Design and Implementation of AT Mega 328 microcontroller based firing control for a tri-phase thyristor control rectifier

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Abstract

Design, development, testing, and installation of a firing controller for a tri phase thyristor rectifier. AT Mega 328 microcontroller is used as the firing controller. This IC chip provides logical input and output, analog-to-digital conversion, timer for the delay counting, and various interrupt vectors for timing. The software algorithm consists of the detection of the zero crossing of the synchronization voltage to start the timing of a period. A special test is programmed to control the value of the firing angle.

Controlled power is a fundamental prerequisite of various sectors. A scheme of microcontroller based firing angle control, using AT Mega 328 MCU & associated hardware circuitry is designed. Basic idea is to achieve reliable, consistent control that will result in improved performance of converter.

The design develops triggering circuit of 3-phase, 6-pulse, ac to dc controlled converter using AT Mega 328 microcontroller. The microcontroller will generate six equidistant, synchronized triggering pulses for the converter which finds application in power systems (high voltage DC transmission) and industrial drive systems. The controller is required to sense the input voltage and generate the required six trigger pulses irrespective of the variation of the mains frequency and to control the delay angle of these signals equally to control the DC output voltage.

Keywords: Microcontroller, AC/DC converter, Synchronization technique, gate triggering technique, DC motor.

I. Introduction

Set-up consists of ATmega-328 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.

Power electronics applications span the whole field of electrical power system, with the power range of these applications extending from a few VA/ watts to several MVA/MW. The main task of power electronics is to control and convert electrical power from one form to another. In case of SCR based converters, gate signal is generated from a separate gate trigger circuit. These signals are used to control the conduction period of SCR which ultimately controls the output or the performance of the power electronic converters. As far as triggering circuits are concerned, simple triggering circuits can be realized by R or RC network but they depend on gate trigger characteristics of the thyristors used, and they cannot be used easily in self-programmed, automatic or feedback controlled systems. Because the use of power-electronic controllers is increasing steadily in industry as well as in power systems, different types of controllers are required for specific applications. In a controller, a group of thyristors or power-semiconductor devices are required to be switched at different switching instants for different durations and in a particular sequence. Different three-phase converters, for example dual converters, cycloconverters, and regenerative reversible drive, may require 12 to 36 such devices. Thus switching a large no. of these power devices with different control strategies by a simple trigger circuit becomes almost impossible. Moreover, incorporation of feedback and different control approaches for same load or drive systems requires an intelligent controller. Therefore the use of advanced triggering circuits becomes necessary. Some modules of power semiconductor devices include a gate drive as well as transient protection circuitry. Such commercially available modules are called intelligent modules or smart power. They include input-output isolation and gate drive circuits, microcomputer control, a protection and diagnostic circuit (for over current, short-circuit, open load, overloading and excess voltage) and a controlled power supply. In case of three phase converters, six trigger pulses are required for each SCR. Therefore generation of six trigger pulses and their delay control, equally and simultaneously, becomes difficult using conventional analog and digital circuits. Moreover these circuits become complex and proper control over wide range becomes difficult.

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. 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-328 controller programmable pulse train is to 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-328 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.

II. Hardware and software platform

1. Hardware

Hardware consists of three phase power rectifier, synchronization circuit, voltage regulator circuit, gate trigger circuit, firing angle control circuit. Embedded board based on AVR microcontroller is used, it consists of ATMega-328 controller, Analog voltage (0-5 V) is for operation control, LCD display for displaying firing angle, transistorized conditioning circuit & main rectifier module.

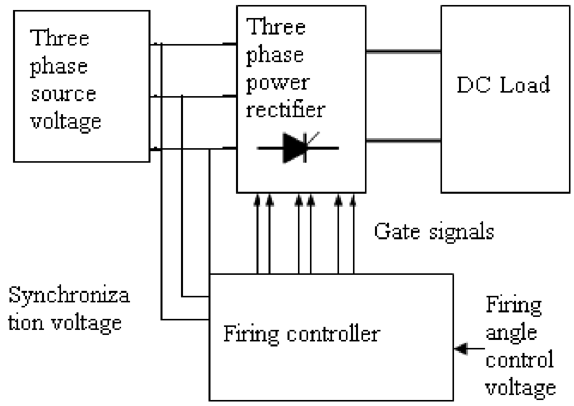


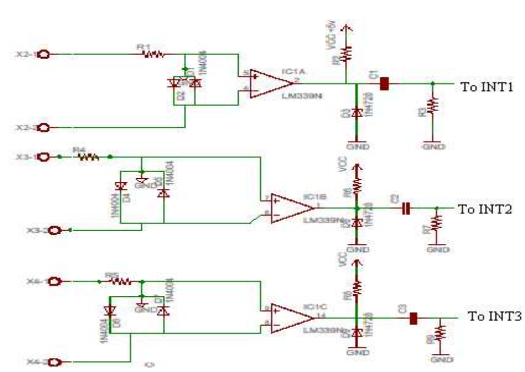
Fig 1: The Triphase control Rectifier Block Diagram.

2. 0–5 V controlling voltage

Analog Voltage (0-5 V) is used for controlling the converter power, ADC of Atmega-328 microcontroller is 10 bit resolution. 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. Synchronization Signal Circuit:

Synchronization voltage can be obtained from line voltage which come from thyristors circuit and this can ensure that zero-crossing point from negative to positive of synchronization voltage is just corresponding to shift phase angle ($\alpha = 0^0$) of the three-phase bridge full-controlled rectifier circuit.



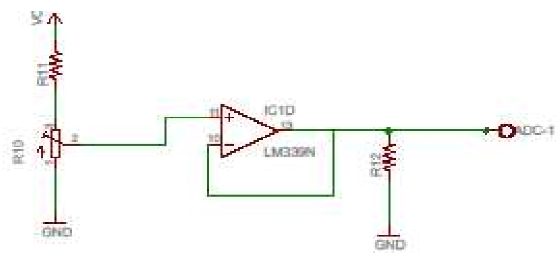


Fig:2 Synchronization circuit.

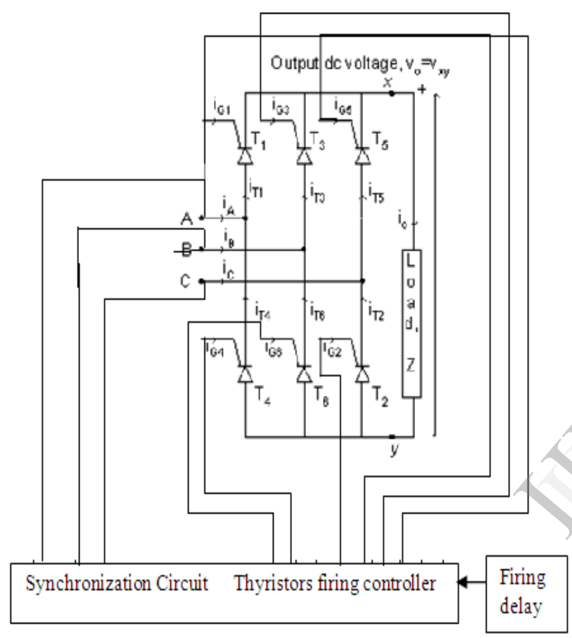


Fig:3 Schematic diagram for power converter

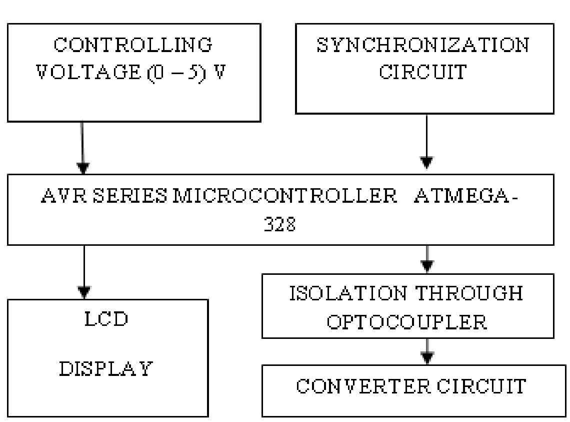


Fig: 4 Block Diagram

4. Microcontroller Atmega-328

The high-performance Atmel 8-bit AVR RISC-based microcontroller combines 32KB ISP flash memory with read-while-write capabilities, 1KB EEPROM, 2KB SRAM, 23 general purpose I/O lines, 32 general purpose working registers, three flexible timer/counters with compare modes, internal and external interrupts, serial programmable USART, a byte-oriented 2-wire serial interface, SPI serial port, 6-channel 10-bit A/D converter (8-channels in TQFP and QFN/MLF packages), programmable watchdog timer with internal oscillator, and five software selectable power saving modes. The device operates between 1.8-5.5 volts.

By executing powerful instructions in a single clock cycle, the device achieves throughputs approaching 1 MIPS (Microprocessor without Interlocked Pipeline Stages) per MHz, balancing power consumption and processing speed.

5. 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.

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 theconverters output. ADC output is 0-1023 which is use to control firing angle 0^0-180^0.

7. Pulse Output Circuit.

With the pulse output circuit, the 6 trigger pulses are outputted from the pin P1.0 to pin P1.5 of the MCU. Each pulse is sent to opt isolator to be isolated from power grid; then its output is sent to pulse transformer, and last the pulse from pulse transformer triggers the corresponding thyristor.

8. Programming flow:

1. ADC: Analog voltage (0-5 V) is fed to the ADC of ATmega-328 through port, 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. Synchronization signal circuit:
With synchronization signal circuit, synchronization voltage can be obtained from line voltage which come from thyristors circuit and this can ensure that zero-crossing point from negative to positive of synchronization voltage is just corresponding to shift phase angle ($\alpha = 0^0$) of the three-phase bridge full-controlled rectifier circuit. Square wave is outputted through the synchronization signal circuit which is used to generate the subroutine. In subroutine the triggering pulse is output with the desired firing angle decided by the analog voltage (0-5 V).
Here the programming flow is described as:

1. Initialization of input output ports.
2. Check the voltage level on ADC port.
3. Using synchronization signal circuit, detect the zero crossing of ac mains
4. Synchronization signal circuit outputs the square wave, it is fed to the subroutine of At mega 328, and falling edge of square wave will cause subroutine.
5. Based on ADC value, the delay is generated which is known as firing angle.
6. In subroutine the square wave is outputted.
7. This pulse is provided to the thyristor via optocoupler for isolation of driver and power circuit.
8. Controlled dc output.

3. Trigger Pulse Generation: When subroutine is detected the trigger pulse having Ton period of 100 micro second is used to trigger the thyristor. Thyristor gets commutated when the supply voltage becomes negative because of natural commutation. In the next cycle again the subroutine is generated which is used to trigger the thyristor.

Objective & Scope

The major task involved in design, development, testing, and installation of a firing controller for a triphase thyristor control rectifier is to control the speed of DC Motor.

Objective is categorized into the following:

1) To design reliable firing circuit using AT mega 328 microcontrollers for firing SCRs of three phase fully controlled rectifier.
2) To test designed circuit using DC motor for speed control.

Conclusion

The design is isolated from electromagnetic interference at input and output side. Power control is possible by varying α (firing angle) with controlling voltage with the use of At mega 328 microcontroller and by programming the analog voltage given it controls the firing angle and controls the speed of the DC motor.

Integration of modules will result in Full controlled converter with superior performance over other ordinary control techniques.

By executing powerful instructions in a single clock cycle, the device achieves throughputs approaching 1 MIPS (Microprocessor without Interlocked Pipeline Stages) per MHz, balancing power consumption and processing speed.

Since analog voltage (0-5 V) is used for controlling the converter power, ADC of Atmega-328 microcontroller is 10 bit resolution. Analog voltage (0-5 V) is converter into (0 – 1023) count and conversion takes around 250 micro second. PWM is achieved with the help of variable controlling voltage.

Hence this gives precise control of DC motor speed in a very short span of time.

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