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Digital Synchronisation with Mains for the Purpose of the Phase Motion Control

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Abstract: The induction or asynchronous motors are the most popular motors for industrial and consumer applications. Phase control is the most common form of thyristor or triac power control. The paper presents an approach for digital control of the ignition pulses generation using the possibilities of the enhanced capture timer module of the microcontrollers from the MC9S12D-Family. An algorithm for mains synchronization is proposed. Some fragments of code are presented. The practical implementation of the approach is explained.

Keywords: motion control, phase control, mains synchronisation, digital control, embedded systems.

1. INTRODUCTION

A large number of electric motors are in use everywhere in the human activities. AC induction machines are popular due to their simplicity, reliability and direct operation from an AC line voltage. Available voltage control methods include control by a transformer or by using electronic switches. The first method is not so easy to do with an AC speed control motor. In the second case the speed control is obtained by controlling the effective (RMS) value of the AC voltage applied to the motor. When the triac switch is connected between the AC power supply and the motor, the power flow can be controlled by varying the RMS of the AC voltage. This is called an AC voltage controller. There are two types of control normally used. On-off control - the triac switches connect the load to the AC source for a few cycles and then disconnect it for another few cycles of the source voltage. Alternately, the triac switches connect the load to the AC source for a moment in each half cycle of the AC voltage (50 or 60Hz) applied to the motor as it is mentioned by Shirahata.

Because of the wide spreading of the embedded control, the low prices of the microcontrollers and the permanent increase of their possibilities it is affordable to implement the digital control in the drives. According to Medina (2008) using microcontrollers in combination with the basic triac topology is cost-performance solution. Selection of an embedded microcontroller (MCU) for motor control applications requires to be considered multiple parameters. Nowadays, motor control applications are not dedicated drives for rotating machines but have become complex systems including several interfaces, real-time operating systems, high-performance peripherals and other elements.

Applications requiring the motor to operate with a required speed (pumps, fans, compressors, etc.) are speed controlled. The actual motor speed is maintained by a speed controller to reference speed command. The goal of this investigation is to propose an approach for AC motor control using microcontroller but this task has to be in addition to the main one and the others. It is emphasised on the tasks management and it is proposed the drive to be controlled by servicing interrupt requests but not in the main programme.

2. PROBLEM STATEMENT

Random phase triac drivers are designed to be phase controllable. They may be triggered at any phase angle within the AC sine wave. Phase control may be accomplished by an AC line zero cross detector and a variable pulse delay generator which is synchronised to the zero cross detector. The same task can be accomplished by a microprocessor which is synchronized to the AC zero crossing as it is described by Fairchildsemi (2014).

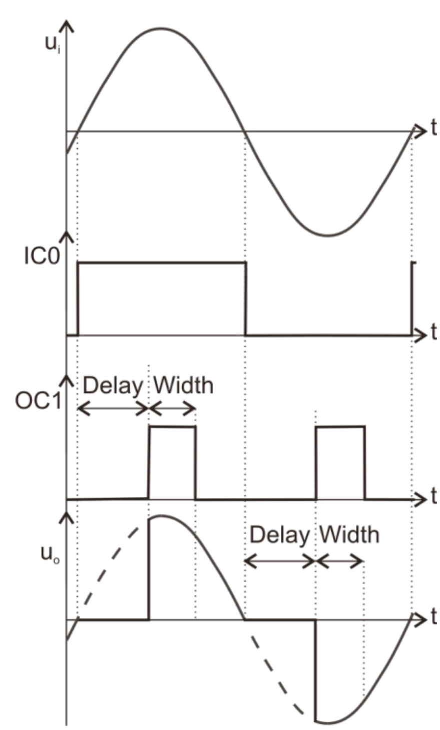

Fig. 1. Plot of the AC voltages and the control signals in the phase motion control.

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In Fig. 1 are presented the timing diagrams of the signals concerned by the processing. The signals u_i and u_o are respectively the input AC line voltage and the output voltage applied to the AC motor. It is shown that generally the rms value of the output voltage is less than the value of the input voltage and this is due to not applying the whole halves of the sine voltage. To synchronise the ignition pulses with the mains a zero cross detector is used and the signal *IC0* is shaped. The output pulses that are applied to the gate of the triac are labelled as *OC1*. The names of the square wave signals are chosen to be equal to the names of the corresponding channels of enhanced capture timer module of the microcontroller MC9S12A32 and their intended functions. *IC0* is an input signal and it is applied to the pin which serves as input capture for channel 0. Respectively *OC1* is an output signal which is produced by channel 1 serving as an output compare.

In phase control applications the driver is intended to be able to control each AC sine half wave from 0 to 180 degrees. Turn on at zero degrees means full power and turn on at 180 degree means zero power. This is not quite possible in reality because triac driver and triac have a fixed turn on time when activated at zero degrees. At a phase control angle close to 180 degrees the driver's turn on pulse at the trailing edge of the AC sine wave must be limited to end 200 microseconds before AC zero cross. This assures that the triac driver has time to switch off. Shorter times may cause loss of control at the following half cycle. The *Delay* time in Fig. 1 defines the phase angle after which the triac will turn on. The *Width* of the ignition pulse is chosen considering the requirement mentioned above.

3. IMPLEMENTATION OF THE DIGITAL SYNCHRONISATION

The project is based on the microcontroller of Freescale MC9S12A32. It is a 16-bit device composed of standard on-chip peripherals including a 16-bit central processing unit (HCS12 CPU), 32K bytes of Flash EEPROM, 4K bytes of RAM, 1K bytes of EEPROM, two asynchronous serial communications interfaces (SCI), one serial peripheral interfaces (SPI), an 8-channel IC/OC enhanced capture timer, one 8-channel, 10-bit analog-to-digital converters (ADC), an 8-channel pulse-width modulator (PWM). For the purpose of the digital synchronisation is used the enhanced capture timer module. Its basic features are: 16-Bit Buffer Register for four Input Capture (IC) channels, four 8-Bit Pulse Accumulators with 8-bit buffer registers associated with the four buffered IC channels which can be configured also as two 16-Bit Pulse Accumulators, 16-Bit Modulus Down-Counter with 4-bit Prescaler and four user selectable Delay Counters for input noise immunity increase. The module has 8 Input Capture, Output Compare (IC/OC) channels. When channels are selected as input capture by selecting the IOSn bit in TIOS register, they are called Input Capture (IC) channels. The software is organised in a way where the phase control is performed with servicing interrupt requests. This will save time and resources of MCU to execute the main programme. Some fragments of the assembly language code illustrating the operation of the digital synchronisation will be presented. First is the initialisation.

```
LDAA   #%10000000
STAA   $0046          ; TSCR1
LDAA   #%00000010     ; TIOS
STAA   $0040
LDAA   #%00000000     ;
STAA   $0048          ; TCTL1
LDAA   #%00001000
STAA   $0049          ; TCTL2
LDAA   #%00000000
STAA   $004A          ; TCTL3
LDAA   #%00000011     ; IC0 CAPTURE ON ANY EDGE
STAA   $004B          ; TCTL4
LDAA   #%00000001     ; TIER - IOC0 INTERRUPTS
STAA   $004C          ; REQUESTED
```

The first writing in Timer System Control Register 1 enables the timer and allows it to function normally. Next after the writing to the Timer Input Capture/Output Compare Select Register the intention of every channel is defined. Timer Channels can be configured as input capture channels or output compare channels. Writing 1 in a bit of this register configures the corresponding channel as output compare and writing 0 – respectively as input capture. So channel 0 will operate as input capture and channel 1 – as output compare. Initially after the writing in Timer Control Register 1/Timer Control Register 2 the output line OC1 is cleared to zero. After the writing in Timer Control Register 3/Timer Control Register 4 IC0 is forced to capture on any edge (rising or falling) and after the writing in Timer Interrupt Enable Register IC0 is enabled to request interrupts.

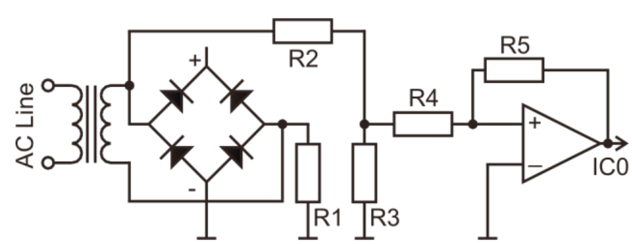

Fig. 2. Zero cross detector.

The zero cross detector which circuit diagram is depicted in Fig. 2 shapes square wave pulses which change their level when the input AC voltage crosses the zero line. As a source is used the system power supply unit and the terminals of the secondary winding of the transformer are loaded with the resistors R1, R2 and R3 in order to not produce parasitic pulses. The comparator produces square wave pulses as it is shown in Fig. 1 and its output is connected to IC0 pin of the microcontroller.

The flow chart of the routine which services the interrupt request causing by the zero cross detector is shown in Fig. 3. The routine uses two variables – DELAY which is two bytes long and LEVEL with one byte length. In DEALY is stored the value of the time representing the phase angle at which the triac switch will be turned on. In the presented project the bus frequency of the microcontroller is chosen to be 2MHz, so the time base is 0,5 microseconds. In this case if the mains frequency is 50Hz, the time that corresponds to 180 degrees will be 10 milliseconds and the maximum value which

DELAY may contain is 20000. The value of DELAY is loaded in the main programme in accordance with the value of the parameter which is controlled by varying the speed of the AC motor. The variable LEVEL stores the state of the OC1 output pin.

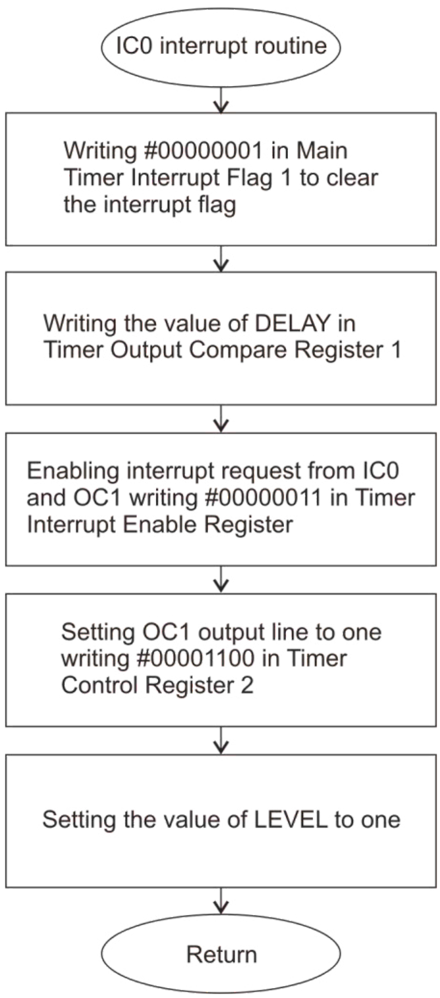

Fig. 3. The flow chart of the routine servicing the caused by IC0 interrupt requests.

The following code fragment executes the flow chart.

```
IC0
      LDAA   #%00000001
      STAA   $004E
      LDD    $0044
      ADDD   DELAY
      STD    $0052
      LDAA   #%00000011    ; TIER – IC0, OC1
      STAA   $004C         ; INTERRUPTS REQUESTED
      LDAA   #%00001100
      STAA   $0049
      INC    LEVEL
      RTI
```

The first operation is to clear the corresponding to IC0 bit in the Main Timer Interrupt Flag register. After that the value of DELAY is written in the Output Compare Register 1 to produce the delay time to the switching on the triac. Because of that the time or actually the phase angle is started the interrupt request by OC1 is enabled after the writing 1 to the corresponding to OC1 bit in the Timer Interrupt Enable Register. The next steps are to enable setting the OC1 output line to 1 after the time defined by the value of DELAY elapses and to set the value of LEVEL to 1. So automatically the output line OC1 will be set to 1 after elapsing the DELAY time and it will be executed by servicing the interrupt requested by OC1.

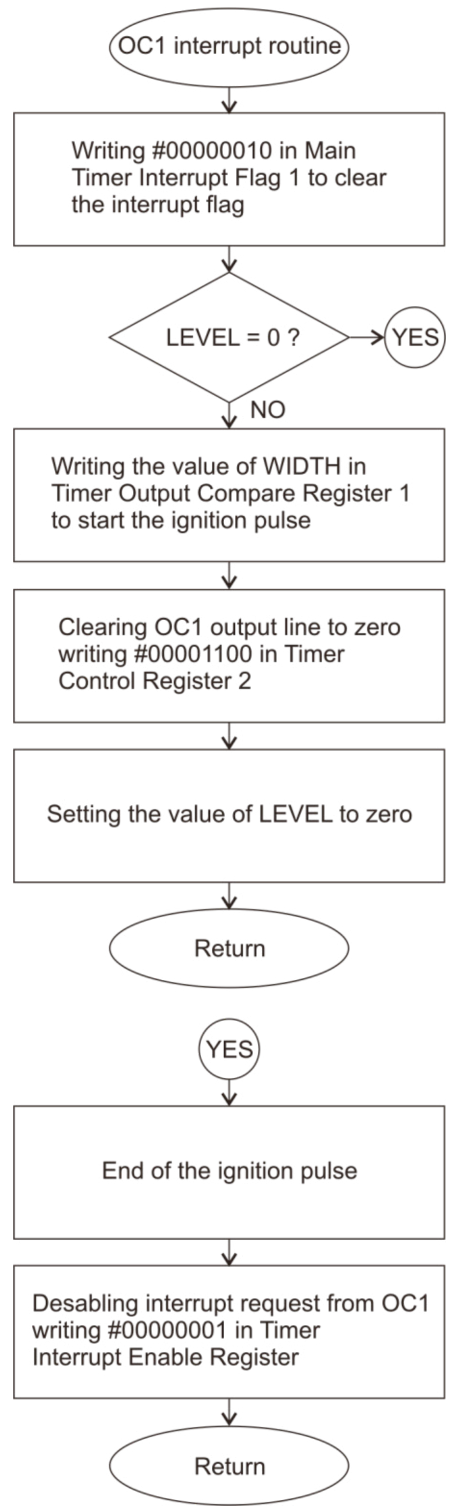

Fig. 4. The flow chart of the routine servicing the caused by OC1 interrupt requests.

The first action of the flow chart of the routine servicing the interrupt request caused by OC1 which is shown in Fig. 4 is to clear the corresponding to OC1 bit in the Main Timer Interrupt Flag register. After that the programme continues in two branches depending on the value of LEVEL. If it is one the ignition pulse is to start so the value of its width stored in the two bytes variable WIDTH is loaded in the Timer Output Compare Register 1. The next step is to force the clearing of the OC1 output line to zero as a result of the next interrupt which will end the ignition pulse with the set width. The routine finishes with setting the value of LEVEL to zero which shows that the next interrupt request will be the end of the ignition pulse. The second branch of the routine is executed when the value of LEVEL is 0. The ignition pulse has finished so the interrupt request by OC1 is disabled after the writing 0 to the corresponding to OC1 bit in the Timer Interrupt Enable Register. The following code fragment illustrates the operation of the routine.

```
OC1
    LDAA   #%00000010
    STAA   $004E
    LDAA   LEVEL
    BEQ    BR1
    LDD    $0044
    ADDD   WIDTH
    STD    $0052
    LDAA   #%00001000
    STAA   $0049
    CLR    LEVEL
    RTI
BR1
    LDAA   #%00000001    ; TIER – OC1 INTERRUPTS
    STAA   $004C         ; REQUESTS DISABLED
    RTI
```

The circuit diagram of the triac driver is shown in Fig. 5. There is used the optoisolator MOC3023M consisting an infrared LED optically coupled to a non–Zero–crossing silicon bilateral AC switch (triac). The MOC3023M Series isolates low voltage logic from 115 and 240 Vac lines to provide random phase control of high current triacs or thyristors. The LED is triggered by the OC1 line of the microcontroller according to the described flow chart.

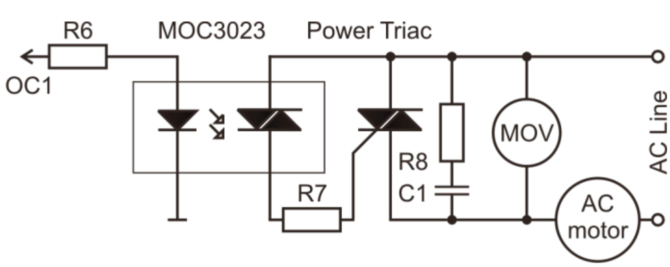

Fig. 5. Triac driver.

For usage in noisy environments the snubber components R8 and C1 are recommended. The MOV (Metal Oxide Varistor) protects triac and driver from transient overvoltages as it is proposed by Fairchildsemi (2014).

The described circuits, flow chart and code have been implemented by Iovev et al. (2013) in a differential temperature controller for drain back solar system. Differential temperature controllers have been gaining popularity in solar thermal systems and nowadays are the most common choice for correct system operation. Thermal solar systems are designed to capture the sun's energy and transfer it to a thermovector fluid, which in turn transfers it to the water required by the user. The main unit is based on the microcontroller MC9S12A32. There are four inputs for measuring the temperatures of three solar collectors and the temperature of the solar tank. The unit controls up to three pumps with AC motors. Phase control using the mentioned above principles is applied to motor drives with rated parameters 230V/3A. The range of speed regulation of the circulation pumps is from 40% to 100%. The differential controller has four relay outputs and three of them control the magnet valves, which are necessary to drain back the water from collectors. If the solar tank temperature is inadequate to provide sufficient hot water (low solar irradiation), the fourth relay output is used to ensure the reheating of the solar tank by a conventional heat source. The main programme deals with temperature measurements, relay outputs control and data communication with the control board. The pumps are controlled by servicing interrupt requests caused by the zero cross detector and output compare channels.

4. CONCLUSIONS

In this paper an approach for digital synchronisation with mains for the purpose of the phase control of AC motor drives is proposed. The approach combines the hardware and software advantages of the embedded control. The investigation is based on the microcontroller MC9S12A32 and on the possibilities of its timer module. They allow the phase control to be realised by servicing interrupt requests. The advantage is that the microcontroller is free to handle the other tasks. The approach is implemented in the practice and the operation of the hardware and software has been verified. It could be implemented in other applications like power converters where the phase control is used.

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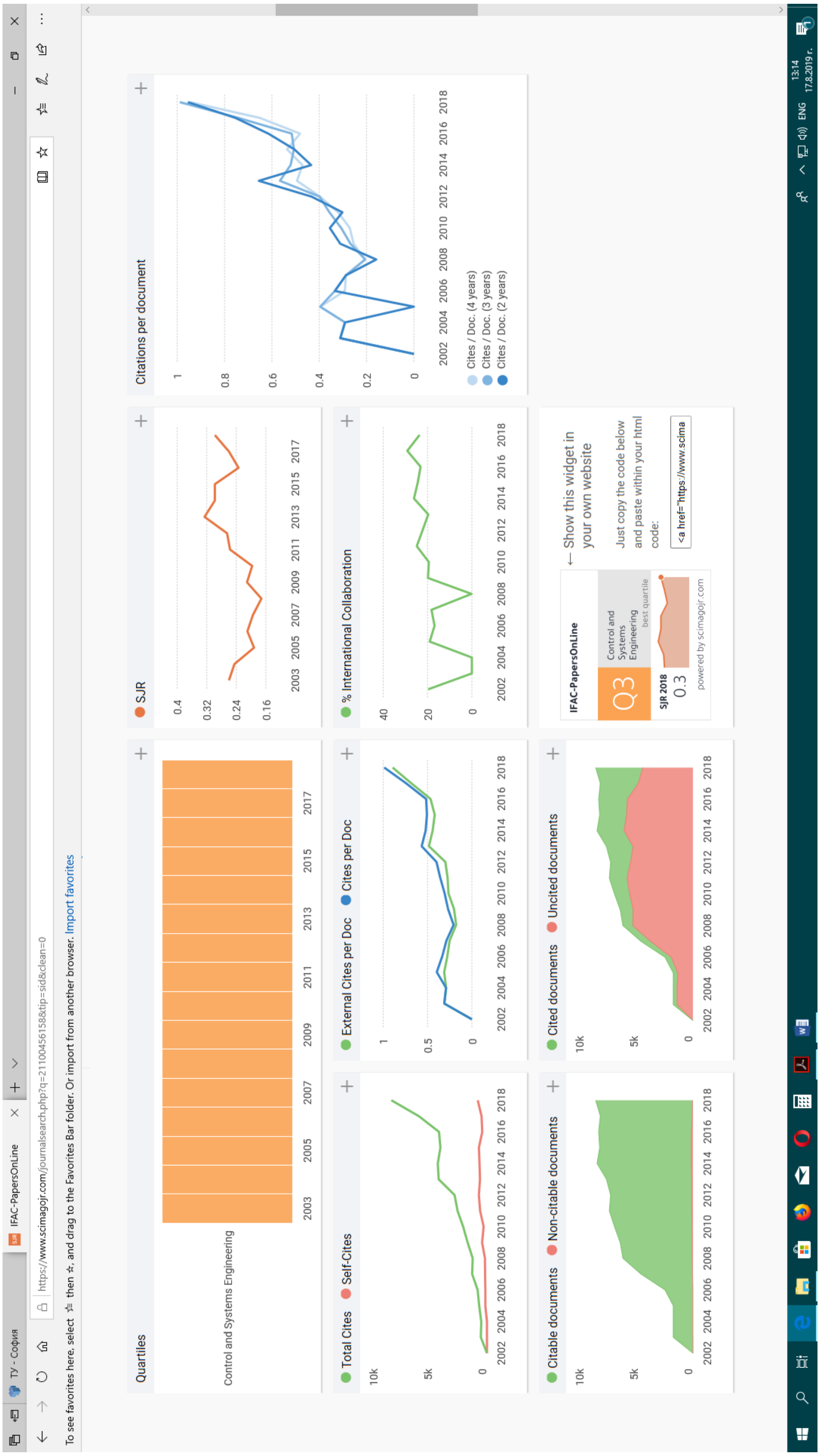

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