Motor control strategy based on ISCPWM and THIPWM

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***Abstract*—In order to obtain a reduced harmonic content in the frequency domain and to enhance the fundamental output voltage, in this paper we use a control technique based on a Third Harmonic Injection PWM (THIPWM) reference wave, modulated by an Inverted Sine Carrier Pulse Width Modulation (ISCPWM) carrier signal. This technique was tested by Spice cat simulation, but also practically, by implementing it on the C8051F120 microcontroller, which controls the three-phase inverter bridge based on IRAMX16UP60A. The calculations volume per time unit is impressive, therefore, in the microcontroller implementation part, we made some approximations.**

I. Introduction

With a view to increasing the amplitude of the voltage fundamental at the output of a three-phase inverter controlled by PWM, without reaching the overmodulation area, the value of the amplitude modulation ratio (Ma) is increased towards 1. If we take into account the inverter input voltage Vd and the amplitude modulation ratio Ma=1 for a load with star connection, the maximum amplitude of the phase voltage fundamental is Vd/2. By using a 3rd harmonic injection (THIPWM) sinusoidal wave as a reference wave [1], the amplitude of the output voltage can be around 15% higher than for a sinusoidal reference wave (SPWM) [2]. Aiming to increase the amplitude of the output voltage, we also used an inverted sine carrier signal (ISCPWM) as a modulating wave [3]. This type of wave will lead to the lengthening of the conduction time for the control of power transistors within a three-phase inverter [4].

II. Theoretical Considerations

Figure 1 presents the waveform of a 3rd harmonic injection (THIPWM) reference signal, of a ISCPWM (Inverted Sine Carrier Pulse Width Modulation) modulator signal and of the control signal for transistor Q^+_A. Figure 2 presents the schematic of the three-phase inverter made up of transistors Q^+_A, Q^-_A, Q^+_B, Q^-_B, Q^+_C and Q^-_C. As it is illustrated in Figure 1, as long as the value corresponding to the carrier signal waveform (ISCPWM) is higher than the value of the reference signal waveform (THIPWM), transistor Q^+_A is blocked [5]. Each intersection between the two signals leads to intersection points named p1, p2, p3, p4, p5, etc. In these time intervals, transistors turn from conduction to blocking and vice versa [6]. The control signal for transistor Q^-_A is obtained by reversing the control signal for Q^+_A.

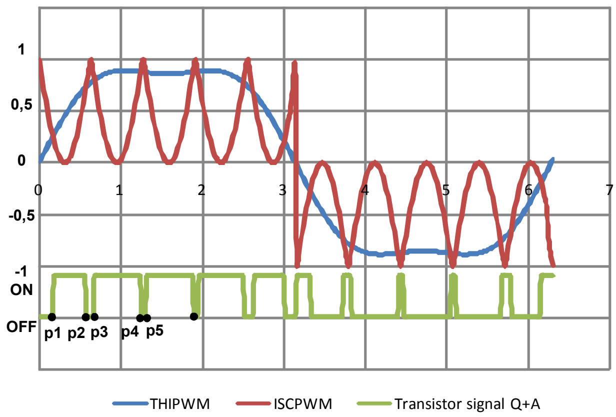

Figure 1. Waveforms of the Third Harmonic Injection Pulse Width Modulation (THIPWM) reference signal, Inverted Sine Carrier Pulse Width Modulation (ISCPWM) carrier signal and command signal for Q^+_A transistor.

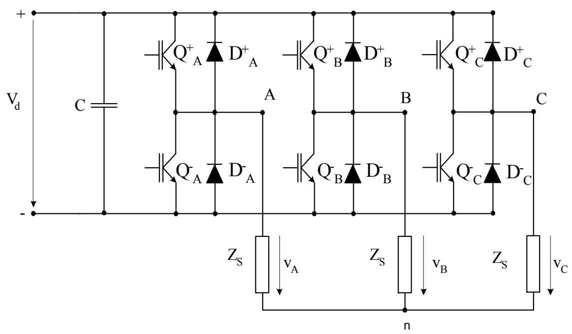

Figure 2. Schematic of the three-phase inverter

The intersection points (p1, p2, p3, etc.) between ISCPWM and THIPWM signals can be calculated based on the following equations.

$$y = 1 - \sin\left[M_f \cdot p_i - \frac{\pi}{2}(i-1)\right],\ i = 1,3,5\ \ldots \quad (1)$$

$$y = 1 - \sin\left[M_f \cdot p_i - \frac{\pi}{2}(i-2)\right],\ i = 2,4,6\ \ldots \quad (2)$$

where M_f is the frequency ratio,

p_i represents the points of intersection between THIPWM and ISCPWM,
i is the number of points.

If we consider the THIPWM equation

$$y = 1{,}15 * \left[\sin p_i + 0{,}167 * \sin\left(3 * p_i\right) \right] \qquad (3)$$

and substitute equation (3) in (1) and (2), we obtain equations (4) and (5), which help us find intersection points p1, p2, p3, p4, p5, etc. [7,8].

$$1{,}15 * \left[\sin p_i + 0{,}167 * \sin\left(3 * p_i\right) \right] + \sin\left[M_f \cdot p_i - \frac{\pi}{2}(i-1) \right] = 1,\ i = 1,3,5 \ldots \qquad (4)$$

$$1{,}15 * \left[\sin p_i + 0{,}167 * \sin\left(3 * p_i\right) \right] + \sin\left[M_f \cdot p_i - \frac{\pi}{2}(i-2) \right] = 1,\ i = 2,4,6 \ldots \qquad (5)$$

Based on equations (4) and (5), we calculate the intersection points which help us draw a waveform as a modulating signal (ISCPWM-THIPWM). This waveform can be seen in Figure 3, next to the waveform of a 3rd harmonic injection signal (THIPWM). It is very clear that the new waveform (ISCPWM-THIPWM) has higher amplitude than the THIPWM waveform for the same time intervals.

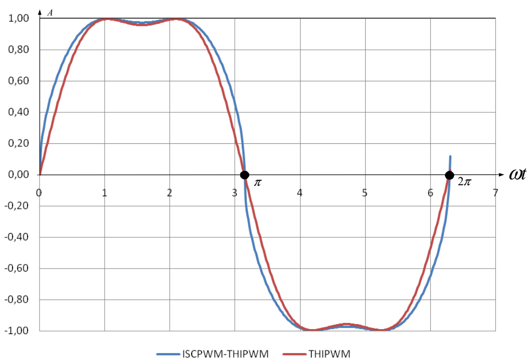

Figure 3. Waveforms of the ISCPWM-THIPWM and THIPWM signals

In order to better illustrate this increase in amplitude of the ISCPWM-THIPWM signal for a single period of a modulating wave, Figure 4 presents the ISCPWM signal, the reference signal (THIPWM) and a classic PWM modulation signal. D_1 and D_2 represent the conduction times of the Q^+_A transistor. The D_1 time corresponds to the situation when the reference signal (THIPWM) is higher than the modulating signal (ISCPWM), and the D_2 time is measured when the reference signal is higher than a classic PWM modulating signal. As we can see in this figure, the conduction time D_1 is longer than D_2.

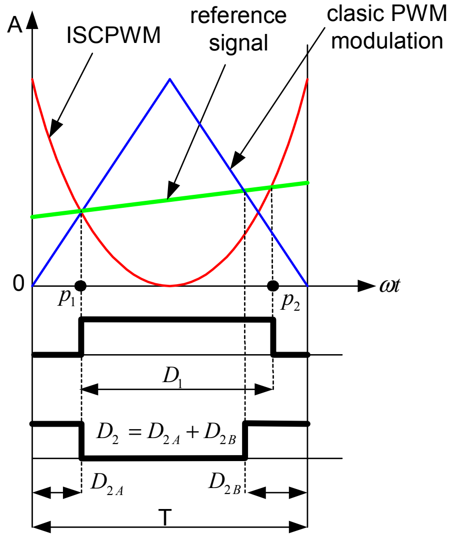

Figure 4. Waveforms of the ISCPWM, THIPWM and a classical PWM signals

III. COMMAND AND CONTROLL ALGORITHM

We present below the control diagram implemented as software, by means of the C program, on the C8051F120 microcontroller, produced by Silicon Laboratories [9]. The microcontroller is initialized first, followed by the main program routine. It contains functions for reading the currents in the motor, reading the buttons and displaying certain parameters on a LCD. The most important elements occur in the interrupt routine 1, called on by the T1 timer every 1ms. It contains the equations for the generation of the THIPWM signal and the equations for calculating the ISCPWM-THIPWM time; then, it updates the PWM registers within the microcontroller.

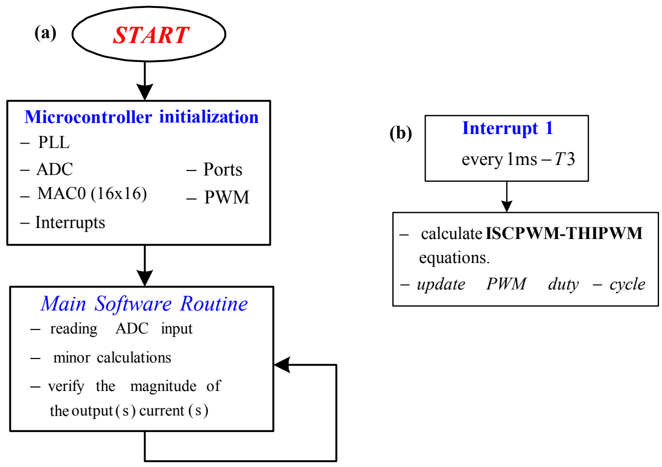

Fig. 5(a). Software control flowchart
Fig. 5(b). Flowchart of Interrupt 1

IV. SOFTWARE CONTROL

As we mentioned above, the microcontroller control software was written in the C programming language and is presented below. In this software routine, 3 reference signals (THIPWM) are created and named f0, f1 and f2; subsequently they are modulated by the ISCPWM signal. The calculation volume is very large; therefore we resorted to some approximations in order to help the microcontroller in solving the equations.

```
  void iscpwm_thipwm (void)
  {
f0 = 1.15*(sin(tr0)+0.167*sin(3*tr0));
if (tr0 <= 3.14)
  {
        f0a = 3.1415 - 2*asin(1 - f0);
  }
else    if(tr0<=6.28 && tr0>3.14)
  {
        f0a = 2*asin(1 + f0) - 3.1415;
  }
  else if(tr0<=9.42 && tr0>6.28)
        {
                f0a = 3.1415 - 2*asin(1 - f0);
        }
        else    f0a = 2*asin(1 + f0) - 3.1415;

f0a = f0a / 3.1415;
s = f0a*0x7F;
p = amplitude * (signed int)s;
o = p>>8;
o += 0x80;
PCA0CPH0 = o;

f1 = 1.15*(sin(tr1)+0.167*sin(3*tr1));
if (tr1 <= 3.14)
  {
        f1a = 3.1415 - 2*asin(1 - f1);
  }
else    if(tr1<=6.28 && tr1>3.14)
  {
        f1a = 2*asin(1 + f1) - 3.1415;
  }
  else if(tr1<=9.42 && tr1>6.28)
        {
                f1a = 3.1415 - 2*asin(1 - f1);
        }
        else    f1a = 2*asin(1 + f1) - 3.1415;

f1a = f1a / 3.1415;
s = f1a*0x7F;
p = amplitude * (signed int)s;
o = p>>8;
o += 0x80;
PCA0CPH1 = o;

f2 = 1.15*(sin(tr2)+0.167*sin(3*tr2));
if (tr2 <= 3.14)
  {
        f2a = 3.1415 - 2*asin(1 - f2);
  }
else    if(tr2<=6.28 && tr2>3.14)
        {
                f2a = 2*asin(1 + f2) - 3.1415;
        }
  else if(tr2<=9.42 && tr2>6.28)
        {
                f2a = 3.1415 - 2*asin(1 - f2);
        }
        else    f2a = 2*asin(1 + f2) - 3.1415;

f2a = f2a / 3.1415;
s = f2a*0x7F;
p = amplitude * (signed int)s;
o = p>>8;
o += 0x80;
PCA0CPH2 = o;
}
```

V. Simulation and Experimental Results

After implementing the above software on the microcontroller, the ISCPWM-THIPWM signal and the THIPWM signal can be seen in Figure 6.

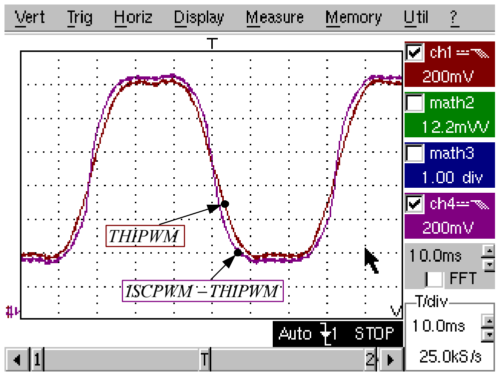

Figure 6. Oscilloscope waveforms of the ISCPWM-THIPWM and THIPWM signals implemented on the microcontroller

For the simulation and for the practical realization, we used a supply power of 310V, and the frequency of the carrier signal was 17.27KHz. For the practical part, we used as a load a three-phase motor with 3 pairs of poles of 0.37KW.

Figure 7 shows the line to line voltage between the B and C phases read on the oscilloscope - on the left side, and the harmonic content of this voltage is presented below. On the right side, you can see the line to line voltage between the B and C phases, obtained by simulations, and the harmonic spectrum of the line to line voltage between B and C phases, obtained also by simulations.

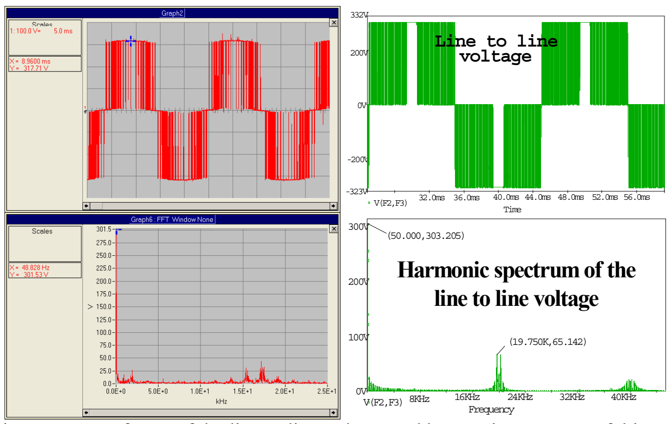

Figure 7. Waveforms of the line to line voltage and harmonic spectrum of this voltage obtained by simulations and from oscilloscope

Figure 8 shows the phase voltage B, read on the oscilloscope, and the harmonic content of this voltage is presented below - on the left side. On the right side, you can see the phase voltage B, obtained by simulations, followed by the harmonic spectrum of the phase voltage B, obtained by simulations.

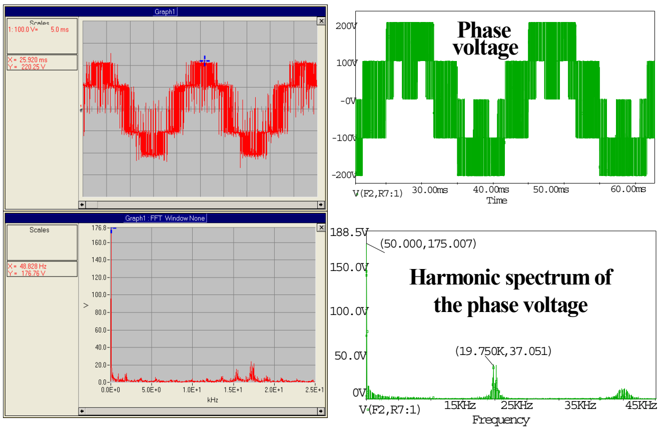

Figure 8. Waveforms of the phase voltage and harmonic spectrum of this voltage obtained by simulations and from oscilloscope

Figure 9 shows the phase current B, read on the oscilloscope, and the harmonic content of this current is presented below - on the left side. On the right side you can see the phase current B, obtained by simulations, followed by the harmonic spectrum of the phase current B, obtained by simulations.

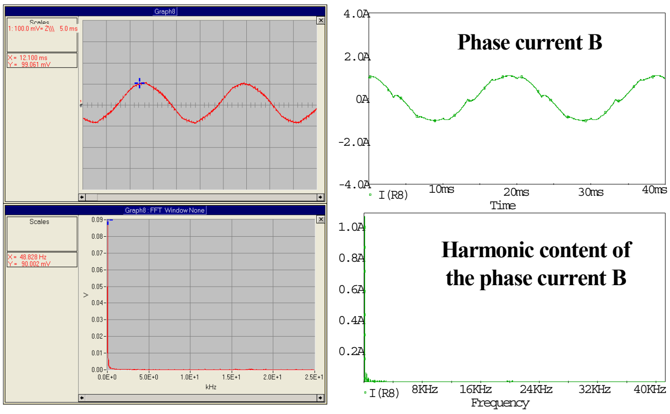

Figure 9. Waveforms of the phase current B and harmonic spectrum of this current obtained by simulations and from oscilloscope

Figure 10 shows the practical circuit used for testing.

Figure 10. Practical circuit contain: microcontroller, three-phase inverter, 0,37KW motor, a LCD.

VI. CONCLUSION

In this paper we use the ISCPWM-THIPWM algorithm to command a three-phase inverter. This algorithm was tested by simulations and practically. We compared the results of the simulations to the results obtained with the practical circuit in order to emphasize the performances of this control algorithm. As the results show, we obtained high values for the amplitudes of the fundamental frequency of the line and phase voltages and, implicitly, of the currents in the motor. However, this control algorithm has a drawback: it requires a large calculation volume at its implementation on a computer system (microcontroller, DSP, microprocessor).

ACKNOWLEDGMENT

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