SIMULATION AND SIMPLE IMPLEMENTATION OF SINGLE PHASE PWM INVERTER WITH MINIMUM HARMONICS

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Abstract—This paper presents a new approach of control algorithm for single phase inverter with minimum harmonics values. Minimum harmonics is based on elimination of selected low order harmonics. The calculated switching angles are utilized in the control algorithm which is simply written in matlab using m-file to finally generate inverter switches pulses. The code is very simple and it is written in C-language very close to that written in the experimental results. The low order harmonics up to the 21st are eliminated. An LC filter with low size is utilized leading to full elimination of low and high order harmonics. Implementation of the system is carried out and an inexpensive dsPIC30F2010 microcontroller is used resulting in extremely reduction in hardware complexity. Experimental results verify the effectiveness of the proposed inverter and they are very close to simulation results.

Keywords—Harmonics Elimination, Switching Angles, Filter.

I. INTRODUCTION

Single phase dc-ac inverters are applied in enormous applications when the control of load voltage, load frequency or both are required [1-4]. These applications include uninterruptible power supplies and single phase induction motors. Single phase induction motors with their different categories require the application of dc-ac inverter to adjust the speed and torque of the motor [2, 5]. Single phase inverters are mainly divided into two types: Half bridge and full bridge inverters. The utilization of dc supply is more effective with full bridge inverters. Several categories of single phase dc-ac inverters are found depending on the method of controlling the inverter switches [1, 3]. Conventional inverters are simple but their main drawbacks are the high values of low order harmonics in which the size and cost of filters are high. Conventional PWM can be applied based on the comparison of triangular wave (carrier) and sinusoidal wave [1]. Conventional PWM inverters improve the performance of the inverter but the low order harmonics still have significant values. These harmonics cause an increase of the load temperature and torque ripples in the motors [1]. Low pass filter can be employed to cancel the low order harmonics but the filter has a big size and a high cost. With the increasing improvements of power electronics switches in the recent decades, another types of single phase inverters called selective harmonics elimination pulse width modulation inverters SHEPWM, are introduced and utilized to overcome the problem of low order harmonics [6-10].

Selected number of low order harmonics can be fully eliminated by a proper choice of the switching angles of the inverter switches over one fourth of the fundamental cycle. These switching angles are determined by solving set of nonlinear equations called “transcendental equations” numerically. Solutions of the transcendental equations are presented in the literature using different methods such as pattern search and genetic algorithm [9, 11]. Analogue implementation are utilized to generate the control signals of the inverter switches which suffer from the complexity especially when several harmonics are required to be cancelled [10]. This paper proposes a new approach of the control algorithm for dc-ac inverter based on SHEPWM and verify the inverter experimentally. Control algorithm of the inverter switches is based on matlab function and m-file. The code in the m-file is very close to that written in the experimental results. While the control algorithm can be applied for any number of switching angles, eleven switching angles in one fourth of cycle are chosen as a case of study in this paper. i.e. eleven pulses every one half of the fundamental cycle. Low order harmonics up to the 21st harmonic are eliminated in the load voltage. The inexpensive dsPIC30F2010 microcontroller is used in the experimental results. Using microcontroller overcomes the complexity of analogue control and reduces the cost significantly. A simple LC filter is applied in simulation and hardware implementation in which higher order harmonics are fully cancelled. Since the load is RL, the load current is nearly sine-wave. Simulation and experimental results present high performance of the inverter and they are very close to each other as well.

II. ANALYSIS OF THE INVERTER BASED ON SHEPWM

The basic full bridge single phase inverter circuit is shown in Fig. 1. Unipolar PWM technique is applied in which the inverter output voltage takes the values “Vdc”, “-Vdc”, or “zero”. The output voltage for “N” number of pulses per half cycle is given in Fig. 2. The output voltage is even function and therefore even harmonics are naturally eliminated. To fully
eliminate (N-1) number of odd harmonics, the following conditions must be fulfilled:

\[
\sum_{k=1}^{n} (-1)^{k+1} \cos \left( \frac{k}{4} \theta_k \right) - \frac{\pi}{4} M_a = 0 \quad (1)
\]

\[
\sum_{k=2}^{N} (-1)^{k+1} \cos \left( \frac{k\pi}{2} \right) = \theta_k = 0 \quad (2)
\]

Where \( M_a \) is the modulation index which is defined as:

\[ M_a = \frac{V_1}{V_{dc}} \]

\[ n = 3, 5, 7, \ldots, 2N - 1 \]

and

\[ 0_1 < 0_2 < \theta_3 < \ldots < 0_N < 90^\circ \]

\( V_1 \) is the fundamental output voltage value

Equations 1 and 2 are called transcendental equations and they must be solved simultaneously to get the switching angles \( \theta_1, \theta_2, \theta_3, \ldots, \theta_N \) for a given “N” and modulation index. Different methods can be applied to solve these transcendental equations such as Newton-Raphson, Pattern Search and Genetic Algorithm. Numerical solution of equations 1 and 2 for \( N=11 \) and modulation index \( = 0.95 \) leads to the following switching angles:

\[
\theta_1 = 12.8367^\circ; \theta_2 = 15.8273^\circ; \theta_3 = 25.8131^\circ; \theta_4 = 31.6929^\circ; \theta_5 = 47.6598^\circ; \theta_6 = 52.8487^\circ; \theta_7 = 63.8494^\circ; \theta_8 = 67.3821^\circ; \theta_9 = 80.4056^\circ; \theta_{10} = 83.0185^\circ
\]

The switching angles over one half of the fundamental frequency can be easily estimated due to symmetry around \( 90^\circ \). The control signal of switch \( T_1 \) is the same as the output voltage in Fig. 2 from \( 0^\circ \) to \( 180^\circ \). The control signal of switch \( T_3 \) is the same as that of \( T_1 \) but shifted \( 180^\circ \). \( T_2 \) is kept “on” over the first half cycle while \( T_4 \) is kept “on” over the second half cycle. To generate the control signal of \( T_1 \), a carrier signal having a wave shape as in Fig. 3 is generated. The carrier has “N” shapes each \( 180^\circ \).

Each carrier shape has its own width and peak depending on the successive switching angles as described in the following sequence:

The switching angles over \( 180^\circ \) are stored in a vector \( \theta \) where

\[
\theta = [\theta_1 \ \theta_2 \ \theta_3 \ldots \ \theta_{2N}]^T \quad (3)
\]

The corresponding instants of switching are calculated and stored in vector \( t \) depending on the fundamental frequency.

\[
t = [t_1 \ t_2 \ t_3 \ldots \ t_{2N}]^T \quad (4)
\]

From \( t_k \) to \( t_{k+1} \) the carrier takes a straight line where at \( t = t_k \), carrier = zero

\[
(5)
\]

which is the initial point in the interval \( t_k \) to \( t_{k+1} \)

and at \( t = t_{k+2} \), carrier = \( 360 f \theta_k \)

\[
(6)
\]

which is the initial point in the interval \( t_k \) to \( t_{k+2} \)

\( k = 0, 2, 4, \ldots \) \( (2N-2) \) and \( f \) is the fundamental frequency.
It must be noted that the carrier waveform is not as the conventional carrier but it has different widths and heights as shown in Fig. 3. The width and height of the carrier depend on the switching angles and their corresponding instants.

![Fig. 3 Carrier wave](image1)

**Fig. 3 Carrier wave**

**Fig. 4 Comparison between carrier and \( \theta_k \)**

![Fig. 4 Comparison between carrier and \( \theta_k \)](image2)

**III. SIMULATION RESULTS**

The inverter is modeled using MATLAB SIMULINK and m-file is written as mentioned above to generate the carrier waveforms, compare the carrier with the switching angles and finally generate the control signals of the inverter switches. The complete block diagram is shown in Fig. 5. The pulse generator with the subsystem block has two functions; the first is the generation of control signals for switches \( T_2 \) and \( T_4 \). The second is to distinguish between the first and second half cycles since the output of the matlab function repeats itself each 180°. Details of the subsystem1 are given in Fig. 6 where the sample time of the unit delay is 1/2f = 0.01 m sec. The frequency is set at 50 Hz and the current instant is adjusted to range from “0” to “1/2f” using the repeating sequence block. The load is RL where \( R = 380 \Omega \) and \( L = 0.6 \) H.

![Fig. 6 Details of the subsystem or subsystem1](image3)

Fig. 7 presents the control signals of switches \( T_1 \), \( T_3 \), \( T_4 \) and \( T_2 \) respectively. Load voltage and current are given in Fig. 8. The load current has nearly sinusoidal waveform. The load voltage harmonic spectrum is shown in Fig. 9 and it can be noted that the load voltage has odd harmonics of orders higher than 21.

![Fig. 5 inverter model without filter and with filter](image4)

**Fig. 5 inverter model**

A low pass LC filter is inserted in the output with \( L = 50 \) mH and \( C = 4.7 \mu F \), therefore higher order harmonics of the load voltage waveform are fully eliminated. And this is clear from the load voltage and load current shown in Fig. 10. In addition, Fig. 11 gives the spectrum analysis of the load voltage.

![Fig. 11 Spectrum analysis](image5)
Simulation and Simple Implementation of Single Phase PWM Inverter With Minimum Harmonics

IV. EXPERIMENTAL RESULTS

To validate the proposed algorithm, a low scale hardware inverter system has been built, experimentally tested and compared with the simulation results. The inverter switches are built using four units of MOSFET switches IRF620. A dsPIC30F2010 microcontroller is used to implement the m-file code and then to generate switches pulses. MikroC PRO for dsPIC software is utilized for writing and compiling the program code. MPLAB IDE v8.92 is applied for programming the microcontroller via pic kit-3 programmer and universal programming module 2 board. Isolation is achieved through 4N25 opto-couplers. RL load with same parameters values that used in simulation are adopted also to achieve experimental results. The control signals are given in Fig. 12. Load voltage and current are presented in Fig. 13. Experimental results are very close to simulation results where the load current is almost sinusoidal and the load voltage is very close to that in simulation results. When applying the LC low pass filter which has the same values as mentioned above in the simulation results, the load voltage becomes closer to sinusoidal shape and obviously the load current as shown in Fig. 14.
Simulation and Simple Implementation of Single Phase PWM Inverter With Minimum Harmonics

CONCLUSION

Single phase dc-ac inverter with selective harmonics elimination is modeled using a new approach. Low order harmonics up to the 21st harmonic are eliminated. LC low pass filter with low size and consequently low cost is utilized to eliminate the harmonics of 23rd and higher harmonics. Experimental validation is carried out with and without the low pass filter. Experimental results are very close to simulation results and the results verify the effectiveness of the proposed algorithm.

REFERENCES