Design and Implementation of a Wind Turbine Parameter Measurement, Data Logging and Telemetry Unit

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT

DESIGN AND IMPLEMENTATION OF A WIND TURBINE PARAMETER MEASUREMENT, DATA LOGGING AND TELEMETRY UNIT

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Wind power potential varies from region to region due to the both topographic and climatic conditions. Hence, measurement of wind parameters accurately becomes very important. In this thesis, wind data measurement, logging and telemetry unit using arduino mega 2560 microcontroller has been designed and developed.

From Atmel family arduino mega 2560 microcontroller based data logging unit has been developed in order to measure wind parameters of a region or a small scale wind turbine. This unit measures and stores wind parameters at specific time intervals into a sd card with time and date using real time clock. Furthermore, unit can monitor wind parameters by connecting to the personal computer using USB through serial port via written interface monitoring program that is coded with Microsoft Visual Studio.Net C# platform. In addition to this, unit can transmit data wirelessly to a remote site using radio frequency telemetry module.

The developed unit can be used to analysis wind energy potential of any region. In this way, it can be make a decision that wind power potential is enough or not for the proposed site. Moreover, a small scale wind turbine can be controlled using wind speed, phase current and phase voltage information during operation with the help of this study and if needed, it can be interfered to operate safely.

Keywords: *wind energy, wind turbine, wind parameters, data measurement, data logging, arduino mega 2560 microcontroller*

ÖZET

BİR RÜZGAR TÜRBİNİ PARAMETRE ÖLÇÜMÜ, VERİ KAYDI VE TELEMETRİ ÜNİTESİ TASARIMI VE UYGULAMASI

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Rüzgar güç potansiyeli topoğraf ve iklim şartlarından dolayı bölgeden bölgeye değişir. Bundan dolayı rüzgar parametelerinin doğru bir şekilde ölçümü çok önemli olmaktadır. Bu tezde, arduino mega 2560 mikrodenetleyicisi kullanılarak rüzgar veri ölçümü, kayıt ve telemetri ünitesi tasarlanmış ve geliştirilmiştir.

Atmel ailesinden arduino mega 2560 mikrodenetleyici tabanlı veri kayıt ünitesi bir bölgenin veya küçük ölçekli bir rüzgar türbininin rüzgar parametrelerinin ölçülmesi amacıyla geliştirilmiştir. Bu ünite, gerçek zaman saati kullanarak rüzgar parametrelerini ölçer ve belirli zaman aralıklarında SD karta zaman ve tarih ile kaydeder. Dahası, ünite Microsoft Visual Studio.Net C# platformu ile kodlanarak yazılan arayüz görüntüleme programı aracılığıyla seri port üzerinden USB ile kişisel bilgisayara bağlanarak rüzgar parametrelerini izleyebilir. Buna ek olarak, ünite radyo frekansı telemetri modülü kullanarak verileri kablosuz bir şekilde uzak bir sahaya iletebilir.

Geliştirilen ünite herhangi bir bölgenin rüzgar güç potansiyelini analiz etmek için kullanılabilir. Bu sayede, önerilen saha için rüzgar güç potansiyelinin yeterli olup olmadığı kararı verilebilir. Ayrıca, bu çalışma ile küçük ölçekli bir rüzgar türbini çalışması esnasında rüzgar hızı, faz akımı ve faz gerilimi bilgileriyle kontrol edilebilir ve gerekirse, güvenli işletim için müdahale edilebilir.

Anahtar Kelimeler: *rüzgar enerjisi, rüzgar türbini, rüzgar parametreleri, veri ölçümü, veri kaydı, arduino mega 2560 mikrodenetleyici*

“To my family”

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LIST OF SYMBOLS/ABBREVIATIONS

SD:	secure digital
RTC:	real time clock
PC:	personal computer
RF:	radio frequency
USB:	universal serial bus
LCD:	liquid crystal display
ZCD:	zero crossing detector
ADC:	analog to digital conversion
EEPROM:	electrically erasable programmable read-only memory
I2C:	inter integrated circuit
SDA:	serial data
SCL:	serial clock
SPI:	serial peripheral interface
MOSI:	master output slave input
MISO:	master input slave output
SS:	slave select
CE:	chip enable
Pa:	Pascal
RH:	relative humidity
I:	current
V:	voltage
IDE:	integrated development environment
ρ:	air density

IC:	integrated circuit
kW:	kilowatt
m:	mass of air
ν:	air speed
A:	swept area of blades

CHAPTER 1

INTRODUCTION

Renewable energy sources have a very critical role to generate electric energy all over the world. These energy systems come into prominence as electrical energy demand. They are often preferred to produce electric power because of being clean, inexhaustible and sustainable. Scientists show more interest in renewable energy sources day by day [1]. Nowadays solar energy, geothermal energy, biomass energy, wind energy and wave energy are among the popular renewable energy sources [2]. These environmentally friendly energy sources are more preferred than nonrenewable energy sources such as fossil fuel [3]. Fossil fuel sources are restricted and they are harmful environmentally. For this reason, the usages of renewable energy sources are extremely important [4]. Among the renewable energy sources wind energy is more attractive and popular [1,2,3].

Nowadays number of wind turbines in Turkey is increasing quickly as in the world. Also, many people and organizations inspired by the large wind turbines are installing small-scale wind turbines such as 1 kW, 5 kW and 11 kW in urban region [5]. Before installing turbines, some parameters such as wind speed and direction and temperature, humidity and pressure must be measured to estimate the wind power potential of a region. It is possible to decide that wind power potential of a region is suitable or not for producing energy by analyzing the measured data. In addition to this data, current and voltage data can be used to observe the performance of a turbine during operation. In order to overcome these issues, parameter measurement and logging unit should be developed [6].

In this thesis, wind data measurement, logging, telemetry and monitoring unit has been developed. The developed unit can be used to investigate wind power potential of any region. So, it can be decided that wind energy potential is sufficient or not for the related region. Furthermore, through this study, a small scale wind turbine can be controlled using wind speed, current and voltage information during operation and if needed, it can be interfered to operate safely.

Arduino mega 2560 microcontroller based data logging unit has been designed in order to measure wind parameters of a region or a small scale wind turbine. This unit measures and stores wind data at specific time intervals into a secure digital (SD) card with calendar and time using real time clock (RTC). Also, designed unit can show data by connecting to the personal computer (PC) using universal serial bus (USB) through serial port via written interface monitoring program in Microsoft Visual Studio.Net C# platform. Additionally, this unit transfers parameters wirelessly to a remote region using radio frequency (RF) telemetry unit.

1.1 Overview of the Chapters

A brief review of the contents of this thesis is given as follows:

Chapter 2: It gives information about the wind energy, wind turbines and their types and literature survey related to the study.

Chapter 3: This chapter explains how to measure small scale wind turbine parameters such as wind speed and direction and other parameters. Also, a simple prototype wind tunnel for calibration of anemometer is designed and performance evaluation is conducted. Additionally, the procedure for calibration of anemometer and wind vane is demonstrated step by step. In order to measure wind speed safely, efficient zero crossing detector circuit is designed, tested and used.

Chapter 4: It mentions about operation of the entire system. This chapter also explains other required components that are used for designed unit.

Chapter 5: This chapter informs the used software programs for arduino mega 2560 microcontroller programming and for written interface monitoring program.

Chapter 6: It contains about the thesis conclusion.

CHAPTER 2

WIND ENERGY

2.1 Introduction

Electrical energy is produced using different techniques. One of them is using nonrenewable energy technologies. These sources may be coal, oil or gas and fossil fuels. Often these raw materials cause some problems as follows;

- Environmental pollution.
- Global warming.
- Oxygen reduction
- Increase the amount of carbon dioxide.
- Acid rains can occur.
- Changes in climate
- Spilled gas and particles adversely affects human health due to fossil fuels.

However, renewable energy sources are environmentally friendly. Wind energy is very popular among them as mentioned before and it does not cause above problems. Contrarily, wind energy is a very clean sources. Wind turbines use the natural power of the wind to drive a generator. Hence, this type of energy will never run out. It will continue to produce electricity power in optimal conditions during day and night.

Some required information about wind power and wind turbines are given in details in the following sections. Literature review for wind energy is also mentioned in this chapter.

2.2 Wind Power

Wind occurs from air in atmosphere and blows horizontally from right to left or left to right according to the characteristic of a region [7]. Air molecules actually flow from high pressure regions to low pressure regions and this flow naturally creates the wind. When the movement of the air molecules increase, the wind force increase proportionally. Additionally, the wind is extremely variable according to the geographic conditions and seasonal time. Thus, this difference condition causes various climatic regions all over the world. In this way, wind forces of the regions will be different from each other.

The first studies to generate electric power using wind were performed at the end of the nineteenth century. The spread of traditional windmills in Europe and America started during these years. But the first attempt systematically to generate electricity using wind power achieved in Denmark [8]. Most of the countries are increasing interest in wind power because of being sustainability and clean since those years. Wind power system technology is rapidly growing with these developments.

The generators in wind power system convert the kinetic energy into electrical energy. They can be with a range of power from a few kilowatts up to megawatts level that are called small scale and large scale, respectively.

Betz's limit in theory shows the maximum possible power that can be obtained energy from the wind regardless of the design and capacity of a turbine. Wind turbines built in recent years run close to this constant. Theoretical Betz's constant is given in equation below [9].

$$C_{max,betz} = \frac{16}{27} = 0{,}593 \qquad (2.1)$$

The kinetic energy in wind power system is calculated from the following equation [10].

$$E_k = \frac{1}{2} m v^2 \qquad (2.2)$$

where m indicates the mass of air and v denotes the air speed.

In the wind turbines available electric output power in W/m^2 varies directly proportional to the cube of the speed as in the following equation [11]. The wind power density given by the following equation indicates the capacity of wind potential in a region.

$$P_{out} = \frac{1}{2} A \rho v^3 \quad (2.3)$$

where A is swept area of blades (m^2), ρ is air density (ρ =1.225 kg/m^3 dry air and 1 atm and 15 C^o) and v is the mean wind speed (m/s). Swept area is proportional to the length of the blades. Air density depends on air pressure, temperature, humidity, height above sea level and gravity. Wind velocity varies with topographic conditions.

Wind quality and wind speed are two important parameters for wind energy. The locations where there is no turbulence are the most appropriate places for wind turbines. Turbulence affects negatively the efficiency of a turbine. Wind power can be categorized according to the wind speed and wind power density as shown Table 2.1 in seven groups [12]. For instance, fifth category wind power in 10 m height demonstrates power density between 250 and 300 W/m^2. Similarly, sixth category wind power in 50 m height demonstrates power density between 600 and 800 W/m^2.

Table 2. 1. Wind power categories [12]

Wind power category	10 m in height		50 m in height	
	Wind power density (W/m^2)	Wind speed (m/s)	Wind power density (W/m^2)	Wind speed (m/s)
1	0	0	0	0
1-2	100	4,4	200	5,6
2-3	150	5,1	300	6,4
3-4	200	5,6	400	7,0
4-5	250	6,0	500	7,5
5-6	300	6,4	600	8,0
6-7	400	7,0	800	8,8
7	1000	9,4	2000	11,9

It is not suitable to install wind turbine without analyzing wind power potential of a region. In order to install a turbine in any region, accurate measurements have a very significant role. Therefore, it is very crucial to investigate wind parameters at a region at least a year. After collecting data, wind power potential forecasting can be carried out in detail.

2.3 Wind Turbines

Kinetic energy produced by wind energy is converted into electrical energy using wind turbines. Wind turbines are getting cheaper and becoming more efficient over the years. These machines have different components as shown Figure 2.1 [13].

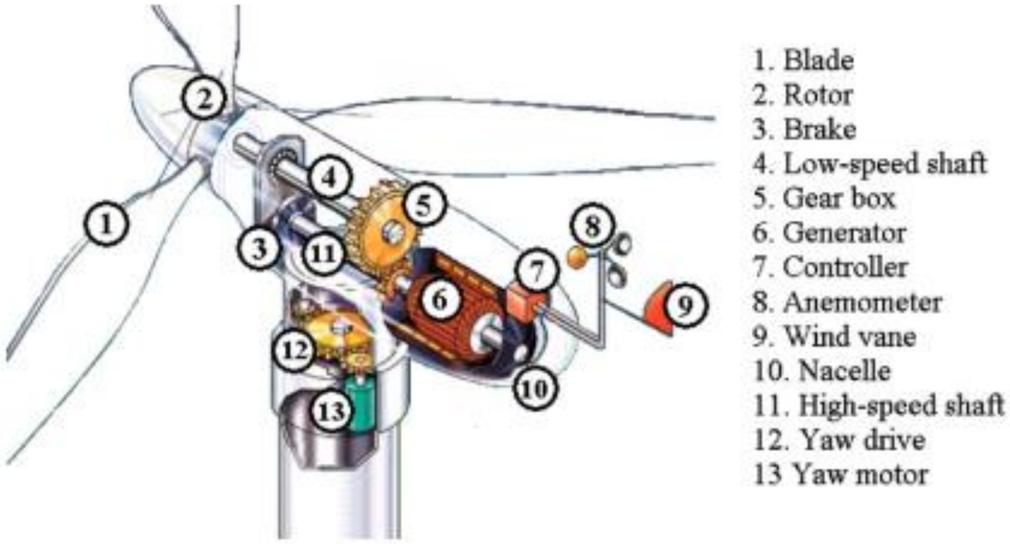


Figure 2. 1. The components of a wind turbine [13]

A short introduction of components are given below [13].

Blade: Wind blows over blades and rotates over them. Generally wind turbines have three blades.

Rotor: Hub and blades are together named rotor.

Brake: In emergencies stops the running rotor. Brake can be three different types electrically, hydraulically or mechanically.

Low-speed shaft: Rotor turns the low speed shaft approximately 30-60 rpm.

Gear box: Connects low-speed shaft to high-speed shaft.

Generator: Converts the mechanical energy into the electrical energy with different power levels.

Controller: Starts up and shuts off the turbine at specific value.

Anemometer: Wind speed is measured using anemometer. This device also sends the measured data to the controller.

Wind vane: Wind direction is determined using wind vane.

Nacelle: Generator, gear box, shafts, brake and controller are placed in nacelle.

High-speed shaft: The generator is driven using high-speed shaft.

Yaw drive: The direction of a turbine is turned against wind using yaw drive when the wind direction changes.

Yaw motor: Yaw drive is powered using yaw motor.

There are two general types of wind turbines which are known horizontal axis and vertical axis wind turbine, respectively. The blades of a horizontal axis wind turbine rotate as a parallel to the ground. On the other hand, the blades of a vertical axis wind turbine rotate as a perpendicular to the ground. Additionally, there are onshore and offshore wind turbines that are classified according to where they installed.

2.3.1 Horizontal Axis Wind Turbines

Horizontal axis wind turbine is the one of the most common type of wind turbines all over the world. It has generally two or three blades and is located on the parallel to the ground. It consists of a tower, blades, a generator, a controller, a rotor and other machine components. The wind perpendicular to the blades is rotated to rotor and this movement is transmitted to the generator which produces electricity [12]. A typical configuration of a horizontal axis wind turbine is shown in Figure 2.2 [14].

2.3.2 Vertical Axis Wind Turbines

Vertical axis wind turbine has a main shaft which is vertical to the ground. It is generally categorized as a Savonius and Darrieus wind turbine. However, it is not widely used and not popular. Since the slow movement, it is not sufficient to produce electricity. Therefore, they are not mostly preferred by the investors [12]. A typical configuration of a vertical axis wind turbine is indicated in Figure 2.2 [14].

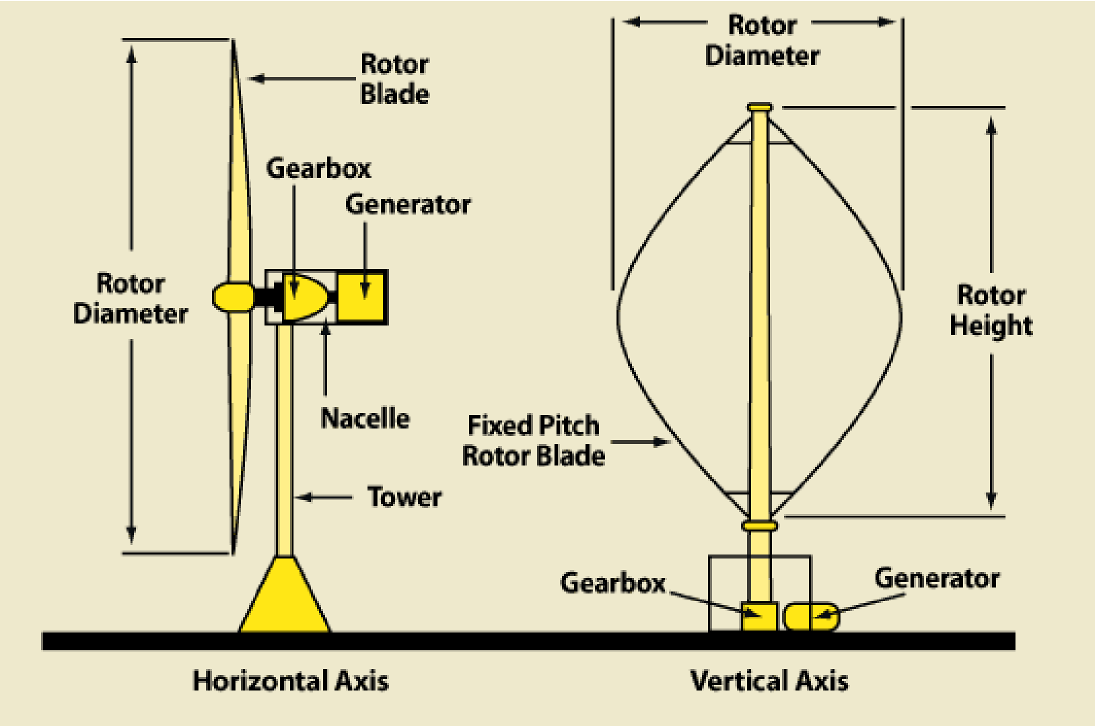


Figure 2. 2. The view of a horizontal and vertical axis wind turbines [14]

2.4 Literature Review related with the Study

Shuvra Dey Babu, Agom Sree Acharjya and Samina Alam (2014) presents a microcontroller based wind speed and direction monitoring system. In this study, portable measurement system has been designed and developed. Practical implementation has been tested and successfully carried out. Design methodology for the system has been explained in detail [15].

V. Aiswarya and N. K. Prakash (2013). This paper gives information about instrumentation system for wind turbines using Labview tool. Some turbine parameters such as wind speed, wind direction, temperature and pressure have been measured using Labview and reported in this work. Developed system is very sensitive [6].

D. W. Wekesa, J. N. Kamau and J. N. Mutuku (2013). In this study, data logging measurement system has been described for wind speed and direction. The instrumentation system is based on microcontroller which measures the calibrated parameters accurately. Experimental measurement results have been given graphically in detail [16].

Haci Can and Vedat M. Karslı (2007). They proposed in this study that data logging device has been developed to measure wind speed and direction and to store these data into an EEPROM with real time. Calibrated sensors have been used for the measurement system [17].

Keun-Young Kang, Mohamed A. Ahmed and Young-Chon Kim (2014). In this paper wind parameters have been measured accurately and these parameters have been transmitted to the data collection unit. This smart device is useful for the application of small scale wind turbines [18].

Ersan Kabalcı, Alper Gorgun and Yasin Kabalcı (2013). This study presents a voltage and current measurement monitoring system for renewable energy applications. Instrumentation and monitoring system have been developed using microcontroller [19].

Tobias Schneiderhan, Johannes Schulz-Stellenfleth, Susanne Lehner, Jochen Horstmann and Thomas König (2004) have proposed a new measurement technique based on synthetic aperture radar (SAR). SAR wind measurement method has been explained in detail. Moreover, wind direction and wind speed analysis have been carried out [20].

H. I. Schlaberg, Y. Liu, Z. Li and S. Liu (2013) have designed a system about instrumentation of wind speed and direction with narrowband ultrasonic sensors using dual frequencies. This study aims that wind speed and direction can be measured in a different way [21].

Lay Nandar Soe, Kyaw Soe Lwin and Hla Myo Tun (2014). They proposed in this study that sensing unit in transmitter for wireless weather station. Using microcontroller all data are transmitted to a remote station with the help of RF module. The most important advantages of their system were cost-effective, greater portability and smaller size [22].

2.5 Summary

The wind energy is a clean, renewable and sustainable energy source. The operation of wind turbines are based on converting kinetic energy coming from the wind into electrical energy. Wind turbines have different components which are known anemometer, wind vane, blade, braking system, rotor, generator, controller etc… There are generally two types of wind turbines; horizontal axis and vertical axis, respectively. It can be said that there are different studies related with the work as seen from the literature review. There are also various techniques to measure wind speed and direction and other wind parameters. Some of studies are related with data measurement and logging and others are related with wireless data transmission.

CHAPTER 3

MEASUREMENT OF WIND TURBINE PARAMETERS

3.1 Introduction

In this chapter measurement of wind turbine parameters is explained in detail. First and most importantly wind speed and direction and temperature, humidity and pressure information are reported and how can be measured using sensors and which sensors can be used to determine wind parameters. Furthermore, measurement of a phase voltage and current for a small scale wind turbine is expressed. All these parameters are stated deeply in sections.

Wind speed is measured using anemometer (wind speed meter). There are some types of anemometer. In order to measure wind speed accurately, zero crossing detector (ZCD) has been designed, developed and explained. Anemometers must be calibrated before measurement with the help of a wind tunnel. A prototype wind tunnel has been designed and performance evaluation has been carried out. Wind vane is used to determine wind direction which also has to be calibrated for accuracy measurement. Other wind parameters such as voltage, current, temperature, humidity and pressure are measured using digital and analog sensors which are compatible with microcontroller.

The measurement and calibration procedure of sensors and connections of peripherals to the microcontroller are given in a detail way in the following sections.

3.2 Wind Speed Measurement

An anemometer (wind speed meter) is used to measure wind speed that is very critical parameter for the evaluation of a region’s wind power potential. Wind speed is measured with a set of three cups which rotate on a vertical axis. When the wind occurs, the cup will rotate at a speed proportional to the speed of the apparent wind. In this study, cup type anemometer has been preferred and implementation has been carried out for this type of anemometer. Given in Figure 3.1 cup type NRG maximum #40 anemometer produces a sine wave output signal [23].

Figure 3. 1. NRG maximum #40 anemometer

The some important specifications of the anemometer is shown in Table 3.1 [23].

Table 3.2. Some specifications of NRG Maximum #40

Sensor Type	3 cup anemometer
Applications	Wind energy, Meteorology
Sensor Range	1 m/s to 96 m/s (highest recorded)
Signal Type	Low level AC sine wave, frequency proportional to the wind speed
Transfer Function	m/s=(Hz*0.765)+0.35
Output Signal Range	0 Hz to 125 Hz

3.2.1 Zero Crossing Detector Circuit

The sine wave signal coming from anemometer is converted into a square wave using zero crossing detector circuit. This circuit provides also to reduce noise effects on signal. The output of zcd is connected to Schmitt trigger integrated circuit to sharpen signal before applying to the microcontroller. The schmitt trigger IC (CD4093) is placed at the end of the zero crossing detector circuit to reduce the noise. It is actually a comparator based hysteresis. The operational logic diagram is illustrated in Figure 3.2.

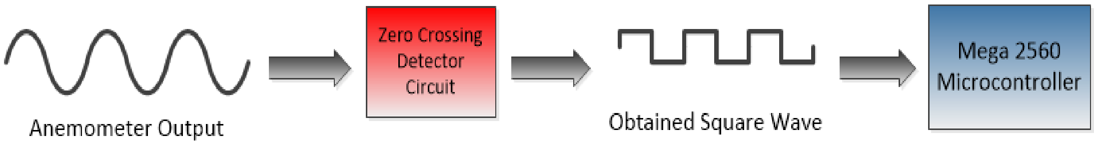


Figure 3. 2. Operational logic diagram

In this thesis, effective zero crossing detector circuit has been designed and developed. Developed zcd circuit has been tested at different frequencies. The results including very low frequencies have been highly efficient. Designed circuit diagram is shown in Figure 3.3.

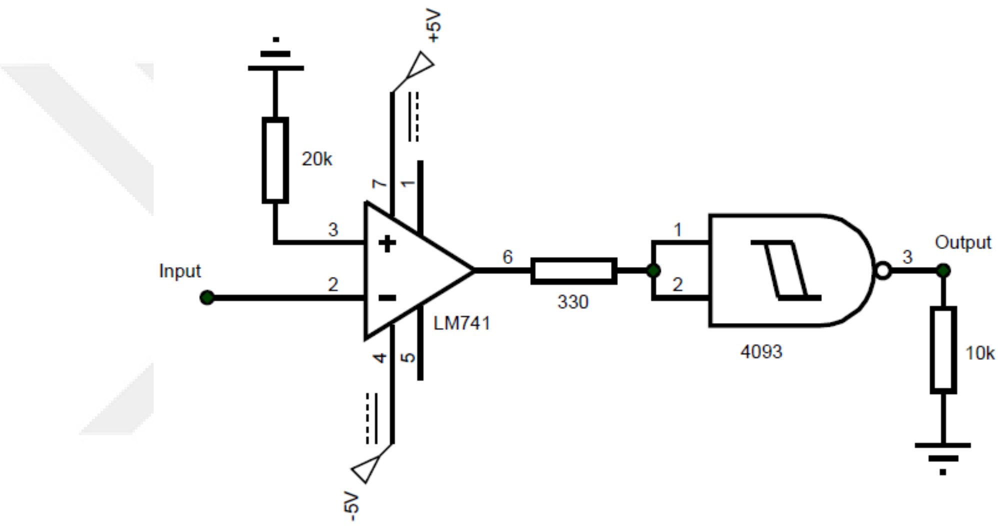


Figure 3. 3. Developed zero crossing detector circuit

After obtaining smooth square wave, the output of combined circuit is connected to the mega 2560 microcontroller to calculate frequency of the square wave signal in each cycle. Microcontroller is programmed to determine frequency of signal between the falling edges of the pulse. In the final step, wind speed can be calculated easily using transfer function of the anemometer.

3.2.2 Design and Construction of a Prototype Wind Tunnel

Anemometer is one of the most important devices for wind turbines. This device must be calibrated before starting the measurement because of reliability of wind speed data to be determined. In this study, a simple wind tunnel has been designed for the calibration of cup anemometers and performance evaluation has been conducted in the next section [24].

In Figure 3.4 preliminary work model of designed prototype wind tunnel is illustrated clearly. One of the most critical points in the wind tunnel is that the power of the used fan is as high as possible. In this case, the air flow will be more.

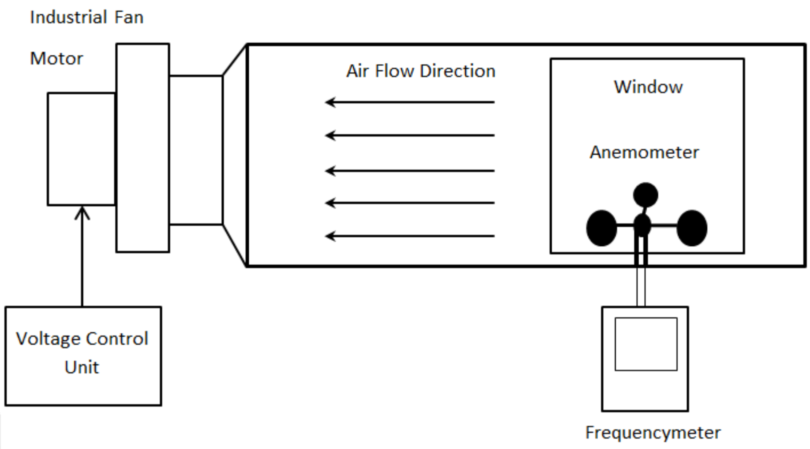


Figure 3. 4. Preliminary work model for the designed wind tunnel

Designed tunnel was initially thought to be about 180 cm long. The circular diameter of the tunnel was 40 cm and the area of the outer section of the air entering the tunnel was approximately 1256 cm^2. Industrial type fan used in the tunnel has label values of 230 V, 50 Hz, 1000 W, 4,75 A, 2700 rpm, IP 54 type and single phase asynchronous motor are formed. Galvanized sheet metal for the pipe system of the tunnel has been provided and the system has been designed in this way. A window have been added for the purpose of placing and observing the anemometer to be measured in the tunnel. The speed of the motor in the tunnel was controlled using voltage control unit and air flow was provided at different magnitudes. The initial view of the designed tunnel system is shown in Figure 3.5.

Figure 3. 5. Initial view of the designed wind tunnel

The air flow was unexpectedly non-homogeneous. Therefore, the tunnel system has been rearranged as illustrated Figure 3.6. Designed tunnel was about 230 cm long at the end of arrangement. In addition, the surface area of the air has been increased to about 1800 cm^2.

Figure 3. 6. A view from the final state of the designed wind tunnel

3.2.3 Performance Evaluation of a Designed Prototype Wind Tunnel

The transfer function for cup type anemometer is given in the following equation [25].

$$v = A * f + B \tag{3.1}$$

Given in the equation, wind speed is symbolized as v, A is corresponding to the slope of the linear equation, output frequency of the anemometer is represented with f, B is corresponding to the air flow speed at $f = 0$.

In this evaluation, air flow speed has been determined using Lutron-AM4220 digital anemometer as shown Figure 3.7.

Figure 3. 7. Lutron-AM4220 digital anemometer

Cup anemometer shown in Figure 3.1 has been firstly calibrated using wind tunnel that is illustrated with working principle given in Figure 3.8.

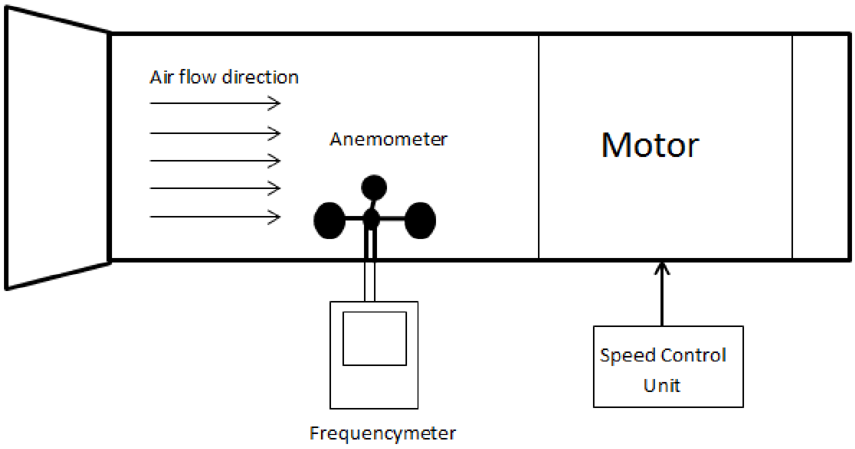


Figure 3. 8. Principle schema for Plint & Partners wind tunnel

Plint & Partners wind tunnel is approximately 4 m long. Air flow speed is provided with three phase motor. This tunnel is named Plint & Partners in the mechanical engineering department at University of Gaziantep. The tunnel which has been used as a reference is illustrated in Figure 3.9.

Figure 3. 9. View of Plint & Partners wind tunnel

Measurement results using Plint & Partners are shown in Table 3.2. Obtained graph of linear equation and transfer function is given in Figure 3.10. When output frequency of the anemometer is equal to 10 Hz, air flow speed can be calculated using obtained transfer function. After simple calculation in equation (3.2), air flow speed is obtained as 8,2554 m/s.

$$v\left[\frac{m}{s}\right] = 0{,}7538 * f[Hz] + 0{,}7114 \tag{3.2}$$

Table 3.2. Obtained data from Plint & Partners wind tunnel

Output frequency of NRG Maximum #40 (Hz)	Air flow speed measured by digital anemometer (m/s)
3,297	3,2
3,552	3,4
3,766	3,6
3,868	3,7
4,207	3,9
4,464	4
4,64	4,2
4,916	4,4
5,089	4,5
5,327	4,8
5,64	5
5,792	5,1
6,011	5,2
6,179	5,4
6,471	5,5
6,621	5,7
6,98	5,9
7,169	6,1
7,217	6,2
7,482	6,4
7,696	6,6

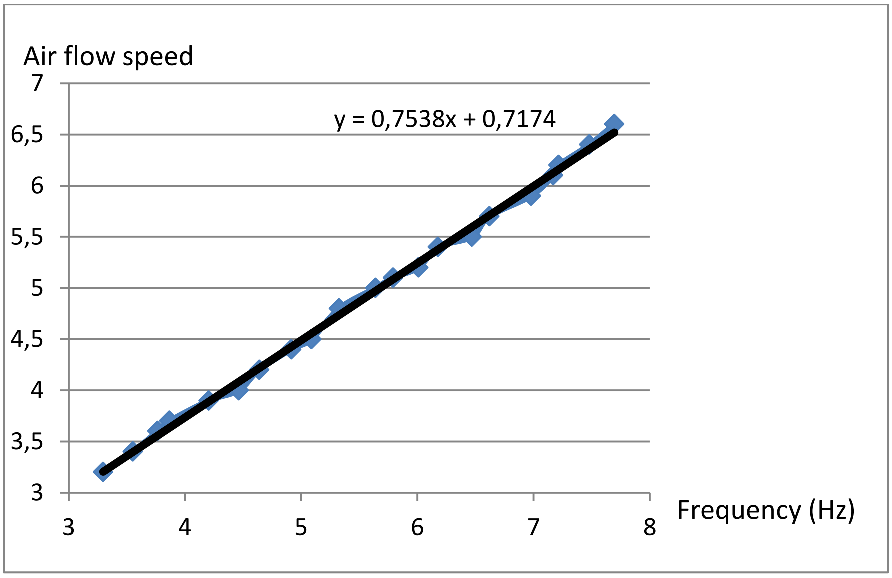


Figure 3. 10. Linear trend line obtained from Plint & Partners wind tunnel

Obtained data from designed wind tunnel is given in Table 3.3. Transfer function is determined with the help of measurement results as in the following equation. In addition, obtained linear equation in graphical form is illustrated in Figure 3.11. When output frequency of the anemometer is equal to 10 Hz, air flow speed can be calculated using obtained transfer function. After simple calculation in equation (3.3), air flow speed is obtained as 8,2108 m/s.

$$v\left[\frac{m}{s}\right] = 0{,}7688 * f[Hz] + 0{,}5228 \quad (3.3)$$

Table 3.3. Obtained data from designed wind tunnel

Output frequency of NRG Maximum #40 (Hz)	Air flow speed measured by digital anemometer (m/s)
2,492	2,5
2,836	2,6
3,12	2,9
3,271	3
3,515	3,2
3,652	3,3
3,735	3,5
4,051	3,7
4,189	3,8
4,311	3,9
4,489	4
4,579	4
4,779	4,1
4,806	4,2

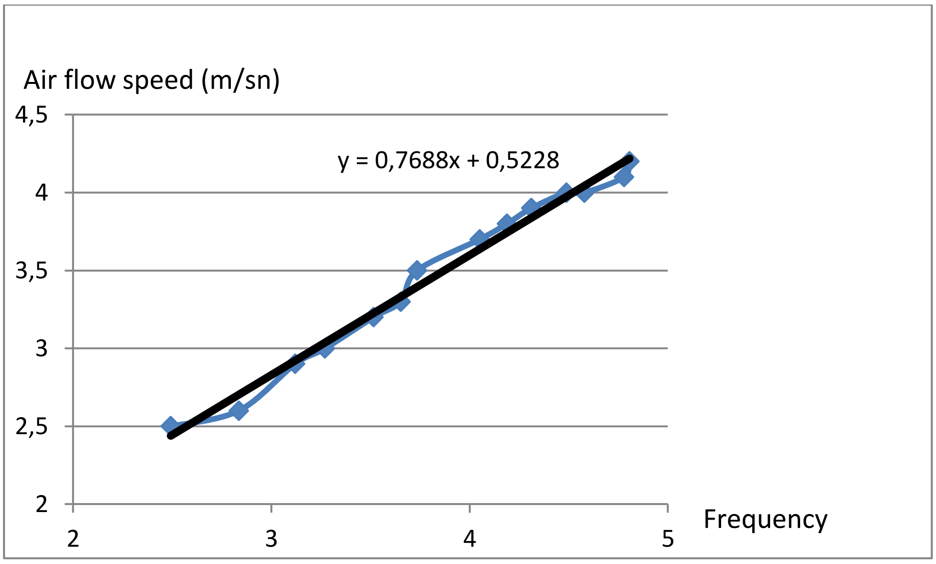


Figure 3. 11. Linear trend line obtained from designed wind tunnel

After the test anemometer has been calibrated seperately in both tunnel systems which are constructed one and Plint & Partners TE 54 model one, comparison has been carried out using data sets taken from tunnel systems. It is important in calibration that obtained transfer function from measurements. Error rate of the system has been identified with the obtained data at the end of the performed experimental study. As a result of the experimental study, the comparison of the tunnels is shown in Table 3.4. According to the Plint & Partners wind tunnel that is used as a reference, error rate of the designed wind tunnel is determined as 0,54 %.

Table 3.4. Comparison of wind tunnels at 10 Hz.

NRG Maximum #40 Anemometer				
Wind Tunnels	**Slope (A)**	**Intersection (B)**	**Air flow speed (m/s)**	**% Difference**
Plint & Partners TE 54	0.7538	0.7174	8.2554	0.54
Designed	0.7688	0.5228	8.2108	

Experimental data prove that the designed tunnel system can be used in non-critical applications. Furthermore, the designed tunnel system offers more economical solutions. The study shows that calibration of the anemometers can be done with a prototype tunnel system which is more advantageous according to the similar ones in economical respects.

3.3 Wind Direction Measurement

Wind direction is utilized to determine in which direction at a region wind power potential is more than other. Wind direction is determined with the help of a wind vane which is directly connected to a potentiometer in the main body. The output voltage of vane represents wind direction. Shown in Figure 3.12 NRG #200P wind vane gives analog DC output voltage from 10k ohm potentiometer [26].

Figure 3. 12. NRG #200P wind vane

The some important specifications of the wind vane is given in Table 3.5 [26].

Table 3.5. Some specifications of NRG #200P wind vane

Sensor Type	Continuous rotation potentiometric wind direction vane
Applications	Wind energy, Meteorology
Sensor Range	360^0 mechanical, continuous rotation
Signal Type	Analog Dc voltage from 10K ohm potentiometer
Supply Voltage	1V to 15V DC
Output Signal Range	0V to excitation voltage

The output of vane is read by a ten bit an analog-to-digital converter (ADC) unit in mega 2560 microcontroller to determine the wind direction. The wind directions are divided into 16 parts as clearly illustrated Figure 3.13. North is also the reference direction of the vane. According to the output voltage of the wind vane, wind direction can be determined using ADC unit of microcontroller.

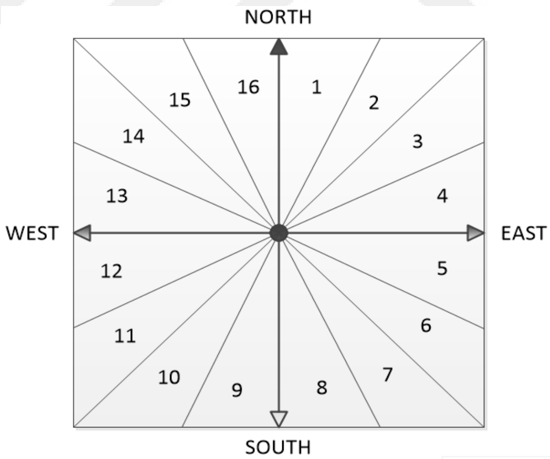


Figure 3. 13. Wind directions

The potentiometer of wind vane is applied +5V and voltage on potentiometer is detected using 10 bit serial analog to digital converter. The voltage difference between two directions is equal to 0,3125V (5V/16). Voltage limits corresponding to the directions are given in Table 3.6. According to the measured voltage value, microcontroller is coded to determine wind directions.

Table 3.6. The relation between ADC values and directions

Voltage values on potentiometer (V)	Hexadecimal representation of ADC value	Wind Directions
0,0000-0,3125	0	1
0,3125-0,6250	1	2
0,6250-0,9375	2	3
0,9375-1,2500	3	4
1,2500-1,5625	4	5
1,5625-1,8750	5	6
1,8750-2,1875	6	7
2,1875-2,5000	7	8
2,5000-2,8125	8	9
2,8125-3,1250	9	10
3,1250-3,4375	A	11
3,4375-3,7500	B	12
3,7500-4,0625	C	13
4,0625-4,3750	D	14
4,3750-4,6875	E	15
4,6875-5,0000	F	16

3.3.1 Calibration of Wind Vane

Wind vane consists of a 10k potentiometer and the resistance of terminals is increased or decreased by changing of wind direction as explained before section. In order to calibrate wind vane, it should be located in the center of a smooth surface. After this stage, calibration is performed by measuring the resistance of vane using ohmmeter. By rotating of vane in every 20 degree increment, the terminal resistance of it has been measured. Values of resistance corresponding to the angles are tabulated below.

Table 3.7. Resistance values with angular position

Angular Position (Degree)	Resistance Value (Ohm)
0	96,5
10	365
30	392

50	1580
70	2090
90	2733
110	3142
130	3765
150	4330
170	4835
190	5425
210	6032
230	6580
250	7140
270	7650
290	8260
310	8710
330	9770
350	10190

After calibration process, results are illustrated in graphical form as in the following figure. The obtained trend line clearly shows that the terminal resistance is proportional to the angle.

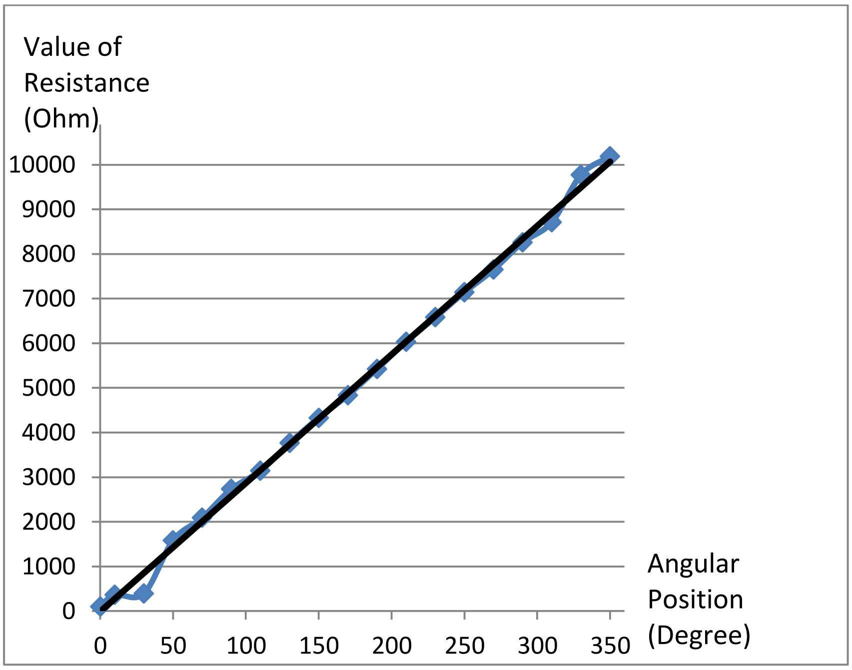


Figure 3. 14. Calibration result for wind vane

3.4 Temperature Measurement

Temperature is measured using DS18B20 sensor. The DS18B20 digital temperature sensor gives Celsius (Centigrade) temperature measurements. It needs only one data line for communication with a microcontroller unit. It does not need any external calibration. It is connected to the microcontroller with any digital input pin using a 4.7 kΩ resistor between data and power lines [27]. The temperature sensor connection to the microcontroller is shown in Figure 3.15.

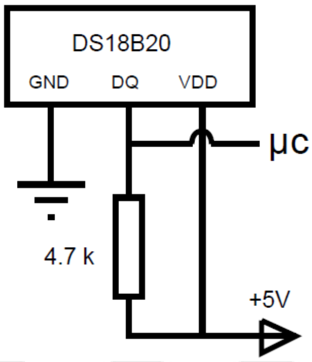


Figure 3. 15. Connection diagram of temperature sensor

3.5 Humidity Measurement

Humidity is taken from DHT11 sensor that is high reliability and perfect long term stability. It is connected to a microcontroller with any digital input pin using a 5 kΩ resistor between data and power lines [28]. The humidity sensor connection to the microcontroller is illustrated below.

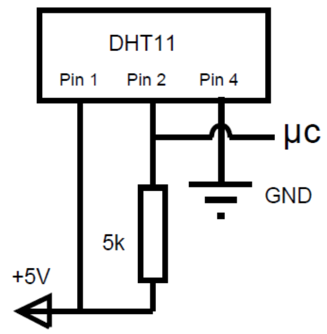


Figure 3. 16. Connection diagram of humidity sensor

3.6 Pressure Measurement

BMP180 sensor is used to measure pressure. It has high accuracy and linearity. Inter-Integrated Circuit (I2C) protocol which provides for easy integration is used to communicate with a microcontroller [29]. The pressure sensor connection to the microcontroller is given in the below diagram.

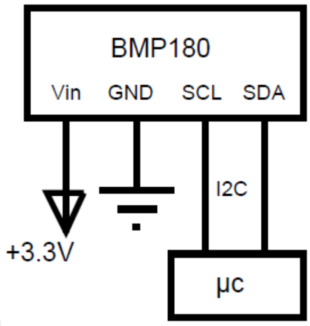


Figure 3. 17. Connection diagram of pressure sensor

Required supply voltage, measuring range and accuracy for temperature, humidity and pressure sensor are tabulated below.

Table 3.8. Some properties of sensors

Sensor Type	Model	Some Specifications
Temperature	DS18B20	Supply Voltage: 3.0V to 5.5V Measuring Range: -55°C to +125°C ±0.5°C accuracy from -10°C to +85°C
Humidity	DHT11	Supply Voltage: 3.0V to 5.5V Measuring Range: 20-90% RH Humidity Accuracy: ±5% RH
Pressure	BMP180	Supply Voltage: 1.8V to 3.6V Measuring Range: 300 to 1100 hPa Relative Accuracy: ±0.12 hPa

3.7 Voltage Measurement

For a wind turbine system terminal voltages such as line to line and phase voltage can be measured with the help of a microcontroller by designing a measurement circuit. The components which will be used for measurement must be selected according to circuit requirements. For instance, voltage and current limits must be taken into account for reliability and accuracy measurement. Sensors on the market are generally expensive and inadequate in terms of voltage upper limit. Therefore, in order to determine line to line or phase voltage value for three phase system, a circuit given below has been designed and developed.

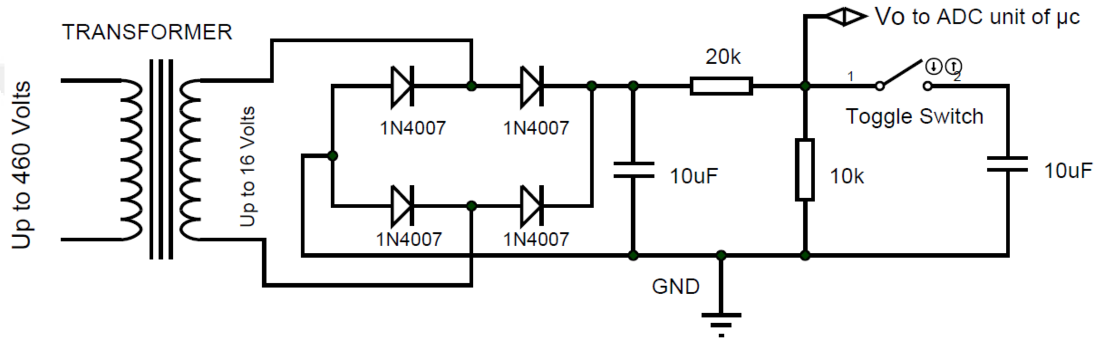


Figure 3. 18. Circuit diagram for voltage measurement

In the circuit given above, high voltage level is decreased to low voltage level with the help of a step down transformer which has 230/6 V, 1 VA nameplate values. Because the rating power is low in the transformer, flowing current on the secondary side is too low. Using two identical type of transformers as shown in the figure 3.19, voltage level can be increased up to 460 V level. After this step, sinusoidal voltage is rectified using bridge diodes. The smooth voltage signal is obtained by filtering by aid of 10 μF capacitor.

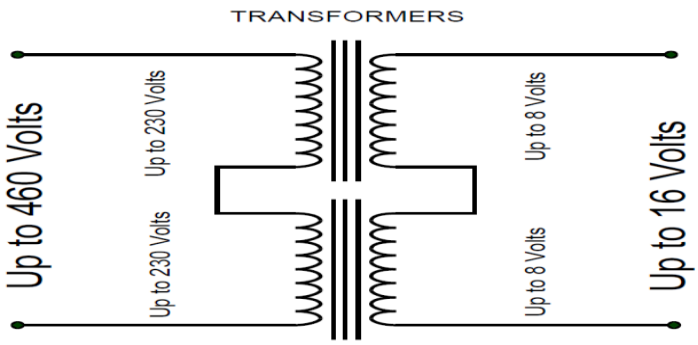


Figure 3. 19. Connection topology for two transformers

The filtered voltage is reduced with the help of voltage divider using resistors (20K and 10K) in order to deliver maximum 5V into the microcontroller. At the end of this step, the obtained voltage is changeable according to the applied voltage in primary side of the transformer. Output voltage is proportional to the input voltage so that applied voltage can be measured using analogue-to-digital (ADC) unit of the microcontroller. If needed, when the toggle switch is off fully regulated output voltage can be obtained with the help of 10 μF capacitor. The voltage measurement circuit has been tested with various versions both simulation and experimentally and the results have been successfully observed.

3.8 Current Measurement

In wind turbines phase currents have to measure in order to control or follow the turbine during operation. Current measurement circuit or sensor must be used for this purpose. In this study, ACS709 current sensor has been tested in order to measure the current. This sensor measures the current up to 75A level. This sensor provides economical solution in industrial, commercial and automotive systems. It consists of a linear Hall sensor integrated circuit. Connecton diagram for sensor and microcontroller is given in the following figure [30].

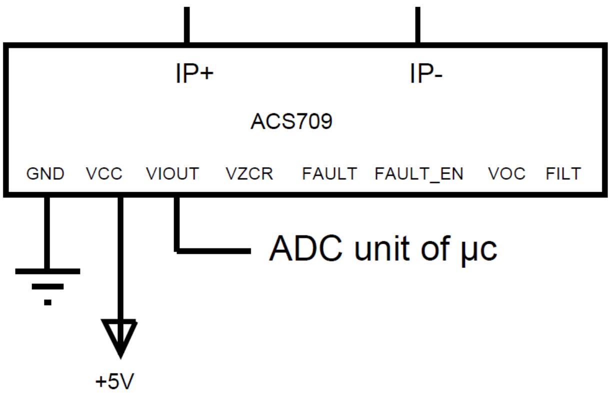


Figure 3. 20. Connection diagram of current sensor

The ACS709 produces an analog output voltage from the Hall sensor IC linearly tracks the magnetic field generated by the applied current. The current to be measured is determined using transfer function of the sensor with the help of ADC unit of microcontroller. The voltage on the VOC pin allows users to determine an overcurrent threshold for the device. If the current flowing through the conduction path (between IP+ and IP- pins on the sensor) exceeds the threshold, overcurrent pin will transition to a logic low state. This pin in normal conditions is not used. ACS709 current sensor is often used in the following applications.

- Power conversion and battery systems.
- Electrical load management and overcurrent protection.
- Motor control and drives.
- Uninterruptible power supplies.

3.9 Summary

In this chapter a wind turbine data measurement has been explained in a detailed way. Primarily wind speed and direction and temperature, humidity and pressure information have been discussed and how can be measured using sensors and which sensors can be used to define wind data. Additionally, measurement of a phase voltage and current for a wind turbine has been expressed. All these data are stated in sections. The calibration and measurement procedure of sensors and connections of peripherals to the microcontroller have been also explained in a deeply way in the previous sections.

CHAPTER 4

HARDWARE OF THE UNIT

4.1 Introduction

The hardware of the prototype unit generally consists of wind sensors, real time clock, SD card, radio frequency module, keypad and LCD. Output of the anemometers that produces sinusoidal signal is applied to zero crossing detector circuit in order to convert into a square wave before applying to a microcontroller. Analog output voltage of wind vane is read using ADC of microcontroller in order to determine wind direction. Other wind sensors such as temperature, humidity and pressure are connected to microcontroller in order to measure related data. Current and voltage information also are measured using a current sensor and designed voltage measurement circuit. All these data can be displayed on LCD by commanding from keypad. Besides, all wind parameters are stored into a SD card in one second interval with real time and calendar. The written interface program in C# platform can monitor all data by connecting the unit to a PC. Besides, wind parameters can be sent wirelessly to a remote point with the help of RF telemetry module.

4.2 Operation of The Entire Unit

Arduino mega 2560 microcontroller development card is often used component in electronic areas. The wind parameter measurement unit is developed based on mega 2560 board from Atmel microcontroller family. This card has six external interrupts and ten bit an analog-to-digital converter (ADC) unit. Interrupt is an event that interrupts the processing program and allows a special function [31]. The details of the design steps have been explained in this section.

In this thesis, a 4x4 membrane keypad is used to select related parameter in real time that is displayed on LCD. Desired functions of the program are selectable using keypad. The block diagram of the entire unit is shown in the Figure 4.1.

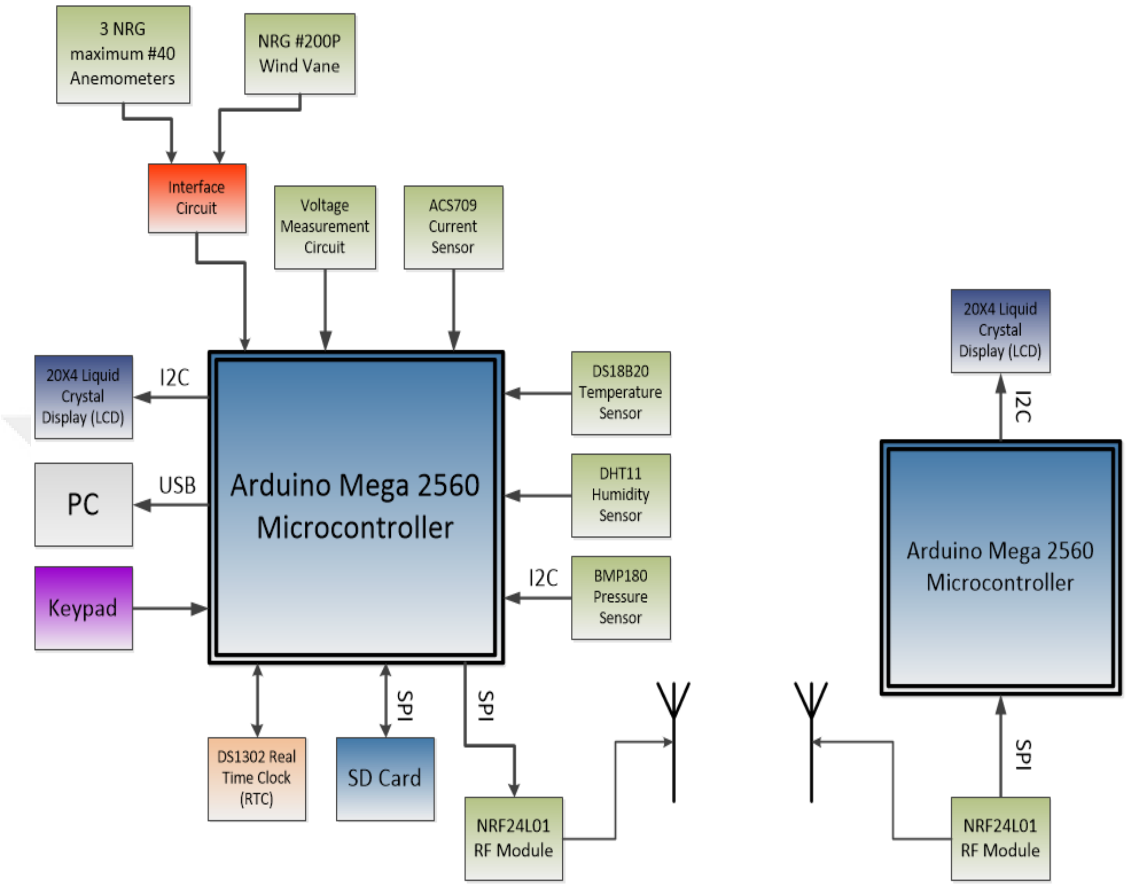
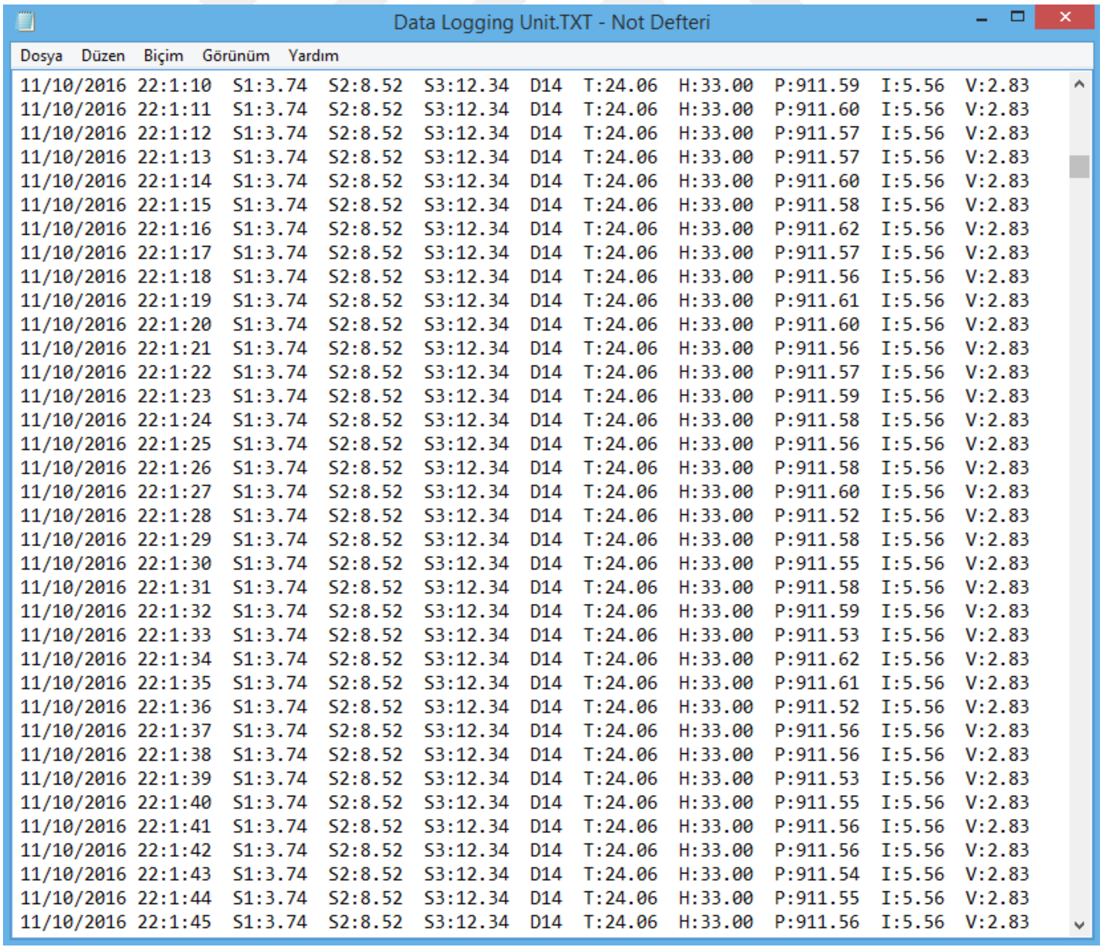


Figure 4. 1. Functional block diagram of entire unit

A 20x4 character LCD has been used to display real time, wind speed, wind direction, temperature, humidity, current and voltage information. This screen can communicate with microcontroller unit with the help of I2C protocol [32]. That is why, I2C converted card driver connects this screen to microcontroller unit. In this intercommunication, four pins are used data line and six pins for choosing LCD, starting LCD, read/write operation, setting contrast, +5V supply and ground. All the pins are transmitted to only two lines that are known Serial Data (SDA) and Serial Clock (SCL) through I2C protocol.

DS1302 real time clock module has been used to get date and time information. It communicates with a microcontroller via synchronous serial interface. It provides and counts automatically seconds, minutes, hours, day, date, month and year information.

Secure digital (SD) memory card is used to keep wind information for future use. Storage capacity can easily be increased if needed. The SD module takes data from microcontroller using serial peripheral interface (SPI) [33]. Custom SPI pins are assigned for communication in mega 2560 microcontroller. Wind parameters are stored into a SD card in one second interval with real time in text format in a sequential manner. Data is recorded for each second with the help of a timer interrupt of the microcontroller. Test results of data logging are given below as a screenshot in text document format. Real date and time, three wind speeds, wind direction, temperature, humidity, pressure, current and voltage values are measured and stored on any line in a sequential manner. Measured and stored parameters can be increased with changing in software. In this way, data logging is performed in detail and collected data can be analyzed to estimate wind energy potential for a region.


Data Logging Unit.TXT - Not Defteri

Dosya Düzen Biçim Görünüm Yardım

```
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11/10/2016 22:1:11  S1:3.74  S2:8.52  S3:12.34  D14  T:24.06  H:33.00  P:911.60  I:5.56  V:2.83
11/10/2016 22:1:12  S1:3.74  S2:8.52  S3:12.34  D14  T:24.06  H:33.00  P:911.57  I:5.56  V:2.83
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11/10/2016 22:1:14  S1:3.74  S2:8.52  S3:12.34  D14  T:24.06  H:33.00  P:911.60  I:5.56  V:2.83
11/10/2016 22:1:15  S1:3.74  S2:8.52  S3:12.34  D14  T:24.06  H:33.00  P:911.58  I:5.56  V:2.83
11/10/2016 22:1:16  S1:3.74  S2:8.52  S3:12.34  D14  T:24.06  H:33.00  P:911.62  I:5.56  V:2.83
11/10/2016 22:1:17  S1:3.74  S2:8.52  S3:12.34  D14  T:24.06  H:33.00  P:911.57  I:5.56  V:2.83
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11/10/2016 22:1:24  S1:3.74  S2:8.52  S3:12.34  D14  T:24.06  H:33.00  P:911.58  I:5.56  V:2.83
11/10/2016 22:1:25  S1:3.74  S2:8.52  S3:12.34  D14  T:24.06  H:33.00  P:911.56  I:5.56  V:2.83
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11/10/2016 22:1:44  S1:3.74  S2:8.52  S3:12.34  D14  T:24.06  H:33.00  P:911.55  I:5.56  V:2.83
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```

Figure 4. 2. Experimental test results of data logging

Wind data can be monitored on PC with written interface monitoring program in Visual Studio C# platform. The details of this program will be explained in the next chapter. In addition to these features, wind parameter may be sent to a remote microcontroller that can display data using a RF module. Taken data wirelessly from main unit can be displayed on 20x4 character LCD.

4.3 Arduino Mega 2560 Microcontroller Board

Arduino mega 2560 is a microcontroller card based on the Atmega2560 from Atmel family. This board includes everything needed to support the microcontroller. It can be programmed with the arduino software (IDE). It has some features to communicate with a computer or other board. The view of this board is illustrated below figure [34].

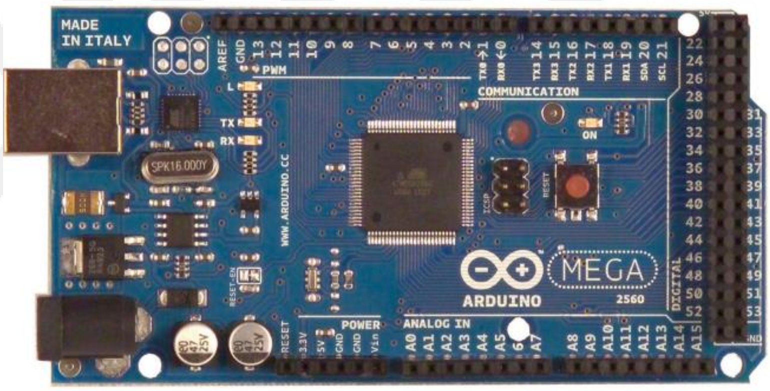

Figure 4. 3. Arduino mega 2560 microcontroller development board [34]

Table 4.1. Some specifications of mega 2560 microcontroller board

Operating Voltage	5V
Digital I/O Pins	54 (15 provide PWM output)
Analog Input Pins	16
Flash Memory	256 KB
SRAM	8 KB
Clock Speed	16 MHZ

4.4 Real Time Clock (RTC)

Real time clock module contains DS1302 integrated circuit to keep the current time. It can be used in widespread electronic applications. This chip includes 31 bytes of static RAM. It can communicate with a microcontroller via a simple interface. Three wires are necessary to intercommunicate with the chip enable (CE), input/output (I/O) and serial clock (SCLK). It also operates on very low power. It needs an external 32.768 kHz crystal. Operation circuit is shown below [35].

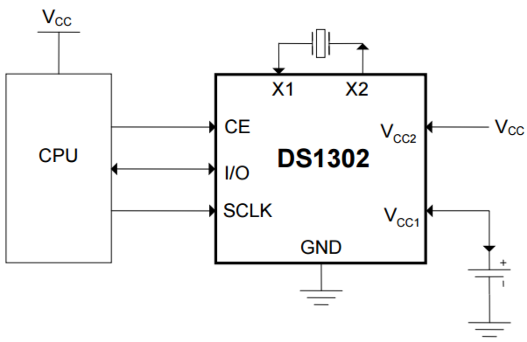

Figure 4. 4. Typical operation circuit for DS1302

4.5 SD Card

Secure Digital (SD) card is very useful component for reading/writing operations in microelectronic applications. It communicates with microcontroller unit via SPI protocol. Operating voltage value is +3.3V. Chip select pin of SD card can be abbreviated as CS. Connection diagram of SD module to microcontroller is drawn below [36].

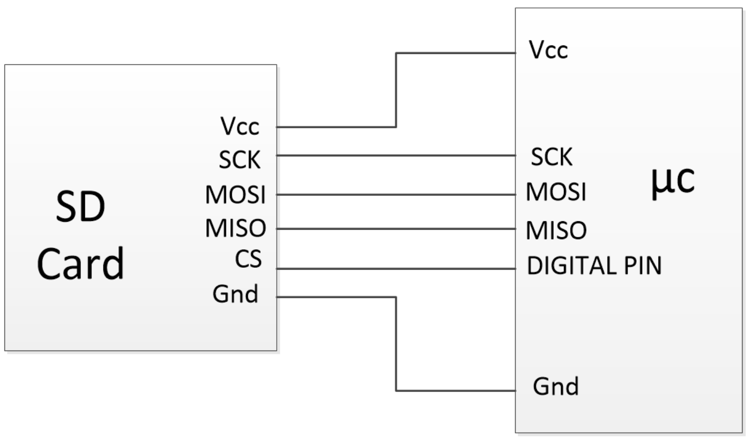

Figure 4. 5. Typical connection of SD module to unit

4.6 Liquid Crystal Display (LCD)

Liquid Crystal Display (LCD) is a device that can be different sizes. Typical examples of it are 16x2, 16x4 and 20x4. In this thesis, 20x4 LCD module has been used to display all measured data in character text format. This type of LCD is suitable to use with I2C protocol which is provided using I2C converter card.

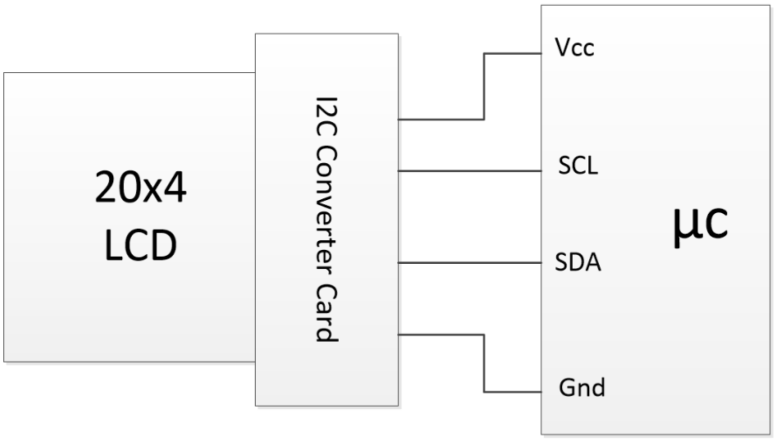

Figure 4. 6. Connection of LCD to unit via I2C converter card

4.7 Keypad

Keypads are frequently preferred as a primary input equipment in embedded system applications. They consist of a number of swithces. A 4x4 keypad is used in the designed unit and some keys are determined in order to help the user to manage functions of written program. Microcontroller scans the keys if any button is pressed or not. If any button is active or logic high, related sub-program is performed.

Table 4.2. Related keypad functions

Key	**Function**
A	Enter menu
1	Show real time
2	Display wind speed values
3	Display wind direction
4	Display temperature
5	Display humidity
6	Display pressure
7	Display current
8	Display voltage
B	Transmit data using RF module
C	Clear display

4.8 Radio Frequency (RF) Module

NRF24L01 rf module is manufactured by Nordic Semiconductor company. It is a single chip 2.4 GHz transreceiver and is designed for low power wireless studies. It is operated through SPI protocol. It has also a bidirectional communication feature. It needs +3.3V rating value to communicate with microcontroller. Any NRF24L01 module can be used as a transmitter or receiver. It can transmit data with antenna up to 1000 m distance [37].

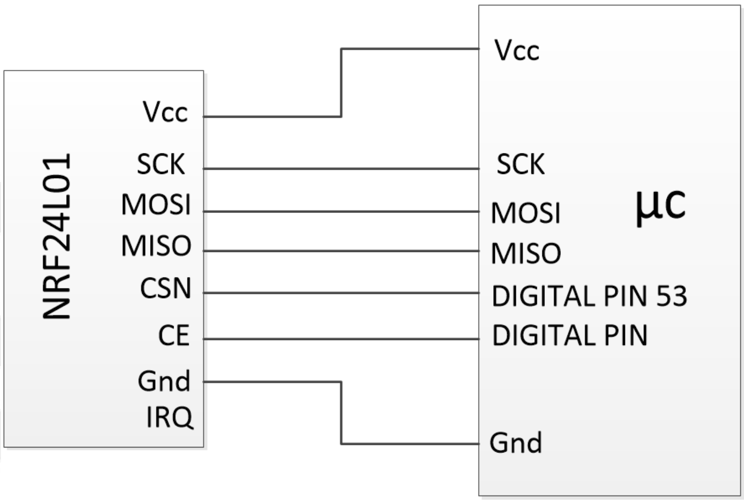

Figure 4. 7. Connection of NRF24L01 to unit

4.9 Interface Circuit

In this thesis an interface circuit can also be called as wind speed and direction measurement circuit. An interface circuit helps to read the sinusoidal wave signals coming from the anemometers before applying microcontroller unit. This processing is achived by converting the sine wave signal into a square wave signal with the help of developed zero crossing detector circuit. Designed interface circuit has also the ability to transmit analog wind direction information into ADC unit of microcontroller. The implemented circuit includes some components such as voltage regulators, capacitors for filtering, connectors, resistors, LM741 op-amp ICs and CD4093 schmitt trigger IC as shown below figures. Output of anemometers have a corresponding zero crossing detector.

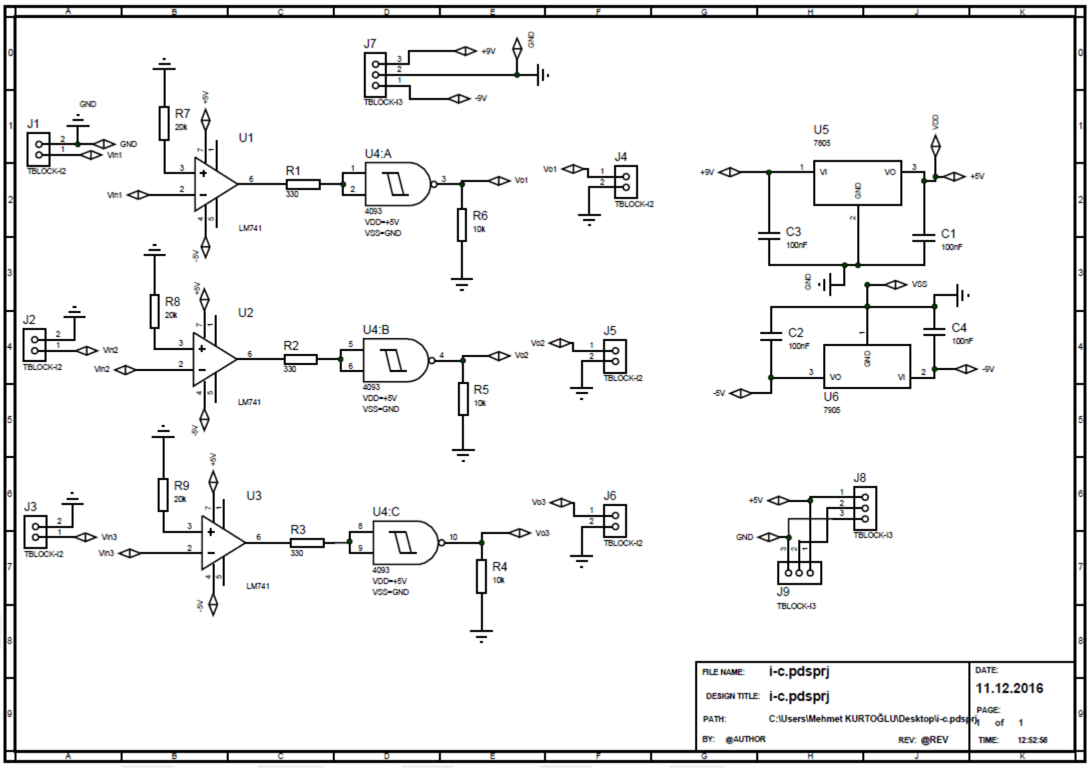

Figure 4. 8. Wind speed and direction measurement circuit

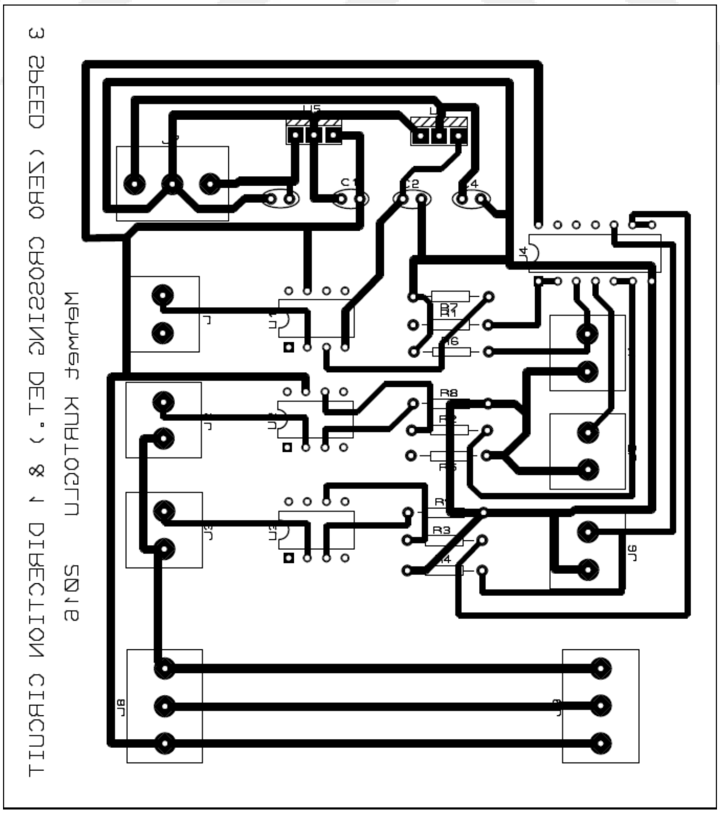

Figure 4. 9. Layout of interface circuit

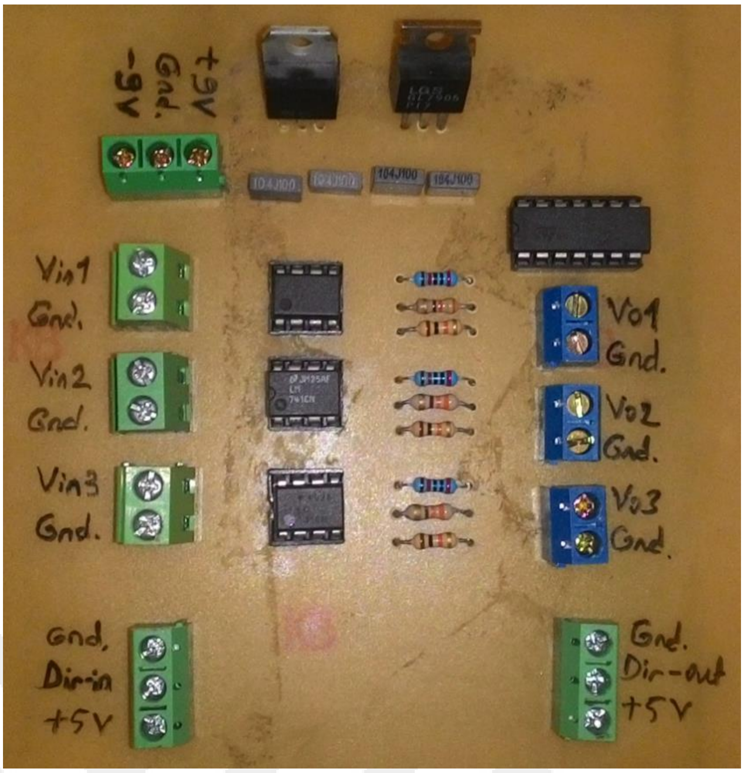

Figure 4. 10. An apperance of interface circuit

In this way, a square wave is obtained from a sine wave in each cycle as shown below.

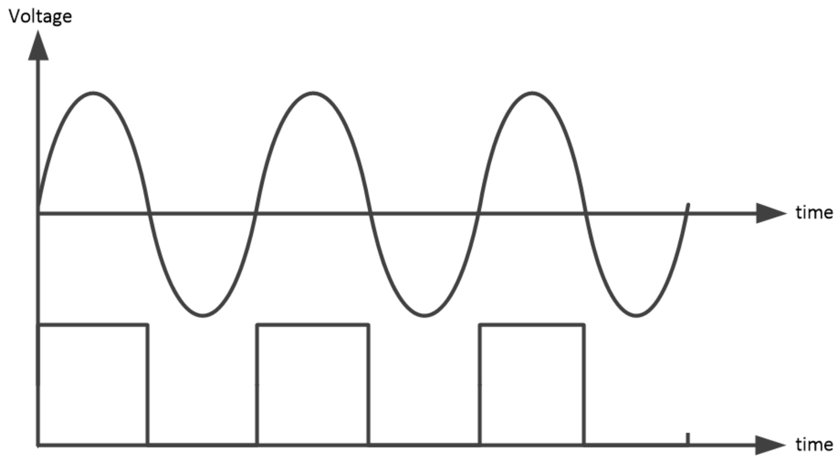

Figure 4. 11. Converting sine wave to square wave

Interrupt enabled pins in mega 2560 microcontroller can be used to determine the frequency value from obtained square wave. The power supply circuit provides constant voltages to all the related component in the interface circuit. The components have been selected to deliver clean voltages. The regulators (7805 and 7905) is have been chosen to produce +5V and -5V, respectively.

In order to ensure that the circuit operates safely, using an oscilloscope and a signal generator the circuit has been tested at different frequency values. Some measurement results are illustrated below figures. According to the test results, the circuit operates very efficiently to determine wind speed.

Firstly, the frequency and amplitude of the input signal is approximately **35.03 Hz** and **1.839 V**, respectively. Secondly, the frequency and amplitude of the input signal is **15.03 Hz** and **0.751 V**, respectively. Lastly, the frequency and amplitude of the input signal is **180.9 mHz** and **0.01 V**, respectively. In all these conditions, input sine waveform which is channel A, output square waveform which is channel B and oscilloscope screen are given below figures.

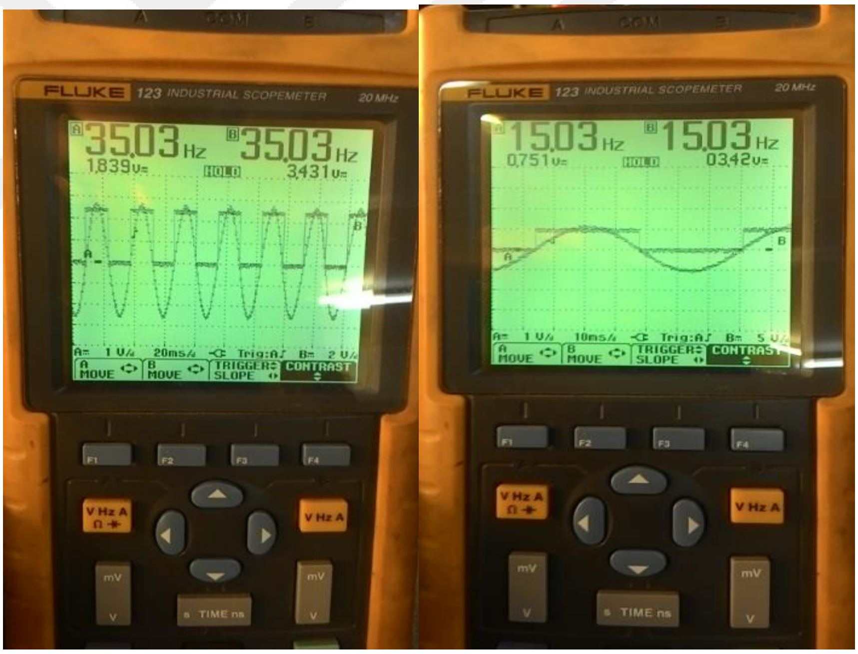

Figure 4. 12. The view of the zoomed oscilloscope screen with input signal and output signal with different frequency values

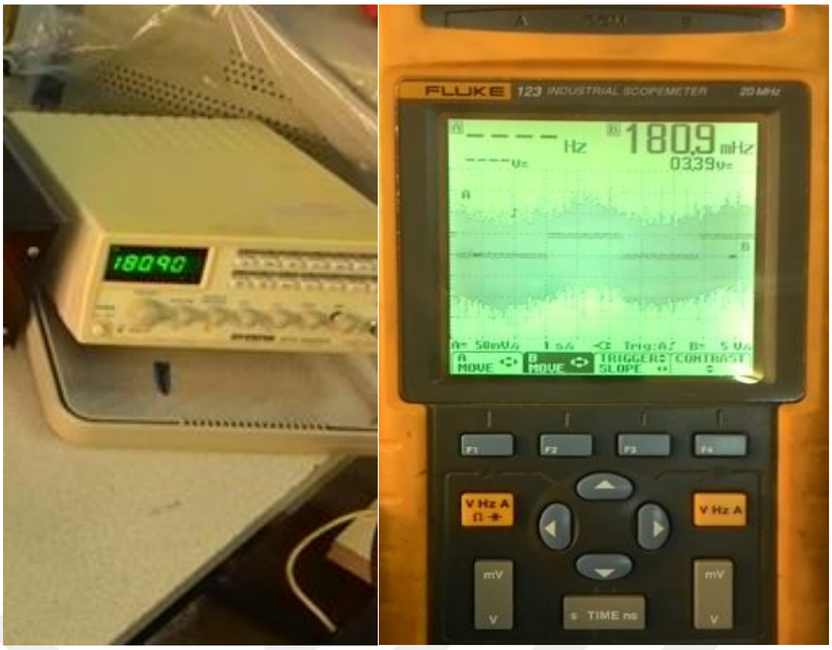

Figure 4. 13. The view of the zoomed oscilloscope screen with output signal with very low frequency value

4.10 Summary

In this chapter, the hardware of the prototype unit and its components have been explained in a detailed way. The functional schematic of the unit has been given clearly. This chapter also presents the development of an efficient zero crossing detector circuit. In order to measure the wind speed safely and accurately using microcontroller, interface circuit has been designed. The circuit has been investigated as simulation study and practical study. As a result of the investigation, the satisfactory results have been obtained. Thus, implemented circuit is useful in helping wind speed measurement application. In the next chapter, the software of the unit will be discussed.

CHAPTER 5

SOFTWARE OF THE UNIT

5.1 Introduction

The software section of the unit can be categorized into two parts. These are programming microcontroller that is developed in Arduino compiler and a PC program that is coded in Microsoft Visual Studio C# platform, respectively. Because writing all the codes will be too long, the algorithms of microcontroller and PC program are explained briefly. A brief information about SPI and I2C protocols are also described in this chapter.

5.2 Arduino Mega 2560 Microcontroller Program

Using arduino mega 2560 microcontroller compiler program, the required functions of the developed unit has been implemented. The compiler program is based on C programming language which is easy to use. After writing related library for sensors and definition of timer interrupt, variables, program scans if any key is pressed or not. In case of any pressed key, the related sub-program is called by fundamental program. All related sub-programs have been written and tested for each sensor separately. Following the tests, all the sub-programs have been combined in a single embedded software and run successfully.

In microcontroller software, there are four main functions given below;

a. Storing all measured wind data into a SD card in a second with real time using timer interrupt.
b. Monitoring all data on PC.
c. Showing all wind data with real time on LCD.
d. Sending data to a remote point with the help of a RF module.

The flowchart of the microcontroller program is shown with general parts.

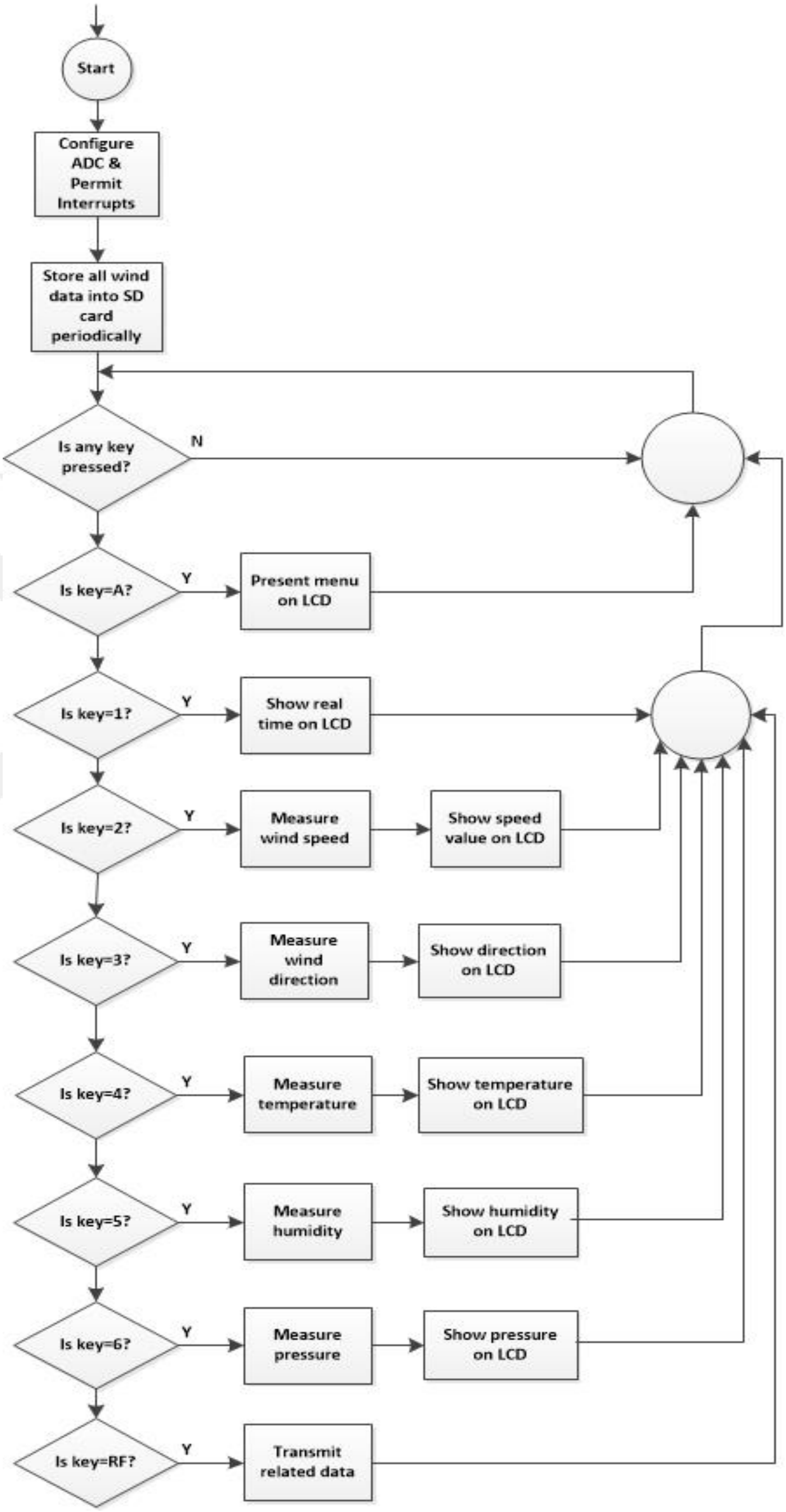

Figure 5. 1. Flowchart of microcontroller program

Microcontroller program reads all measured parameters and stores them into SD card in one second interval with real time information periodically with the help of timer interrupt.

5.3 Visual Basic C# Program

Visual Studio is an Integrated Development Environment (IDE) developed by Microsoft. It consists of windows form applications, web sites, web applications and web services and it is used to design console and graphical user interface applications. The general view of the compiler screenshot is shown below.

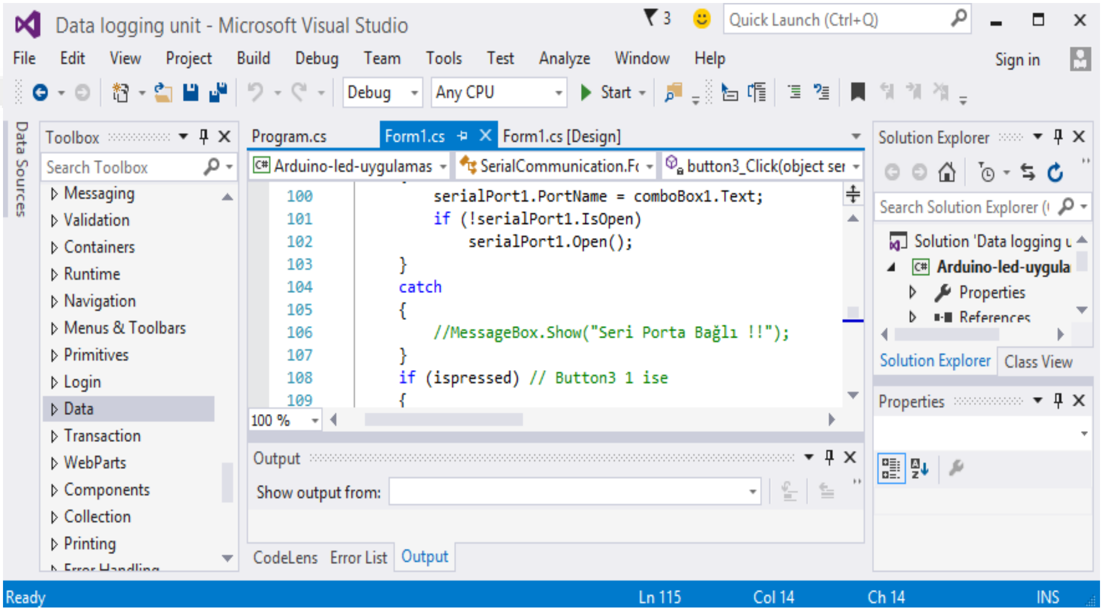

Figure 5. 2. Compiler screenshot of Visual Studio C# platform

Using Visual Studio C# platform, an interface program is developed to monitor wind parameters. Wind speed and direction and other wind parameters can be displayed separately via serial communication between microcontroller and computer through universal serial bus (USB). The screenshot of written interface monitoring program is illustrated below.

Figure 5. 3. Monitoring main screen

This written program has different forms that several tabbed pages. It also includes a dynamic page, serial port selector, operational bar that have buttons, combobox, progressbars, textboxes. After USB port is selected, serial communication starts and all measured data can be monitored. In case of a command is sent from PC to microcontroller, the related sub-procedure is operated. If a user wants to display any wind parameter, initially data acquisition must be stopped then related data can be taken. For instance, when wind speed value is displayed on the screen, stop data button must be firstly activated then other required parameter can be monitored. The some part of the written codes in C# platform is given following lines with their explanations.

```
using System;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.Drawing;
using System.Linq;
using System.Text;
using System.Threading.Tasks;
using System.Windows.Forms;
using System.IO.Ports;

namespace SerialCommunication
{
    public partial class Form1 : Form
    {
        bool LEDDurum = false;
        bool ispressed = true;
```

```
        // Determine baudrate for serial communication
         public Form1()
         {
             InitializeComponent();
             serialPort1.BaudRate = 115200;
         }

         // Activating button1
         private void button1_Click(object sender, EventArgs e)
         {

             try
             {
                 serialPort1.PortName = comboBox1.Text;
                 if (!serialPort1.IsOpen)
                     serialPort1.Open();
             }
             catch
             {
                 //MessageBox.Show("Connected to serial port!!!");
             }
             serialPort1.Write("1"); // Sending "1" value to Serial port
             textBox1.BackColor = Color.Green; // Coloring the Textbox
             button1.Enabled = false; // Deactivating button1
             button2.Enabled = true; // Activating button2
             LEDDurum = true; // Determining the state of the LED
             MessageBox.Show("Connected Successfully", "Information",
MessageBoxButtons.OK, MessageBoxIcon.Information);
         }

         private void Form1_Load(object sender, EventArgs e)
         {
             for (int i = 0; i <
System.IO.Ports.SerialPort.GetPortNames().Length; i++)
             {

comboBox1.Items.Add(System.IO.Ports.SerialPort.GetPortNames()[i]);
             }

         }

         // Serial port shutdown when form on C# closes
         private void Form1_FormClosing(object sender, FormClosingEventArgs
e)
         {
             if (serialPort1.IsOpen) serialPort1.Close();

         }

         // Using button2
         private void button2_Click(object sender, EventArgs e)
         {
             try
             {
                 serialPort1.PortName = comboBox1.Text;
                 if (!serialPort1.IsOpen)
                     serialPort1.Open();
             }
             catch
```

```
            {
                //MessageBox.Show("Connected to serial port!!!");
            }
            serialPort1.Write("0"); // Sending "0" value to Serial port
            textBox1.BackColor = Color.Red; // Coloring the Textbox
            button1.Enabled = true; // Activating button1
            button2.Enabled = false; // Deactivating button2
            LEDDurum = false; // Determining the state of the LED
        }

        private void textBox1_TextChanged(object sender, EventArgs e)
        {

        }

        // Using button3
        private void button3_Click(object sender, EventArgs e)
        {
            try
            {
                serialPort1.PortName = comboBox1.Text;
                if (!serialPort1.IsOpen)
                    serialPort1.Open();
            }
            catch
            {
                //MessageBox.Show("Connected to serial port!!!");
            }
            if (ispressed) // If Button3 is equal to 1
            {
                serialPort1.Write("1"); // Sending "1" value to Serial
port

                button3.BackColor = Color.ForestGreen; // Coloring the
button3

                ispressed = false; // Changing the state of Button3 as 0
            }
            else
            {
                serialPort1.Write("0"); // Sending "0" value to Serial
port

                button3.BackColor = Color.DarkRed; // Coloring the button3
                ispressed = true; // Changing the state of Button3 as 1
again

            }

        }

        private void timer1_Tick(object sender, EventArgs e)
        {
            try
            {

                serialPort1.Write("2");
                float receiveddata =
Convert.ToInt16(serialPort1.ReadExisting());
                // float değer gösterirken float n=0.53249586742 ise
Console.WriteLine(n.ToString("0.0000") bu şekilde format ayarlanabilir
```

```
                label1.Text = (receiveddata * 5 / 1023).ToString("0.00") +
"  V";
                textBox2.Text = receiveddata.ToString();
                progressBar1.Value = Convert.ToInt16(textBox2.Text);
                // progressBar1.Value = receiveddata;
                System.Threading.Thread.Sleep(100);
            }
            catch (Exception ex) { }
        }

        private void button4_Click(object sender, EventArgs e)
        {
            timer1.Start();

        }

        private void button5_Click(object sender, EventArgs e)
        {
            timer1.Stop();

        }

        private void timer2_Tick(object sender, EventArgs e)
        {
            try
            {

                serialPort1.Write("3");
                float receiveddata =
Convert.ToInt16(serialPort1.ReadExisting());
                label3.Text = (receiveddata * 5 / 1023).ToString("0.00") +
"  V";
                textBox3.Text = receiveddata.ToString();
                progressBar2.Value = Convert.ToInt16(textBox3.Text);
                // progressBar1.Value = receiveddata;
                System.Threading.Thread.Sleep(100);
            }
            catch (Exception ex) { }
        }

        private void button6_Click(object sender, EventArgs e)
        {
            timer2.Start();
        }

        private void button7_Click(object sender, EventArgs e)
        {
            timer2.Stop();
        }

    }
}
```

The flowchart of the written interface monitoring program is illustrated in a clear and understandable way.

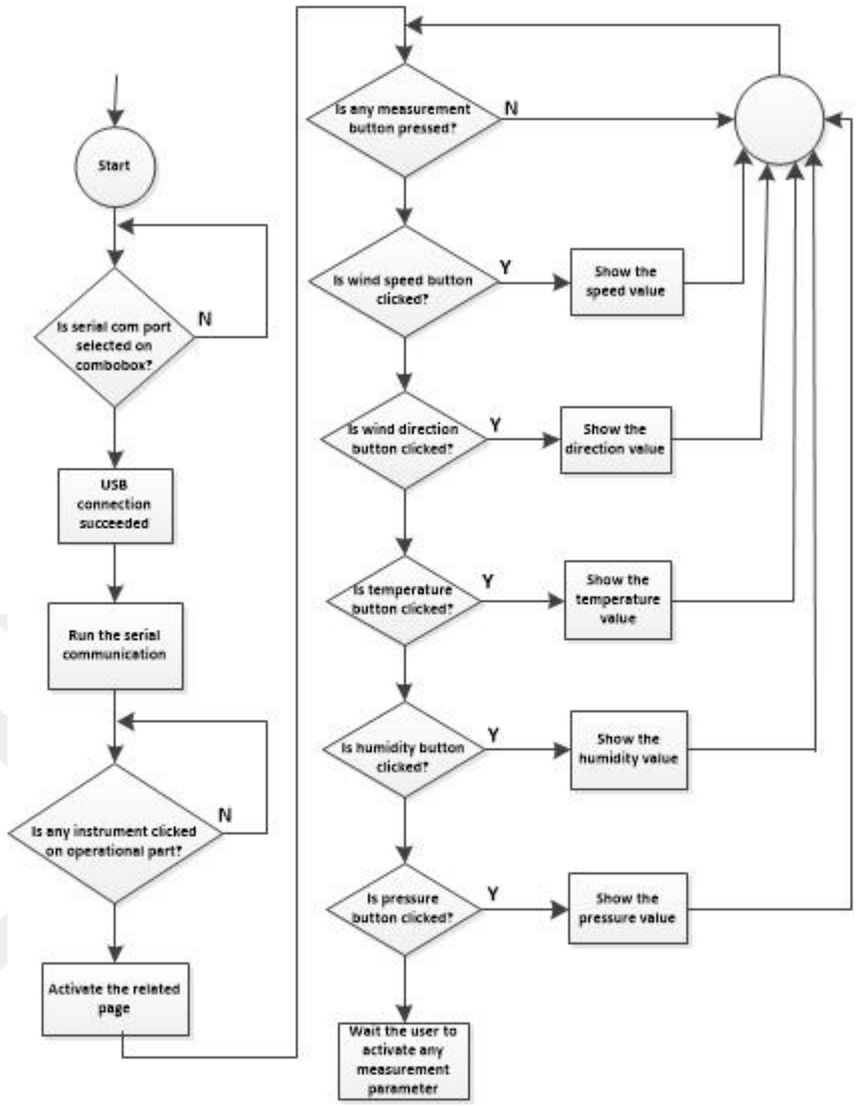

Figure 5. 4. Flowchart of PC program

5.4 I2C Protocol

I2C bus means that **I**nter **I**ntegrated **C**ircuit bus. It is known as a serial and synchronuos protocol. It consists of two wires called SDA and SCL, respectively. SDA is the serial data line and SCL is the serial clock line. All peripheral devices are connected to master device with these lines. There are also ground (0V) and power lines (+5V or +3.3V) with the data and serial lines. Connection of slave devices to the master device in I2C protocol is given in the Figure 5.5 [32].

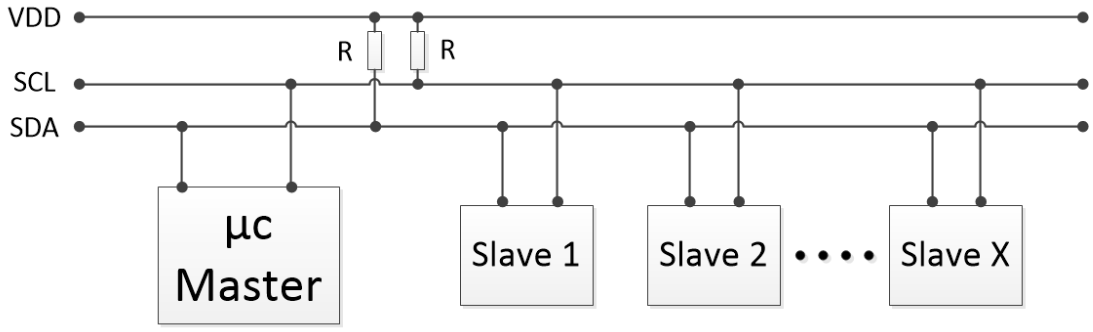

Figure 5. 5. Connection of peripherals in I2C bus

There are some benefits of I2C protocol. These are given below;

- Simple hardware structure.
- Simple protocol.
- Easy to use devices.
- Only two wires for printed circuit board (pcb).

5.5 SPI Protocol

SPI is an abbreviation for **S**erial **P**eripheral **I**nterface. This protocol is used in many applications in embeddeb systems. Typical example of it is SD cards. It is also known as four wires serial bus that are given following;

- SCLK: **S**erial **Cl**oc**k**
- MOSI: **M**aster **O**utput **S**lave **I**nput
- MISO: **M**aster **I**nput **S**lave **O**utput
- SS: **S**lave **S**elect

The SPI communication can be driven by a microcontroller with its SPI running. SPI pins of microcontroller is used for data transmission in microcontroller applications [33]. A brief overview of advantages of SPI protocol is given below;

- Higher throughput than I2C.
- Simple hardware interface.
- Offers bidirectional communication.
- Provides high speed.

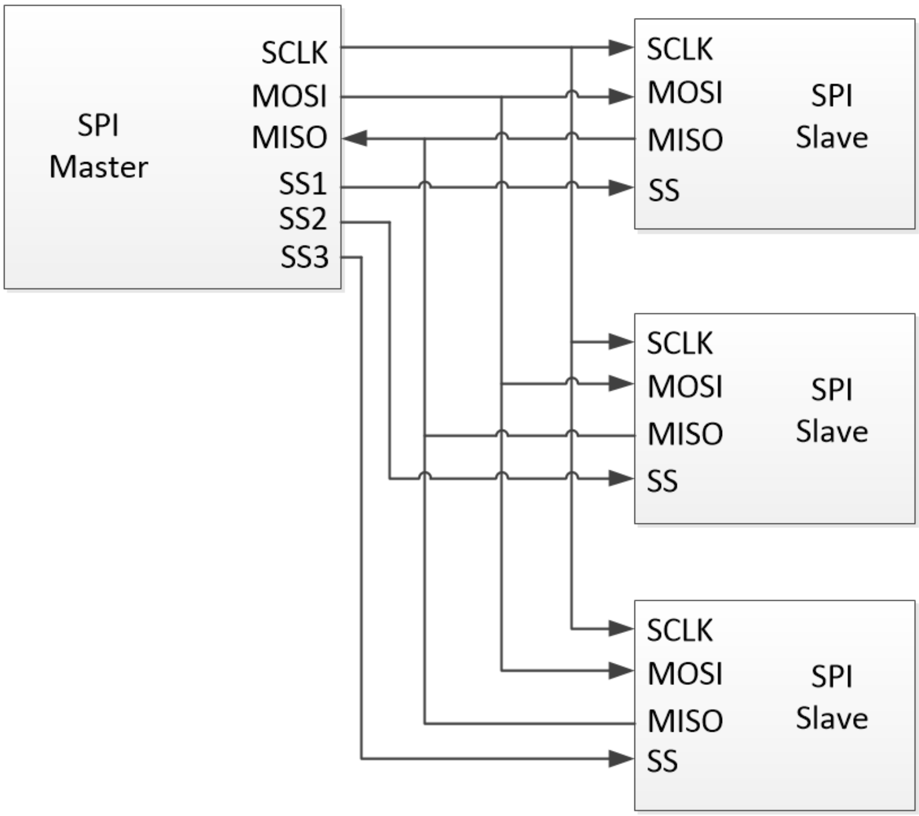

Figure 5. 6. Master and three independent slaves in SPI protocol

5.6 Summary

The microcontroller program of entire and receiver unit has been written using arduino compiler program based on C language. The coded program can read all wind parameters, stores all data into a SD card and transmits data to a remote receiver point. PC program written in Visual Studio C# platform in the main unit allows user to monitor all data.

CHAPTER 6

CONCLUSION

In order to investigate the wind power potential of a region, wind speed and direction information are primarily required. Temperature, humidity and pressure information are also necessary. In addition to these data, current and voltage information for a small scale wind turbine are necessary to analysis operating condition. In this thesis, mega 2560 microcontroller based data measurement, logging and telemetry unit has been designed and developed.

The developed prototype unit can be used to create a comprehensive database to determine wind power potential for any region. Moreover, instantaneous wind data can be followed on LCD with this unit for the related region. In order to calibrate an anemometer, a simple prototype wind tunnel has been designed and constructed. Performance evaluation for designed wind tunnel has been carried out by comparison way and according to the measurement results prototype wind tunnel can be used in calibration process in non-critical applications. Sensitive zero crossing detector circuit has been also designed, developed and tested to measure wind speed accurately. Very low wind speeds can be measured with the help of designed zero crossing detector. Additionally, with the help of written interface program in Microsoft Visual Studio C# platform, wind parameters can be monitored on P.C. The developed unit has a large memory to store wind data in real time for further use. Storage capacity can be enlarged by increasing SD card memory. Besides, wind data can be sent to a remote unit that can display coming data with the help of a RF module. Taken data wirelessly from main unit can be displayed on 20x4 character LCD. The unit allows up to 1000 m distance between base unit and remote unit. This distance can be extended with the help of a different RF module.

The main contribution of this thesis is to develop a data measurement and logging unit for estimating of a wind power potential of any site. The data collection unit can be installed to collect sensing data from different sensors. The implemented unit can be used to create very detailed data sets to determine wind power characteristic for any region. Moreover, instantaneous wind data can be monitored with the help of designed unit for the related region. In this thesis, developed unit can be used as measurement device and data logger at any region. The unit is reliable, low cost and easy to use. Price of developed unit is also lower than the market price. Different features can be added to the prototype unit by doing some studies on the software and hardware. Consequently, the developed prototype unit will be helpful in analyzing detailed wind power characteristic of any region.

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