Software Control for PWMA (Angular Pulse Width Modulation)

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***Abstract*--This paper describes a software control method using the equations of PWMA modulation to command a three-phase inverter.**

I. INTRODUCTION

The modulation strategy has the role to modify the ratio between the fundamental magnitude voltage from the inverter output and the power supply value and also to improve the harmonic content of the voltage and load current. [1],[2],[3].

The various modulation techniques differ by the method of calculation of the switching time moments of the switching device. Most of these modern technique modulations are based on the calculation of these moments according to the desired output voltage and use digital control systems or microcontrollers. [4],[5],[6].

II. COMMAND AND CONTROL ALGORITHM

The command software was made for C8051F120 microcontroller. This microcontroller was used because it has high working speed (100MHz -> 100MIPS) and it is easy to use. In order to generate the command signals for the three-phase inverter control, the PWM internal block was used. The flowchart of the control software algorithm is presented in Figure 1a, Figure 1b and 1c show the flowchart of Interrupt 1 and Interrupt 2.

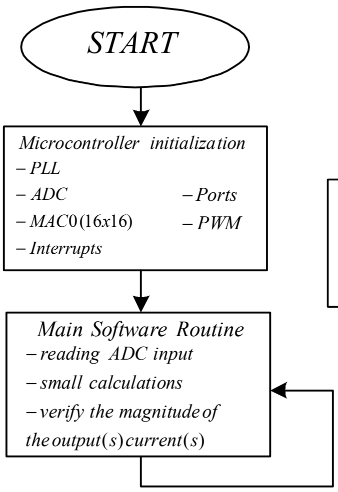


Figure. 1a Software control flowchart

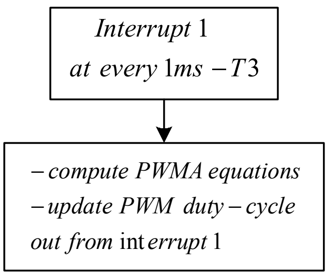


Figure. 1b Flowchart of Interrupt 1

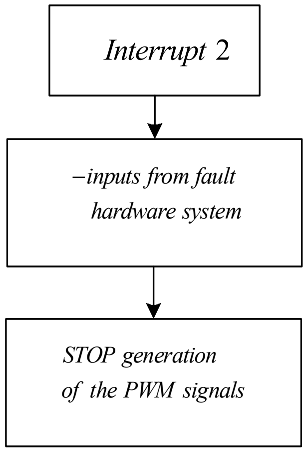


Figure. 1c Flowchart of Interrupt 2

The first step is the microcontroller initialization (Input/Output Ports, ADC, PLL, Timers, PWM, etc.), the second step is the execution of the main software routine, written in C language where the value of the Analog to Digital Converter is continually read. This value is useful for the calculation of the magnitude modulation of the wave for desired signal. The software contains also two interrupt routines:

Interrupt 1 appears at every 1ms because the Timer T3 surpasses itself. In this routine all three command signals are computed (with 120° phase-shift between them); there are three signals because it is necessary to command transistors Q_A^+, Q_B^+ and Q_C^+ , and for Q_A^-, Q_B^- and Q_C^- transistors, the command signals are obtained by the complementation of the original signals.

Interrupt 2 is used in order to disable the PWM command block when the load current (at least one of the output currents) exceeds the over-current limit (10A) or the short-current limit (50A). (values obtained after two successive measurements at 10µs).

III. THEORETICAL CONSIDERATIONS REGARDING THE MODULATION SIGNAL

The modulation signal has the waveform shape shown in Figure 2 and contains the equations (1), which are true for certain interval moments.

$$s_{j3}=\begin{cases} m_a(\sin\omega_m t+0.16\sin 3\omega_m t)-m_a/3; & 0\le\omega_m t\le\pi/3 \\ 1; & \pi/3\le\omega_m t\le 2\pi/3 \\ m_a(\sin\omega_m t+0.16\sin 3\omega_m t)-m_a/3\,; & 2\pi/3\le\omega_m t\le\pi \\ m_a(\sin\omega_m t+0.16\sin 3\omega_m t)+m_a/3; & \pi\le\omega_m t\le 4\pi/3 \\ -1; & 4\pi/3\le\omega_m t\le 5\pi/3 \\ m_a(\sin\omega_m t+0.16\sin 3\omega_m t)+m_a/3; & 5\pi/3\le\omega_m t\le 2\pi \end{cases} \qquad (1)$$

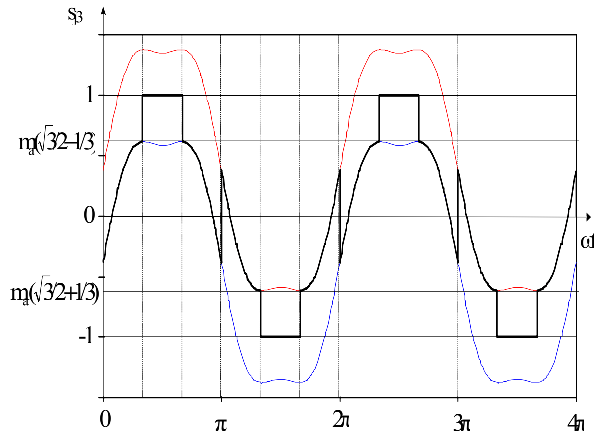


Figure. 2 The modulation signal s_{j3}

This modulation signal s_{j3} has at its origin the signal with 3rd harmonic injection, and the usual m_a=1.15.

Figure. 3 shows the power inverter schematics used for the simulation.

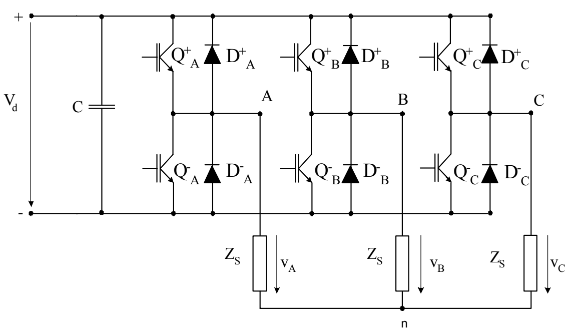


Figure. 3 Power Inverter architecture

The PWMA command system with modulation wave s_{j3}, compared with other command systems having modified modulation wave, allows a reduction of the commutation of the power transistors because this method reduces the total number of power transistor commutations during a semi-period of the modulation signal.

Figure 4 shows the waveforms of the command signals (s_{1a}, s_{1b} and s_{1c}) obtained for PWMA and the control signals for all six transistors within the power inverter.

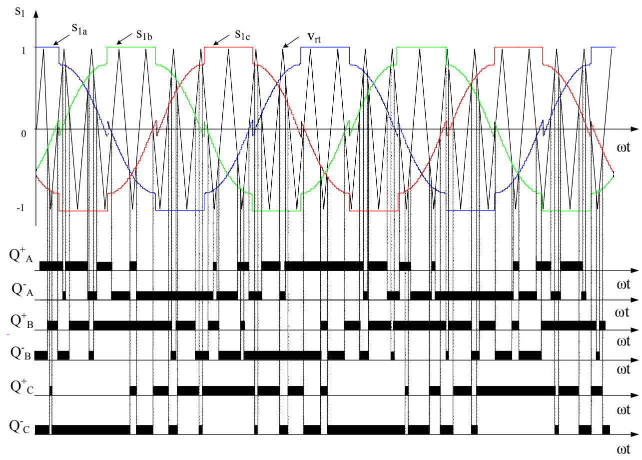


Figure.4 Waveforms of the command and control signals

IV. SOFTWARE CONTROL

The command software is written in C language, applied to C8051F120 microcontroller made by Silicon Laboratory Company. The software routine for the calculation of the PWMA signals (s_{1a}, s_{1b} and s_{1c}) is shown below. It should be taken into consideration the fact that all these calculation are made in Interrupt 1 routine (having a lower priority), which is executed at every 1ms when Timer T3 surpasses itself. The necessary computing time is approximately 400µs, performance obtained using MAC 16x16 (Multiply and Accumulate) block and high working speed of the microcontroller (100MHz-100MIPS / millions of instructions per second).

```
void Timer3_ISR (void) interrupt 14   // at every 1ms
{
        unsigned char SFRPAGE_SAVE = SFRPAGE;
        gigi();
        SFRPAGE = TMR3_PAGE;
        TF3   = 0;
        SFRPAGE = SFRPAGE_SAVE;
}
//-------------------------------------------------
// Compute modulation signals 1
//-------------------------------------------------
void gigi(void)
{
        signed char s;          // signed sine
        unsigned char o;        // output value
        unsigned int p;         // 16 bit product
        unsigned char SFRPAGE_SAVE = SFRPAGE;

        float f0, f1, f2, tr0, tr1, tr2;
        Sum += (freq << 6);
        q0 = (Sum >> 8);
        tr0 = (q0/40.6);

                if(!reverse)
                {
                        tr1 = tr0 + xx1;
                        tr2 = tr0 + xx2;
                }
                else
                {
                        tr2 = tr0 + xx1;
                        tr1 = tr0 + xx2;
                }
SFRPAGE    = PCA0_PAGE;
```

```
f0 = lac(tr0);
s = f0*0x7F;
p = amplitude * (signed int)s;          //multiply by v
o = p>>8;                     // throw away low byte
o += 0x80;                    // center sinewave at 50%
PCA0CPH0 = o;
        f1 = lac(tr1);
s = f1*0x7F;
p = amplitude * (signed int)s;          //multiply by v
o = p>>8;                     // throw away low byte
o += 0x80;                    // center sinewave at 50%
PCA0CPH1 = o;
        f2 = lac(tr2);
s = f2*0x7F;
p = amplitude * (signed int)s;          //multiply by v
o = p>>8;                     // throw away low byte
o += 0x80;                    // center sinewave at 50%
PCA0CPH2 = o;
SFRPAGE = SFRPAGE_SAVE;      }
//-----------------------------------------------------
// Compute modulation signals 2
//-----------------------------------------------------
float lac(float tr)
{       float iti;
        if(tr<1.046 && tr>0)
        {iti = ma*(sin(tr)+0.167*sin(3*tr))-0.38;}
        if(tr<2.093 && tr>1.046)
                {iti = 1;}
        if(tr<3.151 && tr>2.093)
        {iti = ma*(sin(tr)+0.167*sin(3*tr))-0.38;}
        if(tr<4.186 && tr>3.151)
        {iti=ma*(sin(tr)+0.167*sin(3*tr))+0.38;}
        if(tr<5.233 && tr>4.186)
                {iti = -1;}
        if(tr<6.28 && tr>5.233)
        {iti = ma*(sin(tr)+0.167*sin(3*tr))+0.38;}
        if(tr<7.326 && tr>6.28)
        {iti = ma*(sin(tr)+0.167*sin(3*tr))-0.38;}
        if(tr<8.373 && tr>7.326)
                {iti = 1;}
        if(tr<9.42 && tr>8.373)
        {iti = ma*(sin(tr)+0.167*sin(3*tr))-0.38;}
        if(tr<10.466 && tr>9.42)
        {iti = ma*(sin(tr)+0.167*sin(3*tr))+0.38;}
        return iti;    // finish of  T3 - ISR.   }
```

V. SIMULATION AND EXPERIMENTAL RESULTS

Figures 5 shows two modulation signals (s_{1a} and s_{1b}) having a $\frac{2\pi}{3}$ phase-shift between them, obtained by measurement. These signals are a graphical representation of the equations presented in “float lac(float tr)” software routine.

Figure 6a and 6b show the waveforms of the command signals for Q_A^+ *and* Q_B^+ transistors from the three-phase inverter. It is important to mention that the modulation was a triangular modulation wave with 21.5KHz carrier frequency.

Figure 7 shows the same waveforms for Q_A^+ and Q_B^+ transistors, and the area was magnified significantly. It can be seen clearly the “center align” method, often used in Inverter command to control motors such as (AC, BLDC, etc.).

After simulation using Spice – Orcad – Cadence program, the following waves were obtained, shown in Figure 8.

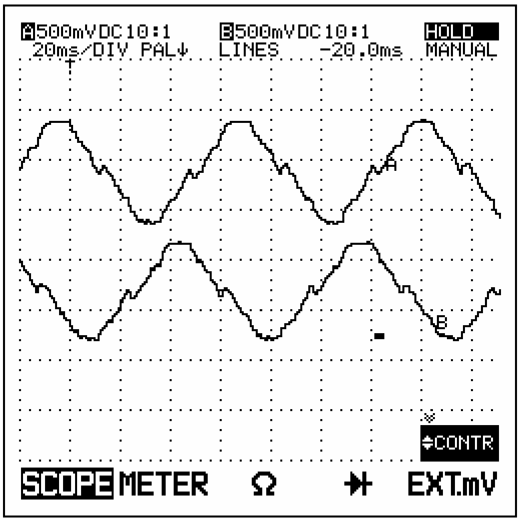
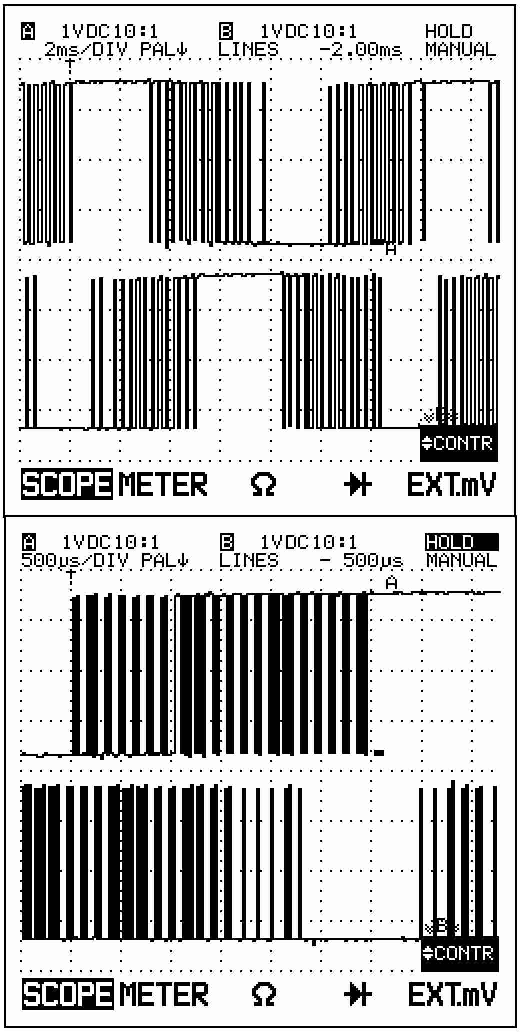


Figure. 5 Modulation signals (s_{1a} and s_{1b}) obtaind by measurement



Figures 6a and 6b show the measurement waveforms from the Oscilloscope, of the command signals for Q_A^+ *and* Q_B^+ transistors.

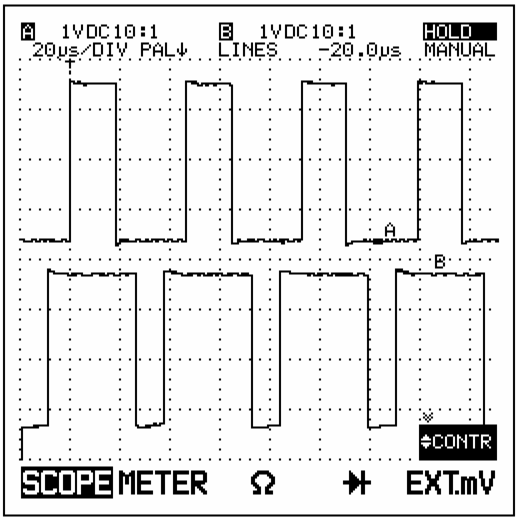


Figure. 7 Center align signals – s_{1a} and s_{1b} signals

VI. CONCLUSION

This paper aimed at implementing the PWMA algorithm using microcontroller for three-phase Inverters command. Although this PWMA technique is of high performance, we can't say that this technique is the best (considering also the frequency response), but it offers a great advantage, determining a reduction of the number of the commutations of the power transistors from the three-phase Inverter. This will determine small power losses, increasing the efficiency of the inverter.

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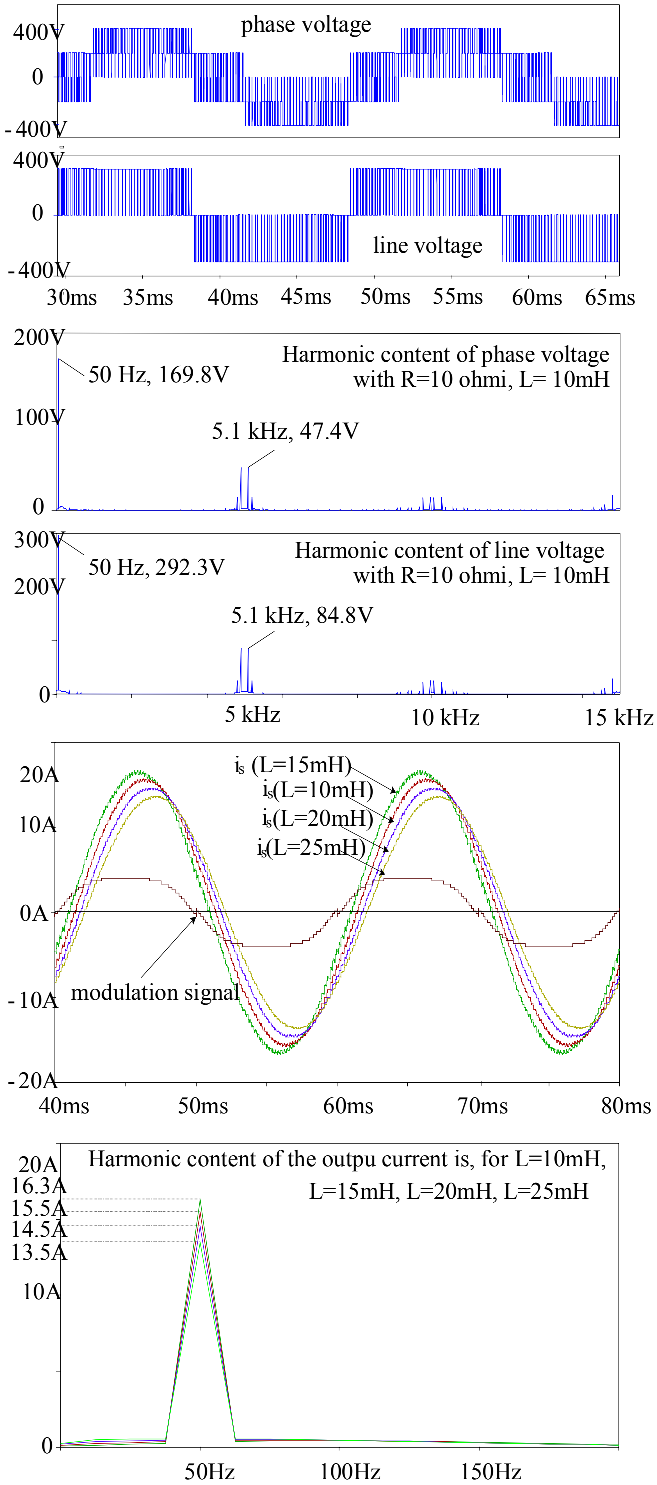

Figure. 8 Waveforms of the output voltage (line voltage and phase voltage) and output current obtained by simulations.