Here, a simulation using the MATLAB/Simulink software to produce the switching angle by using the formula Newton-Raphson method to generate PWM is shown in figure 2.

Figure 2: Switching angle is generated using Newton Raphson Formula

The selective harmonic elimination PWM is a technique that matches among the modern modulation techniques. The integration of PWM with filter technologies would reduce the elimination harmonic on both sources [14–15]. The switching angle is programmed to eliminate the lower harmonics and required a solution set of nonlinear equations. Below is the equation of the Fourier series expansion output voltage:

\[ V_{an}(\omega t) = \frac{4V_{dc}}{\pi} \sum_{n=1}^{\infty} [\sum_{i=1}^{3} \cos(n\theta_1)] \sin(n) \]  

(1)

\[ V_{DC} = V_1 + V_2 + V_3 \]  

(2)

Where

- \( V_{DC} \) = Voltage source
- \( \theta_1 \) = Switching angle
- \( n \) = Harmonic order

The nonlinear equation of the fundamental component:
For the odd harmonic equation

\[
\frac{4V_{dc}}{\pi} \left[ \cos(\theta_1) + \cos(\theta_2) \right] = n_1
\]

(3)

The Switching angle matrix as shown below

\[
\theta = \begin{bmatrix}
\theta_1 \\
\theta_2
\end{bmatrix}
\]

(5)

Where the nonlinear system matrix is shown in equation (6) and (7)

\[
F = \begin{bmatrix}
\cos \theta_1 + \cos \theta_2 \\
\cos 3(\theta_1) + \cos 3(\theta_2)
\end{bmatrix}
\]

(6)

\[
dF = \begin{bmatrix}
-\sin(\theta_1) - \sin(\theta_2) \\
-3*\sin(3\theta_1) - 3*\sin(3\theta_2)
\end{bmatrix}
\]

(7)

This programme was used for five level switching angles and to find the low order harmonics. By using this equation, the guessing angle for the multilevel inverter is needed also this method can find the optimum solution for other values of the modulation indices.

3.0 Result and Discussion

The third and fifth order harmonic elimination is simulated by MATLAB/Simulink software. In this section, the modulation index between 0.75 – 0.85 has been simulated and in table 1 and table 2 shows the result of switching angle for the third order and fifth order.

| M Index | THD %  | Theta 1 | Theta 2 |
|---------|--------|---------|---------|
| 0.75    | 25.53  | 3.03    | 56.97   |
| 0.8     | 18.24  | 10.45   | 49.55   |
| 0.81    | 18.24  | 12.19   | 47.82   |
| 0.82    | 16.43  | 14.12   | 45.88   |
| 0.83    | 16.6   | 16.3    | 43.7    |
| 0.85    | 19.54  | 21.64   | 38.36   |

The five level outputs are generated and switching angle is recorded. The harmonic elimination is set to produce the lowest THD value.
Table 2: Switching angle for Fifth Order

| M Index | THD %  | Θ1    | Θ2    |
|---------|--------|-------|-------|
| 0.79    | 18.26  | 13.67 | 55.11 |
| 0.8     | 18.24  | 13.72 | 54    |
| 0.83    | 17.5   | 11.83 | 50.53 |
| 0.84    | 15.8   | 10.82 | 49.25 |
| 0.85    | 16.34  | 9.71  | 48.01 |

From this elimination process, the lowest THD value is manipulated from the modulation index. In figure 3(a), the modulation index 0.82 is the lowest THD percentage, which is 16.43% for third order and figure 3(b) shows that 0.84 of modulation index is the lowest THD percentage, which is 15.8% fifth the fifth order.

![Graph](image)

**Figure 3:** The differences of THD for (a) Third (b) Fifth Order

The results show that the fifth order is the lowest from the third order at the 0.84 modulation index and the THD value is 15.8%. The fifth order is the best harmonic elimination method compared to the third order because the fifth order gets the lowest THD value from this simulation. Therefore, the waveform parameter of the output has been plotted using MATLAB/Simulink as shown in figure 4.

![Graph](image)

**Figure 4:** Five level inverter output voltage for 220Vdc

Also, in figure 5 shows the output graph of the modulation index 0.84 from this graph the peak voltage is 232.6 V (164.5 Vrms and the value of THD is 15.80%).
In the Newton-Raphson method the value of the input voltage does not affect the switching angle and the value of THD, otherwise the guessing angle and the modulation index are the same. The simulation and experimental for the input voltage 12Vdc are implemented based on 5th order harmonic elimination at 0.84 modulation index.

Figure 6 shows the harmonic elimination to generate the output peak voltage that generated 232.6 V and the rms value is the 164.5 Vrms have been shown in figure 7 that the output is the same as the previous output peak voltage of 220Vdc. From this simulation result, the input voltage does not give any changing response unless the simulation of modulation index is changed.
In this experiment, oscilloscope is used to measure THD of the inverter. The experimental setup is based on a simulation parameter in the graph shown that the THD value is lowest among the other as shown in figure 8. Thus, the output of THD with the simulation and experimental result is not the same. Figure 8 shows the experimental results of five level inverter when tested without a resistive load, connected to three H-bridge cells. Each H-bridge cell is supplied with 12 V dc voltage. Figure 8 illustrates the THD elimination of 5-level inverter. The inverter output voltage THD is 17.9%. As it is obvious in Figure 8, the 5th harmonics are eliminated.

Figure 8: Experimental for harmonic elimination and the THD result for m= 0.84

4.0 Conclusion
In conclusion, the suitable and optimum angles to eliminate the chosen harmonic while reducing the THD for five level multilevel inverter were recorded. The differences of THD in simulation and experimental in still in the area of tolerance. Thus, the THD for this guessing angle is lowest too in experimental that was 17.9%. The elimination of the fifth harmonic, the optimum switching angles are 10.82 and 49.25 with 0.84 as modulation index will reduce the THD, which was 17.9%. The modulation index in five level multilevel inverter was 0.85 modulation index tends to bring the THD low.

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