

People's Democratic Republic of Algeria
Ministry of Higher Education and Scientific Research
University M'Hamed BOUGARA – Boumerdes



Institute of Electrical and Electronic Engineering
Department of Electronics

Final Year Project Report Presented in Partial Fulfilment of
the Requirements for the Degree of

MASTER

In Control

Option: Control Engineering

Title

**VIRTUAL MEASUREMENT SYSTEM
FOR ELECTRICAL MACHINES
USING LABVIEW**

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ABSTRACT

Virtual Measurement System for AC Machine Using LabVIEW is the project which makes use of LabVIEW to monitor and control operation of the electrical machine. In this project, the real-time variables of electrical machine are measured and given to LabVIEW through DAQ. LabVIEW allows us to program as per our requirements. We continuously observe the operating voltage and current of the motor and trip the circuit if the motor exceeds a safe value. A comparison has been made such that the voltage or current above safe value would generate a signal of 5V at a selected line on the DAQ. This 5V is drawn into the relay arrangement, which is used to energized itself and trip the contact, hence isolating the machine from the main supply. A Data Acquisition Card (DAQ) is used to perform the core of the control action by switching on the relay. The NI USB 6009 DAQ is selected for this project. In order to provide precise input voltages to the DAQ, such that change in each volt of voltage or amp of current is observable; In the studied case only voltages, currents (of the three-phase system), speed and torque are measured and recorded in real time, while power, reactive power, apparent power, total harmonic distortion...etc. are calculated according to the IEEE (Institute of Electrical and Electronic Engineering) STD 1495-2010.

A graphical user interface is created to allow an accurate measurement display and data recording using the TDMS function

Dedication

TO MY FAMILY AND LOVED ONES

AHMED

I would like to dedicate this work to all my family especially my mother, To the memory of my father, To my brothers and their wives, To my sisters, To my lovely nephews Islem, Roumaissa, Ouassim, Housseem, Aness.

I also dedicate this work to my many friends whom i spent five years of my life and shared unforgettable memories together. and who have supported me throughout the process. I will always appreciate all they have done.

Yassine

ACKNOWLEDGMENT

Bissmillah irrahmani Rahim

Alhamdulillah. Thanks to Allah SWT, whom with His willing gave us the opportunity to complete this Final Year Project titled Virtual Measurement System for AC Machine Using LabVIEW. This final year project report was prepared for the institute of electrical and electronic engineering, University of BOUMERDES.

Firstly, we would like to express our deepest thanks to our supervisor **Dr. OUADI Abd El Rahman** for taking time to read through this report and his positive criticism and advices for the project.

Our sincere thanks go to all lecturers and members of the staff of the institute of electrical and electronic engineering, IGEE, who helped us in many ways and made our education journey at IGEE pleasant and unforgettable. Many thanks go to M04 member group for their excellent cooperation, inspirations and supports during this study. This five year experience with all you guys will be remembered as important memory for us to face the new chapter of life as engineers.

Deepest thanks and appreciation to our parents, family for their cooperation, encouragement, constructive suggestion and full support for the completion of the project, from the beginning till the end. Also thanks to all of our friends and everyone contributed to this project directly or indirectly. we acknowledge their comments and suggestions, which were crucial for the successful completion of this work.

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INTRODUCTION

Taking measurements with instruments helps science and technology progress. Scientists and engineers use instruments to observe, control, and understand the physical universe, to perform research in life sciences and medicine; to design, test, and manufacture electronics; and to improve machine and process control in countless industries.

The simplest phenomena on electrical machines are related to their steady-state behavior. These can easily be studied with the use of common instruments like Vmeters, A-meters, oscilloscopes etc. However, when more complex phenomena need to be studied like transient behavior, notches and harmonic distortion, then more sophisticated equipment is required. Such instruments are multichannel oscilloscopes, measurement recorders etc, which are very expensive and many times prove to be inadequate.

Virtual instrumentation combines hardware and software with industry-standard computer technologies to create user-defined instrumentation solutions.

The real time electrical and mechanical variables of the electrical machine are measured using DAQ board and acquired using virtual instrument designed using LABVIEW software [1] [2].

The designed data acquisition program allows a continuous graphical observation of all inputs and outputs, and may include protective function and generates digital outputs to shut down the system in case of exceeding the safety conditions.

The aim of this project is to design a data acquisition measurement system based on LabVIEW for measuring the different electrical and mechanical parameters (voltage ,current,speed and torque) of a 3 phase squirrel cage induction motor.

The project is subdivided into two parts,the hardware part and the software part.

We are going to design and implement the different circuits to measure current,voltage,speed and torque.the hardware part is based on the cs 100-vp current sensor,step down transformer for volage measurement,photo-cell m18 sensor for measuring the speed and the SUP1 load cell torque sensor.all the previous parameters are measured and recorded in real time , while power, reactive power, apparent power,total harmonic distortion...etc are calculated according to the IEEE(Institute of Electrical and Electronic Engineering) std 1459-2010

Then we condition the sensors signals to adapt it to the requirements of the hardware acquisition system (DAQ) that we will interface with the labview to creat a benching system for measurement of different electrical and mechanical quatities associated with the three phase electrical machine.

CHAPTER 1 : INDUCTION MOTOR THEORY & MEASUREMENT

- 1.Introduction.
- 2.Three Phase System
3. Induction Motor
4. Components ad Methods for Measurement
5. Chapter Conclusion

Chapter I: INDUCTION MOTOR THEORY & MEASUREMENT

I-1 Introduction

The basic structure of three-phase system consists of voltage source connected to load via transformers and transmission lines. The basic circuit is shown in Figure 1.1

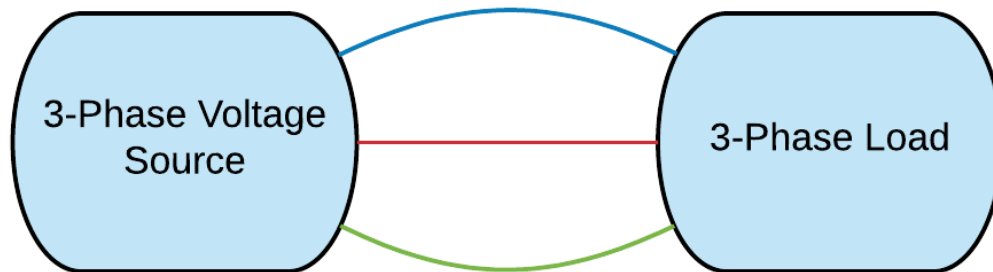


FIGURE 1.1 BASIC STRUCTURE OF 3 PHASE SYSTEM

I-2 Three Phase System

I-2.1 Balanced three-phase voltages

A set of three-phase voltages consists of three sinusoidal voltages that have identical amplitudes and frequency but are out of phase with each other by exactly 120° . In discussing three phase circuits, it is standard practise to refer to the three phases as a,b and c.the three voltages that compose the three-phase set are referred to as the a-phase voltage, b-phase voltage, c-phase voltage. [3]

Since the phase voltages are out of phase by exactly 120, there are two possible phase relationships that can exist between the the a-phase voltage, b-phase voltage, c-phase voltage.one possibility for the b-phase voltage to lag the a-phase voltage by 120, in which case the c-phase voltage must lead the a-phase voltage by 120° . This phase relationship is known as the abc,or positive phase sequence. The only other possibility is for the b-phase to lead the a-phase voltage by exactly 120, in which case the c-phase voltage must lag the a-phase voltage by 120. This phase relationship is known as the acb, or the negative phase sequence. in phasor notation, the two possible sets of balanced phase voltages are :

$$\begin{aligned} V_a &= V_m \angle 0^\circ \\ V_b &= V_m \angle -120^\circ && \text{balanced phase voltages(positive sequence)} && (1.1) \end{aligned}$$

$$\begin{aligned} V_c &= V_m \angle +120^\circ \\ V_a &= V_m \angle 0^\circ \\ V_b &= V_m \angle +120^\circ && \text{balanced phase voltages(negative sequence)} && (1.2) \end{aligned}$$

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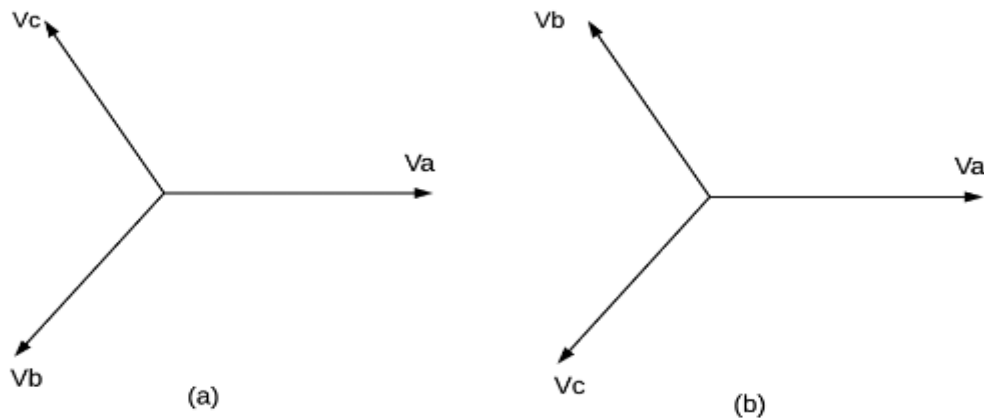


FIGURE 1.2 (A) POSITIVE (ABC) SEQUENCES, (B) NEGATIVE (ACB) SEQUENCE.

Another important characteristic of a set of balanced three phase voltages is that the sum of the voltages adds to zero, thus:

$$V_a + V_b + V_c = 0 \quad \text{sum of balanced voltages is zero [3]} \quad (1.3)$$

I-2.2 Three Phase Systems advantages :

1. The transmitted instantaneous power is constant:
 - the mechanical power at the generator is constant.
 - the mechanical shaft torque at the generator is constant.
2. We need only one neutral wire (which carries current only in the unbalanced case) less wires are necessary than three equivalent single-phase circuits which can reduce materials and installation costs.
3. Less wires results in less power losses.
4. 3-phase motors have better power factor and efficiency as compare to 1-phase motor.
5. 3-phase induction motor is self-started as the magnetic flux produced by 3-phase supply is rotating in nature with constant magnitude. [3]

I-2.3 Star or wye connection

The wye or star connection is made up by connecting each of the three-phase windings together in a star (Δ) or wye (Y) connected system, phase current and line current are the same where as the line voltage is higher than the phase voltage by a factor of $\sqrt{3}$

$$I_{line} = I_{phase} \quad (1.4)$$

$$V_{line} = \sqrt{3} \times V_{phase} \quad (1.5)$$

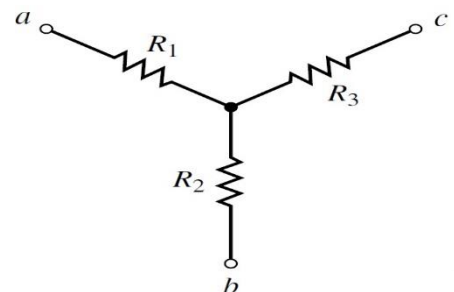


FIGURE 1.3 STAR (WYE) NETWORK

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I-2.4 Power in three phase system

Electrical power is the “rate” at which energy is being consumed in a circuit and as such all electrical and electronic components and devices have a limit to the amount of electrical power that they can safely handle.

The amount of power in a circuit at any instant of time is called the instantaneous power . [4]

The power triangle: is the representation of a right angle triangle showing the relation between active (real) power, reactive power and apparent power. When each component of the current that is the active component ($I\cos\phi$) or the reactive component ($I\sin\phi$) is multiplied by the voltage V , a power triangle is obtained shown in the Figure 1.4 [4]

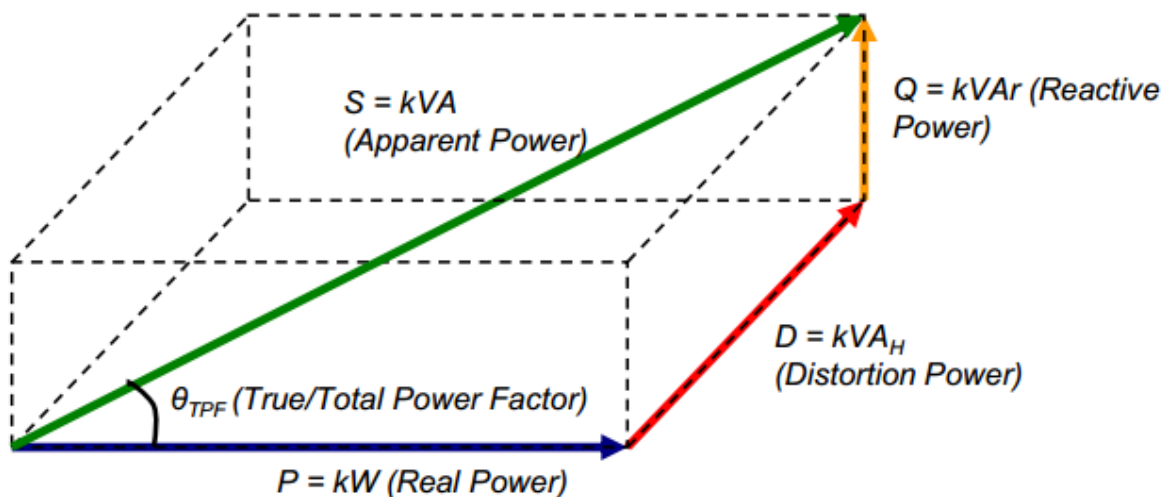


FIGURE 1.4 POWER TRIANGLE

The power which is actually consumed or utilized in an AC Circuit is called True power or **Active Power** or real power. It is measured in kilowatt (kW) or (MW). The power which flows back and forth that means it moves in both the direction in the circuit or react upon it, is called **Reactive Power**. The reactive power is measured in kilovolt-ampere reactive (kVAR) or (MVAR). The product of root mean square (RMS) value of voltage and current is known as **Apparent Power** this power is measured in (KVA) or (MVA). [4]

From the power triangle shown above the power, the factor may be determined by taking the ratio of true power to the apparent power

$$\text{Power factor } \cos\phi = \frac{\text{Active power}}{\text{Apparent power}} = \frac{KW}{KVA} \quad (1.06)$$

In the case of single phase, the active power is given by [5]

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$$P = V I \cos \phi \quad (1.07)$$

In the case of three phase, obviously this must apply for each of the three phases. Thus

$$P = 3 V_p I_p \cos \phi \quad (1.08)$$

For a balanced **star** connected load with line voltage V_L and line current I_L [5]

$$V_{\text{star}} = V_L / \sqrt{3}, \quad I_{\text{star}} = I_L \quad (1.09)$$

$$S_{\text{star}} = 3 V_{\text{star}} I_{\text{star}} = \sqrt{3} V_L I_L \quad (1.10)$$

$$P_{\text{star}} = \sqrt{3} V_L I_L \cos \phi \quad (1.11)$$

$$Q = \sqrt{3} V_L I_L \sin \phi \quad (1.12)$$

And for any three phase system [3] :

$$\text{Apparent Power : } \sqrt{3} V_L I_L \quad (1.13)$$

$$\text{Active Power : } \sqrt{3} V_L I_L \cos \phi \quad (1.14)$$

$$\text{Reactive Power : } \sqrt{3} V_L I_L \sin \phi \quad (1.15)$$

I-3 Induction Motor

I-3.1 what in an induction motor ?

An electrical motor is an electromechanical device which converts electrical energy into a mechanical energy. In case of three phase AC operation, most widely used motor is **Three phase induction motor** as this type of motor does not require any starting device or we can say they are self starting induction motor. This Motor consists of two major parts:

- **Stator:** Stator of three phase induction motor is made up of numbers of slots to construct a 3 phase winding circuit which is connected to 3 phase AC source. The three phase winding are arranged in such a manner in the slots that they produce a rotating magnetic field after 3Ph AC supply is given to them.
- **Rotor:** Rotor of three phase induction motor consists of cylindrical laminated core with parallel slots that can carry conductors. Conductors are heavy copper or aluminum bars which fits in each slots & they are short circuited by the end rings. The slots are not exactly made parallel to the axis of the shaft but are slotted a little skewed because this arrangement reduces magnetic humming noise & can avoid stalling of motor.

I-3.2 Working principle of Induction Motor

Induction motors are frequently used in both industrial and domestic applications. Within the induction motor, an electrical current in the rotor is induced by a varying magnetic field in the

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stator winding. The rotor current produces its own magnetic field, which then interacts with the stator field to produce torque and rotation. It works on the principle of transformer. So it is also called the rotating transformer. That is, when an EMF is supplied to its stator, then as a result of electromagnetic induction, a voltage is induced in its rotor. So an induction motor is said to be a transformer with rotating secondary. Here, primary of transformer resembles stator winding of an induction motor and secondary resembles rotor [6].

I-3.3 Induction Motor Equivalent Circuit

We can utilise the equivalent circuit of a transformer to model an induction motor.

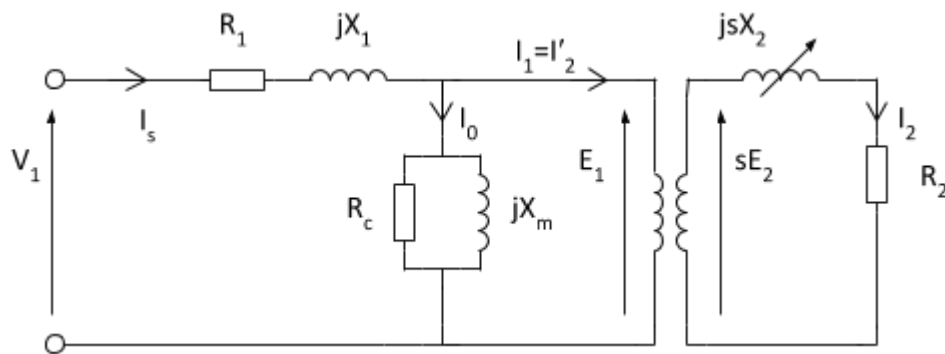


FIGURE 1.5 INDUCTION MOTOR EQUIVALENT CIRCUIT

In the equivalent circuit R_1 represents, the resistance of the stator winding and X_1 the stator leakage reactance (flux that does not link with the air gap and rotor). Magnetising reactance required to cross the air gap is represented by X_m and core losses (hysteresis and eddy current) by R_c .

An ideal transformer of N_1 and N_2 turns respectively represents the air gap. For the rotor side, the induced emf is affected by the slip (as the rotor gains speed, slip reduces and less emf is induced). The rotor resistance and reactance are represented by R_2 and X_2 ; with X_2 being dependant on the frequency of the inductor rotor emfs.

f - frequency (stator circuit), Hz

f_r - frequency (rotor circuit), Hz

I_1, I_s - stator current, A

I_2 - rotor current, A

n_r - rotor speed, rev.s^{-1} or rpm

n_s - synchronous speed, rev.s^{-1} or rpm

R_1 - rotor circuit resistance, Ω

R_2 - stator circuit resistance, Ω

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s - slip

X_1 - stator leakage reactance, Ω

X_2 - rotor circuit reactance, Ω

X_m - magnetising reactance, Ω

I-3.4 Induction Motor Power Flow

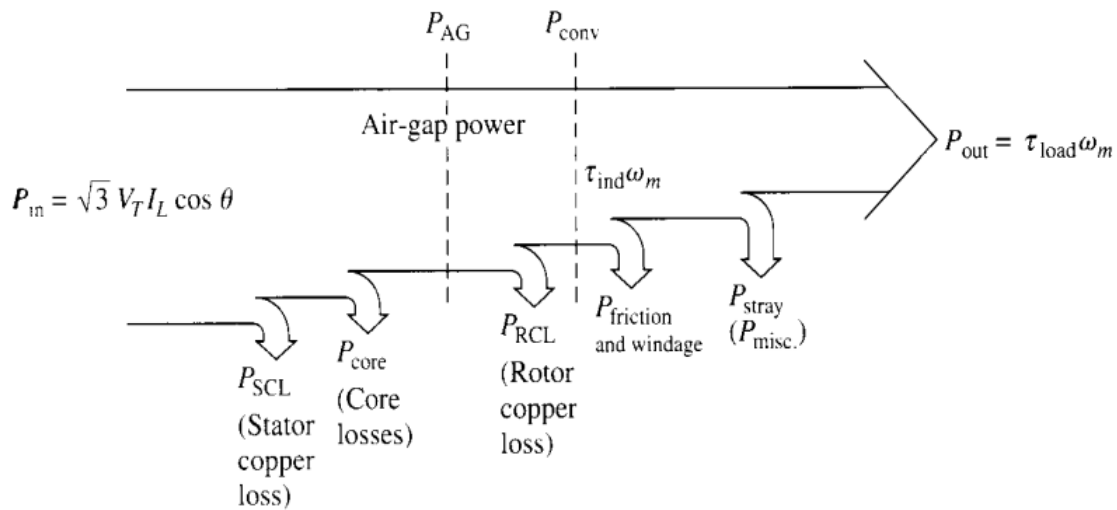


FIGURE I.6 INDUCTION MOTOR POWER FLOW

I-4 Components and Methods for Measurement

I-4.1 introduction

Current measurement components and methods must provide an accurate output signal as well as preventing damage to the associated printed circuit board.

Current sensing is used to perform two essential circuit functions. First, it is used to measure “how much” current is flowing in a circuit, which may be used to make decisions about turning off peripheral loads to conserve power or to return operation to normal limits. A second function is to determine when it is a “too much” or a fault condition. If current exceeds safe limits, a software or hardware interlock condition is met and provides a signal to turn off the application, perhaps a motor in a stalled condition or short circuit. It is essential to choose the appropriate technology with the necessary robustness to properly withstand the extreme conditions that can exist during a fault. [7]

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I-4.2 Current Measurement Methods

A signal to indicate the “how much” condition and the “too much” condition is available in a variety of measurement methods:

1-Resistive (Direct) : a. Current Sense Resistors

2-Magnetic (Indirect): a. Current Transformer b. Hall Effect Device

Each method has advantages for current measurement, but also comes with tradeoffs that can be critical to the end reliability of the application. They can also be classified into two main categories of measurement methods; direct or indirect. The direct method means that it is connected directly in the circuit being measured and that the measurement components are exposed to the line voltage, whereas the indirect method provides isolation that may be necessary for design safety.

I-4.2.1 Current Sense Resistor

The resistor is a direct method of current measurement that has the benefit of simplicity and linearity. The current sense resistor is placed in line with the current being measured and the resultant current flow causes a small amount of power to be converted into heat. This power conversion is what provides the voltage signal

I-4.2.2 Current Transformer

A current transformer’s three key advantages are that it provides isolation from the line voltage, provides lossless current measurement, and the signal voltage can be large providing a measure of noise immunity. This indirect current measurement method requires a changing current, such as an AC, transient current, or switched DC; to provide a changing magnetic field that is magnetically coupled into the secondary windings (Figure 1.7). The secondary measurement voltage can be scaled according to the turns ratio between the primary and secondary windings. This measurement method is considered “lossless” because the circuit current passes through the copper windings with very little resistive losses. However, a small amount of power is lost due to transformer losses from the burden resistor, core losses, and primary and secondary DC resistance. [7]

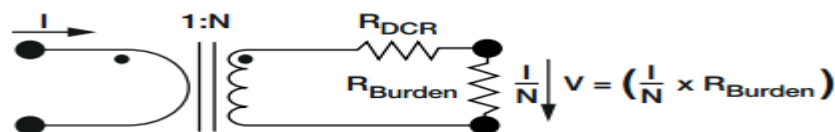


FIGURE 1.7 IDEAL CURRENT TRANSFORMER CIRCUIT

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I-4.2.3 Hall Effect

When a current carrying conductor is placed in a magnetic field, as shown in Figure 1.8, a difference in potential occurs perpendicular to the magnetic field and the direction of current flow. This potential is proportional to the magnitude of the current flow. When there is no magnetic field and current flow exists, then there is no difference in potential. However, when a magnetic field and current flow exists the charges interact with the magnetic field, causing the current distribution to change, which creates the Hall voltage. [7]

The advantage of Hall effect devices is that they are capable of measuring large currents with low power dissipation.

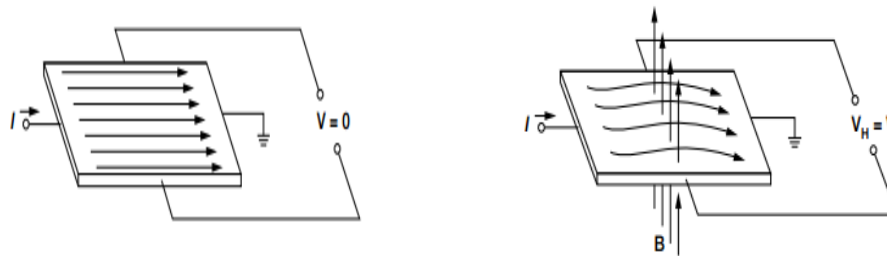


FIGURE 1.8 HALL EFFECT PRINCIPLE (A) NO MAGNETIC FIELD (B) MAGNETIC FIELD PRESENT

I-4.3 Voltage Measurement Methods

Voltage is sometimes called ‘potential difference’, and corresponds to the ‘potential’ or ability for electrons to flow around a circuit. So measuring voltage always requires direct connections to the two terminals we are trying to measure.

- Capacitive Voltage Measurement

Capacitive voltage sensors are mainly utilized in low frequency electric measurements. The voltage to be measured can be reduced by means of capacitive dividers as shown in figure 1-9: [8]

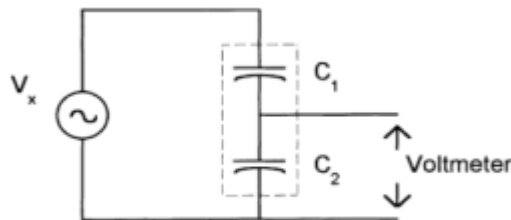


FIGURE 1.9 SCHEMATIC ARRANGEMENT OF A CAPACITIVE DIVIDER

I-4.4 Force and Torque Measurement

Force is the product of mass times acceleration, where mass describes the quantity of mater that a body contains, according to newton’s second law of motion :

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$$\text{Force} = \text{mass} \times \text{acceleration} \quad (1.15)$$

The standard unit of force is newton .

Forces can be applied in either a horizontal or vertical direction. a force applied in a downward, vertical direction gives rise to the term weight, which is defined as the downward force exerted by a mass subject to gravitational force :

$$\text{Weight} = \text{mass} \times \text{acceleration due to gravity} \quad (1.16)$$

The torque can be regarded as a rotational force. when applied to a body, torque causes the body to rotate about its axis of rotation. [9]

I-4.4.1 Force and Torque Measuring Devices

An analytical or lever balance is a device that is simple and accurate, and operates on the principle of torque comparison. When in balance, the torque on one side of the fulcrum is equal to the torque on the other side of the fulcrum, from which we get:

$$W_1 \times L = W_2 \times R \quad (1.17)$$

where W_1 is a weight at a distance L from the fulcrum, and W_2 the counterbalancing weight at a distance R from the fulcrum.

I-4.4.2 Strain Gauge Sensors

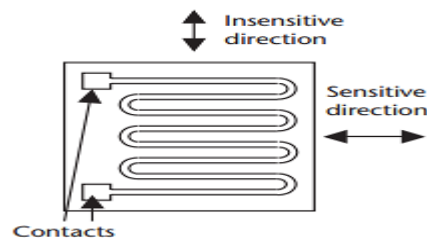


FIGURE 1.10 STRAIN GAUGE

Strain gauges are resistive sensors, which can be deposited resistors or piezoelectric resistors (Figure 1.10). The resistive conducting path in the deposited gauge is copper or nickel particles deposited onto a flexible substrate in a serpentine form. If the substrate is bent in a concave shape along the axis perpendicular to the direction of the deposited resistor, or if the substrate is compressed in the direction of the resistor, then the particles themselves are forced together and the resistance decreases. If the substrate is bent in a convex shape along this axis, or if the substrate is under tension in the direction of the resistor, then the particles tend to separate and the resistance increases.

Elements are normally configured as a Wheatstone Bridge and integrated with the conditioning electronics. The resistance change in a strain gauge element is

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proportional to the degree of bending, compression, or tension. The resistance change in strain gauges is small and requires the use of a bridge circuit for measurement, as shown in Figure 1.11. The strain gauge elements are mounted in two arms of the bridge, and two resistors, R_1 and R_2 , form the other two arms. The output signal from the bridge is amplified and impedance matched. [10]

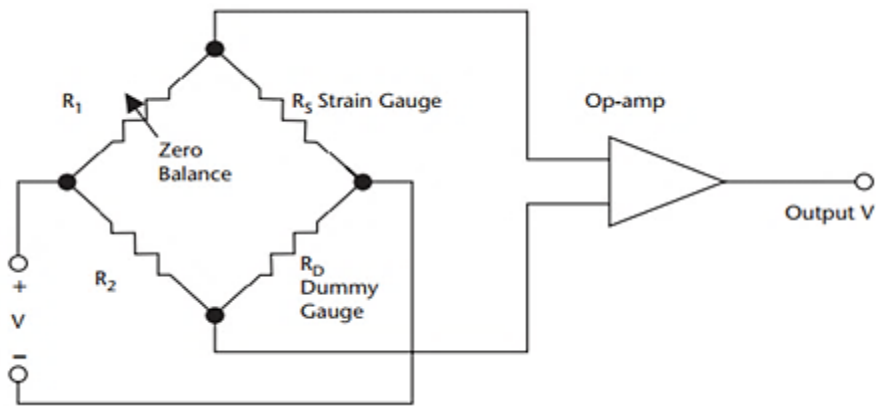


FIGURE 1.11 CONFIGURATION FOR STRAIN GAUGE ELEMENTS

I-4.5 Speed Measurement

This section discusses field devices and methods for measuring the rotational speed of a shaft in revolutions per minute (RPM). RPM measurement is important when controlling or monitoring the speed of motors, conveyors, turbines, and so on.

- **Sensors for RPM Measurement**

A sensor is necessary to sense shaft speed. Typical devices used for this purpose are shaft encoders (rotary pulse generators), proximity sensors, and photoelectric sensors. Each of these devices sends speed data in the form of pulses. Two factors affect the quality of this data:

- Number of pulses per revolution of the shaft (referred to as PPR). Higher PPR values result in better resolution.
- Symmetry of pulses. The symmetry of one pulse to the next can play a role in how consistent the RPM readings are. Symmetrical pulses give more accurate data.

speed measurement methods:

- **Encoders**

Shaft encoders are the best solution for the sensing device. They offer high resolution (typically 1 to 5000 PPR) and clearly defined, symmetrical pulses. However, sometimes it is not feasible to mount an encoder to the shaft being monitored. [11]

- **Proximity Sensors**

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Proximity sensors provide medium- or low-resolution sensing, depending on the number of pulses measured per revolution. The best method of using a proximity sensor is to sense the teeth on a gear. This type of sensing typically has options for 60, 120, or 240 PPR, and the pulses are relatively clearly defined and symmetrical. If a gear is not available, a proximity sensor can be used to sense the head of a bolt attached to the shaft. The drawback of this method is the low PPR (low resolution). If more than one bolt head is used, resolution improves, but pulses are often inconsistent and not symmetrical. [11]

➤ **Photoelectric Sensors**

Photoelectric sensors usually provide low resolution, due to the low number of pulses measured per revolution. A photoelectric sensor must sense a reflective target on the shaft. If more than one target is used to increase the PPR, then the symmetry from one pulse to the next is likely to be poor.

I-5 Conclusion

In this chapter, we have described the equations that govern the behavior of the three-phase electrical lines and stated the overall advantages of usage, we also described the electrical machines components, working principles and power consumption , we stated as well the most known methods of measurement.

CHAPTER 2 HARDWARE IMPLEMENTATION

1. Introduction
2. Voltages Measurement -Simulation and Design
3. Currents Measurement -Simulation & Design-
4. Torque Measurement
5. Speed & Frequency Measurement
6. Chapter Conclusion

Chapter II: HARDWARE IMPLEMENTATION

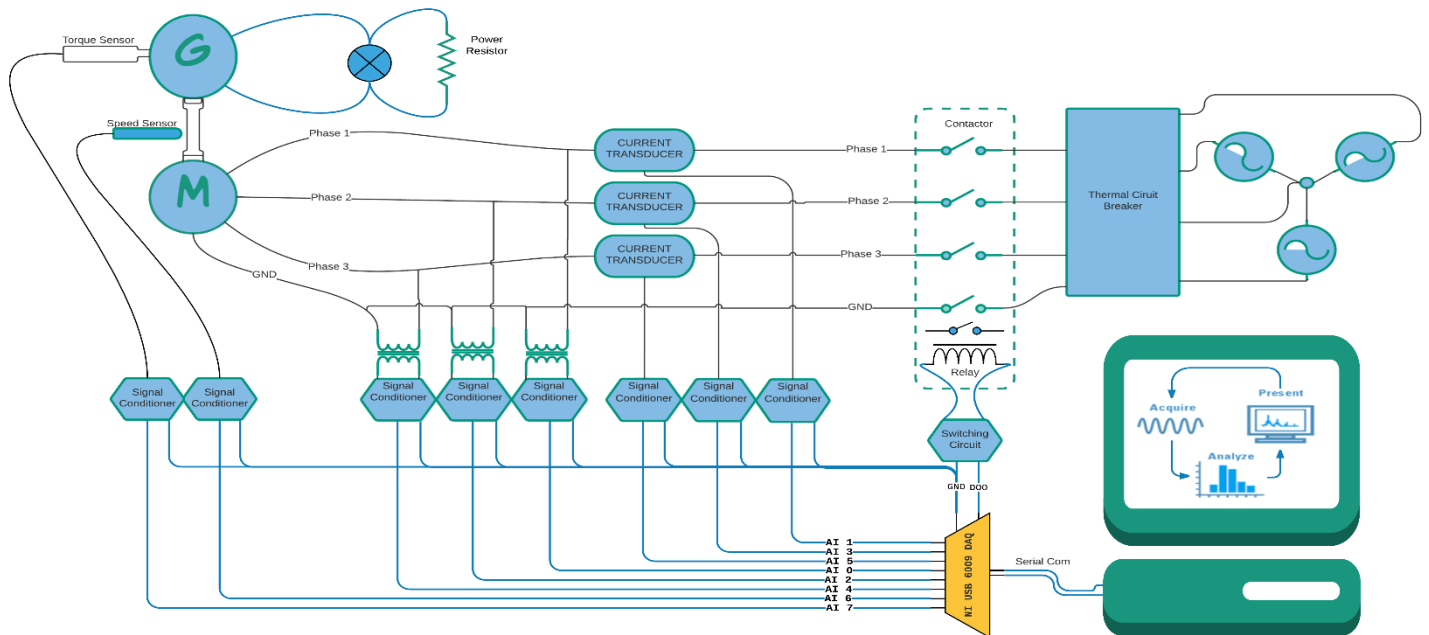


FIGURE 2.1 SYSTEM OVERVIEW

II-1 Introduction

Accurate measurement is obviously beneficial, but higher accuracy comes with a higher cost and there are also some fundamental limits and hardware limitations to how accurate we can measure. A sensor is a device that detects and responds to some type of input from the physical environment. The specific input could be light, heat, motion, moisture, pressure, or any one of a great number of other environmental phenomena. The output is generally a signal that is converted to human-readable display at the sensor location or transmitted electronically over a network for reading or further processing.

II-2 Voltage Measurements -Simulation and Design-

II-2.1 Voltage Signals

Voltage is the energy per unit charge flowing through a conductor. The following equation describes the voltage associated with an alternating current.

$$v(t) = V_0 \sin(2\pi ft + \phi) \quad (2.1)$$

where V_0 is the peak voltage, or the maximum amplitude of the voltage waveform

ϕ is the initial phase

t is the time

Chapter II: HARDWARE IMPLEMENTATION

II-2.2 Step Down Transformer

In measuring the 3 phase voltages we used a 240V/24V (rms) step down transformer which is one whose secondary voltage is less than its primary voltage. It is designed to reduce the voltage from the primary winding to the secondary winding. This kind of transformer “steps down” the voltage applied to it.

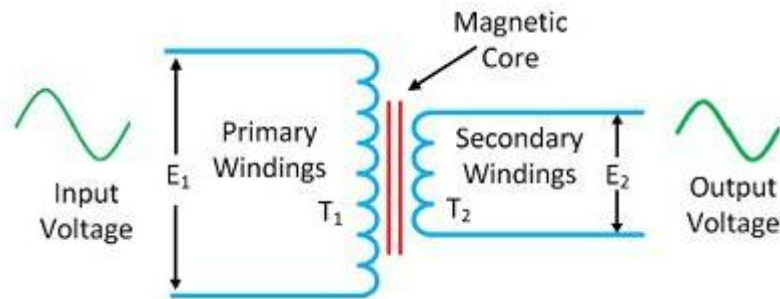


FIGURE 2.2 STEP DOWN TRANSFORMER

E_1 - is the Primary Voltage

E_2 - is the Secondary Voltage

T_1 - is the Number of Primary Windings

T_2 - is the Number of Secondary Windings

The turn ratio of the transformer use dis given by :

$$\text{Turn ratio} = n = \frac{N_1}{N_2} = \frac{E_1}{E_2} = \frac{230}{24} \quad (2.2)$$

II-2.3 Signal conditioning circuit

As the data acquisition board has a range up to 10 v peak input voltage.the 24 v from the secondary of the transformer needs to be mapped to satisfy the requirement for the input voltage to the daq.

For this purpose we used a simple voltage divider circuit

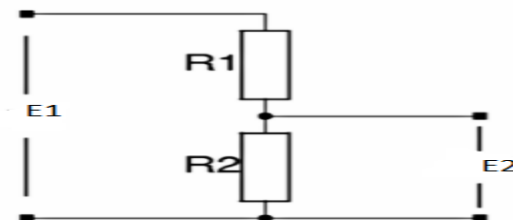


FIGURE 2.3 VOLTAGE DIVIDER CIRCUIT

The equation to obtain the voltage across the resistor 2 is as follows

$$E_2 = \frac{E_1 \times R_2}{R_1 + R_2} \quad (2.3)$$

Chapter II: HARDWARE IMPLEMENTATION

where $R_1 = 30 \text{ k}\Omega$ $R_2 = 10 \text{ k}\Omega$ which produces a gain of $\frac{R_1}{R_1+R_2} = 0.25$

II-2.4 Low Pass Filter (Butterworth Second Order) Design

By definition, a low pass filter passes lower frequencies up to the cut-off frequency and attenuates the higher frequencies that are above the cut-off frequency

- Anti-Aliasing Filter Theory

A/D Converters are usually operated with a constant sampling frequency when digitizing analog signals. By using a sampling frequency (f_s), typically called the Nyquist rate, all input signals with frequencies below $f_s/2$ are reliably digitized. If there is a portion of the input signal that resides in the frequency domain above $f_s/2$, that portion will fold back into the bandwidth of interest with the amplitude preserved. The phenomena makes it impossible to discern the difference between a signal from the lower frequencies (below $f_s/2$) and higher frequencies (above $f_s/2$). [12]

This frequency folding phenomena can be eliminated or significantly reduced by using an analog low pass filter prior to the A/D Converter input. This concept is illustrated in Figure 7. In this diagram, the low pass filter attenuates the second portion of the input signal at frequency (2). Consequently, this signal will not be aliased into the final sampled output. There are two regions of the analog low pass filter illustrated in Figure 7. The region to the left is within the bandwidth of DC to $f_s/2$. The second region, which is shaded, illustrates the transition band of the filter. Since this region is greater than $f_s/2$, signals within this frequency band will be aliased into the output of the sampling system. The affects of this error can be minimized by moving the corner frequency of the filter lower than $f_s/2$ or increasing the order of the filter

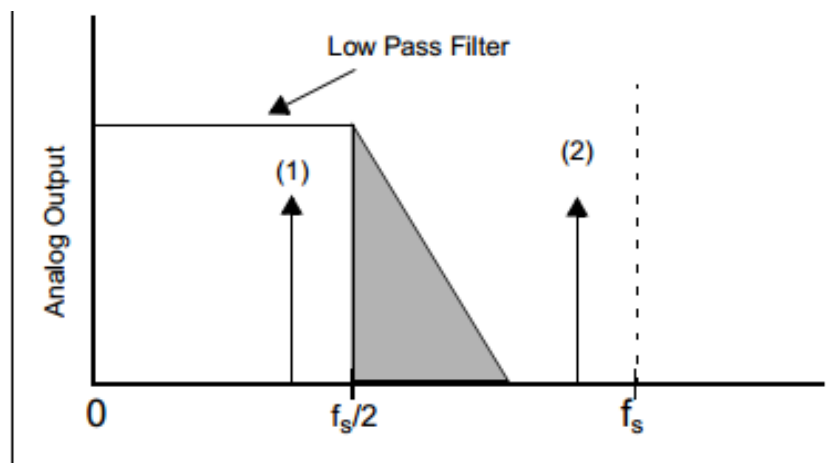


FIGURE 2.4 FREQUENCY RESPONSE OF LOW PASS FILTER

Chapter II: HARDWARE IMPLEMENTATION

By using Texas instruments FilterPro software we generated a 2KHZ cutoff frequency second order low pass sallen-key butterworth filter as in the following figure:

Where: $R_1=2.70K$; $R_2=33.0K$; $C_1=3.30nF$; $C_2=22nF$

final voltage measurement circuit in figure 2.6

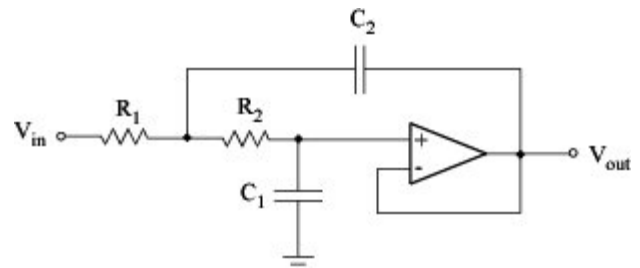


FIGURE 2.5 SALLEN-KEY LOW PASS FILTER

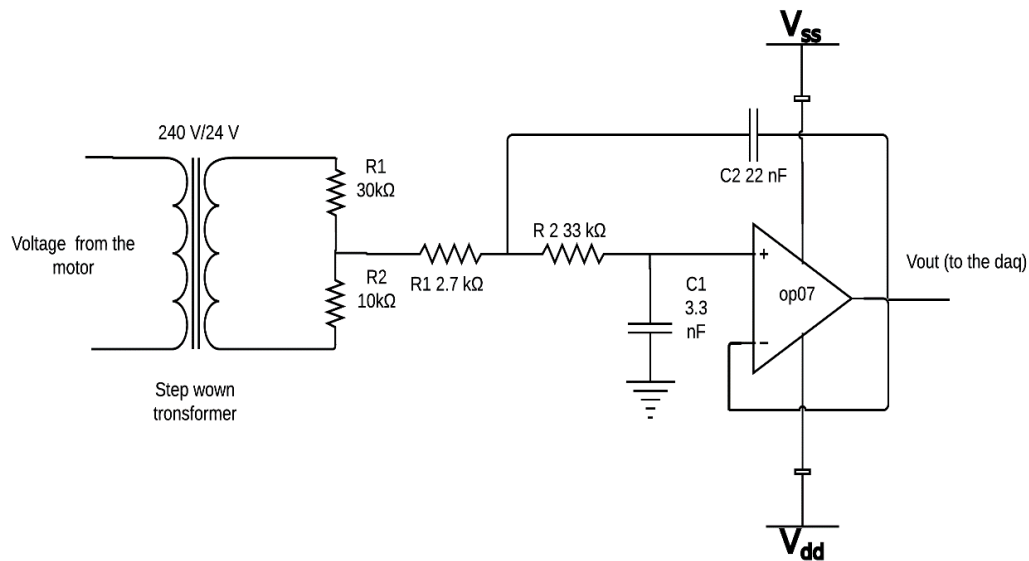


FIGURE 2.6 CIRCUIT FOR VOLTAGE MEASUREMENT

II-3 Current Measurements -Simulation & Design-

II-3.1 CS 100-vp Current Sensor

Before introducing the design and simulation results. It is important to state some details about CS 100-vp Hall Effect current sensor.

CS 100-vp is a current transducer, used to measure DC, AC, pulsed ...current with galvanic isolation between the primary circuit (high power) and the secondary circuit (electronic circuit). It is also a closed loop sensor.

Closed loop sensors amplify the output of the Hall Effect sensor to drive a current through a wire coil wrapped around the core. The magnetic flux created by the coil is exactly opposite of the magnetic field in the core generated by the conductor being measured (primary current). The net effect is that the total magnetic flux in the core is driven to zero, so these types of sensors are also called null balance current sensors. The secondary current in the coil is an exact image of the

Chapter II: HARDWARE IMPLEMENTATION

current being measured reduced by the number of turns in the coil. Passing the secondary current through a load resistor gives a voltage output.

II-3.2 Current Measurement's Block Diagram

After explaining the principle of the Hall Effect current sensor CS 100-vp, we can introduce the design methodology



FIGURE 2.7 BLOCK DIAGRAM OF THE CURRENT MEASUREMENTS

II-3.3 Supply Circuit

From CS 100-vp datasheet we know that the typical range of voltage supply is $\pm 12 \dots \dots \pm 18$ V. For the supply circuit we used the supply voltage generator found in the lab it generates up to 30V with 3 Amperes limit for both supply and testing circuit which will limit our testing to a maximum of 3A.

In order to implement the testing circuit three resistors were used 5Ω with 25W each, to make sure they can support up to 3A current. In order to measure the output current I_S a 60Ω resistor was used.

II-3.4 Practical Results

After implementing the testing circuit, we measured the input current to the sensor. The results are shown below

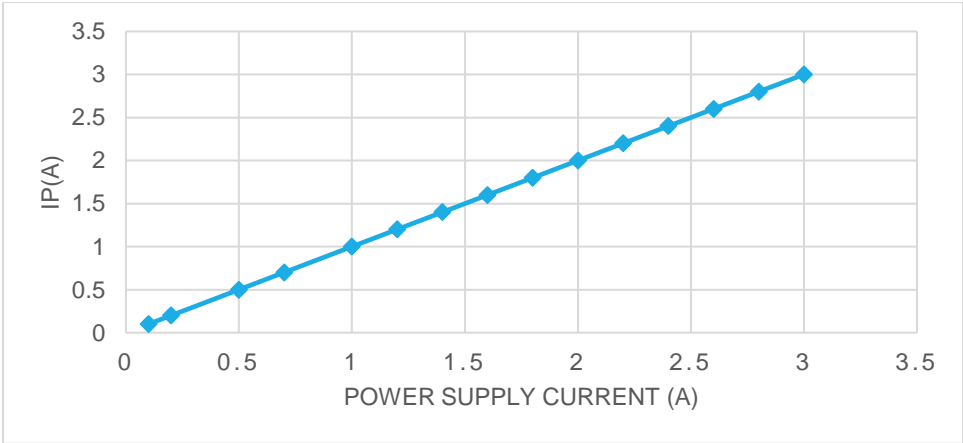


FIGURE 2.8 I_P VS. CURRENT FROM POWER SUPPLY

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After that we measured the voltage across the resistor R_m , its output voltage was amplified using the INA 101 instrumentation amplifier.

II-3.5 Signal Conditioning Circuit

As the data acquisition board has a limit of 10V input, the voltage across the resistor R_m (60Ω) needs to be mapped to be in the range 0...10V. An instrumentation amplifier with a gain of 102 was designed. The instrumentation amplifier INA 101 which is a high accuracy instrumentation amplifier designed for low-level signal amplification and general purpose data acquisition, was used by connecting an external resistor R_G to the pins 5 and 10 [13].

$$\text{Where: } G = 1 + \frac{40K\Omega}{R_G} \quad (2.4)$$

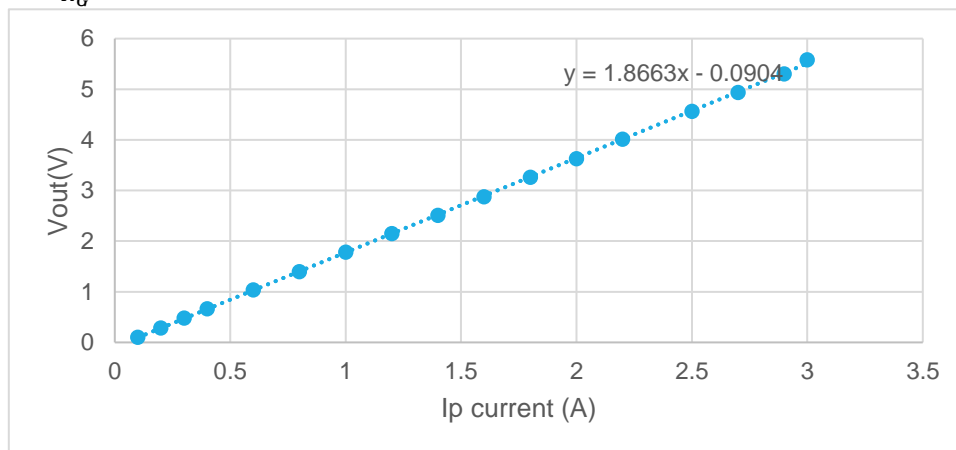


FIGURE 2.9 OUTPUT VOLTAGE VS IP

We cascade a Butterworth lowpass filter with the output of the conditioning circuit of the current measurement with the same values of one mentioned in chapter 2, section 2, subsection 4 .

II-4 Torque Measurement

the hardware for the measurement is the load cell. A load cell is a device that is used to measure weight or force. When a force is applied to it in a specific manner, a load cell produces an output signal that is proportional to the applied force.

II-4.1 Torque Sensor

The load cell SUP1 is a strain gauge based measuring instruments whose output voltage is proportional to applied torque. The strain gages are wired together to form a Wheatstone bridge, as illustrated in Figure 2.10

Chapter II: HARDWARE IMPLEMENTATION

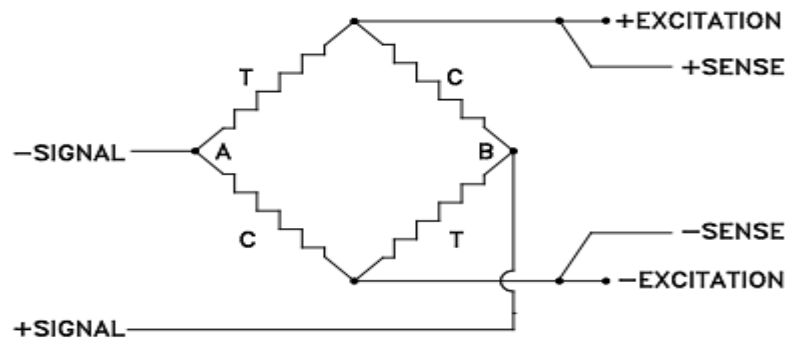


FIGURE 2.10 WHEATSTONE BRIDGE

A stable excitation voltage is applied to opposite corners of the Wheatstone bridge, and a signal is measured across the others, points A and B in Figure 2.10. With no load applied to the cell, all gages have the same resistance and hence there is no voltage difference between points A and B. As load is applied to the cell, the resistance of the tension gages increases, while that of the compression gages decreases. The bridge now becomes “unbalanced” and a voltage difference (signal) proportional to applied load can be measured across points A and B. After explaining briefly how does the SUP1 torque sensor work..we can introduce the design methodology. The following block diagram represents the measurement circuit



FIGURE 2.11 BLOCK DIAGRAM FOR TORQUE MEASUREMENT

II-4.2 Supply Circuit

From the SUP1 datasheet we know that the typical range of voltage supply is 0.1V up to 15 V. For the supply circuit we used the supply voltage generator found in the lab it generates up to 30V. 5 V is applied to the terminals of the sensor (Red: + excitation, black :- excitation).different masses were applied on it and each time we measured the voltage across its output terminals (green:+ signal,white:- signal) by using a voltmeter. [14]

II-4-3 Practical Results

the Figure 2.12 shows the graphical representation of the previous measurements:

Chapter II: HARDWARE IMPLEMENTATION

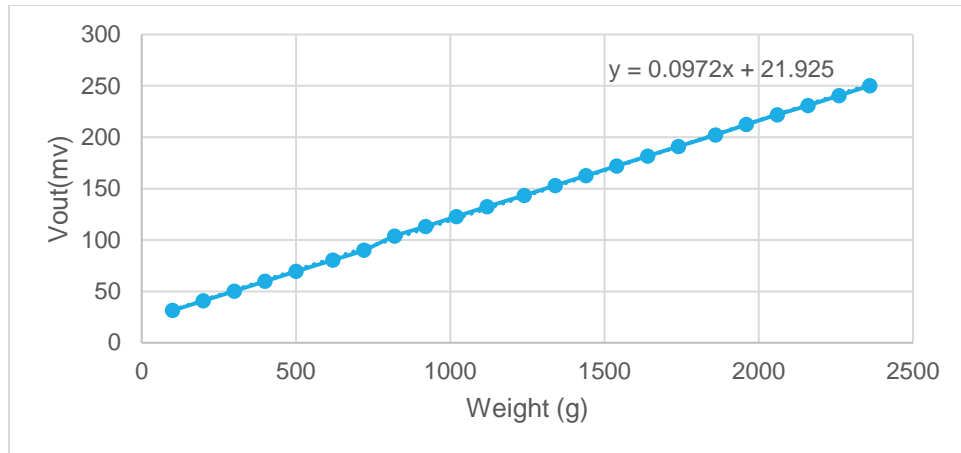


FIGURE 2.12 V_{OUT} VS WEIGHT

As we can see from the curve, The output voltage has a linear relation with the input (applied weight) which is as follows :

$$V_{out} = 0.0972m + 21.925 \quad (2.5)$$

To calculate the Force weights have to be converted from « Kilogram Kg » to « Newton N » as follows :

$$Force [F] = Mass [Kg] \times 9.81 \left[\frac{m}{s^2} \right] \quad (2.6)$$

The graph below (figure 2.12) shows the force (N) acting on the sensor versus the output voltage from the sensor

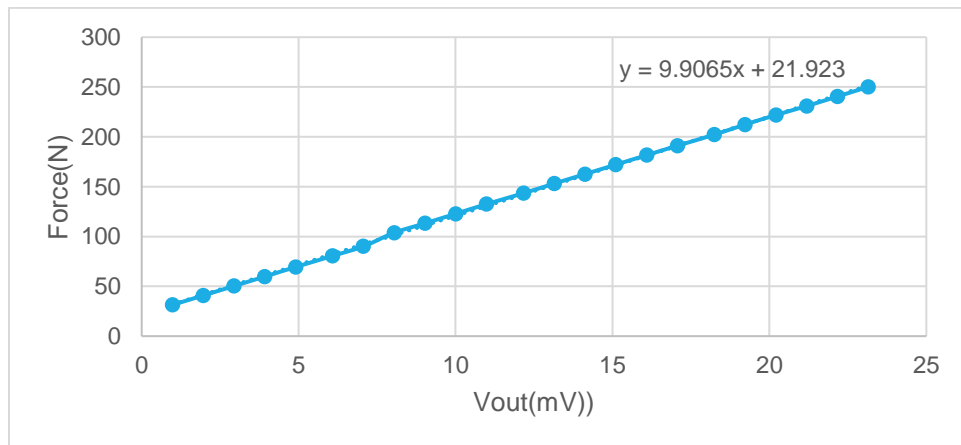


FIGURE 2.13 FORCE VS VOUT

The torque is calculated using the following formula :

$$T = F \times L \quad (2.7)$$

Where : F=Force (N); L=Moment arm (m)

Chapter II: HARDWARE IMPLEMENTATION

$$T = (9.9065 \times V_{out} + 21.923) \times L [N.m] \quad (2.8)$$

II-4.4 Signal Conditioning Circuit

Since the SUP1 torque sensor has very small voltage level, so that it must be amplified before the data acquisition system can effectively and accurately measure the signal. And since the data acquisition board has a range of 0 to 10 V, so we are going to need another device to increase the resolution of the input signal. This is where an amplifier, the INA 101 in our case, comes in handy. We designed the instrumentation amplifier with a gain of 102. For that, we used a 390 Ω resistor ($R_G=390 \Omega$).

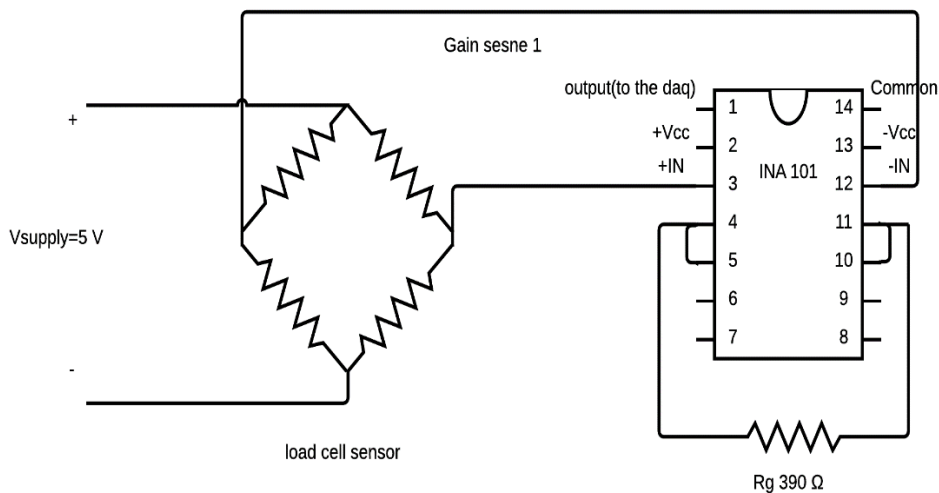


FIGURE 2.14 TORQUE MEASUREMENT CIRCUIT

II-5 Speed & Frequency Measurement

II-5.1 The Photoelectric Sensor

Photoelectric sensor (M18 caliber) is a generic name for sensors which detect an object by using light. The optical signal transmitted from the emitting part of the sensor is modified by being reflected, transmitted, absorbed, etc., by the sensing object and is then detected by the receiving part of the sensor to generate a corresponding output signal. Further, it can also be a sensor which detects light radiated from the sensing object to generate an output signal.

After explaining the principle of the photoelectric sensor M18, we can introduce the design methodology:

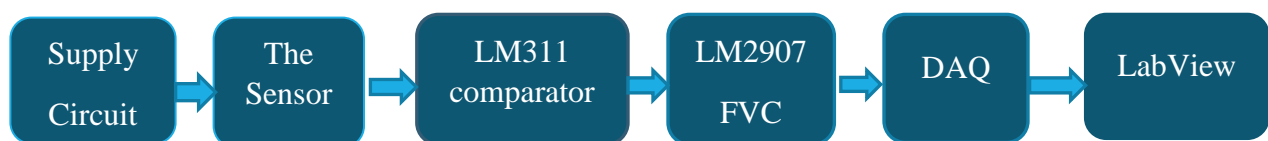


FIGURE 2.15 BLOCK DIAGRAM FOR SPEED MEASUREMENT

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II-5.2 Supply Circuit

From the datasheet of the m18 photoelectric sensor the power supply voltage range is 10 to 30 V.. ± 15 V is applied to the sensor from its input terminals(brown(+), blue (-)) and since the PNP transistor is an open collector a 4.7 k Ω resistor is placed between the output terminal and the VCC.

The sensor was placed about 1 cm from the shaft of the motor and the output was displayed on the scope as in the figure 2.16 :

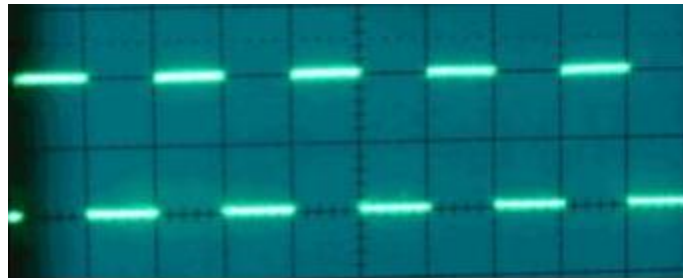


FIGURE 2.16 OUTPUT OF THE SPEED SENSOR

As we can see from the figure, a pulse is generated whenever dark or color is detected.

To measure the frequency from the output of the sensor we have to use another device which is in this case a frequency to voltage converter (LM 2907).

II-5.3 How to Use the LM2907

For the LM2907N-8 (8 pins) in the configuration seen below, a frequency signal is applied to the input of the charge pump at pin 1. The voltage appearing at pin 2 will swing between two values which are approximately $\frac{1}{4}(V_{CC}) - V_{BE}$ and $\frac{3}{4}(V_{CC}) - V_{BE}$. The voltage at pin 3 will have a value equal to $V_{CC} * f_{IN} * C_1 * R_1 * K$, where K is the gain constant (normally 1.0).

The size of C2 is dependent only on the amount of ripple voltage allowable and the required response time

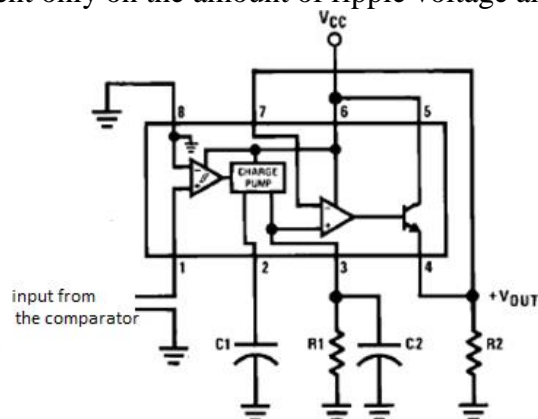


FIGURE 2.17 LM 2907 CONFIGURATION

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Where : $V_{cc}=15v$ $C1= 33nF$ $C2= 4.7 \mu F$ $R1= 5.1 k\Omega$ $R2= 10 k\Omega$

The 8-pin LM2907 has one input internally grounded so that an input signal must swing above and below ground and exceed the input thresholds to produce an output.

Since the output from the m18 sensor does not swing all the way to ground, here we used the LM 311 comparator.

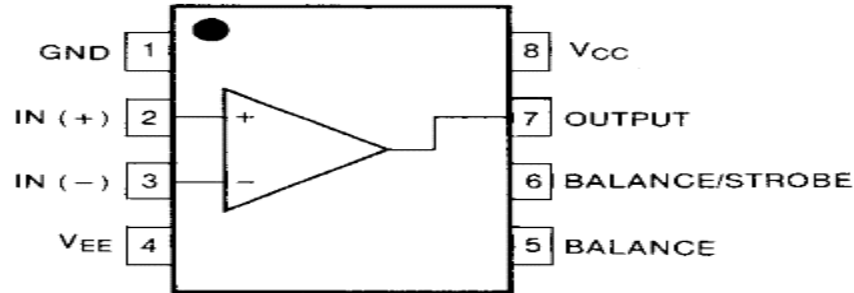


FIGURE 2.18 LM311 COMPARATOR

The sensor signal goes to pin (2) We set the comparator threshold (pin 3) to the midpoint of the sensor signal and we put a $1 k\Omega$ resistor between output and VCC (open collector)

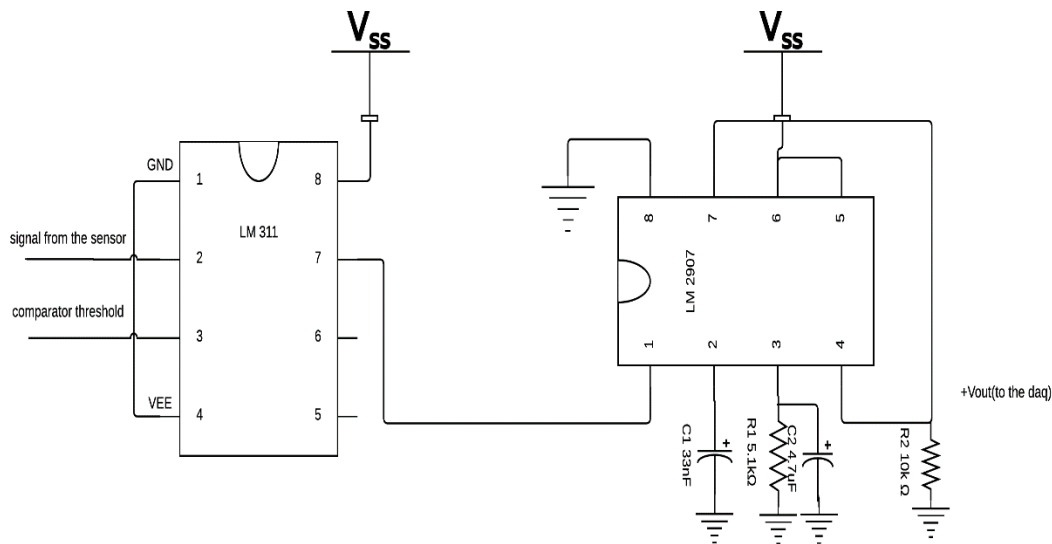


FIGURE 2.19 CIRCUIT FOR SPEED MEASUREMENT

Then the output from the comparator goes to the input(pin 1) of the LM 2907 frequency to voltage converter.

Chapter II: HARDWARE IMPLEMENTATION

II-5.4 Practical results

Using the function generator found in the lab ,a frequency Vs voltage graph is shown below :

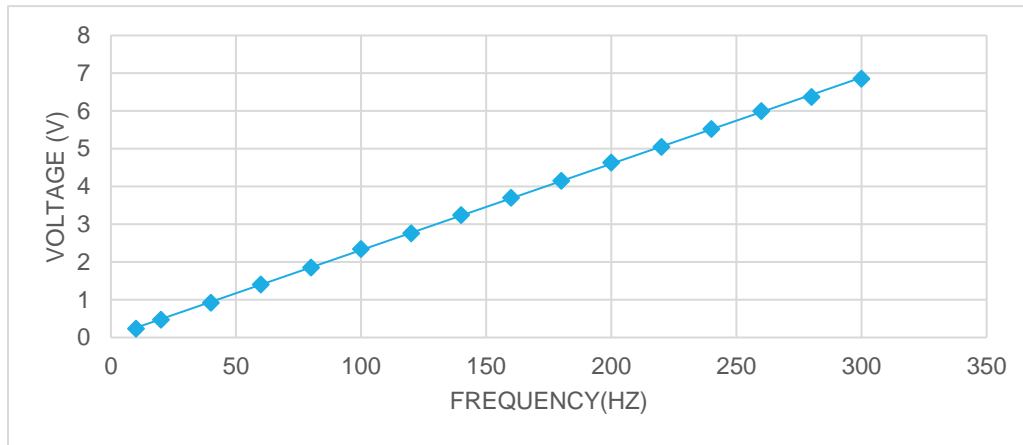


FIGURE 2.20 FREQUENCY (HZ) VS VOLTAGE (V)

II-6 Conclusion

In this chapter, we tested all the sensors used in the measurement system and applied analysis on their appropriate signal conditioning circuit to give us the accurate conversion functions for digital restoration after the acquisition .

CHAPTER 3 SOFTWARE DISCRPTION

1. LabVIEW
2. LabVIEW Environment
3. LabVIEW Project Design
4. Experimental Results
5. Chapter Conclusion

CHAPTER III: SOFTWARE DESCRIPTION

III-1 LabVIEW

LabVIEW (short for Laboratory Virtual Instrumentation Engineering Workbench) is a platform and development environment for a visual programming language from National Instruments. LabVIEW is commonly used for data acquisition, instrument control, and industrial automation on a variety of platforms including Microsoft Windows, various flavors of UNIX, Linux, and Mac OS X. The code files have the extension “.vi”, which is an abbreviation for “Virtual Instrument”. LabVIEW offers lots of additional Add-Ons and Toolkits.



FIGURE 3.1 LABVIEW
LOGO

III-1.1 Dataflow programming

The programming language used in LabVIEW, also referred to as G, is a dataflow programming language. Execution is determined by the structure of a graphical block diagram (the LV-source code) on which the programmer connects different function-nodes by drawing wires. These wires propagate variables and any node can execute as soon as all its input data become available. Since this might be the case for multiple nodes simultaneously, G is inherently capable of parallel execution. Multi-processing and multithreading hardware is automatically exploited by the built-in scheduler, which multiplexes multiple OS threads over the nodes ready for execution.

III-1.2 Graphical programming

LabVIEW ties the creation of user interfaces (called front panels) into the development cycle. Each VI has three components: a block diagram, a front panel, and a connector panel. The last is used to represent the VI in the block diagrams of other, calling VIs. Controls and indicators on the front panel allow an operator to input data into or extract data from a running virtual instrument. However, the front panel can also serve as a programmatic interface. Thus, a virtual instrument can either be run as a program, with the front panel serving as a user interface, or, when dropped as a node onto the block diagram, the front panel defines the inputs and outputs for the given node through the connector pane. This implies each VI can be easily tested before being embedded as a subroutine into a larger program.

III-1.3 Benefits

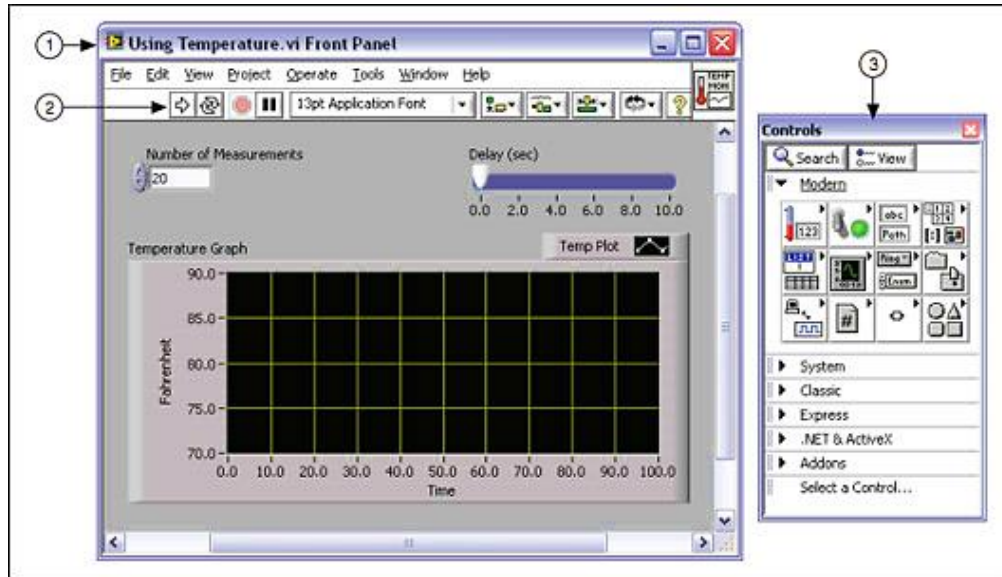
One benefit of LabVIEW over other development environments is the extensive support for accessing instrumentation hardware. Drivers and abstraction layers for many different types of instruments and buses are included or are available for inclusion. These present themselves as graphical nodes. The abstraction layers offer standard software interfaces to communicate with hardware devices. The provided driver interfaces save program development time. The sales pitch of National Instruments is, therefore, that even people with limited coding experience can write programs and deploy test solutions in a reduced time frame when compared to more conventional or competing systems. A new hardware driver topology (DAQmx Base), which consists mainly of G-coded components with only a few registers calls through NI Measurement Hardware DDK (Driver Development Kit) functions, provides platform independent hardware access to numerous data acquisition and instrumentation devices [15].

CHAPTER III: SOFTWARE DESCRIPTION

III-2 LabVIEW Environment

III-2.1 LABVIEW front panel:

The LABVIEW front panel (figure 3.2) is the window where, different controls (such as switch, knobs, numeric inputs, etc.) and indicators (such as LEDs, graphs, numeric outputs, etc.) can be viewed; it can also be called as LABVIEW HMI (Human Machine Interface)

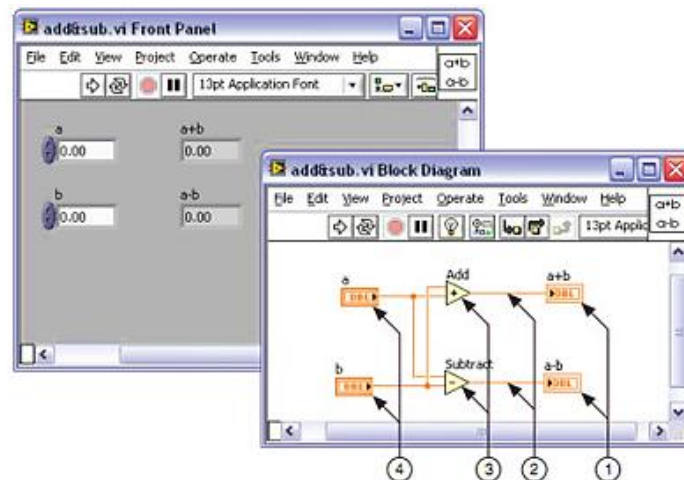


(1) FRONT PANEL WINDOW / (2) TOOLBAR / (3) CONTROLS PALETTE

FIGURE 3.2 EXAMPLE OF A FRONT PANEL

III-2.2 LABVIEW block diagram:

LABVIEW block diagram (Figure 3.3) serves as the brain of the program. It contains the graphical source code that defines the functionality of the VI. Front panel objects appear as terminals on the block diagram. The block diagram basically consists of different functions such as mathematical functions, Boolean functions, programming loops, etc.



(1) INDICATOR TERMINALS / (2) WIRES / (3) NODES / (4) CONTROL TERMINALS

FIGURE 3.3 EXAMPLE OF A BLOCK DIAGRAM AND CORRESPONDING FRONT PANEL

CHAPTER III: SOFTWARE DESCRIPTION

LABVIEW program also contains the following three types of pallet which give you the options you need to create and edit the front panel and block diagram

• Tools Palette

The Tools palette (figure 3.4) is available on the front panel and the block diagram. A tool is a special operating mode of the mouse cursor. It automatically makes the choice for the user from the variety of tools it contains. When we select a tool the cursor icon changes to the tool icon.



FIGURE 3.4 TOOLS PALLET

• Controls Palette

The Controls palette (figure 3.5) is available only on the front panel. It simulates the input mechanisms on a physical instrument and supplies data to the block diagram of the VI. It contains numerical controls, numerical indicators, LEDs, graphs, string & path controls as well as indicators.

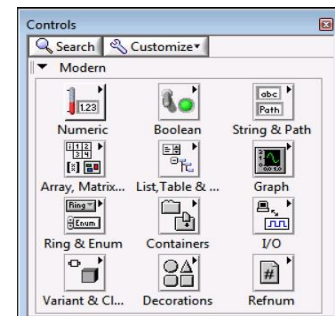


FIGURE 3.5 CONTROLS PALLET

• Functions Palette

The Functions palette is available only on the block diagram. It contains VIs, functions, block diagram structures, and constants.

[16] [17]

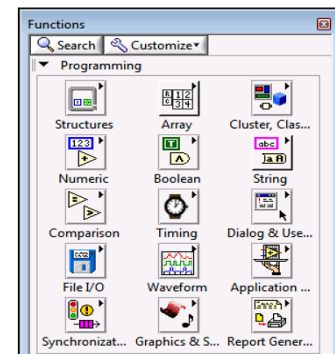


FIGURE 3.6 FUNCTIONS PALLET

Now that we defined LabVIEW and its basic components, in the next part we will be describing the steps taken and techniques used to complete this project. The figure 3.7 shows the three main parts of the software building process (refer to appendix A for the complete programs flowchart).



FIGURE 3.7 BLOCK DIAGRAM OF THE PROJECT

CHAPTER III: SOFTWARE DESCRIPTION

III-3 LabVIEW Project Design

III-3.1 Data Acquisition & Scaling

III-3.1.1 Data acquisition

Data acquisition is the process of measuring an electrical or physical phenomenon such as voltage, current, temperature, pressure, or sound with a computer. The system consists of sensors, DAQ measurement hardware, and a computer with programmable software.

LabVIEW software enabled us to acquire data using DAQ board the process block diagram is shown in the following figure

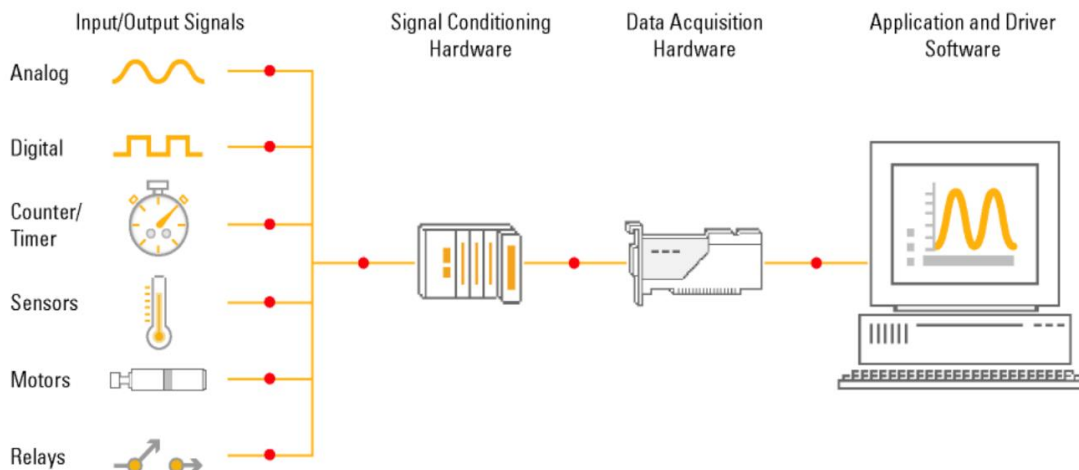
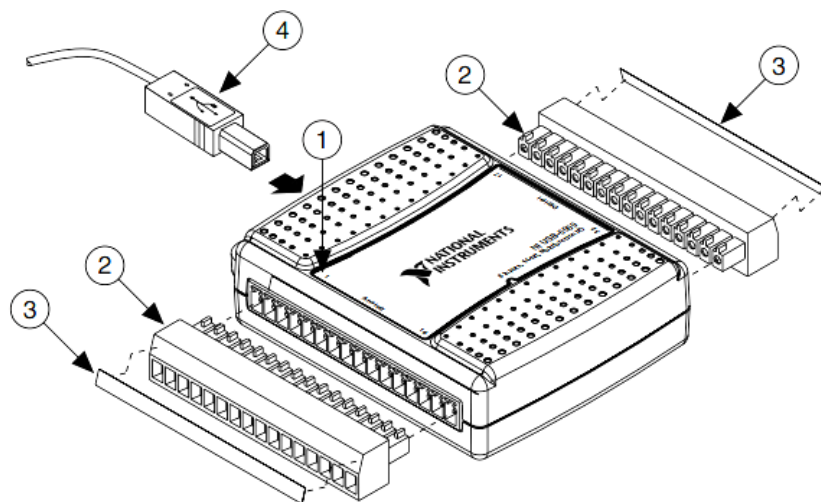


FIGURE 3.8 DATA ACQUISITION USING DAQ BOARD PROCESS BLOCK DIAGRAM

For this process, we used the National Instruments USB-6009 device which provides eight single-ended analog input (AI) channels, two analog output (AO) channels, 12 DIO channels, and a 32-bit counter with a full-speed USB interface (following figures describe it all). [18]



(1) LABEL WITH PIN ORIENTATION | (2) TERMINAL CONNECTOR | (3) SIGNAL LABEL | (4) USB CABLE

FIGURE 3.9 SIGNAL LABEL APPLICATION DIAGRAM

CHAPTER III: SOFTWARE DESCRIPTION

TABLE 3.2 NI USB-6009 CHARACTERISTICS

Feature	NI USB-6009
AI resolution	14 bits differential, 13 bits single-ended
Maximum AI sample rate, single channel	48 kilo Sample/s
Maximum AI sample rate, multiple channels	48 kilo Sample/s
DIO configuration	Each channel individually programmable as open collector or active drive



FIGURE 3.10 NI DAQ

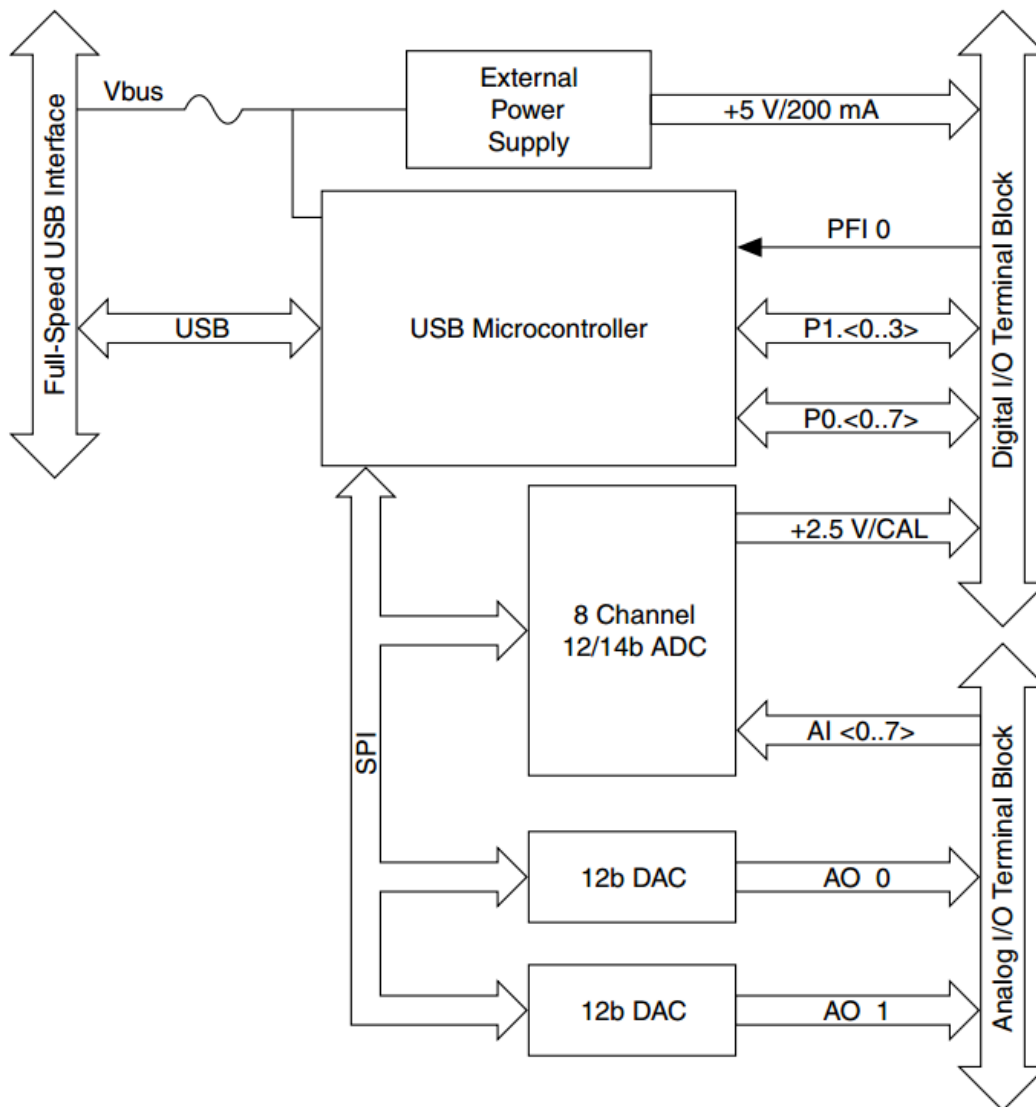


FIGURE 3.11 NI USB-6009 BLOCK DIAGRAM

CHAPTER III: SOFTWARE DESCRIPTION

NI DAQmx: is The Driver for NI USB-6009, it's the layer of software for easily communicating with the hardware. It prevents a programmer from having to do register level programming or complicated commands in order to access the hardware functions. Each LabVIEW version has its unique hardware driver to avoid communication troubles, it comes either as NI DAQmx Base for basic functions or NI DAQmx for the total package [19]

NI-DAQmx driver configures

- Triggering
- Sample rates
- Clocking
- Buffering
- Signal routing
- etc...

We can communicate between the software and hardware using two methods (figure 3.12):

- The DAQ Assistant: included with NI DAQmx, is graphical interactive guide for configuring, testing and acquiring measurement data it provides easy connectivity between LabVIEW and your hardware.
- Programmatic interface DAQ functions: offers the job as the DAQ Assistant with overall better performance and qualities such as speed, reliability and flexibility of configuration which makes it the ideal tool for the development of this speed sensitive LabVIEW project.

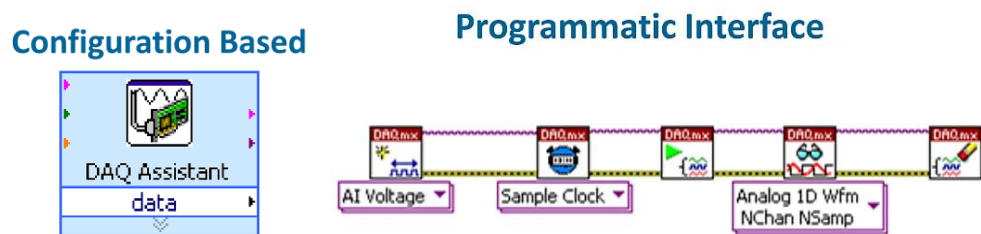


FIGURE 3.12 DAQ FUNCTIONS

III-3.1.2 Scaling

before to start the analysis on the input signal we need to digitally scale it back to its original form for that we use custom scales, NI-DAQmx includes built-in support for many of the most common transducers, sensors, and actuators. However, NI-DAQmx does not explicitly support our transducers, so we create an NI-DAQmx Custom Scale that specifies a conversion from the pre-scaled units measured by a channel to the scaled units associated with the sensor. Using a custom scale does not modify the physical measurement; only the way the data is interpreted.

Pre-scaled Vs. Scaled Units: *Pre-scaled* refers to values expressed in the unit of the channel prior to the custom scale being applied. Usually, pre-scaled units are volts or amps since most channels will natively measure or generate signals of this kind. However, it is possible to associate a scale with a channel that contains a transducer explicitly supported by NI-DAQmx. In this case, the pre-

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scaled units are those used by the supported transducer channel. For example, if we associate a scale with an analog input resistance channel, the pre-scaled units would be ohms and the scale would specify how to convert from ohms to the desired scaled units. *Scaled* refers to values expressed in the final unit after NI-DAQmx applies the custom scale. we are able to define scaled units however it fits the application, Linear, Map Ranges, Polynomial or Tables. for our application we will be using the linear scale [20]

Linear scale:

Creates a custom scale that uses the equation $y = m x + b$, where x is a pre-scaled value, and y is a scaled value. The equation is identical for input and output. we can represent m and b with the slope and y-intercept inputs of the DAQmx Create Scale.vi, respectively [20]. All the equations used are described in the hardware implementation part of the thesis.

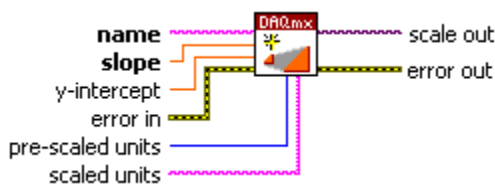


FIGURE 3.13 CUSTOM LINEAR SCALE.

III-3.2 Storage & Analysis Methods & Design Patterns Used:

III-3.2.1 Design Patterns:

III-3.2.1.1 Event-Driven Architectures:

Events are caused by actions the user performs. For example, clicking the mouse generates a mouse event, pressing a key on the keyboard generates a keyboard event, and so on. When a system event occurs, the operating system is responsible for identifying and responding to the event. Different operating systems implement this process in various ways. However, all operating systems respond to the system event by broadcasting a system event message. Any application running on the system can react to the system event by executing code written for that specific system event.

In an event-driven program, the program first waits for events to occur, responds to those events, then returns to waiting for the next event.

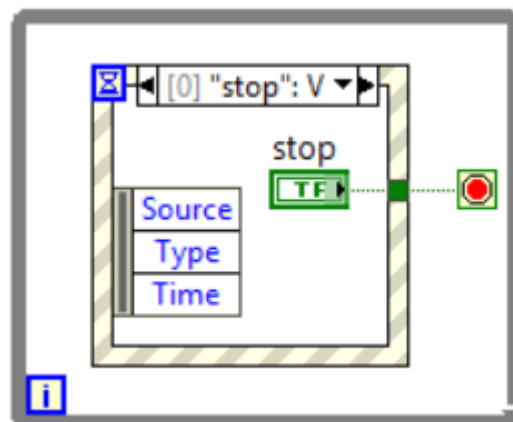


FIGURE 3.14 EVENT STRUCTURE

CHAPTER III: SOFTWARE DESCRIPTION

How the program responds depend on the code written for that specific event? The order in which an event-driven program executes depends on which events occur and on the order in which those events occur. While the program waits for the next event, it frees up CPU resources that might be used to perform other processing tasks.

In LabVIEW, you can use the Event structure to handle events in an application, you can add multiple cases to the Event structure. You can then configure those cases to handle one or more events. When those events occur, LabVIEW executes the corresponding case.

Using the Event structure minimizes the CPU usage because the VI no longer must continually poll the front panel for changes. In contrast to polling, the Event structure does not lose user events because the structure uses an event queue to store user events and handle the user events in the order in which they occur. [20]

The following block diagram illustrates how this Event-Driven Architecture was implemented in our graphical user interface

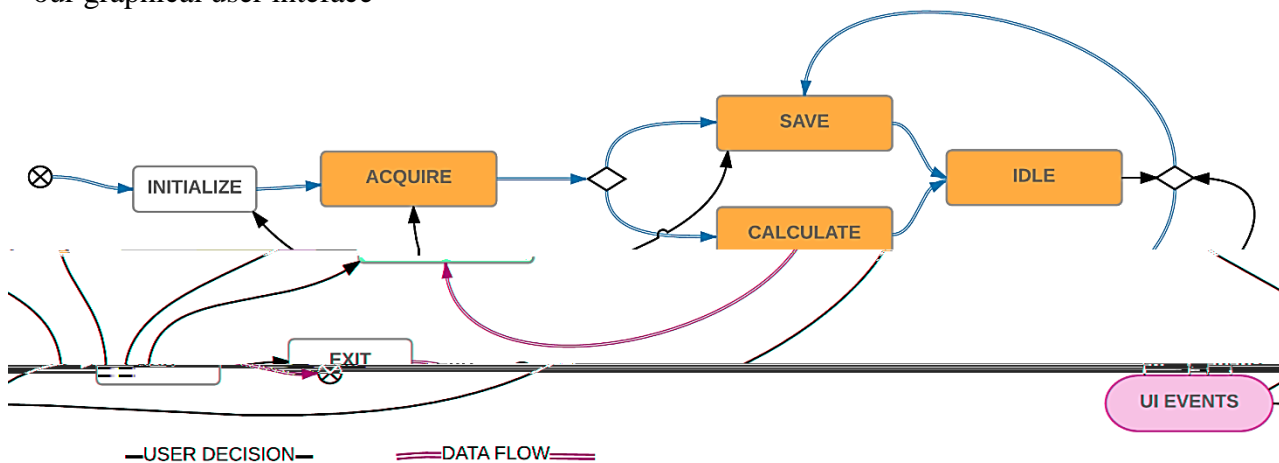


FIGURE 3.15 UI EVENTS FLOWCHART OF THE PROJECT

III-3.2.1.2 Producer/Consumer pattern:

The Producer/Consumer design pattern is based on the Master/Slave pattern, and is geared towards enhanced data sharing between multiple loops running at different rates. As with the standard Master/Slave design pattern, the Producer/Consumer pattern is used to decouple processes that produce and consume data at different rates. The Producer/Consumer pattern's parallel loops are broken down into two categories; those that produce data, and those that consume the data produced. Data queues are used to communicate data between loops in the Producer/Consumer Design pattern. These queues offer the advantage of data buffering between producer and consumer loops.

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The Producer/Consumer pattern is commonly used when acquiring multiple sets of data to be processed in order. We could conceivably put both the producer and consumer in the same loop for this application, but the processing queue will not be able to add any additional data until the first piece of data is done processing. The Producer/Consumer pattern approach to this application would be to queue the data in the producer loop, and have the actual processing done in the consumer loop. This in effect will allow the consumer loop to process the data at its own pace, while allowing the producer loop to queue additional data at the same time.

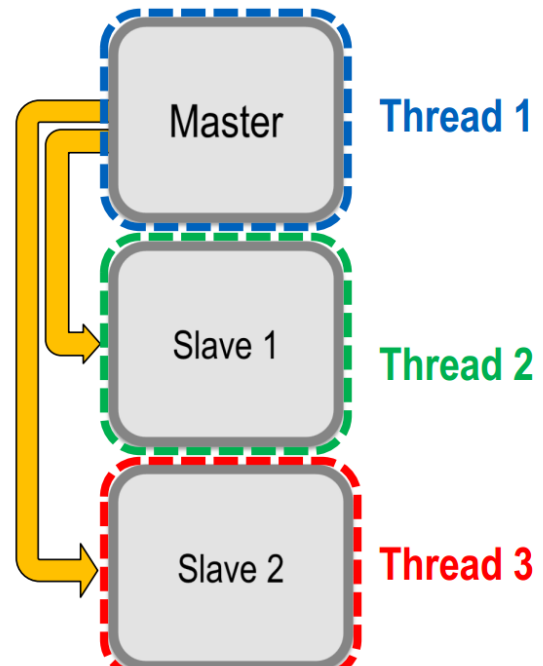


FIGURE 3.16 PRODUCER/CONSUMER DESIGN PATTERN

For our application using simple queue operations will introduce a problem of latency in the processed data the reason being the producer loop runs at a higher frequency than the consumer loop to solve this we implemented a special kind of queue called Notifier in the LabVIEW environment, the working concept is the same its role is to transfer data between the loops the difference being that the consumer loop will receive the most up to date data to make the monitoring real-time, this change of queue does affect the ata storage operation. Data will not be lost . The below figure shows how both design patterns interact with each other

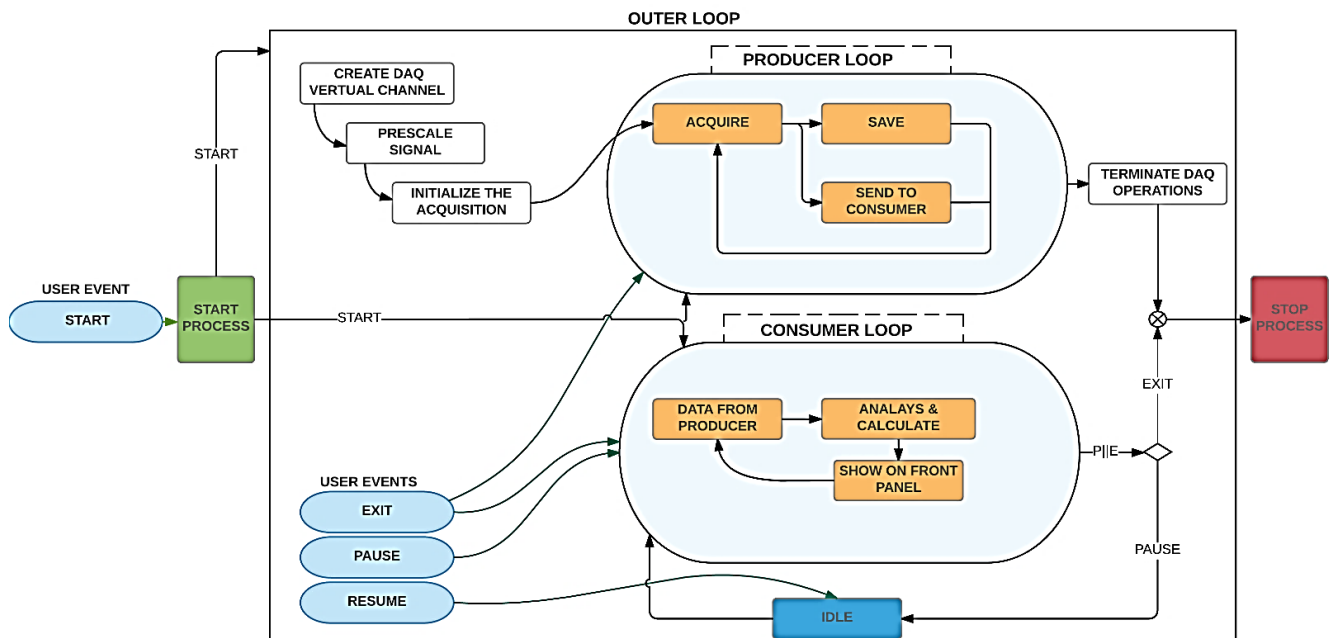


FIGURE 3.17 BLOCK DIAGRAM COMBINING BOTH DESIGN PATTERNS AND HOW THEY INTERACT

CHAPTER III: SOFTWARE DESCRIPTION

III-3.2.2 Storage

several roadblocks can impede the optimal exchange of technical information. The most notorious is the improper capture of information at the time of test or simulation. All too often data is stored without descriptive information, in inconsistent formats, and scattered about on arrays of computers, creating a graveyard of information that makes it extremely difficult to locate a particular data set and derive decisions from it. When data sets cannot be located, tests or simulations must be recreated. As a result, many companies see decreased efficiency and drastically increased development costs. To meet these challenges, National Instruments has defined a technical data management solution (TDM).

Table 3.2 shows the pros and cons of some of the most commonly chosen storage options for measurement data.

TABLE 3.3 THE TDMS FILE FORMAT BENEFITS OVER SEVERAL DATA STORAGE OPTIONS

	ASCII	Binary	XML	Database	TDMS
Exchangeable	✓		✓		✓
Small Disk Footprint		✓			✓
Searchable				✓	✓
Inherent Attributes			✓		✓
High-Speed Streaming		✓			✓
NI Platform Supported	✓	✓	✓	✓*	✓

The National Instruments Technical Data Management Streaming (TDMS) is the file format used to save the data captured in this project because of the deficiencies of other data storage options commonly used in test and measurement applications. The binary TDMS file format is an easily exchangeable, inherently structured, high-speed-streaming-capable file format that, when combined with

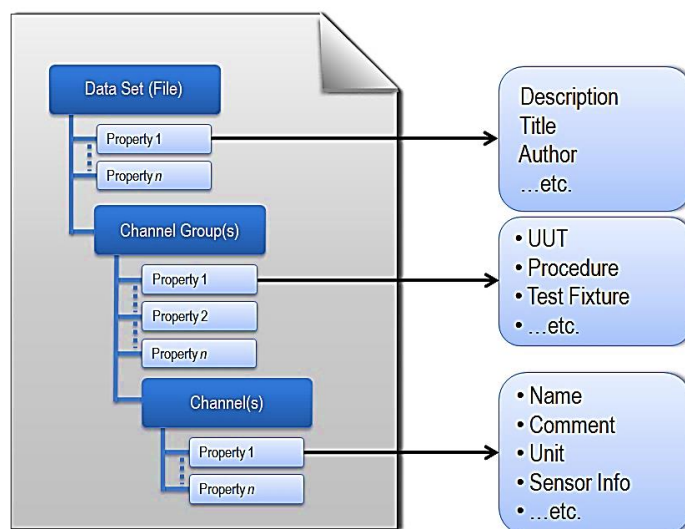


FIGURE 3.18 EACH TDMS FILE CONTAINS DESCRIPTIVE INFORMATION ON THE FILE, GROUP, AND CHANNEL LEVELS.

CHAPTER III: SOFTWARE DESCRIPTION

the other technologies in the NI TDM solution, becomes quickly searchable without the need for complicated and expensive database design, architecture, or maintenance. [21]

III-3.2.3 Analysis & Measurement Computations

The Fast Fourier Transform (FFT) and the power spectrum are powerful tools for analyzing and measuring signals from plug-in data acquisition (DAQ) devices. we can effectively acquire time-domain signals, measure the frequency content, and convert the results to real-world units and displays as shown on traditional benchtop spectrum and network analyzers. using these digital signal processing techniques & a plug-in DAQ devices, we can build a lower cost measurement system and avoid the communication overhead of working with a stand-alone instrument and have the flexibility of configuring the measurement processing to meet our needs.

- Antialiasing and Acquisition Front Ends for FFT-Based Signal Analysis [23]

FFT-based measurement requires digitization of a continuous signal. According to the Nyquist criterion, the sampling frequency, F_s , must

be at least twice the maximum frequency component in the signal. If this criterion is violated, a phenomenon known as aliasing occurs. Figure 3.19 shows an adequately sampled signal and an under sampled signal. In the under sampled case, the result when the Nyquist criterion is violated, frequency components above half the sampling frequency appear as frequency components below half the sampling frequency, resulting in an erroneous representation of the signal. a

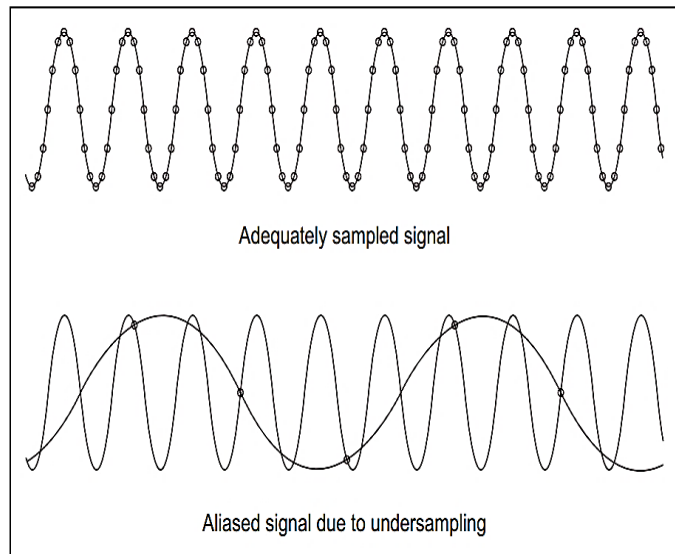


FIGURE 3.19 ADEQUATE AND INADEQUATE SIGNAL SAMPLING

component at frequency $\frac{F_s}{2} < F_0 < F_s$ appears as the frequency $F_s - F_0$

- Computations Using the FFT

The power spectrum shows power as the mean squared amplitude at each frequency line but includes no phase information. Because the power spectrum loses phase information, we use the FFT to view both the frequency and the phase information of a signal. The phase information the FFT yields is the phase relative to the start of the time-domain signal. In our case, the concern is the relative phases between components, or the phase difference between two signals acquired simultaneously. We can view the phase difference between two signals by using some of the

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advanced FFT function called the Cross Power Spectrum which yields the product of the RMS amplitudes of two signals and the phase difference between them while The FFT returns a two-sided spectrum in complex form (real and imaginary parts), which we convert to polar form to obtain magnitude and phase. The amplitude of the FFT is related to the number of points in the time-domain signal. We Use the following equation to compute the amplitude and phase versus frequency from the FFT.

$$\text{Amplitude spectrum in peak} = \frac{\text{Magnitude [FFT(A)]}}{N} = \frac{\sqrt{[\text{Real [FFT(A)]}]^2 + [\text{Imag [FFT(A)]}]^2}}{N} \quad (3.1)$$

$$\text{Phase spectrum in radians} = \text{Phase[FFT(A)]} = \text{Arctangent} \frac{\text{Imag [FFT(A)]}}{\text{Real [FFT(A)]}} \quad (3.2)$$

$$\text{Cross power Spectrum } S_{AB}(f) = \frac{\text{FFT(A)} \times \text{FFT}^*(A)}{N^2} \quad (3.3)$$

where the arctangent function here returns values of phase between $-\pi$ and $+\pi$, a full range of 2π radians

Using these analysis methods, we calculate the amplitude, frequency, THD, phase...etc. according to the equations described in the IEEE STD 1459-2010 of both the input signals (Voltage & Current) and other electrical quantities indicated in the figure 3.21 using the functions indicated in the LabVIEW generated hierarchy figure 3.20

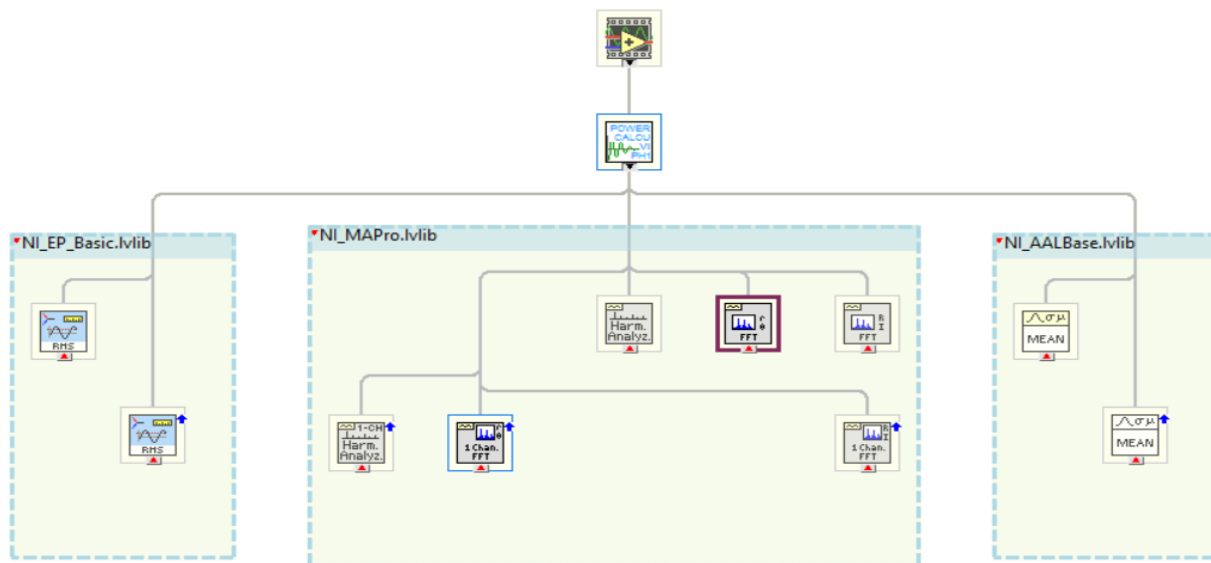


FIGURE 3.20 LABVIEW GENERATED HIERARCHY

Using a LabVIEW technique, we turn this program to a subprogram (Sub Vi) for our main project to minimize the work because the calculations for each phase of the three phases is the same, after we call it in the main program we give it the input signal and get the corresponding electrical quantities as shown in figure 3.21 below

CHAPTER III: SOFTWARE DESCRIPTION

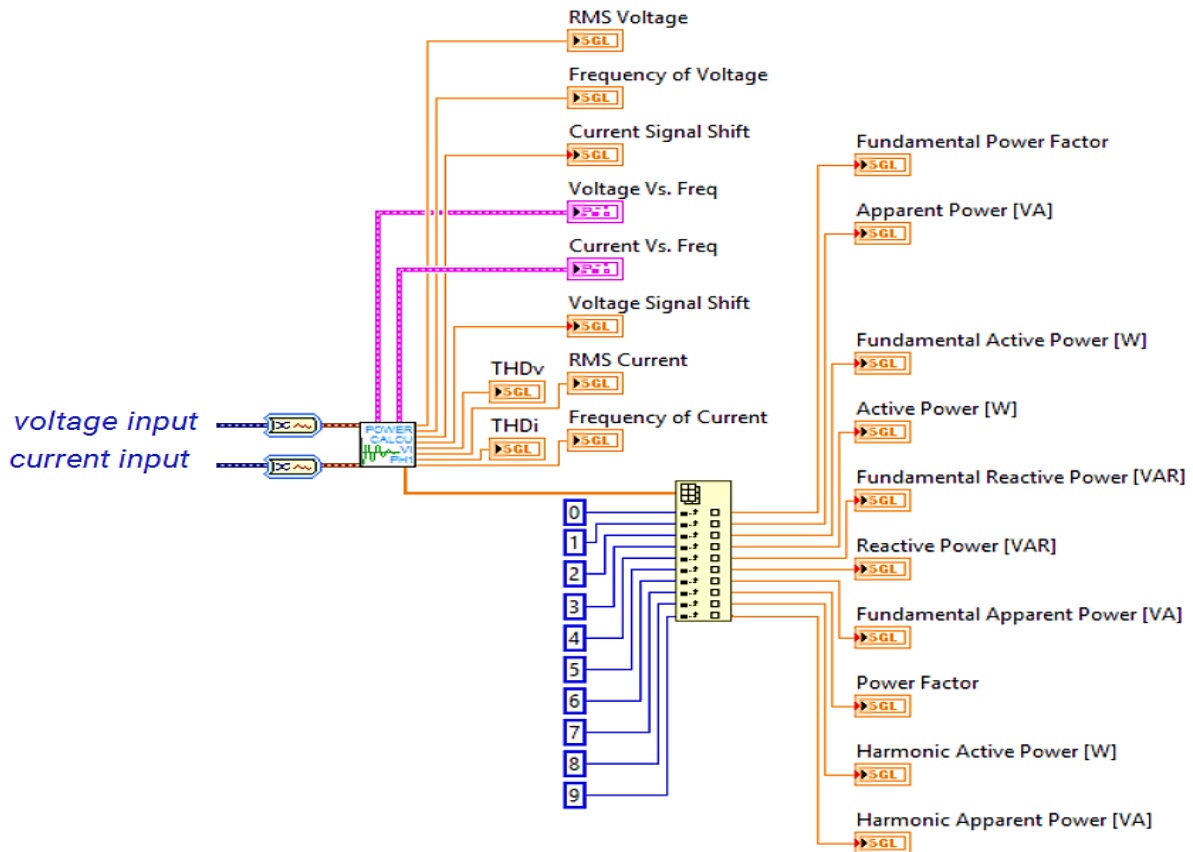


FIGURE 3.21 INPUTS & OUTPUTS OF SUB VI FOR CALCULATING A SINGLE PHASE'S ELECTRICAL QUANTITIES

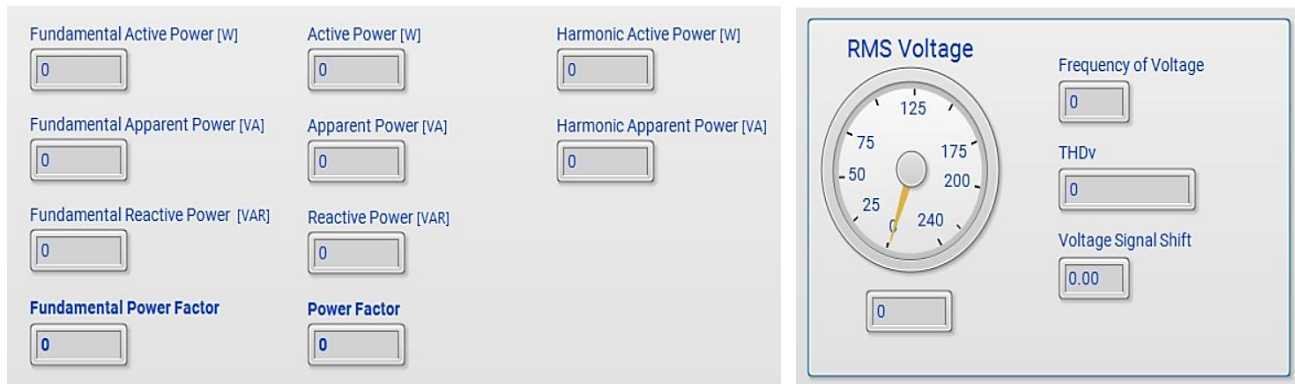
III-3.3 Presentation

The presentation is done in the front panel of the LabVIEW it has three main components

III-3.3.1 Main Panel

we have three main panels

- Phases individually: these three tabs control offers the possibility to monitor each phase electrical quantities individually as shown in figure 3.22



(1) POWER CONSUMPTION

(2) VOLTAGE (SAME FOR THE CURRENT)

FIGURE 3.22 PHASES PANEL SNIPPETS

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- Configuration: in these three tabs control we configure the acquisition channels, saving path, scaling settings and the rated voltage and current for the electrical machine see figure 3.23

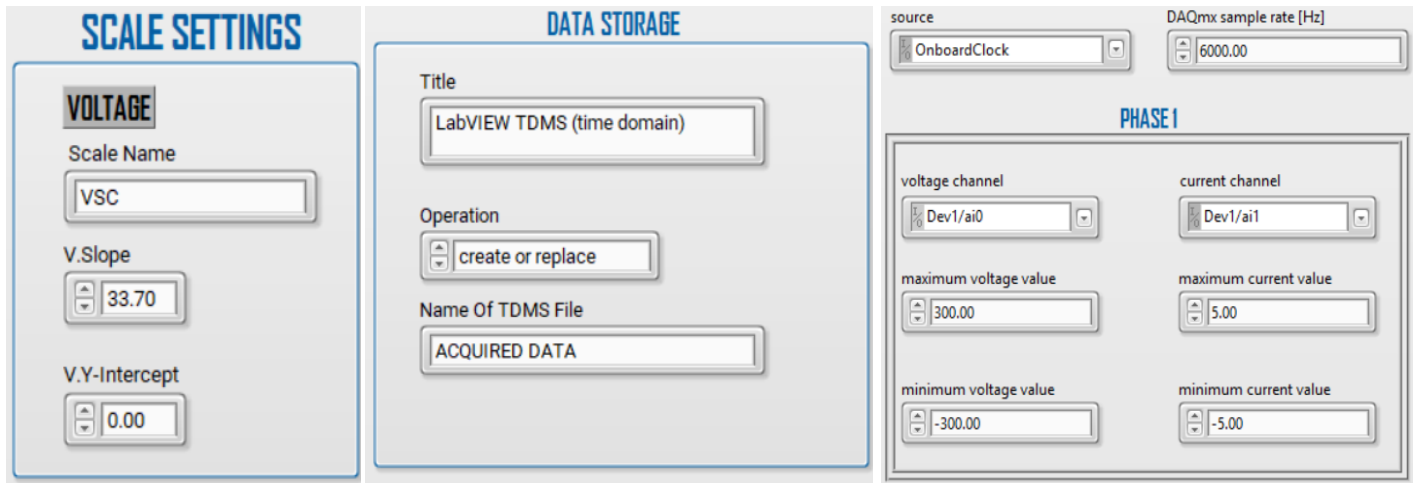


FIGURE 3.23 CONFIGURATION PANEL SNIPPETS

- Total: In these three tabs panel the monitor will find graphs of both the 3-phase voltage and current, speed meter of the motor, torque, wright applied as well as the total power (see figure 3.24).

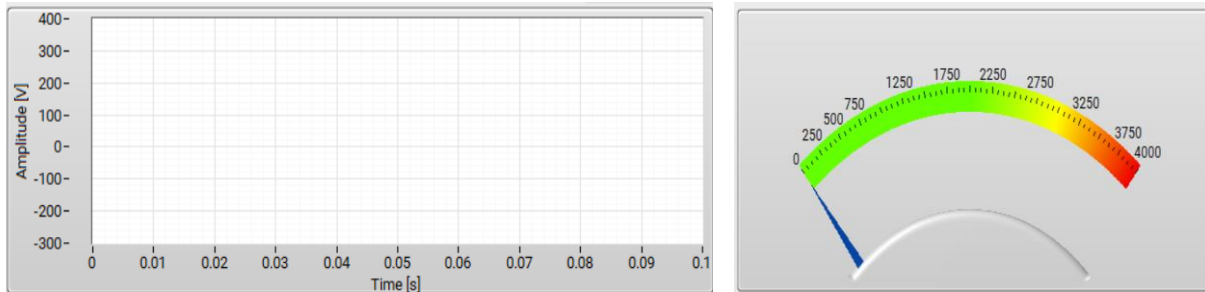


FIGURE 3.24 SNIPPETS FROM TOTAL PANEL

III-3.3.2 Control Panel

The control panel's main job is to wait for user events for the program to execute them

It has

1. Start button: starts both the acquisition and analysis loops
2. Pause button: pauses the consumer loop while the producer still works and data is being saved to where the user wants



FIGURE 3.25 CONTROL PANEL

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3. Select Menu: for the user to navigate through the different main panels
4. Stop button: to stop the entire system and exit the program.

III-3.3.3 Motor Control & Status Panel

This panel has two controls:

1. On/off button controls the state of the motor and switches between both the cases on and off.
2. Manual / Auto: switches from programmatically stopping the motor when one or many electrical values surpass the values defined by the user and manually stopping the motor

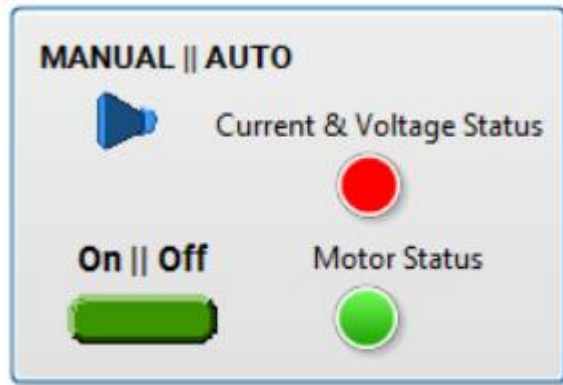


FIGURE 3.26 MOTOR CONTROL & STATUS PANEL

And has two indicators:

1. Motor status: lights up in green in case it and dims in case its off.
2. Current & Voltage status: lights up in red in case either the voltage or current of each or all of the 3 different phases goes above the technical plat of the motor

III-4 Experimental results

The system was tested and calibrated in laboratory, it provides continuous monitoring of a three phase system the input currents and voltages wave graphs are shown in the following figures

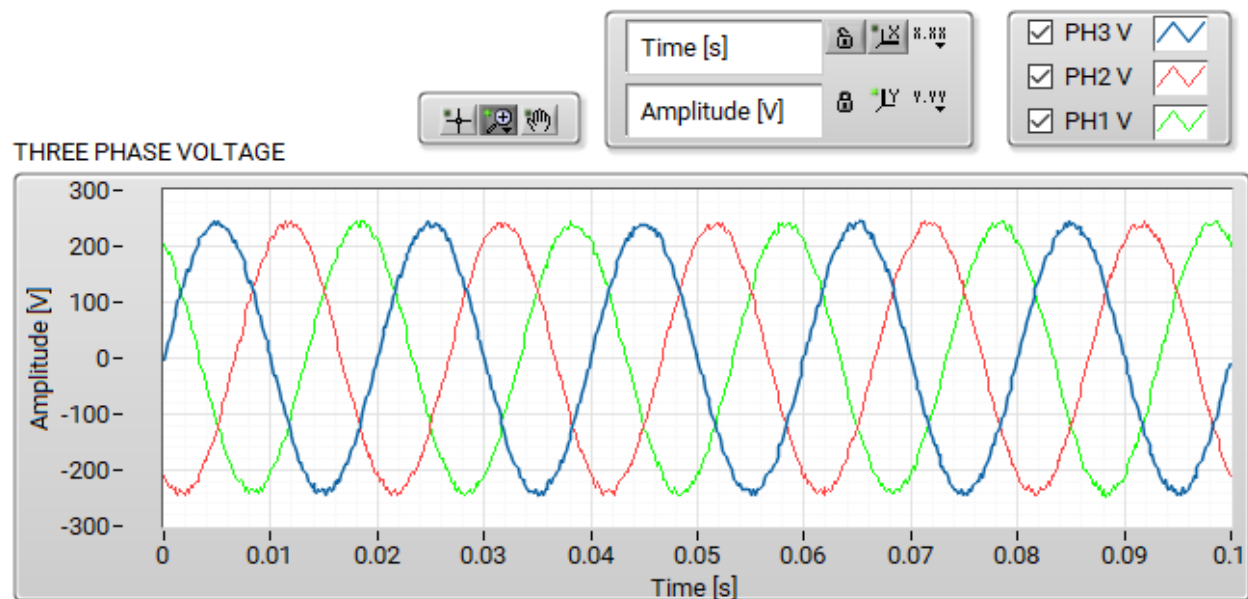


FIGURE 3.27 EXPERIMENTAL RESULTS OF THREE-PHASE VOLTAGES MONITORING

CHAPTER III: SOFTWARE DESCRIPTION

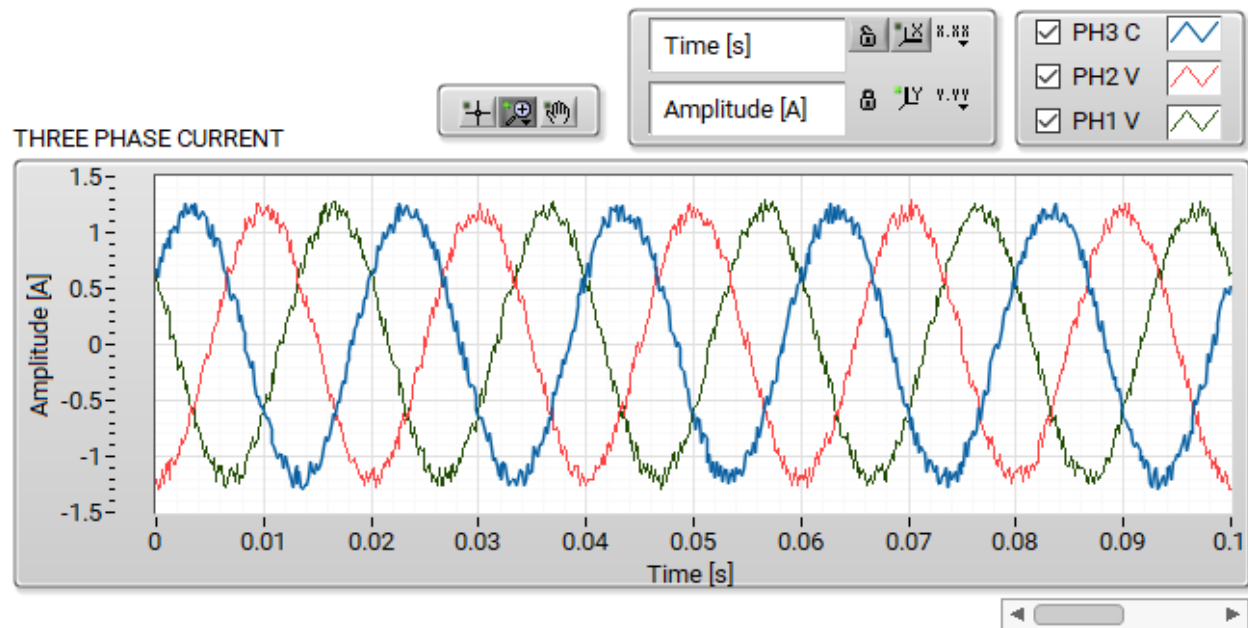


FIGURE 3.28 EXPERIMENTAL RESULTS OF THREE-PHASE CURRENT MONITORING

The user interface for the speed shows 2955 rpm and is depicted in Figure 3.29

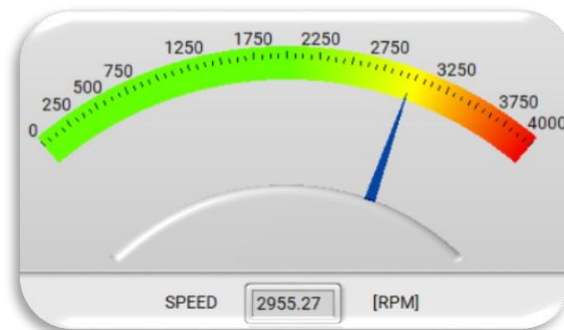


FIGURE 3.29 RPM GRAPHICAL AND NUMERICAL PRESENTATION

The application is capable for logging measured values in real time, this method of recording data helps in the diagnosis of the system malfunction either in the online or offline measurements.

It allows the user to determine the exact time and date of the malfunction of the system.

Measured Data TIME	Measured Data phase 1 voltage	Measured Data phase 1 current	Measured Data phase 2 voltage	Measured Data phase 2 current	Measured Data phase 3 voltage	Measured Data phase 3 current	Measured Data speed	Measured Data torque
6/4/2017 09:51:24.179	143.710275	-1.324038	-238.481629	-0.010079	110.330055	1.129626	2786.520402	0.035582
6/4/2017 09:51:24.179	132.049259	-1.352751	-240.647900	0.050481	121.098048	1.095511	2790.534864	0.033032
6/4/2017 09:51:24.179	115.991467	-1.374629	-244.789300	0.115528	132.375767	1.042291	2794.549326	0.022832
6/4/2017 09:51:24.179	101.717874	-1.374629	-244.853013	0.182817	146.839284	0.986342	2791.873018	0.022832
6/4/2017 09:51:24.179	92.095943	-1.370527	-241.030183	0.236649	162.449687	0.923570	2786.520402	0.030482
6/4/2017 09:51:24.179	81.390748	-1.373261	-239.501050	0.303938	174.300850	0.853975	2787.858556	0.033032
6/4/2017 09:51:24.180	66.352498	-1.373261	-242.113318	0.384686	182.711353	0.774827	2790.534864	0.030482
6/4/2017 09:51:24.180	50.995641	-1.366425	-243.196453	0.456461	192.523607	0.701138	2789.196710	0.030482
6/4/2017 09:51:24.180	40.290446	-1.358221	-237.780776	0.528237	204.693350	0.627449	2786.520402	0.022832
6/4/2017 09:51:24.180	32.197829	-1.358221	-231.791675	0.620199	215.397626	0.537385	2791.873018	0.020283

FIGURE 3.30 SNIPPET OF THE 3 PHASE VOLTAGE DATA SAVED

CHAPTER III: SOFTWARE DESCRIPTION

The system is operating with real power of 4 W, power factor of around 18% this is due to the non existence of the load which is within the normal operating point of the asynchronous motor as shown in table 3.3 [24]

TABLE 3.4 TYPICAL POWER FACTORS

Device	Power Factor
Lamp, fluorescent uncompensated	0.5
Lamp, fluorescent compensated	0.93
Lamp, incandescent	1
asynchronous Motor, induction 100% load	0.85
asynchronous Motor, induction 50% load	0.73
asynchronous Motor, induction 0% load	0.17
synchronous Motor	0.9
Oven, resistive heating element	1
Oven, induction compensated	0.85
Pure resistive load	1

Current THD 3.4 %, voltage THD 3.2% all the other parameters can be read from appendix B

III-5 Conclusion

In this chapter, we described in general the LabVIEW software and its most essential components, we also mentioned the used functions and design patterns in this project and illustrated how they interact with block diagrams, then we showed snippets of the end program and presented experimental results.

Conclusion

A current, voltage and speed measurements of three-phase, 1.5 KW squirrel cage induction motor of our laboratory are presented and displayed in the LABVIEW.

A hardware circuitry has been implemented to measure the required signals needed for the machine characterization and power parameters calculation.

After discussing the measurements sensing methods, and testing the needed sensors, we designed and implemented the signal conditioning circuitry to interface it with LABVIEW. Based on the standard equations, a LABVIEW program was developed and the obtained results were displayed on the LABVIEW front panel and the data was stored in TDMS format.

Further work on this subject can be proposed in the following:

1. Identification of the motor parameters using AC induction parameter extraction methods which may be required for driving designing the ac induction machine controllers [24].
2. Using a better algorithm for detecting phase deference between the voltage and current signal like PLL (phase locking loop) .
3. A software can be further developed to include three phase AC unbalanced power conditions.
4. The software can be extended to measure DC rotating machine, AC transformers, AC fault recorder, system diagnosis.

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APPENDIX A

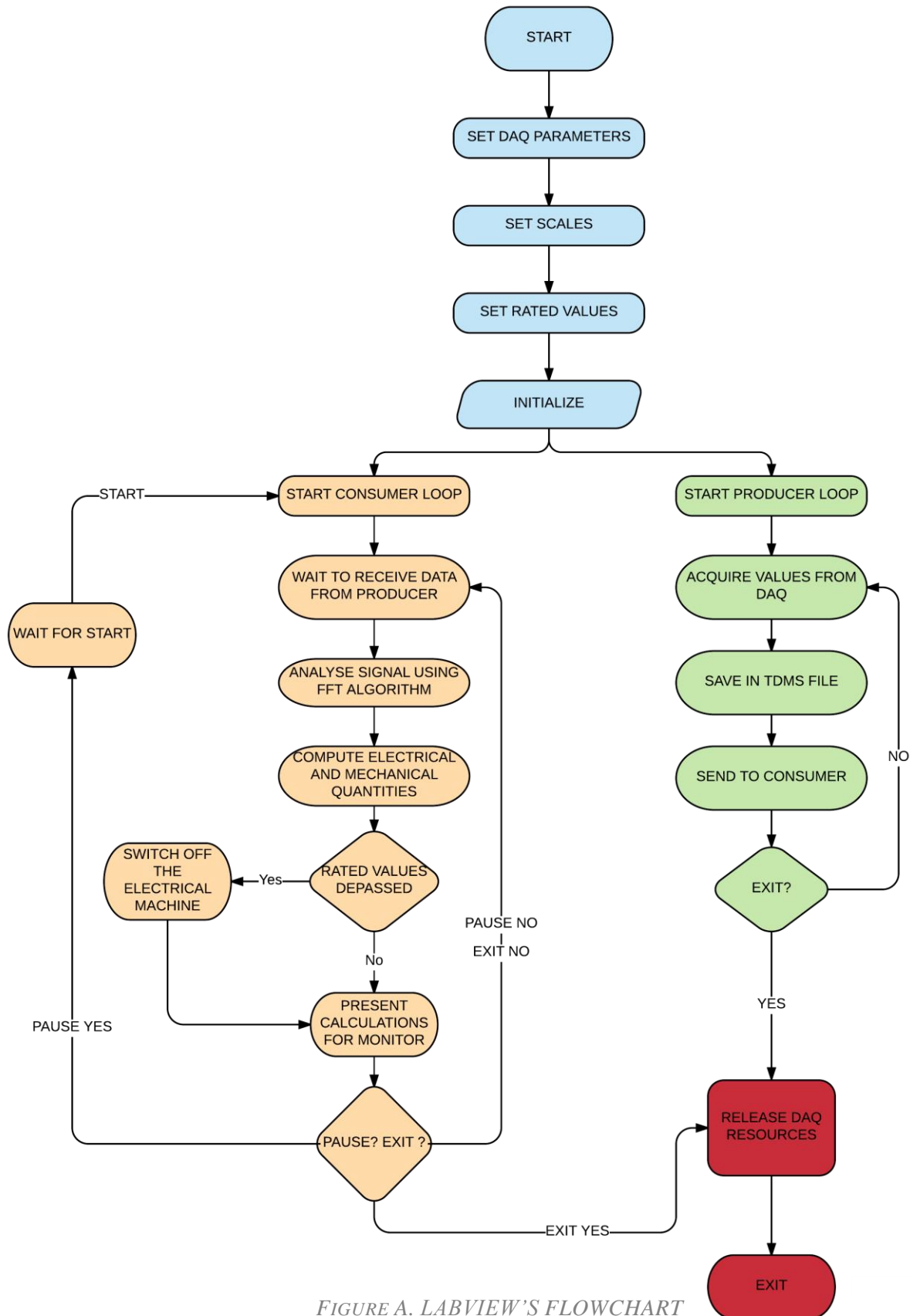


FIGURE A. LABVIEW'S FLOWCHART

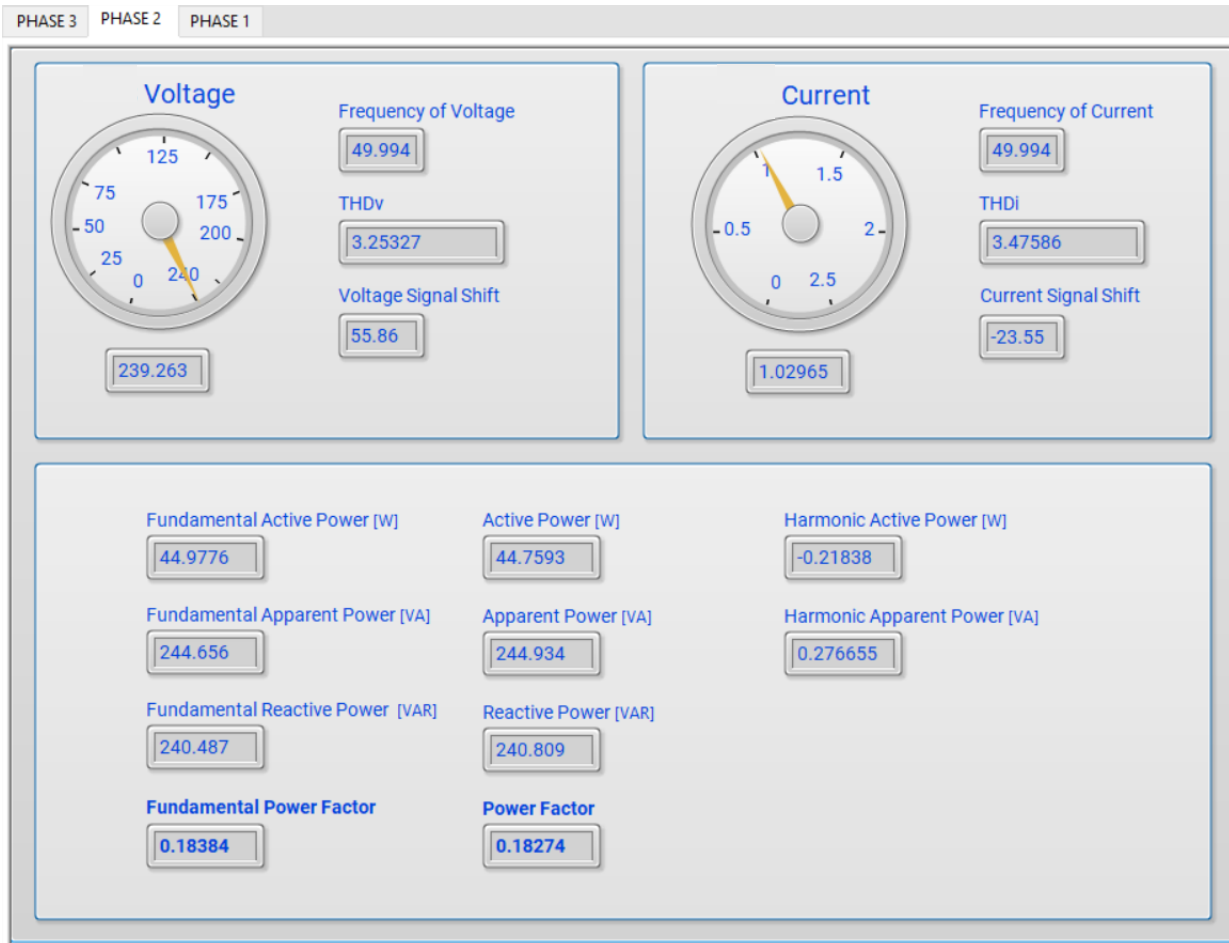


FIGURE B MEASURED ELECTRICAL QUANTITIES FOR A SINGLE PHASE DURING EXPERIMENT

APPENDIX C

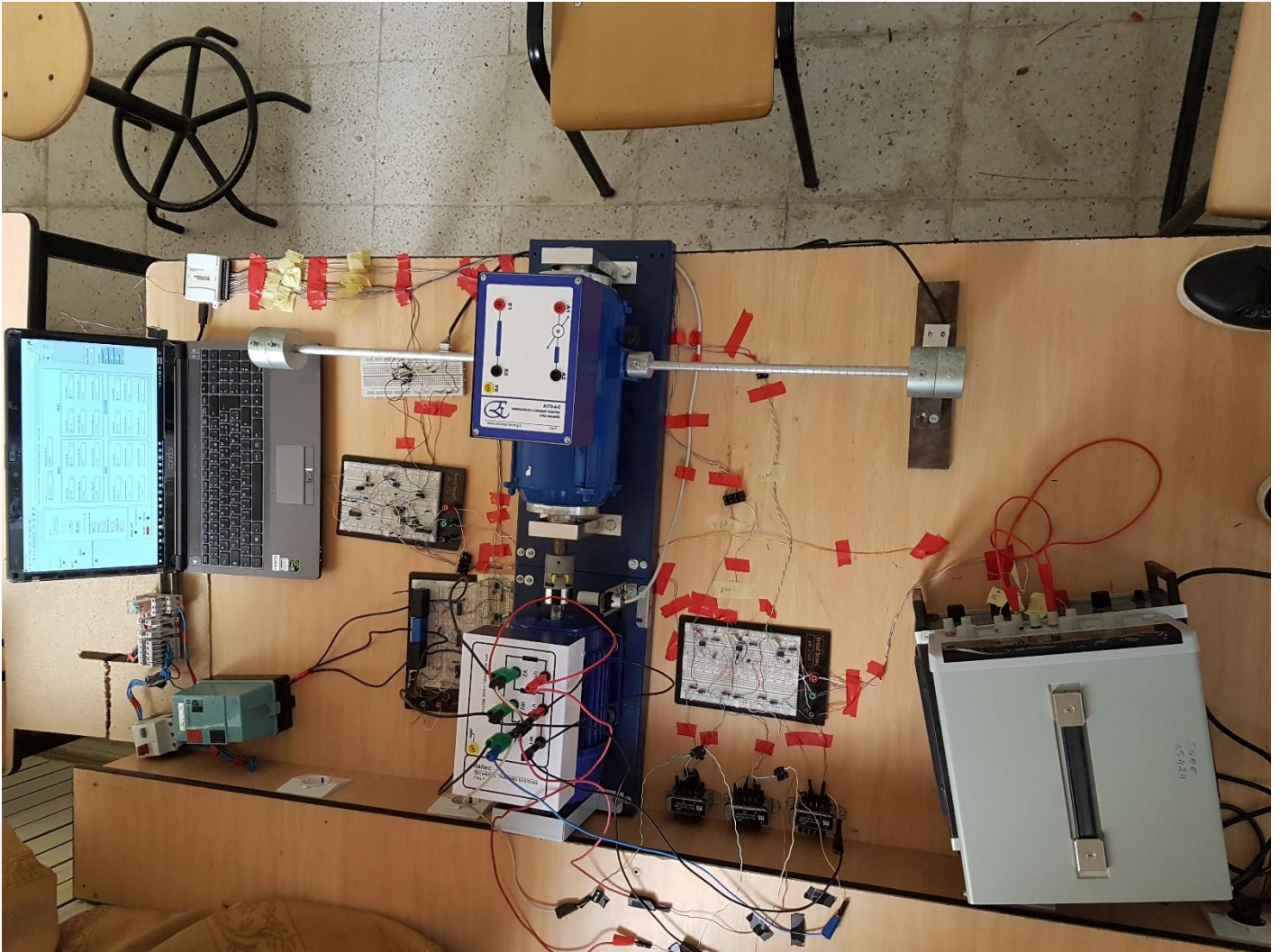


FIGURE C. IMAGE FROM BENCHING SYSTEM