

DEVELOPMENT OF A SCADA SYSTEM  
FOR ALTERNATIVE ENERGY

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A Thesis

Presented to

the Faculty of the College of Business and Technology

Morehead State University

---

In Partial Fulfillment

Of the Requirement for the Degree

Master of Science

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by

Molom-Ochir Mijid

April 18, 2019

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Accepted by the faculty of the College of Elmer R. Smith Business and Technology, Morehead State University, in partial fulfillment of the requirements for the Master of Science degree.

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## DEVELOPMENT OF A SCADA SYSTEM FOR ALTERNATIVE ENERGY

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Morehead State University, 2019

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The renewable energy is the most prospective future resource on the globe that is practicable with currently available technologies and modern techniques, including wind turbine, solar photovoltaics and so on. Possible renewable energy can be maximized when managed and acquired efficiently with a fully controlled automation system for the renewable energy complex system. There are many ways to control renewable energy; the most common is the SCADA system.

This research presents the development of a SCADA system for alternative energy using PLC. This study will undertake the following steps:

First, finding and developing the right environment for SCADA system development. Environment plays a crucial role in the performance of the system. Therefore, special consideration is devoted to this step.

Second, designing the SCADA architecture, which involves computers, networked data communications, and graphical user interfaces (GUI) for high-level management. Also, the SCADA system uses external devices such as programmable logic controllers (PLC's), motor drives, data acquisition module (DAQ), and operator panel.

Thirdly, configuration and commissioning for the SCADA control monitoring system. This was accomplished through multifunctional software, using communication drivers and protocols.

Fourthly, programming in Studio 5000 Logix Designer and Indusoft Web Studio. These two main software packages provide software programming on the SCADA system. This includes updating software and applying bug fixes and enhancements.

Lastly, testing and performance analysis of the SCADA system. The system was tested and is ready for use. The performance was analyzed by comparing the energy generated against the average energy generated by other systems.

Accepted by: \_\_\_\_\_, Chair

Dr. Ahmad Zargari

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First, I would like to thank Dr. Moody for making this project possible and for reading my revisions and making some sense of any confusions. As my background is in the field of Industrial electricity, it was important for me to work on this project to advance my background.

Secondly, I would like to express my sincere gratitude to Dr. Zargari and Dr. Grise' for giving general advice, suggestions, and ideas for improvements.

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## CHAPTER I - INTRODUCTION

### 1.1 Overview

The term SCADA (Supervisory Control and Data Acquisition) refers to an independent system that manages software and hardware components to monitor data coming from various sensors, either off-site or in close proximity. The central system monitors, gathers, processes, and turns the raw data into valuable control data by interacting with sensors, motors, pumps, microcontrollers, and valves.

SCADA systems are widely used in renewable energy for supervisory control of data acquisition for wind and solar energy. Renewable energy is the energy generated from a source that is not depleted when used. Wind and solar power are the most common examples of renewable energy. The utilization of renewable energy sources for the generation of energy has helped in the reduction of carbon emissions (Banos et al, 2011). To improve the system's efficiency, the use of SCADA for the designing and implementation of renewable energy has helped. In order to be efficient, it is crucial to constantly monitor the renewable energy state in order to determine the amount of energy that is generated at all times, given the unpredictable nature of renewable energy sources. Supervisory control and data acquisition (SCADA) system provide a good platform for remote monitoring of data.

A SCADA system includes and involves signal hardware (in this research, a Data Acquisition Module), external hardware controllers (PLC's), networks (Industrial communication), a user interface (HMI), and communications equipment and software (Studio 5000, Indusoft Web Studio). The Data Acquisition Module (DAQ) hardware acts as the interface between a PLC and signals from the outside world. There are three key components of a DAQ device used for measuring signals such as analog-to-digital converter (ADC), signal conditioning circuitry, and computer bus. A PLC is currently the most suitable and widely used system for control industrial controller. It requires a programming device, usually a computer, to be able to upload data to the CPU of the PLC's. Lastly, PLC's read signals from different sensors and input devices. Inputs can be either in digital or analog signal form. Meanwhile, motors and solenoid valves are some of the output devices in an automated system.

This thesis describes in detail the development in each functional step and will address issues associated with the controller system are detailed. The effectiveness of the development of a SCADA system for alternative energy management control is demonstrated to conclude the thesis.

## **1.2 Problem Statement**

Compared to conventional energy technologies, renewable energy technologies are clean sources of energy that have a much lower environmental impact. However, it will be practically impossible to station personnel to monitor constantly the state of the sources, or problems in the complexity of the system configurations, hence the need for a remote monitoring system. The intelligent operating and control solutions should be applied to the renewable energy industry. The SCADA system provides a good platform for remote monitoring of data, and so can help to improve the efficiency of the system.

## **1.3 Objectives**

This research has these three main objectives:

1. Designing electrical schematics for PLC and the Alternative Energy Learning System
2. Interfacing between real control system (PLC) and a DAQ module
3. Programming the PLC in Studio 5000 Logix Designer and Indusoft Web Studio

## **1.4 Definition of terms**

**PLC:** Programmable Logic Controller, PLC, is a user-friendly specialized computer(microprocessor-based) that carries out control functions of many types and at many levels of complexity. Being user-friendly and easy to use, it is programmable, controllable, and operable by an individual who is unskilled in operating basic computers. “The PLC’s operator essentially draws the lines and devices of ladder diagrams” (Jon W. Webb 1995).

**Digital Signals:** A digital signal, a way of transmitting data, converts typical analog data to discrete values based on a binary code that the computer systems will be able to comprehend. Discrete values can come in packets of strings of ones and zeros. Unlike analog signals, the digital signals are not continuous.

**Analog Signals:** An analog signal is a continuous signal that changes in either amplitude, phase, or frequency for each instant of time. Time plays an important role as a time variance and change is represented in various systems. Unlike digital signals, which use a numeric method of transmitting information, analog signals use incremental variations in magnitude, frequency, or phase in the signal itself to pass information (wise GEEK, 2014).

**Communication Protocol:** A system of rules that allows communication systems to communicate. It includes rules, access methods, allowed physical topologies, speed of data transfer, syntax, and error recovery methods.

**Ethernet:** “Ethernet computer networking technologies work for local area networks (LANs) and metropolitan area networks (MANs). It is a wired network technology that is defined by IEEE8.2 standards. It was first deployed in 1976 and has since emerged as the dominant standard for wired connections in local area networks. “(June Jamrich Parson,2014) The Ethernet RJ45 cable can be used to connect devices. Since then, it has been used to support higher bit rates and longer link distances.

**Studio 5000 Logix Designer:** The Studio 5000 Logix Designer software is designed to work with Logix5000 controller platforms. This software is an IEC 61131-3 compliant software package that offers useful symbols ranging from relay ladders, structured texts, and function block diagrams to sequential function chart editors for the designer to develop application programs. One can create his or her own instructions by encapsulating a section of logic in any programming language into an Add-On INSTRUCTION (Studio 5000 Logix Designer Programming Software).

**Ladder Diagram:** Ladder Diagrams are specialized schematics commonly used to document industrial control logic systems. They are called “ladder” diagrams because they resemble a ladder, with two vertical rails (supply power) and as many “rungs” (horizontal lines) as there are control circuits to represent. If we wanted to draw a simple ladder diagram showing a lamp that is controlled by a hand switch, it would look like this: Ladders diagrams are used only on 2-wire control circuits, not for the power circuit of the driven or controlled equipment. (Kenneth G. Oliver, 1990.)

**DAQ:** Data acquisition (DAQ) is the process of measuring an electrical or physical phenomenon such as voltage, current, temperature, pressure, or sound with a computer. A DAQ system consists of various sensors. DAQ systems exploit the processing power, productivity, display, and connectivity capabilities of industry-standard computers to produce a more powerful, flexible, and cost-effective measurement solution (National Instruments)

**HMI:** Human-machine interface (HMI) is a component of certain devices that are capable of handling human-machine interactions. The interface consists of hardware and software that allow user inputs to be translated as signals for machines that, in turn, provide the required result to the user. Human-machine interfaces help in integrating humans into complex technological systems. (technopedia.com,)

**Indusoft Web Studio:** InduSoft Web Studio is a powerful and integrated SCADA software for Human Machine Interface (HMI) development, Supervisory Control and Data Acquisition (SCADA) systems, and embedded instrumentation and control applications. InduSoft Web Studio's application works in Windows NT / 2000 / XP / CE / CE .NET environments and adapts to industry standards such as Microsoft .NET, OPC, DDE, ODBC, XML, and ActiveX. (Studio, InduSoft Web.)

**MiniOS7 Utility:** MiniOS7 Utility is a tool for configuring and uploading files to all products embedded with ICP DAS (Industrial Control Products and Data Acquisition Software) such as ET-7017-10 which is used for this project. MiniOS7 APIs (Application Programming Interface) support programmer to send MiniOS7 command or upload file from a host PC. Programmers can integrate APIs into an application to let the user set IP, update firmware and so on. The user doesn't need to install ICPDAS MiniOS7 Utility anymore. Since version 3.1.1, the utility can allow users remotely access the controllers (7188E,8000E, ...etc.) through the Ethernet. (MPAC-5000User Manual. June 2010)

## CHAPTER II - LITERATURE REVIEW

### 2.1 What is a SCADA system, a brief historical review

The term SCADA (Supervisory Control and Data Acquisition) refers to an independent system that manages software and hardware components to monitor data coming from various sensors, offsite or in close proximity, to control industrial processes. The central system monitors, gathers, processes, and turns the raw data to useable data for process control and monitoring data by interacting with sensors, motors, pumps, microcontrollers, and valves. SCADA technology has existed since the early sixties and throughout the years it has evolved and has become more efficient. There are now two other competing possible approaches – distributed control system (DCS) and programmable logic controller (PLC). Furthermore, as smart devices and cell phones are advancing, there has been a rising trend to implement smart instruments for all these systems.



**Figure 1. Supervisory Control and Data Acquisition**

#### **Evolution of SCADA**

1890's - Remote Control and Remote Indication



1920's - Telecommand and control

1930's - Check Before Operate (CEO) Systems Based on Electro-Mechanical Technology

1960's - Supervisory Control Systems (Remote Control & Status Indication)

1960's - Data Acquisition Systems gained popularity and SCADA came into being

1980's - Load Dispatch Centre and Control

1990's - Energy Control Centre

2000's - Energy Management Systems

### **Benefits of SCADA**

The important benefits of SCADA derive from the following functions:

1. Continuous monitoring of process
2. Real-time control
3. Automation and Protection
4. Remote control and operation

In this study, the SCADA system is developed with a powerful automation HMI (human machine interface) software tool that is the Indusoft Web Studio educational 8.0 version.

### **2.2 Alternative Energy Learning System**

The 850-AEC Alternative Energy Learning System has a real-world component that is commonly used in commercial and residential environments such as a small wind turbine and solar panel. System connection, operation, programming of solar PV (photovoltaic) cells or panels, and small wind systems in commercial and residential applications are some of the most critical features that were involved during the development of this system.



**Figure 2. 850-AEC Alternative Energy Learning System ([www.amatrol.com](http://www.amatrol.com), 2018)**

Amatrol's 850 series Alternative Energy Learning System supports the training necessary to prepare for selected aspects of the solar and small wind alternative energy system by addressing the topics below:

- Safety
- Solar Panel Operation
- Solar Panel Performance
- PV Array Connection
- Wind Turbine Operation
- Wind Turbine Performance
- Wind Turbine Connection

- Solar/Wind Batteries
- Charge Controllers
- Inverters
- A balance of System Components
- AC/DC Solar Systems
- AC/DC Wind Systems
- Energy Conservation and Demand
- System Performance

### **2.3 Programmable Logic Controller**

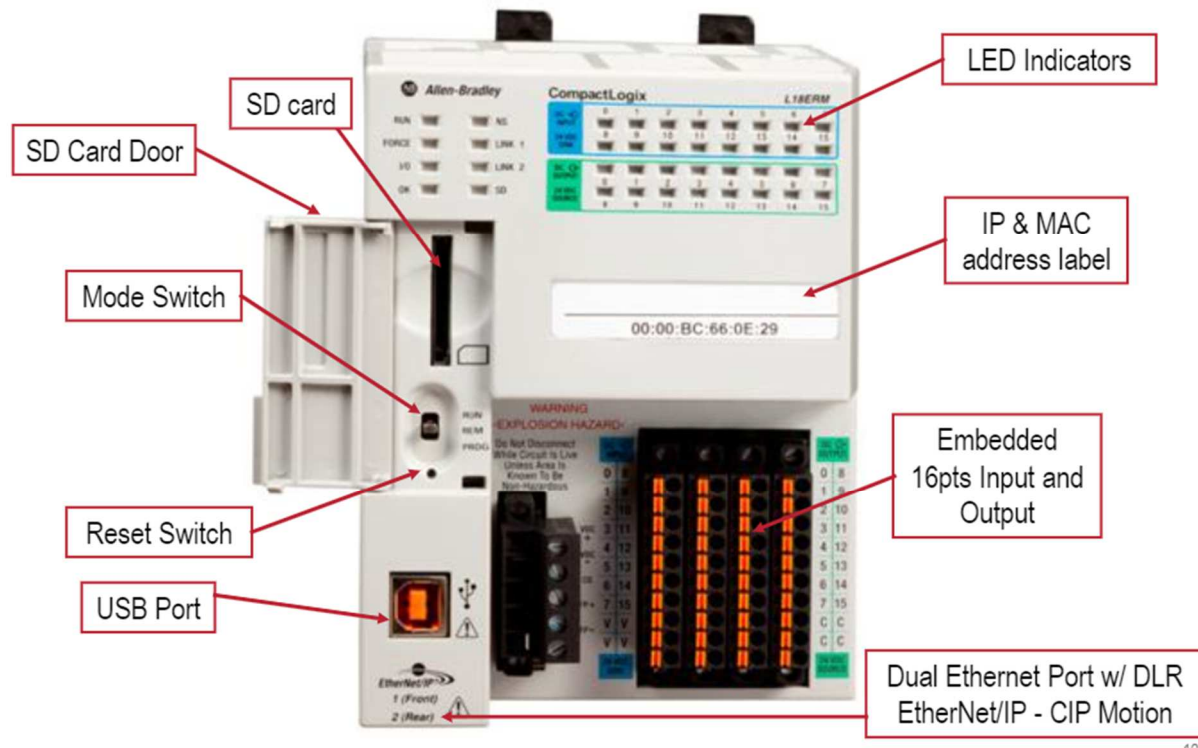
A programmable logic controller (PLC) is a mini computer that monitors communications and the states of inputs and outputs and makes decisions for automated processes or machines. In a way, it is similar to Raspberry Pi but much stronger in terms of its circuitry protection, efficiency, and ability to handle high and low temperatures. PLCs are waterproof and weatherproof, surviving the more rugged industrial conditions. The programming language for PLCs are simple and can be programmed without much challenge.

As PLC's advanced, a specially dedicated software from the PLC was built for PLCs to make work efficient and easier. Ladder Logic, Sequential Function Charts, Structured Text, and Function Block Diagram are the most widely used PLC programming languages. Ladder Logic language represents a program by symbols and lines to emulate the real world set up. For example, in Ladder Logic, the symbols are connected by lines, indicating the flow of current through wires and coils. Over the years, the programs have developed and become more elaborate, increasing the number of symbols.

In Ladder Logic, completed programs look like and are shaped like a ladder, representing an electrical circuit. For example, left and right rails represent the positive and ground of a power supply, respectively. Moreover, rungs could represent a connection between different components.

PLCs read both analog and digital signals from various sensors and input devices. These can be mouse, keyboards, touch pads, switches, sensors or microprocessors. On the other hand, output devices such as motors, pumps, or solenoid valves complete the automated system.

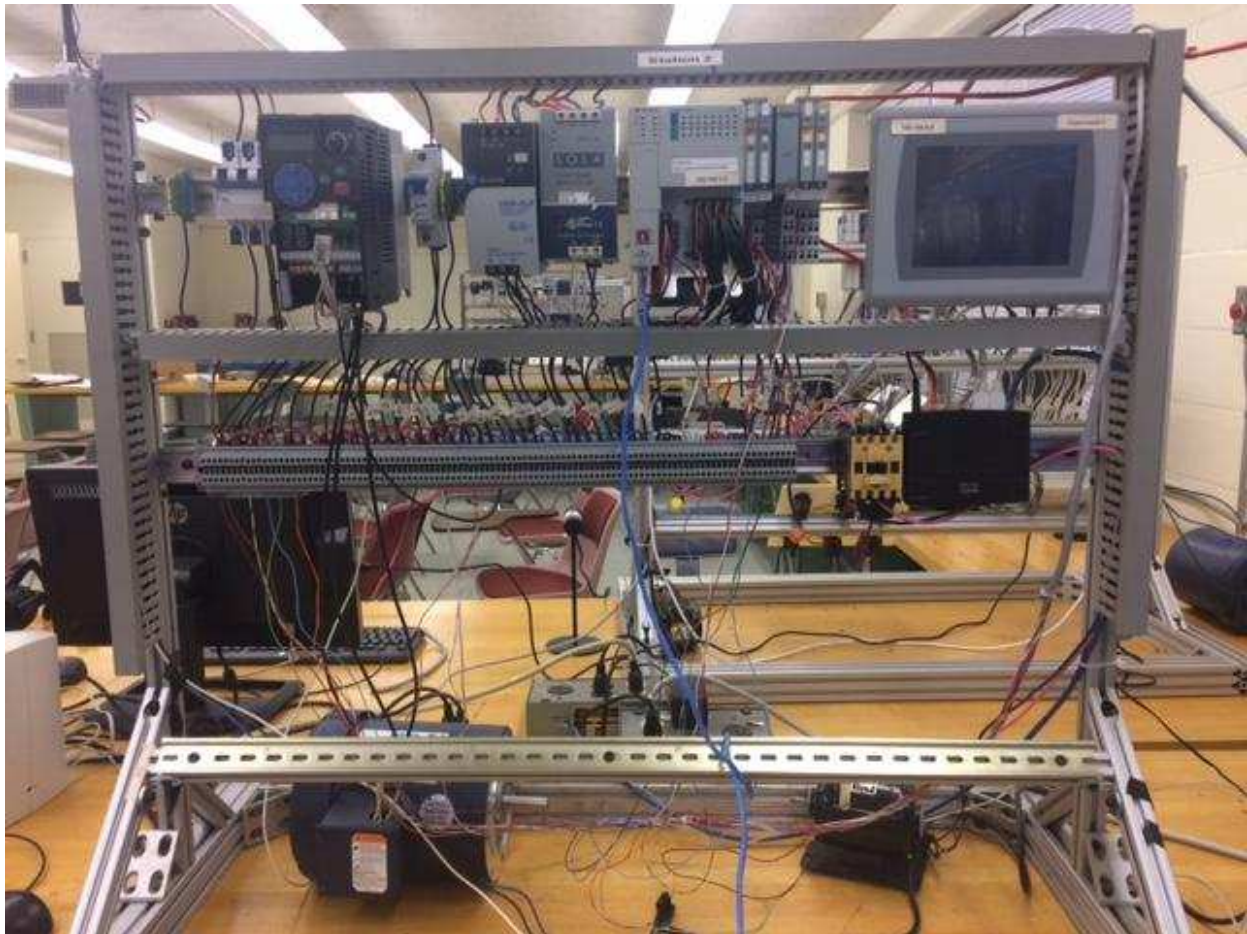
This research used the Allen Bradley PLC CompactLogix 5370 L1 series controller with Dual Ethernet with DLR (device lever ring) capability, 1MB Memory, 8 I/O Expansion via 1734 POINT I/O.



**Figure 3. CompactLogix 5370 L1 series**



**Figure 4. Allen Bradley PLC (LC MSU)**



**Figure 5. PLC Station #2 (LC MSU)**

### 2.3.1 Hardware Overview

The CompactLogix 5370 L1 programmable controller is composed of a base unit, which contains a power supply, input and output circuits, and processor. The controller is available with 16 points of embedded I/O including 24VDC power supply, DC, and common. Additional I/O may be added using compact I/O expansion modules. It includes LEDs that display activated inputs and outputs. There is a communication port to communicate with the computer, checking communication connections in the RSLinx software. Tables below display the features of the hardware system.

#	CompactLogix 5370 L1 Overview	L18ER-BB1B
1	Memory	512KB
2	Embedded I/O Points (24VDC)_	32 (16I/16O)
3	Local Expansion Modules	8
4	Max Expansion I/O Points (Avg 8 per Module)	96
5	Ethernet/IP I/O Nodes	8
6	Programs per task	100
7	Built-in Communication Ports	USB and EtherNet/IP (2 ports supporting DLR)
8	Flash Memory Card	Industrially rated and certified Secure Digital (SD) memory card (1 and 2 GB options); all controllers shipped with 1 GB card
9	Controller/TCP connections	256 / 120

10	Operating voltage	10....28.8 VDC (24 VDC nominal)
11	Software / Firmware	RSLogix 5000 V20 and RSLinx Classic V2.59 Firmware v20.11.70 or later

**Table 1. CompactLogix 5370 L1 PLC Overview**

#	Hardware	Quantity
1	1769 L18ER-BB1B <u>COMPACTLOGIX</u> L18ERM PROCESSOR, 512 KB MEMORY	1
2	1734-IV8 24V DC 8 CHANNEL SINK <u>INPUT MODULE</u>	1
3	1734-OW4 24V DC 8 CHANNEL SOURCE <u>OUTPUT</u> <u>MODULE</u> , ELECTRONICALLY PROTECTED	1
4	1734-IE2V 4 CHANNEL <u>ANALOG VOLTAGE IN</u>	1
5	1734-OE2V 4 CHANNEL <u>ANALOG VOLTAGE OUT</u>	1
6	1606-XLE80E <u>POWER SUPPLY</u> , 24-28V DC, 80 W, 120/240V AC INPUT	1

**Table 2. Controller Hardware System**

#	Hardware	Description	Quantity
1	1783-BMS10CGP STRATIX 5700 <u>MANAGED</u> <u>SWITCH</u> WITH DLR(Device Lever Ring)	Communication Hardware	1
2	2711P-B7C22A9P PANELVIEW PLUS 7 5.5” TFT COLOR, <u>TOUCH TERMINAL</u>	HMI Hardware	1
3	25C-D2P3N104 POWERFLEX 527 <u>DRIVE</u> , 1 HP FRAME A	Drive Hardware	1

**Table 3. Other Hardware Systems**

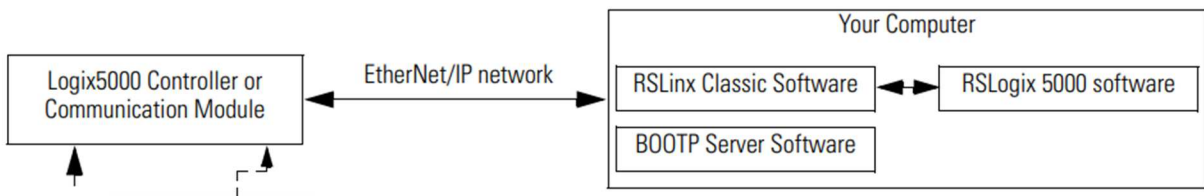


### 2.3.2 Software Overview

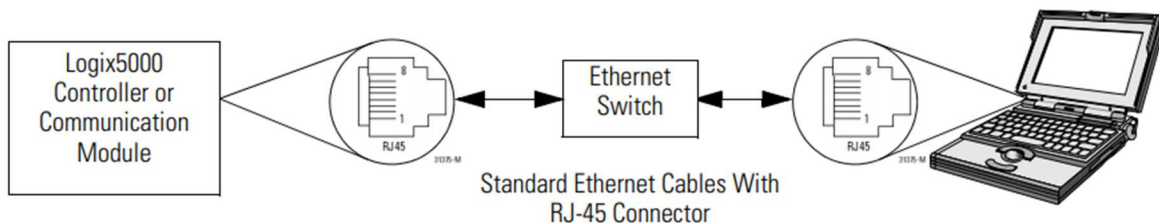
Logix 5000 Controllers can be programmed using Studio 5000 Logix Designer (in Standard, Full, or Pro versions). A key advantage of this project architecture is the ability to use Studio 5000 common integrated motion programming, configuring, commissioning, and tools for the PowerFlex 527, PanelView PLUS 7 and family of products. According to its System Requirements, certain special features can be made available if the most current version of the software is purchased,

### 2.3.3 Communication

To establish EtherNet/IP communication with the controller, RSLinx Classic software handles communication between Logix5000 controllers and the system designer's software programs, such as Studio 5000 Logix Designer. To communicate with a controller (download or monitor data), one must configure RSLinx Classic software for the required communication.



**Figure 6. EtherNet/IP communication**



**Figure 7. Communication with standard Ethernet cable**



### 2.3.4 Configuration

This controller-based low-cost system demonstrates the power and scalability of the Integrated Architecture on an EtherNet/IP based network. This system utilizes standard EtherNet technology to easily mix and match high-speed motion control, I/O control, drive control, and HMI on a single EtherNet/IP network.

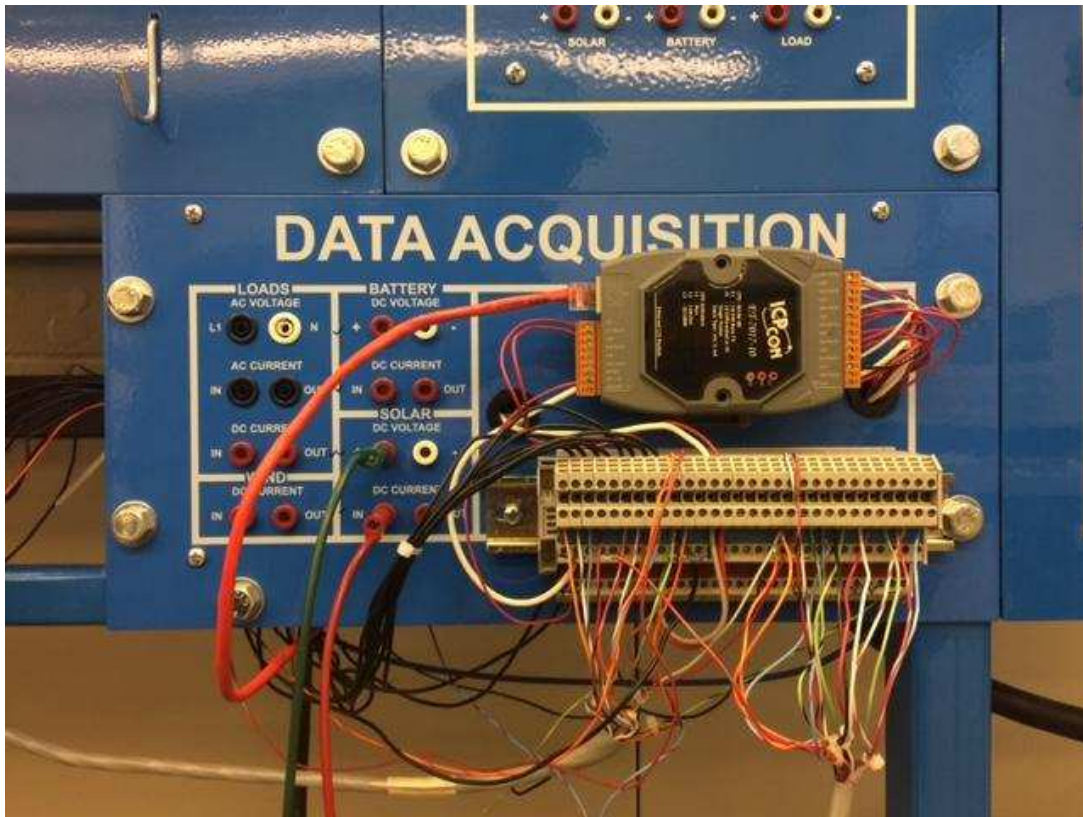
### 2.4 Data Acquisition System

When some electrical or physical value is measured using a computer with the help of sensors or other devices, it is called Data Acquisition. The DAQ device acts as a bridge between sensors and a computer. DAQ device is responsible for signal conditioning, while the computer, which uses a Modbus to communicate with the DAQ device, is responsible for running the driver software and application software. DAQ systems exploit the processing power, productivity, display, and connectivity capabilities of industry-standard computers providing a more powerful, flexible, and cost-effective measurement solution (National Instruments, n.d) To sum up, data acquisition is a method of digitizing and visualizing the world and its phenomena around us with the help of sensors and appropriate software.



**Figure 8. ET-7017-10 Data Acquisition Module**

The current project used the ICP DAS Company ET-7017-10 module with 10/20 channel analog input.



**Figure 9. ET-7017-10 in nature**

Main characteristics:

- Built-in Web Server
- Web HMI
- Support for both Modbus TCP and Modbus UDP Protocols
- Communication Security

- 2-port Ethernet Switch for Daisy-Chain Topology
- Dual Watchdog
- Wide Operating Temperature Range: -25 ~ +75°C
- I/O Pair Connection
- Built-in I/O
  - AI: 8 Channels with 240 Vrms Overvoltage Protection
  - DO: 4 Channels

## CHAPTER III - METHODOLOGY

### 3.1 Design an electrical schematic for SCADA

A main electrical schematic created for SCADA that communication between 850-AEC, PLC, and DAQ.

- A small control panel with indicator lights, push buttons and emergency button for the situation of the wind simulator motor and sun simulator
- A terminal block of wiring of the signal and control wires
- 2 contractors, 10A, 120V AB-100-C09 with auxiliary contact, for control
- 2 relays for indicator lights
- A circuit breaker, 30A, 120V AB-1492-SP-C30
- change within the electrical diagram of the wind simulator DC motor that the motor controlled by the analog output signal from PLC?

The functional schematic diagram of the SCADA implementation system was shown in Figure 10. There were three modules in the system architecture: Power supply AC 120V and two contractors. Other parts include a control panel with selector switch, 24 VDC circuit for light indicator and PLC signal wiring.

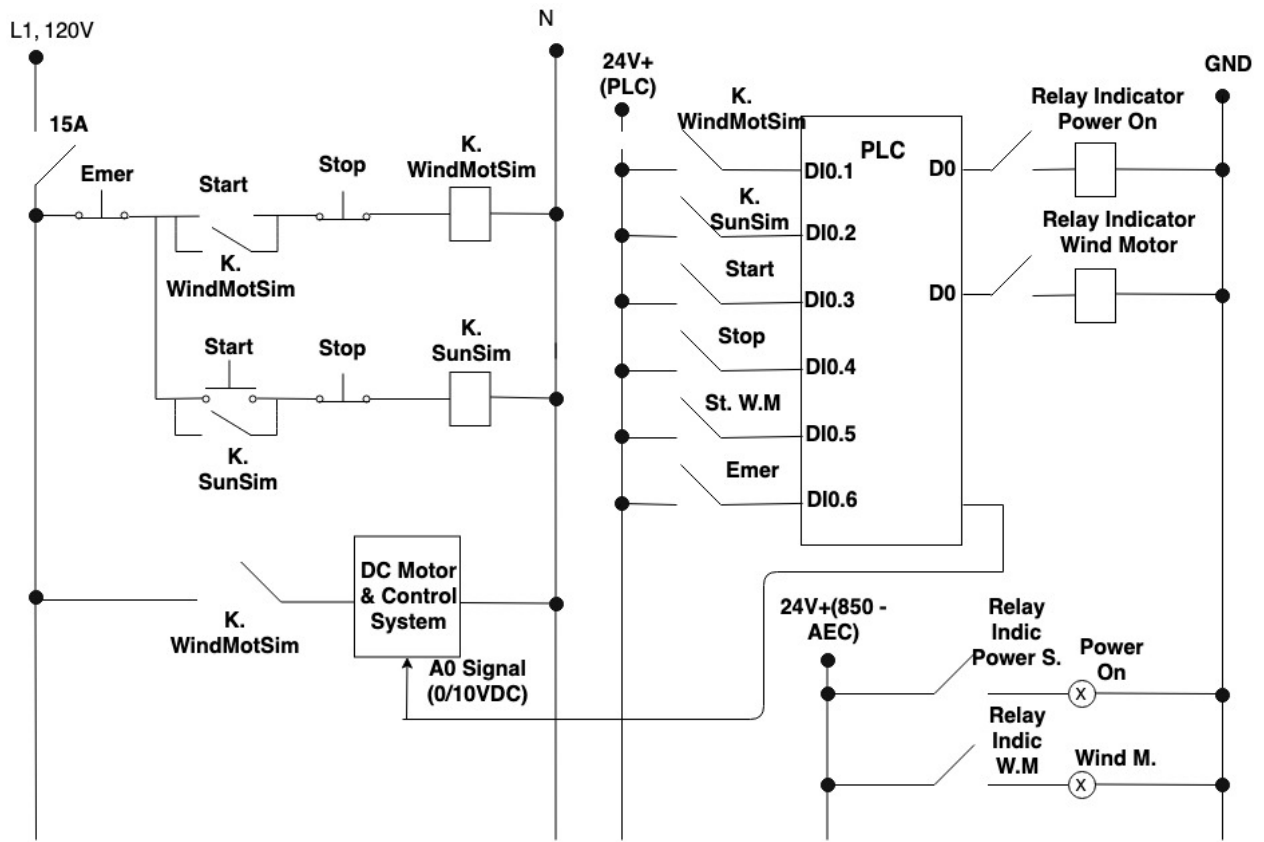
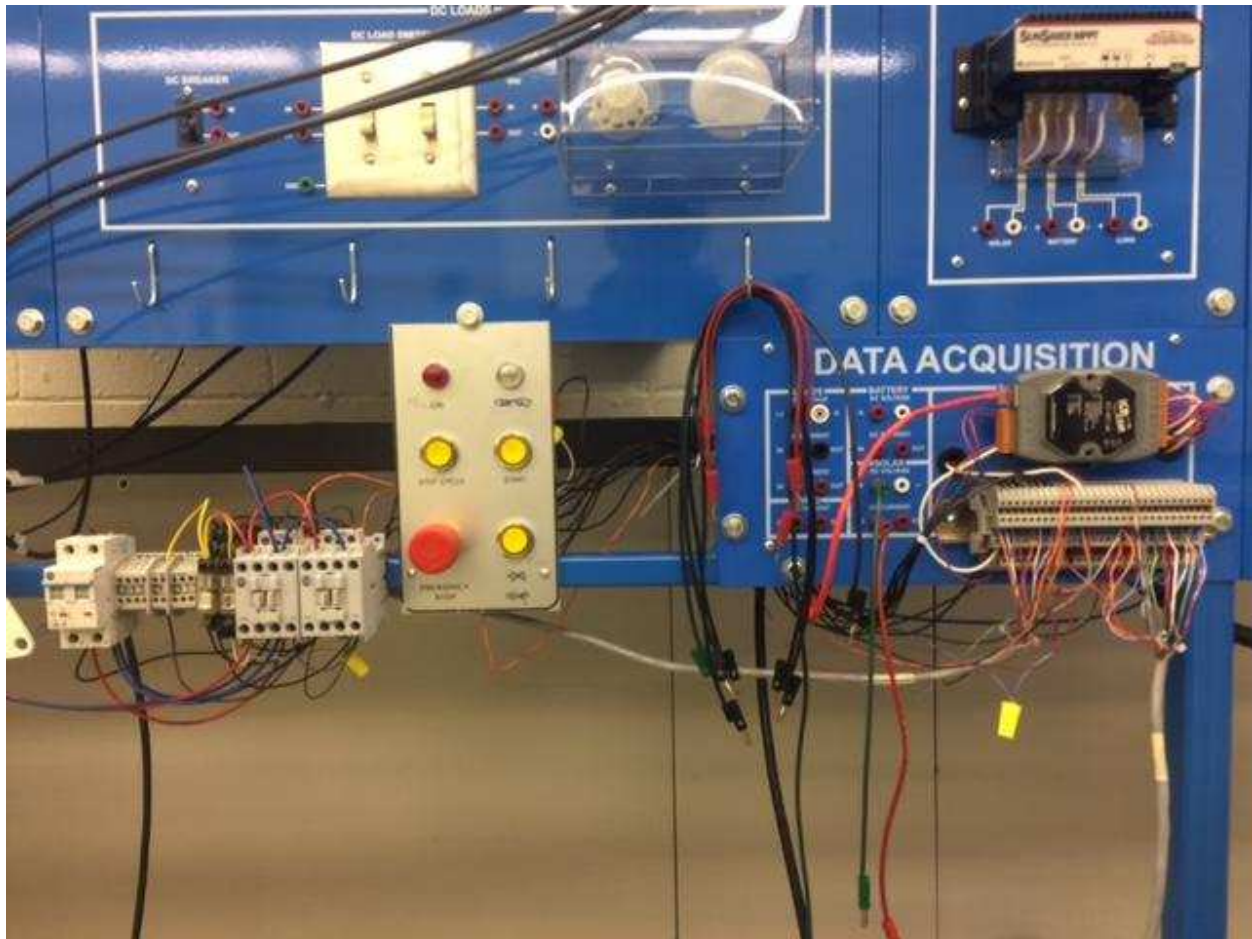


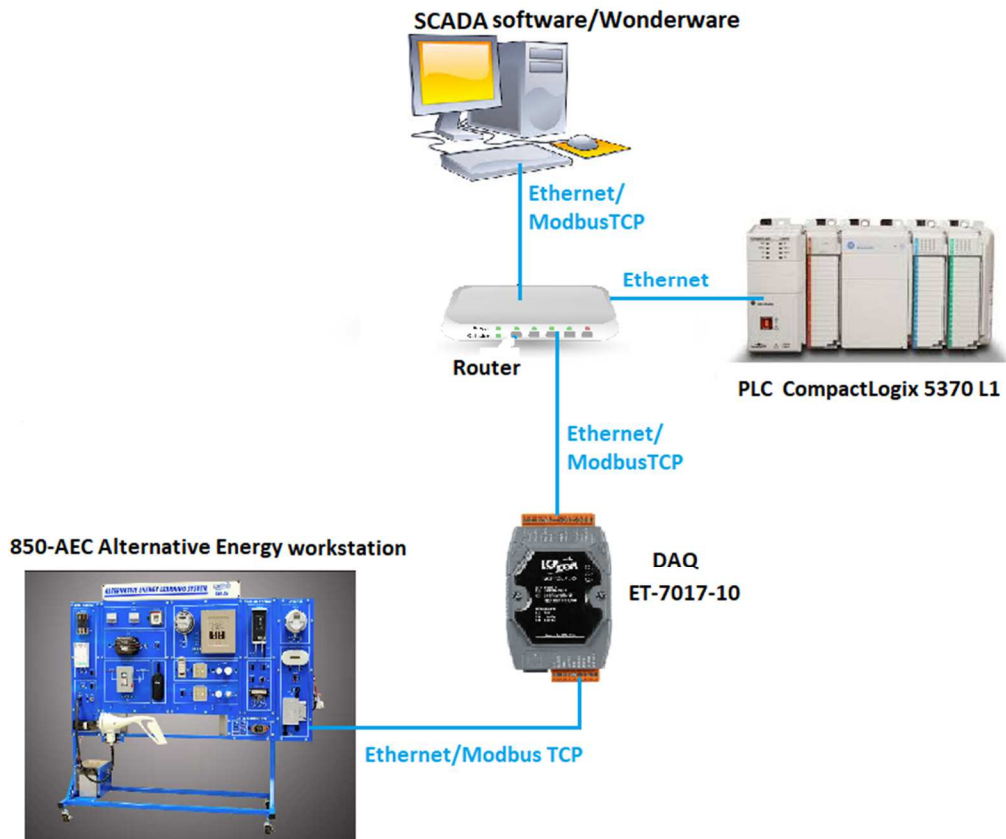
Figure 10. Electrical schematic for SCADA



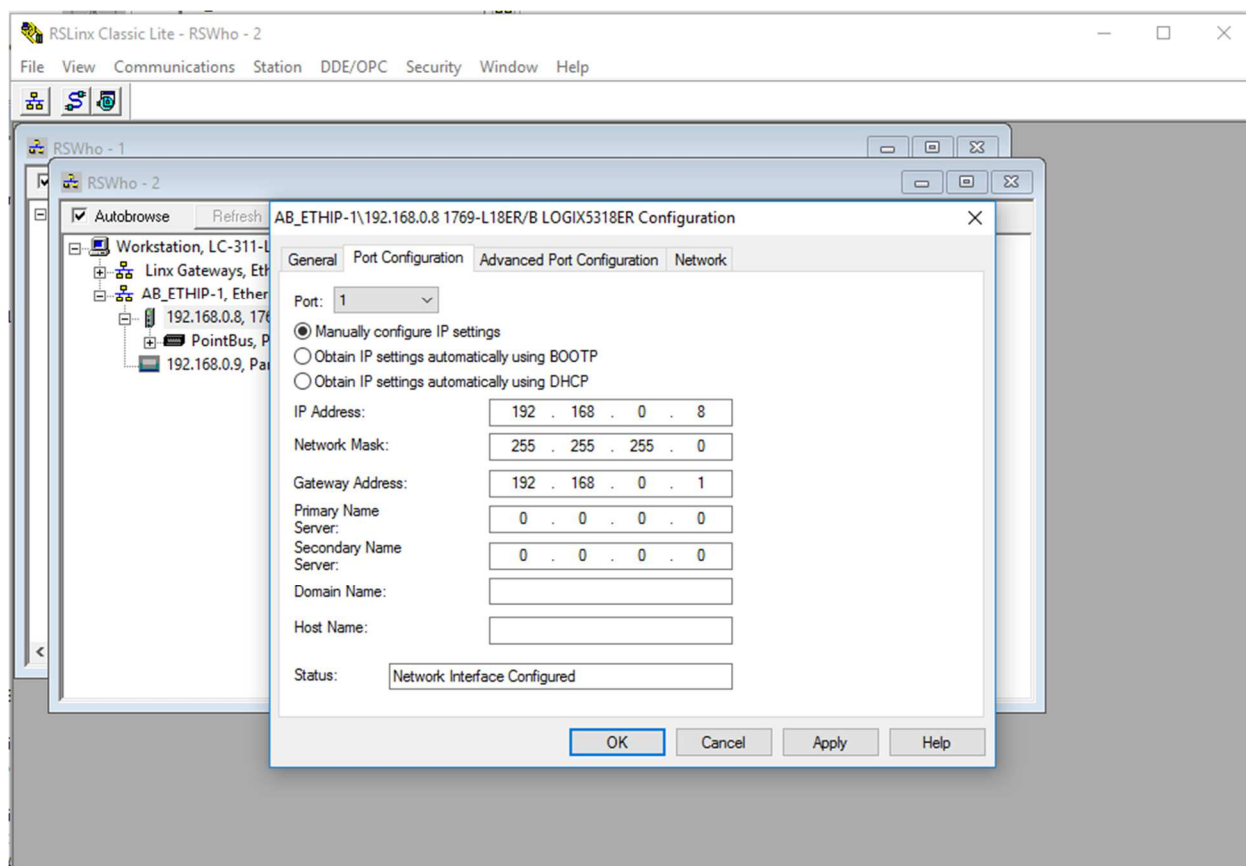
**Figure 11. Electrical schematic for SCADA**

### **3.2 Configuration for real control system (PLC) with the SCADA control monitoring system using DAQ**

The PLC is connected to the Alternative Energy System with a DAQ module, internally converting the real-world physical signals into digital numeric values that can be shown, graphed, and analyzed by a computer. Data acquisition systems, abbreviated by the acronyms DAS or DAQ, convert analog signals into digital values for processing, and they also take care of signal conditioning, which is critical for maximizing the accuracy of the DAQ system [14].



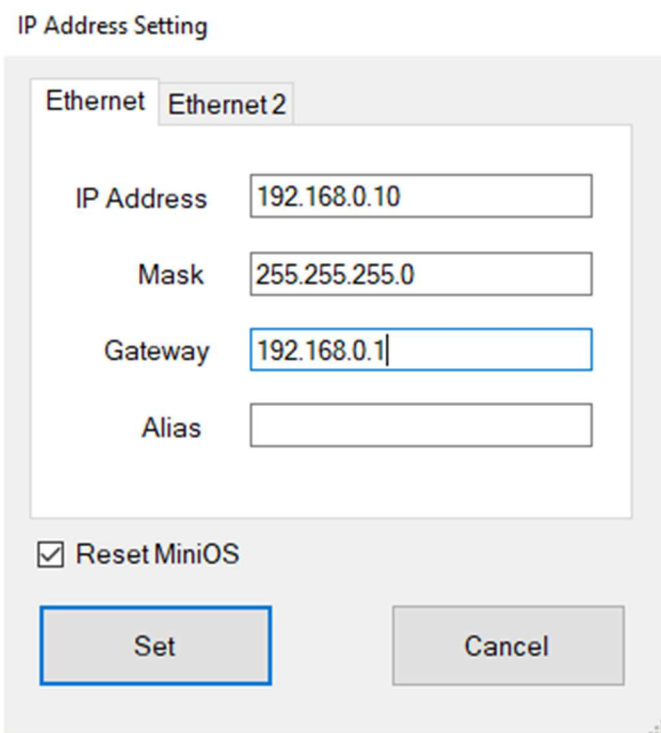
**Figure 12. Connect PLC with the 850-AEC using ET-7017**



**Figure 13. Set IP address for PLC**

Any device connected through an Ethernet connection should have an IP address. If PLC and ET-7017 DAQ connect to an Ethernet by a router as shown in Figure 12, they use DHCP (Dynamic Host Configuration Protocol) Server to get the IP address dynamically. It is convenient to connect the device through Ethernet.





The image shows a dialog box titled "IP Address Setting". At the top, there are two tabs: "Ethernet" and "Ethernet 2", with "Ethernet 2" selected. Below the tabs, there are four input fields: "IP Address" with the value "192.168.0.10", "Mask" with "255.255.255.0", "Gateway" with "192.168.0.1", and "Alias" which is empty. Below these fields is a checkbox labeled "Reset MiniOS" which is checked. At the bottom, there are two buttons: "Set" and "Cancel".

**Figure 14. Setting the IP address for the ET-7017**

After making a convenient connection using the IP address through Ethernet, the IP address, which is 192.168.0.10 in this case, should show up on the ET-7000 Web configuration page. When accessing the ET-7000 Web configuration page, settings such as network setting, basic settings, and module I/O settings need to be modified.

Model Name	ET-7017-10
MAC Address	00:0d:e0:64:59:bf
Module Information	
Firmware Version	1.1.1 (Mar 21 2011)
I/O Firmware Version	1.09
OS Version	2.2.10 (Jun 4 2009)
DI channels	0
DO channels	0
AI channels	10
AO channels	0

**General Description**  
The ET-7000 series is a selection of cost effective, high performance 10/100 Mbps I/O modules designed for remote data collection and remote Ethernet configuration. Modbus TCP/IP port and web port, with a built-in simple HMI that makes configuration and access easy, together

**Figure 15. ET-7000 Web configuration page**

### 3.3 Programming in Studio 5000 Logix Designer and Indusoft Web Studio

After configuration and interfacing, programming the software was completed. First, as previously stated, the PLC ladder diagram is used for programming. In the ladder diagram, input and output instructions are inserted on each rung. The stored instruction set, which is programmed into a PLC, is called the work cycle program. The work cycle program is derived from a program of instruction and/or a process flow for the application being controlled. Second, the SCADA system for the Alternative energy system should be developed using Indusoft Web Studio Educational version 8.0. In the meantime, it is possible to use commissioning tags (signals) with RSLogix 5000 by the accepted communication driver ABCIP(Allen Bradley Ethernet CIP Protocol).

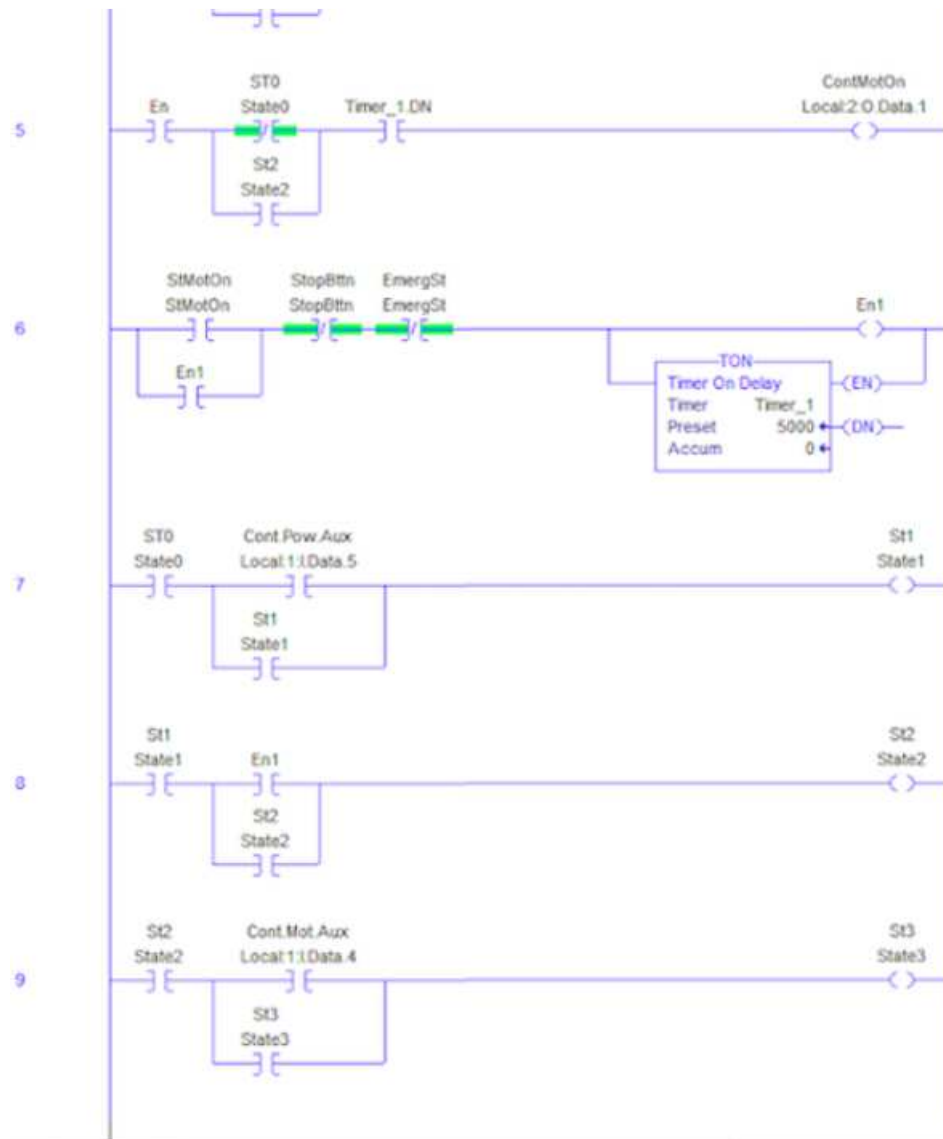
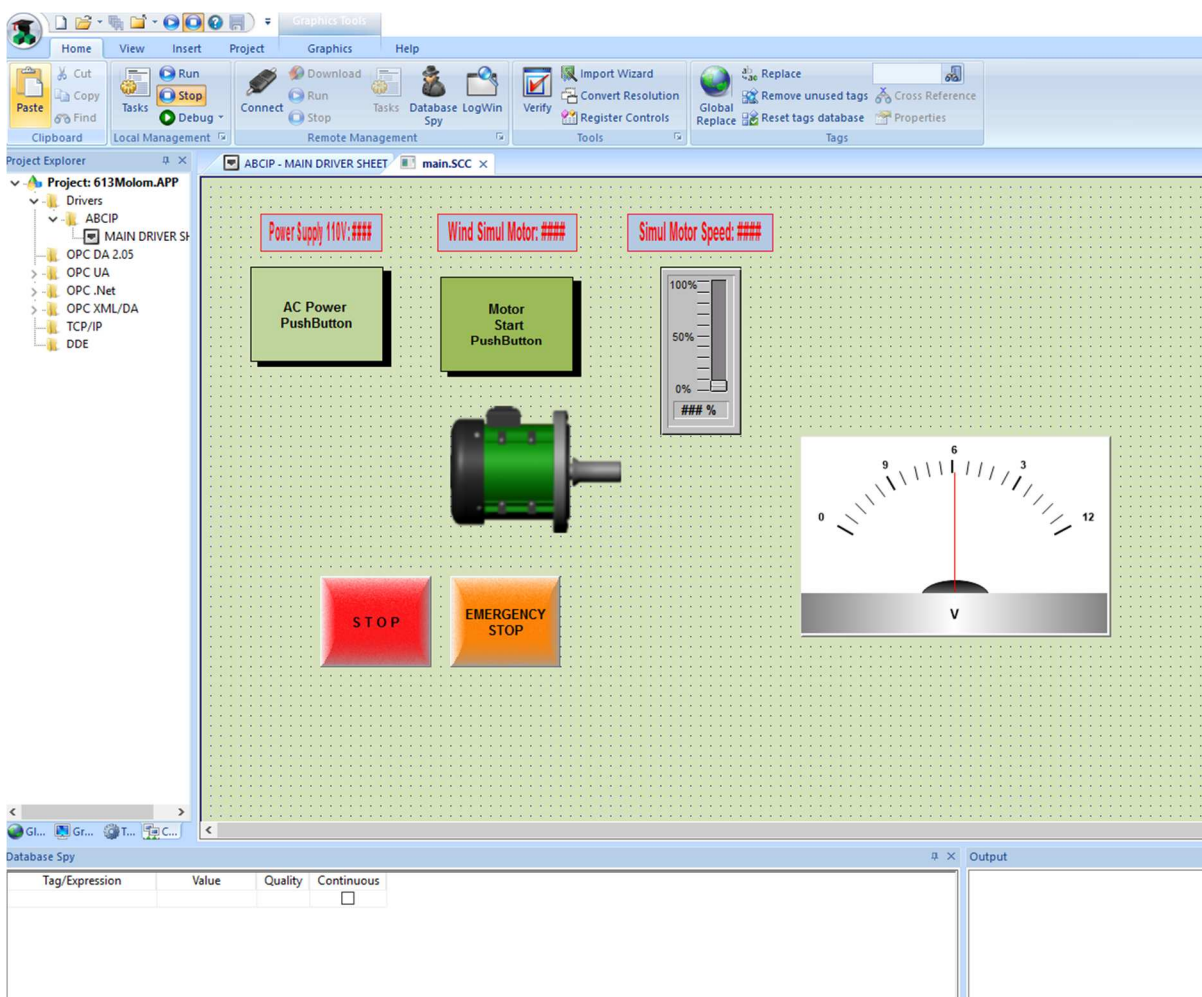


Figure 16. Ladder Logic Program (Studio 5000 Logix Designer)

The screenshot displays the Indusoft Web Studio interface. The top menu bar includes Home, View, Insert, Project, and Help. Below the menu is a ribbon with various tool groups: Clipboard, Local Management, Remote Management, Database LogWin Spy, Tools, and Tags. The Project Explorer on the left shows a project named 'scada116.APP' with a 'Tag List (12)' containing items like AI, AO, AOToModbus, DI, DO, EmergSt, ModbusToAI, MotorSpeed, State3, StMotOn, StopBttn, and StPowOn. The main window shows a table of project tags.

	Name	Array	Type	Description	Scope
	Filter text	F...	(All)	Filter text	(All)
1	StPowOn	0	Boolean		Server
2	StMotOn	0	Boolean		Server
3	StopBttn	0	Boolean		Server
4	EmergSt	0	Boolean		Server
5	MotorSpeed	0	Integer		Server
6	State3	0	Boolean		Server
7	AI	7	Real	Monitor the voltage...	Server
8	AO	3	Real	Output the voltage	Server
9	ModbusToAI	0	Integer	Modbus data conv...	Server
10	AOToModbus	0	Integer	AO value converts L...	Server
11	DI	15	Boolean	DI	Server
	DO	15	Boolean	DO	Server
*			Integer		Server
*			Integer		Server
*			Integer		Server
*			Integer		Server
*			Integer		Server

Figure 17. Programming in Indusoft Web Studio (Project tags)



**Figure 18. Programming in Indusoft Web Studio (building main screen blocks)**

### 3.4 Implementation of the SCADA system

When configuration and interfacing between PLC and Alternative Energy System using DAQ is done, the real-world electric components in the Alternative Energy System should work according to the SCADA control monitor functionality. The first step is to download PLC software, Studio 5000 Logix Designer, to your device or computer. In Studio 5000 Logix Designer, programming will be done via ladder logic by giving the address of the bits and creating new addresses for input and outputs. The same address could be given for different output commands.

Then, one opens Indusoft Web Studio, goes to the project explorer, opens a graphics window and then, the main screen, which is labeled main.scc, should come up on the screen. It will act as the main screen for the rest of the project. Then, one opens the Home toolbar and clicks the Run button to go online for the SCADA system. The Alternative energy SCADA system, that includes the real-world energy components, will work according to the functional signals. If any error occurs in the online mode due to any errors in the program or in the communication connections, the user can troubleshoot the error stage by stage as the program shows the exact location of the error. After modification, the program can be compiled. After a successful run of the SCADA system, the performance of the control and monitor system will be verified.

### CHAPTER IV - TESTING AND ANALYSIS

Commission and interfacing between Studio5000 and Indusoft were successfully accomplished, resulting in being able to monitor and control alternative energy work station electrical signals as shown in Figure 19 and 20.

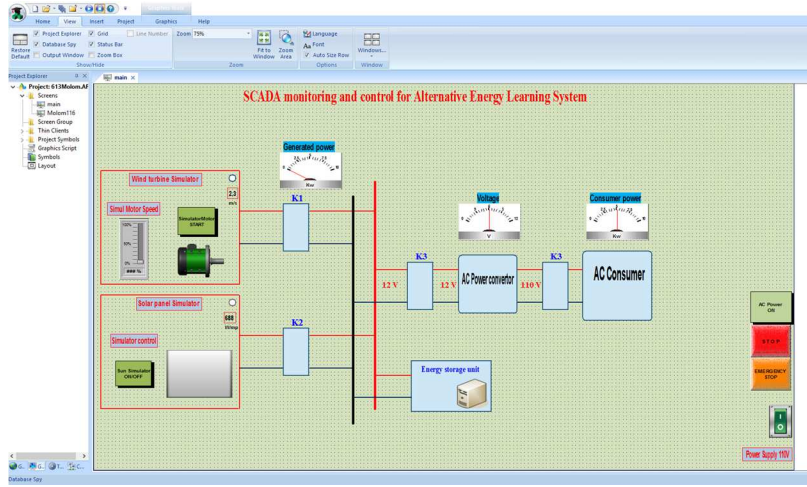


Figure 19. SCADA status page

The screenshot shows the SCADA event logging interface. The main window displays a table of tags with the following columns: Name, Array, Type, Description, and Scope. The table contains 12 rows of data, including tags for motor status, emergency stop, motor speed, state, AO, ModbusToAI, AOToModbus, DI, and DO.

Name	Array	Type	Description	Scope
1	SIPOwOn	0	Boolean	Server
2	SIStMotOn	0	Boolean	Server
3	SIStopBtm	0	Boolean	Server
4	SIEmergSt	0	Boolean	Server
5	SI MotorSpeed	0	Integer	Server
6	SI State3	0	Boolean	Server
7	SI AI	7	Real	Monitor the voltage from AO channel
8	SI AO	3	Real	Output the voltage
9	SI ModbusToAI	0	Integer	Modbus data converts to Modbus data
10	SI AOToModbus	0	Integer	AO value converts to Modbus data
11	SI DI	15	Boolean	DI
12	SI DO	15	Boolean	DO

Figure 20. SCADA event logging

## 4.1 Testing

The intelligent operating and control solutions, such as the SCADA system, should be applied to the renewable energy industry as it will be practically impossible to station personnel to monitor constantly the state of the sources, or problems in the complexity of the system configurations. Calculating how accurate the system is and finding the rated output power are crucial as these were not found for the system's wind turbine.

In order to acquire the key findings, the DC motor simulator, which simulates wind for the system, is controlled and monitored by InduSoft Web Studio HMI SCADA Development Software. Since generating wind at different speeds was not suitable for the setting of the project, the simulator DC motor's speed was altered using Simulator Motor Speed Slider Potentiometer, which controlled the speed from 0% to 100% signal in increments of 5% using the software. This signal is later translated to PLC's absolute 0-10V analog output using Studio 5000 software.

As a summary, four findings were found for the wind turbine: cut-in speed, rated output power, rated output speed, stall mode, and cut-out speed. Table 4 and 5 include a raw data which are used to find the four findings.

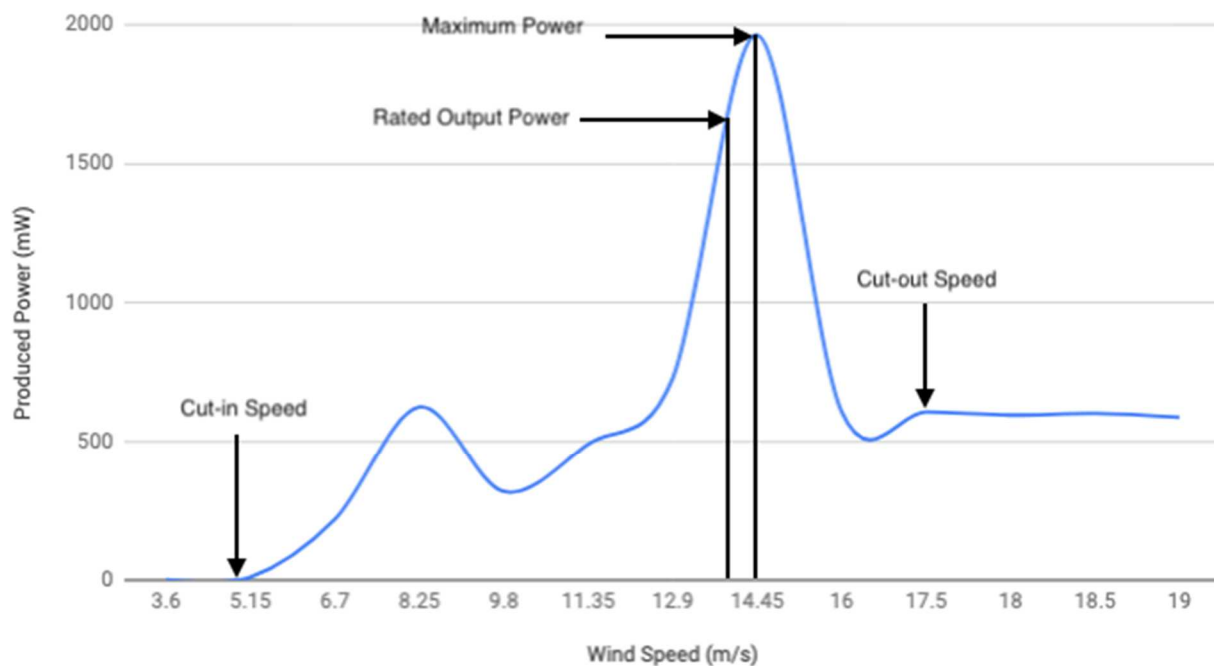
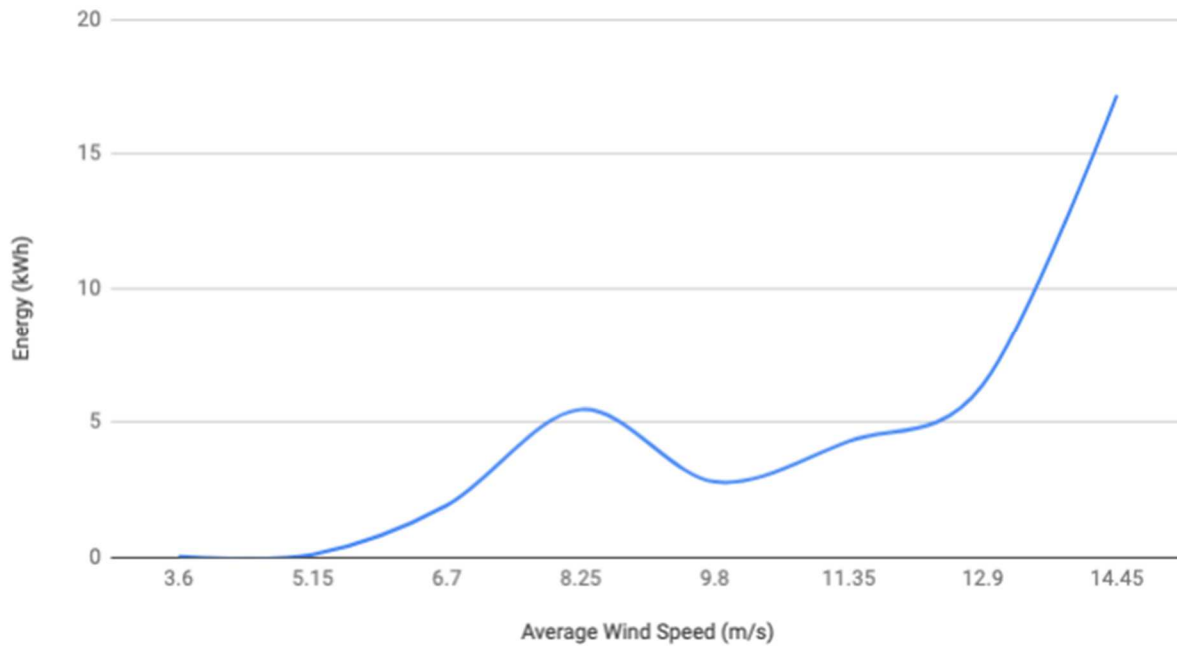
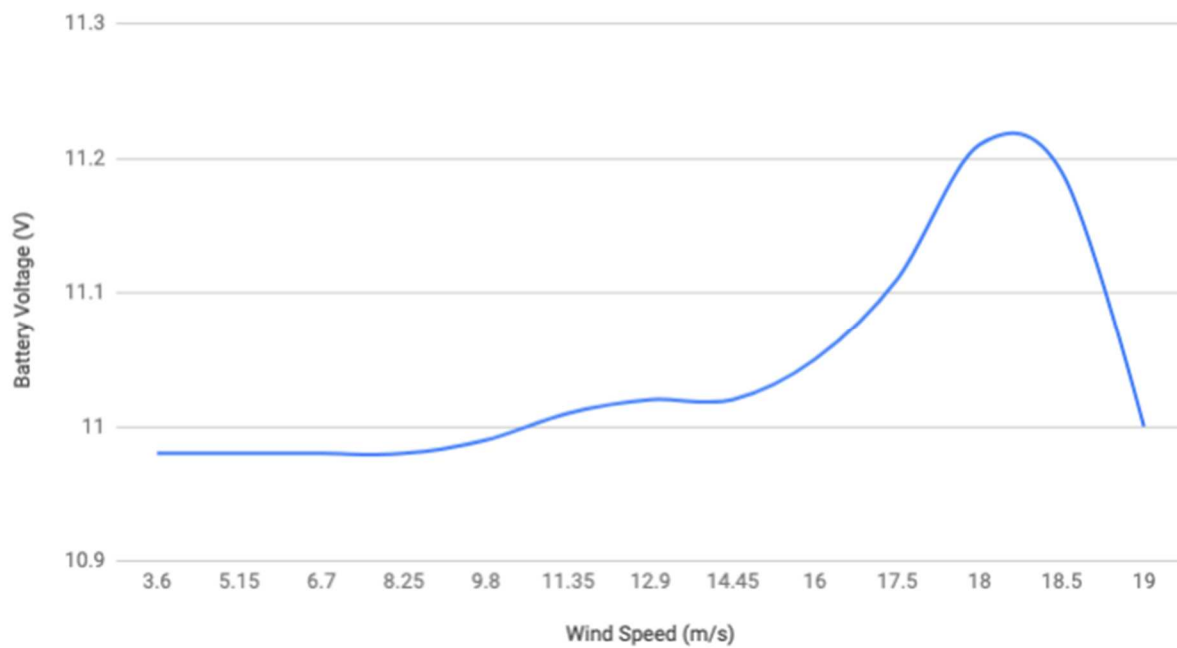


Figure 21. Power Curve





**Figure 22. Annual Energy Production**



**Figure 23. Wind Speed (m/s) vs Voltage of the Battery(V) when connected to the main battery**

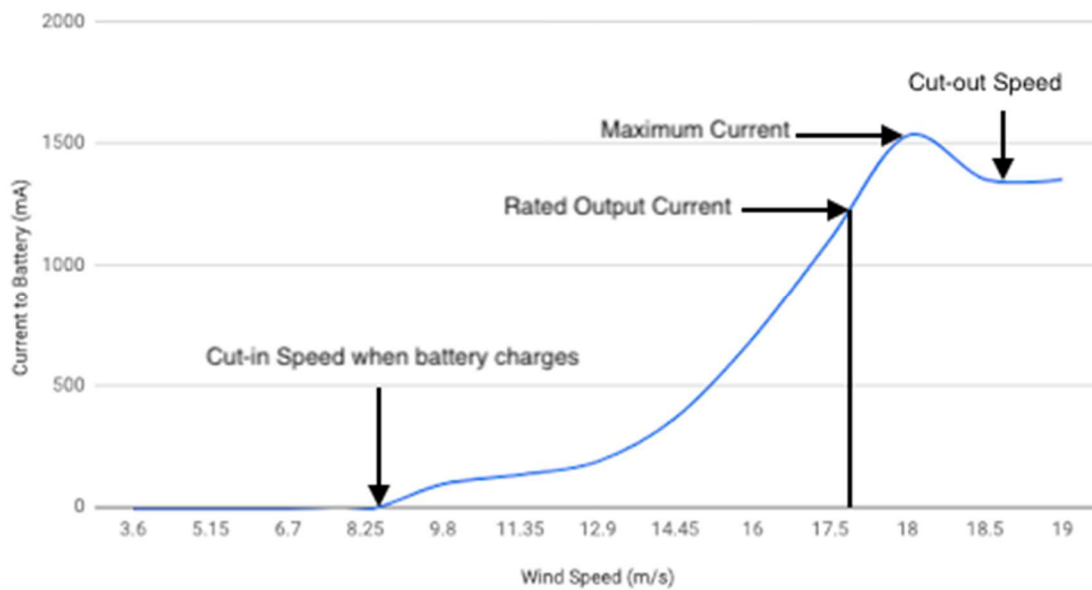


Figure 24. Wind Speed (m/s) vs Generated Current (mA) when connected to the main battery

#	Wind Speed m/s	RPM Motor	Voltage Signal %	Current Load (mA)	Voltage Load (V)	Produced Power (mW)
1	3.6	135	40	1.55	1.32	2.046
2	5.15	193.125	45	5.4	1.91	10.314
3	6.7	251.25	50	106	2.06	218.36
4	8.25	309.375	55	281	2.22	623.82
5	9.8	367.5	60	77	4.13	318.01
6	11.35	425.625	65	100	4.9	490
7	12.9	483.75	70	126	5.78	728.28
8	14.45	541.875	75	305	6.43	1961.15
9	16	600	80	110	5.51	606.1
10	17.5	656.25	85	109	5.56	606.04
11	18	675	90	109	5.46	595.14
12	18.5	693.75	95	110	5.47	601.7
13	19	712.5	100	110	5.34	587.4

Table 4: Table for the wind turbine test when connected to a load.

#	Wind Speed m/s	RPM Motor	Voltage Signal %	Current to Battery (mA)	Voltage Battery (V)	Produced Power (mW)
1	9.8	367.5	60	95	10.99	1044.05
2	11.35	425.625	65	134	11.01	1475.34
3	12.9	483.75	70	188	11.02	2071.76
4	14.45	541.875	75	366	11.02	4033.32
5	16	600	80	692	11.05	7646.6
6	17.5	656.25	85	1103	11.11	12254.33
7	18	675	90	1530	11.21	17151.3
8	18.5	693.75	95	1350	11.19	15106.5
9	19	712.5	100	1350	11	14850

**Table 5: Table for the wind turbine test when connected to the battery.**

### A systematic description of the results

First, as shown on the Power Curve, optimum produced power was found and a stall mode for the wind turbine was evident from the graphed data. The cut-in speed, or the minimum wind speed needed for the turbine to start generating electricity, is rated at 3.6 m/s. At this point, the power output rose above zero. Next, at 14.45 m/s, the rated output speed is found, making the rated output power, or the maximum power, 1961.15 kW. This is found to be the most efficient wind speed for the system to generate maximum power. During the testing, after 14.45 m/s, output voltage reached the regulation setpoint, stopping to generate current and going into a stall mode. From there on, the produced power drastically decreased, ceased to accelerate and the turbine broke into very low speed. Starting at 16 m/s, the produced power was kept at around 600 kW.

Second, shown in Figure 22, annual energy production was calculated. This graph is particularly crucial when determining the costs and benefits of a wind turbine system.

Third, the rated output speed was rediscovered in Figure 23. Before 14.45 m/s, the voltage of the battery did not rise significantly. However, once the wind speed reached 14.45 m/s, the voltage of the battery increased dramatically, proving the rated output speed to be 14.45 m/s.

Lastly, in Figure 24, wind turbine generated current was plotted against the wind speed. This closed circuit included a light bulb and did not include a battery. The cut-in speed was at 8.25 m/s. At this wind speed, the light bulb lit up. At 16.02 m/s, the turbine reached the

regulation setpoint and the generated current started decelerating. 16.02 m/s is found to be the rated output speed. Going up from 16.02 m/s, the wind turbine's generated current did not exceed 1530 mA, going into a stall mode.

#### **4.2 Analysis of the SCADA System for Alternative Energy**

The results for the wind turbine power and current generation test were as expected and presented explanations for the results and the discussion above has presented an explanation for the results. However, there were two things that were not expected: sudden power drop in the "Power Curve" and a decrease in produced power after the rated output speed or in the stall mode.

As shown in the Power Curve, at 9.8 m/s, the produced power drastically dropped and starting at 11.25 m/s, it came back. Compared to other similar experiments, a produced power does not drop as shown in the Power Curve graph. Next, decrease in produced power and generated current after the rated output speed on the Power Curve was not expected. Generally, produced power stays constant at rated output power once the system reaches its rated output speed. Although it did not stay constant at 2 W as it should have, it stayed constant at around 500 kW.

Compared to Figure 22 of "Power characteristic of the ENERCON E70 Wind Turbine" from "Modeling and Design Optimization of Variable-Speed Wind Turbine Systems by Ulas Eminoglu and Saffet Ayasun,"[20] the SCADA system's wind turbine performs very similarly to "ENERCON E70 Wind Turbine" in terms of cut-in speed, rated output power, rated output speed, and the cut-out speed.

In general, in the future, in order to employ best practices, testing the wind turbine with real blades in a strong wind simulated environment could help. We can hypothesize that gear connection between the simulator motor and the wind turbine was not fully efficient due to resistance. In conclusion, at 14.45 m/s, the rated output speed is found, making the rated output power 1961.15 kW for the SCADA System for Alternative Energy.

## **CHAPTER V - RESULTS AND CONCLUSIONS**

### **5.1 Results**

In this research, a SCADA system that communicates between 850-AEC, PLC's, and DAQ was developed. There were two different types of options (auto/manual) which can be chosen by the selector switch. An industrial communication between the real control system and Alternative energy system was created successfully. The physical signals were changing from PLC and DAQ (Alternative energy system). There were digital and analog signals from SCADA software to the Alternative energy system through PLC station. For example, the wind simulator DC motor is monitored by an analog output signal from the slider of the SCADA main screen on the Indusoft Web Studio. Likewise, the converted analog voltage signals go from DAQ to the PC. The implementation of a SCADA system did not have a specific method, but a collection of processes helped achieve the desired result.

### **5.2 Conclusions**

This project has successfully been able to implement SCADA system for a micro generating renewable energy system. The information from the real-world electronics components acquired through DAQ gives a good approximation of the character of energy generation at any given time.

This project, entitled "a SCADA system for alternative energy," is designed to utilize PLC's and a DAQ system, which facilitate effective control on the entire system. The development of each function step and the issues associated with the controller system are detailed. A SCADA technology was utilized to collect and analyze data, monitor performance, and control other devices. The effectiveness of the development of a SCADA system for alternative energy is much depended on a combination of powerful tools and hardware such as Studio 5000 Logix Designer (Allen Bradley PLC) and Indusoft Web Studio (SCADA technology). The recommended tool is Indusoft Web Studio for SCADA. In order to find the effectiveness of the development of the SCADA system, the wind turbine was successfully tested in two different environments and the testing yielded expected results.

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