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Motor Control using Discontinuous Signals

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Introduction

This paper presents a comparative analysis of the behaviour of an alternating current motor, submitted to different control methods. We used two control techniques based on discontinuous reference signals, namely DPWM-S4 and DPWM-S5. These signals were preferred because the efficiency of the power circuit (the three-phase inverter) controlled by these signals is higher than with other well-known control techniques, such as: Space Vector Modulation (SVM), Sinusoidal Pulse Width Modulation (SPWM) [1], etc. These control techniques allow the increase of the power efficiency of the three-phase inverter since, in a switching period of the control signals, the transistors within the inverter don't switch constantly at the carrier frequency (e.g. 17KHz), but, for certain time intervals, they remain permanently in conduction or they are blocked. For instance, if the period of the control signal is made up of 6 time intervals, in two of these the power transistors are either in conduction, either blocked; thus, their switching is not continuous, which means that the power loss on commutation is minimal. Taking into consideration all these aspects, the power transistors will heat less, therefore they will need smaller heat sinks; as a result, the whole system (made up of the control circuit and the power circuit) will be more compact and less expensive [2–7].

Theoretical considerations regarding the modulation signals

The mathematical relations for the discontinuous reference signals DPWM-S4 and DPWM-S5 are presented in (1) and (2) and their graphical representations can be seen in Fig. 1. It can be seen that the modulating signal DPWM-S4 is made up of 6 time intervals of $\pi/3$ for one period, while the modulating signal DPWM-S5 is made up of only 3 intervals having a $2\pi/3$ length. For both modulating signals, S4 and S5, there are moments in a time period when the reference signals are 1 and -1, respectively. In these time intervals, the power transistors controlled by these signals are either in continuous conduction, either blocked. This is why the power dissipated on commutation on the power transistors is smaller.

$$s_4 = \begin{cases} \sqrt{3}m_a \cos\omega_m t + m_a \sin\omega_m t - 1, & 0 \le \omega_m t \le \pi/3; \\ \sqrt{3}m_a \cos\omega_m t - m_a \sin\omega_m t + 1, & \pi/3 \le \omega_m t \le 2\pi/3; \\ -1, & 2\pi/3 \le \omega_m t \le \pi; \\ \sqrt{3}m_a \cos\omega_m t - m_a \sin\omega_m t + 1, & \pi \le \omega_m t \le 4\pi/3; \\ \sqrt{3}m_a \cos\omega_m t + m_a \sin\omega_m t - 1, & 4\pi/3 \le \omega_m t \le 5\pi/3; \\ 1, & 5\pi/3 \le \omega_m t \le 2\pi; \end{cases} \quad (1)$$

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

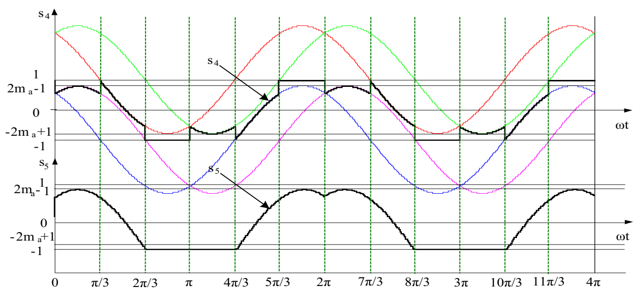

Fig. 1. The modulating signals DPWM-S4 and DPWM-S5

Fig. 2 shows the power inverter that will be controlled by DPWM-S4 and DPWM-S5 signals.

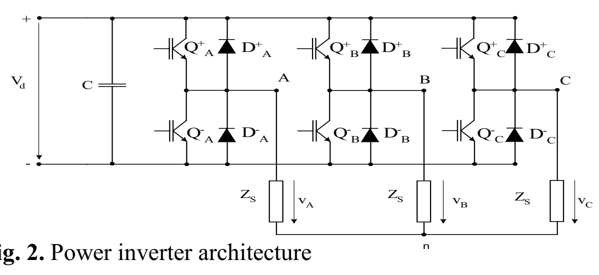

Fig. 2. Power inverter architecture

We present below the control signals for the 6 transistors within the three-phase inverter, Q_A^+, Q_A^-, Q_B^+, Q_B^-, Q_C^+ and Q_C^-, when it is controlled by DPWM-S4 and DPWM-S5, respectively. We have to mention that three-phase systems need 3 reference signals, phase shifted by $2\pi/3$, therefore signal DPWM-S4 becomes s4a, s4b and s4c (Fig. 3), and signal DPWM-S5 becomes s5a, s5b and s5c (Fig. 4).

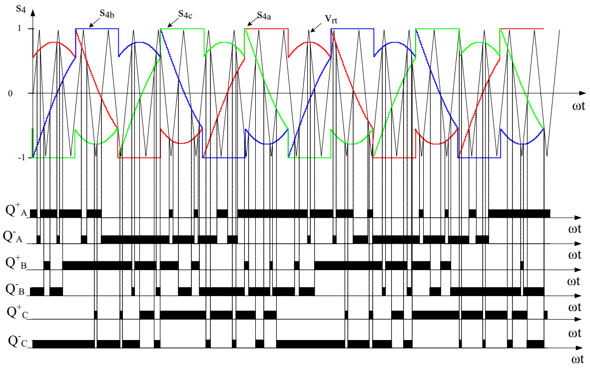

Fig. 3. Waveforms of the modulating (DPWM-S4) and control signals for all six transistors

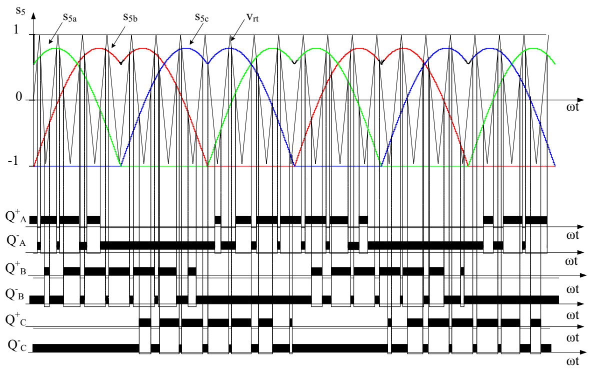

Fig. 4. Waveforms of the modulating (DPWM-S5) and control signals for all six transistors

Control Algorithm

Both control techniques based on discontinuous signals DPWM-S4 and DPWM-S5 were implemented in C programming language, on the microcontroller C8051F120, produced by Silicon Laboratories. This microcontroller was preferred because it is fast (it executes 100 million instructions per second - MIPS) and it has an 8 bit internal configuration (it does not need a more complex 16 or 32 bit architecture).

Both control techniques follow the flowcharts in Figures 5 a, b and c. In Fig. 5a, the microcontroller internal blocks are initialized, namely PLL, ADC, MAC, Interrupts, Ports and PWM. After initialization, the microcontroller will execute main routine instructions, such as reading buttons, displaying values (frequency, voltages, currents, etc.) on a graphic display, establishing RS232 communication with a personal computer. Fig. 5 b presents the flowchart of the software routine executed in the interruption shown by timer T3 every 1ms. (1) and (2) are calculated here in approximately 200 µs–400 µs, and when results are known, the values of the PWM blocks controlling directly the transistors within the three-phase inverter are updated. Fig. 5c presents the flowchart of the software routine performed when an external interruption request occurs (INT0). This routine is called on and executed only if there is a hardware malfunction or if the values of the output currents are higher (in the present situation) than 10A. This routine includes the deactivation of the PWM blocks controlling the transistors within the three-phase inverter and the optical and acoustic (alarm) signaling of the malfunction.

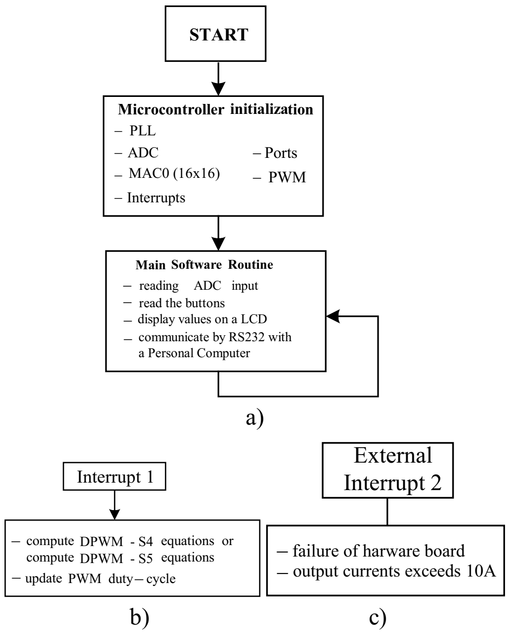

Fig. 5. Flowcharts of the initialization and main routine software (a); interrupt 1 when Timer T3 surpasses itself at every 1 ms (b); External Interrupt INT0 (c)

Software Control

We present below the C language program executed by microcontroller C8051F120 in order to obtain the two discontinuous signals DPWM-S4 and DPWM-S5. The programming routines are similar, only the implementation of equations (1) and (2) differs.

Table 1. Program text

```
void Timer3_ISR(void) interrupt 14
{
unsigned char SFRPAGE_SAVE = SFRPAGE;
calc();
SFRPAGE = TMR3_PAGE;
TF3  = 0;
SFRPAGE = SFRPAGE_SAVE;
}

// Compute modulation signals S4
void calc(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 = s4(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 = s4(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 = s4(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;    }



//---------------------------------------------
float s4(float tr)
{
        float dpwm4;
        if(tr<=1.046 && tr>0)
{dpwm4 = (sqr3*ma*cos(tr)+ma*sin(tr)) - 1;}
        if(tr<=2.093 && tr>1.046)
{dpwm4 =(sqr3*ma*cos(tr)-ma*sin(tr)) + 1;}
        if(tr<=3.151 && tr>2.093)
{dpwm4 =-1;}
        if(tr<=4.186 && tr>3.151)
{dpwm4 = (sqr3*ma*cos(tr)+ma*sin(tr)) + 1;}
        if(tr<=5.233 && tr>4.186)
{dpwm4 =(sqr3*ma*cos(tr)-ma*sin(tr)) - 1;}
        if(tr<=6.28 && tr>5.233)
{dpwm4 =1;}
        if(tr<=1.046+6.28 && tr>0+6.28)
{dpwm4 = (sqr3*ma*cos(tr)+ma*sin(tr)) - 1;}
        if(tr<=2.093+6.28 && tr>1.046+6.28)
{dpwm4 = (sqr3*ma*cos(tr)-ma*sin(tr)) + 1;}
        if(tr<=3.151+6.28 && tr>2.093+6.28)
{dpwm4 = - 1;}
        if(tr<=4.186+6.28 && tr>3.151+6.28)
{dpwm4 = (sqr3*ma*cos(tr)+ma*sin(tr)) + 1;}
        if(tr<=5.233+6.28 && tr>4.186+6.28)
{dpwm4 =(sqr3*ma*cos(tr)-ma*sin(tr)) - 1;}
        if(tr<=6.28+6.28 && tr>5.233+6.28)
{dpwm4 =1;}
return dpwm4;
}

//---------------------------------------------
// Compute modulation signals s5
float s5abc(float tr)
{float dpwm5;
if(tr<=2.093 && tr>0)
{dpwm5 = 1 - (sqr3*ma*cos(tr)+ma*sin(tr));}
if(tr<=3.14 && tr>2.093)
{dpwm5 =  1;}
if(tr<=4.18 && tr>3.14)
{dpwm5 =  1;}
if(tr<=6.28 && tr>4.18)
{dpwm5 = 1 - (sqr3*ma*cos(tr)-ma*sin(tr));}
return dpwm5;
}
//------------------------------------------
```

Experimental results

After implementing the above software on the microcontroller, signals s_{4a} s_{4b} and s_{5a} s_{5b} are obtained and shown in Fig. 6 and Fig. 7.

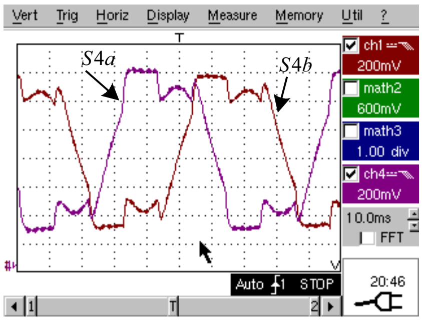

Fig. 6. Modulating signals s_{4a} and s_{4b} obtained by measurement

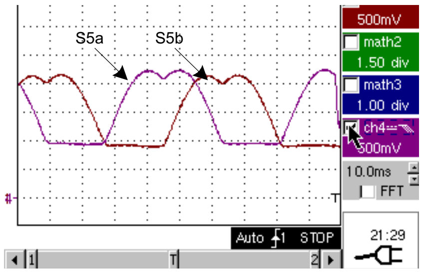

Fig. 7. Modulating signals s_{5a} and s_{5b} obtained by measurement

Experiments were based on a DC supply power of 310V and a load impedance - three-phase motor of 370W.

Fig. 8 illustrates the waveforms of line to line voltages, on the left for modulating signal DPWM-S4, and on the right for modulating signal DPWM-S5. Below, we included the frequency spectrums of these voltages. We have to mention that the fundamental harmonic for DPWM-S4 is 282.87V in amplitude, and for DPWM-S5 it is 302.35V.

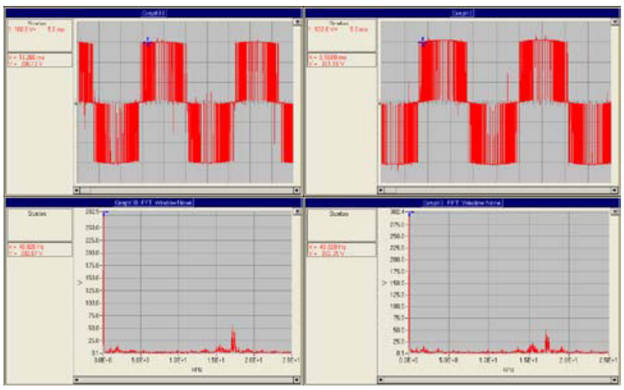

Fig. 8. Line to line voltage using DPWM-S4 signal (left side) an DPWM-S5 signal (right side)

Fig. 9 presents the waveforms of the phase voltages, on the left for modulating signal DPWM-S4, and on the right for modulating signal DPWM-S5. Below we included the frequency spectrums of these voltages. Again, we have to mention that the fundamental harmonic for DPWM-S4 is 166.25V in amplitude, and for DPWM-S5 it is 170.30V.

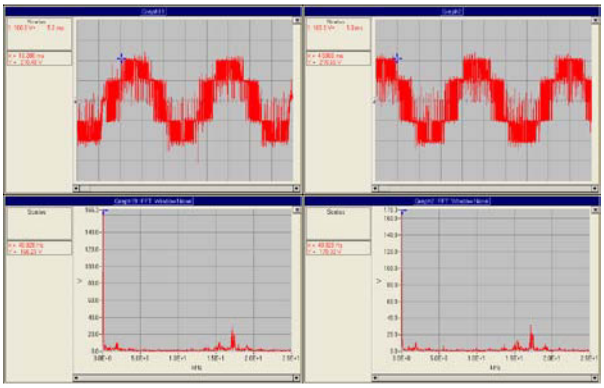

Fig. 9. Phase voltage using DPWM-S4 signal (left side) and DPWM-S5 signal (right side)

Acknowledgements

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Conclusions

This paper aims at comparing the results obtained from the software implementation of two control techniques based on discontinuous signals DPWM-S4 and DPWM-S5. We determined that both line to line and phase voltages show an increase in value by 14V and 4V respectively (for the DPWM-S5 signal), therefore we can deduce that, by using a DPWM-S5-based control technique, the efficiency is 4.5% higher than with the DPWM-S4 signal. However, we can conclude that both control techniques allow the decrease of power losses on the switching transistors, when modulating signals DPWM-S4 and DPWM-S5 have the values 1 and -1, respectively.

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This paper makes a comparative analysis of the behaviour of an alternating current motor with different control methods. Two control techniques were used, based on discontinuous reference signals, namely DPWM-S4 and DPWM-S5. Ill. 9, bibl. 7, tabl. 1 (in English; abstracts in English and Lithuanian).

C. Aghion, O. Ursaru. Pertraukiamųjų signalų taikymas varikliams valdyti // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2011. – Nr. 2(108). – P. 15–18.

Pateikta skirtingais metodais valdymų kintamosios srovės lyginamoji analizė. Buvo taikomi du valdymo metodai, pagrįsti pertraukiamųjų signalų (DPWM-S4 ir DPWM-S5) taikymu. Il. 9, bibl. 7, lent. 1 (anglų kalba; santraukos anglų ir lietuvių k.).