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DESIGN AND IMPLEMENTATION OF A UNIVERSAL INVERTER FOR SUPPLYING AC AND DC ELECTRIC MOTORS

In the paper the novel universal motor driver using three different modulation method of output waveform has been presented and discussed. It should be noted that in today's world, most of driver of electrical motors are consist of four or six transistors forming appropriate bridges. Appling specified modulation methods enable to drive both single- and three-phase induction and synchronous motors of any kind. The construction of typical transistor bridge that consists of six transistors can be also used to control the direct current motors by switching off one of the pairs of transistors. In this paper the process of construction of universal motor driver has been presented, in which has been implement the modified method of Sinusoidal Pulse Width Modulation (SPWM), Space Vector Pulse Width Modulation (SVPWM) and also the basic Pulse Width Modulation (PWM) for DC motors. The fundamentals of applied modulation algorithms have been discussed and basic equations have been shown. The developed motor controller has been used to power three different types of motors, single-phase induction motor, three-phase induction motor and magnetoelectric DC motor. The results of the conducted research have been reported in this work.

KEYWORDS: inverters, universal motor driver, SVPWM, SPWM, PWM.

1. INTRODUCTION

In recent years the growing interest in new kinds of electric machines can be observed, particularly the permanent magnet synchronous motors (PMSM) [1÷3]. It leads to a fast development of more and more complex inverters in order to ensure low distortions of output waveforms of current and voltage; and high efficiency of a control system [4÷6]. Furthermore, a huge progress over the recent years that has been made in microcontroller embedded systems construction, has contributed in development of different kind of modulation methods like the Direct Digital Synthesis (DDS), the Sinusoidal Pulse Modulation Method (SPWM) or the Space Vector Pulse Width Modulation Method

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(SVPWM). Moreover, the growing computing power and memory space of modern embedded systems enables implementation of many modulation methods in a single control system, therefore Authors have proposed a new approach for a motor driver that enables to control both single- and three-phase motors like permanent magnet synchronous motors or induction motors, and also popular DC motors in any windings connection combination. During the research, the novel control system of the multifunctional motor driver has been elaborated and implemented on constructed inverter. The obtained results have been converted from their original domain into frequency domain by means of Fast Fourier Transform analysis FFT in order assess the total harmonic distortion of output current waveforms.

2. FUNDAMENTALS OF THE SINUSOIDAL PULSE WIDTH MODULATION (SPWM)

In proposed control way of the elaborated inverter a control of a single-phase AC motors is accomplished by application of a modified Pulse Width Modulation Method of a sine wave. However, the standard PWM method is quite complicated in application due to usage of comparators and reference signals generators. In order to avoid application of additional systems Authors have proposed to use the modified modulation method called the Sinusoidal Pulse Width Modulation method SPWM which combines advantages of the standard Pulse Width Modulation PWM and Direct Digital Synthesis Modulation DDS methods [7]. The concept of the modulation method is to generate sine proportional PWM impulses by using only a microcontroller hardware and software. To accomplish the purpose, algorithm executes equations (1) and (2) in order to calculate microcontroller's timer parameters, fills in *Look-up* and *duty* tables and starts generating a control signal of inverter shown in Fig. 1.

$$f_{out} = \frac{\mathrm{M} \cdot \mathrm{f_s}}{\mathrm{m} \cdot (\mathrm{n} \cdot \mathrm{ARR} + 2)} \tag{1}$$

$$f_s = \frac{M \cdot f_{clk}}{PSC \cdot (ARR + 1)} \tag{2}$$

where: M is a control word, m is the number of modulated halves of the sine wave, n is the number of modulated quarters of the sine wave, ARR is the Auto-Reload Register of STM 32 microcontroller, f_s is the switching frequency, f_{clk} is the frequency of clock of the microcontroller and PSC is the prescaler register of STM32 microcontroller.

Look-up and *duty* tables calculated by equations (3) and (4) contain of respectively values of sine wave for a given angle and values of duty cycles corresponding to that angle:

$$LUT[i] = A \cdot \sin\left(\frac{\pi \cdot i}{n \cdot ARR + 2}\right) \tag{3}$$

$$duty[i] = LUT[i] \cdot (ARR + 1) \tag{4}$$

where: A is an amplitude factor value and $i = 0, 1, 2, \ldots, ARR+1$.

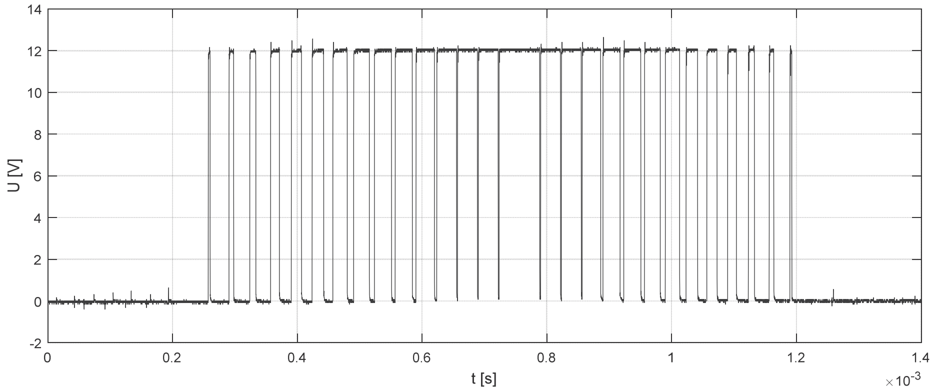


Fig. 1. The waveform of the SPWM control signal

Referring to Fig. 1 it is crucial to maintain an equal value of samples in each quarter-period, since it provides symmetry and decrease significantly the total distortion of the output waveform.

3. FUNDAMENTALS OF THE SPACE VECTOR PULSE WIDTH MODULATION (SVPWM)

In order to control three-phase alternating current AC motors Authors of the work have implemented on STM microcontroller the Space Vector Pulse Width Modulation Method SVPWM [8]. The recent growing interest of this type of methods there leads to the creation of many varieties of the SVPWM [9-10]. However, due to limited resources of used STM microcontroller the basic form of the SVPWM has been implemented. In the presented article the symmetric 7-segment switching technique with usage of both null vectors has been implemented. This variation of the SVPWM consists of eight voltage vector located in α-β coordinate system. The transformation from three-phase reference frame is accomplished by usage of Clarke Transformation [11]. Six of them represent effective states and the other two –null states. In Fig. 2 the vectors plane frame has been shown.

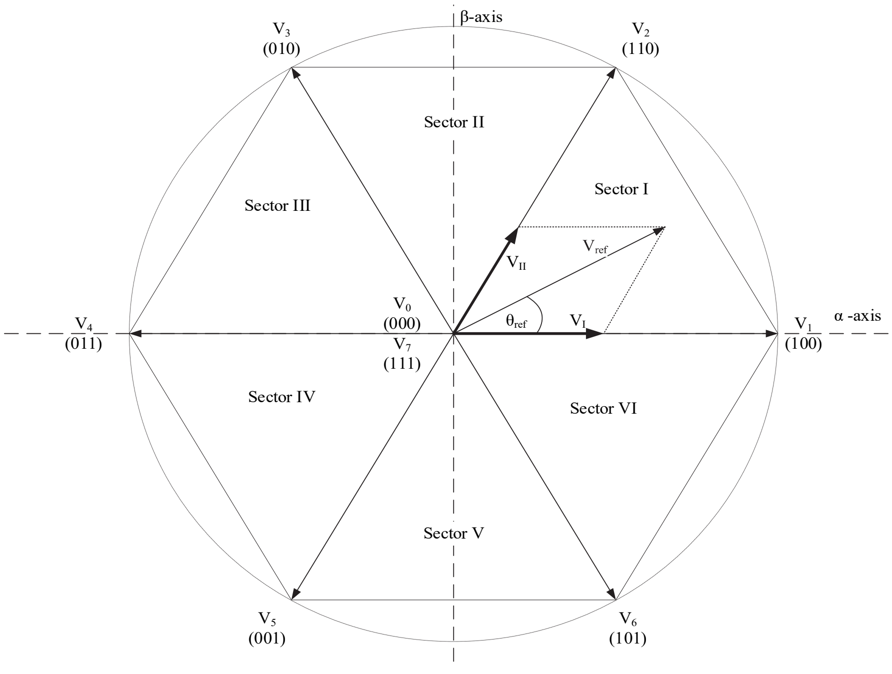


Fig. 2. The SVPWM vector plane frame

The reference vector $\boldsymbol{V_{ref}}$ is calculated according to (5):

$$\vec{V}_{ref} = \frac{T_0}{T_s}\vec{V}_0 + \frac{T_1}{T_s}\vec{V}_I + \frac{T_2}{T_s}\vec{V}_{II} \tag{5}$$

where: $\boldsymbol{V_{ref}}$ is the vector of the reference voltage, T_0, T_1, T_2 are duration times of respectively $\boldsymbol{V_0}$ or $\boldsymbol{V_7}$, $\boldsymbol{V_I}$ and $\boldsymbol{V_{II}}$ and T_s is the sampling period.

Duration times of vector components for a sector I are calculated be given equations [12]:

$$T_s = T_0 + T_1 + T_2 \tag{6}$$

$$T_1 = \frac{\sqrt{3}\cdot\left|\vec{V}_{ref}\right|\cdot T_s}{V_{DC}}\cdot\sin\left(\frac{\pi}{3} - \theta_{ref}\right) \tag{7}$$

$$T_2 = \frac{\sqrt{3}\cdot\left|\vec{V}_{ref}\right|\cdot T_s}{V_{DC}}\cdot\sin\left(\theta_{ref}\right) \tag{8}$$

where: V_{DC} is the DC-link voltage value of the inverter.

The implemented control algorithm is based on the equations (6)÷(8) for a given angle and magnitude of vector $\boldsymbol{V_{ref}}$ with the specified frequency in order to set up appropriate parameters of the timer that is supposed to generate the three-phase PWM control signal (Fig. 3). After each sampling period T_s the reference angle θ_{ref} is incremented by a given step. The result is the rotating reference vector which components are in fact V_α and V_β obtained by the Clarke Transform.

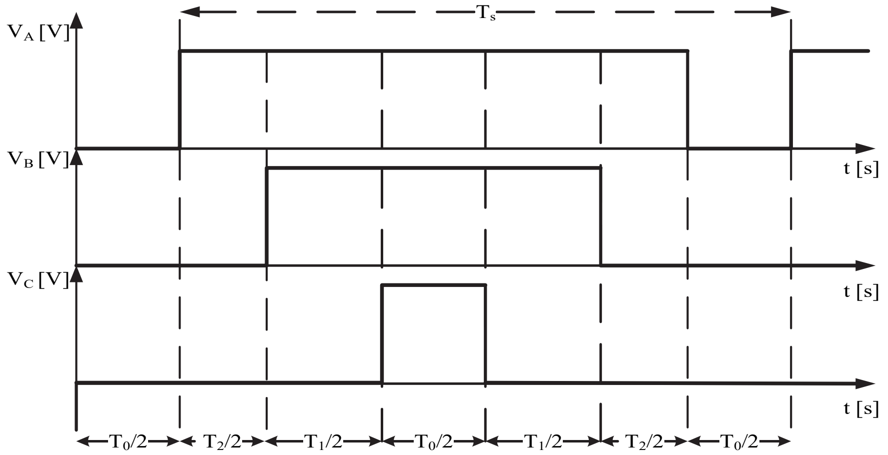


Fig. 3. The waveform of the SVPWM control signal for the sector I, where V_A, V_B, V_C are values of voltage of phases A, B and C respectively

4. FUNDAMENTALS OF CONTROL OF DC MOTORS

To control the direct current (DC) motors Authors have implemented the most popular variation of the Pulse Width Modulation Method PWM. On the contrary to PWM method presented in chapter 2, the main purpose of discussed method is to control an average output voltage value over a period in accordance to (9):

$$V_{avg} = \frac{1}{T}\int_0^T V(t)\,dt \tag{9}$$

where: V_{avg} is an average voltage value and T is a period of PWM signal.
According to (10) and (11), both rotational speed and electromagnetic torque depend on a supply voltage value so that they can be controlled by regulation of an average value of the voltage [13].

$$n = c\frac{U-(R_a+R)I_a}{\varphi} \tag{10}$$

$$T_e = c\cdot\varphi\cdot I_a \tag{11}$$

where: n is a rotational speed of the motor, U is the supply voltage of the motor, R_a is the armature resistance, R is the additional resistance in armature winding, I_a is the current flowing through the armature winding, ϕ is the magnetic flux generated by a field winding and T_e is the electromagnetic torque.

During the research the magnetoelectric DC motor has been used so the change of an average supply voltage results only in the change of an armature current.

5. INVERTER CONSTRUCTION

In order simplify construction modification and increase reliability of designed inverter, Authors of the work have decided to divide the system into six separate modules which are a control module, power module, microcontroller module, measuring module and also interface module. Each module has specified purpose; for example control module consists of gate drivers and its goal is to control the inverter bridge; interface module ensures simply and clear handling of whole system and measuring module is supposed to transmit instantaneous values of measuring voltage from current shunts to the microcontroller placed in microcontroller module. The power module has been constructed of six NPN type of MOSFET transistors connected into H-bridge [14]. In Fig. 4 the constructed inverter has been presented.

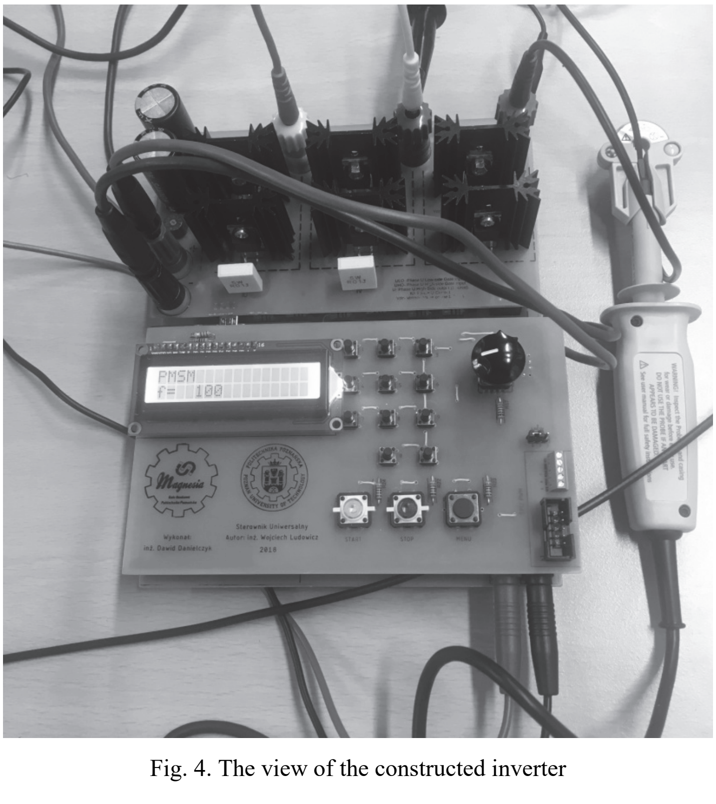


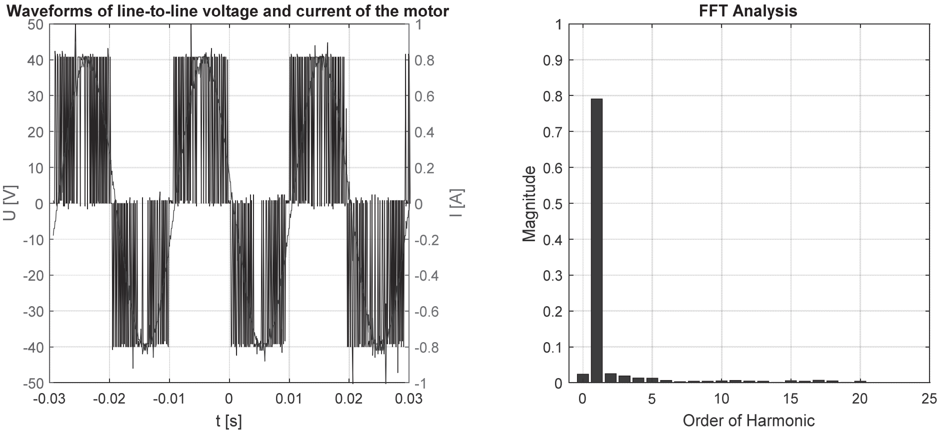
Fig. 4. The view of the constructed inverter

The discussed, here, inverter has been designed for supplying both AC and DC motors with maximum power value of 800 W; and the maximum value of the amplitude of the supply voltage equal to 80 V.

6. THE OBTAINED RESULTS

High efficiency and low factor of the total harmonic distortion of waveform of output current is the main criterion for assessing of most of the motor drivers. Therefore, tests have been carried out by means of FFT in order to evaluate the quality of an output waveform. In Figs 5 and 6 the current and voltage waveforms and also corresponding FFT waveform current obtained for the single phase induction motor of type D1058-444 with work capacitor have been shown. The motor has been supply by a voltage of amplitude value equals to 40 V and loaded with a given torque. The value of capacitance of the work capacitor was equalled to 1.5 μF. Tests have been carried out for two different frequencies – 50 Hz and 100 Hz.

By analysing obtained waveforms in Figs 5 and 6, it can be concluded that share of higher harmonics in the motor current waveform is negligible. Tests have been carried out with two different frequencies; it can be observed that in both situations the first harmonic is dominant. It should be also noted, that in both cases the power factor is close to value of 1.


Waveforms of line-to-line voltage and current of the motor

FFT Analysis

Fig. 5. Line-to-line voltage and current waveforms obtained for the single-phase motor at frequency of 50 Hz and corresponding FFT current analysis

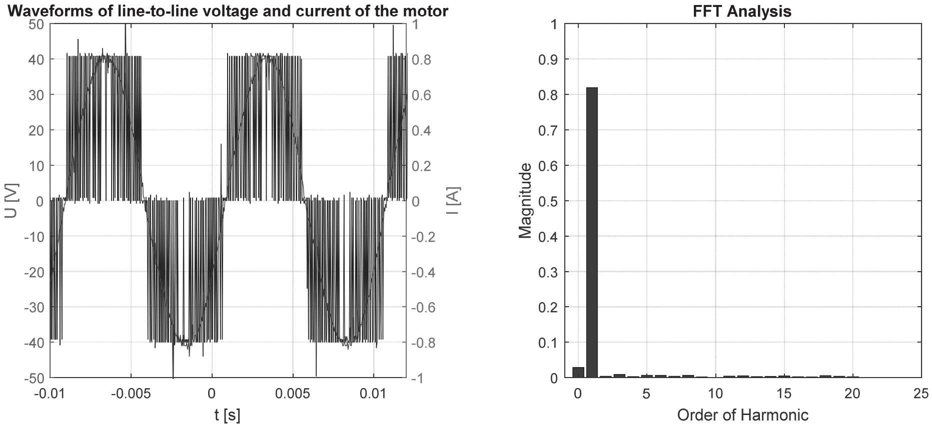


Fig. 6. Line-to-line voltage and current waveforms obtained for the single-phase motor at frequency of 100 Hz and corresponding FFT current analysis

According to the chapter 1, the SVPWM algorithm has been implemented in order to control three-phase electric motors. Authors have decided to apply elaborated inverter as a supply for the three-phase induction motor about rated power and work frequency equal to $P_n = 180$ W and $f = 60$ Hz, respectively. In Fig 7 and Fig 8 the waveforms of line-to-line voltage and current, as well as also corresponding FFT current analysis have been presented for two different frequencies of the supply voltage about values equal to 35 Hz and 50 Hz, respectively. The values of amplitudes of supply voltage for these two cases was 40 V and 60 V, respectively

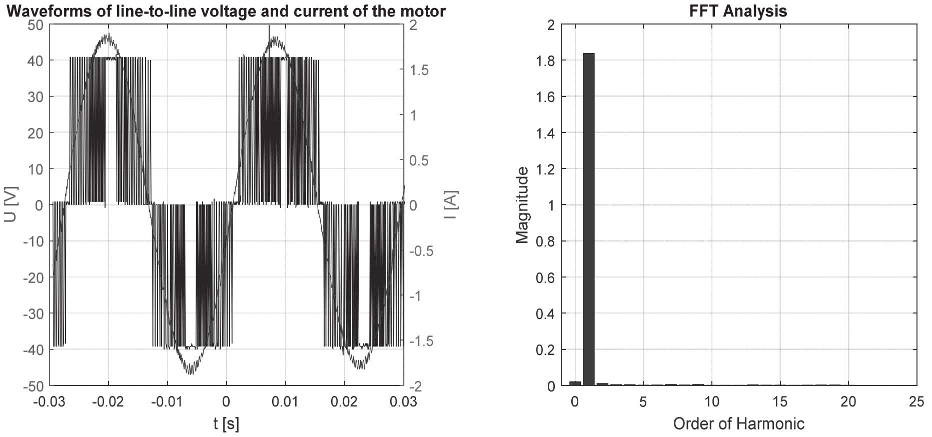


Fig. 7. Line-to-line voltage and current waveforms obtained for the three-phase induction motor at frequency of 35 Hz and corresponding FFT current analysis

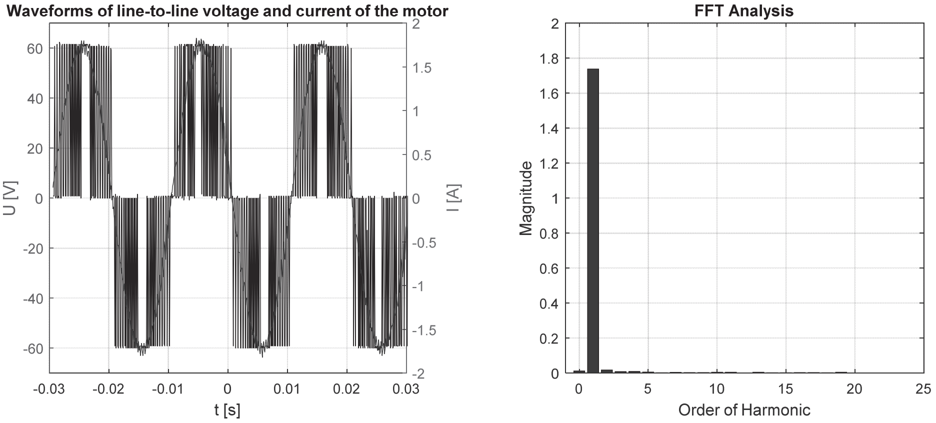


Fig. 8. Line-to-line voltage and current waveforms obtained for the three-phase induction motor at frequency of 50 Hz and corresponding FFT current analysis

The obtained waveforms presented in Figs 7–8 and corresponding FFT current analyses prove that the SVPWM method is suitable for control three-phase motors due to low value of total harmonic distortion factor. Interestingly, in case of use of the SVPWM method the peak ripple magnitudes of obtained waveforms of output voltage and current are lower than in case of use of the SPWM method.

As a third part of the research, the application of constructed inverter with the magneto-electric DC motor has been discussed. The motor has been loaded with an initial torque and supplied by a voltage of amplitude value equals to 30 V. The supply voltage and current waveforms have been presented in Fig. 9.

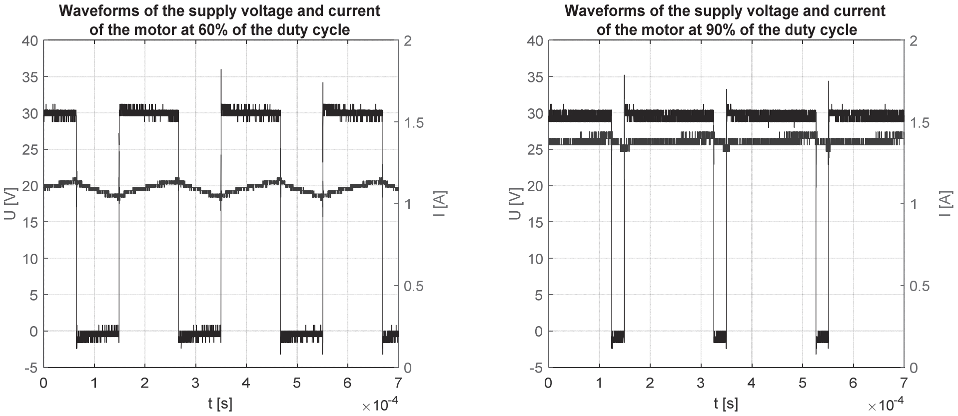


Fig. 9. Waveforms of the supply voltage and current of the magneto-electric motor at duty cycle equals to 60% and 90%

Looking at Fig. 9, it should be noted that although the waveform of the supply voltage is a square waveform, the current rises and falls periodically according to commutation laws.

7. CONCLUSION

In the work the new approach for implementation of inverters software has been presented. As a result of the research that has been carried out, the inverter with implemented novel, multifunctional software that enables control of different kind of electric motors has been constructed. The obtained results in form of output waveforms of current and voltage that supply the motor have been verified in terms of content of higher harmonics by means of FFT. The obtained waveforms and FFT analyses prove the high quality of output waveforms due to low value of total harmonic distortion. It can be concluded, that constructed inverter with the implemented control algorithm can successfully operate with tested electric motors ensuring competitive quality parameters and also wide regulation range of output waveforms.

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