



**MURDOCH**  
**UNIVERSITY**  
PERTH, WESTERN AUSTRALIA

# Motor Generator Dynamometer Setup

ENG470 Engineering Honours Thesis

**Mark Anthony Rondilla**

**Supervisor: A/Prof. Graeme Cole**

**Associate Supervisor: Dr. Greg Crebbin**

**9 January 2017**

## Disclaimer

I hereby submit the following Thesis: *“Motor Generator Dynamometer Setup”*

This project was started and completed throughout the second semester of 2016.

I declare that the following work to be my own. Unless otherwise stated, it was referenced as defined by Murdoch University’s Plagiarism and Collusion Assessment policy

## Abstract

The motor-generator set is widely used in the industry for converting large amounts of power energy to a different form of energy although the topic for this project motor-generator is smaller than usually utilized by an industrial company. The primary purpose of this small version motor-generator is for learning tool used by students associated with Electrical Power Engineering or Industrial Computer System Engineering at Murdoch University. The equipment is located in 1.003 Pilot Plant Engineering & Energy Building and was used in previous years by students at Murdoch University.

The fundamental aim of the project is to get the apparatus operating correctly and establish accurate communication and control. Investigate the effects of Variable Speed Drive on the motor, the effects of rotor speed and loads on the generator. To design and implement a working communication and control program in the system using LabVIEW software, it should display the following outputs; Field Voltage, Armature Voltage, Current, Power, Synchronous Speed of Motor, Rotor Speed, Force, and Torque.

It will be discussed in this report the fundamentals of motor-generator, National Instrument Data Acquisition card, and the LabVIEW software that being used and also the different components used as communication for the motor-generator. The major equipment of the system that will investigate are the following; Variable Speed Drive (VSD), Induction Motor, DC Generator, and the NI DAQ card. With understanding these pieces of equipment, it would determine accurate data information in the outputs. Allen Bradley variable speed drive powered and control the induction motor's speed, while the National Instrument Data Acquisition card receives the systems information and addresses the controls. The four-kilowatt three-phase induction motor with 415 Voltage and 7.7 Amps which runs at 1455 revolution per minute. The DC generator converts mechanical energy into electrical energy and produces the measured DC voltage output with a variable load bank. The software control for this project is LabVIEW, which reads and writes to different components of the project through NI 6013, 50 pin DAQ card.

To ensure the implementation of the communication and control program, it was run with many trials that produced accurate results. The output results of Voltage, Current and Power are displayed in the waveform were expected, the Strain Gauge that measured force were also shown as well as the torque concerning the level arm of the generator. The rotor speed was calculated based on the synchronous speed and slip of the motor and not measured by a proximity sensor. The calculated values of rotor speed were compared to the tachometers measured value.

## Acknowledgement

Firstly, I would like to express my gratitude to my academic supervisor, Associate Professor Graeme Cole and Associate supervisor Dr. Gregory Crebbin for their enthusiastic support and guidance throughout this project. I would like to take this opportunity to thank my supervisors for the support they provided throughout my studies in Murdoch University.

I would also like to show my gratitude to the rest of the staff in the School of Engineering for guiding and facilitating in my studies in the university. As well as to John Boulton and Iafeta 'Jeff' Lavaa for the support they have given in this project.

Most importantly, I would like to express my thanks to my family for their encouragement and support in my studies in the university

## Table of Contents

Abstract.....	ii
Acknowledgement .....	iii
List of Figure.....	vi
List of Tables .....	vii
Acronyms and Symbols used in this Thesis Report.....	viii
1 Introduction .....	1
1.1 Thesis Objectives.....	2
1.2 Motor-Generator Dynamometer .....	2
1.3 National Instrument Data Acquisition .....	2
2 Background and Literature Review .....	3
2.1 Variable Speed Drive (VSD) .....	3
2.2 Induction Motor .....	4
2.2.1 3-Phase Induction Motor .....	5
2.2.2 Rotor of Induction Motor.....	5
2.2.3 Concept of Rotor Slip .....	7
2.3 Generator.....	8
2.3.1 AC Generator .....	8
2.3.2 DC Generator .....	9
2.4 Data Acquisition (DAQ) .....	10
3 Design Method.....	12
3.1 Motor-Generator set .....	12
3.2 Load Bank.....	14
3.3 Strain Gauge – Load Cell .....	14
3.4 Dataforth Modules.....	15
3.5 Variable Speed Drive (VSD).....	16
4 Implementation .....	18
4.1 National Instrument Hardware .....	18
4.1.1 Data Acquisition Card.....	18
4.1.2 Dataforth Modules.....	20
4.2 Software .....	20
4.2.1 LabVIEW .....	21
4.2.2 Features in LabVIEW .....	21
4.3 Calibration of VSD .....	24

4.4 Synchronization of Control Panel to VSD.....	25
4.5 Full-Load Limits .....	26
4.6 Strain gauge .....	27
4.6.1 Calibration of the Load Cell.....	27
5 Experimental Data & Results .....	29
5.1 Synchronous and Mechanical shaft speed against frequency.....	29
5.2 No-Load Condition .....	30
5.3 Full-Load Condition .....	33
6. Conclusion.....	35
7. Future Works .....	36
Bibliography .....	38
Appendices.....	41
Appendix A: Front Panel Control and Monitoring Interface.....	41
Appendix B: NI 6014 DAQ Hardware Block Diagram .....	42
Appendix C: NI 6014 DAQ I/O Connector Pin Assignment.....	43
Appendix D: VSD Block Diagram Connector .....	44
Appendix E: Generator – Load Wiring Diagram.....	45
Appendix F: Overall System Wiring Diagram .....	46

## List of Figure

Figure 1: Motor Generator Setup .....	1
Figure 2: Background of the Project .....	3
Figure 3: Branches of Motors.....	4
Figure 4: Induction motor components .....	5
Figure 5: Squirrel cage rotor .....	6
Figure 6: Wound rotor .....	6
Figure 7: Branches of Electric Generator .....	8
Figure 8: Rotation of magnetic field in AC generator .....	9
Figure 9: Rotation of magnetic field in DC generator .....	9
Figure 10: Equivalent circuit of Separately Excited.....	10
Figure 11: Equivalent circuit of Self-excited .....	10
Figure 12: Process of measuring the signal .....	11
Figure 13: Wiring in the terminal of generator.....	13
Figure 14: Equivalent circuit of Load Bank.....	14
Figure 15: Wheatstone bridge circuit .....	15
Figure 16: Signal conditioning in the field and control room .....	16
Figure 17: VSD Frequency control terminal.....	16
Figure 18: VSD Start & Stop control terminal .....	17
Figure 19: VSD Enable & Reverse control terminal.....	17
Figure 20: Analog output connection .....	19
Figure 21: Digital I/O connections to field .....	20
Figure 22: Front panel VSD control.....	22
Figure 23: Front panel load control .....	22
Figure 24: Field & Armature Voltage, Current and Power Outputs.....	23
Figure 25: Output values in Waveform.....	23
Figure 26: a) System Running Indicator, b) System Fault Indicator.....	24
Figure 27: Data Logging.....	24
Figure 28: VSD frequency control from block diagram.....	26
Figure 29: Limits on the Loads .....	26
Figure 30: Calculation of strain gauge in block diagram - formula note.....	27
Figure 31: Synchronous and Rotor speed vs. Frequency .....	30
Figure 32: No-Load – Voltage, Current and Power vs. Frequency .....	31
Figure 33: No-Load – Force and Torque vs. Frequency .....	32
Figure 34: Full-Load @35Hz – Voltage, Current and Power vs. Frequency .....	33
Figure 35: Full-Load @35Hz – Force and Torque vs. Frequency.....	34
Figure 36: Control and Monitoring Interface.....	41
Figure 37: NI 6014 Hardware block diagram .....	42
Figure 38: NI 6014 pin connector.....	43
Figure 39: 3Wire VSD pin connector .....	44
Figure 40: Generator - Load Wiring Diagram.....	45
Figure 41: Overall System Wiring Diagram .....	46

## List of Tables

Table 1: 3-Phase AC Induction Motor Name Plate .....	12
Table 2: DC Generator Specification .....	12
Table 3: AI measurement precision .....	18
Table 4: Frequency Input Setup .....	24
Table 5: Data on Calibrating Load Cell .....	28
Table 6: Data on Synchronous and Mechanical Speed .....	29
Table 7: No-Load –Voltage, Current and Power .....	31
Table 8: No-Load – Force and Torque.....	32
Table 9: Full-Load –Voltage, Current and Power .....	33
Table 10: No-Load – Force and Torque.....	34



## Acronyms and Symbols used in this Thesis Report

VSD	Variable Speed Drive
DC	Direct Current
AC	Alternating Current
NI	National Instrument
DAQ	Data Acquisition
SSR	Solid State Relay
LabVIEW	Laboratory Virtual Instrument Engineering Workbench
VI	Virtual Instrument
SG	Strain Gauge
AISENSE	Analog Input Sense
AI	Analog Input
AO	Analog Output
I/O	Input / Output
A	Ampere
V	Voltage
kV	Kilovolts
mV	Millivolts
$\mu\text{V}$	Microvolts
I	Current
R	Resistance
P	Power
Hz	Hertz
$\Omega$	Ohm
kg	Kilogram
kgf	Kilogram – force
m	Meter
$\text{m/s}^2$	Meter per second square
N	Newton
N.m	Newton – meter
kW	Kilowatt
HP	Horse Power
RPM	Revolution per Minute
@	At
$\eta_{sync}$	Synchronous Speed of Induction Motor
$\eta_{slip}$	Slip Speed
$\eta_m$	Mechanical Speed of the Motor (Rotor Speed)
f	Frequency
P	Number of Pole
$E_{ind}$	Induced Voltage
$v$	Magnetic fields velocity on the bar
$B$	Vector of Magnetic Flux Density
$l$	Length of conductor in the Magnetic Field
$E_g$	Integrated Voltage
$I_A$	Armature Current
$I_L$	Line Current

USB	Universal System Bus
PCI	Peripheral Component Interconnect
CPU	Central Processing Unit
ADC	Analog – to – Digital Converter
DAC	Digital – to – Analog Converter
HMI	Human Machine Interface
NRSE	Nonreferenced Single-Ended
DIFF	Differential
PGA	Programmable Gain Instrumentation Amplifier

Additional Information	
Wye	Is one of the types of three-phase electrical connection. A wye connection is when an AC system are connected at a single point and also known as Y-configuration.
Tachometer	A devise that measures the speed of the rotor in revolution per minute.
Proximity sensor	A devise that was attached to the induction motor that measures the rotation of the rotor in revolution per minute.
Dataforth	Is the name of the supplier of some devices used in the thesis and specialise in data acquisition, signal conditioning and filtering.

*This page is intentionally left blank.*

## 1 Introduction

The motor generator project involves developing a computer-based communication and control system to display various output values so that it can be used as a learning tool for the students associated in the field of Electrical Power Engineering and Industrial Computer System Engineering. The system of the motor-generator setup has two sides which are the field side and control side.

The field side consists of a 4 kilowatts three-phase induction motor coupled to a DC generator that, the motor is powered by a Variable Speed Drive (VSD) and the generator feeds a Load bank that comprises different values of resistors.

The control side of the system consists of individual modules that are connected to their respective devices such as Dataforth, a Solid State Relay (SSR), and a National Instruments Data Acquisition Unit (DAQ) that provides the system with the capability to send and receive information. The DAQ uses LabVIEW software as the control and monitoring program for the motor generator.

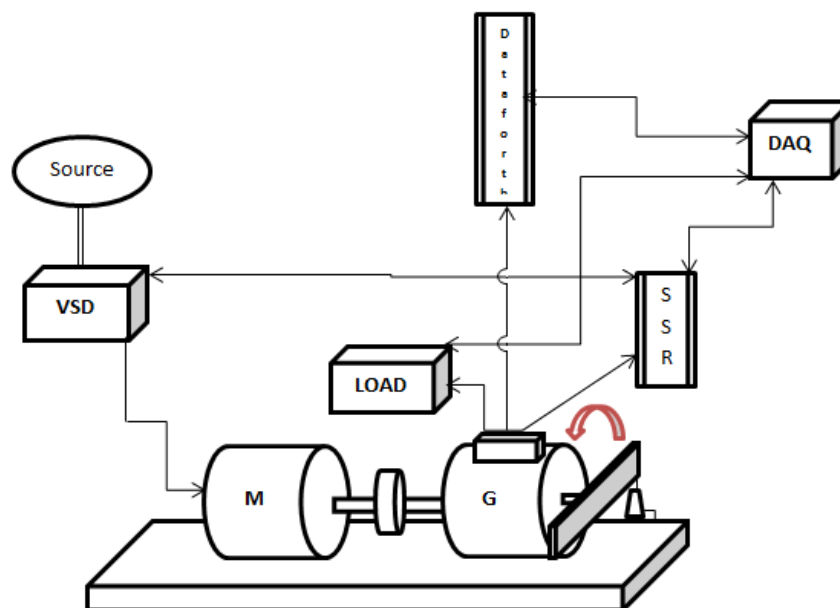


Figure 1: Motor Generator Setup

## 1.1 Thesis Objectives

The general aim of the project is to get the apparatus operating correctly and establish accurate communication and control between the equipment and computer. The specific aims are:

- To investigate the effects of the VSD on the motor, the effects of rotor speed on the generator, and the effects of loads on the generator.
- To design and implement a working communication and control program for the system using LabVIEW software.
- To display real-time Output Data on the computer via a LabVIEW program. This data includes:
  - Voltage
  - Current
  - Torque
  - Speed

## 1.2 Motor-Generator Dynamometer

The main piece of equipment for this project is the motor-generator set, which consists of a 3-phase induction motor with a specification of 4 kW, 415 rated voltage, a frequency of 50 Hz and speed of 1400 rpm. The induction motor is mechanically coupled through a common shaft to a 5 kilowatts DC generator rated at 220 Volts and 22.75 Amps. This motor generator set is powered by an Allen Bradley Variable Speed Drive.

## 1.3 National Instrument Data Acquisition

A National Instrument Data Acquisition device was used to act as the interface between the hardware and the computer. It receives the incoming signals from the field and then the computer with programmable software can interpret the signals [1]. The communications are done via an NI 6014 DAQ card, with LabVIEW version 2015 software as the control and monitoring program for the motor generator. The NI 6014 DAQ unit features a 50-pin connector with eight channels for Digital I/O, 15 channels for analog input, one channel dedicated to AI SENSE and two channels for analog output [2].

## 2 Background and Literature Review

Prior to commencement of this project, the state of the Motor Generator Dynamometer system was a compilation of work done by Murdoch University engineering students over the previous five years. This project had been handed from student to student in the ENG454 Industrial Computer System Design unit for learning purposes. Since 2011 as seen from figure2, the design of the equipment and programs for the motor generator system has been changed by the students who have worked on the system throughout the years. The components used in Motor Generator Dynamometer Setup project are described in the following sections.

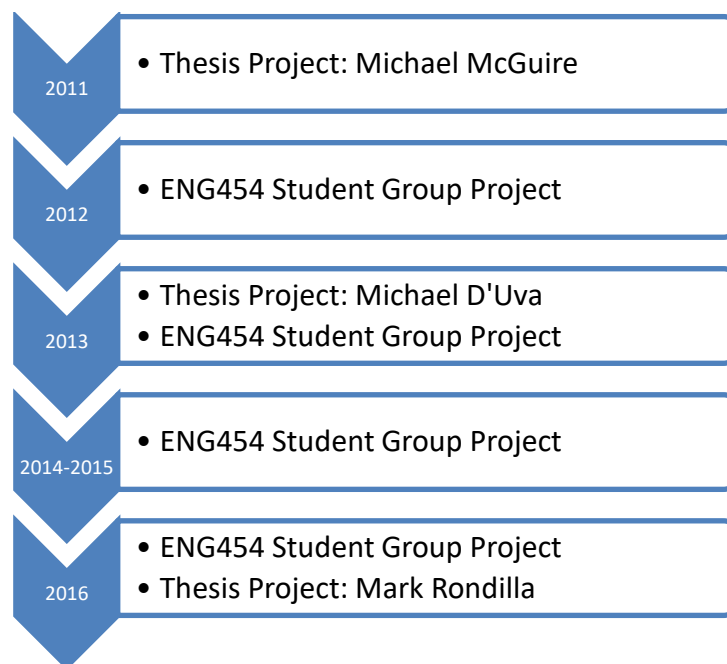


Figure 2: Background of the Project

The initial state of this project was that the induction motor was burned by a group of students in the ENG454, but later on a new three-phase induction motor was installed. Some of the wirings are modified to accommodate the new induction motor. The software program were modified to accurately measure and calculate the output data on the computer.

### 2.1 Variable Speed Drive (VSD)

The Variable Speed Drive, also known as Variable Frequency Drive, is an electrical device that varies the speed of an AC induction motor. In other words, the frequency controls the RPM of the induction motor. Factors that need to be considered before the frequency can alter the speed of the motor are the number of poles in the stator and the frequency of the supply voltage. Generally, a Variable Speed Drive system involves AC motor, controller, and operator interface. The most

common motor attached to a VSD is a 3-phase induction motor because of its versatility and cost-effectiveness compared to other motors. [3].

## 2.2 Induction Motor

The family of motors is separated into different types and classifications as show in figure 3. The two main types of motor are Direct Current (DC) Motors and Alternating Current (AC) Motors. Under AC motors, there are synchronous motors and Asynchronous (Induction) motors. There are two types of induction motor, which are Squirrel Cage and Slip-Ring [4, 346-466]. The squirrel cage 3-phase induction motor was used in this project to couple with a generator. It will be discussed in more detail later in this section.

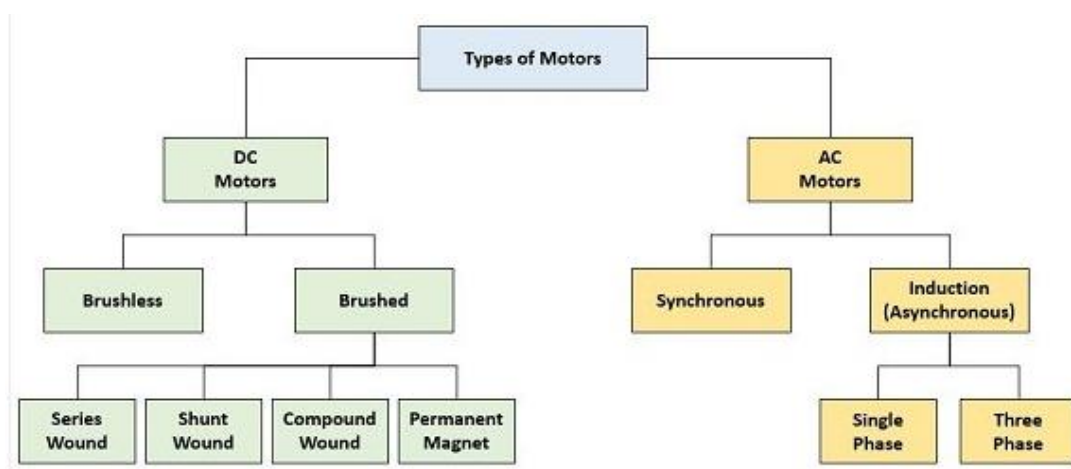


Figure 3: Branches of Motors [5]

### Synchronous Motor

In synchronous motors, currents in the rotor winding are supplied from the stationary frame (stator) of the motor through a rotating contact [6]. The synchronous motor and synchronous generator are the same physical machine [4, 346-466]. The speed of rotation of a synchronous motor is constant; from no load to maximum load on the motor, the speed is given by [4, 346-466]:

$$\eta_m = \eta_{sync} = \frac{120 * f}{P}$$

Equation 1: Synchronous Motor Speed of Rotation

where  $\eta_{sync}$  is the Synchronous Speed of Induction Motor,

$\eta_m$  is the Mechanical Speed of the Motor (Rotor Speed),

f is the Frequency in hertz, and

P is the Number of poles in the machine

## Asynchronous Motor

In an asynchronous machine or induction motor, currents are induced in the windings of the rotor by the motion of the rotor relative to the stator and the time variation of stator currents [6]. The physical stator of the induction motor is the same as the synchronous motor, but the rotor has a different construction. The induction motor has two different types of rotor, which are cage rotor and wound rotor [4, 346-466].

### 2.2.1 3-Phase Induction Motor

The 3-phase AC induction motor is generally used in power stations and industry to produce a significant amount of power. It is a relatively simple motor that only requires power to be connected to its stator. It is durable, extremely reliable, even when used in a harsh environment [7]. The 3-phase induction motor consists of two major parts, the stator and rotor, as shown in figure 4. The stator is the stationary part, having coils supplied with actuating current to generate a rotating magnetic field. The rotor is the rotating part that's attached to the shaft; and it derives its torque from the rotating field. The principles of the 3-phase induction motor are that a continuously rotating field flux around the air gap is produced by the stator windings, and that its rotating field flux will induce currents in the rotor conductors. It will then generate torque that will make the rotor spin and convert the electrical energy into mechanical energy that can be drawn from the motor shaft [7].

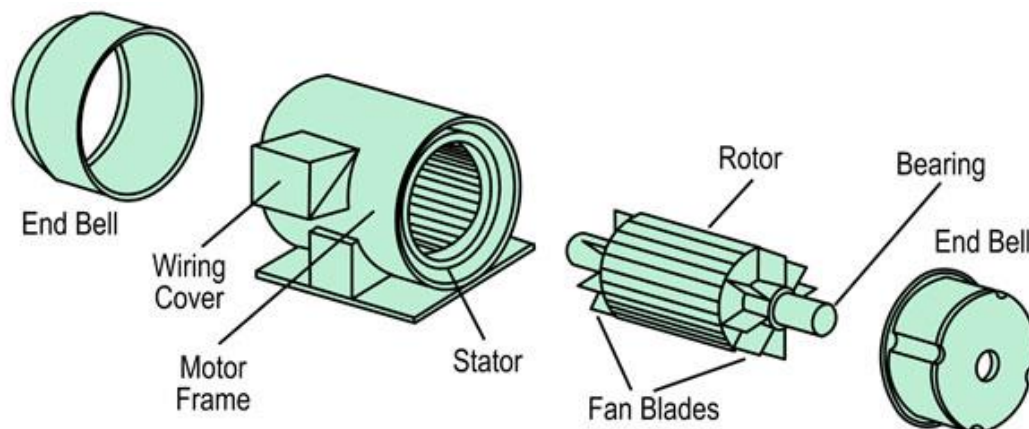


Figure 4: Induction motor components [8]

### 2.2.2 Rotor of Induction Motor

The rotor is the rotating part of induction motor, which is connected to the mechanical load through the shaft. The two types of a rotor in a 3-phase induction motor are classified as squirrel cage rotor and wound rotor.



**Cage rotor** – A cage rotor is referred to as squirrel cage rotor because it looks like one of the wheels that squirrels runs on (see figure 5). The Cage Rotor is the most common type of rotor used in an induction motor because it is simple to construct, it is relatively inexpensive and it is robust. It has a cylindrical laminated core with copper, aluminium or alloys used for conductors. The rotor consists of a series of conducting bars located in the face of the rotor and short circuited at the ends by a large ring. The cage rotor is more efficient than the wound rotor [4, 346-466].

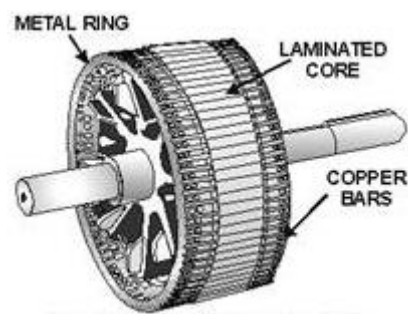


Figure 5: Squirrel cage rotor [9]

**Wound rotor** – The wound rotor has a complete set of three-phase windings, similar to those on the stator. The three phases of the rotor windings are wye connected, and the three end terminals are connected to slip rings on the rotors shaft. A wound rotor is also called a Slip-ring rotor. The rotor windings are short-circuited through brushes on the slip rings. A Wound-rotor has rotor currents that flow through the rotors brushes where they can be investigated, and where external resistances can be added into the rotor circuit. If an external load is added in the circuit, then it is possible to change the rotor resistances to increase the torque in the motor. However, it is more expensive than cage rotors, and the brushes and slip rings require maintenance [4, 346-466].

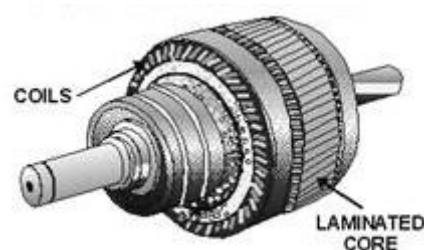


Figure 6: Wound rotor [9]

### 2.2.3 Concept of Rotor Slip

When a 3-phase voltage is applied to the stator, the stator currents will flow and produce a magnetic field. The speed of rotation of the magnetic field is called the synchronous speed of the motor, and is given by equation 1 [4, 384-387]:

The rotating magnetic field will pass through the rotor bars, and they will induce a voltage in the rotor bar as given by equation 2 [4, 384-387]:

$$E_{ind} = (v \times B) \cdot l$$

Equation 2: Faraday's Law of Induction

where  $v$  is the magnetic fields velocity on the bar,

$B$  is the vector of the magnetic flux density, and

$l$  is the length of conductor in the magnetic field.

The voltage induced in the rotor bar is dependent on the speed of the magnetic field. The rotor speed is slightly less than the synchronous speed. Thus the difference between synchronous speed and rotor speed is called slip speed. The relationship between the slip speed, synchronous speed, and rotor speed are given in equation 3 [4, 384-387]:

$$\eta_{slip} = \eta_{sync} - \eta_m$$

Equation 3: Slip Speed

where  $\eta_{slip}$  is the slip speed of the motor,

$\eta_{sync}$  is the Synchronous Speed of magnetic field, and

$\eta_m$  is the Rotor Speed

The relative speed of the motor as a per-unit is given by equation 4:

$$Slip = \frac{\eta_{sync} - \eta_m}{\eta_{sync}} * 100\%$$

Equation 4: Slip

If the slip is equal to zero, then the speed of rotation of the rotor is the same as the synchronous speed, while if the rotor is stationary the slip will be equal to one. The operating slip should be between zero and one. It is also possible to express the mechanical shaft speed of the motor in terms of slip and synchronous speed as shown in equation 5 [4, 384-387]:

$$\eta_m = (1 - Slip) * \eta_{sync}$$

Equation 5: Mechanical Shaft Speed

## 2.3 Generator

Electric generators are machines that convert mechanical energy into electrical energy. All generators are driven by a source of mechanical power that is called the prime mover of the generator [4, 594-619]. A form of energy could be transformed from one form to another which in this case the process of energy conversion between electrical and mechanical energy is known as electromechanical conversion [10]. A generator can be divided into two categories, which are Alternating Current (AC) generators and Direct Current (DC) generators as shown in figure 7. The basic principles of how AC and DC generators work are the same, but some details of the construction of AC and DC generator may differ, and the prime mover may be different [4, 230-533].

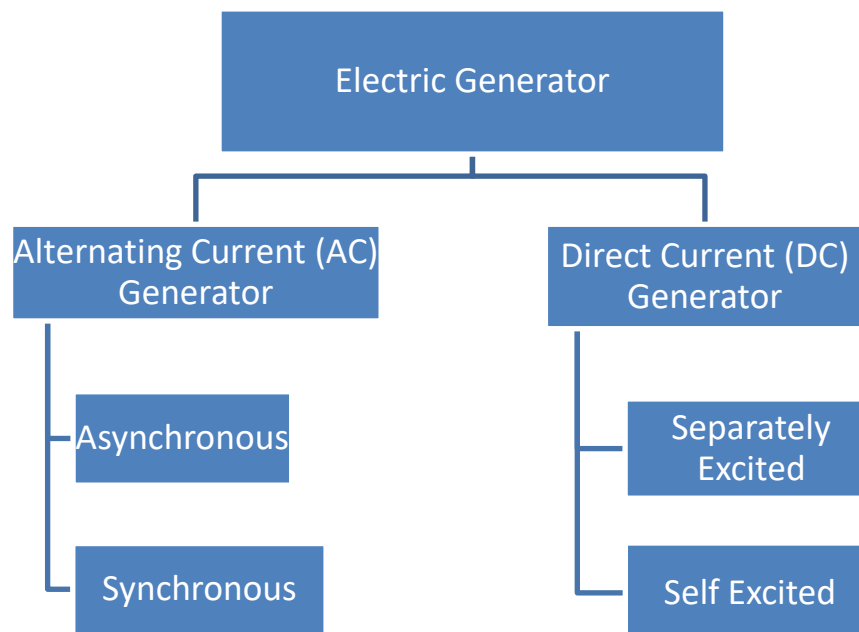


Figure 7: Branches of Electric Generator [4]

### 2.3.1 AC Generator

As mentioned in Section 2.3, the working principles of an AC generator is similar to the fundamental principles of a DC generator. Figure 8 shows that an alternating voltage is generated by the rotation (clockwise) of the coil in a magnetic field. The value of the voltage generated depends on the speed at which the magnetic field rotates and the number of turns in the coil [11].

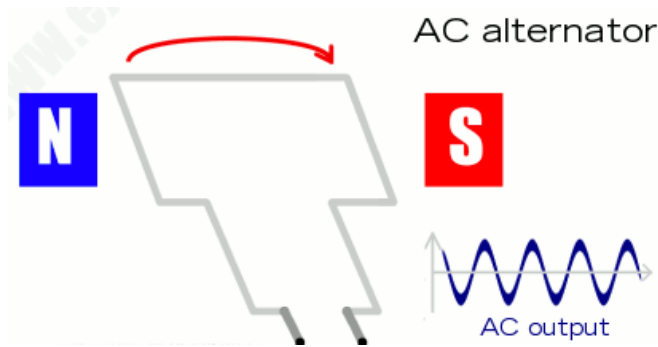


Figure 8: Rotation of magnetic field in AC generator [12]

### 2.3.2 DC Generator

As the name implies a DC generator generates direct current electricity. According to Faraday's Law of Electromagnetic Induction, the DC generator produces electrical energy when a conductor moves in a magnetic field where an electromotive force is induced in the conductor. The magnitude of induced electromotive force depends upon the rate of change in flux linkage with the conductor. The electromotive force will cause induced current to flow if the conductor is a closed circuit [13].

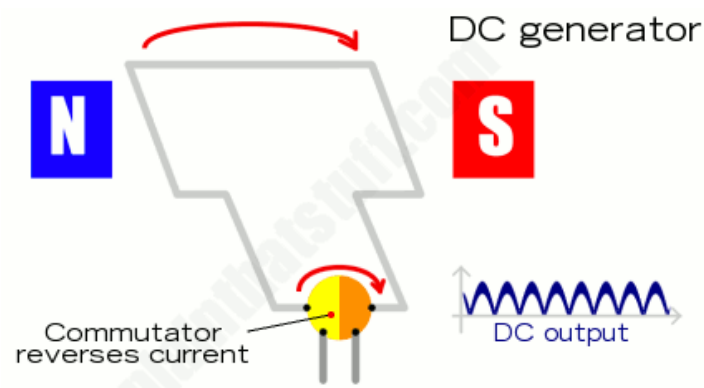


Figure 9: Rotation of magnetic field in DC generator [12]

There are five major types of dc generators, which are classified according to the produced field flux: separately excited generator, shunt generator, series generator, cumulative compounded generator and differentially compounded generator [4, 594-619]. The separately excited and shunt dc generators are the only types of generator that will be discussed in this project.

#### 2.3.2.1 Separately excited

The separately excited generator's field winding is powered by an external DC source, independent of the generator itself [4, 594-619]. The equivalent circuit of the separately excited generator is shown in figure 10. In this circuit, the voltage  $V$  represents the voltage measured at the terminal of

the generator and  $I_L$  is the line current which is flowing into the terminals. The armature voltage is  $E_g$  and the armature current is  $I_A$ . It can be seen that the armature current is equal to the line current [4, 594-619].

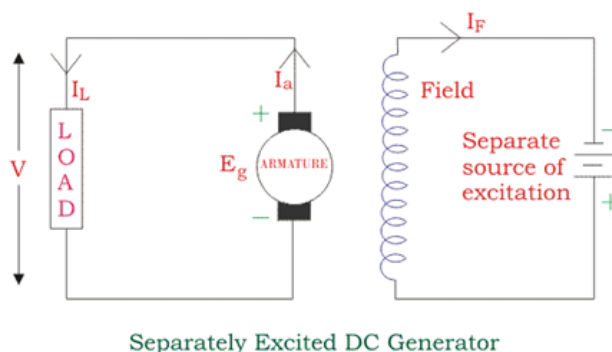


Figure 10: Equivalent circuit of Separately Excited [14]

### 2.3.2.2 Shunt dc generator

The shunt dc generator is a generator that supplies its own field current. It is also known as a self-excited generator, where the field coil is connected across the terminals of the machine [4, 594-619]. The equivalent circuit of the self-excited generator is shown in figure 11. In this circuit the sum of the field current and current supplied to the load is equal to the armature current [4, 594-619].

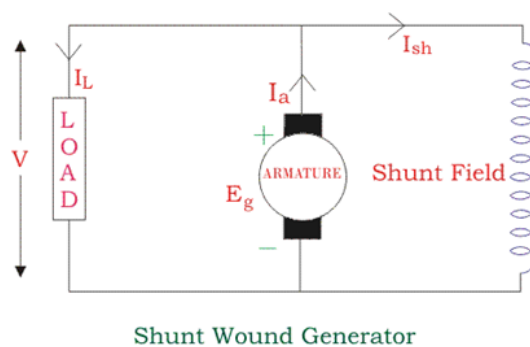


Figure 11: Equivalent circuit of Self-excited [14]

## 2.4 Data Acquisition (DAQ)

Data acquisition is the process of measuring physical phenomena, such as voltage, current, pressure, temperature or sound, with a computer. It is comprised of three parts: Sensor, Data Acquisition hardware and a computer with programmable software [1]. Most of the data acquisition can be classified as either an external box or an internal plug-in board. Some examples of an external box are Ethernet and Universal System Bus (USB), while Peripheral Component Interconnect (PCI) is

considered an internal system. The advantage of the external box is that the actual measurements can be located near the sensors and actuators [15]. The location of the I/O interface near to the actual measurement significantly reduces the length of the field wiring to connect the data acquisition system. The plug-in board systems have the advantage of closer connectivity with the CPU, which allows the plug-in board system to function at higher sampling rates when collecting the information data [15].

Figure 12 shows the process of measuring the signal: Data acquisition starts with measuring physical phenomena such as strain, a pressure inside the cylinder, temperature of the water inside the tank and much more [16]. The sensor converts the physical phenomena into a desired measurable electrical signal. Usually, the signal that the sensor receives is distorted by a lot of noise, so signal conditioning is required to filter the noise [1]. The signal conditioning is used before the DAQ hardware; it has features of amplification, filtering, sampling or hold: These features improve the performance and quality of the system [16]. In order to convert the analog signals into digital signals, DAQ hardware has a function of analog-to-digital conversion (ADC), that acts as the interface between the analog signals and a computer. Lastly, when the analog signal has been converted into a digital signal, the computer will be able to display the data [1].

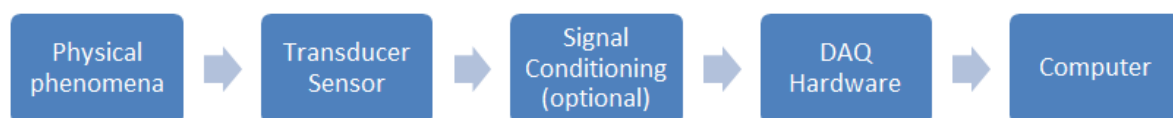


Figure 12: Process of measuring the signal [1]

### 3 Design Method

This project required the separate design of each section of the whole system, and then bringing the parts together to become a single unit. The system consists of a motor, a generator, load bank, variable speed drive and associated control and monitoring circuitry. Each part needs extensive research to understand its specification and purpose before implementing them in the system. The parameters and specification of the key corporals of the project are discussed in this section.

#### 3.1 Motor-Generator set

One of the major pieces of equipment shown in figure 1 is the motor-generator dynamometer setup. The performance of the induction motor is given in the specifications written on the name plate by the manufacturer, which is reproduced in Table 1. This data was investigated to understand the functionality of the induction motor.

**Table 1: 3-Phase AC Induction Motor Name Plate**

Manufacturer: RCG Electric Motor Group						
V	Hz	A	r/min	kW	FRAME: MSHE112M – 4	
415 delta / 720 wye	50	7.7 delta / 4.44 wye	1455	4.0	MNT: 88.3%	INS.CL.F
					IP 55	SERIAL NO:13080560291
					S1	BRG: DE 6306, NDE 6306
					AC TEFC PREMIUM MOTOR	39 Kg

From Table 1, it can be seen that to operate the induction motor it needs an input of 3-phase 415 Voltage with delta connected windings, which can be obtained from any three-phase 50 Hertz outlet. The rated current of the induction motor at full-load is 7.7 A with a speed of 1455 rpm.

The DC generator specification is written on its name plate, which is reproduced in Table 2. The generator has a rated output of 220V with a speed of 1450 rpm and a maximum output power of 5kW.

**Table 2: DC Generator Specification**

Manufacturer: K.L. Electric Co Pty Ltd		
DC Generator	Output: 5 kW	Type: ODX
Volts (rated): 220 V		Stator (rated): 22.75 A
HP: 5		Rating: Cont.
RPM: 1450		
Phase: DC		Style: 537/46
Stator Conn: Shunt Inter		Serial No: EI 2

Using the information on the name plate of the Induction motor and DC generator, the relevant output values that will be displayed on the computer are; Voltage, Speed, Current, and Torque.

**Voltage** – The output of the DC generator is the voltage that needs to be measured; this voltage can be measured across the output terminals of the generator.

**Speed** – The speed of the mechanical shaft is measured by using a tachometer, rather than a proximity sensor. Each time the motor runs at a specified frequency, the tachometer will measure the speed of the mechanical shaft. At this frequency, the synchronous speed can be calculated from equation 1, as the number of poles in the motor is 4. With known values for mechanical shaft speed and synchronous speed, the value of slip can be calculated.

**Current** – The current is calculated from the value of voltage and load attached to the generator. Unfortunately, the output current of the generator wasn't measured directly. It should have been measured using a current shunt and the Dataforth module, instead of using voltage and load resistance.

**Torque** – The torque is measured by using a Strain Gauge that is attached to the level arm of the generator. When the magnetic field starts to build in the generator the level arm of the generator will start to turn counter-clockwise, which will apply a force to the strain gauge. For further information refer to Section 4.6.

Throughout the previous years, the generator has been rewired many times. A group of students in ENG454 has wired the generator in both self and separately excited configuration, as seen in figure 13 and 14. The switching between self-excitation and separately-excitation is controlled by a relay [14].



Figure 13: Wiring in the terminal of generator [14]



It has been discovered that the generator has been running in the wrong direction (clockwise) for a long period of time, which had resulted in demagnetisation of the core. The group in ENG454 lead by Dave Pol re-magnetised the core: it outputs 72V when separately excited and 330V when self-excited [14].

### 3.2 Load Bank

The load bank is composed of different values of resistor that are connected to the generator output terminal. As seen in figure 15 the resistors configured in parallel to each other, with a solid state relay (SSR) that can enable or disable the resistor. The 303.1 $\Omega$  resistor is always connected to the generator output terminal. The resistances are 303.1  $\Omega$ , 150.2  $\Omega$ , 39.4  $\Omega$ , 20 $\Omega$  and 73 $\Omega$ , which can be configured into different values with 15 possible combinations.

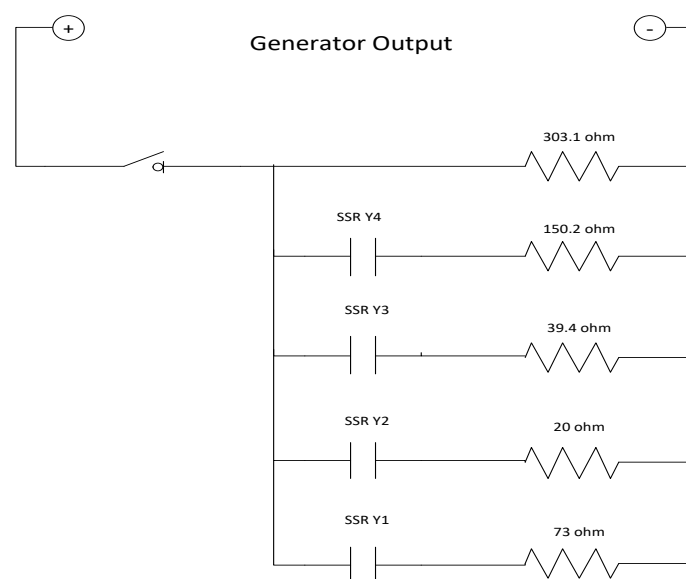


Figure 14: Equivalent circuit of Load Bank

### 3.3 Strain Gauge – Load Cell

A strain gauge is a device that measures changes in resistance that are proportional to pressure or force applied to the device. Strain gauge – load cell – is a mechanical element that senses the force by the deformation of a conductive metal or strain gauge on the element [17]. If a force is applied to the device, the strip of conductive metal will stretch and become skinnier, which changes the

electrical resistance of the conductive metal. However, if the force is compressive, it will broaden and shorten the conductive metal, which will result in a negative output value [18].

The load cell used in the project is configured in a Wheatstone bridge circuit consist of four strain gauges. Figure 16 shows the Wheatstone bridge configuration with four separate resistors. When the force is applied to the metallic strip of the strain gauges, there will be changes in resistance of the resistors [19].

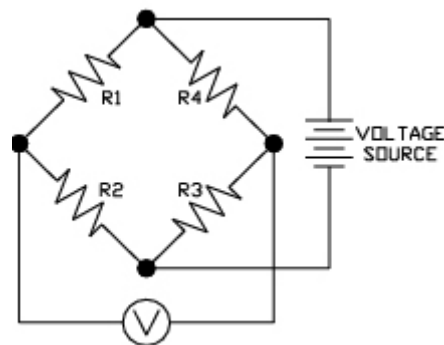


Figure 15: Wheatstone bridge circuit [19]

### 3.4 Dataforth Modules

Dataforth modules have been used in this project for amplifying and filtering the signal coming into the DAQ card. Dataforth modules are a renowned technology used in signal conditioning, data communication and acquisition products for industrial application. Figure 17 shows the essential elements, and the division between the field and control room [20].

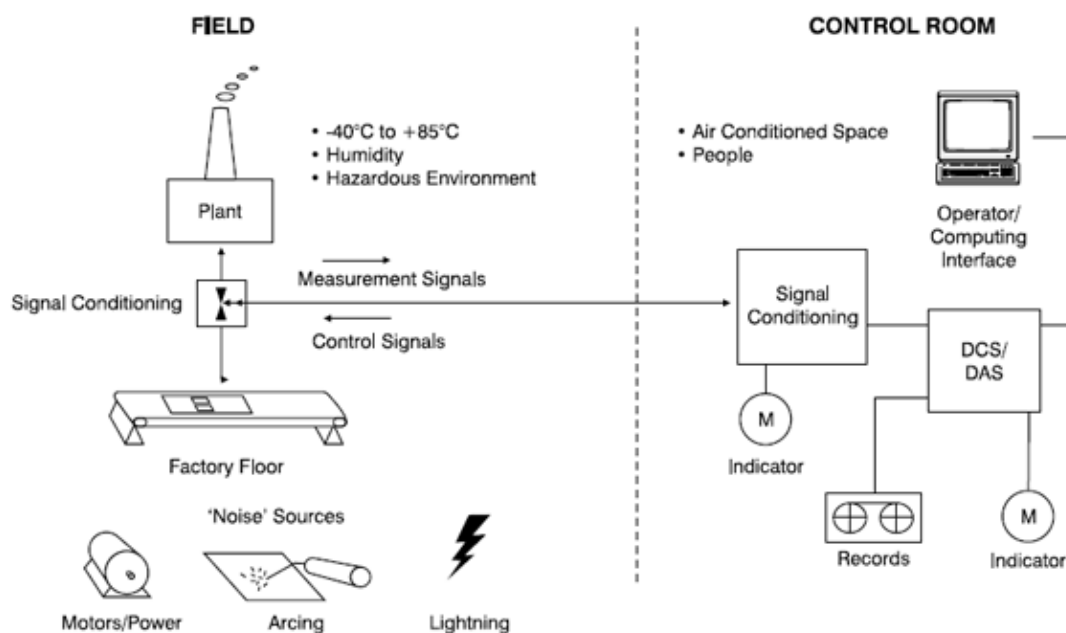


Figure 16: Signal conditioning in the field and control room [20]

The field is where physical phenomena that must be measured while all the measured variables are being processed in the control room where all the potential noise will be filtered out to produce a smooth signal.

### 3.5 Variable Speed Drive (VSD)

An Allen Bradley variable speed drive was used in the project. It has a function to control the start/stop and the direction (forward or reverse) of an induction motor manually or remotely. The VSD has a human machine interface (HMI) panel that is used to configure the parameters and control the device manually. The VSD has a 20 pin terminal block (see Appendix D): In figure 18 the terminals 2 and 3 are used to control the speed of the VSD by applying a voltage variable ranging from 0 to 10V signal across the terminals [21].

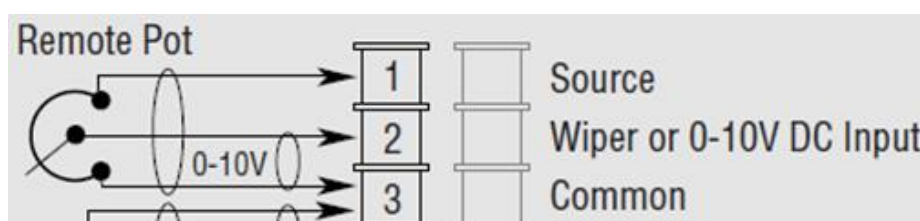


Figure 17: VSD Frequency control terminal [21]

Terminals 6 and 8, which are used for start and stop respectively, must be connected to terminal 7 (common) to complete the circuit as shown in figure 19. The wiring diagram is provided by the manufacturer [21].



Figure 18: VSD Start & Stop control terminal [21]

The emergency stop is a normally closed switch. The emergency stop switch has been connected between terminals 11 and 12, which are enable and common respectively of the terminal block. If the emergency stop is disengaged, then the circuit between the terminal 11 and 12 is complete (see figure 20) [21].

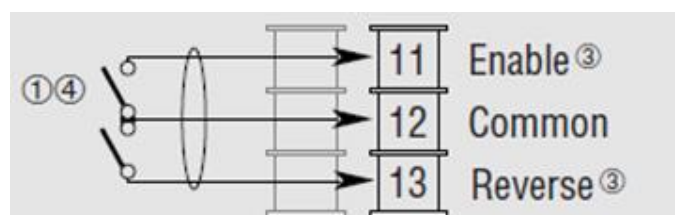


Figure 19: VSD Enable & Reverse control terminal [21]

When the emergency stop is engaged, then the circuit between terminal 11 and 12 is opened. As a result, it will halt the induction motor and the VSD monitor will display a message of “Not Enabled”. This state of the VSD will remain until the emergency stop button is release after the reset of the emergency stop, after which the condition of the VSD will be enabled again [21].

## 4 Implementation

This phase of the project involves the construction of the project parts. The necessary parameters are to be monitored that will help the students to evaluate the results. To develop a computer based communication and control system first is the signals coming from the field devices [22].

### 4.1 National Instrument Hardware

#### 4.1.1 Data Acquisition Card

National Instrument PCI-6014 was used as the interface between the field signals and Computer. The NI 6013 data acquisition unit features a 50 pin connected with 16 channels for eight differential, 16-bit analog inputs, two channels of 16-bit analog output, and eight channels of digital I/O that can be individually configured for either input or output [23].

#### Analog Input

In AI section of the data acquisition unit has two analog input modes – nonreferenced single-ended (NRSE) mode and differential (DIFF) mode. Nonreferenced Single Ended mode provides 16 channels, and if a channel is configured in NRSE mode it uses one analog input line which connects to the positive input of the programmable gain instrumentation amplifier (PGIA) and the negative input of PGIA is connected into AI sense (AISENSE). The differential mode provides eight channels, and if a channel is configured in DIFF mode it uses two analog input lines: The first line is connected to the positive input of a PGIA on the device and the second line is attached to the negative input of the PGIA [23].

Each channel of the NI 6014 has a bipolar input range that changes with its gain. The gain can be programmed as 0.5, 1.0, 10 and 100 to maximize the Analog-to-Digital Converter resolution. Table 3 shows the different gains with their input ranges and precision [23].

Table 3: AI measurement precision [23]

Gain	Input Range	Precision
0.5	-10 to + 10 V	305.2 $\mu$ V
1.0	-5 to +5 V	152.3 $\mu$ V
10.0	-500 to +500 mV	15.3 $\mu$ V
100.0	-50 to +50 mV	1.53 $\mu$ V

Analog inputs are used to receive the analog signals coming from the motor generator. The inputs receive the Strain Gauge output data, generator field voltage and armature voltage output. The proximity sensor is wired as well into an analog input, but unfortunately, it's not attached to the

induction motor to measure the speed of the mechanical shaft. The induction motor doesn't have any holes for the bolts of a proximity sensor can attach to.

### Analog Output

The NI 6014 provides two channels for analog output, both are 16-bit AO I/O connectors. These have  $\pm 10$  V fixed bipolar output ranges [23]. Figure 21 shows the wiring diagram for the analog output connected to the variable speed drive.

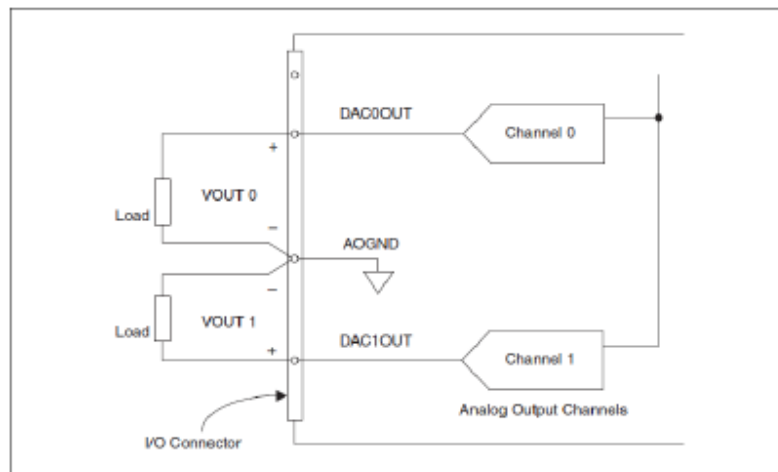


Figure 20: Analog output connection [23]

### Digital I/O

As discussed in data acquisition card implementation, the digital I/O has eight lines from DIO0 to DIO7 for general purpose. Software is used to individually configure each line into input or output [23]. Figure 22 shows the connections and purposes of the digital I/O: The line DIO0 was used for starting the VSD; DIO1 was used for stopping the VSD; DIO2, DIO5, DIO6 and DIO7 are connected into the generator's load1, load2, load3 and load 4 respectively; DIO3 was configured into switching the excitation of the generator from self-excitation to separately excitation; Lastly, DIO4 was connected into the VSD's control for enable and disable, as it needs to be enabled first before starting up.

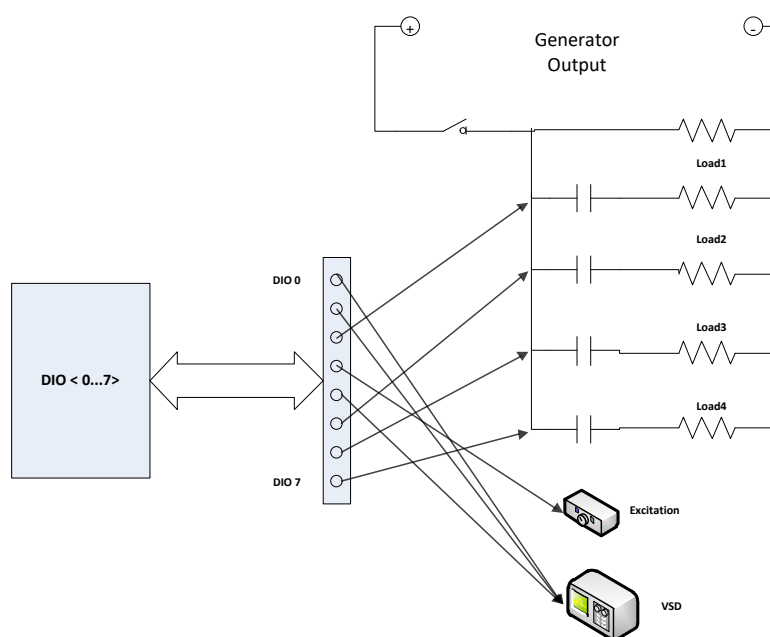


Figure 21: Digital I/O connections to field

#### 4.1.2 Dataforth Modules

Dataforth modules used in this project are the SCM5B38 and SCM5B31 modules. There are currently three Dataforth modules being used; they are a SCM5B38 for Isolated Strain Gauge Input, and two SCM5B31s for Isolated Voltage Input.

SCM5B31 – This module is called Analog Voltage Input; it is connected to the output terminal of the generator to measure the field voltage and armature voltage. It provides a single analog input channel which is filtered, isolated and amplified. After the field side filtering it converts the signal into a high-level analog voltage output [24].

SCM5B38 – This module called Strain Gauge Input has features similar to the Analog Voltage input module. This module is connected directly into the load cell that measures the force applied by the level arm of the generator in the strain gauge; it provides a single analog input channel, for a signal that will be filtered, isolated, amplified and converted into high-level analog voltage output [25].

#### 4.2 Software

Data acquisition software is needed in order for the NI 6014 unit to work with the computer. The driver of the device performs writes and reads on the hardware, and the software allows a computer to perform tasks such as transferring and storing of the data. With the use of software, computers are able to process the sampled signal and later display these in waveform or tabular form that are easy to understand.

### 4.2.1 LabVIEW

The Laboratory Virtual Instrument Engineering Workbench, also known as LabVIEW, is a system developed as a visual programming language by national instruments [26]. The software used with the data acquisition hardware is National Instruments LabVIEW version 2015. The LabVIEW program uses graphical data flows, formula nodes for putting mathematical formulas into simple form, and simulation diagrams, all for the purpose of modelling and analysing dynamic systems [27]. LabVIEW programs are called virtual instruments or VI due to the appearance of the components and operations that emulate real equipment like an oscilloscope, multi-meter and many more. It contains extensive tools for analysing, displaying and storing data [28].

#### Front Panel

When the VI is opened a window appears called the Front Panel. The front panel is the interface between the user and the VI; where the user can interact with the program. The Front panel features numerous controls and indicators of data types; Numeric, Boolean and String. Controls and indicators are the inputs and outputs respectively of the front panel [28].

#### Block Diagram

The Block diagram is the second window that appears when the VI is opened: It has objects that include terminals, subVI, nodes, functions, constants and wires that transfer the data between blocks. The block diagram window contains a graphical representation of functions to control the objects in the front panel [28].

### 4.2.2 Features in LabVIEW

The LabVIEW program will be used as a start-up tool for future students who will continue to work on this project. The program has the necessary features to operate the motor generator setup as well as to display and records the fundamental output data.

#### 4.2.2.1 Variable Speed Drive Controls

In this part of the controls (see figure 23), the user can control the functions of the variable speed drive which enable or disable the VSD. With the start/stop button, the motor will start running as soon as the button is executed. There's an indication on the control whether the VSD is enabled or disabled; the same applies to the start or stop button. The user can freely choose the frequency of the VSD between 0Hz to 50Hz. The LabVIEW code has been modified to limit the frequency input so that the rate cannot be higher than 50Hz or lower than 0Hz. It has an excitation switch and indicator



which can choose the wirings on the terminal of the generator between self-excited or separately excited.

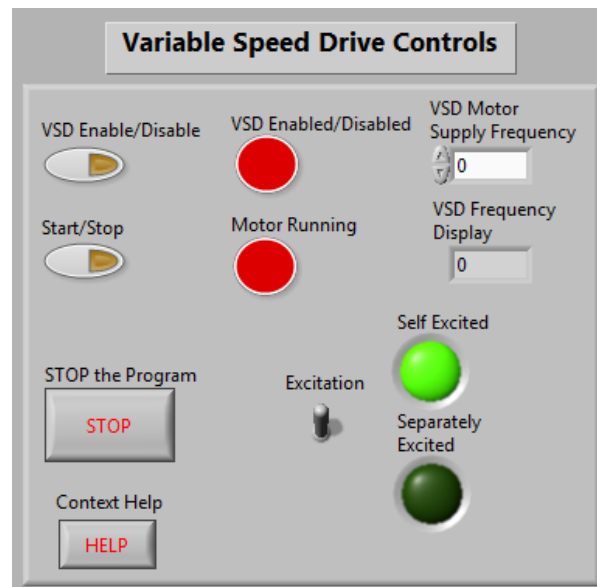


Figure 22: Front panel VSD control

#### 4.2.2.2 Load Controls

Figure 24 shows the control panel for the loads to attach to the generator. The user can freely manipulate the loads and whenever the load is active the indicator will turn green to indicate that the load has activated. If all four loads are disabled, the constant impedance is 303.1 ohms. It also shows the equivalent resistance connected to the generator.

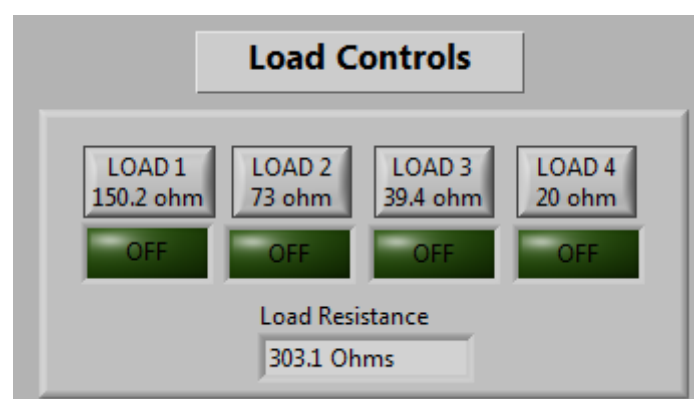


Figure 23: Front panel load control

#### 4.2.2.3 Data Display

All the necessary outputs such as voltage, current, power, speed, force and torque, are displayed in numeric form and as waveforms. The outputs are separated into their corresponding groups. The generator tab shows the field voltage and armature voltage of the generator. The frequency tab

indicates the speed of the rotation of magnetic field in the stator and the speed of the mechanical shaft. The strain gauge tab shows the waveform of the force applied to the load cell by the level arm of the generator and the calculated torque based on the length of the level arm. The power tab shows the measured value of the voltage output of the generator and resistance in the load bank while the current and power are calculated with respect to the output voltage of the generator. The last tab is Full data sets where all the relevant data are compared to each other. It is displayed as waveforms so that it can be easy to understand and analyze the changes in the system, as seen in figure 26.

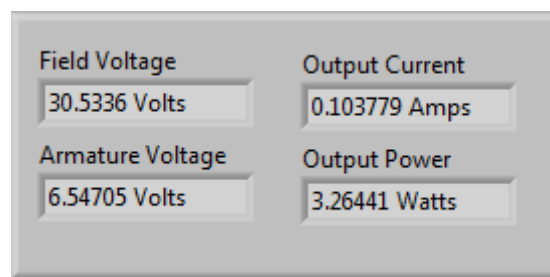


Figure 24: Field & Armature Voltage, Current and Power Outputs

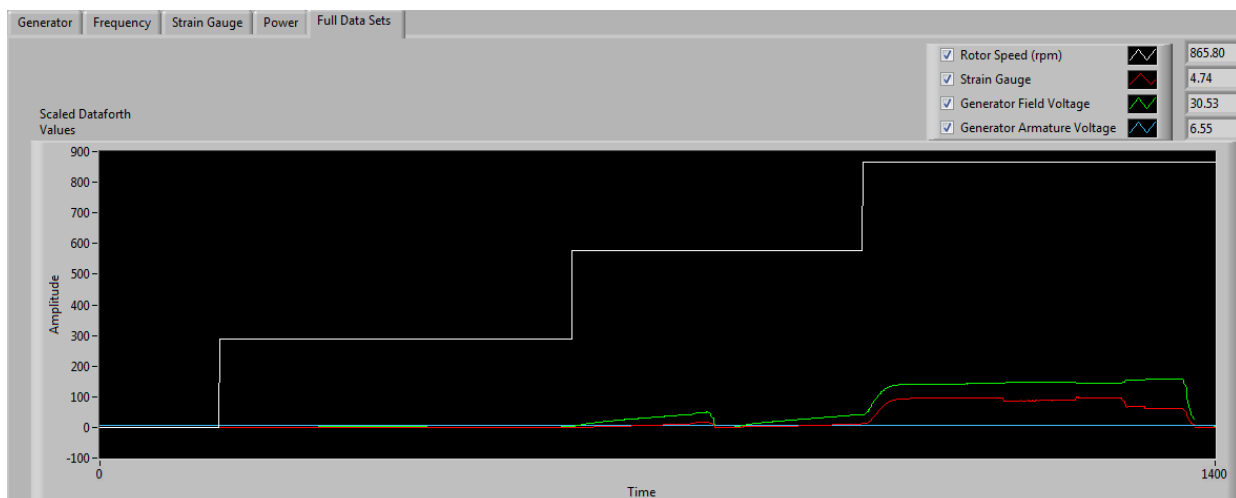


Figure 25: Output values in Waveform

#### 4.2.2.4 System indicators

System indicators have been added to the program for the user to identify whether the program is running or not. If the program is being executed, the indicator on the system will be flashing a green light that indicates the program is in working mode. If there is a fault in the system or in the program, the indicator will turn on a solid red light.



Figure 26: a) System Running Indicator, b) System Fault Indicator

#### 4.2.2.5 Data Logging

One of the features in the program is the ability to log the data into a text file. The data logging function is in subVI created for storing data only, as seen in figure 28. This features stores the data into a spread sheet and can be plotted for analyzing and comparing the data results.

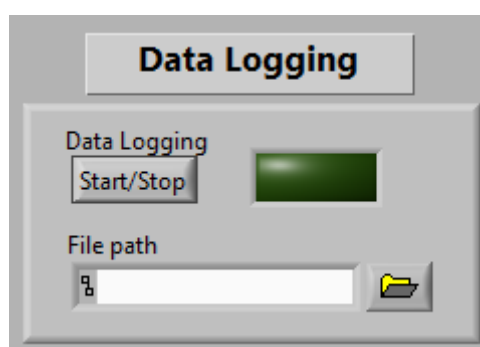


Figure 27: Data Logging

### 4.3 Calibration of VSD

The user manual '1305 Adjustable Frequency AC Drive (Series C)' by Allen-Bradley for the VSD is used to specifically change the parameters so they are compatible with the new three-phase induction motor. Under Setup in the table below, the Input mode, Frequency Select 1, Base Frequency, Base Voltage, Max Voltage, Minimum and Maximum frequency are the only parameters that have been changed to appropriate values, the other parameters are set to factory default value [21].

Table 4: Frequency Input Setup [21]

Setup	Parameters
Input mode	3W/2 <sup>nd</sup> Acceleration
Frequency Select 1	4-20 mA
Accelerate Time 1	10 sec

<b>Decelerate Time 1</b>	10 sec
<b>Base Frequency</b>	50 Hz
<b>Base Voltage</b>	415 V
<b>Max Voltage</b>	415 V
<b>Min Frequency</b>	0 Hz
<b>Max frequency</b>	50 Hz
<b>Stop Select</b>	Ramp
<b>Current Limit</b>	150 %
<b>Overload Mode</b>	No De-rating
<b>Overload Current</b>	10.35 Amps
<b>Sec Current Limit</b>	0 %
<b>Adaptive Limit</b>	Enabled

The Input Mode is set to 3W/2nd Acceleration to have a three wires connected to the 3-phase induction motor and second acceleration for the forward and reverse control. [21]. To match the parameters of the motor, the base frequency is changed to 50Hz with a minimum of 0Hz and maximum of 50Hz. The Base and Max voltage are changed as well to 415V.

#### 4.4 Synchronization of Control Panel to VSD

When the variable speed drive has been enabled and it starts running the start-up frequency of the VSD is 18.86Hz. To calibrate the VSD, a formula note was put in the analog output subVI block diagram of the control panel to calculate the frequency being sent to the induction motor. The formula note in the figure below shows the calculation to have a 1:1 ratio between the VSD and the program control panel. In the formula shown in figure 29, the V is the output voltage calculated based on the start-up frequency. The constant 18.825 and 6.2403 are values to get the output voltage between -3V and +5V. The voltage output values is scaled from -3V to +5V with a 4mA to 20mA signal, where -3V is the minimum voltage for the 4mA signal and +5V is the maximum voltage for the 20mA signal.

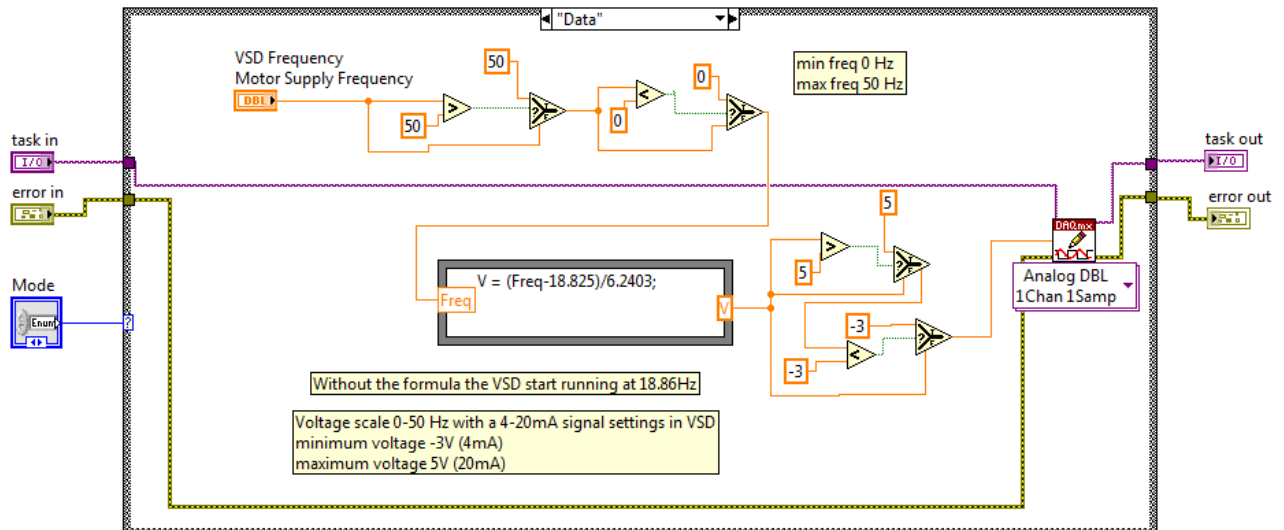


Figure 28: VSD frequency control from block diagram

## 4.5 Full-Load Limits

In the full-load condition, the figure below shows the logic circuit where the frequency is limited to 35Hz. When all the individual loads are switched on, the maximum frequency of the VSD should be 35Hz. This limit was made to make sure that the generator is still running within its safe zone: When the frequency is at 35Hz and under full-load conditions, the power that from the generator is 3.192kW; whereas if the frequency is beyond 35Hz the generator will start to produce a spark and burning smell inside the generator. The cause of burning smell and spark is due to the friction made by the small turbine rubbing around its metal cage.

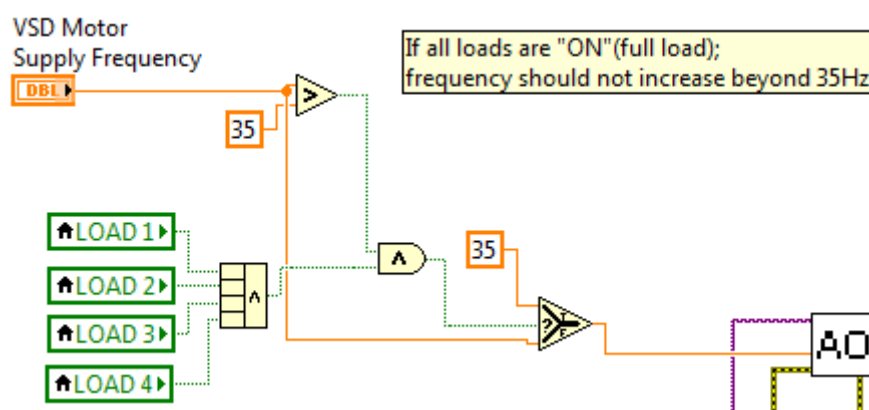


Figure 29: Limits on the Loads

## 4.6 Strain gauge

The torque that the motor applies to the generator is measured using a strain gauge that is attached to the side of the generator. The device used to measure the strain is a DBBP S-beam load cell. It is designed for industrial scale conversion and comprises of four pieces of a strain gauge in a Wheatstone bridge structure. The rated capacity of the load cell is 50kgf with a rated output of 3.0mV/V. This output will be amplified by the SCM5B38 – Strain Gauge Input module, with an output range from -5V to +5V. The capacity of the load cell is 50kgf (kilogram-force), where 1kgf is equal to 9.8N (newton).

The amplified output of the load cell would be 50kgf per 5V, which means that for every 10kilogram-force there will be an increase of 1 volt in the output. The conversion of kilogram-force per voltage to Newton per voltage is shown in the equation below.

$$Force = \frac{50 \text{ kgf}}{5 \text{ V}} * \frac{9.81 \text{ N}}{1 \text{ kgf}} = \frac{98.1 \text{ N}}{\text{V}}$$

The length of generator level-arm which is the distance from the point of measurement to the fulcrum is measured at 0.28 m. The calculation of the torque as a function of voltage is given by equation 6.

$$Torque = Force * Distance$$

Equation 6: Torque of Strain Gauge

Figure 31 shows the formula note created in the LabVIEW program to measure the force applied to the load cell, then the formula was inserted for the calculation of torque.

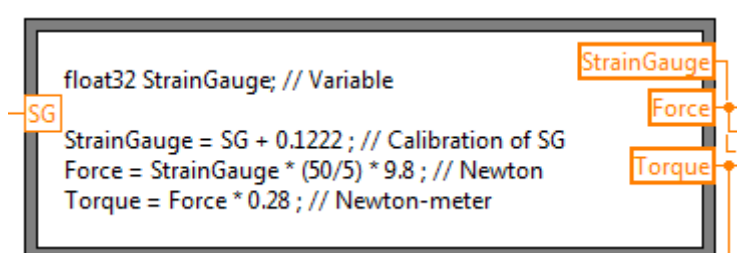


Figure 30: Calculation of strain gauge in block diagram - formula note

### 4.6.1 Calibration of the Load Cell

Before measuring the force generating by the level arm of the generator, it was calibrated first to verify the force outputting by the load cell. To verify the output generated by the load cell the method used is by using a metal mass weights of 1kg, 2kg, 5kg and 10kg.

Experimental Data: Use metal weights to determine the output voltage of SCM5B38 Dataforth module and calculate the force and torque with respect to the given value of gravity, strain gauge and the distance from the generator to load cell.

$$Gravity = 9.81 \text{ m/s}^2$$

$$SG = \frac{50\text{kg}}{5\text{V}} = 10\text{kg/V}$$

$$Distance (l) = 0.28 \text{ m}$$

By using the equations 6 and 7, the force and torque can be calculated

$$Force = Weight * SG * gravity$$

#### Equation 7: Force

Table 5: Data on Calibrating Load Cell

Weight (kg)	Strain Gauge (V)	Force (N)	Torque (N.m)
1	0.1	9.81	2.744
2	0.2	19.6	5.488
3	0.3	29.4	8.232
4	0.4	39.2	10.976
5	0.49	48.02	13.4456
6	0.59	57.82	16.1896
7	0.69	67.62	18.9336
8	0.79	77.42	21.6776
9	0.9	88.2	24.696
10	0.99	97.02	27.1656
11	1.9	186.2	52.136
12	1.2	117.6	32.928
13	1.29	126.42	35.3976
14	1.39	136.22	38.1416
15	1.49	146.02	40.8856

The data results from the experiment are given in the table. The value of 10kg corresponds to 0.99V, which confirms the proportional of the equation. Unfortunately there's no 50kg of weight to prove the output of 5V. Since there's no 50kg weight available, it was assumed that the risky extrapolation maximum weight is 50kg will correspond to an output of 5V.

## 5 Experimental Data & Results

The final stage of the project is the testing of apparatus which will acquire all the data associated with the project. The results of all the experiments conducted in this project will be discussed in three parts. The first part is the synchronous and mechanical shaft speed against frequency, where the induction motor runs at a specific frequency, and measurement taken of the synchronous speed of the motor and the rotation speed of mechanical shaft, as well as a calculation of the slip of the motor. The second part is the no-load condition, where the system is running at a particular frequency to measure the terminal voltage of the generator and calculate the current passing through the load. While the system is running without a load, the force applied to the strain gauge by the level arm of the generator is measured and the torque is calculated. The last part of the experiment is the same method as used in the second part, although in this case the system runs under full-load conditions where all the loads are activated in the system.

### 5.1 Synchronous and Mechanical shaft speed against frequency

The first part of the experiments is the synchronous and mechanical shaft speed against frequency. In this experiment, the induction motor runs at a specify frequency of 10, 20, 30, 40, and 50 hertz whilst the induction motor runs at the given frequency the synchronous speed are being calculated and the mechanical shaft speed are being measured by using the tachometer. Table 6 gives a comparison between the stator's magnetic field speed and rotor speed at the same frequency. In theory, the rotor speed should be less than the synchronous speed and should not be equal to the synchronous speed. The rotor speed was measured using a tachometer, the slip was calculated, where the slip is the difference between the synchronous speed and rotor speed.

**Table 6: Data on Synchronous and Mechanical Speed**

Frequency (Hz)	Synchronous Speed (RPM)	Mechanical Shaft Speed (RPM)
10	300	288.6
20	600	577.2
30	900	865.8
40	1200	1154.4
50	1500	1443

Equation 1, as discussed in the concept of rotor slip, calculates the synchronous speed of the motor, where the number of poles in the induction motor is 4. Since the frequency is given and the number of poles is known, then the speed of the magnetic field in the induction motor can be calculated.

As seen in Table 6 above, the maximum speed of the mechanical shaft is 1443 rpm, which is less than the synchronous speed of 1500 rpm.



When the calculated value for synchronous speed and the measured value of rotor speed are known, then the slip can be calculated by using equation 4 (see concept of rotor slip). At maximum speed, the calculated slip is 0.038. As discussed in Section 2.2.3, the slip should be between 0 and 1.

Figure 32 shows the difference in speed of the stator and rotor against frequency, as the frequency increases the synchronous speed increases as well, while the rotor's speed is 3.8% less than the speed of stator's magnetic field. This only shows that the rotor of the induction motor can speed up to be close to synchronous speed, but it can never be equal to synchronous speed.

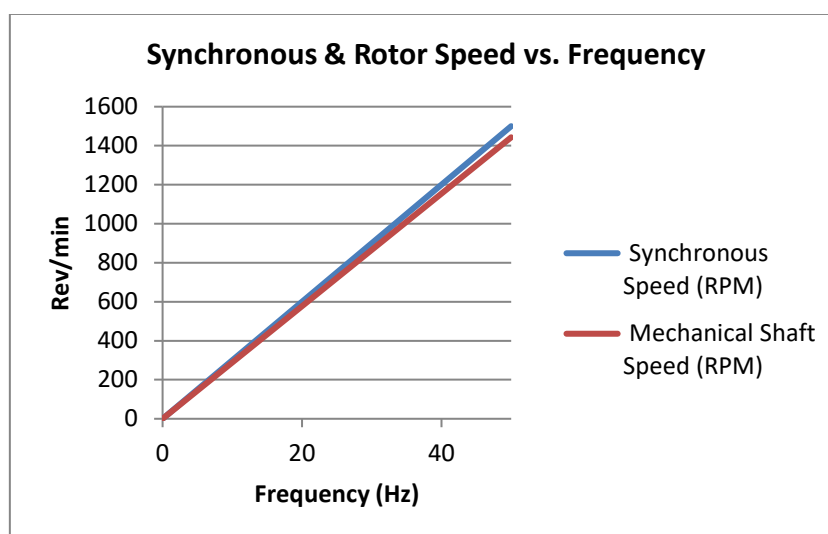


Figure 31: Synchronous and Rotor speed vs. Frequency

## 5.2 No-Load Condition

The system runs under no-load conditions, when all the loads are deactivated except for the 303.1 ohms, which is the constant impedance connected to the generator. When the system is running at a particular frequency the voltmeter was used to measure the output voltage of the generator and calculate the current.

The results shown in Table 7 were measured under no-load conditions. The maximum output voltage across the generator's terminals was measured at 285V. Since the voltage is known, and the resistance value is 303.1 ohms, the current can be calculated by using ohm's law, See equation 8:

$$V = IR$$

Equation 8: Ohm's Law

where V is voltage

I is current, and

R is resistance

The power generating in the generator is calculated by using equation 9:

$$P = VI$$

Equation 9: Power formula

Table 7 shows the data gathered in the experiment. At maximum speed, the power delivered by the generator is 269.207 W, whereas the rated output power of the dc generator is 5kW. Clearly, the maximum power under no-load conditions is relatively small compared to the rated output power of 5kW.

Table 7: No-Load –Voltage, Current and Power

Frequency (Hz)	Voltage (V)	Current (A)	Power (W)
10	4.7537	0.01568	0.07455
20	67.6843	0.2233	15.11
30	157.412	0.5183	81.4387
40	233.3063	0.7697	179.583
50	285.65	0.9424	269.207

Figure 33 displays the results found in Table 7, which shows more clearly the behavior of voltage, current and power when the frequency changes. The maximum speed of the induction motor coupled with the generator produces voltage, current and power values of 285.65V, 0.9424A and 269.207W respectively.

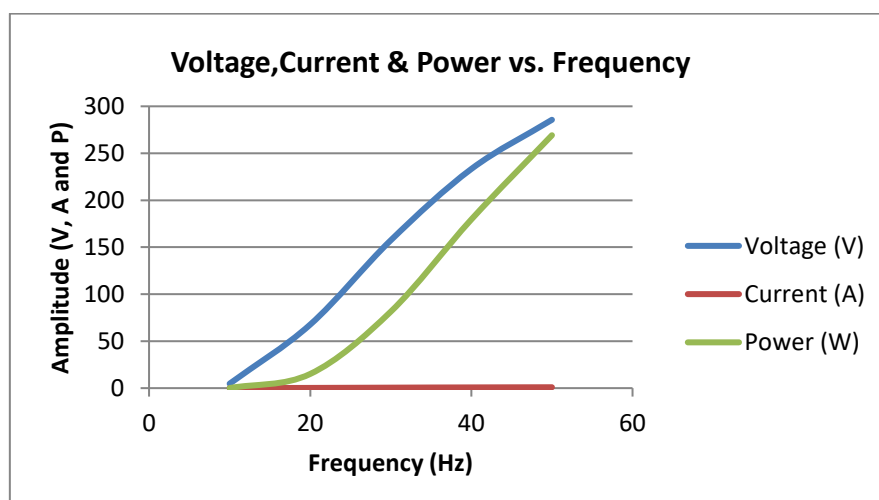


Figure 32: No-Load – Voltage, Current and Power vs. Frequency

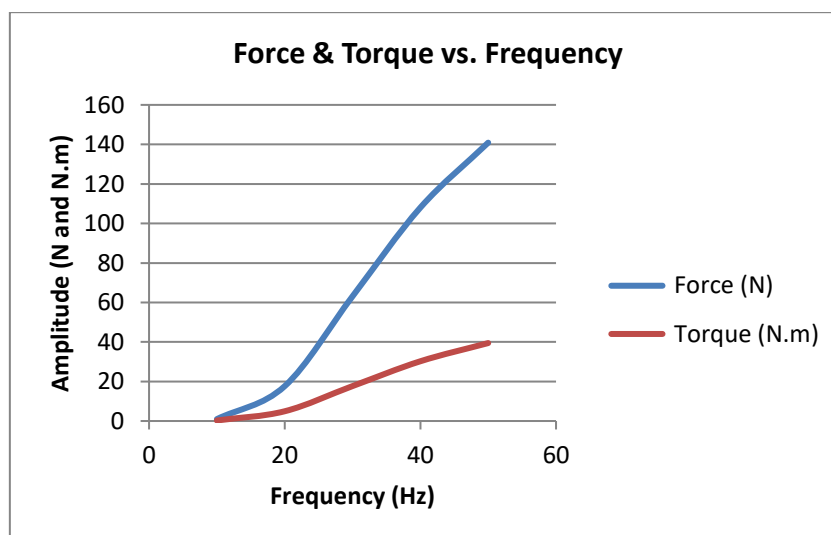
While the system is running without a load, the force applied to the strain gauge by the level arm of the generator is measured and the torque is calculated.

The force was being measured by the load cell with four strain gauge strips. As seen in Table 8, at maximum speed the force applied by the level arm of the generator is 140.89 Newton and produces a torque of 39.4492 Newton-meter.

**Table 8: No-Load – Force and Torque**

Frequency (Hz)	Force (N)	Torque (N.m)
10	0.955	0.2675
20	17.645	4.9406
30	63.136	17.678
40	108.021	30.2461
50	140.890	39.4492

Figure 34 illustrates the measured force in the strain gauge and the calculated torque against the frequency. It shows that if the distance of the load cell from the generator is four times its length, then the torque would be equal to the applied force.



**Figure 33: No-Load – Force and Torque vs. Frequency**

### 5.3 Full-Load Condition

The system runs under full-load conditions when all the loads are activated, with an equivalent resistance of 10.097 ohms. Under full-load conditions, the maximum speed that the generator can handle is 35Hz, as discussed in the section on full-load limits. Table 9 shows that there is a voltage drop in the load relative to its input resistance, but there's an increase in current and power. According to Ohm's law, if the resistance decreases, and if the voltage doesn't change then the current and power will increase. At 35Hz, the voltage, current, and power produced by the generator are 179.528V, 17.779A and 3192W respectively.

Table 9: Full-Load –Voltage, Current and Power

Frequency (Hz)	Voltage (V)	Current (A)	Power (W)
10	6.6654	0.66	4.4
20	67.602	6.695	452.6
30	146.61	11.858	2129
35	179.528	17.779	3192

The figure 35 shows that under full-load conditions at 35Hz, the calculated current is 17.779A which is seventeen times the value of the no-load current at full speed. The power increases tremendously under full-load conditions, to be 3192W at 35Hz, compared to the no-load condition of 269.2W at full speed.

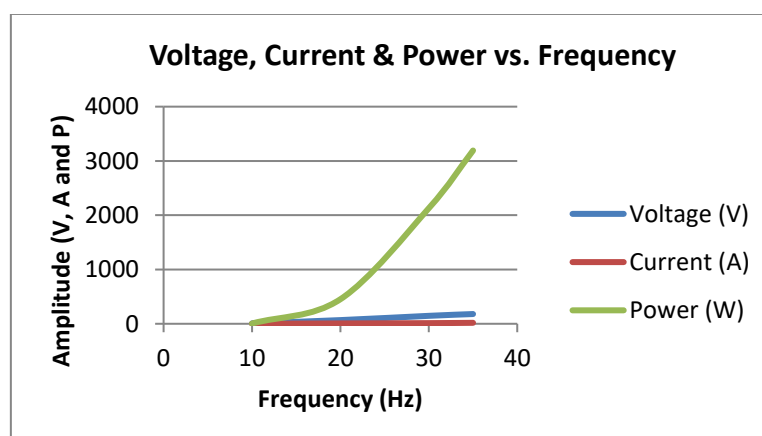


Figure 34: Full-Load @35Hz – Voltage, Current and Power vs. Frequency

Under full-load conditions, at 35Hz, the force measured by the load cell is 132.5146N and the calculated torque is 37.1041N.m (see table 10).

Table 10: Full-Load – Force and Torque

Frequency (Hz)	Force (N)	Torque (N.m)
10	1.3426	0.3759
20	24.9282	6.9799
30	98.1577	27.4841
35	132.5146	37.1041

Figure 36 illustrates the measured force in the strain gauge and the calculated torque against the frequency with a full load condition at 35Hz. It shows that there is an increase in force applied to the load cell by the generator. If the measured force increases then the calculated torque would increase as well.

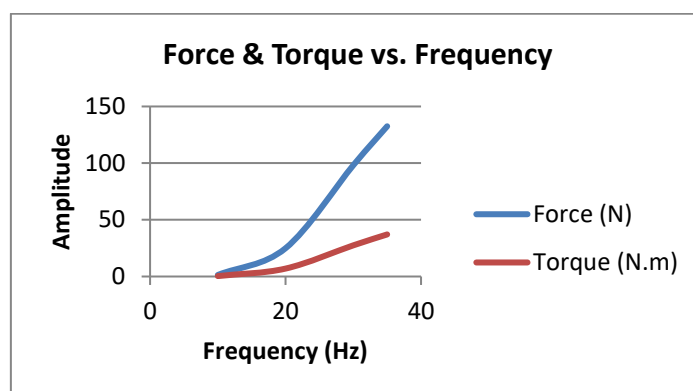


Figure 35: Full-Load @35Hz – Force and Torque vs. Frequency

## 6. Conclusion

The implementation of a communication and control program in the motor-generator setup using LabVIEW software, which reads and writes to the corresponding hardware through NI 6013 data acquisition unit, the filtering and amplifying signal using Dataforth modules, and the displaying the desired outputs of Voltage, Current, Torque and Speed has been accomplished.

The initial state of the motor-generator before starting the thesis was incomplete. The induction motor was burned by a group of students in ENG454, but later on a new 3-phase induction motor was installed.

The phases that were carried out in this project were; initiation, Design, implementation and testing. In the initiation phase, the work done was to compile and assimilate the literature review associated with motor-generator dynamometer setup. Within compiling and assimilating the literature review, a number of aspects were noted in the project. In particular, the equipment used had been damaged and had changed over the past years as well as the design of the LabVIEW program. In the stage of compiling all the reports, the installation of new induction motor into generator was assembled.

Within the design phase, the work done was to create a proportional control front view panel in the LabVIEW software, as seen in appendix A, for the user to control and monitor the inputs and outputs respectively. In the implementation phase, the project takes shape. All the information that had been covered in the design phase was implemented in the motor generator dynamometer setup. Within this phase, the calibration of the variable speed drive was conducted to have the same specification as the new induction motor. As discussed in the section in the synchronization of the control panel to VSD, the frequency output was successfully computed to have a ratio of 1:1 frequency. Lastly, the final phase was testing of the program that was created for the project. The results in the testing phase of the project were successful, all the desired output values such as voltage, current, torque, and speed were displayed on the front control panel of the LabVIEW program.

## 7. Future Works

There are possible improvements that can be made in the motor-generator dynamometer setup, as the small pieces of the whole system can be changed for better results. Several ways to improve the system are as follows:

1. Verify the Current measurements from the current shunt – one of the available modules in the Murdoch University is the SCM5B39 Isolated Current Output module, which has input ranges from -10V to + 10V and output range from -20mA to + 20mA. It has a feature of Digital-to-Analog Converter (DAC) mode which can be enabled or disabled freely by the users' command. As discussed in the 'Experimental Data and Results, the current calculated can be compared with the measured value of the current shunt.
2. Noise issues – the noise coming from the motor generator is affecting the signals received by the data acquisition card. One of the possible solutions is to change the wiring coming from the motor generator into shielded cables, as these can protect the other equipment from being disrupted by the electrical noise.
3. Investigate solutions to minimize exposure to high voltages. The motor-generator dynamometer setup can generate 4kW and 220V, which have the potential to cause injury. When conducting an experiment or operating the apparatus, the students can freely move around the motor-generator, which means the workplace is hazardous. The motor part of the apparatus has an exposed rotating mechanical shaft – loose items such as clothing and long hair could become entangled/caught and subsequently dragged into the apparatus, resulting in harm to the entrapped person.
4. Introduce a Proximity Sensor; which measures directly the rotor speed. This sensor is a suitable choice in this type of motor generator setup. The structure of the induction motor is to have a sensor which reads the speed of the mechanical shaft that requires an accurate and non-contact detection of the metallic object. The proximity sensor can be used to detect the metal object that's attached to the mechanical shaft of the motor in order to measure the speed of the mechanical shaft.

5. Investigate the relationship of Self-excitation and Separately-excitation and compare the output results – The motor generator setup has two modes, first is the self-excited and the second is separately excited. The self-excited mode has been executed that it produces the values of voltages, current, speed and torque. The wiring for the separately-excitation has been done, as discussed in the 'Design Method'. Perform testing on separately excited mode could be carried out to compare it with the output of self-excited mode.
  
6. Investigate the performance of the generator under full-load condition at full speed (50Hz). The system wasn't able to run at full-speed in a full-load condition hence it didn't achieve the maximum output voltage, current and power in the generator.



## Bibliography

- [1] National Instruments, “What is data acquisition? – national instruments”, 2009. [Online]. Available: <http://www.ni.com/data-acquisition/what-is/>. [Accessed: Nov. 1, 2016].
- [2] National Instruments, “NI 6013/6014 User Manual,” 2002. [Online]. Available: [https://fenix.tecnico.ulisboa.pt/downloadFile/1970943312269459/LAB.DAQ\\_NI6013.pdf](https://fenix.tecnico.ulisboa.pt/downloadFile/1970943312269459/LAB.DAQ_NI6013.pdf). [Accessed: Nov. 1, 2016].
- [3] A. Automation, “AC motors, controllers, and variable frequency drives,” 2016. [Online]. Available: <http://www.anaheimautomation.com/manuals/forms/ac-motor-guide.php#sthash.YTO8CqF1.EAWnfrzU.dpbs>. [Accessed: Nov. 10, 2016].
- [4] S. Chapman, *Electric Machinery Fundamentals*, 4<sup>th</sup> Edition. New York, New York City: McGraw-Hill, 2005.
- [5] Bill, “Different types of motors and their use,” 2016. [Online]. Available: <https://www.rs-online.com/designspark/different-types-of-motors-and-their-use>. [Accessed: Nov. 15, 2016].
- [6] A. E. Fitzgerald, C. Kingsley, Jr., S. D. Umans, *Electric Machinery*, 6<sup>th</sup> Edition. New York, New York City: McGraw-Hill, 2003, pp. 176-184.
- [7] D. Finney, *Variable frequency AC motor drive system*. London, United Kingdom: Peter Peregrinus Ltd, 1988, pp. 2-4.
- [8] T. Kugelstadt, “Capacitive isolated gate drivers spin AC induction motors,” 2013. [Online]. Available: <http://electronicdesign.com/analog/capacitive-isolated-gate-drivers-spin-ac-induction-motors>. [Accessed: Nov. 10, 2016].
- [9] K. Blattenberger, “Navy electrical and electronics training series (NEETS), module 5, 4-1 through 4-10,” in *RF Café*. [Online]. Available: <http://www.rfcafe.com/references/electrical/NEETS-Modules/NEETS-Module-05-4-1-4-10.htm>. [Accessed: Nov. 16, 2016].
- [10] M. Bolotinha, “Basic theory of generators,” 2016. [Online]. Available: <https://www.linkedin.com/pulse/basic-theory-generators-manuel-bolotinha>. [Accessed: Nov. 15, 2016].
- [11] K. Daware, “Kiran Daware,” 2014. [Online]. Available: <http://www.electricaleasy.com/2014/02/AC-generator-alternator-construction-working.html>. [Accessed: Nov. 15, 2016].
- [12] C. Woodford, “How electricity generators and dynamos work,” Explain that Stuff, 2016. [Online]. Available: <http://explainthatstuff.com/generators.html>. [Accessed: Nov. 15, 2016].

- [13] K. Daware, "Kiran Daware," 2014. [Online]. Available: <http://www.electriceasy.com/2012/12/basic-construction-and-working-of-dc.html>. [Accessed: Nov. 9, 2016].
- [14] R. Porter, H. Ear, N. Liyange, and D. Pol, *Motor Generator*, Phase4. Murdoch University, 2016.
- [15] U. E. Industries, "Data acquisition systems: Definition and description – UEI," 2016. [Online]. Available: <http://www.ueidaq.com/data-acquisition-systems.html>. [Accessed: Nov. 10, 2016].
- [16] J. K. Bhutto, B. S. Chaudhary, and P. Khatri, *Review Paper: Real Time Based Data Acquisition System*. 2016. [Online]. Available: [http://www.ijritcc.org/download/browse/Volume\\_4\\_Issues/May\\_16\\_Volume\\_4\\_Issue\\_5/1465367390\\_08-06-2016.pdf](http://www.ijritcc.org/download/browse/Volume_4_Issues/May_16_Volume_4_Issue_5/1465367390_08-06-2016.pdf). [Accessed: Nov. 14, 2016].
- [17] Contributors and S. Al-Mutlaq, "Load cell – 200kg, disc (TAS606)," [Online]. Available: <https://learn.sparkfun.com/tutorials/getting-started-with-load-cells>. [Accessed: Nov. 11, 2016].
- [18] A. Kingatua, "Strain gauges: Electrical instrumentation signals – electronics textbook," [Online]. Available: <http://www.allaboutcircuits.com/textbook/direct-current/chpt-9/strain-gauges/>. [Accessed: Nov. 11, 2016].
- [19] Loadstar Sensors, "What is a load cell?." 2016. [Online]. Available: <http://www.loadstarsensors.com/what-is-a-load-cell.html>. [Accessed: Nov. 16, 2016].
- [20] "Signal conditioning," 1995. [Online]. Available: <http://www.dataforth.com/signal-conditioning.aspx>. [Accessed: Nov. 14, 2016].
- [21] Rockwell Automation, "1305 Adjustable Frequency AC Drive (Series C) User Manual", Rockwell Automation. September 1998.
- [22] IDC Technologies Pty Ltd, "Introduction to Computer Based Control Systems," in *IDC technologies*, 2012. [Online]. Available: [http://www.idc-online.com/downloads/ALL\\_DD\\_Intro%20to%20Computer%20Based%20Control%20Systems\\_Rev1.pdf](http://www.idc-online.com/downloads/ALL_DD_Intro%20to%20Computer%20Based%20Control%20Systems_Rev1.pdf). [Accessed: Nov. 12, 2016].
- [23] National Instruments. "DAQ NI 6013/6014 User Manual." National Instruments Corporation, 2002.
- [24] Dataforth Corporation, "Isolated Analog Signal Conditioning Products," in *Dataforth*. [Online]. Available: [https://www.dataforth.com/catalog/pdf/scm5b30\\_31.pdf](https://www.dataforth.com/catalog/pdf/scm5b30_31.pdf). [Accessed: Nov. 11, 2016].
- [25] Dataforth Corporation, "Isolated Analog Signal Conditioning Products," in *Dataforth*. [Online]. Available: <https://www.dataforth.com/catalog/pdf/scm5b38n.pdf>. [Accessed: Nov. 11, 2016].

- [26] National Instruments, "LabVIEW system design software – national instruments," 2012. [Online]. Available: <http://www.ni.com/labview/>. [Accessed: Nov. 14, 2016].
- [27] S. Curley and Uclan, "What is LabVIEW?," 2010. [Online]. Available: <http://www.ni.com/newsletter/51141/en/>. [Accessed: Nov. 14, 2016].
- [28] National Instruments, "LabVIEW environment basics – national instruments," 2016. [Online]. Available: <http://www.ni.com/getting-started/labview-basics/environment>. [Accessed: Nov. 14, 2016].

# Appendices

## Appendix A: Front Panel Control and Monitoring Interface



Figure 36: Control and Monitoring Interface

## Appendix B: NI 6014 DAQ Hardware Block Diagram

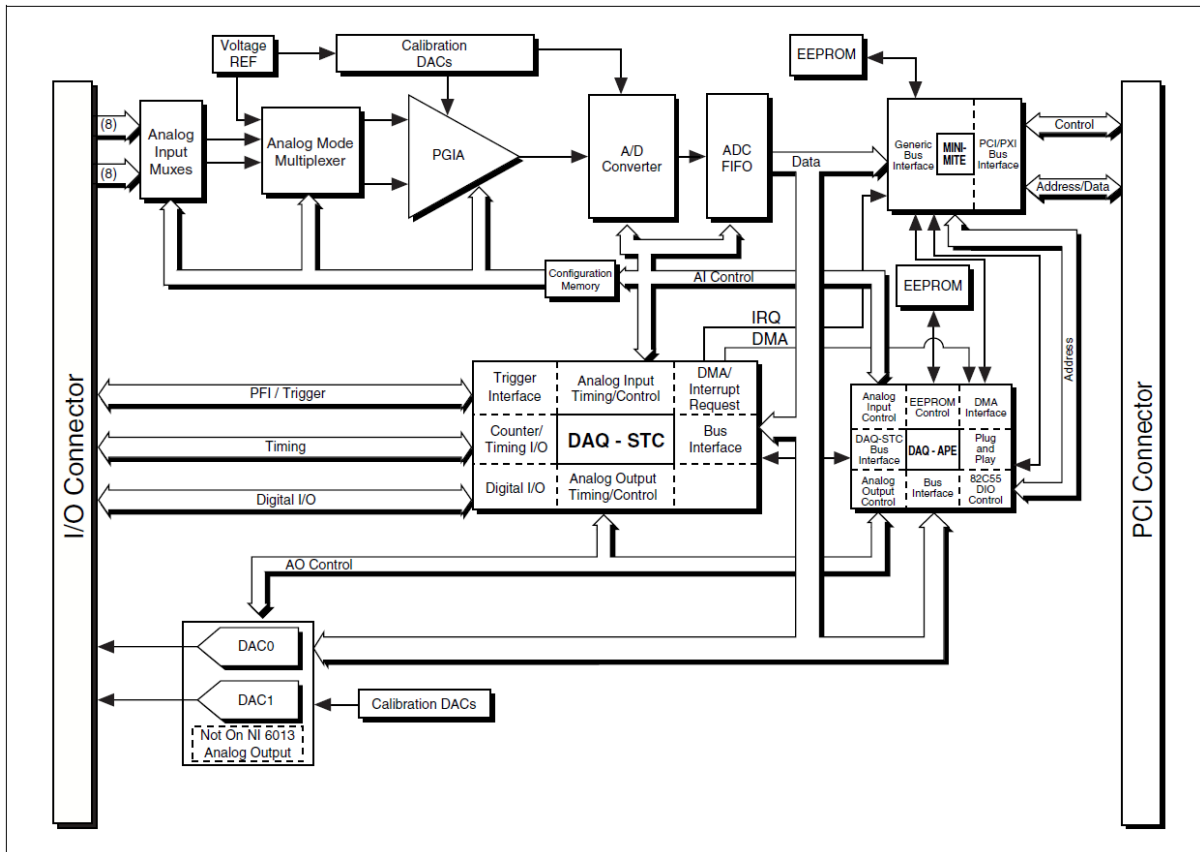


Figure 37: NI 6014 Hardware block diagram [23]

## Appendix C: NI 6014 DAQ I/O Connector Pin Assignment

I/O Connector Pin Assignment for the NI 6014

ACH8	34	68	ACH0
ACH1	33	67	AIGND
AIGND	32	66	ACH9
ACH10	31	65	ACH2
ACH3	30	64	AIGND
AIGND	29	63	ACH11
ACH4	28	62	AISENSE
AIGND	27	61	ACH12
ACH13	26	60	ACH5
ACH6	25	59	AIGND
AIGND	24	58	ACH14
ACH15	23	57	ACH7
DAC0OUT <sup>1</sup>	22	56	AIGND
DAC1OUT <sup>1</sup>	21	55	AOGND
RESERVED	20	54	AOGND
DIO4	19	53	DGND
DGND	18	52	DIO0
DIO1	17	51	DIO5
DIO6	16	50	DGND
DGND	15	49	DIO2
+5V	14	48	DIO7
DGND	13	47	DIO3
DGND	12	46	SCANCLK
PFI0/TRIG1	11	45	EXTSTROBE*
PFI1/TRIG2	10	44	DGND
DGND	9	43	PFI2/CONVERT*
+5V	8	42	PFI3/GPCTR1_SOURCE
DGND	7	41	PFI4/GPCTR1_GATE
PFI5/UPDATE*	6	40	GPCTR1_OUT
PFI6/WFTRIG	5	39	DGND
DGND	4	38	PFI7/STARTSCAN
PFI9/GPCTR0_GATE	3	37	PFI8/GPCTR0_SOURCE
GPCTR0_OUT	2	36	DGND
FREQ_OUT	1	35	DGND

<sup>1</sup> Not available on the NI 6013

Figure 38: NI 6014 pin connector [23]

## Appendix D: VSD Block Diagram Connector

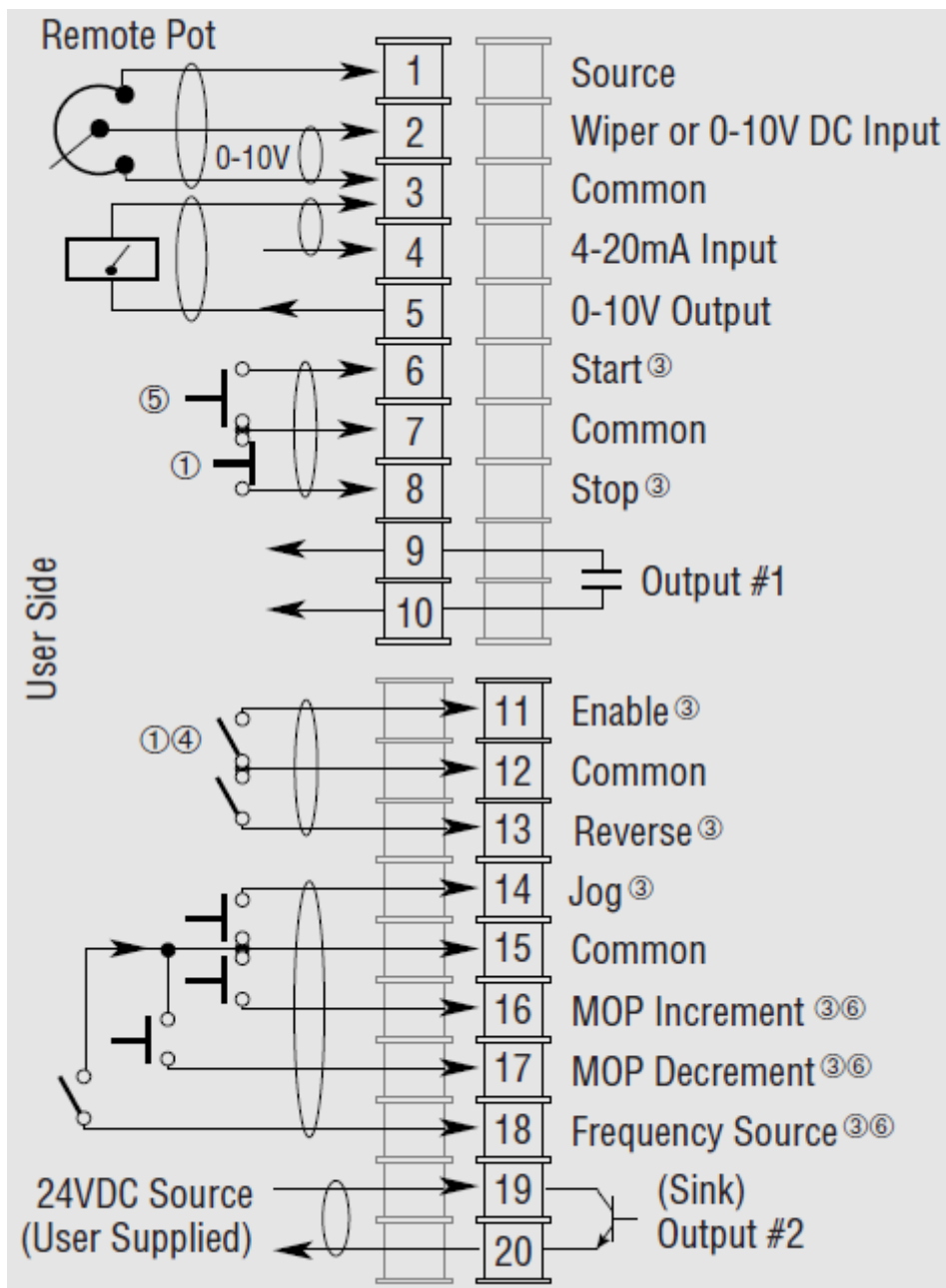


Figure 39: 3Wire VSD pin connector [21]

## Appendix E: Generator - Load Wiring Diagram

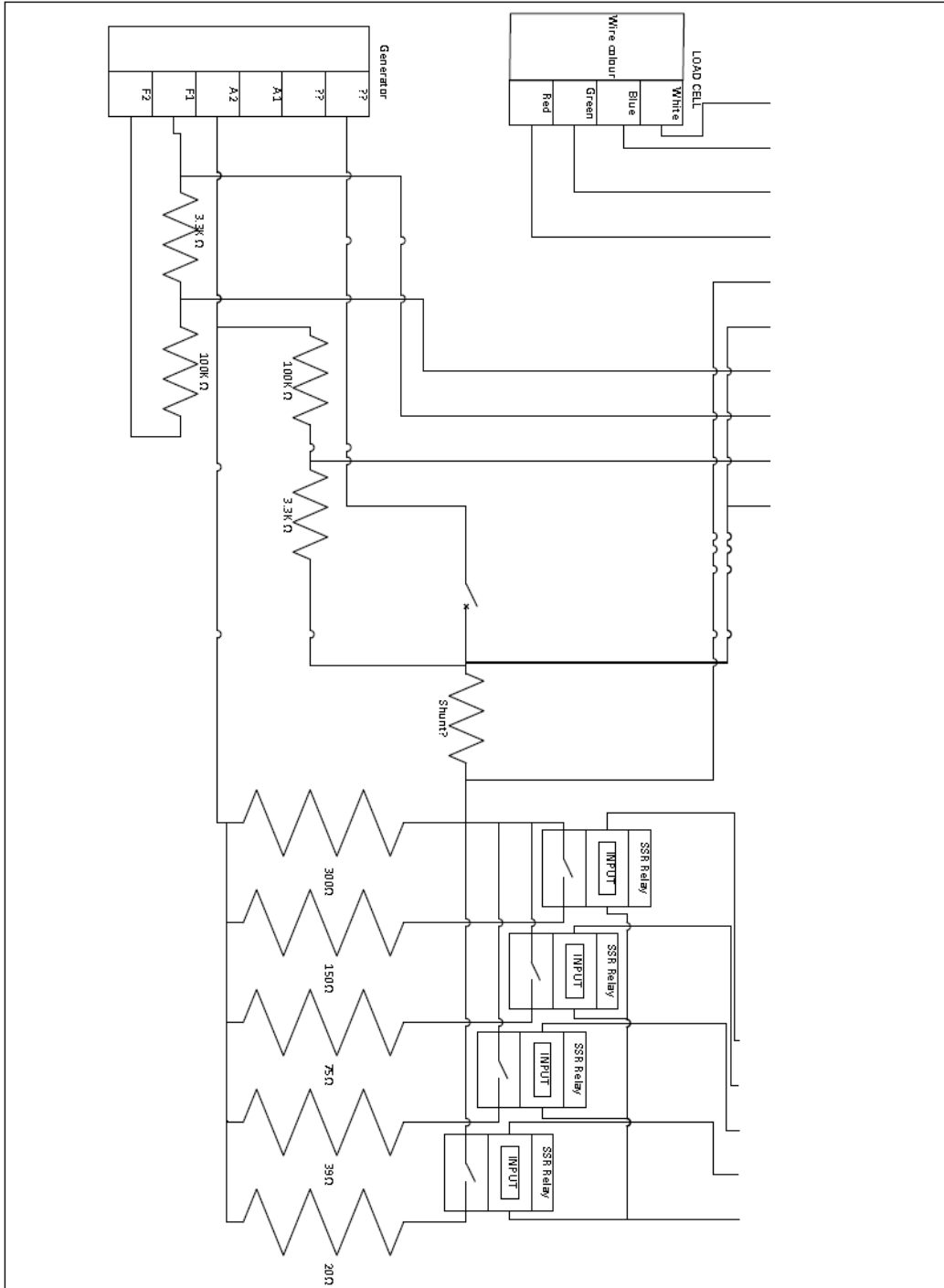


Figure 40: Generator - Load Wiring Diagram



## Appendix F: Overall System Wiring Diagram

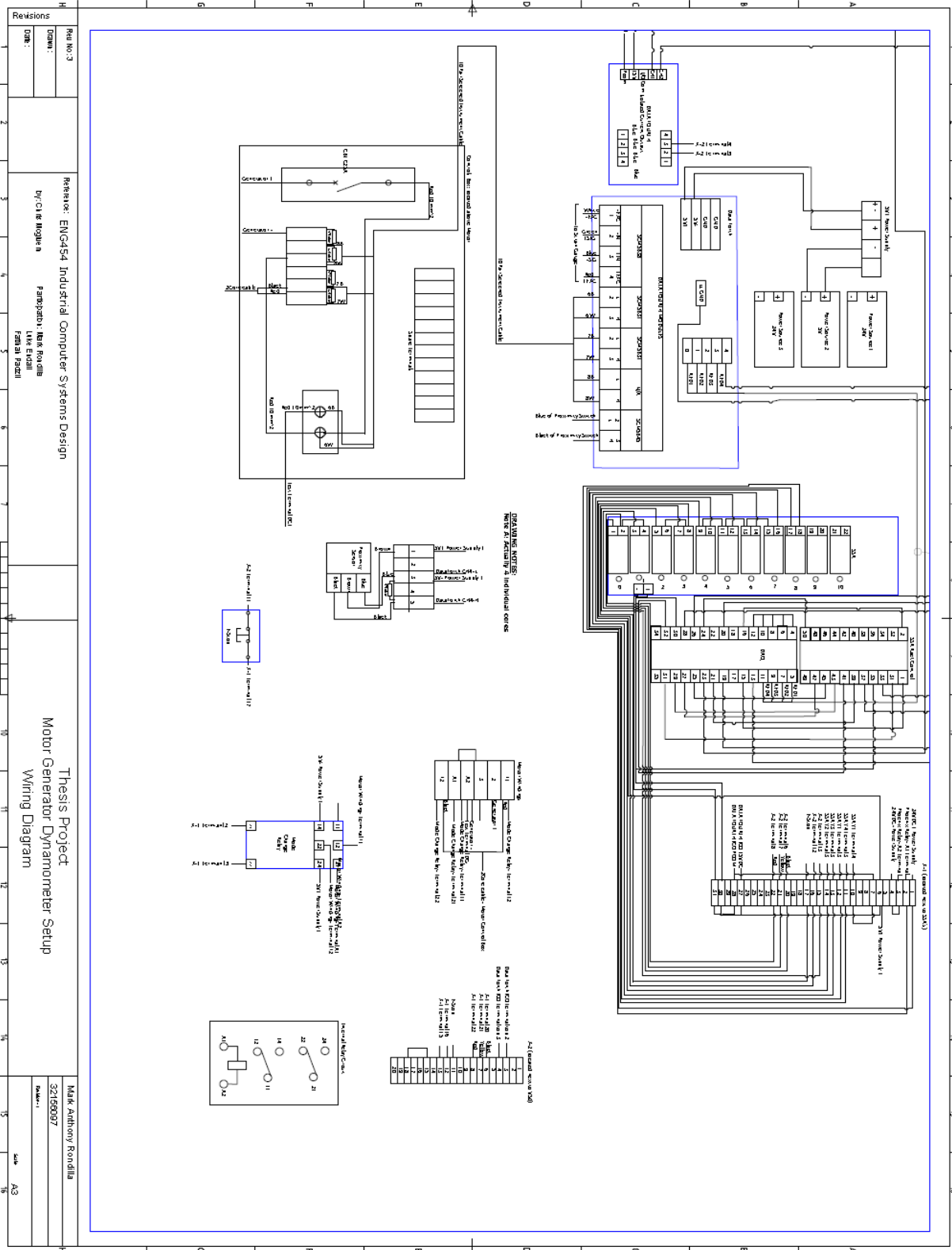


Figure 41: Overall System Wiring Diagram