The three-phase inverter controlled by PWMA technique, used in AC motors supply

asist. ing. C. Aghion, prof. dr. ing. M. Lucanu,
sl. dr. ing. O. Ursaru, drd. ing. C. Pavel, drd. ing. C. Petrea
"Gh. ASACHI" Technical University of Iasi, Faculty of Electronics and Telecommunications, Bulevardul Carol I, nr.11, RO-700506 Iasi

Abstract

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. The various modulation techniques differ by the method of calculation of the switching time moments of the switching device. This paper studies by comparison the results obtained from the simulation of the three-phase inverter controlled by PWMA (Angular Pulse Width Modulation) technique and the results obtained from the practical design of the circuit tested by simulation.

Introduction

PWMA [1] command technique is a high performance computational control method, having as a main advantage the reduction of the number of commutations of the power transistors within the three-phase inverter, as compared to other modulation techniques, eg. Sinusoidal Pulse Width Modulation (SPWM) [2], Space Vector Modulation (SVM) [3], etc. The number of commutations is reduced, as considering equations (1), for two time intervals (out of six), some transistor are in continuous conduction, and the power looses in commutation should be theoretical by with $\frac{1}{3}$ smaller if SPWM or SVM techniques were used. With a reduced number of commutations, power looses on the transistors is decreasing, caloric power is decreasing also and as a result, smaller heat-sinks are needed on the same transistors.

Theoretical considerations

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

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

This modulation signal s_{j3} [4] has at its origin the signal with 3^{rd} harmonic injection [10], and the usual $m_a = 1.15$.

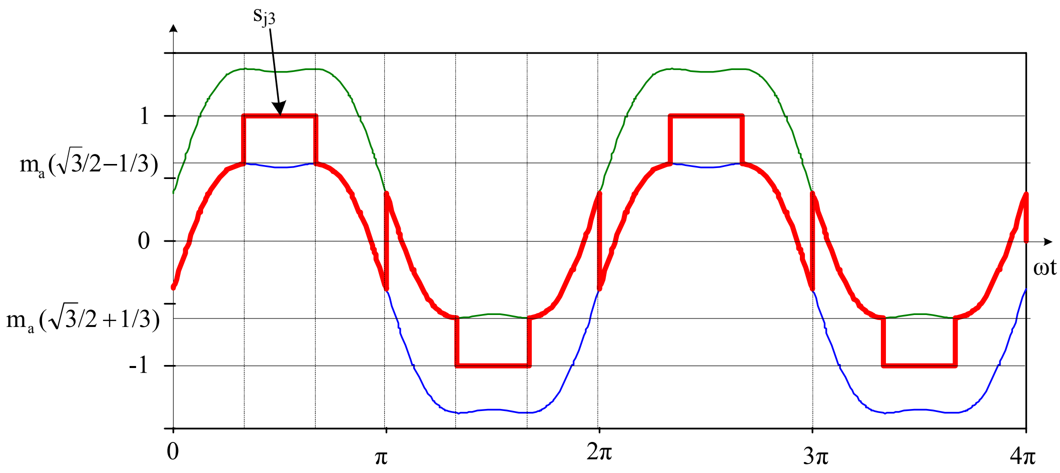

Fig. 1 Show the waveform of the modulation signal s_{j3}

Simulation results

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.
Fig. 2 shows the power inverter schematics used for the simulation.

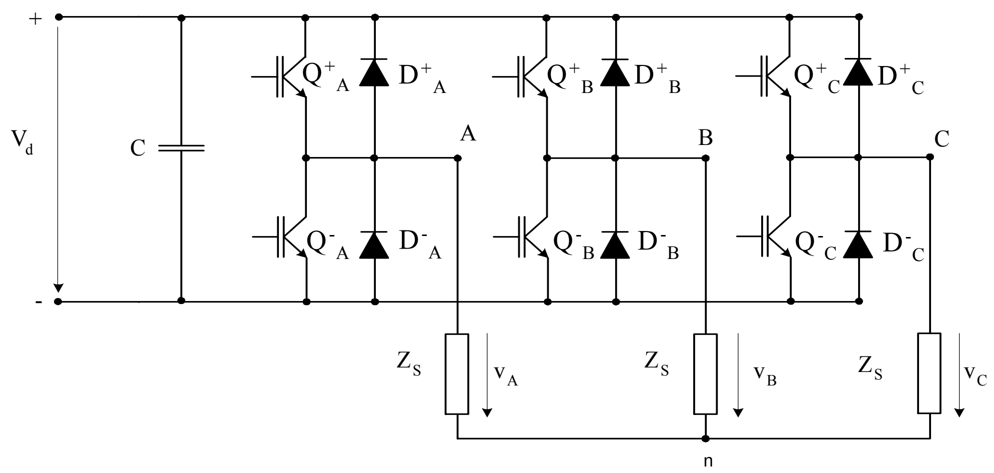

Fig. 2 Three-phase power inverter architecture

Fig. 3 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.

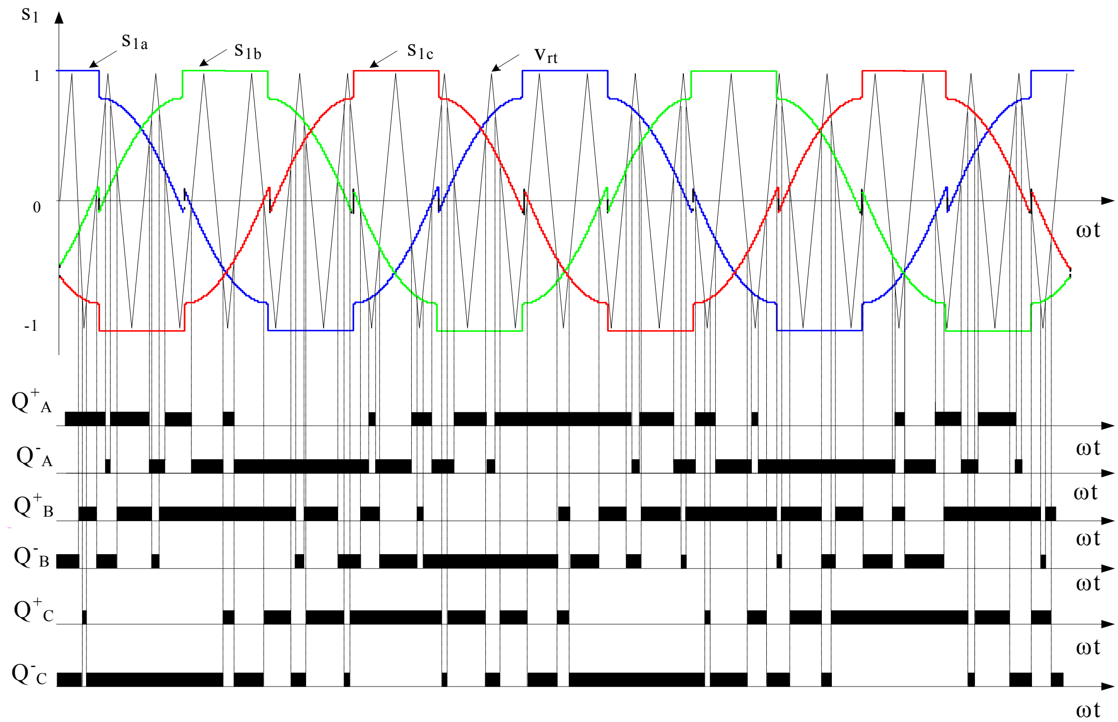

Fig.3 Waveforms of the command and control signals

Fig. 4 a) shows the waveform of the phase voltage A-n, Fig. 4 b) shows the line to line voltage between A and B phases and Fig. 4 c) shows the output current waveform from A phase, after simulation. For the simulation, we used a symmetrical connected star-load, having the Z_S impedance made up of R_L = 250 ohm and L_L = 40mH.

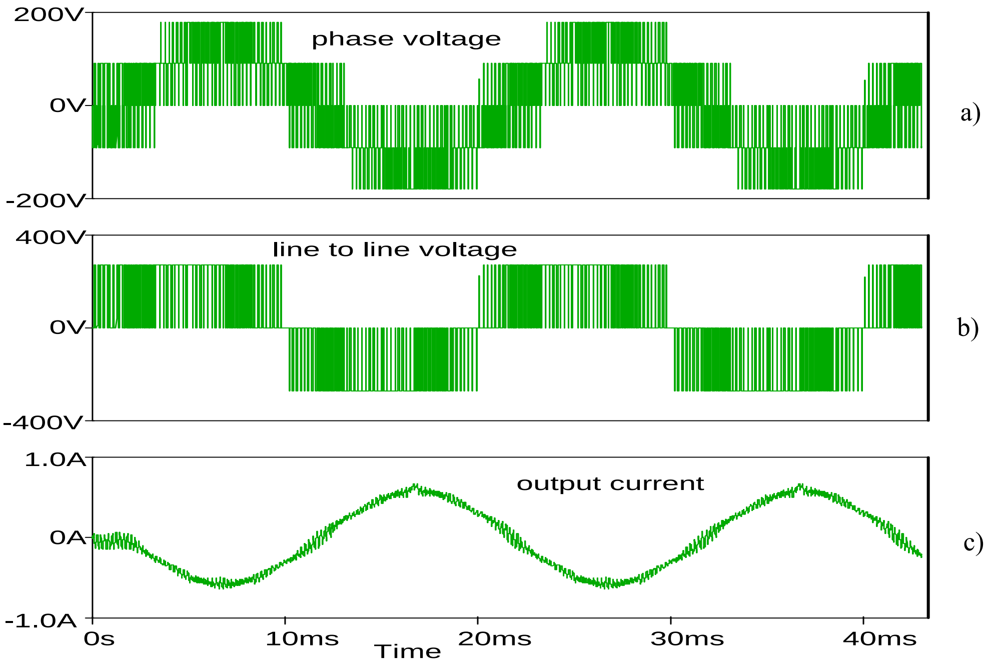

Fig. 4 a) shows the waveform of the phase voltage A-n, Fig. 4 b) shows the line to line voltage between A and B phases and Fig. 4 c) shows the output current waveform from A phase

Fig. 5 a) shows the harmonic spectrum of the phase voltage A, Fig. 5 b) shows the harmonic spectrum of the line to line voltage between A and B phases and Fig. 5 c) shows the harmonic spectrum of the output current form phase A.

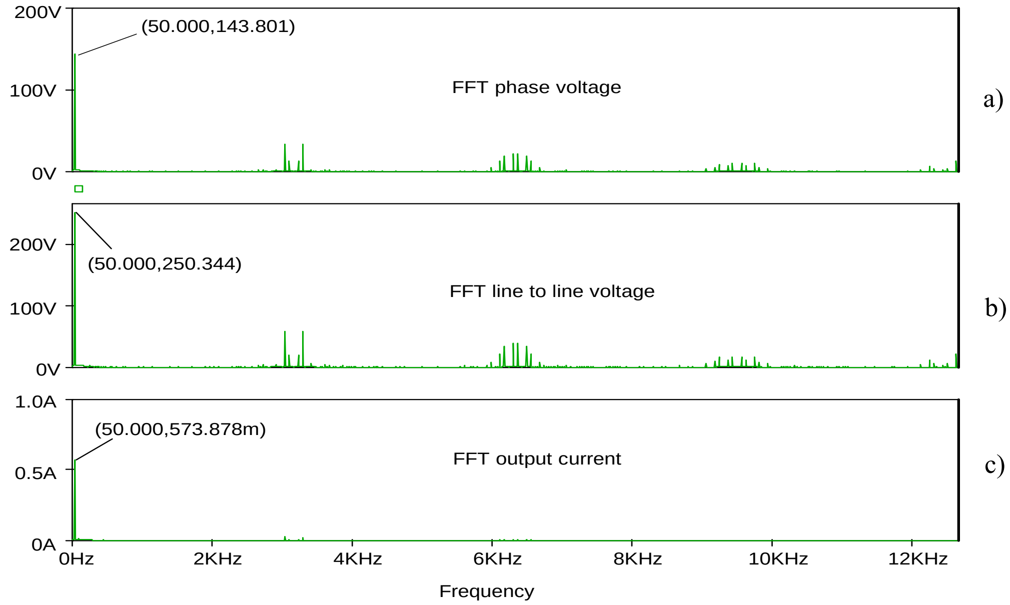

Fig. 5 a) shows the harmonic spectrum of the phase voltage A, Fig. 5 b) shows the harmonic spectrum of the line to line voltage between A and B phases and Fig. 5 c) shows the harmonic spectrum of the output current form phase A

Practical results

The load of the three-phase inverter is an 0.37KW AC motor. The inverter is controlled by C8051F120 microcontroller having software implemented PWMA technique.

Software description

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

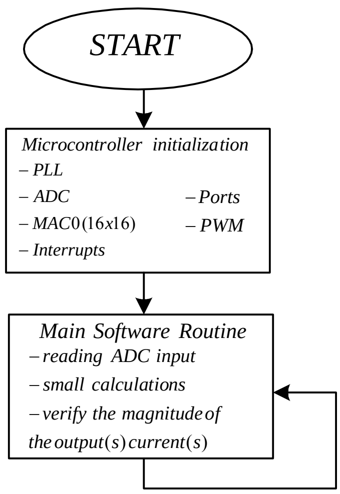

Fig. 6 a) Software control

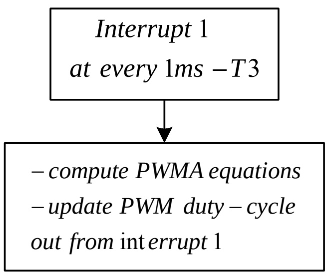

Fig. 6 b)
Flowchart of
Interrupt 1

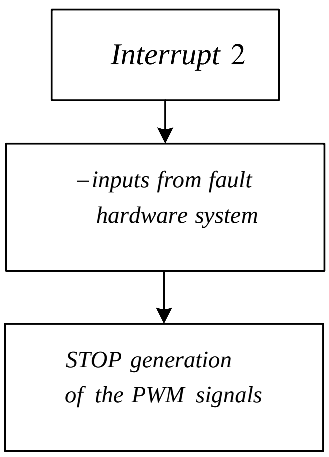

Fig. 6 c)
Flowchart of
Interrupt 2

inverter control, the PWM internal block was used. The flowchart of the control software algorithm is presented in Figure 6 a) Fig. 6 b) and 6 c) shows the flowchart of Interrupt 1 and 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).

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;
}

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.
}
```

Implementing the above software on the microcontroller, the signal s_{1a} is obtained, it is shown in Fig. 7. Fig. 8 shows s_{1a} and s_{1b} signals, which are them with $\frac{2\pi}{3}$ degrees.

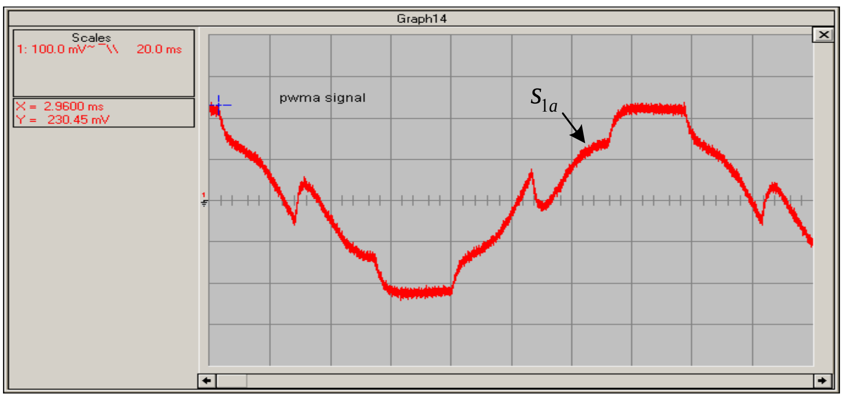

Fig. 7 waveform of s_{1a} signal, obtained from the oscilloscope

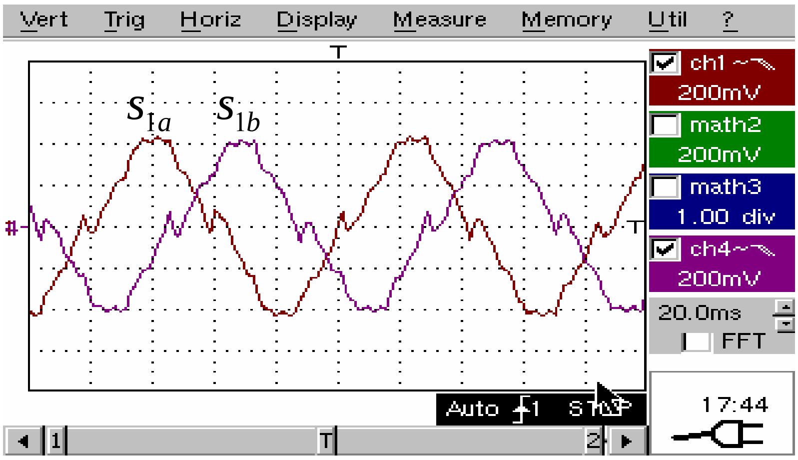

Fig. 8 waveforms of s_{1a} and s_{1b} signals, obtained from the oscilloscope

Fig. 9 shows the line to line voltage between A and B phases, and Fig. 10 shows the harmonic content of the same voltage.

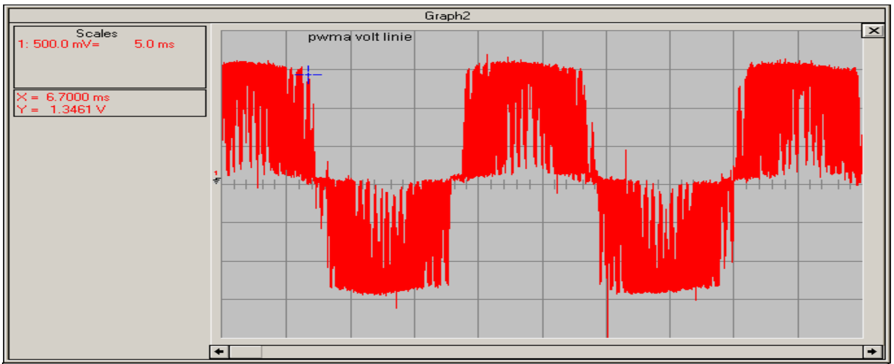

Fig. 9
Line to line voltage between A and B phases, captured from the oscilloscope

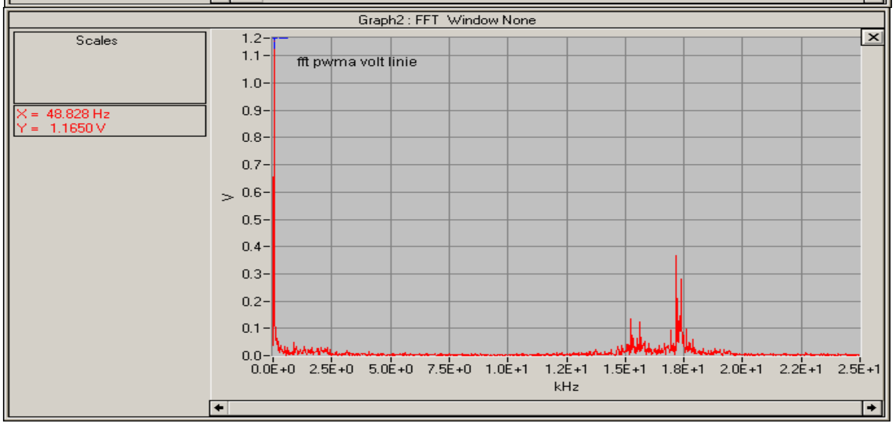

Fig. 10
Harmonic content of the line to line voltage between A and B phases

Fig. 11 a) shows the harmonic content of the line to line voltage at 50 Hz frequency, and Fig. 11 b) shows the harmonic content of the line to line voltage at 17.2 KHz frequency. It is important to mention, the magnitude of the line to line voltage at 50 Hz frequency is 233V.

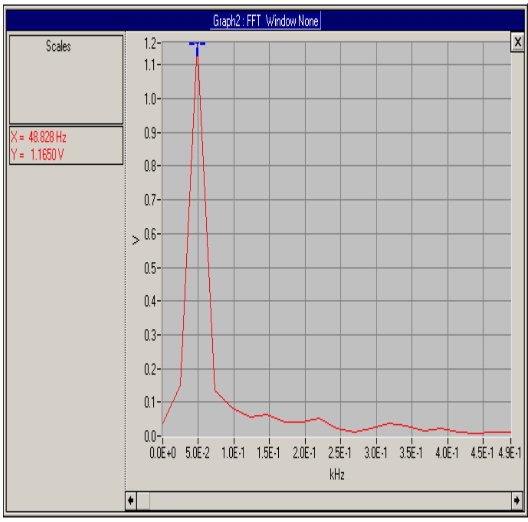

Fig. 11 a) Magnified area of the harmonic content of the line to line voltage, at 50Hz

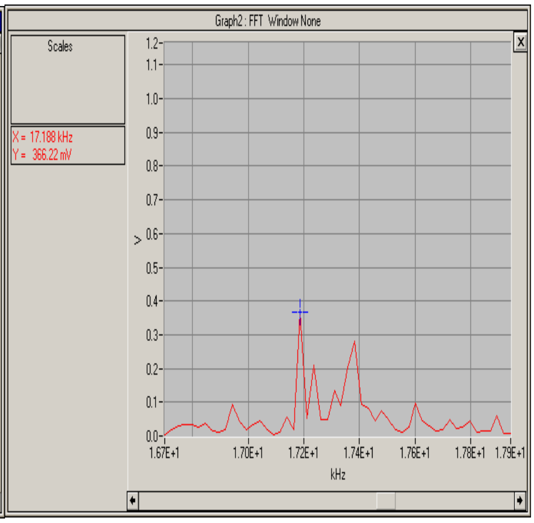

Fig. 11 b) Magnified area of the harmonic content of the line to line voltage, at 17.2 KHz

Fig. 12 shows the current waveform from A phase, and Fig. 13 shows the harmonic content of this current. It is important to mention that, the magnitude of the current at 50Hz is 0.642A, when a 0.37KW AC motor was used as a load.

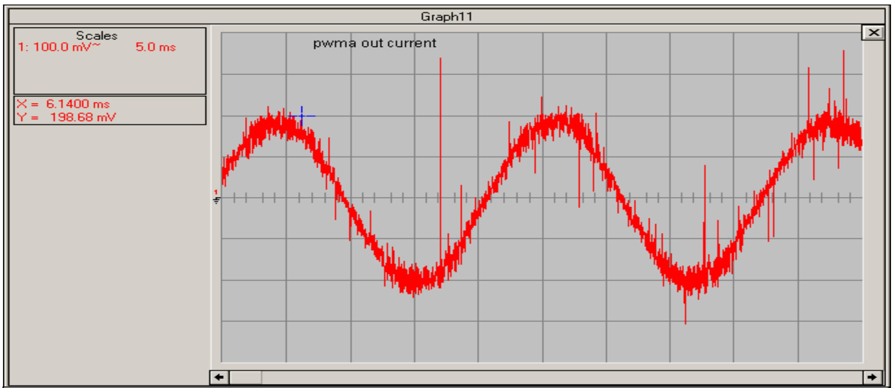

Fig. 12 Current waveform from A phase.

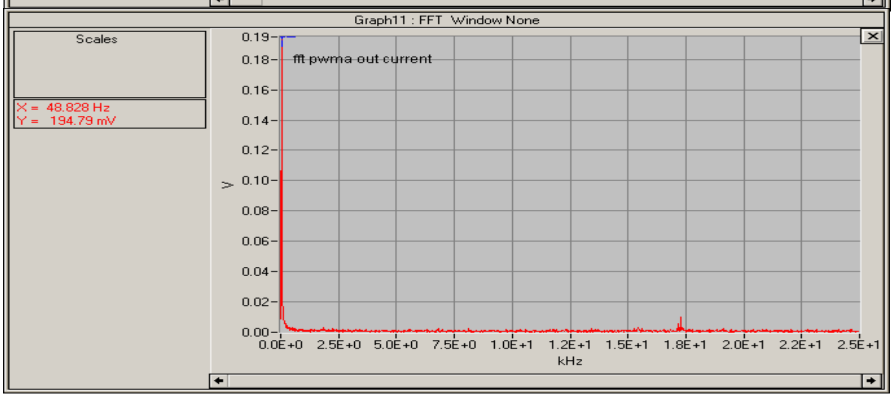

Fig. 13 Harmonic content of the current from A phase.

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 of the output voltage), 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 lead to small power losses, increasing the efficiency of the inverter.

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