3-phase motor speed regulator based on microcontroller and intelligent power driver controller

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Abstract: *This paper describes the design and practical implementation of speed controller for 3-phase induction motor based on ATmega 2560 microcontroller. Based on the theoretical analysis of the induction motor, are defined the requirements that the controller should satisfy them. Then, based on the specificity of the selected controller, the operating mode of the ATmega 2560 controller is designed. The specificity of this solution is that the driver circuit, which is connected between the controller and the motor, is realized with an intelligent power controller. Finally, the results of the practical work of this motor controller are given.*

***KEYWORDS**: 3-PHASE MOTOR REGULATOR, ATMEGA 2560, INTELLIGENT POWER CONTROLLER*

1. Introduction

In modern industrial power plants the tendency is to use induction motors controlled by V/F converters. The main reason for this in terms of the motor is the advantage which offered by induction motors, primarily in terms of DC motors, and in terms of the converter is the need to regulate the speed of the motor and thus its power. This ensures that the motor runs at the speed and power required by the operating process [1], [2], [3], [4].

There are a number of methods of speed control of an induction such as pole changing, frequency variation, variable rotor resistance, variable stator voltage, constant V/f control, slip recovery method etc. The constant V/f speed control method is the majority generally used. In this method, the V/f ratio is kept constant which in turn maintains the magnetizing flux constant so that the maximum torque remains unchanged. Thus, the motor is totally utilized in this method [5], [6].

In this paper, the main emphasis is on the work of the microcontroller and the driver's circuit, ie. power converter. The microcontroller generates a 3-phase SPWM signal that provides V/F operation of the motor [7]. In the paper, the power converter is realized in an integrated technique, so-called intelligent power module (IPM).

2. SPWM Microcontroller and Intelligent Power Module

Guided by the main goal of the paper, implementation of the microcontroller in generating SPWM signals and realization of the converter with intelligent power module (IPM), here will be explained the functioning of these three interconnected parts, ie. SPWM, microcontroller and IPM.

In the Fig. 1 is shown a block diagram on 3-phase motor which is controlled by microcontroller.

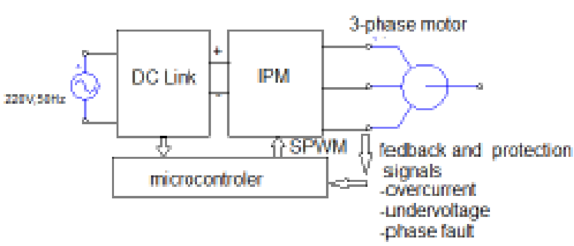

Fig. 1 Block diagram on 3-phase motor controlled by microcontroller.

2.1 SPWM signal

Here we take a look over the concepts of SPWM signal which is a width modulated signal but with certain values on such a way that we could create a sine shape wave at the output. This with used on MOSFET or IGBT transistors could result in a sine wave inverter.

It is generally known that PWM signal is pulse width modulation. That means we modulate the width of a square signal and by that we could control power. But, this width in case of normal PWM is always the same. In case of SPWM or sinusoidal pulse width modulation, the width of the signal is increasing and decreasing and my that simulating the curve of the sine wave. With small width pulse, the output will increase a little bit and that represents the zone after the 0 cross of the sine wave. Then with bigger widths, the output is getting bigger and bigger and then it starts to get lower, just as a sine wave. Using two transistors switching, can could get both the positive and negative sides of the sine wave, Fig. 2.

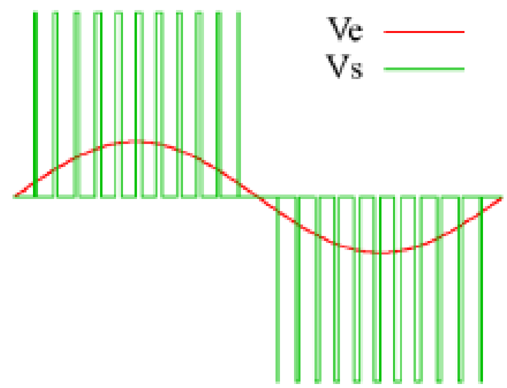

Fig. 2 Construction of SPWM signal.

In the Fig. 3 below can see a bit better how the width of the SPWM can create a good sinusoidal shape at the output. Will use the microcontroller to generate this SPWM signal. We apply this signal to the intelligent power module driver. These will be connected to the motor. In the Fig. 3 is shown SPWM signal and the current and voltage waveforms of the motor.

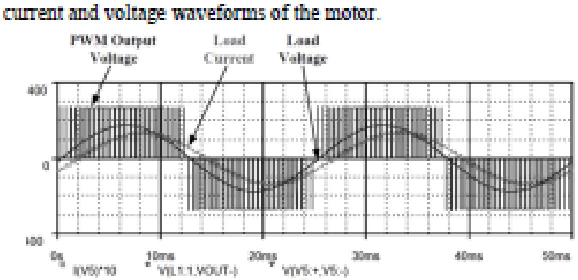

Fig. 3 SPWM signal and the current and voltage waveforms of the motor.

2.2 Microcontroller

The main task of the microcontroller is to generate SPWM signals [8]. Because the motor is three-phase, the controller needs to generate two asymmetric outputs for each phase. So microcontroller needs generate three phase SPWM signals. These signals will be connected to the inputs of the intelligent power converter.

Because Atmega 328P microcontroller on arduino uno board has three timers and one of them is used for interrupt it can not be used. Therefore here is used an Atmega 2560 microcontroller embedded on arduino mega board. Arduino mega 2560 board have five timers and 15 PWM capable pins [9]. The basic features of this controller are:

Micro-controller	ATmega2560	
	Operating Voltage	5V
	Input Voltage (recom-mended)	7-12V
	Input Voltage (limits)	6-20V
	Digital I/O Pins	54 (of which 14 provide PWM output)
	Analog Input Pins	16
	DC Current per I/O Pin	40 mA
	DC Current for 3.3V Pin	50 mA
	Flash Memory	256 KB of which 4 KB used by bootloader
	SRAM	8 KB
	EEPROM	4

In Fig. 4 is shown microcontroller Atmega2560, used in arduino mega board.

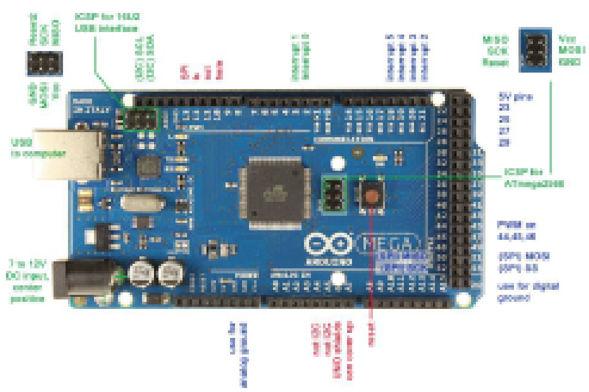

Fig.4 Microcontroller Atmega 2560 used in arduino mega board.

To solve our task, generating three SPWM signals requires knowledge of the microcontroller timers. So we'll see the corresponding between timers and pins:

-Timer 0-pin 4 (OC0B) and pin 13(OC0A)
-Timer 1-pin 11(OC1A) and pin 12(OC1B)
-Timer 2-pin 9(OC2B) and pin 10(OC2A)
-Timer 3-pin 2(OC3B), pin 3(OC3C) and pin 5(OC3A)
-Timer 4-pin 6(OC4A), pin 7(OC4B) and pin 8(OC4C)
-Timer 5-pin 44(OC5C), pin 45(OC5B) and pin 46(OC5A)

Timer 1 is used for , Timer 0 for first phase, Timer 2 for the second phase and Timer 3 for the third phase with OCxA for positive half duty cycle and OCxB for the negative half duty cycle like in the Fig. 5 [10].

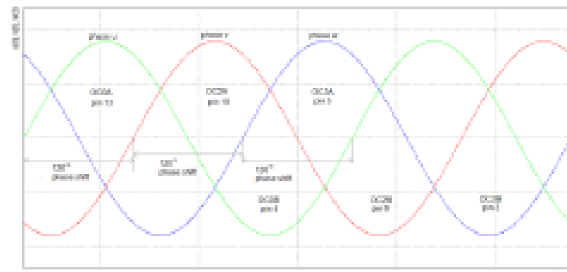

Fig. 5 Condition of the registers OCxA and OCxB (x = 0, 2, 3) on pins 13, 10, 5 and 4, 9, 2.

If for 180 degrees we have 314 elements, for 120 degrees we have 209 elements so the second signal must start when the first is at 209 pulse and the third must start when the second is at 209 pulse.

So, when the program starts, the interrupt is enabled and first is executed the first signal part (with element i). When i take the 209 value the second signal is enabled (with element j). When j takes the 209 value the third signal is enabled. In this way these three signals are at 120 degrees phase shift.

To ensure the phase shift we use an "if" function and for the second wave is like below:

"if ((i==209) || OK1==1){ OK1=1;"

When "i" has 209th value the "if" function is enabled and everything in it is executed. To mantain the execution of that part for the second signal after the value of i(209) is changed we use a variable which enables the "if" function continuously.

For the third signal the if function is like below:

"if ((j==209) || OK3==1){ OK3=1;"

In this case, the third signal is enabled when "j" (the element for the second signal) has the 209th value. After that, the "if" function is executed like for the second signal.

The waveforms that illustrate the last explanation will be given below in the text.

2.2 Intelligent Power Module Driver

In power electronics, in recent decades, usually in controlling of the motor (not only induction but also DC motors), the connection between the controlling part (in the case is microcontroller) and the motor has been realized with a discreet driver circuit and power bridge converter realized with MOSFET or IGBT transistors [11]. One such solution is shown in the Fig. 6.

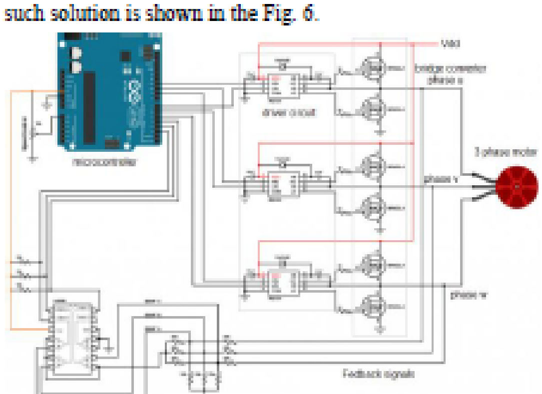

Fig.6 Controller with discreet driver circuit and bridge converter.

In recent years, the direction of development and application of intelligent controllers has been practiced not only for control electronics but also for the driver circuit [12]. These intelligent power controllers consist of a driver circuit and a bridge converter. In this way the hardware construction of the device is facilitated and the protection functions are improved.

In the Fig. 7 is shown motor speed controller controlled with microcontroller and intelligent power module.

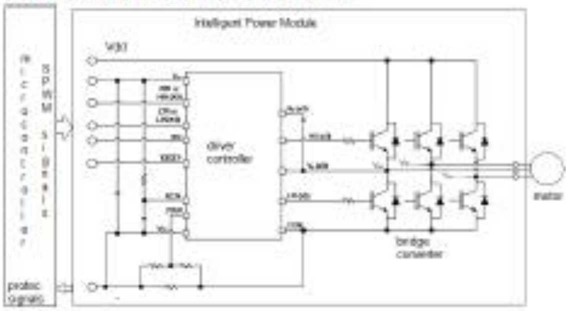

Fig. 7 Motor controller controlled with microcontroller and intelligent power module.

3. Design of Speed Regulator

To design the task in the paper we use microcontroller Atmega 2560 in arduino mega board and monolithic intelligent motor controller MC3PHAC (product of Motorola) embedded in intelligent power module TM35 [12].

MC3PHAC is designed specifically to meet the requirements for low-cost, variable-speed, 3-phase ac motor control systems. The device is adaptable and configurable, based on its environment. It contains all of the active functions required to implement the control portion of an open loop, 3-phase ac motor drive. One of the unique aspects of this device is that although it is adaptable and configurable based on its environment, it does not require any software development. This makes the MC3PHAC a perfect fit for customer applications requiring ac motor control but with limited or no software resources available. The device features are:

- Volts-per-Hertz speed control
- Digital signal processing (DSP) filtering to enhance speed stability
- 32-bit calculations for high-precision operation
- Internet enabled
- No user software development required for operation
- 6-output pulse-width modulator (PWM)
- 3-phase waveform generation
- 4-channel analog-to-digital converter (ADC)
- User configurable for standalone or hosted operation
- Dynamic bus ripple cancellation
- Selectable PWM polarity and frequency
- Selectable 50/60 Hz base frequency
- Phase-lock loop (PLL) based system oscillator
- Serial communications interface (SCI)
- Low-power supply voltage detection circuit.

Included in the MC3PHAC are protective features consisting of dc bus voltage monitoring and a system fault input that will immediately disable the PWM module upon detection of a system fault.

Some target applications for the MC3PHAC include:

- Low horsepower HVAC motors
- Home appliances
- Commercial laundry and dishwashers
- Process control
- Pumps and fans.

In the Fig. 8 is shown the block diagram of IPM TM35 with built motor controller MC3PHAC, and on the Fig. 9 is shown the appearance of real IPM TM35.

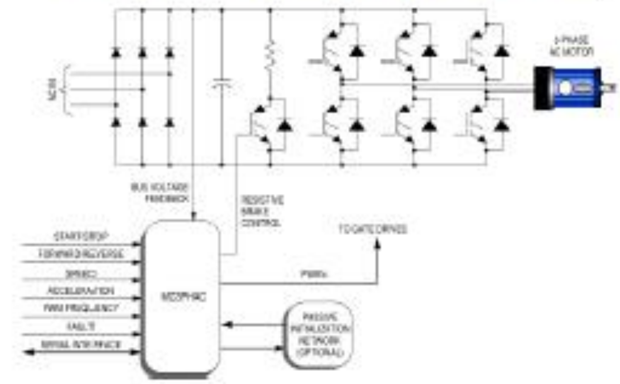

Fig. 8 Block diagram of IPM TM35 with built motor controller MC3PHAC.

Fig. 9 Appearance of real IPM TM35.

In the Fig. 10 is shown block diagram on speed motor regulator based of microcontroller Atmega 2560 and intelligent power module TM 35.

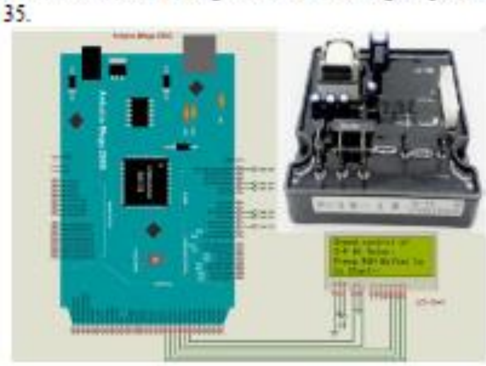

Fig. 10 Block diagram on speed motor regulator based of microcontroller Atmega 2560 and intelligent power module TM 35.

From the Fig. 10 can be see that is used LCD display 2004 on which the modes of operation of the regulator are visualized.

4. Experimental results

In the Fig. 11 is shown experimentally test the circuit of motor speed regulator.

Fig. 11 Experimentally test the circuit of motor speed regulator.

In the Fig. 12 are shown waveforms on the PWM signals from the microcontroller for SPWM frequency (switching frequency) 4 kHz and motor frequency 19 Hz.

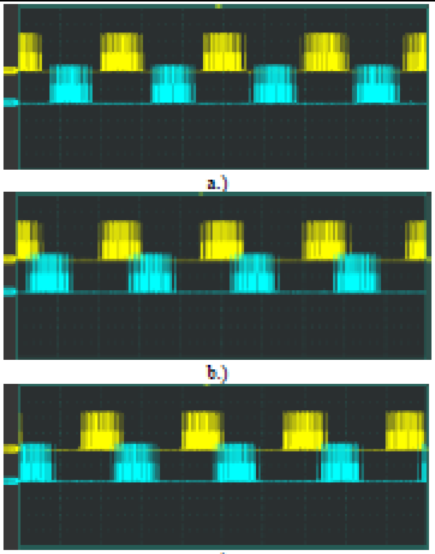

Fig. 12 Waveforms on theS PWM signals from the microcontroller: a.) PWM signals on phase u pin 4 (channel 1) and pin 13 (channel 2), b.) SPWM signals on phase u pin 4 (channel 1) and phase v pin 9 (channel 2), c.) SPWM signals on phase v pin 9 (channel 1) and phase w pin 2 (channel 2), Ch1 = 2 V/div, Ch2 = 2 V/div, time = 2 mS/div.

From the Fig. 12 a.) can be seen that the PWM signals on one phase (in case phase u) are shifted by 180° and that there is a dead between the failling and the rising edge of the signals. From Fig. 12 b.) and Fig. 12 c.) can be seen that SPWM signals on phase u pin 4 (channel 1) and phase v pin 9 (channel 2) are shifted by 120°, and SPWM signals on phase v pin 9 (channel 1) and phase w pin 2 (channel 2) are also shifted by 120°.

In the Fig. 13 is shown waveforms on SPWM signals on phase u pin 4 (channel 1) and phase v pin 9 (channel 2) for illustration on the SPWM switching (f_s = 4 kHz) and motor frequency (f = 50 Hz).

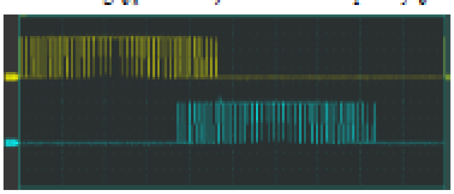

Fig. 13 Waveforms on SPWM signals on phase u pin 4 (channel 1) and phase v pin 9 (channel 2) for illustration on the SPWM switching (f_s = 4 kHz) and motor frequency (f = 50 Hz).

From the Fig. 13 can be seen that SPWM switching frequency is f_s = 4 kHz (T_s = 250 µS), and motor frequency in case is maximal f = 50 Hz (T = 20 mS). The number of SPWM pulses per half-period is 40. SPWM signals with such waveforms will provide phase voltages to the motor displaced by 120°.

On the channel 1 in the Fig. 14 is shown waveform of the phase voltage u, and of the channel 2 is shown waveform of the phase voltage v for motor frequency 50 Hz.

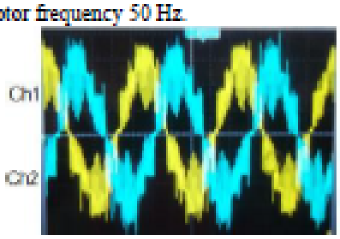

Fig. 14 Waveform of line voltage: on the channel 1 is the phase voltage u, and on the channel 2 is the phase voltage v for motor frequency 50 Hz, Ch1 = 100 V/div, Ch2 = 100V/div, time = 4 mS/div.

In Table I are given dates for effective values of the phase voltage of the motor U_{eff} for different motor frequency f.

***Table I:** Effective values of phase motor voltage U_{eff} for different motor f frequency.*

U_{eff}(V)	10.8	39.3	65.55	91	110.05	133.20	152.04	179
f(Hz)	3	11	19	26	31	37	42	50
U_{eff}/f	3.60	3.57	3.45	3.50	3.55	3.60	3.62	3.58

In the Fig. 15 is shown the ratio of the effective value of the phase voltage of the motor and the motor frequency (U_{eff}/f) obtained by measuring on the developed prototype of the speed motor regulator.

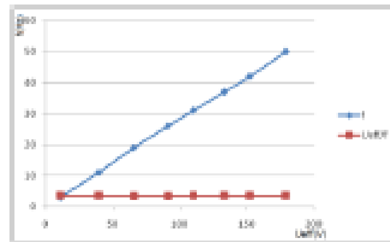

Fig. 15 Ratio of the effective value of the phase voltage of the motor and the motor frequency (U_{eff}/f) obtained by measuring on the developed prototype of the speed motor regulator.

From the dates in Table I and the Fig. 15 can be seen that the ratio of the effective value of the phase voltage to the motor and the frequency (U_{eff}/f) is maintained constant by applying the solution in the paper. Maintaining a constant ratio U_{eff}/f means that the flux i.e. the moment of the motor is constant.

5. Conclusion

In this paper is design and practically realized V/F speed regulator for 3-phase induction motor based on microcontroller. The specificity of the solution in the paper is the use of an intelligent power module for the power converter. Experimental results from the operation of the designed motor speed regulator show that it provides operation of the motor with a constant V/F ratio. This maintains the constant flux i.e. the moment of the motor.

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