Design and Implementation of Digital Trigger Circuit for Converter

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Abstract

Controlled power is a fundamental prerequisite of various sectors. A scheme of microcontroller based firing angle control, using ATmega 32 MCU & associated hardware circuitry is discussed. Basic idea is to achieve reliable, consistent control that will result in improved performance of converter. Set-up consists of ATmega-32 controller, LCD display for displaying firing angle, transistorized conditioning circuit, main rectifier module and input from user in the form of analog voltage for firing angle control. Integration of these modules will result in full controlled converter with superior performance over other ordinary control techniques.

1. Introduction

In industrial, agronomic production and house hold applications the controlled powers through electronic technology have been widely used. The power is provided to the application via rectifier, cycloconverter, frequency converter and inverter. Among these four types, rectifier is generally used in the equipment, where in trigger circuit is very important. Because of advances in the switching technology the analog trigger circuits are replaced by digital trigger circuits [8]. The circuit like converter, cycloconverter, rectifier and inverter make use of thyristor as an elementary unit. The three terminal thyristors having additional terminal gate, along with anode and cathode; is employed to trigger the thyristor at a precise angle, known as firing mechanism [10].

It is observed that in analog triggering circuit, trigger circuit is too complex with many components; which may lead to debugging difficulties, uneven spacing of the adjacent trigger pulses and shifting phase inaccuracies. Hence digital trigger mechanism is designed which overcomes the limitations of analog trigger circuit.

Using ATMega-32 controller programmable pulse train is be generated in desired sequence as six outputs of microcontroller port. These pulse trains can be manipulated with software program for microcontroller. These manipulated pulses will be used through proper isolation, for triggering SCR gates thereby controlling converter's output. Synchronization will be achieved by using sample from raw AC signal, converting it in square wave pulse & using it for interrupt of MCU. Firing angle control is achieved by varying analog voltage (0-5 V), which is converted by ADC of ATmega-32 into digital value, and this value is used as firing angle by proper mathematical calculation to trigger the converter circuit at desired firing angle, thereby controlling the output voltage.

In section-I the overview of power electronic technology is discussed along with its importance in household and commercial application. Hardware and software platform for digital trigger circuit is discussed in Section-II. Section-III gives a detail view of Methodology incorporated in project. Results are discussed in section IV. Section V concludes the paper.

2. Hardwar and software platform

2.1 Embedded board

Embedded board based on AVR microcontroller is used, it contains several sensors, LCD screen, LEDs, etc. all on the same board. No need to connect any additional hardware for multiple applications. Board has various features like: AVR ATmega32 microcontroller, 2-line LCD display, 8 LEDs, temperature sensor, RTC (Real Time Clock) chip, serial port, four on-board keys for input, external interrupt pins, operation using 9V battery or AC adapter.

2.2 Software Platform

WinAVR is a collection of executable software development tools for the ATmega AVR processor hosted on Windows and Cygwin is software that provides a Unix-like environment and software tool set to users of any modern version of MS-Windows.

3. Methodology

Set-up is consist of ATMega-32 controller, Analog voltage (0-5 V) is for operation control, LCD display for displaying firing angle, transistorized conditioning circuit & main rectifier module. Integration of these modules will result in Full controlled converter with superior performance over other ordinary control techniques.

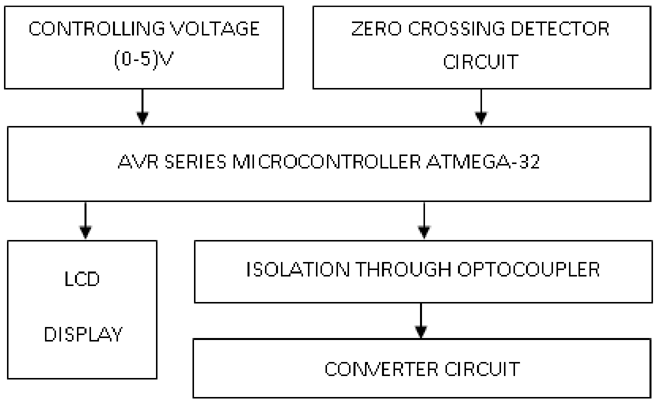


Figure 1 Block Diagram

3.1 0-5 V controlling voltage

Analog Voltage (0-5 V) is used for controlling the converter power, ADC of Atmege-32 microcontroller is 10 bit resolution. Port A is used for ADC in Atmege-32. Channel 0 and 1 are reserved for light and temperature sensor, that's why channel 2 is used for accepting analog voltage. Analog Voltage (0-5 V) is converted in to (0-1023) count. Analog voltage is provided to one of the channel of ADC port. As per variation in the analog voltage there is change of digital value. ADC conversion takes around 250 micro second. PWM is achieved with the help of variable controlling voltage.

3.2 Zero Crossing Detector circuit

Zero Crossing Detector circuit distinguish between start of positive half cycle or negative half cycles. To have full control over the firing angle of the SCR, it is necessary to precisely detect the zero crossing of the sinusoidal input.

Signal from mains is provided as a input, which is scaled down by transformer to the alternating voltage of lower value around 12V. It is necessary that the output at the secondary of T remain in-phase with the input on its primary. This scaled down and isolated AC input is then scaled down further by using a resistor divider network consisting of R1 and R12. Diode is for the rectification followed by resistor divider network to scale down the voltage level. Transistor 2N2222 is used for generation of square wave which acts as a switch. At collector terminal we have square wave with amplitude of 4.88 volt.

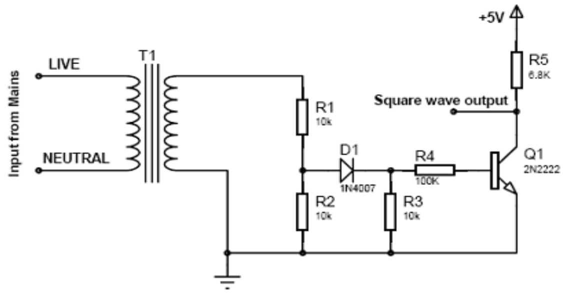


Figure 2 Zero crossing detector

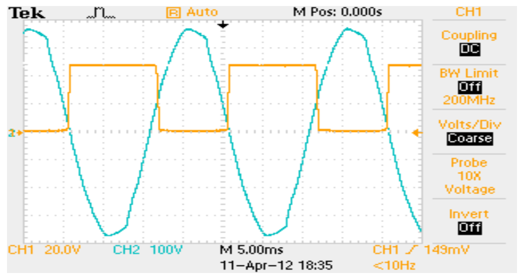


Figure 3 Waveform of ZCD

Fig 2 shows circuit diagram of ZCD and Fig 3 provides the waveforms of AC signal and square wave generated by ZCD.

3.3 Microcontroller Atmega-32

It is a high-performance, Low-power AVR 8-bit Microcontroller having advanced RISC architecture, 32K bytes of in-system self-programmable flash, 1024 Bytes EEPROM , 2K byte internal SRAM. 8-channel 10-bit ADC, External and Internal Interrupt Sources 32 Programmable I/O Lines.

It accepts analog controlling voltage form ADC channel 2, which is converted in to digital value, this value is used for PWM. Signal from zero crossing detectors is given at INT0 pin of ATmega-32. Falling edge of the square wave is detected as the interrupt. In interrupt subroutine first trigger pulse is output.

3.4 Display

Embedded board with 2-line LCD display is used for showing the ADC value and respective firing angle. Values on the display are instantaneous with the change in the analog voltage values of ADC and firing angle changes.

3.5 Programming

C language is used for programming AVR microcontroller. First requirement is a compiler, which is required to convert C code to machine code (Hex code), which is ultimately transferred to flash memory of microcontroller. Here WINAVR2006 compiler is used. The second requirement is a programmer which transfers the .hex file (created by the compiler) to the chip. BSD programmer is used for that. AVRDUDE software is used for programming ATmega32 CPU.

Here for coding Embedded C language is used for programming Atmega-32 controller, Embedded C language has certain advantages over ALP.

3.6 Generation of triggering pulse.

At any time when zero crossing (falling edge of square wave) is detected on the AC mains, microcontroller is interrupted and the latest values of ADC is used to manipulate firing delay which is use to determine firing angle with proper mathematical calculations. According to the firing angle, the triggering pulse is generated for gate terminal of SCR to trigger the thyristor. On LCD, ADC output and firing angle which is calculated from ADC reading is displayed for the observer who is controlling the converters output.

ADC output is 0-1023 which is use to control firing angle 0^0-180^0. Let *ADC* is the output from analog to digital converter and α is the firing angle. So the relationship between firing angle and ADC is given in equation (1).

$$\alpha = ADC/5.68 \qquad (1)$$

Now it is needed to calculate the delay as per the firing angle which is based on the ADC output and ADC output is based on the analog voltage (0-5V). Here relationship between delay in the generation of firing pulse and ADC output is determined. Converter output is controlled up to 180^0, as AC supply is 50Hz it have the time period of 20ms and for positive half cycle time period is 10ms, As ADC of ATmega32 is of 10-bit resolution hence the maximum value from the ADC with +5 volts reference will be 1023 for which 10ms delay is required. ADC reading is converted into a delay after which firing pulse is to be generated. Relationship between ADC reading and firing angle delay is shown in (2). If *ADC* is output of ADC and *d* is the delay in microseconds, then,

$$d=(ADC*5)*1.955 \qquad (2)$$

1.955 here is the scaling up factor for the ADC reading and 5 is the reference voltage. Hence for ADC = 1023, the delay d will be 9999.825 microseconds which is nothing but time period of half positive cycle. MCU generates firing pulses on its output port with on-time of 100 microseconds.

Figure 4 shows the waveform of ZCD output and trigger pulse without firing angle. When analog voltage is 0V, then ADC output is also 0. Hence the delay in the generation of triggering pulse is also 0 ms. Trigger pulse is output when there is zero crossing of AC mains. Figure 5 shows the waveform of ZCD output and trigger pulse with 90^0 firing angle. When analog voltage is raised up to 2.5 V, ADC output will be 512 and delay will be 5ms, triggering pulse is generated with the firing angle of 90^0.

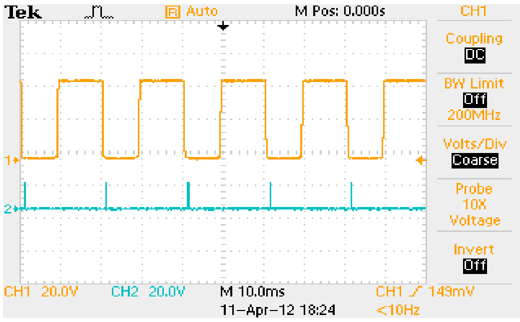


Figure 4 ZCD o/p and Trigger pulse without firing angle

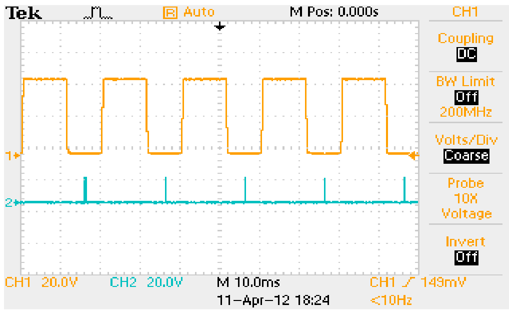


Figure 5 ZCD o/p and Trigger pulse with 90^0 firing angle

3.7 Isolation using MOC 3021

The triggering pulse is generated at the port A of ATmega 32 is 4.8V. This pulse is provided to the MOC 3021 as the input signal for its operation [16].

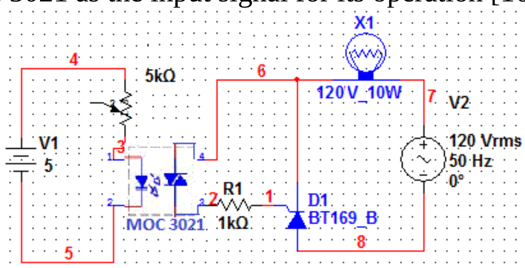
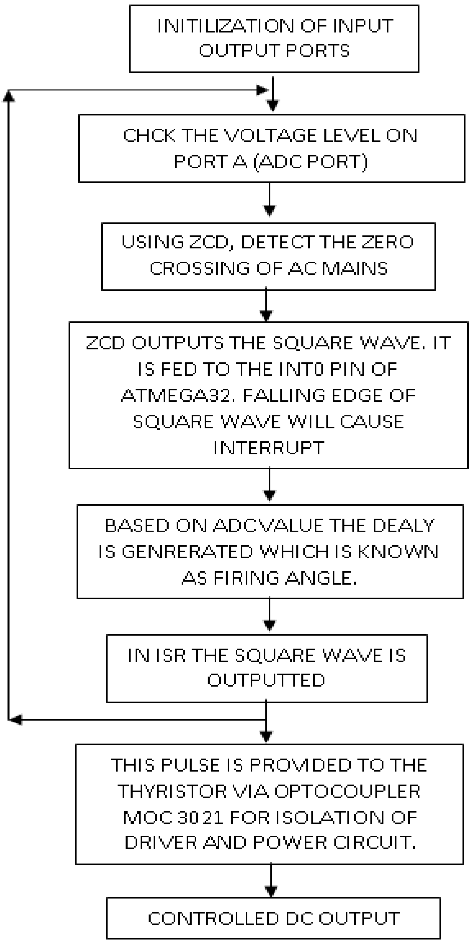


Figure 6 Thyristor Driver Circuit using Optocoupler MOC 3021

Internal structure of this IC MOC 3021 contains diode and DIAC. When triggering pulse is input to the optocoupler MOC 3021, starts working and the gate pulse is provided to the thyristor BT169 as a result thyristor gets fired.

3.8 Thyristor Driver Circuit using Optocoupler MOC 3021

Flowing flowchart depicts sequence of events undertaken.



Here the programming flow is described as:

1. ADC: Analog voltage (0-5 V) is fed to the ADC of ATmega-32 through port A, which converted to 0 to 1023 count. This count after proper mathematical manipulation is used to generate the delay in the generation of trigger pulse.
2. ZCD: Zero Crossing Detector Circuit is used to detect the zero crossing of the AC signal, Synchronization is achieved with the help of raw AC signal as a input to ZCD. Square wave is output through the ZCD which is used to generate the interrupt. In ISR the triggering pulse is output with the desired firing angle decided by the analog voltage (0-5 V)
3. TRIGGER PULSE GENERATION: When interrupt is detected the trigger pulse having Ton period of 100 micro second is use to trigger the thyristor. Thyristor gets commutated when the supply voltage becomes negative because of natural commutation. In the next cycle again the interrupt is generated which is used to trigger the thyristor.

4. Result

For the experimental setup ATmega-32 embedded board is used. Following are the result obtained during experimentation.

1. Analog voltage (0-5) is use as controlling voltage for the adjustment in the firing angle. It is observed that for voltage from 0V to 5V, ADC conversion time is constant which is 600 µsec. Reading of Voltage, ADC value, Firing Angle, Delay as,

Table 1 Measurement of Controlling Voltage, ADC, Firing Angle and Delay

Sr. No.	Controlling Voltage	ADC Value	Firing Angle	Delay (ms)
1.	0	15	2	1
2.	0.5	112	19	1.8
3.	0.8	192	33	2.6
4.	1.0	220	38	3.0
5.	1.3	286	50	3.6
6.	1.5	318	56	3.8
7.	1.8	384	67	4.4
8.	2.0	415	73	4.8
9.	2.3	472	83	5.2
10.	2.5	527	93	5.8
11.	2.8	575	101	6.4
12.	3.0	624	110	6.8
13.	3.3	671	118	7.2
14.	3.5	711	125	7.6
15.	3.8	783	138	8.2
16.	4.0	807	141	8.4
17.	4.3	896	158	8.8
18.	4.5	968	164	9.2
19	4.8	1016	179	9.6
20.	5.0	1023	180	10.0

2. ZCD is used to detect the zero crossing of AC mains, falling edge of square wave of ZCD output acts as a interrupt to CPU. Trigger pulse is output after that. Reading for ZCD and trigger pulse from ATmega-32 controllers port is as given in table 2.
3. With the help of ATmega32 triggering pulse is generated this pulse is provided to the thyristor through the optocoupler MOC3021 for the purpose of isolation.

Table 2 Reading for ZCD and Trigger pulse form ATmega-32 controllers port

Sr. No	Parameter	ZCD Output	Triggering Pulse
1.	Rise Time	180 µsec	35.50 µs
2.	Fall time	226 µsec	35.38 µs
3.	Positive Width	10.00 ms	100 µs
4.	Negative Width	10.00 ms	19.90 ms
5.	Frequency	50 Hz	50Hz
6.	Period	20 ms	20 ms
7.	Peak	4.3 V	4.88 V

4. It is observed that there is synchronization in the generated trigger pulse with reference to ZCD and AC mains at the load side.
5. The circuit is tested for 1 phase converter, it is observed that trigger pulse of 100 micro second is sufficient to trigger the thyristor. The train of pulses are used as the triggering pulses for thyristor, reason behind the use of train of pulses is that in case the thyristor is not trigger because of the first trigger pulse then second pulse form the train of pulses will trigger the thyristor. If second pulses do not trigger the thyristor then remaining pulse will trigger the thyristor. In Figure 8 train of pulses are outputted after detection of falling edge of the square wave as interrupt.

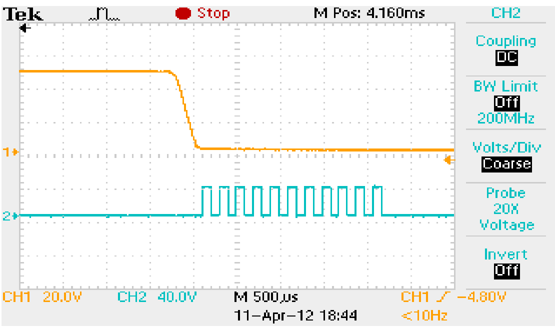


Figure 8 Train of pulses for triggering of SCR

6. This design has been fully tested and verified by driving incandescent lamps, circuit is capable to fire the SCR at any angle ranging from 0 to 180 degrees without any noise or fluctuations on main lines. It is observed that when the controlling voltage is low firing angle is also low, more portion of positive half cycle is provided to the load (lamp) more voltage available at load as the result brightness of the lamp is very high. When the controlling voltage is going on increasing firing angle is also goes on increasing, less portion of positive half cycle is provided to the load (lamp) less voltage is available at the load as the result brightness of the lamp goes on decreasing.
7. Figure 9 shows the voltage waveform across resistive load controlled by SCR BT 169 fired at 150 degrees

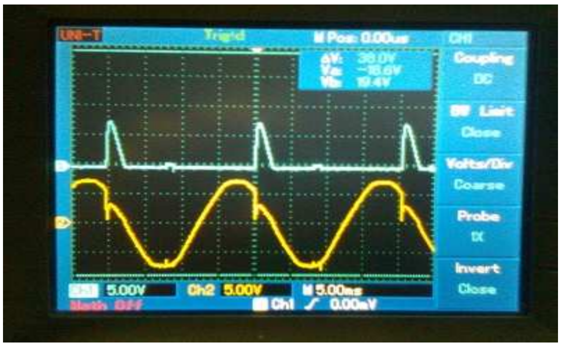


Figure 9 Voltage waveform across resistive load controlled by SCR fired at 150 degrees

8. For three phase full wave converter three Zero Crossing Detector Circuits are required to detect the individual phase of three phase converter. After detection of three phases interrupt is generated at the falling edge of square waves which is a output from the ZCDs. In ISR the triggering pulses are generated, which are use for triggering the elements of 3 phase converter circuit.

5. Conclusion

The design is isolated from electromagnetic interference at input and output side. Power control is possible from 0-180^{0} with controlling voltage. Very few components are use in this design which are easily available and are cheap. The design is software based hence can be easily upgraded to control other power devices for controlling power.

References

[1] R. Arockiasamy and S. Doraipandy, “A novel trigger scheme for Thyristor operating under variable frequency anode supply,” IEEE Trans. Ind. Electron. Contr .Instrum., vol. IECI−22, No. 1, pp. 83−85, Feb.1975.

[2] R. Simard and V. Rajagopalan, “Economical equidistant pulse Firing scheme for Thyristorized D.C. drives,” IEEE Trans. Ind. Electron. Contr. Instrum., vol. IECI-22, No.3, pp. 425−429, 1975.

[3] S. Murugesan and C.Kameswara, "Simple adaptive analog and Digital trigger circuits for thyristors working under wide range of Supply frequency,” IEEE Trans. Ind. Electron. Contr. Instrum., vol. IECI-24, No. 1, pp.46−49, 1977.

[4] L.H.Hoang ,"A digitally controlled thyristor trigger circuit," Proc. IEEE, vol. 66, No.1, pp. 89−91, Jan. 1978.

[5] B. Ilango, R. Krishman, R. Subramanian, and S. Sadasivam, "Firing circuit for three-phase thyristor-bridge rectifier," IEEE Trans. Ind. Electron. Contr. Instrum., vol. IECI−25, no. 1, pp. 45−49, 1978.

[6] S.C.Gupta, K.Venkatesan, And K.Eapen, "A Generalized Firing Angle Controller Using Phase-Locked Loop for Thyristor Control," IEEE Transactions On Industrial Electronics And Control Instrumentation, vol. IECI-28, No. 1, February 1981.

[7] P.C. Tang, S.S.Lu, and Y.C.Wu, "Microprocessor-Based Design of a Firing Circuit for Three-Phase Full-Wave Thyristor Dual Converter," IEEE Transactions on Industrial Electronics, vol. IE−29, No. 1, February 1982.

[8] XU Wuxiong, "Design of Thyristor Digital Trigger Circuit Based on Microcontroller Unit," The 1st International Conference on Information Science and Engineering (ICISE2009)

[9] M. U. Rafique, "A Universal and Optimized Embedded System to Control Firing Angle of Thyristors with Double-Sided," 2011 Third International Conference on Communications and Mobile Computing.

[10] T. C. Pimenta, L. L. G. Vermaas, P. C. Crepaldi, R. L. Moreno "The Design of a Digital IC for Thyristor Triggering," 10th Intentional Conference on VLSI Design−January 1997.

[11] Muhammad H. Rashid, Power Electronics (Circuits, Devices, and Applications), 3rd ed., Pearson Prentice Hall, 2006, pp. 339.

[12] S.S.Upadhya, K. Kant and G. Singh, "A New Microprocessor Interfacing Hardware for SCR Triggering," proceeding of the IEEE, vol. 70, No. 10, October 1982.

[13] T. Thepmanee, S. Pongswated, P. Ukakimapurn, and K. Tirasesth "The Technique to Generate Firing Signal for Converter for Linear DC Output," SICE Annual conference, The University Electro-communication, Japan 2008.

[14] Mr. Shashikant Lahade, S. R. Hirekhan" Study of Analog and Digital Firing Methods for Converters" IJECCE Volume 3 Issue 2, Mar. 2012 pp 21-24

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