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# LOW COST SOLUTION FOR AC MOTOR CONTROL APPLICATIONS

BY

**CRISTIAN AGHION*, MIHAI LUCANU and OVIDIU URSARU**

"Gheorghe Asachi" Technical University of Iaşi
Faculty of Electronics, Telecommunications and Information Technology

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**Abstract.** This paper presents a simple, low-cost, effective solution for AC motor control. The AC motor is driven by a three-phase inverter which is controlled, in turn, by a microcontroller functioning based on the Discontinuous Pulse Width Modulation control algorithm. The circuit was simulated and implemented practically in order to demonstrate its adequate functioning.

**Key words:** power conversion; circuit simulation; software.

## 1. Introduction

The asynchronous motor is the most frequently used medium- and high-power motor in general use applications. Unlike other types of motors, it has advantages such as: simple and robust structure, low price and low maintenance costs (Bose, 1987). One of the characteristics of asynchronous machines is the fact that their rotation speed is slightly different from the speed of the rotating field, hence their name of asynchronous motors. For this type of motors, speed diminishes slightly with load, and this is why their mechanical characteristic is called derivation characteristic. Asynchronous motors are used in operations that require speed to be independent from load: common machine tools, blowers, certain lifting machines, elevators etc. (Cetin & Sazak, 2009). If there was no friction in the system, the rotor would spin at synchronous speed, but the

*Corresponding author: *e-mail*: aghion@etti.tuiasi.ro

motor would not produce effective torque. When applying load on the motor, its speed decreases, making the rotor bars cross the magnetic lines of the rotor field and generate the rotor rejection force. The rotating magnetic field will induce voltage into the rotor coil by means of electromagnetic induction. The voltage creates electric current through the coil; the electromagnetic force applied on it sets the rotor in motion in the direction of the rotating magnetic field. The motor is also called asynchronous because motor speed is always lower than the rotating magnetic field speed, also called synchronism speed.

Given the interest in AC motors, various control techniques with increasing efficiency were developed in order to obtain maximum dynamic motor performance, maximum motor torque and low electromagnetic disturbances in the network and in the motor, respectively (Neacşu, 2013). The most frequently used modulation techniques for AC motor control are the following: Sinusoidal Pulse Width Modulation (SPWM), Space Vector Modulation (SVM), Third Harmonic Injection Pulse Width Modulation, Discrete Pulse Width Modulation, etc. (Neacşu, 2013; CRC Press, Rata, 2012)

This paper presents an implementation method of the Discrete Pulse Width Modulation (DPWM) control technique (Aghion, 2010; Valachi, 2009) on a microcontroller that controls further a three-phase inverter (Ursaru, 2009) in order to make a three-phase asynchronous motor rotate at different speeds one way or another (Erfidan, 2008). The DPWM control technique was chosen because has it an important advantage: it reduces the number of commutations in an output voltage period. Out of 6 conduction intervals, in two intervals the transistors in the inverter are in continuous conduction and in the other four there are switching moments; this also results from eq. (1) (Hava, 1998; Aghion 2010). The reduced number of commutations in an output voltage period means diminished power losses on the power transistors, which leads to less heating and therefore, the use of smaller heat-sinks for these transistors.

## 2. Circuit Analysis

Fig. 1 presents the block diagram of the development platform, made up of: one-phase rectifier, inverter and microcontroller control circuit.

Fig. 2 presents the electronic diagram of an inverter used for controlling a three-phase asynchronous motor.

The program implemented on the microcontroller respects the Discrete Pulse Width Modulation (DPWM) control technique that uses the reference signal S5 characterised by:

$$s_5 = \begin{cases} \sqrt{3} m_a \cos \omega_m t + m_a \sin \omega_m t - 1; & 0 \le \omega_m t \le 2\pi/3 \\ -1; & 2\pi/3 \le \omega_m t \le \pi \\ -1; & \pi \le \omega_m t \le 4\pi/3 \\ \sqrt{3} m_a \cos \omega_m t + m_a \sin \omega_m t - 1; & 4\pi/3 \le \omega_m t \le 2\pi \end{cases} \tag{1}$$

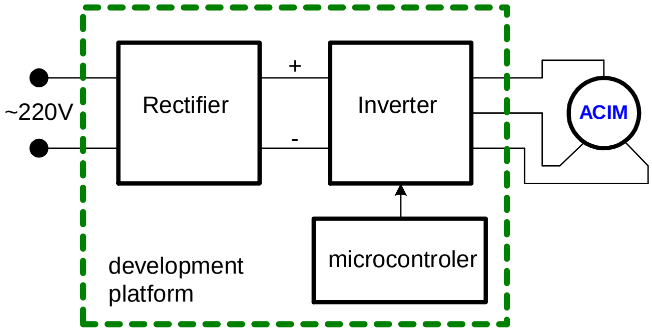



Fig. 1 – Block diagram of the development platform.

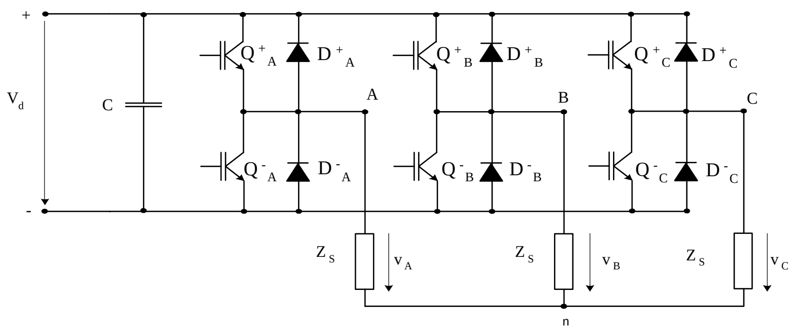



Fig. 2 – Power inverter architecture.

Matlab was used for deducing the switching moments used in the microcontroller program (Comsa, 2012). The switching moments are meant to set the conduction periods of the six transistors in the three-phase inverter. See below the program used for obtaining the DPWM S5 reference signal.

```
ma = 0.95;
a  = 0:pi/32:4*pi;
a1 = length(a)
    for a2 = 1:a1
            if (a(a2)>=0 & a(a2)<2*pi/3 )
            bf(a2)=(sqrt(3)*ma*cos(a(a2))+ma*sin(a(a2))-1);
            end
            if (a(a2)>=2*pi/3 & a(a2)<pi)
                bf(a2) = -1;
            end
            if (a(a2)>=pi & a(a2)<4*pi/3)
                bf(a2) = -1;
            end
            if (a(a2)>=4*pi/3 & a(a2)<2*pi)
            bf(a2)=(sqrt(3)*ma*cos(a(a2))-ma*sin(a(a2))-1);
            end
    end
plot(a,bf)
AXIS([0 12.5+2*pi/3 -1.5 1.5])
grid on
```

Fig. 3 presents the graphic representation of the Discrete Pulse Width Modulation (DPWM) S5 reference signal.

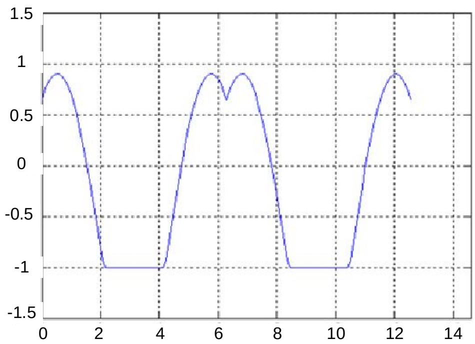



Fig. 3 – Discrete Pulse Width Modulation (DPWM) S5 signal obtained using Matlab program.

The Discrete Pulse Width Modulation (DPWM) S5 reference signal is modulated by a $t_r$ triangular signal in order to obtain the control times for the transistors making up the three-phase inverter ($Q_A^+, Q_A^-, Q_B^+, Q_B^-, Q_C^+$ and $Q_C^-$). Fig. 4 illustrates the waveforms of the modulator signals (s5a, s5b and s5c) obtained for the DPWM-S5 technique and the control signals for the transistors within the three-phase inverter.

More precisely, switching moments are calculated for transistors $Q_A^+, Q_B^+$ and $Q_C^+$ and control signals for transistors $Q_A^-, Q_B^-$ and $Q_C^-$ will be obtained by complementing the signals corresponding to transistors $Q_A^+, Q_B^+$ and $Q_C^+$; this is carried out by the practical circuit.

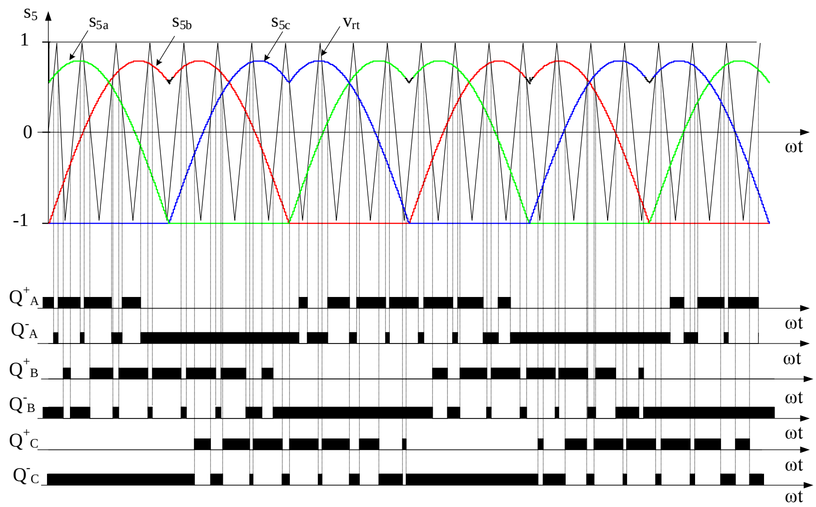



Fig. 4 – Waveforms of the reference and modulator signals and control signals for all six transistors.

### 3. Software Control

The program used for generating the control signals of the transistors in the three-phase inverter ($Q_A^+, Q_B^+$ and $Q_C^+$) was written in C language for the Microchip PIC18F4431 microcontroller (Bârleanu *et al.*, 2012). Since this microcontroller is low-cost and low-performance (low operating speed, reduced RAM and ROM memory), we opted for the ROM storage of the switching values for transistors ($Q_A^+, Q_B^+$ and $Q_C^+$) in the form of a look up table. This way we avoided the real time calculation of eq. (1). The diagram of the program is shown in Fig. 5. Microcontroller PIC18F4431 is initialized first (Input/Output Ports, Timer1, ADC, Interrupts), followed by the execution of the instructions in the main program loop. The T1 timer causes the *main loop program* to generate an interruption at a variable frequency, depending on the frequency chosen by the user. Thus, during the interruption generated by TMR1, update is performed on the duty-cycle values for the generation of the signals corresponding to the transistors ($Q_A^+, Q_B^+$ and $Q_C^+$). See below a part of the software implemented on the microcontroller.

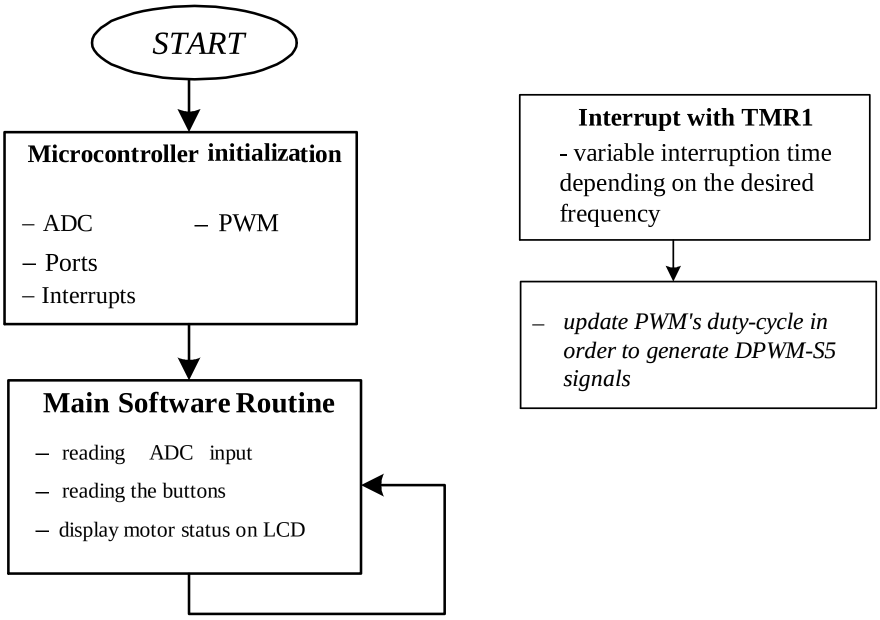



Fig. 5 – Software control diagram.

```
void interrupt ISR(void)
{
       if(TMR1IF && TMR1IE)
```

```
        {
                unsigned char temp_index1, temp_index2;
                unsigned char sin1, sin2, sin3;
                TMR1IF = 0;
                TMR1 = timer1_base;
                if(volts_offset)
                {
                        OVDCOND = 0B11111111;
                        if(sens == FWD) //
                        {
                                temp_index1 = (sin_index+43)%64;
                                temp_index2 = (sin_index+85)%64;
                        }
                        else //
                        {
                                temp_index2 = (sin_index+43)%64;
                                temp_index1 = (sin_index+85)%64;
                        }
                        if(freq<48)
                        {
                        sin1=(sin[sin_index]*(freq+volts_offset))>>6;
                        sin2=(sin[temp_index1]*(freq+volts_offset))>>6;
                        sin3=(sin[temp_index2]*(freq+volts_offset))>>6;
                        }



                                PDC0L = sin1<<4;
                                PDC0H = (sin1&0b11110000)>>4;
                                PDC1L = sin2<<4;
                                PDC1H = (sin2&0b11110000)>>4;
                                PDC2L = sin3<<4;
                                PDC2H = (sin3&0b11110000)>>4;

                        sin_index++;
                        if(sin_index==64)
                                sin_index = 0;
                }
                else
                {
                        OVDCOND = 0B00000000;
                }
        }
}
```

## 4. Simulation and Experimental Results

After software implementation on PIC18F4431 microcontroller, it generates modulating signals DPWM-S5, designated as $s_{5a}$, $s_{5b}$ and $s_{5c}$, as illustrated in Fig. 6. Fig. 7 presents the control signals for transistors $Q_A^+, Q_B^+$ and $Q_C^+$. Control signals for transistors $Q_A^-, Q_B^-$ and $Q_C^-$ will be obtained by complementing the signals corresponding to transistors $Q_A^+, Q_B^+$ and $Q_C^+$ which is carried out by the practical circuit.

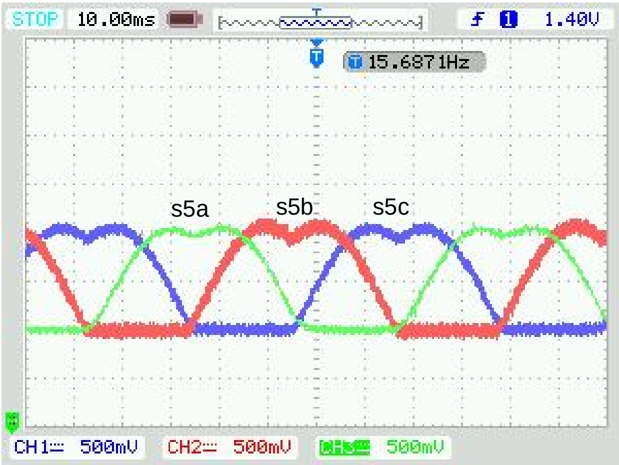



Fig. 6 – Software control diagram.

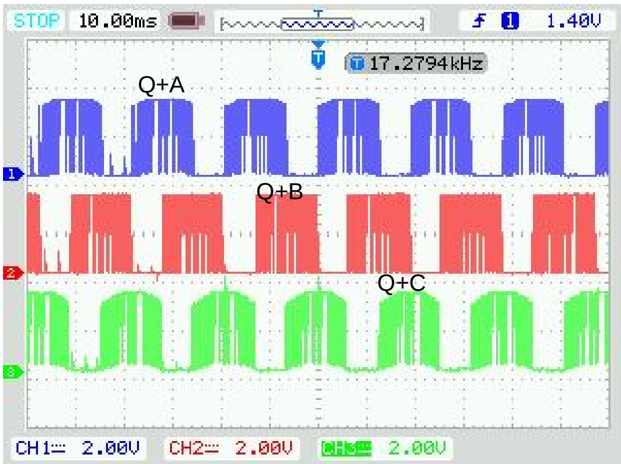
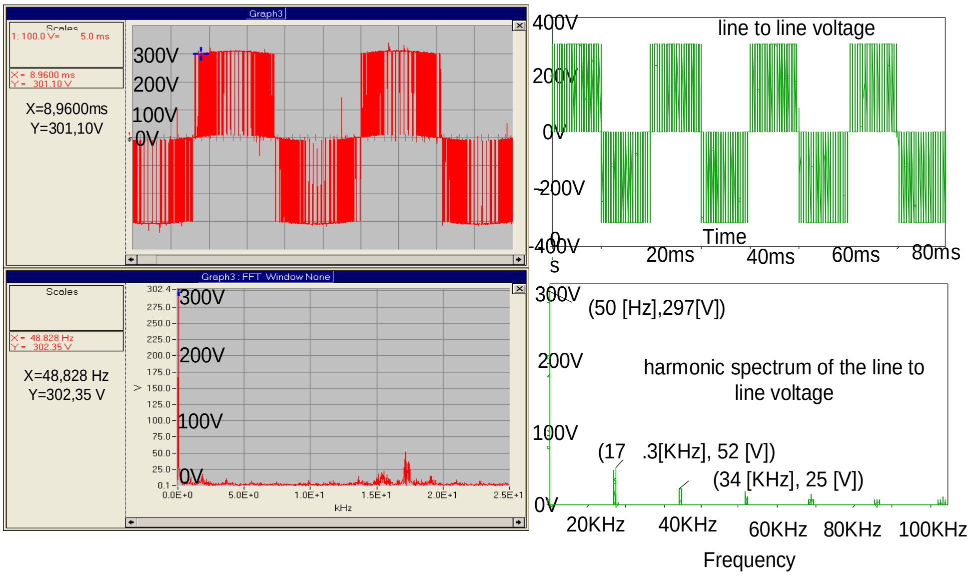



Fig. 7 – Control signals for $Q_A^+, Q_B^+$ and $Q_C^+$ transistors.

Fig. 8 shows waveforms between phases A and B of the line voltage; on the left side these waveforms are read on the oscilloscope, and on the right side, they are obtained by simulations. The harmonic content is presented below.

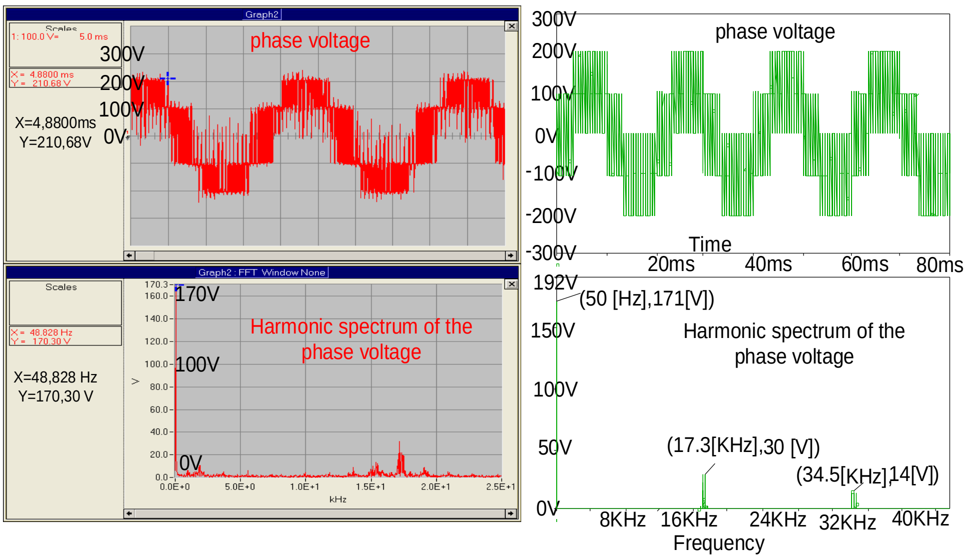
The power supply voltage of the three-phase inverter is 310 V. As load current, we used a 0.37 kW three-phase motor.

Fig. 9 shows the waveform of the voltage between phase A and the virtual neutral point. On the left side the waveform is read on the oscilloscope, and on the right side, it is obtained by simulation. The harmonic content is presented below.




*a* *b*

Fig. 8 – *a* – waveforms and harmonic spectrum of the line to line voltage, obtained from the oscilloscope; *b* – waveforms and harmonic spectrum of the line to line voltage, obtained by simulations.




*a* *b*

Fig. 9 – *a* – waveforms and harmonic spectrum of the phase voltage A, obtained from the oscilloscope; *b* – waveforms and harmonic spectrum of the phase voltage A, obtained by simulations.

Fig. 10 shows the practical circuit that allowed the experimental measurements to be performed. The source of the three-phase inverter is the circuit IRAMX16UP60A.

Fig. 10 – Practical circuit.

## 5. Conclusions

This paper presents a low-cost application used for AC motor control. The software implemented on the PIC18F4431 microcontroller uses the Discrete Pulse Width Modulation (DPWM) control technique that allows the transistors to be on or off in two out of six conduction intervals of the transistors in the three-phase inverter. This is important for reducing the dissipated power and implicitly for the use of a smaller heat sink. We tested the circuit both by simulation and practically and we got very good results.

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## SOLUȚIE DE IMPLEMENTARE DE PREȚ SCĂZUT PENTRU CONTROLUL MOTOARELOR DE CURENT ALTERNATIV

(Rezumat)

Este prezentată o aplicație low cost folosită pentru controlul motoarelor de curent alternativ. Softul implementat pe microcontrolerul PIC18F4431 ține cont de tehnica de comandă Discrete Pulse Width Modulation (DPWM) ce permite ca din şase intervale de conducție ale tranzistoarelor din invertorul trifazat, în două dintre intervale, tranzistoarele să fie în stare conducție sau în stare de blocare. Acest lucru este util pentru a micşora puterea disipată pe acestea şi implicit utilizarea unui radiator mai mic. Circuitul a fost testat în simulare cât şi practic obținându-se rezultate foarte bune. Utilizarea acestei strategii de comandă permite pe de o parte, micşorarea puterii disipate pe dispozitivele semiconductoare şi implicit utilizarea unor radiatoare de dimensiuni reduse, iar pe de altă parte la creşterea randamentului circuitului de comandă a motorului.