Implementation of the ISPWM-DPWM-S2 technique on a microcontroller

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***Abstract*—In this paper, we implemented on a microcontroller a modified-wave reference signal (DPWM-S2) modulated by an Inverted Sine Pulse Width Modulation (ISPWM). The microcontroller commands a three-phase asynchronous motor by means of a three-phase inverter. The results obtained from the practical application were compared to the ones obtained from a practical application using the reference signal (DPWM-S2) modulated by a triangular (classic) signal.**

I. Introduction

In order to obtain high performance products (i.e. high efficiency, low harmonic content, low price etc.), it is necessary to implement more and more sophisticated techniques. Whether they are implemented on Microcontrollers and FPGA's, due to their calculation power, the most difficult equations of control techniques such as Vector Control - Space Vector Modulation [1], Third Harmonic Injection Pulse Width Modulation (THIPWM) [2], Discontinuous Pulse Width Modulation (DPWM) [3] etc., are solved rapidly and in real time [4].

This paper describes the implementation of the reference signal DPWM-S2 modulated by the carrier signal ISPWM [5] on the C8051F120 microcontroller [6], [7]. This reference signal was chosen in order to reduce the switching losses on the transistors that make up the three-phase inverter, as they will remain in conduction or will be blocked on 4 intervals out of 12. On the other hand, the harmonic content of the line and phase voltages is also low. Moreover, because of the modulation of the reference signal with an inverted sine signal, the fundamental amplitudes of the output voltages are higher than in the case of a triangular modulation signal (classic) [8], [9], [10], [11].

II. Theoretical Considerations

Figure 1 presents three waveforms, under different colors: the color green stands for the waveform of the modulation signal inverted sine pulse width modulation (ISPWM), the color red indicates the waveform of the DPWM-S2 signal and the color blue stands for the waveform of the control signal for transistor Q^+_A within the three-phase inverter.

The latter occurs at the intersection of ISPWM and DPWM-S2 signals. Thus, if the ISPWM signal is higher than the DPWM-S2 signal, the control signal for the Q^+_A is **on**, which corresponds to its conduction state. The first intersection between the two signals is marked as q_1 and the second intersection is marked as q_2.

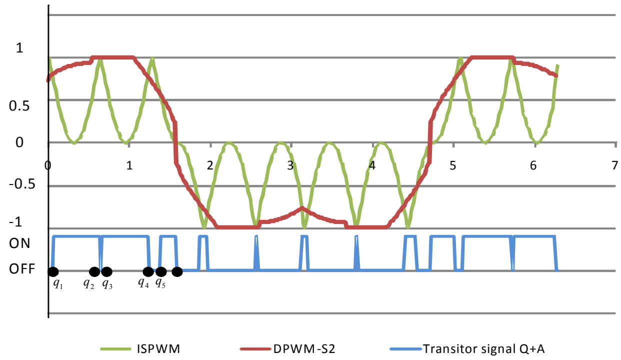

Figure 1. Waveforms of the DPWM-S2 signal, ISPWM signal and command signal for Q^+A transistor.

Figure 2 presents the three-phase inverter made up of the following transistors: Q^+_A, Q^-_A, Q^+_B, Q^-_B, Q^+_C and Q^-_C. The control signal for transistor Q^-_A is obtained by the logic inversion of the control signal for the Q^+_A transistor.

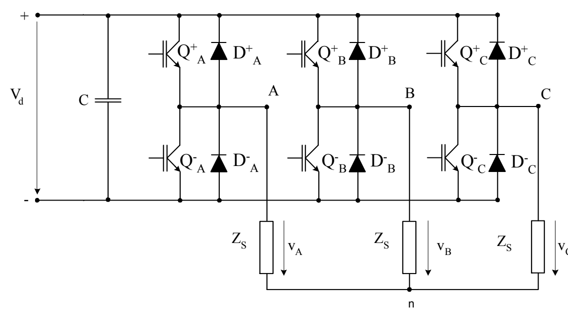

Figure 2. Three-phase inverter

The key to this control technique is finding the intersection points, marked in Fig. 1 as q_1, q_2, q_3, etc. They can be calculated by means of the following equations:

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

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

where q_x stands for the points of intersection between ISPWM and DPWM-S2, M_f is frequency ratio.

If we consider DPWM-S2 equations:

$$s_2 = \begin{cases} \sqrt{3}m_a \cos\omega_m t + m_a \sin\omega_m t - 1\,; & 0 \le \omega_m t \le \pi/6 \\ 1; & \pi/6 \le \omega_m t \le \pi/3 \\ \sqrt{3}m_a \cos\omega_m t - m_a \sin\omega_m t + 1; & \pi/3 \le \omega_m t \le \pi/2 \\ \sqrt{3}m_a \cos\omega_m t + m_a \sin\omega_m t - 1; & \pi/2 \le \omega_m t \le 2\pi/3 \\ -1; & 2\pi/3 \le \omega_m t \le 5\pi/6 \\ \sqrt{3}m_a \cos\omega_m t - m_a \sin\omega_m t + 1; & 5\pi/6 \le \omega_m t \le \pi \\ \sqrt{3}m_a \cos\omega_m t + m_a \sin\omega_m t + 1 & \pi \le \omega_m t \le 7\pi/6 \\ -1; & 7\pi/6 \le \omega_m t \le 4\pi/3 \\ \sqrt{3}m_a \cos\omega_m t - m_a \sin\omega_m t - 1; & 4\pi/3 \le \omega_m t \le 3\pi/2 \\ \sqrt{3}m_a \cos\omega_m t + m_a \sin\omega_m t + 1; & 3\pi/2 \le \omega_m t \le 5\pi/3 \\ 1; & 5\pi/3 \le \omega_m t \le 11\pi/6 \\ \sqrt{3}m_a \cos\omega_m t - m_a \sin\omega_m t - 1; & 11\pi/6 \le \omega_m t \le 2\pi \end{cases} \quad (3)$$

and replace y with each interval of time equation (3) in (1) and (2), we obtain the intersection points q_1, q_2, q_3, etc. If we try to represent these intersection points as a waveform, it can be seen in Fig. 3 next to the original signal DPWM-S2.

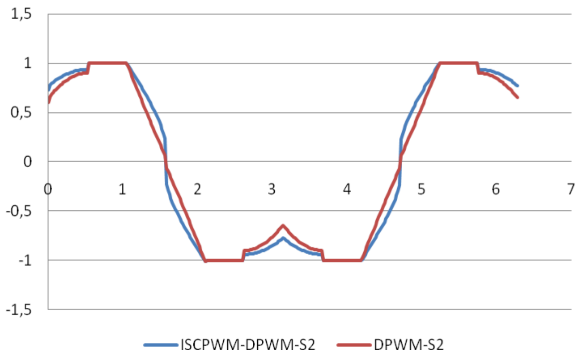

Figure 3. Waveforms of the ISPWM-DPWM-S2 and DPWM-S2 signals

As illustrated in Figure 3, the newly created ISPWM-DPWM-S2 signal has a wider area than the original DPWM-S2 signal, and this finally leads to voltage increase at the output of the three-phase inverter.

In order to clarify this point even further, Figure 4 presents the waveforms of the DPWM-S2 reference signal and of the modulation ISPWM and triangular PWM (classic) signals. The intersection of these signals will determine the conduction periods d_1 and d_2.

III. SOFTWARE ALGORITHM

The ISPWM-DPWM-S2 signal generation software was written in the C programming language for microcontroller C8051F120. First, its internal blocks are initialized, such as Analog to Digital Converter, Timers, PLL, PWM, Ports and UART communication. The software follows the software diagrams presented in Fig. 5 (a) and (b).

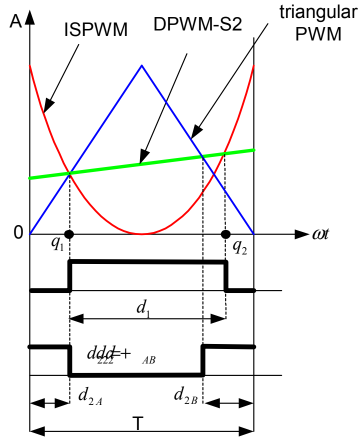

Figure 4. Waveforms of the DPWM-S2, ISPWM, triangular PWM and d1, d2 PWM signals

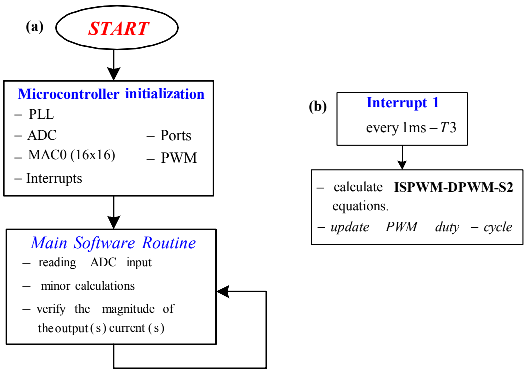

Figure 5. (a) Main control diagram
(b) Diagram of interrupt 1 called by T3 timer

We present next a part of the software written in the C programming language for the generation of signals f0, f1 and f2, corresponding to the ISPWM-DPWM-S2 signals, also called f0 for phase A, f1 for phase B and f2 for phase C. These signals are similar but shifted between them with 120 phase degrees.

```
void ispwm_dpwm_s2(void)
{
f0 = dpwm_s2(tr0);
if (tr0 <= 1.57)
     {
             f0a = 3.1415 - 2*asin(1 - f0);
     }
     else    if(tr0<=4.71 && tr0>1.57)
                    {
                    f0a = 2*asin(1 + f0) - 3.1415;
                    }
             else if(tr0<=4.71+3.14 && tr0>4.71)
                    {
                    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 = dpwm_s2(tr1);
if (tr1 <= 1.57)
```

```
        {
                f1a = 3.1415 - 2*asin(1 - f1);
        }
        else    if(tr1<=4.71 && tr1>1.57)
                {
                f1a = 2*asin(1 + f1) - 3.1415;
                }
                else if(tr1<=4.71+3.14 && tr1>4.71)
                        {
                        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 = dpwm_s2(tr2);
if (tr2 <= 1.57)
        {
                f2a = 3.1415 - 2*asin(1 - f2);
        }
else    if(tr2<=4.71 && tr2>1.57)
        {
                f2a = 2*asin(1 + f2) - 3.1415;
        }
        else if(tr2<=4.71+3.14 && tr2>4.71)
                {
                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;}
```

IV. Simulation and Experimental Results

After the implementation of the above software on C8051F120 microcontroller, the ISPWM-DPWM-S2 and DPWM-S2 signals can be seen on the same print screen of the oscilloscope, in Figure 6.

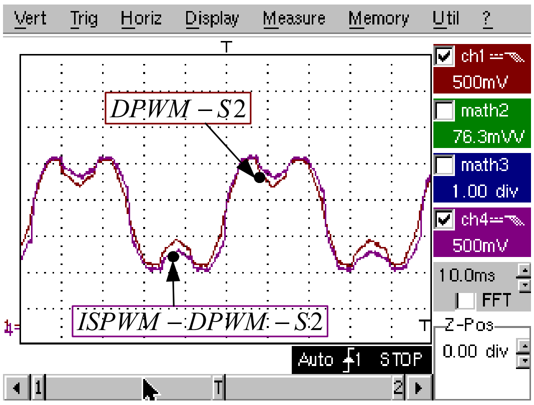

Figure 6. Oscilloscope waveforms of the DPWM-S2 and ISPWM-DPWM-S2 signals

For the simulation and the practical part we used 315V supply voltage, a 0.37KW AC inductance machine and 17.25 Khz switching frequency.

Figure 7 shows the phase voltage A in three cases: (a) phase voltage and harmonic spectrum for the practical part using ISPWM-DPWM-S2 signal, (b) phase voltage and harmonic spectrum obtained by simulations in SPICE and (c) phase voltage and harmonic spectrum for the practical part using the DPWM-S2 signal.

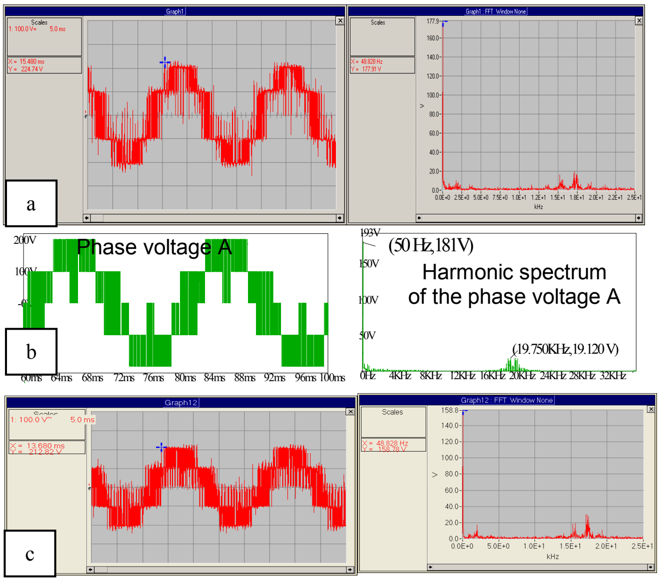

Figure 7. (a) Phase voltage using ISPWM-DPWM-S2 obtained by oscilloscope
(b) Phase voltage using ISPWM-DPWM-S2 obtained by simulations
(c) Phase voltage using DPWM-S2 obtained by oscilloscope

As illustrated in Figure 7, the fundamental harmonic of the phase voltage is 177V in (a), 181V in (b) and 158V in (c). The results obtained in Figure 7 clearly show that the technique of modulating a DPWM-S2 signal by an inverted sinus (ISPWM-DPWM-S2) is more efficient than the classic (triangular) modulation: the reference signal obtained has a wider area and, implicitly, a voltage with a higher fundamental amplitude on the load resistance.

Figure 8 shows the line to line voltage in three cases: (a) line to line voltage and harmonic spectrum for the practical part using ISPWM-DPWM-S2 signal, (b) line to line voltage and harmonic spectrum obtained by simulations in SPICE and (c) line to line voltage and harmonic spectrum for the practical part using the DPWM-S2 signal.

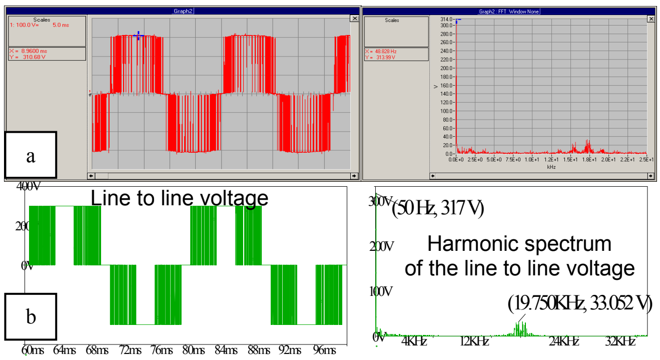

Figure 8. (a) Line to line voltage using ISPWM-DPWM-S2 obtained by oscilloscope
(b) Line to line voltage using ISPWM-DPWM-S2 obtained by simulations

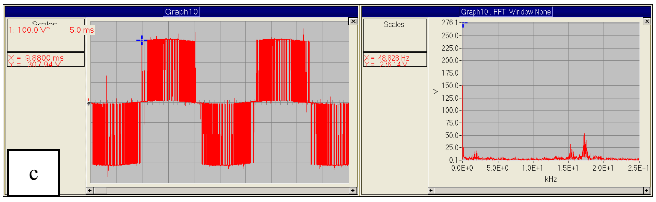

Figure 8. (c) Line to line voltage using DPWM-S2 obtained by oscilloscope

As illustrated in Figure 8, the fundamental harmonic of the line to line voltage is 313V in (a), 317V in (b) and 276V in (c).

Figure 9 shows the phase current A: (a) phase current A and harmonic spectrum for the practical part using ISPWM-DPWM-S2 signal, (b) phase current A and harmonic spectrum obtained by simulations in SPICE and (c) phase current A and harmonic spectrum for the practical part using the DPWM-S2 signal.

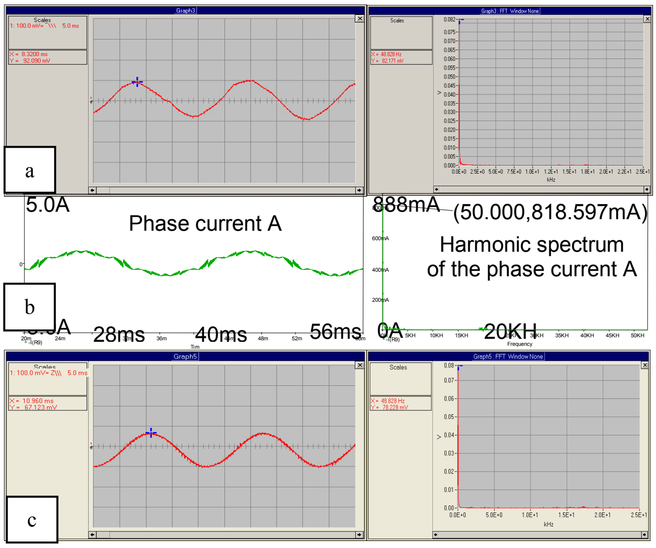

Figure 9. (a) Phase current A using ISPWM-DPWM-S2 obtained by oscilloscope
(b) Phase current A using ISPWM-DPWM-S2 obtained by simulations
(c) Phase current A using DPWM-S2 obtained by oscilloscope

As illustrated in Figure 9, the fundamental harmonic of the phase current A is 0.82A in (a), 0.81A in (b) and 0.78A in (c). Figure 10 shows the practical circuit used for testing.

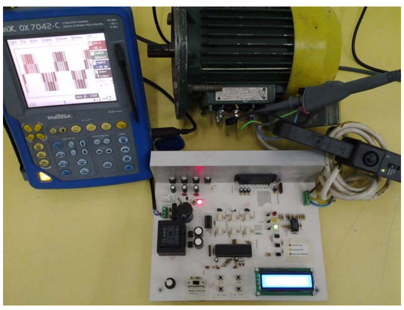

Figure 10. The practical circuit contains: three-phase inverter with microcontroller, AC machine and oscilloscope

V. Conclusion

In this paper we used the ISPWM-DPWM-S2 technique implemented on a microcontroller to control a three-phase inverter. This technique was tested by simulations and practically. We compared the results obtained by simulations with the results obtained based on the practical circuit in order to emphasize the performance of this technique. We also compared these results with the results obtained based on the practical circuit, when we used the control technique consisting in a DPWM-S2 modulated by a triangular (classic) modulation signal. We obtained significant increases of the fundamental harmonics amplitudes of the voltages at the output of the three-phase inverter. However, this control technique has got a drawback: it requires a high calculation volume from the microcontroller.

References

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