Development and Implementation of Algorithm for Automated Synchronization of Alternators

Major Project Report

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By

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CERTIFICATE

This is to certify that the **Major Project Report** entitled **"Development and Implementation of Algorithm for Automated Synchronization of Alternators"** submitted by **Mr. Devendra. P. Parmar (10MEEE07)**, towards the partial fulfillment of the requirements for the award of degree in **Master of Technology (Electrical Engineering)** in the field of **Electrical Power Systems** of Nirma University is the record of work carried out by him under our supervision and guidance. The work submitted has reached a level required for being accepted for examination. The results embodied in this major project to the best of my knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

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Abstract

Generator paralleling is a frequent and essential operation in the power system. Synchronizing a generator to the power system must be done carefully to prevent damage to the machine and disturbance to the power system. The core task of a synchronizer is to estimate the voltage magnitude, frequency and phase sequence at the generator terminal and system bus accurately and rapidly. If standard conditions of synchronization are not matched at the instant of circuit breaker closing, the power system equipment on the two sides of circuit breaker may be damaged due to the inrush current at the instant of closing the circuit.

This project work is focused on the development of an algorithms for automated synchronization of alternators. Algorithm evaluates the existence of necessary conditions for synchronism, and then decides whether or not a command should be issued to allow the circuit breaker to close. Protective relay grade microcontroller device can significantly improve automated synchronization system. The device adopted is PIC16F877A as main controller to realized automated control operation. The data of voltages, frequencies, phase sequence and synchronism time have been transferred to the microcontroller. These data are monitored and evaluated by the control algorithm coded into PIC controller.

As a part of algorithm development process, the specific area of work can be present as below:

- Coding of developed algorithms in C' language using mikroC PRO PIC compiler.
- PIC 40 Pin development board is used implement developed algorithm.
- USB PIC Programmer supports onboard programming through ICSP of any PIC microcontrollers from Microchip is used to load program in PICF877A.
- Simulated testing of developed algorithm is carried out using Real PIC Simulator, ISIS 7 Professional-Proteus which show satisfactory result of algorithm.
- Experimental test of algorithms is carried out which validates developed algorithm satisfactorily.

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Abbreviations

ADC .... Analog to Digital Converter
CCP .... Capture compare pulse width modulation module
CMP .... Compare
DARAM .... Data Access Random Access Memory
DC .... Direct Current
DFT .... Discrete Fourier Transfer
DSO .... Digital Oscilloscope
DSP .... Digital Signal Processor
EEPROM .... Electrical Erasable Programmable Read only Memory
FFT .... Fast Fourier Transform
FPGA .... Field Programmable Gate Array
IEEE .... International Electrical and Electronics Engineer
ICSP .... In Circuit Serial Programming
LCD .... Liquid Crystal Display
PIC .... Peripheral Interface Controller
PSD .... Programmable Storage Device
PSP .... Parallel Slave Port
PWM .... Pulse Width Modulation
PT .... Potential Transformer
RAM .... Randem Access Memory
RISC .... Reduce Instruction Set Computing
SCI .... Serial Communication Interface
SSP .... Synchronous Serial Port
SPI .... Serial Peripheral Interface
USART .... Universal Synchronous Asynchronous Receiver Transmitter
WDT .... Watchdog Timer
ZCD .... Zero Crossing Detector

Nomenclature

ϕ .... Phase

Suffixes

α .... Firing angle of Thyristor

Contents

Chapter 1

Introduction

The process of connecting an alternator in parallel with another alternator or with the common bus bar (the bus bar to which a number of alternators are connected) is called "Synchronizing". [1] an operating mode where system facilities are connected and controlled to operate at the same frequency is known as Synchronized Operation [IEEE Std. 858-1993].[2]

Electrical Power System consist of the interconnection of large number of synchronous generators operating in parallel and interconnected by transmission line which are supplying large numbers of widely distributed load. Advantage of operating multiple alternators in parallel are increased reliability expendability, flexibility, serviceability and efficiency. By using parallel configuration, if one alternator fails, the most critical loads are redistributed among the other units in a system. Using multiple smaller alternators, instead of single large unit offers greater location flexibility.

1.1 Problem Identification

Synchronization of alternators requires three conditions to be satisfied, like same phase sequence, same voltage level and frequency between incoming machines with existing machines or utility bus bar. For that the measurement of voltage, frequency and phase sequence detection on the two sides of circuit breaker is necessary before closing it. The performance of synchronizer chiefly lies on its synchronizing principle that is the method of estimating the difference of frequency, voltage magnitude and phase sequence detection between both sides of generator breaker. So making calculation or estimation accurately or precisely differences of synchronized parameters for automated synchronizer a digital algorithm is developed which estimates above measuring parameters accurately and generate proper control signal so chance of faulty synchronization reduced.

1.2 Objective of Project

This Project deals with development and implementation of an algorithm for automated synchronization of Alternators. Algorithms developed for Automatic Synchronization are:

- **Algorithm developed for Voltage Measurement and it control**
- **Algorithm developed for Frequency Measurement and it control**
- **Algorithm developed for Phase Sequence detection**

1.3 Project Planning

- Literature survey and problem identification
- Project definition and objective of project
- Deciding the suitable PIC Microcontroller for implementation of Algorithm
- Preparation of the Flowchart of the whole system
- Development of algorithm for estimation of synchronization parameters.
- Testing and implementation of algorithm for automated synchronizer.

1.3.1 Scope of Work

In order to achieve the objective of the project, following scope of work is outlined:

- Development of algorithms to check synchronized Condition
- Coding in C' language using mikroC Compiler.
- Testing and implementation of Algorithm.

1.4 Literature Survey

Book [1] give details about what do you mean by parallel operation of Alternators, requirement for parallel operation, Condition for proper Synchronizing. It also give information about various conventional method used for synchronize operation of Alternator. It also focused about synchronizing current, synchronizing Power, effect of reactance on synchronizing process, effect of increasing the driving torque of one of the alternators, effect of unequal voltages on synchronization.

Paper [2] Author present first the Manual Method of Synchronization with it drawback and give further details about Consequence of Faulty Synchronization which cause Potential damage to Prime Mover and Generators, give comparison of Automatic and manual system. Paper is also describe the how the complexity increased if use manual method for synchronization of more than one Generator to common Bus bar. At last give solution above problem by describing how Protective Relay grade Microprocessor device technology can simplify Synchronizing circuits to reduce cost, improve reliability and easily accomplish complete integration, Automation, and remote control of the synchronization system.

Paper [3] introduce that to improve the celerity, reliability and security of the generator paralleling operation, Author introduce Generator automatic quasi-synchronizing device based on PIC16F877 and FPGA (Field Programmable Gate Array). In this paper they mainly focused on hardware and software Design. The device adopted PIC16F877 as main controller and FPGA as assistant controller which realized the control of the output impulse width and displayed the signals of the output actions.

Software analyze and calculate the input signals, forecast closing time, generate control signal. In order to realize parallel operation condition they introduce the quasi-Synchronizing device which monitor following operation.

- Monitor the slip frequency and regulates the generator frequency to reduce the slip (0.2 % to 0.5 %) frequency.
- Monitor the Voltage difference and regulates the Generator Voltage amplitude to reduce the voltage difference (5 % to 10%).
- When the frequency and voltage difference meet the Parallel request and closing command is issued, instantaneous closing phase angle is Zero.

Paper [4] introduces a novel automatic synchronizer, which give idea about two independent CPU modules running under completely different principles, the hardware based one and the software based one respectively. Developed algorithm by author can estimate the parameters precisely with a fixed sampling frequency, even when signal frequency is time varying. The Paper also introduces how Co-ordination between two CPU is made. CPU Module-I test Synchronization Condition independently CPU Module-2 when Paralleling condition satisfy by CPU Module-1 Paralleling with CPU module-2 then after control digital signal sent out for Synchronization. He justify that due to the different working principles and independent hardware circuits, the probability of false synchronization decision that made by both CPU modules at a same time is minimized, He used CPU Module 16 bit Microcontroller unit 80296SA. PSD4135G2 is used to integrate all peripheral devices in a single chip which needed for MCU operation for synchronization so therefore, the cost of synchronizer decreased and reliability improved.

Paper [5] Author introduces the basic principle of the frequency measurement. The frequency measurement is finished by combining PIC16F87 and FPGA (Field Programmable Gate Array) technique. The hardware and software designs were introduced. The device adopted PIC16F877 as main controller and FPGA as assistant controller which detects the frequency and the PIC16F877 manage the data and implements intelligent control. The excellence of the mix design is that two advantages are reinforced. The hardware circuit is simple and the reliability of the system is high, so that the generator realizes quasi-synchronizing quickly and easily.
Paper [6], Author developed an automatic synchronization unit has been for the parallel connection of synchronous generators. Two synchronous generators are connected in parallel automatically with the developed control unit. The voltages, frequencies, phase sequences and synchronism time data have been transferred to the microcontroller. These data are monitored and evaluated by the control algorithm coded into the microcontroller. Parallel operation of generators are realized automatically when all parallel connection conditions are satisfy. So they present that developed microcontroller based automatic synchronization unit is fast, cost effective, reliable and precise to be used for monitoring, measurement and parallel operation of the synchronous generators.
Paper [7] Author presents a digital automatic synchronizer which adopts DSP as microprocessor to improve the calculation speed and accuracy of float data. 16 bit DSP56F807 as Microprocessor derives difference of voltage by means of FFT Algorithm. DSP adjusts the generator voltage and frequency by means of fuzzy control algorithm in order to achieve switch condition rapidly and smoothly. In this paper describe the way of forecasting difference of angle by means of linear interpolation algorithm which can grasp rapidly and reliably synchronization opportunity; In addition, it has functions of event record and wave record. The testing indicates that this device can realize synchronization operation of the generator and grid high accuracy, rapidly, reliable, smoothly.

Paper [9] present, the results of redesign and prototyping of a synchro check relay using an 8952 microcontroller with improved reliability, He present concept of zero crossing, DFT, and phase demodulation to measure the instantaneous value of power system frequency, phase and voltage magnitude. Signal processing and decision making is carried out by software in order to reduce hardware complexity and achieve higher level of reliability.

1.5 Outline of the Thesis

Chapter 1 introduce definition of thesis, problem identification, Project objective, Project planning, Literature survey for automated synchronization of alternators.

Chapter 2 bring out basic of synchronization of alternator, In which necessity of auto synchronization, different method of synchronization introduced, key out the benefit of auto synchronization and standard condition of synchronization. Further in this chapter rating of machines of typical test system and block diagram of automated synchronization discovered.

Chapter 3 brief introduction and features about Microchip PIC16F877A controller which is being use for implementation of developed algorithm for automated synchronization of alternator. The technical aspect of controller during implementation of algorithm is discussed.

Chapter 4 introduce main flowchart for Automated synchronization, digital algorithm for voltage and frequency measurement and control is developed. Algorithm developed for phase sequence detection. The software design includes the flowcharts implementations of algorithm using PIC controller.

Chapter 5 This chapter show the testing of simulated and experimental results of developed algorithms.

Chapter 6 contain conclusion of project work.

Chapter 2

Synchronization of Alternators

2.1 General/Background

In power station power is supplied from several smaller units operating in parallel rather than from large unit capable of taking care of the maximum peak load. The process of connecting an alternator in parallel with another alternator or with the common bus bars (the bus bar with number of alternators are connected) is called **"synchronizing".** [1]

It is imperative that changing from one unit to another or connecting an additional unit in parallel with the other (already operating in parallel) is carried out with the minimum possible disturbance to the existing system.

2.2 Need and Benefits of Synchronization of Alternators

The demand for electrical energy continues to grow at a steady space, electrical utilities and other finds it necessary to increase generating capacity at regular intervals. Power network is becoming more complex due to interconnection of various generating station to satisfy consumer requirements. It is not possible to operate generator in isolated mode to satisfy huge challenging power demand. Alternators operated in parallel mode have following advantages:

- **Efficiency:** As we know any machines operated their highest efficiency at it rated load. Power demand continuously very between peak and light load period. It logical to small unit deliver output when load demand is light and during peak time larger unit connected in parallel with smaller unit. So machines are loaded at their rated capacity and ultimately increased the efficiency of Power system.

- **Reliability:** Continuity of electrical supply is prime importance in competitive electrical market. If we think about continuity of energy synchronization systems offers more sustainable and reliable than single generator. If any reason if one generator shutdown you can continue to nurture critical energy needs with load take/give system.

- **Maintenance and Repair:** It is often desirable to carry out routine maintenance and repair of one or more units in a power plant. For this purpose, the desired units can be shut down without affecting serviceability to customer.

- **Economy:** An existing distribution system may not lend itself to being split into several sections and handled by separate non-paralleled units. When the loads are expected to expand substantially, the initial investment is minimized by installing one smaller generator set, and then adding more sets in parallel as the loads increase.

2.3 Potential Damage to Generators and Prime Mover Due to Faulty Synchronization

The speed (frequency) and voltage of the isolated generator must be closely matched, and the rotor angle must be close to the instantaneous power system phase angle prior to closing the generator breaker to connect the isolated generator to the power system. Poor synchronizing can: [2]

- Damage the generator and the prime mover because of mechanical stresses caused by rapid acceleration or deceleration, bringing the rotating masses into synchronism (exactly matched speed and rotor angle) with the power system.
- Damage the generator and step-up transformer windings caused by high currents.
- Cause disturbances to the power system such as power oscillations and voltage deviations from nominal.
- Prevent the generator from staying online and picking up load when protective relay elements interpret the condition as an abnormal operating condition and trip the generator.

2.4 Condition for Synchronization of Alternators

IEEE Standards C50.12 and C50.13 provide specifications for the construction of cylindrical-rotor and salient-pole synchronous generators respectively. They specify, “Generators shall be designed to be fit for service without inspection or repair after synchronizing that is within the limits listed. When paralleling generators, it is necessary to match the characteristics of the two systems as closely as possible. This is accomplished by minimizing the phase angle difference, slip frequency and voltage difference between the two systems. The limits for both types of generators are: [2]

- **Voltage 0 to +5 %.**
- **Slip +/-0.067 Hz.**
- **Angle +/-10 degrees.**

Further, in case of synchronization of 3-ϕ alternators additional requirement to be met is that phase sequence of the incoming machine shall be same as system to which it is synchronized. IEEE Standard 67, which also discusses synchronizing requirements, does not apply to the prime mover.

2.5 Conventional Methods for Synchronization of Alternators

The synchronizing system must perform the following functions:

- Control the governor to match speed.
- Control the exciter to match voltage.
- Close the breaker as close to a zero-degree angle difference as possible.

These functions can be provided by the operator using manual means, automated control systems, or some combination of both.

Traditionally following three developed method for synchronization of Alternators are:

a. **Manual Method**

b. **Semi- Automatic**

c. **Automated**

In **Manual Method,** *(Two Bright and One Dark Method)* is mostly used for synchronization of alternators. To match condition of synchronization manual speed control of prime mover or frequency control to set point of alternator to match the alternator frequency to system frequency. Similarly, the operator manually adjusts the excitation level or voltage regulator set point of the exciter to match the Alternator voltage to the system voltage.

The operator initiates command of closing breaker when all the synchronized conditions are fulfilled. Instruments that allow the operator to visualize the voltage difference, speed difference (slip), and angle difference of the generator are required for the operator to perform these tasks. These instruments are typically provided on a synchronizing panel in the generator control room Fig.2.1 shows that alternator-A is supplying a load and Alternator-B is needed to be synchronized with alternator A. The alternator B can be phased out by connecting two lamps L1, L3 cross connected between two phases and one of the lamps L2 connected across remaining phase as shown in Fig.2.1.

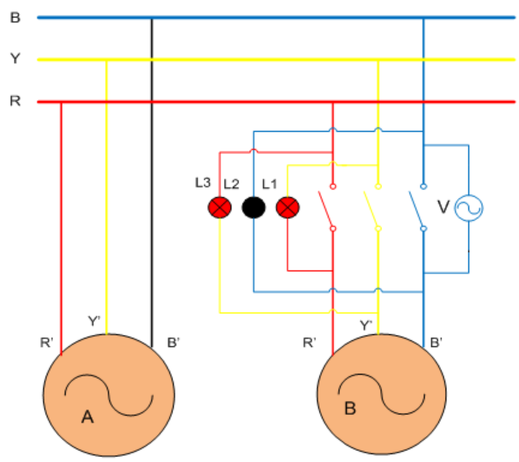

Figure 2.1: Two Bright and One Dark Method

Following observations and interpretations are made during synchronizing process:

Table 2.1: Interpretation of Two Bright one Dark lamp Method

Events of Lamp	**Causes**	**Corrective Steps**
Constantly on	Wrong frequency or Phase Sequence	Adjust speed of prime mover and correct phase sequence
Flicker of lamps	Mismatch in frequency	Adjust speed of prime mover
L1,L3 are bright and L2 is dark	Correct frequency and Phase Sequence and voltage	Switch on breaker

The prime mover of the incoming alternator B is started and brought up close to the rated speed. The alternator than exited and its voltage is raised by increasing the excitation to that of the running alternator or the bus-bars and the lamps are watched closely. If the incoming alternator B is properly connected and all the condition of synchronizing are satisfy than switch on breaker.

In **Semi-Automatic Method**

Synchronizing condition matching is primarily carried out by combination of manual and automatic schemes. In these schemes, the adjustment of the generator frequency and voltage is made automatically. The operator will initiate the procedure and supervise the actual breaker closing. A robust control system of exciter and governor is set up and an electromagnetic or electronic synchrocheck relays is used to improve the reliability of the operation.

Conventional methods have some disadvantages such as higher cost, space requirement and complex integrity of the circuit. These drawbacks can be eliminated in automatic synchronization techniques.

In **Automated Method**

Synchronization by means of manually operated switching served well enough when the individual generators were relatively small, but with the growth of system capacity, it becomes necessary to use automatic devices to ensure the closing of the main switch of the incoming machine at the proper instant.

The scheme introduced here is for the complete automation of synchronization the adjustment of magnitude of voltage and frequency of incoming alternator is done automatically. When all the requirements of synchronization are satisfied, closing of the main switch of the incoming machine is done by the automatic synchronizer.

2.6 Rating of Alternators and Prime Mover

a. **Rating of Alternators**

- 415V, 3.8A, 1800W, 1500RPM, 50Hz.

b. **Prime Mover**

- 3 HP/2.2KW, 13A, 230V, D.C. Motor

2.7 Criteria of Design

The auto synchronizer has been developed to carry out the following tasks related to the synchronization such as:

- To check if the phase sequence of incoming machine is correct or otherwise, in case of wrong phase sequence, to terminate the further steps in the process and also to indicate corrective action.
- To check if frequency of incoming machine is equal to that of busbar and to adjust it to a value nearly equal to the busbar frequency.
- To check machine voltage is equal to that of busbar and to adjust it to a value nearly equal to the busbar voltage.

After ascertaining the fulfilment of the above condition, to give closing signal to the circuit breaker so that the breaker will close the exact in phase instant.

2.8 Block Diagram

Block diagram shown in fig 2.2 is representing the major components and circuits requirement in the experiment of automatic synchronization of alternator. It clearly indicates the flow of power signal and control signals.

Power signal has been derived using potential transformer (PT). It steps down the voltage level from power level to signal level. To eliminate the inherent harmonics and other noise signals having frequency other than fundamental, active low pass filter with 50.048Hz cut off frequency has been implemented. The output of filter is fed to zero crossing detectors for frequency measurement and rectifier circuit for voltage measurement.

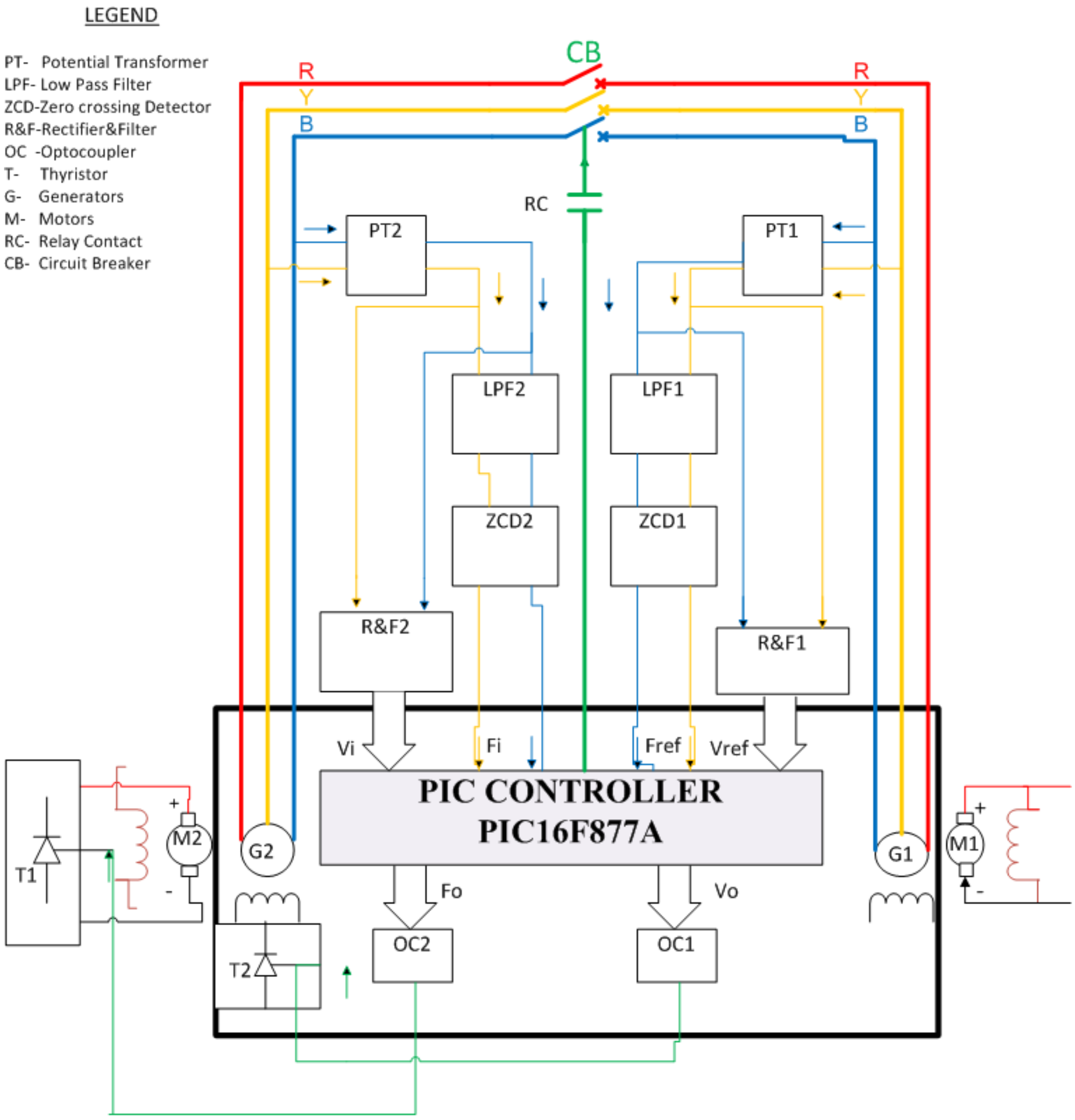

Figure 2.2: Block Diagram of Automated Synchronization of Alternators

On the basis of power signal input, controller will compute and generate appropriate control signal to thyristor. This will result in change in the speed of prime mover and excitation level of exciter. For the purpose of isolation between power and control circuit, opto-coupler is used.

The main processor used in this system is Microchip PIC16F877A microcontroller. The necessary signal processing functions are done through software, and the availability of proper conditions for synchronism is checked after measurements are made on both sides of the circuit breaker. The developed code senses voltage and frequency on both sides of the circuit breaker, determines the phase difference, and checks for the availability of proper precondition for synchronization. Once the prescribe conditions for synchronism are established, a signal is issued to permit or enable the connection.

Before developing algorithm for synchronization, it must be necessary to understand the core structure of controller, so for that next chapter give information plus technical aspect about key features and various modules used for developing algorithm.

2.9 Summary

This chapter introduce basics of synchronization of alternators,It also describe different method of synchronization, standard condition requirement for parallel operation. it also provide data of typical test system with block diagram of automated synchronization.

Chapter 3

Overview of PIC Microcontroller

The PIC16F877A is used for carrying out control through the implementation of control algorithms for operation of automated synchronization of alternators. The reason for selecting this PIC is its features are enough relevant to application, all the modules which modern microcontroller have, its low price, wide range of applications, high quality and easy availability. it is ideal solution like this application where required accurate measurement of different parameters, a control of different process and devices.

3.1 Introduction

PIC microcontrollers are popular processors developed by Microchip Technology with built-in RAM, memory, internal bus, and peripherals that can be used for many applications. PIC originally stood for **"Programmable Intelligent Computer"** but is now generally regarded as a **"Peripheral Interface Controller".** PIC16F877A is a CMOS family 8 bit - Flash microcontrollers. Power consumption is very low, typically less than 2 mA at 5V and 4 MHz, 20 μA at 3 V and 32 MHz. Fully static design allows various operating frequencies from DC to 20 MHz.[12] A PIC microcontroller is a processor with built in memory and RAM and we can use it to control our projects (or build projects around it). So it saves building a circuit that has separate external RAM, ROM and peripheral chips. Thyristor based speed control of DC motor and excitation control of synchronous generator. We need to control pulse width of switching gate pulse signal of thyristor. MICROCHIP PIC16F877A microcontroller does above job to fulfil the required condition.

3.2 Key Features

High Performance RISC CPU

- Only 35 single-word instructions to learn
- All single-cycle instructions except for program branches
- Operating speed: DC 20 MHz clock input DC 200 ns instruction cycle
- Up to 8K x 14 words of Flash Program Memory
- Up to 368 x 8 bytes of Data Memory (RAM)
- Up to 256 x 8 bytes of EEPROM Data Memory

Peripheral Features

- Timer0: 8-bit timer/counter with 8-bit prescaler
- Timer1: 16-bit timer/counter with prescaler
- Timer2: 8-bit timer/counter with 8-bit period register, prescaler and postscaler
- Two Capture, Compare, PWM modules
  - Capture is 16-bit, max. resolution is 12.5 ns
  - Compare is 16-bit, max. resolution is 200 ns
  - PWM max. Resolution 10- bits
- Synchronous Serial Port (SSP) with SPI (Master mode) and I^2C (Master/Slave)
- Universal Synchronous Asynchronous Receiver Transmitter (USART/SCI) with 9-bit address detection

- Parallel Slave Port (PSP) - 8 bits wide with external RD, WR and CS controls (40/44-pin only)

Analog Features

- 10-bit, up to 8-channel Analog-to-Digital Converter (A/D)
- Analog Comparator module with:
  - Two analog comparators
  - Programmable on-chip voltage reference(V^REF) module
  - Programmable input multiplexing from device inputs and internal voltage reference
  - Comparator outputs are externally accessible

3.2.1 Special Microcontroller Features

- 100,000 erase/write cycle Enhanced Flash program memory typical
- 1,000,000 erase/write cycle Data EEPROM memory typical
- Data EEPROM Retention > 40 years
- Self-reprogrammable under software control
- In-Circuit Serial Programming (ICSP) via two pins
- Single-supply 5V In-Circuit Serial Programming
- Programmable code protection

3.3 PIC16F877A Functional Block Diagram

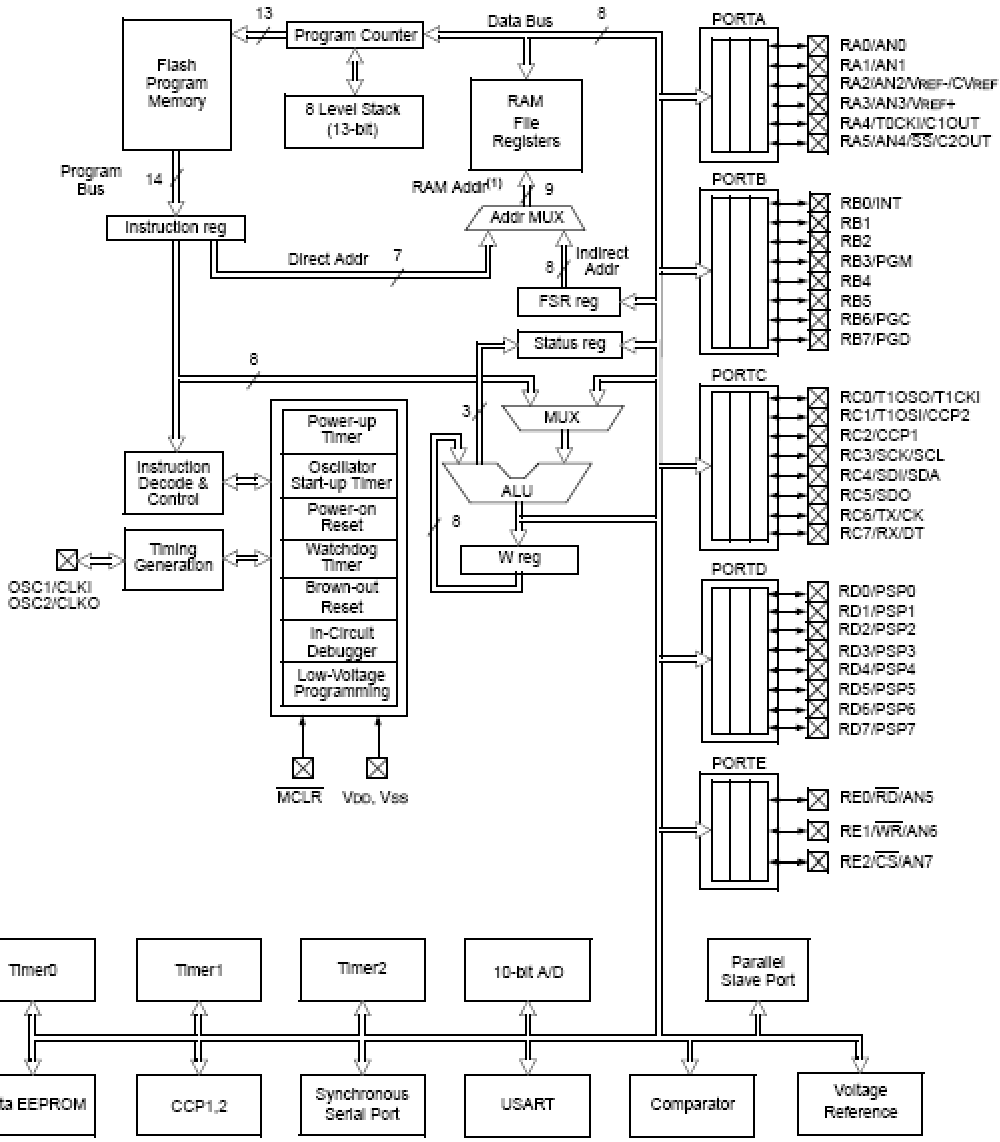

Figure 3.1: PIC16F877A Functional Block Diagram

3.4 PIC16F877A Peripheral Modules

3.4.1 Core SFR

The following text describes the core SFRs of the PIC16F877A microcontroller. Bits of each of these registers control different circuits within the chip, so that it is not possible to classify them in some special groups. For this reason, they are described along with the processes they are in control.

OPTION_REG Register

The OPTION_REG register contains various control bits shown in fig.3.2 to configure Timer0/WDT prescaler,TMR0, external interrupt and pull-ups on PORTB.

R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1
$\overline{\text{RBPU}}$	INTEDG	T0CS	T0SE	PSA	PS2	PS1	PS0
bit 7							bit 0

Figure 3.2: OPTION_REG Register

Bit 7 RBPU: Weak Pull-up Enable bit

1 = Weak pull-ups are disabled

0 = Weak pull-ups are enabled by individual port latch values

Bit 6 INTEDG: Interrupt Edge Select bit

1 = Interrupt on rising edge of INT pin

0 = Interrupt on falling edge of INT pin

Bit 5 T0CS: TMR0 Clock Source Select bit

1 = Transition on T0CKI pin

0 = Internal instruction cycle clock (CLKOUT)

Bit 4 T0SE: TMR0 Source Edge Select bit

1 = Increment on high-to-low transition on T0CKI pin

0 = Increment on low-to-high transition on T0CKI pin

Bit 3 PSA: Prescaler Assignment bit

1 = Prescaler is assigned to the WDT

0 = Prescaler is assigned to the Timer0 module

Bit 2:0 PS2:PS0: Prescaler Rate Select bits

Bit Value	TMR0 Rate	WDT Rate
000	1:2	1:1
001	1:4	1:2
010	1:8	1:4
011	1:16	1:8
100	1:32	1:16
101	1:64	1:32
110	1:128	1:64
111	1:256	1:128

INTCON Register

The INTCON register contains various enable and flag bits shown in fig.3.3 for TMR0 register overflow, PORTB change and external INT pin interrupts.

R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-x
GIE	PEIE	TMR0IE	INTE	RBIE	TMR0IF	INTF	RBIF
bit 7							bit 0

Figure 3.3: INTCON Register

Bit 7: GIE - Global Interrupt Enable bit - controls all possible interrupt sources simultaneously.

1 - Enables all unmasked interrupts.

0 - Disables all interrupts.

Bit 6: PEIE - Peripheral Interrupt Enable bit acts similar to the GIE it, but controls interrupts enabled by peripherals.

1 - Enables all unmasked peripheral interrupts.

0 - Disables all peripheral interrupts.

Bit 5: T0IE - TMR0 Overflow Interrupt Enable bit controls interrupt enabled by TMR0 overflow.

1 - Enables the TMR0 interrupt.

0 - Disables the TMR0 interrupt.

Bit 4: INTE - RB0/INT External Interrupt Enable bit controls interrupt caused by changing the logic state of the RB0/INT input pin

1 - Enables the INT external interrupt.

0 - Disables the INT external interrupt.

Bit 3: RBIE - RB Port Change Interrupt Enable bit. When configured as inputs, PORTB pins may cause an interrupt by changing their logic state

1 - Enables the port B change interrupt.

0 - Disables the port B change interrupt.

Bit 2: T0IF - TMR0 Overflow Interrupt Flag bit.

1 - TMR0 register has overflowed.

0 - TMR0 register has not overflowed.

Bit 1: INTF - RB0/INT External Interrupt Flag bit registers the change of the RB0/INT pin logic state.

1 - The INT external interrupt has occurred.

0 - The INT external interrupt has not occurred.

Bit 0: RBIF - RB Port Change Interrupt Flag bit registers.

1 - At least one of the PORTB general purpose I/O pins has changed state.

0 - None of the PORTB general purpose I/O pins has changed the state.

3.4.2 Input/Output Ports

PIC16F877A support five I/O ports, namely, PORTA, PORTB, PORTC, PORTD, PORTE. PORTA is 6 bit wide, whereas all the remaining ports PORTB, PORTC, PORTD are 8 bit wide. There data direction register TRISA, TRISB, TRISC, TRISD, TRISE corresponding to these ports respectively.

PORTA

PORTA is a 6 bit wide bi-directional port. The I/O direction is decided by the TRISA register. PORTA pin have alternate functions of analog input and V_{REF}. Pin RA4 is multiplexed with Timer 0 module clock input TOCKI pin.

PORTB

PORTB is 8 bit wide bi-directional port. TRISB is the corresponding data direction register. Alternate function of PORTB is low voltage programming RB3/PGM, RB6/PGC and RB7/PGD. PORTB supports one more important feature of PORTB change interrupt, in which a state change on any one or more of pin RB7 to RB4 will cause an interrupt.

PORTC

PORTC is 8 bit wide bi-directional port. TRISC is the corresponding data direction register.There are other peripheral multiplexed with PORTC pin like Timer 1 module clock T1CKI/T1CKO, CCP1, CCP2, TX, RX pins.

PORTD

PORTD is an 8 bit wide port with Schmitt trigger input buffers. Individual pins may be configured as input or output by writing in TRISD. In addition to this, PORTD can be used as an 8-bit parallel slave port.

PORTE

PORTE is 3-bits wide. The alternate functions of PORTE are RE0/RD/AN5, RE1/WR/AN6 and RE2/CS/AN7.When TRISE bit PSPMODE is set, the I/O PORTE serves as control inputs for the parallel slave port.

3.4.3 Timers Module

PIC16F877A supports three timers, namely, Timer 0, Timer 1, and Timer 2, in addition to a watchdog Timer.

Timer 0

Timer 0 is an 8-bit timer that can be read and written. It has software prescaling. The clock to timer can be either internal or external. An interrupt is generated after it overflows from FFh to 00h. The Timer0 module timer/counter has the following features:

- 8-bit timer/counter
- Readable and writable
- 8-bit software programmable prescaler
- Internal or external clock select
- Interrupt on overflow from FFh to 00h
- Edge select for external clock

Fig. 3.4 is a block diagram of the Timer0 module and the prescaler shared with the WDT.

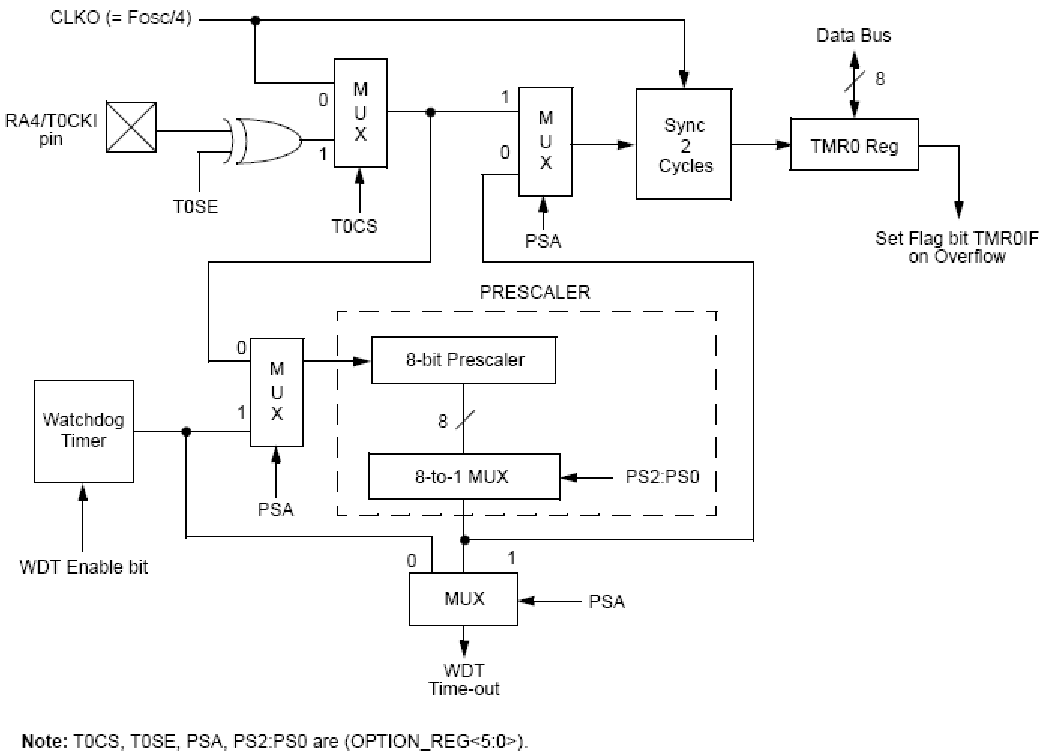

Figure 3.4: Block Diagram of the Timer 0 module

In Short

In order to use TMR0 properly, it is necessary:

Step 1: To select mode

- Timer mode is selected by the T0CS bit of the OPTION REG register, (T0CS: 0=timer, 1=counter).
- When used, the prescaler should be assigned to the timer/counter by clearing the PSA bit of the OPTION REG register.The prescaler rate is set by using the PS2-PS0 bits of the same register.
- When using interrupt, the GIE and TMR0IE bits of the INTCON register should be set.

Step 2: Measuring and Counting

To measure time:

- Reset the TMR0 register or write some known value to it.
- Elapsed time (in microseconds when using 4 MHz quartz) is measured by reading the TMR0 register.
- The flag bit TMR0IF of the INTCON register is automatically set every time the TMR0 register overflows. If enabled, an interrupt occurs.

To count pulses:

- The polarity of pulses are to be counted on the RA4 pin is selected by the TOSE bit of the OPTION_REG register (T0SE: 0=positive, 1=negative pulses).
- Number of pulses may be read from the TMR0 register. The prescaler and interrupt are used in the same manner as in timer mode.

Timer 1

Timer TMR1 module is a 16-bit timer/counter, which means that it consists of two registers (TMR1L and TMR1H). It can count up 65.535 pulses in a single cycle, i.e. before the counting starts from zero.Similar to the timer TMR0, these registers can be read or written to at any moment. In case an overflow occurs, an interrupt is generated if enabled.

The TMR1 timer has following features:

- 16-bit timer/counter register pair;
- Programmable internal or external clock source;
- 3-bit prescaler;
- Interrupt on overflow;
- Wake-up on overflow (external clock); and
- Time base for Capture/Compare function.

T1CON: Timer 1 Control Register

U-0	U-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
—	—	T1CKPS1	T1CKPS0	T1OSCEN	$\overline{\text{T1SYNC}}$	TMR1CS	TMR1ON
bit 7							bit 0

Figure 3.5: Bit Configuration of Timer 1 Control Register

Bit 7-6 Unimplemented: Read as 0

Bit 5-4 T1CKPS1:T1CKPS0: Timer1 Input Clock Prescale Select bits

11 = 1:8 prescale value

10 = 1:4 prescale value

01 = 1:2 prescale value

00 = 1:1 prescale value

Bit 3 T1OSCEN: Timer1 Oscillator Enable Control bit

1 = Oscillator is enabled

0 = Oscillator is shut-off

Bit 2 T1SYNC: Timer1 External Clock Input Synchronization Control bit

When TMR1CS = 1:

1 = Do not synchronize external clock input

0 = Synchronize external clock input

When TMR1CS = 0: This bit is ignored. Timer1 uses the internal clock when TMR1CS = 0.

Bit 1 TMR1CS: Timer1 Clock Source Select bit

1 = External clock from pin RC0/T1OSO/T1CKI (on the rising edge)

0 = Internal clock (FOSC/4)

Bit 0 TMR1ON: Timer1 On bit

1 = Enables Timer1

0 = Stops Timer1

Block Diagram of Timer 1 shown in Fig. 3.6

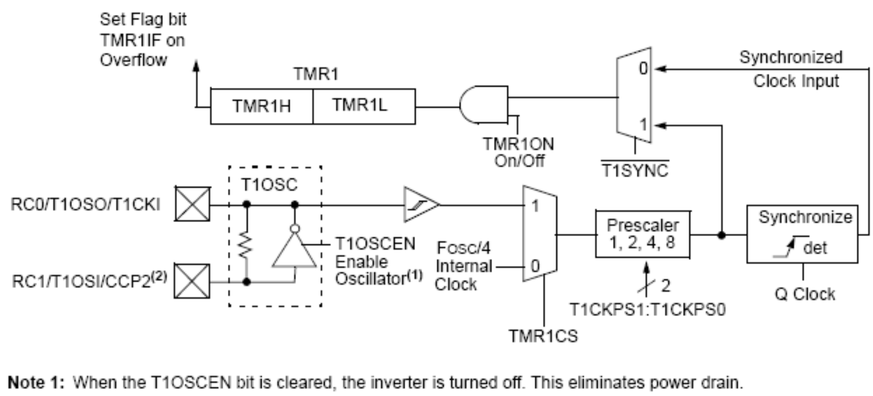

Figure 3.6: Block Diagram of Timer 1

In Short

In order to use the timer TMR1 properly, it is necessary to perform the following:

- Since it is not possible to turn off the prescaler, its rate should be adjusted by using bits T1CKPS1 and T1CKPS0 of the register T1CON (Refer to table).
- Select the mode by the TMR1CS bit of the same register (TMR1CS: 0=the clock source is quartz oscillator, 1= the clock source is supplied externally).
- By setting the T1OSCEN bit of the same register, the oscillator is enabled and the TMR1H and TMR1L registers are incremented on every clock input. Counting stops by clearing this bit.
- By filling both timer registers, the flag TMR1IF is set and counting starts from zero.

3.4.4 Analog to Digital Converter Module

The A/D converter module has the following features:

- The converter generates a 10-bit binary result using the method of successive approximation and stores the conversion results into the ADC registers (ADRESL and ADRESH);
- There are 8 separate analog inputs;
- The A/D converter converts an analog input signal into a 10-bit binary number;
- The minimum resolution or quality of conversion may be adjusted to various needs by selecting voltage references $V_{ref}-$and $V_{ref}+$.

The operation of A/D converter is in control of the bits of four registers:

- ADRESH Contains high byte of conversion result;
- ADRESL Contains low byte of conversion result;

- ADCON0 Control register 0 and
- ADCON1 Control register 1.

Block Diagram of Analog to Digital converter is shown in fig. 3.7

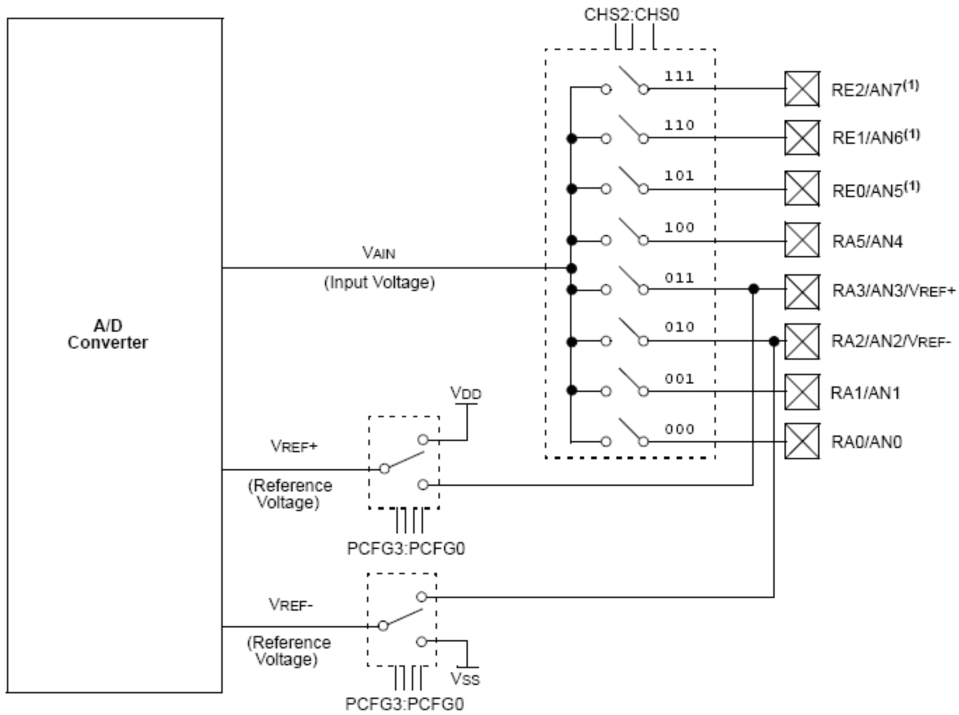

Figure 3.7: Block Diagram of Analog to Digital Converter

ADRESH and ADRESL Registers

The result obtained after converting an analog value into digital is a 10-bit number shown in fig.3.8 that is to be stored in the ADRESH and ADRESL registers. There are two ways of handling it - left and right justification which simplifies its use to a great extent. The format of conversion result depends on the ADFM bit of the ADCON1 register. In the event that the A/D converter is not used, these registers may be used as general-purpose registers.

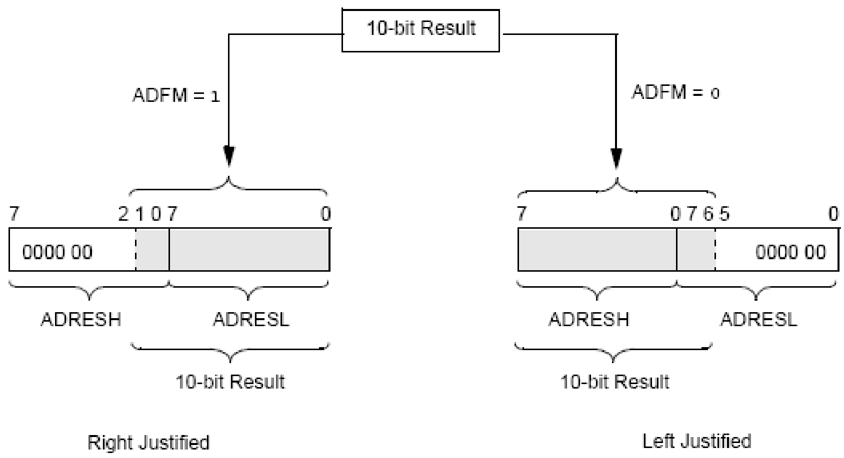

Figure 3.8: A/D 10 bit Register Configurations

ADCON0 Register

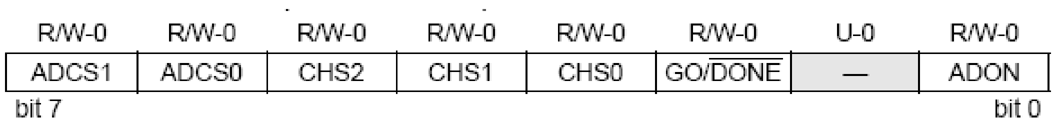

Figure 3.9: ADCON0 Register

Bit 7-6 ADCS1:ADCS0: A/D Conversion Clock Select bits

ADCON1 <ADCS2>	ADCON0 <ADCS1:ADCS0>	Clock Conversion
0	00	FOSC/2
0	01	FOSC/8
0	10	FOSC/32
0	11	FRC (Internal A/D RC oscillator)
1	00	FOSC/4
1	01	FOSC/16
1	10	FOSC/64
1	11	FRC (Internal A/D RC oscillator)

Bit 5-3 CHS2:CHS0: Analog Channel Select bits

000 = Channel 0 (AN0)

001 = Channel 1 (AN1)

010 = Channel 2 (AN2)

011 = Channel 3 (AN3)

100 = Channel 4 (AN4)

101 = Channel 5 (AN5)

110 = Channel 6 (AN6)

111 = Channel 7 (AN7)

Bit 2 GO/DONE: A/D Conversion Status bit

When ADON = 1:

1 = A/D conversion in progress

0 = A/D conversion not in progress

Bit 1 Unimplemented: Read as 0

Bit 0 ADON: A/D On bit

1 = A/D converter module is powered up

0 = A/D converter module is shut-off and consumes no operating current

3.5 Basics of C' Programming

The microcontroller executes the program loaded in its flash memory, that is so called executed code comprised of meaning less sequence of zeros and ones. For practical reason it is much easier for us to deal with hexadecimal number system. The executable code is represented as a sequence of hexadecimal number called as a Hex code. It is used to be written by the programmer. The main advantage of higher level language programming is that simplicity of programme writing. As assembly language programming, a specialized program in a PC called Compiler is in charge of compiling program into machine language unlike assembly compilers, these create an executable code for controller.

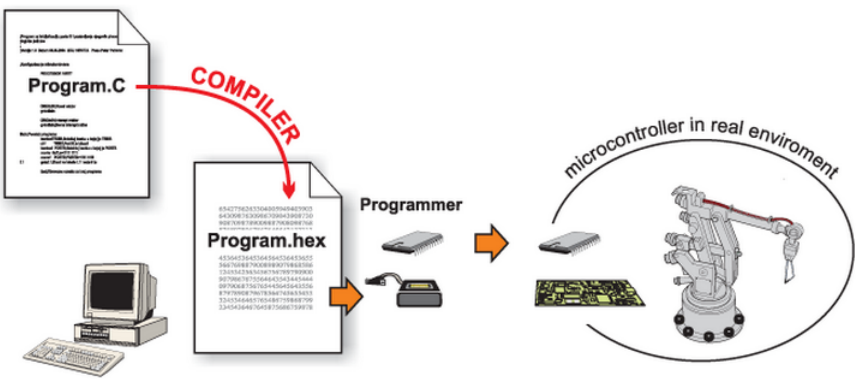

Figure 3.10: Process of compiling program from higher to lower programming language

Fig. 3.10 above give a rough illustration of what is going on during the process of compiling the program from higher to lower programming language.

3.6 Summary

This chapter present complete block diagram of PIC16F877A controller, key features, SFR registers, Timer module, I/O Ports, A/D converter module which is used during developing algorithms. It is also introduced bit configuration of various control register, In last introduce basic of programming in C' language using compiler.

Chapter 4

Algorithm Development

Algorithm is an effective method expressed as a finite list of well defined instruction for calculating a function. Algorithms are used for calculation, data processing, and automated reasoning. In simple words an algorithm is a step-by-step procedure for calculations. As per said in previous chapter coding of developed algorithm is carried out in higher level programming c' language. mikroC pro pic v 3.5.0 compiler is used to developed coding which convert higher level programming into lower level language which is assembly language, compiler is also generate different file like .hex, .lst, .asm . USB PIC Programmer supports onboard programming through ICSP of any PIC microcontrollers from Microchip.This device is specially designed to work with Laptops/Notebooks which doesn't have Parallel or serial port is used to load program into PIC16F877A controller. Further detail about mikroC pro pic, development board and USB PIC programmer is given into Appendix B & C.

4.1 Flowchart of Main Program

The performance of a synchronizer chiefly lies on its synchronizing principle that is, the method of estimating the difference of frequency, voltage magnitude, and phase angle between both sides of generator breaker. In digital algorithm method the data parameter estimated by data acquisition and digital processing.

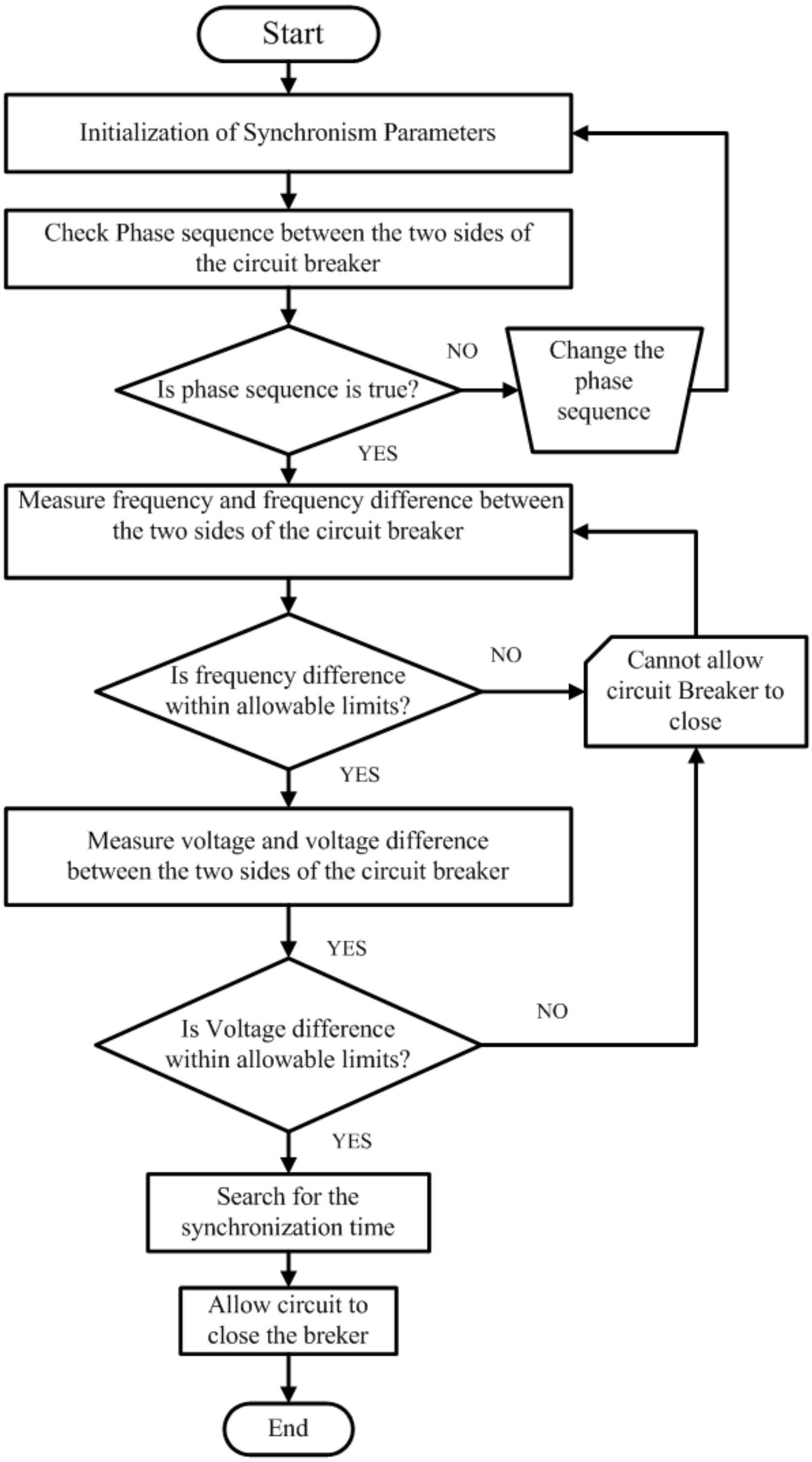

Figure 4.1: Flowchart of the Decision Making Process of Auto Synchronization

Each method has its own characteristics. As we know that the traditional parameter estimating algorithms (such as Fourier transform, least squares estimation etc) used in synchronization re-quire "synchronous sampling". The sampling frequency is exactly integral multiple of the voltage frequencies.Otherwise, considerable errors will occur. The flowchart of the main program for the parallel operation of the SGs is shown in Fig.4.1 as per flowchart - frequency, voltage, and phase sequence of the each SG is determined, respectively and when all the conditions take place the synchronism time is searched to achieve parallel operation of the system.

4.2 Voltage and Frequency Measurement

Voltage and Frequency variations in power systems are slowly changing parameters due to high inertia of power systems is used compute these parameters using software. For paralleling operation of alternators need to measure voltage and frequency accurately at the both end of the circuit breaker.

4.2.1 Voltage Measurement

High level of busbar voltage is step down to 5 V using potential transformer which is further rectified through uncontrolled bridge rectifier to +5V which is suitable to Analog channel AN0 and AN1 of analog to digital converter of PIC16F877A, means the rectified voltage measured is first input to 10 bit 8-channel A/D converter. Sampling is done during complete cycle and the effective value is computed by PIC controller.

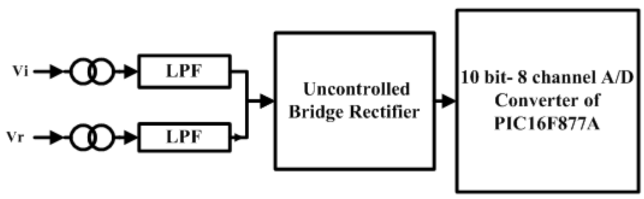

Figure 4.2: Block Diagram of Voltage Rectification and Measurement

The programming involves configuring ADCON0 and ADCON1 register, In ADCON0 register clear CHS0, CHS1, CHS2, So that channel is connected to the internal sample and hold circuit. The ADCON1 register is used to select the clock source for A/D Conversion. However the mikroC Pro PIC has got a built in library function named **ADC_Read()** that, by default uses internal RC clock for ADC operation, So we don't require to initialize the ADCON1 register.

Analog to Digital Conversion Math

For our consider case system we are using PT ratio of 600/5 V. So display primary value on LCD screen require mathematical calculation during ADC conversion so we get exact primary value on Screen. So the analog output voltage (Vout) of P.T at RA0/AN0, RA1/AN1 pin is related to the A/D conversion output. (Digital Number DN)

$$\mathrm{DN} = \mathrm{Vout} * (1024/5) = 204.08 * \mathrm{Vout}$$
$$\mathrm{Vout} = 0.0049 * \mathrm{DN}$$
$$\mathrm{Vin} = \mathrm{Vout} * 120$$
$$\mathrm{Vin} = \mathrm{Vout} * 120 * 0.0049$$
$$\mathbf{Vin = 0.588 * Vout}$$

Last Equation is conversion equation for calculating primary voltage of PT from the 10 bit A/D conversion result.

4.2.2 Frequency Measurement

Signals comes from Zero crossing detector is used to measure the frequency of the both end of circuit breaker, Output of ZCD is connected to Timer 0 (T0CKI) and Timer 1 (T1CKI) pin of PIC Controller. The Timer 0 and Timer 1 module will be used as a counter to count the external clock pulses through RA2/T0CKI, RC0/T1CKI pin of PIC Controller. The external clock source will be derived from the main AC supply. The main AC supply is 415 V, 50 Hz Sine Wave Signals, It will be first stepped down to 5V, 50 Hz signal using P.T. Before applying to PIC Controller, it must be converted into square wave using ZCD circuit, which is suitable for the T0CKI/T1CKI input which is shown in fig.4.3

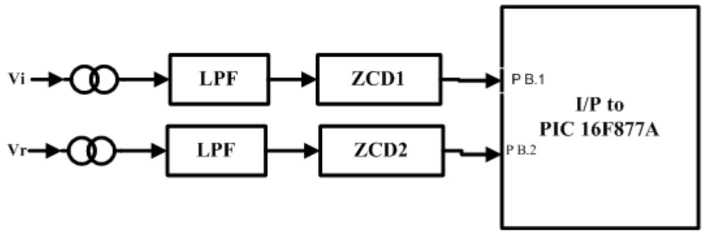

Figure 4.3: Block Diagram of ZCD Output and Frequency Measurement

The output square wave will be connected to the RA2/TOCKI and RC0/T1CKI of PIC16F877A. The TMRO and TMR1 will be start from 0 and count the incoming pulses for 1 Sec. The result will be display on LCD. The number of pulses per second is the frequency of the incoming signals.

4.3 Automated Voltage and Frequency Control

Parallel operation of synchronous generator requirs that both voltage and frequency must be same. for our consider test systems frequency is controlled by means of speed of prime mover(D.C. motor) as it is relative for the generator speed and voltage is controlled by means of field excitation. Standard condition for synchronization of Alternators is:

$$\Delta V_s = |V1 - V2| \leq 0.05V \tag{4.1}$$

$$\Delta f_s = |f1 - f2| \leq \pm 0.067Hz \tag{4.2}$$

To control the voltage and frequency in our consider test systems full wave half controlled bridge converter is used which used two thyristors and two diodes connected in the form of a full wave bridge configuration (Semicontrolled rectifier). Thyristor switch is used to control average voltage across the load through firing angle control.

Delaying the firing pulse by an angle α does the control of the load voltage. Average Voltage is given by:

$$V_0 = Vm/\Pi \times (1 + \cos\alpha) \tag{4.3}$$

Graph of average voltage variation across winding due to change in firing angle is shown in fig.4.4

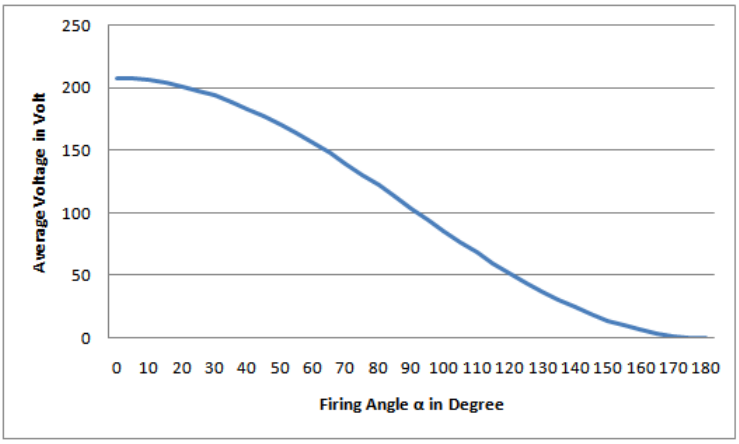

Figure 4.4: Avg. Voltage variation due to change firing angle α

PIC16F877A decides time instant,at which SCR will be turned on to get desired average output voltage. To decide the positive and negative half cycle of A.C. input supply to semiconverter, reference square wave input is given to PORTB.RB0 pin of controller. For considered case system, PIC16F877A generates gating pulse in each half cycle at a particular time delay and stay high for 500 microseconds to fire the thyristor-TYN612. PIC16F877A continuously monitor voltage and frequency at both sides of circuit barker. Initially firing angle is set to maximum. After some time period, firing angle is continuously decreased until synchronizing parameters are matched. When conditions for synchronism are matched, controller will fix the firing angle. Flowchart of C' coding in mikroC compiler for measurement and control of voltage and frequency are shown in fig.4.5 & fig.4.6,respectively.

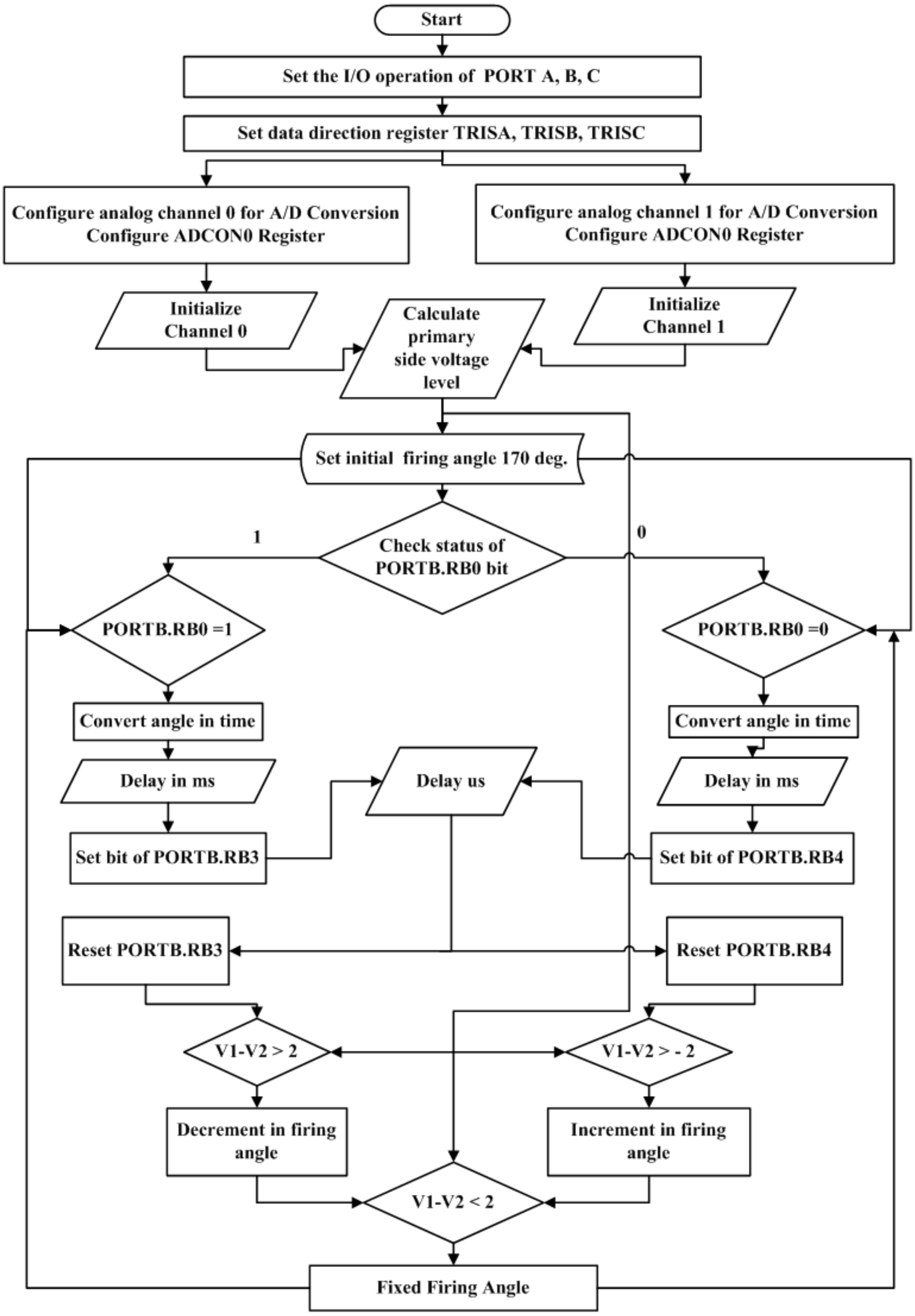

Figure 4.5: Flowchart of C' coding for Voltage Measurement and Control

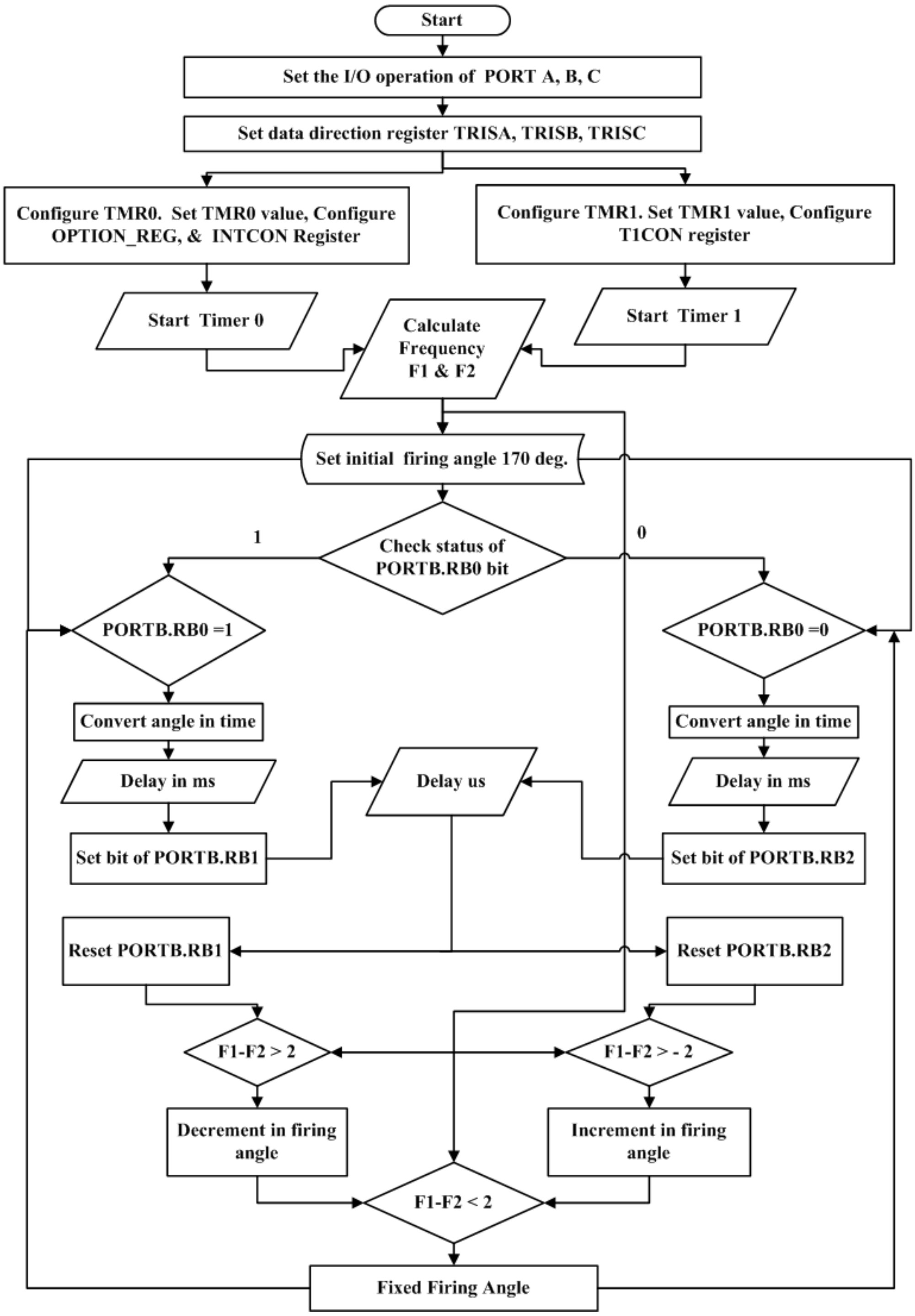

Figure 4.6: Flowchart of C' coding for Frequency Measurement and Control

4.4 Phase Sequence Detection

Correct phase identification of a balanced multi phase system is quite necessary in scientific application. For instance when two 3-phase AC generators are to be synchronized their phase sequence should be matched correctly. Identification of phase sequence for a 3-phase AC power supply is an important routine test during synchronization process for parallel operation of Alternators.

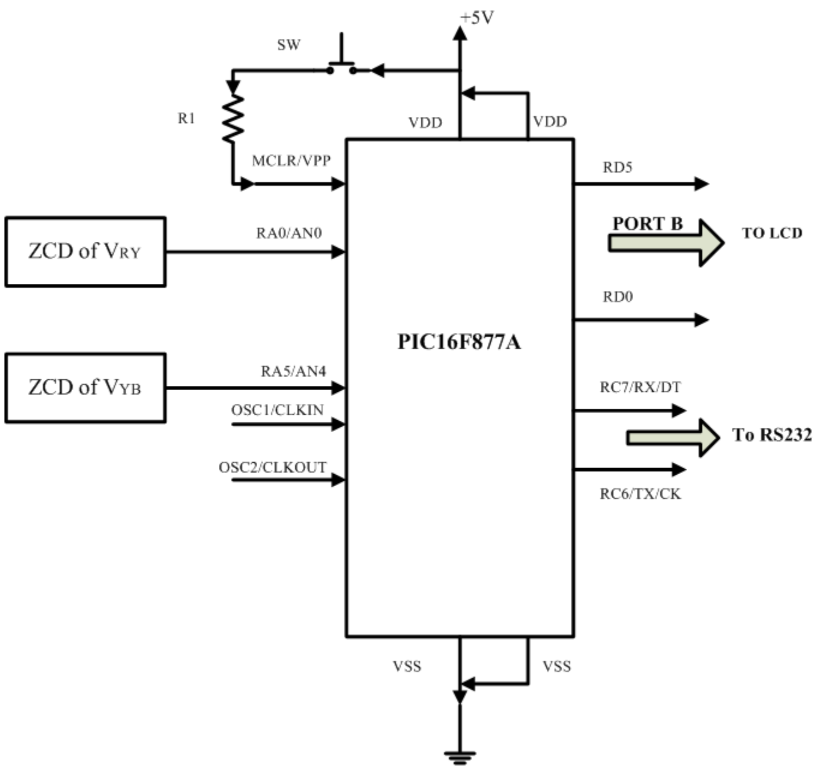

Figure 4.7: Connection of ZCD with PIC controller

Digital microcontroller based method determine sequence of zero crossing instant of 3- phases. In proposed system primary sides of three 600 / 5 V potential transformers (PTs) are connected with R-Y and Y-B phase to phase ac supply. Scaled down sinusoidal voltage signals from secondary side of each PT are fed into two isolated zero crossing detectors (ZCDs). On receiving signal, ZCD emits a series of unipolar rectangular wave signals, in which positive half cycle of sinusoidal voltage signal is converted to rectangular pulse of +5 volt with constant amplitude and negative half cycle is suppressed to 0 volt, Output of ZCD shown in fig.4.8 Rectangular waves are mutually apart in phase angle of 120 or 2 radian with respect to each other having equal time period (20 ms for 50 Hz supply system). Periodical occurrence of leading edge of each rectangular wave at different time instants for positive and negative phase sequences is generated by ZCDs.

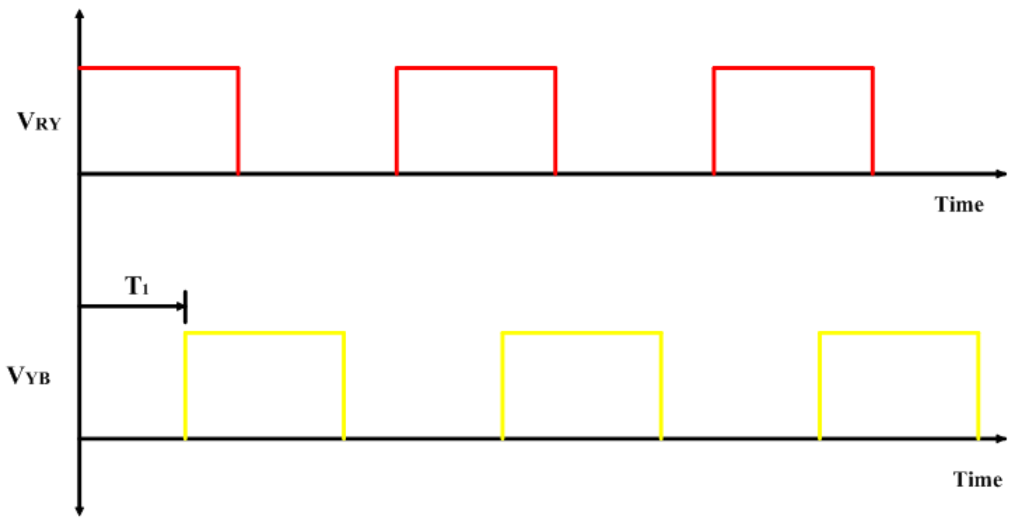

Figure 4.8: Output of ZCD

Output of ZCD of R-Y, Y-B phase is given to RA0/AN0 & RA5/AN4 pin of PIC respectively. PIC will detect positive edge of input signal at a same time initiate time delay for 6.6 milliseconds(120^0), after 7 ms pic check status of RA5/AN4 pin, if it is high than phase sequence is true (R-Y-B) otherwise phase sequence wrong (R-B-Y). Flowchart of coding C'language for phase sequence detection is shown in fig.4.9.

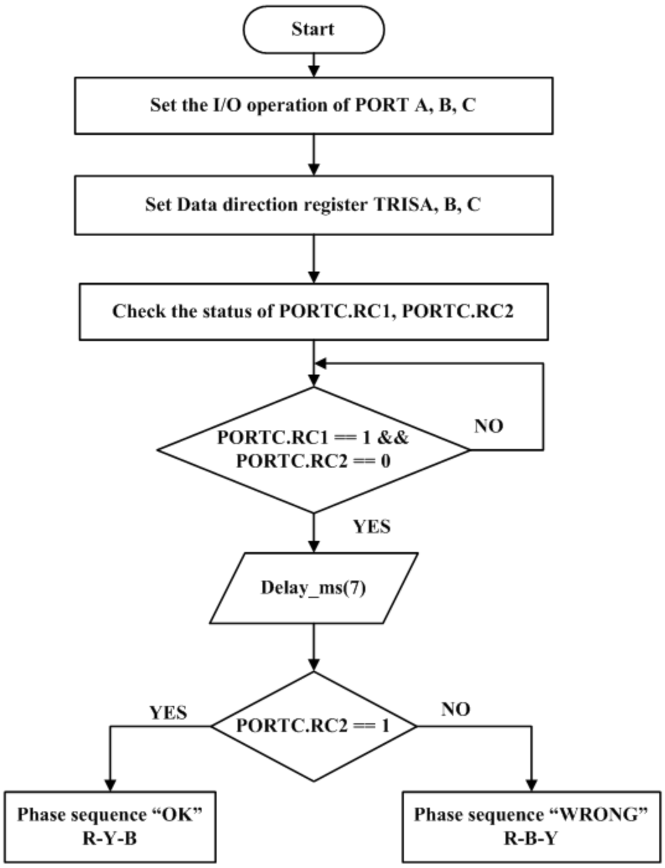

Figure 4.9: Flowchart of coding C'language for phase sequence detection

4.5 Flowchart of Software for Automated Synchronization of Alternators

Complete flowchart of software for automated synchronization of alternators for considered test system shown in figure A.

4.6 Summary

This chapter shows flowchart for Automated synchronization, digital algorithm for voltage and frequency measurement and control, phase sequence detection is described.

Chapter 5

Testing of Algorithms

It is essential to be sure about the effectiveness of the algorithm before it is implemented actually for the particular application.Hence, the algorithms,developed so far in the previous chapters are validated through various simulators and experiments.The chapter incorporates simulated validation through software packages-ISIS 7 Professional and Real PIC Simulator.Further, the experimental testing results of the algorithms is also included.

5.1 Testing of Algorithm for Measurement of Voltage & Frequency in Real PIC Simulator

Real PIC Simulator software is used to test developed algorithm for voltage and frequency measurement. It is a microcontroller simulator having features like, debugger, visualization etc.It is used specially to test the developed coding of PIC Microcontroller. Analog tracker visual component of Real PIC Simulator is connected to ANO and AN1 input pin of controller to vary analog value from 0 to 1023 for voltage measurement. Function generator is used to give hypothetical 50 Hz square wave to AN4/T0CKI, RC0/T1CKI input pin of PIC controller. PORTD of PIC controller is used to interfacing with LCD in 4-bit configuration mode. To run the simulator .hex file of program is need to load in IC. The fig.5.1 & 5.2 clearly shows the measured vales of input voltage and frequency corresponding to input given respectively.

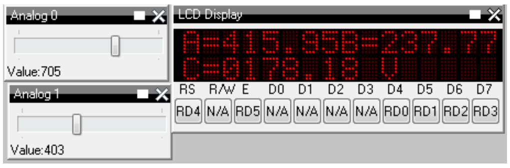

Figure 5.1: Real PIC Simulation of Voltage Measurement

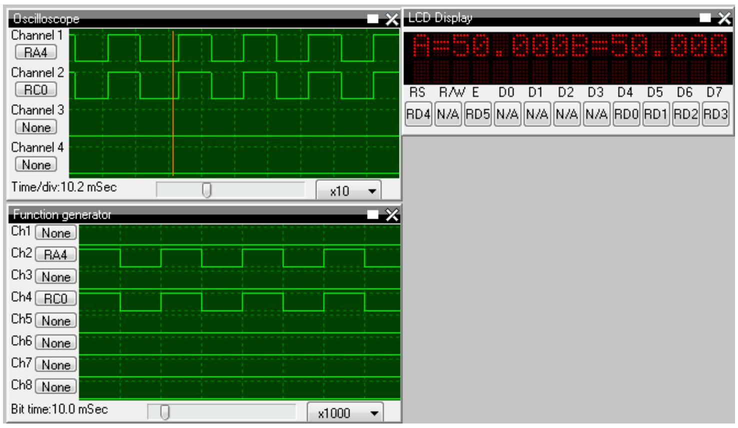

Figure 5.2: Real PIC Simulation of Frequency Measurement

5.2 Circuit Arrangement for Automated Control of Voltage and Frequency

The Fig.5.3 shown below is of circuit arrangement for testing of developed algorithms.The circuit is made in software package ISIS 7 Professional-Proteus.This software consists of inbuilt block for various components and equipments like PIC16F877A, Peripherals, Signal generator, Digital Signal Oscilloscope etc.By Proper interfacing of the component shown in figure and with loading of .hex file of coding the algorithm testing of automated control of voltage and frequency of alternator is carried out in open loop mode. Fig.5.4, Fig.5.5 & Fig.5.6 shown below are of generated firing pulse for SCR. The firing angle of this pulses is decided on the base of input signals of voltage and frequency. Close loop of algorithm is clearly depicted in previous chapter in the form of flowchart.

The same results are validated for typical test condition which is similar to that of simulated, the results are as shown in Fig.5.7,Fig.5.8,Fig.5.9,Fig.5.10,Fig.5.11,Fig.5.12.

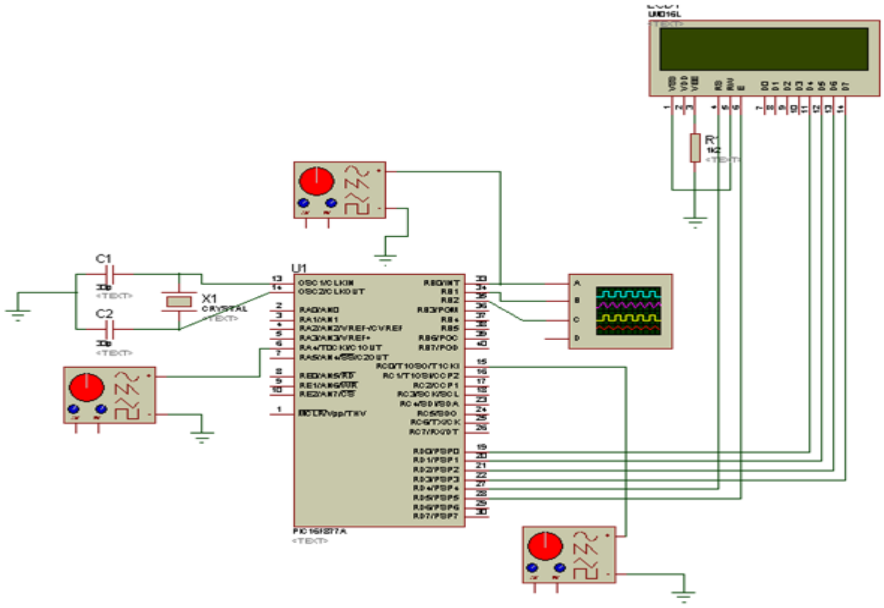

Figure 5.3: Simulated Circuit Arrangement prepared in Software ISIS 7

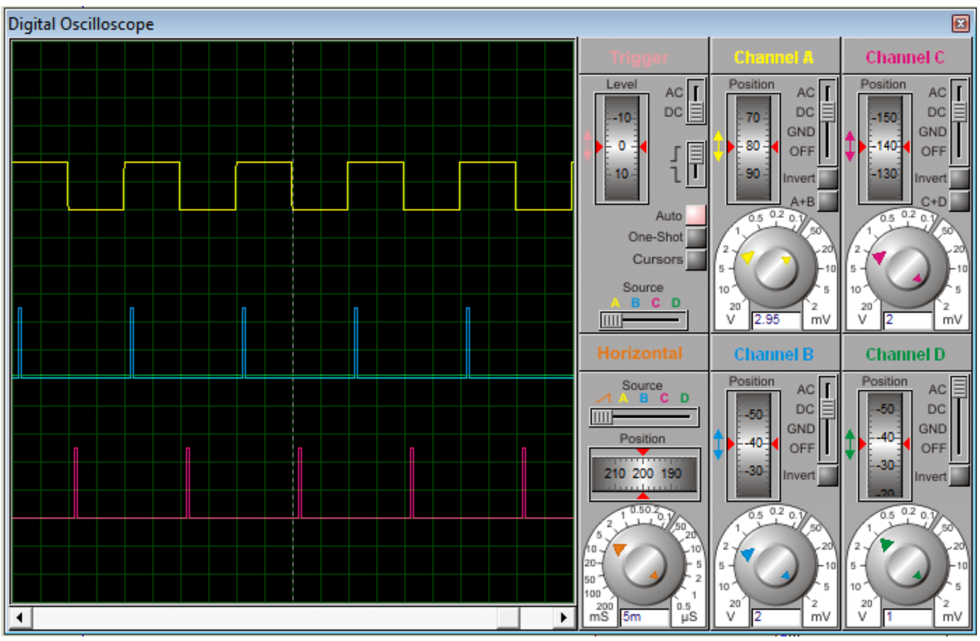

Figure 5.4: Simulated Thyristor Gating Pulses at $\alpha = 10^0$

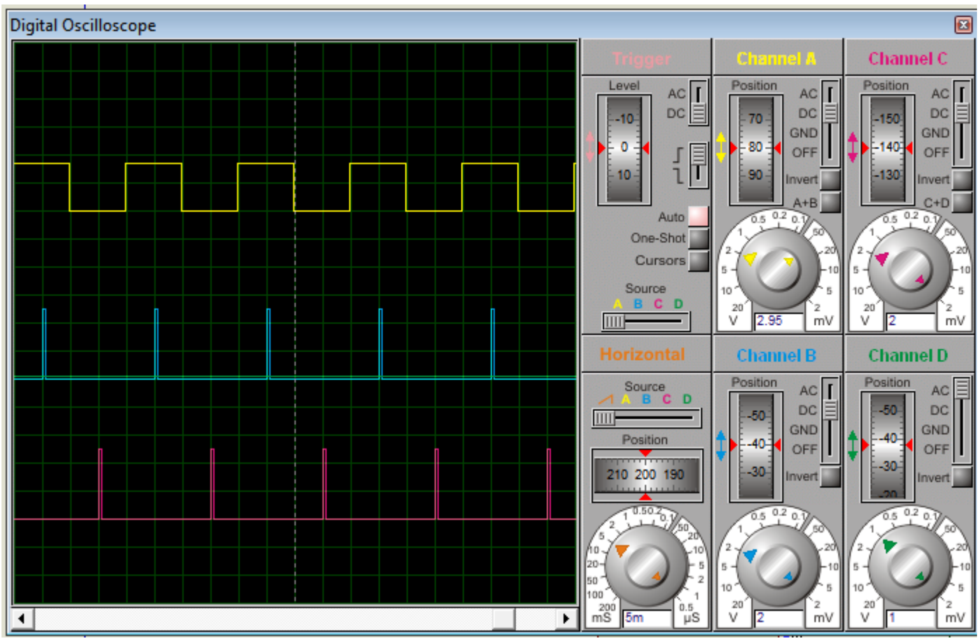

Figure 5.5: Simulated Thyristor Gating Pulses at $\alpha = 90^0$

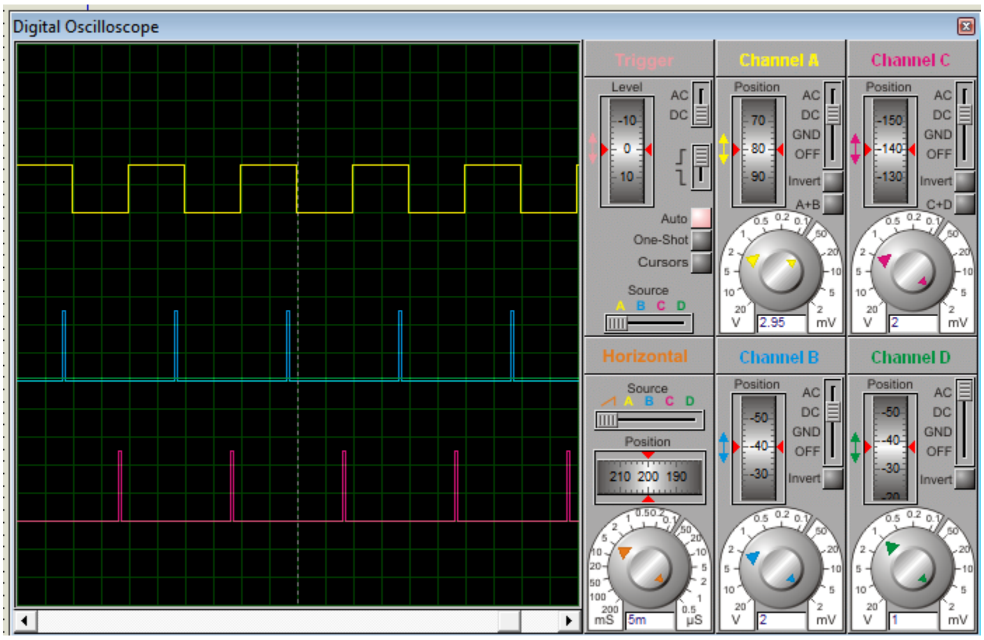

Figure 5.6: Simulated Thyristor Gating Pulses at $\alpha = 150^0$

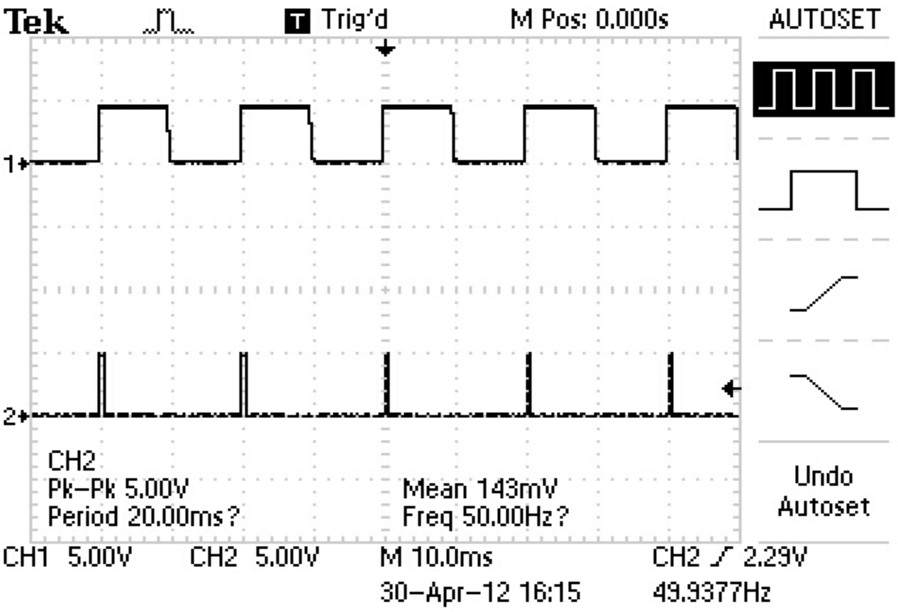

Figure 5.7: Experimental Thyristor Gating Pulses at $\alpha = 10^0$ in Positive Cycle

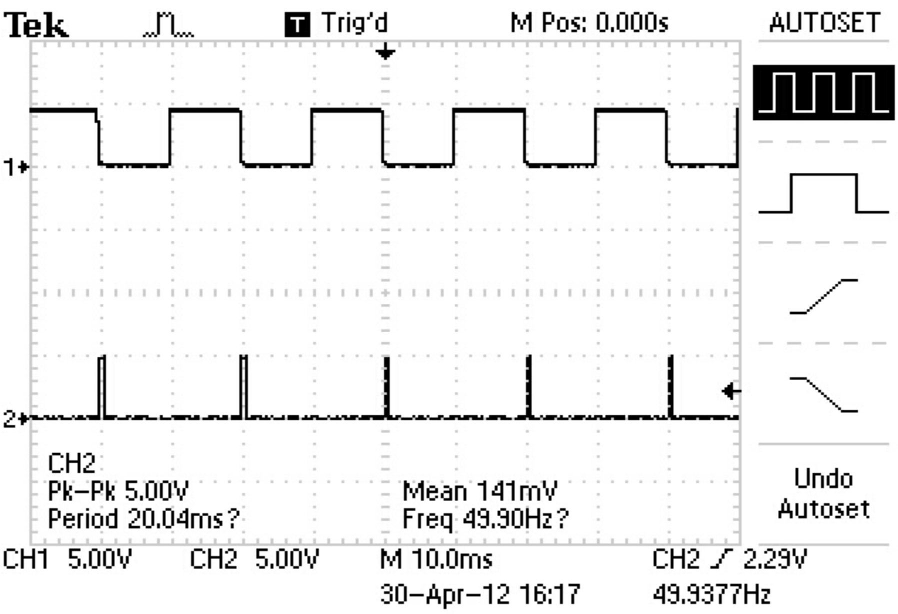

Figure 5.8: Experimental Thyristor Gating Pulses at $\alpha = 10^0$ in Negative Cycle

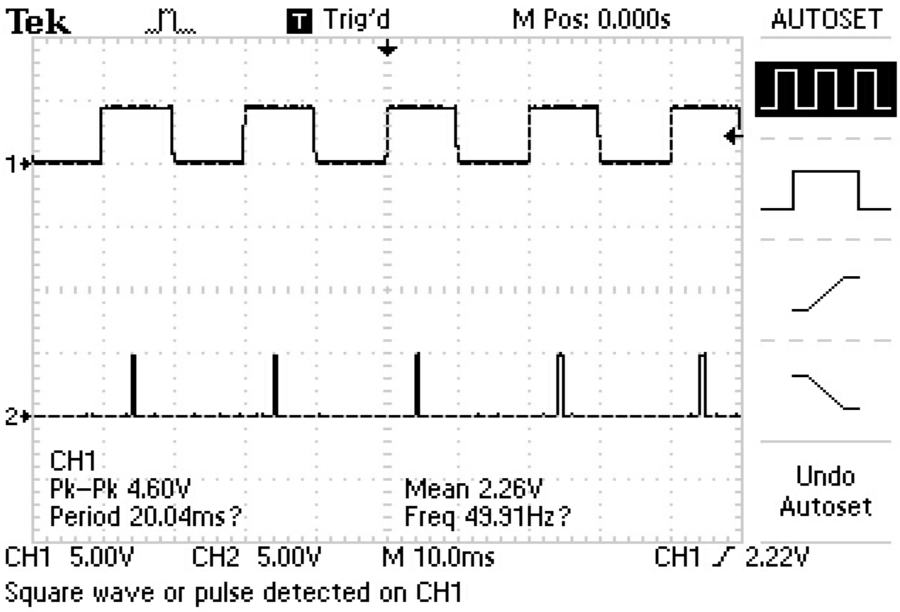

Figure 5.9: Experimental Thyristor Gating Pulses at $\alpha = 90^0$ in Positive Cycle

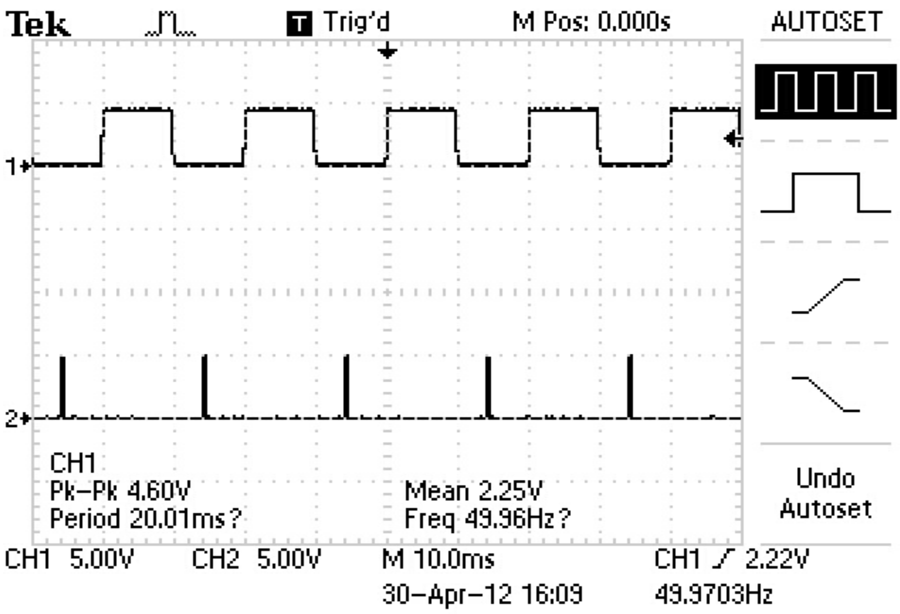

Figure 5.10: Experimental Thyristor Gating Pulses at $\alpha = 90^0$ in Negative Cycle

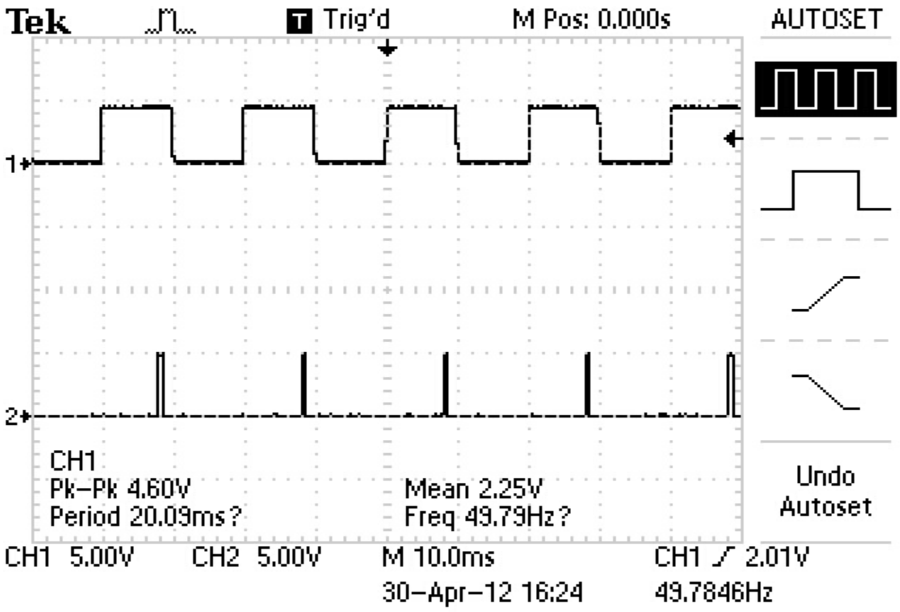

Figure 5.11: Experimental Thyristor Gating Pulses at $\alpha = 150^0$ in Positive Cycle

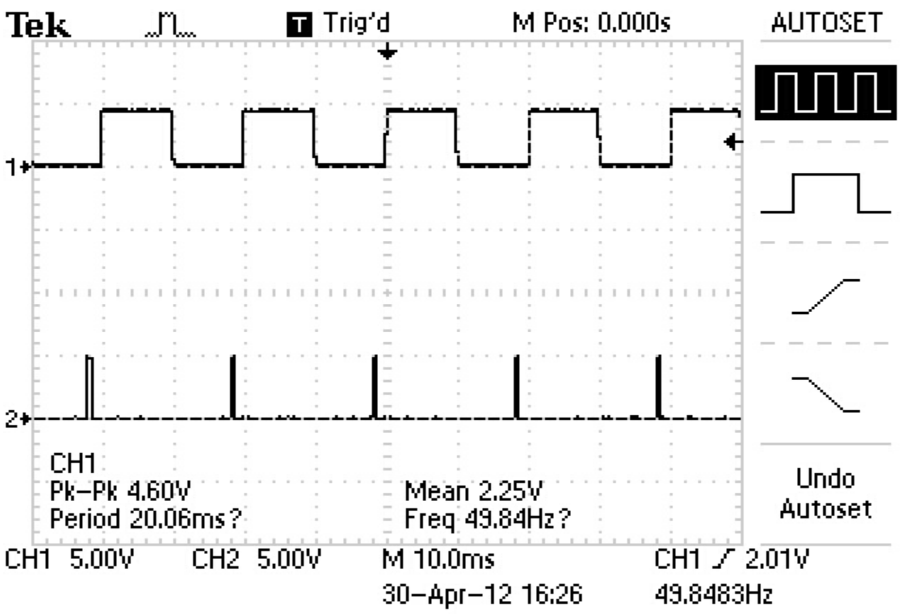

Figure 5.12: Experimental Thyristor Gating Pulses at $\alpha = 150^0$ in Negative Cycle

5.3 Testing of Algorithm for Phase Sequence Detection in Real PIC Simulator

The developed algorithm to check the correct phase sequence of the machine to be synchronized is realized using simulation in Real PIC Simulator. Function generator is used for hypothetical input square wave at 120^0 phase shift at pin no RA0 and RA1 of controller. Fig.5.13 & 5.14 shown below are of indication of correctness of phase sequence.

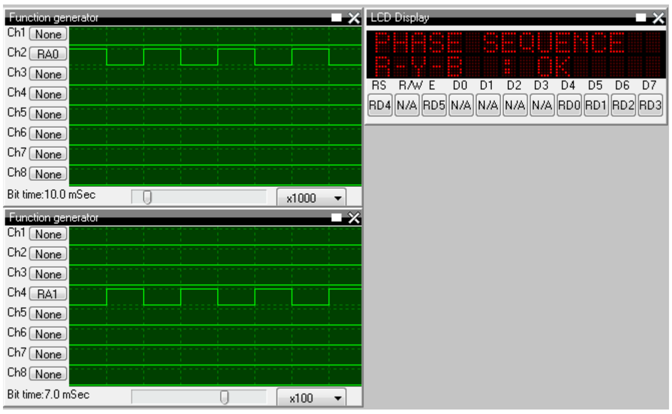

Figure 5.13: Correct Phase Sequence Detection in Real PIC Simulator

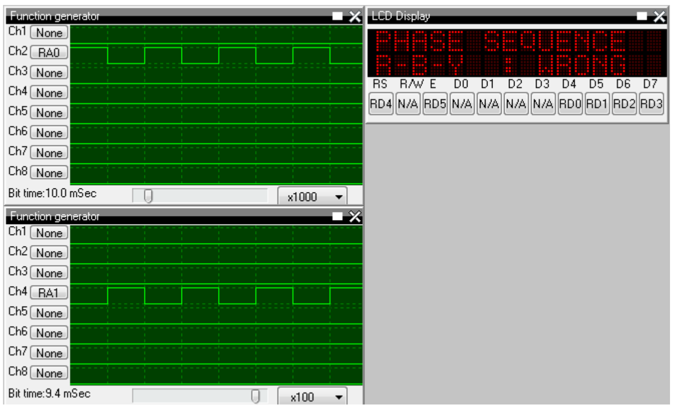

Figure 5.14: Incorrect Phase Sequence Detection in Real PIC Simulator

5.4 Summary

This chapter shows the simulated and experimental validation of developed algorithms.The results for voltage and frequency measurement and control, phase sequence detection is also acceptable. So from the above results it is observable that the developed algorithms are acceptable for automated synchronization of alternators.

Chapter 6

Conclusion

The dissertation work can be concluded as follows:

- Algorithm is developed for measurement of voltage and frequency.
- Algorithm is developed for automated control of voltage and frequency.
- Algorithm is developed for phase sequence detection.
- Coding of all algorithm in C' language developed using mikroC PRO PIC compiler.
- PIC 40 pin development board is used to implement developed algorithms.
- USB PIC programmer supports onboard programming through ICSP of any PIC microcontrollers from Microchip.It is used to load program in PICF877A.
- Simulated testing of developed algorithm is carried out using Real PIC Simulator, ISIS 7 Professional-Proteus which show satisfactory result of algorithm.
- Experimental test of algorithms is carried out which present satisfactory validation of algorithm.

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Appendix A

List of Publication

[1] Vihang M.Dholakiya, Devendra P.Parmar, and Santosh C.Vora, **Designing and Prototyping Automatic Synchronizers for Paralleling of Alternators**, in The Indian Journal of Technical Education of Special Issue of the First National Conference in the Emerging Vistas of Technology in $21^{s}t$ Century, ISSN No.: 0971-3034.

Appendix B

Introduction of mikroC PRO for PIC Compiler

The mikroC PRO for PIC is a powerful, feature-rich development tool for PIC microcontrollers. It is designed to provide the programmer with the easiest possible solution to developing applications for embedded systems, without compromising performance or control.

Features:

mikroC PRO for PIC allows you to quickly develop and deploy complex applications:

- Write your C source code using the built-in Code Editor (Code and Parameter Assistants, Code Folding, Syntax Highlighting, Auto Correct, Code Templates, and more.)
- Use included mikroC PRO for PIC libraries to dramatically speed up the development: data acquisition, memory, displays, conversions, communication etc.
- Monitor your program structure, variables, and functions in the Code Explorer.
- Generate commented, human-readable assembly, and standard HEX compatible with all programmers.
- Use the integrated mikroICD (In-Circuit Debugger) Real-Time debugging tool to monitor program execution on the hardware level.

- Inspect program flow and debug executable logic with the integrated Software Simulator.
- Generate COFF(Common Object File Format) file for software and hardware debugging under Microchip's MPLAB software. Active Comments enable you to make your comments alive and interactive.
- Active Comments enable you to make your comments alive and interactive.
- Get detailed reports and graphs: RAM and ROM map, code statistics, assembly listing, calling tree, and more.

mikroC library:

mikroC compiler provides a number of built in and library routines which help us develop our application faster and easier.

Built in Routines:

mikroC compiler provides a set of useful built in utility function. Built in function do not require any header file to be included. We can use them in any part of our project.

- Delay μs, Delay ms, Vdelay ms, Delay Cyc, Clock khz, Clock Mhz;

Library Routines:

mikroC Compiler provides a set of libraries which simplified the initialization and use of PIC MCU and its module, Library function do not require any header files to be included any where in project.

ADC Library	CAN Library
CANSPI Library	Compact Flash Library
EEPROM Library	Epson S1D13700 Graphic LCD Librar
Ethernet PIC18FxxJ60 Library	Flash Memory Library
Graphic LCD Library	I^2C Library
Keypad Library	LCD Library
Manchester Code Library	Memory Manager Library
PWM Library	RS-485 Library
Software SPI Library	Software UART Library
SPI LCD Library	SPI LCD Library
UART Library	Software I^2C Library

mikroC has other library also like :

Standard ANSI C Libraries	**Miscellaneous Libraries**
ANSI C Ctype Library	Conversions Library
ANSI C Math Library	PrintOut Library
ANSI C Stdlib Library	Trigonometry Library
ANSI C String Library	Time Library

Appendix C

PIC 40 Pin Development Board

This is an easy to use board using the popular PIC16 and 18 Series 40 pin microcontrollers. The board includes everything we need, develop or using for a development application. It is ideal for any kind of autonomous systems.

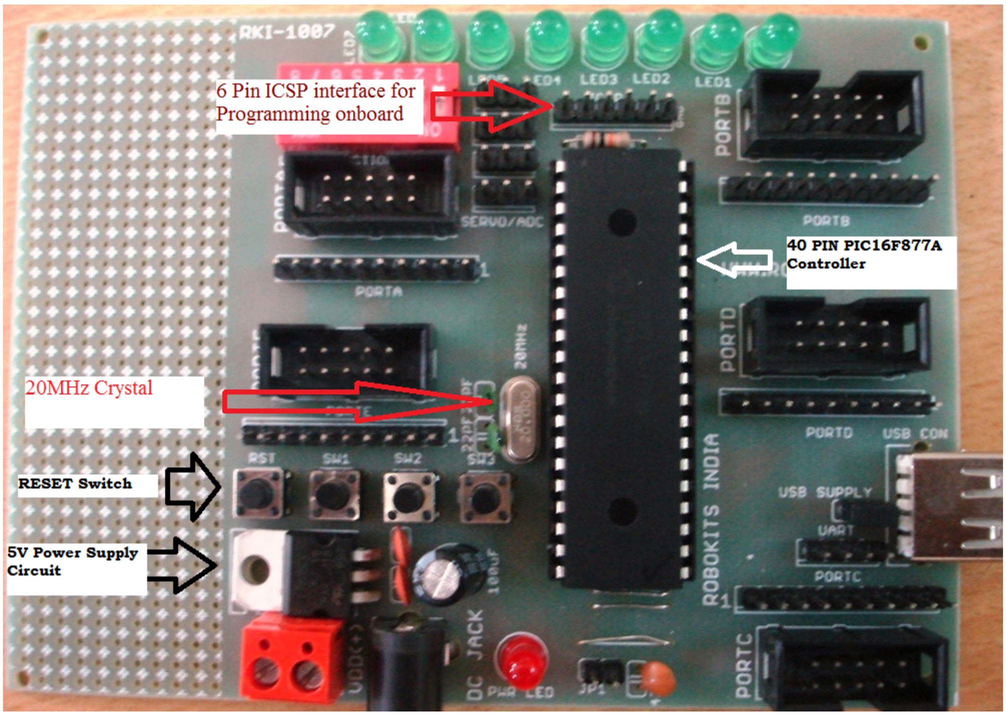

Figure C.1: PIC 40 Pin Development Board

Features

- Can be easily power from an AC DC source or Battery
- On Board Regulator with filters and Operating voltage from 6V - 20 V
- 8 LED's selectable though DIP Switches
- 20MHz crystal for maximum speed
- All ports easily accessible through standard 10 pin FRC and single line male header strip connectors.
- Serial Programmer and PC-MCU serial link external and optional

USB PIC Programmer

USB PIC Programmer supports onboard programming through ICSP of any PIC microcontrollers from Microchip.This device is specially designed to work with Laptops/Notebooks which doesnt have Parallel or serial port.

Features

- Compatible to wide range of PIC microcontrollers
- Auto detects hardware and PIC microcontrollers
- High speed programming Through USB
- 6 pin ICSP interface for programming onboard
- Provides all basic functionality of Read, Write, Erase, Blank check, Configuration bits setting etc.
- No drivers are required for this device to function in any version of windows
- LED indication for Power, Programming and Target power

USB PIC Programmer Setup interface with Computer shown in Figure C.2

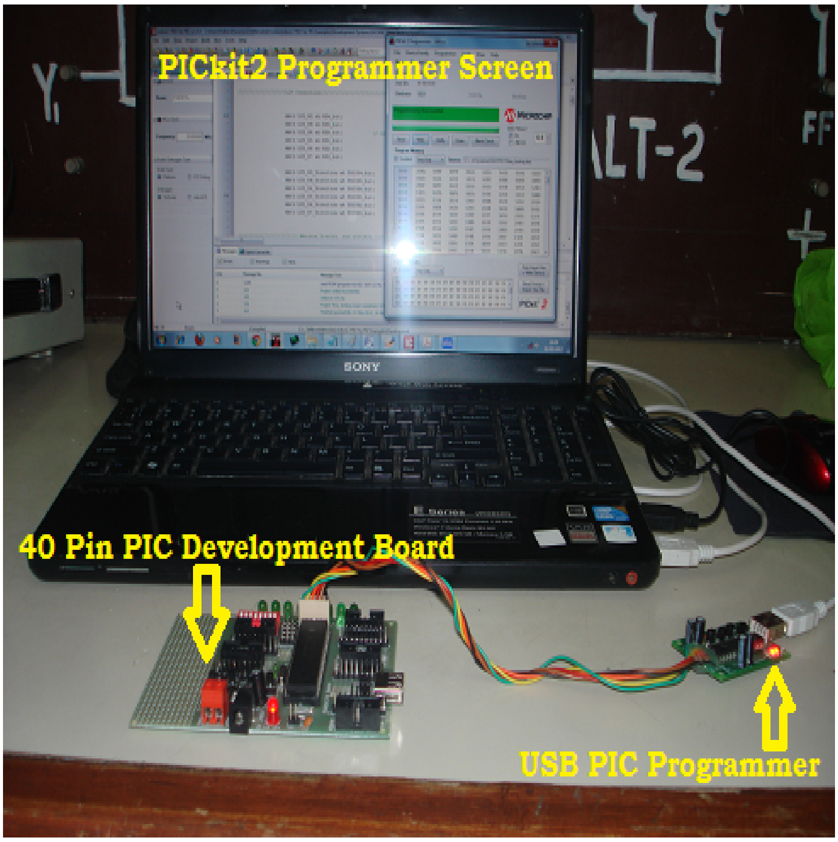

Figure C.2: USB PIC Programmer Setup

Schematic Diagram of Test System with Autosynchronizer Connections is depicted in Figure C.3

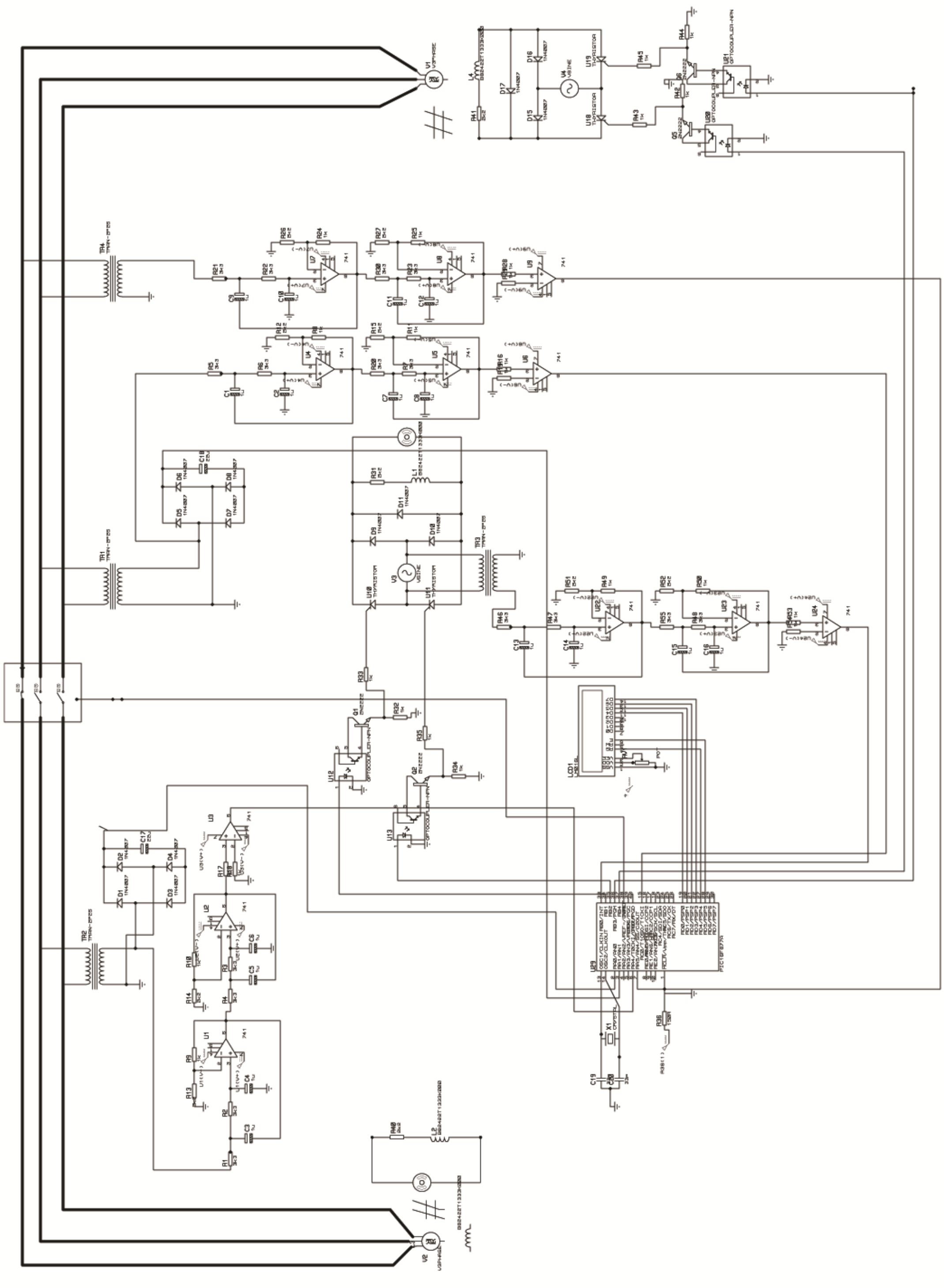

Figure C.3: Schematic Diagram of Test System with Autosynchronizer Connections

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