Modeling and control of 41-level inverter using best switching angles calculation method

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ABSTRACT
In this paper, analysis and modeling of a single-phase H-bridge forty-one level inverter are considered. The control of proposed inverter by equal-phase and half-height methods is implemented. MATLAB/Simulink environments are used to simulate the model and show obtained results of waveforms with FFT analysis. Eventually, the total harmonic distortion obtained for each level with the two methods is presented, comparatively, for a comparison.

Keywords:
Equal-phase method
Half-height method
MATLAB/Simulink
Multilevel inverter
Power electronic

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1. INTRODUCTION
Uses of cascaded H-bridge inverter have become more popular in power electronic applications because the simplicity of control and the ability to generate high output voltage levels [1, 2]. Inverters can be classified into two types, voltage source inverter (VSI) and current source inverter (CSI). If the DC voltage is maintained and constant, the inverter is called VSI or voltage fed inverter (VFI), else if the input current is maintained and constant, the inverter is called CSI or current fed inverter (CFI) [3-6].

In applied power engineering fields, the multilevel inverter used in many applications [7-9], there are three conventional categories of the multilevel inverters: cascaded H-bridge, neutral point clamped and flying capacitor multilevel inverter [10-12]. The multilevel inverter used for Induction heating, Traction systems, Active filtering, Motor drives, High-voltage and Medium-voltage applications [13-14]. The problem is the choice of the switching angles required to control a multi-level inverter with a minimum THD in the system, total harmonic distortion is to the ratio between the RMS value of the signal harmonics (voltage or current) and the RMS value of the fundamental frequency [15].

To overcome the mentioned problem a modeling and simulation of a 41-level inverter using the best switching angles calculation method have been proposed using Simulink/MATLAB program, this solution for multilevel inverter control based on trigonometric calculation method. This paper is organized as follows, in Section II modeling and control of a multilevel inverter using Simulink/MATLAB have been discussed with an analysis of the two control methods, equal-phase (EP) method, half-height (HH) method. The results are presented and compared in Section III. Finally, some conclusions are presented in Section IV.
2. MODELING AND CONTROL OF MULTILEVEL INVERTER

2.1. The model of multilevel inverter

The simulation model of a 41-level inverter is shown in Figure 1, consists of cascaded H-bridge inverters, DC power supplies and control block with adjusting the frequency and switching angles.

![MATLAB/Simulink model of 41-level inverter](image)

Figure 1. The MATLAB/Simulink model of 41-level inverter

2.2. Control of inverter with equal-phase method

Switching angles with the equal-phase (EP) method in degrees is shown in Table 1. The principle of this method is the division of the period (180°) by the inverter levels (m) and multiplicative the result by the number of the angle (i) [5]. The formula of calculation is given by:

\[ \theta_i = \frac{180°}{m} \times i, \quad i = 1,2,3,4, ..., m-1 \]

| Level | Angles switching with the EP method in degrees |
|-------|-----------------------------------------------|
| 3     | 01 = 60                                       |
| 5     | 01 = 36; 02 = 72                              |
| 7     | 01 = 25.7143; 02 = 51.4286; 03 = 77.1429     |
| 9     | 01 = 20; 02 = 40; 03 = 60; 04 = 80          |
| 11    | 01 = 16.3636; 02 = 32.7273; 03 = 49.0909; 04 = 65.4545; 05 = 81.8182 |
| 13    | 01 = 13.8462; 02 = 27.6923; 03 = 41.5385; 04 = 55.3846; 05 = 69.2308; 06 = 83.0769 |
| 15    | 01 = 12; 02 = 24; 03 = 36; 04 = 48; 05 = 60; 06 = 72; 07 = 84 |
| 17    | 01 = 10.5882; 02 = 21.1765; 03 = 31.7647; 04 = 42.3529; 05 = 52.9412; 06 = 63.5294; 07 = 74.1176; 08 = 84.7059 |
| 19    | 01 = 9.4737; 02 = 18.9474; 03 = 28.4211; 04 = 37.8947; 05 = 47.3684; 06 = 56.8421; 07 = 66.3158; 08 = 75.7895; 09 = 85.2632 |
| 21    | 01 = 8.5714; 02 = 17.1429; 03 = 25.7143; 04 = 34.2857; 05 = 42.8571; 06 = 51.4286; 07 = 60.0000; 08 = 68.5714; 09 = 77.1429; 10 = 85.7143 |
| 23    | 01 = 7.8261; 02 = 15.6522; 03 = 23.4783; 04 = 31.3043; 05 = 39.1304; 06 = 46.9565; 07 = 54.7826; 08 = 62.6087; 09 = 70.4348; 10 = 78.2609; 11 = 86.0870 |
| 25    | 01 = 7.2000; 02 = 14.4000; 03 = 21.6000; 04 = 28.8000; 05 = 36.0000; 06 = 43.2000; 07 = 50.4000; 08 = 57.6000; 09 = 64.8000; 10 = 72.0000; 11 = 79.2000; 12 = 86.4000 |
| 27    | 01 = 6.6667; 02 = 13.3333; 03 = 20.0000; 04 = 26.6667; 05 = 33.3333; 06 = 40.0000; 07 = 46.6667; 08 = 53.3333; 09 = 60.0000; 10 = 66.6667; 11 = 73.3333; 12 = 80.0000; 13 = 86.6667 |
| 29    | 01 = 6.2069; 02 = 12.4138; 03 = 18.6207; 04 = 24.8276; 05 = 31.0345; 06 = 37.2414; 07 = 43.4483; 08 = 49.6552; 09 = 55.8621; 10 = 62.0690; 11 = 68.2759; 12 = 74.4828; 13 = 80.6897; 14 = 86.8966 |
| 31    | 01 = 5.8065; 02 = 11.6129; 03 = 17.4194; 04 = 23.2258; 05 = 29.0323; 06 = 34.8387; 07 = 40.6452; 08 = 46.4516; 09 = 52.2581; 10 = 58.0645; 11 = 63.8710; 12 = 69.6774; 13 = 75.4839; 14 = 81.2903; 15 = 87.0968 |
\[ \theta_i = \sin^{-1} \left( \frac{2}{m-1} \left( i - \frac{1}{2} \right) \right) = \sin^{-1} \left( \frac{2i - 1}{m-1} \right), \]

with \( i = 1, 2, 3, \ldots, m-1 \).
3. RESULTS AND DISCUSSION

Some obtained results are presented in this session with a comparison. Figure 2 show the output voltage waveform and Figure 3 show the harmonic spectrum of a 41-level inverter with EP method. Figure 4 show the 41-level inverter output waveform with HH method and Figure 5 show the harmonic spectrum analysis with HH method of a 41-level inverter. Table 3 shows the data comparison and Figure 6 show a graphic comparison of THDs between the EP method and HH method.

![Figure 2. The output voltage waveform of a 41-level inverter with EP method](image1)

![Figure 3. THD Analysis of 41-Level output voltage with the EP method](image2)

![Figure 4. Output voltage waveform for a 41-level inverter with the HH method](image3)

![Figure 5. THD analysis of 41-level output voltage with the HH method](image4)

The Figure 2 and Figure 4 are the output voltage waveforms of the 41-level inverter with the two control methods, EP method and HH method, and the Figure 3 and Figure 5 are the total harmonic distortion THD of the 41-level inverter with the two methods respectively. From the analysis of THD comparison between the two control methods in Figure 6, we can say that there is a decrease of THD with an increase of inverter level, and for each inverter level, the THD with EP control method is higher than that obtained with HH control method. THD of the 17-level inverter with HH control method is down of 5 %, and with EP method is 18.15%. THD of a 41-level inverter with HH control method is 1.98 %, and with EP method is 13.93%. We note that the harmonic voltage is limited by the standard IEEE STD 519 [16]: The total harmonic distortion of voltage THDv<5%, and conclude that the HH method gives a good result with 17-level cascaded H-bridge inverter.
4. CONCLUSION

In this paper, contribution to the modeling and control of 41-level inverter using best switching angles calculation method is presented with two control methods. From simulation and THD compared results it has been observed that HH method is the best method for switching angles than the EP method.

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