Design of single phase inverter using microcontroller assisted by data processing applications software

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Abstract. Inverter is widely used for industrial, office, and residential purposes. Inverter supports the development of alternative energy such as solar cells, wind turbines and fuel cells by converting dc voltage to ac voltage. Inverter has been made with a variety of hardware and software combinations, such as the use of pure analog circuit and various types of microcontroller as controller. When using pure analog circuit, modification would be difficult because it will change the entire hardware components. In inverter with microcontroller based design (with software), calculations to generate AC modulation is done in the microcontroller. This increases programming complexity and amount of coding downloaded to the microcontroller chip (capacity flash memory in the microcontroller is limited). This paper discusses the design of a single phase inverter using unipolar modulation of sine wave and triangular wave, which is done outside the microcontroller using data processing software application (Microsoft Excel), result shows that complexity programming was reduce and resolution sampling data is very influence to THD. Resolution sampling must taking ½ degree to get best THD (15.8%).

1. Introduction

Inverter converts DC voltage into AC voltage [1]. There are two types of inverters commonly used in electric power system which are inverter with variable voltage variable frequency (VVVF) and inverter with constant voltage constant frequency (CVCF) [2]. VVVF inverters are generally used for specific usage such as 3-phase AC motor control for pumps. Inverters with CVCF are widely used for general purpose that does not require changes in frequency. There will be no discussion on CVCF inverter in this paper.

There are several methods for inverter switching including square wave signal method, multiple pulse width modulation (PWM), unipolar sine pulse width modulation and bipolar sine pulse width modulation [3]. This paper discusses the design of a single phase inverter using unipolar modulation of sine wave and triangular wave. The advantages of unipolar switching is lower output harmonics [4].

Many variations of hardware, software and algorithms have been widely used for the inverter, such as the use of multi vibrator circuit using IC CD4047 as a purely electronic control without software [5]. There could be generation of AC wave modulation done in the microcontroller [6, 7], but it may increase the complexity of programming and number of coding. Basically, generating unipolar sine PWM can be performed by comparing two signals/waves namely sine wave as fundamental signal and triangular wave as carrier signal [8]. The result is a noncontinuous square wave PWM, so that the
frequency of the sine wave is equal to the frequency used by the load (usually about 50 Hz and 60 Hz [9].

2. Method

2.1. Unipolar Modulation with Data Processing Software

Software used to generate unipolar modulation is Microsoft Excel, which meets all requirements to generate the computation of triangular and sine waves. Sine wave was generated using the equation (1):

\[ \text{Sine wave} = \sin(A_1 \times \frac{\pi}{180}) \]  

where:
- \( \sin \): sine
- \( A_1 \): number of columns and rows (0 - 360)
- \( \frac{\pi}{180} \): convert radians to degrees [10]

The wavelength of the triangular wave must be determined first to generate a triangular wave. Determining pulse width of triangular wave is the same as determining the carrier frequency. Modulation ratio is the ratio of the fundamental frequency (sine wave) with the carrier frequency (triangular wave) [11]. Optimum modulation ratio is 22.5 [12]. Triangular wavelength (\( \lambda \)) calculation was obtained using equation (2):

\[ \lambda_{\text{Triangular}} = \frac{\lambda_{\text{sine}}}{\text{modulation ratio}} \]

\[ = \frac{360}{22.5} = 16^\circ \]

![Figure 1. Sine and triangular wave modulation.](image)

From equation (2), it was known that \( \lambda \) of triangular wave is 16 degrees (figure 1) which means in range of 16 degrees there are positive half wave and negative half wave. The wavelength of each half wave is 8 degrees, hence for each 8 degrees there would be half to rise and fall. Wavelength to peak is 4 degrees, as shown in figure 2.

Modulation index is ratio between the amplitudes of triangular and sine waves with optimum modulation index of 0.6 [11, 13]. Resolution per degree for the triangular using equation (3):
Resolution per degree of triangular wave was 0.4, meaning each degree of triangular wave is changed by 0.4 units as shown in figure 6. Both sine and triangular waves were compared (with the subtraction) and transformed into zeros and ones depending on the result of the comparison. To transform the result of modulated sine wave with a triangular wave into a digital form can use flowchart as shown in figure 3.

![Flowchart](image)

**Figure 3.** Flowchart modulating sine wave with a triangular wave into a digital.

In this paper we used single phase full bridge inverter (figure 4) which can be viewed as two half bridge inverters. Single phase full bridge inverter uses 4 units power electronic components (T1, T2, T3, and T4) so that binary have 16 possible different combinations of active to cut off conditions [14]. Only two combinations produce an AC voltage at load (T1, T4 = active T2, T3 = cut off, and T1, T4 = cut off T2, T3 = active). Other combinations will result in short circuit, freewheeling or does not
produce AC voltage (see table 1). The column is numbered based on binary, "1" indicated the power
electronic components will be in a state of active, while "0" indicated power electronic components in
a "cut off". Thus power electronic components T1 with T2 and T3 with T4 were always in opposite
number. To get opposite binary column can used the equation "= IF (D2> 0,01)" written in Microsoft
Excel. Equation functioned to give number "1" when column condition was colorless or less than zero
and to give number "0" when column condition is colored or greater than zero.

![Figure 4. Full bridge inverter circuit.](image)

2.2. Programming Look Up Table at Microcontroller
In this paper, trigger for power electronic components was gained from microcontrollers MCS 51
(base 8051 Intel processor) from ATMEL corp. This microcontroller has features for indexed data
store (such as tables). Indexed addressing mode is used to access data elements (look-up table entries)
located at the ROM in 8051 [15]. Instructions used for was “MOVC A, @ A + DPTR. DPTR” was
used to access the ROM. Look-up table was used to access elements in the table for a fast operation.
Microcontroller works as infinitive loops. During power supply applied microcontroller will continue
reading the data on the table from the beginning until the end repeatedly. Microcontroller reads/
processes the program with binary code, however writes data/programs that are downloaded with
hexadecimal code [15]. Therefore, the combination of triggers for the power electronic components
needed to be converted into hexadecimal. According to figure 3, the conversion can be seen in table 1.

| T4 | T3 | T2 | T1 | Hex | Annotation          |
|----|----|----|----|-----|---------------------|
| 0  | 0  | 0  | 0  | 0   | Not used            |
| 0  | 0  | 0  | 0  | 1   | Not used            |
| 0  | 0  | 1  | 0  | 2   | Not used            |
| 0  | 0  | 1  | 1  | 3   | Restricted           |
| 0  | 1  | 0  | 0  | 4   | Not used            |
| 0  | 1  | 0  | 1  | 5   | Freewheeling high side |
| 0  | 1  | 1  | 0  | 6   | Negative cycle       |
| 0  | 1  | 1  | 1  | 7   | Restricted           |
| 1  | 0  | 0  | 0  | 8   | Not used             |
| 1  | 0  | 0  | 1  | 9   | Positive cycle       |
| 1  | 0  | 1  | 0  | A   | Freewheeling low side |
| 1  | 0  | 1  | 1  | B   | Restricted           |
| 1  | 1  | 0  | 0  | C   | Restricted           |
| 1  | 1  | 0  | 1  | D   | Restricted           |
| 1  | 1  | 1  | 0  | E   | Restricted           |
| 1  | 1  | 1  | 1  | F   | Extremely restricted |

From table 1 it can be concluded that besides generating AC voltage at the load a-b (figure 4) in
value hex 6 and hex 9. While some values of hex did not result short circuit this hex would not
produce AC voltage at the load a-b (value 5 hex A hex as freewheeling). Whereas values hex 3, hex 7, hex B, hex C, hex D and hex E had to be restricted to prevent short circuit on one side. Value hex F was extremely restricted because it enables short circuit on both sides. Only three data were entered into look-up table which are hex 3, hex 9 and hex 0, the number of data equivalent to the number of data in Microsoft Excel tables. The same data in series indicated pulse width, the more data to be found same in the series, the wider the pulse is.

In figure 5, “$mod51” was used to initialize MCS51 family of microcontrollers. “org 0h” meant the program would begin at address hex 0. “Mov r3, #180” was used to enter the number 180 into register r3 in an attempt to determine the number of data in a single table. MCS51 was only able to accommodate 255 data, whereas the design requires 360 data. Therefore it took two tables (each consisted of 180 data with different names). “DELLAY: mov R0, #40” was used to create a delay time between data collections. This delay time could determine the final outcome frequency in which the smaller the gap the larger the frequency, vice versa. “DJNZ R0, DELAYL1” was for reducing data in registers until the value of the data was 0. “clr a” aimed to clear data in the accumulator since the accumulator would be filled with new data. The process of moving data from the table into the accumulator was done using the command “MOVC A, @A + DPTR”. Finally, to read the next data in the table the given command was: “inc DPTR” which reduced the addressing DPTR.

3. Results and discussion
Data processing stated in assembler programs is shown in figure 6. It implied that the data in columns was arranged in rows and indexed in the look-up table. Program that contained the data was converted into hex using MCS51 compiler then downloaded to memory in microcontrollers (flash Memory). This paper compare three resolution sample of degrees. The final waveform output of the modulation was presented in figure 7. Figure 7(a) shows the waveform output across the high side and the low side, figure 7(b) displays THD (70.0 %) at 2 degree resolution sampling, figure 7(c) exhibits THD (47.0 %) at 1 degree resolution sampling, and figure 7(d) shows THD (15.8 %) at ½ degree resolution sampling.
Figure 6. Processing of data as outlined in the assembler program.

Figure 7. Modulating waveform and THD at the output hardware.

Calculation for the frequency as explained by Hennessy and Patterson [16] in paper written by Bhandarkar and Clark [17] is:
where:

\[
\text{Time}_{\text{Program}} = \text{Time}_{\text{Cycle}} \times \frac{\text{Cycle}_{\text{Instruction}}}{\text{Instruction}_{\text{Program}}} \times \text{Instruction}_{\text{Program}}
\]

- \(\text{Time}_{\text{Program}}\): time for one wave (second)
- \(\text{Time}_{\text{Cycle}}\): depend on frequency of crystal (12 MHz) [15].
- \(\text{Cycle}_{\text{Instruction}}\): depend on Architecture (CISC = 12) [4].
- \(\text{Instruction}_{\text{Program}}\): number label of code (3), number data lookup table (405), and delay (16)

so the frequency is: \(1/0.01944 = 51.44\) Hz.

The measurement with oscilloscope (figure 7) and manual calculation show the same result.

4. Conclusion

In this paper the single phase inverter design with unipolar method is proposed. Inverter single phase unipolar method could be obtained by modulating the ratio of sine and triangular waves, where the fundamental sine wave was 50Hz while carrier triangular waves were as much as 22.5 times. Both sine wave and triangular wave generations were done using Microsoft Excel, because the software has features that can accommodate the required waveform processing. The data generated in Microsoft excel was transferred to look up tables using assembler programs. AC voltage frequency could be adjusted using delay subroutine in assembler programs. THD at 2 degree resolution sampling are high but its decrease significantly at \(\frac{1}{2}\) degree resolution sampling. Future research for this paper is to secure high side and low side of electrical component with logical calculation.

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