DREXEL UNIVERSITY
Senior Design
Electrical and Computer Engineering

PROJECT REPORT
2015-2016

Team Number ECE - 26

Energy Management System for a Solar Microgrid

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Group Leader's Signature : ______________________________

Advisor's Signature : ______________________________

1. Abstract

An Energy Management System, EMS, is a computer aided tool that is capable of monitoring, controlling, and through its use optimizing the performance of a power system. At Drexel University, the Reconfigurable Distribution Automation and Control Laboratory, RDAC, does not have an EMS that can capture and consider solar generation characteristics and actively control loads in National Instrument's LabVIEW. In 2014, a senior design group at Drexel University interconnected a photovoltaic array for additional power generation to the RDAC lab. The objective of this Senior Design Group, ECE-26, is to design and develop an EMS to control the sectionalizing relays inside the RDAC Lab that will control the load of the system. Furthermore, the EMS will be designed to obtain measurements from the solar energy grid. The final goal is to utilize LabVIEW to display measurements and control the relay switches in the RDAC Lab for future academic experiments in power distribution.

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2. Background, Problem Statement, and Proposed Solution

The computers in the reconfigurable distribution automation and control (RDAC) lab feature a Visual Basic interface that was programmed based on a National Instrument's (NI) platform in 2002. As National Instruments has improved its LabVIEW interface the senior design group will be using this software as an immersive program that will not only improve the existing capabilities of the Visual Basic EMS but also its visual appearance.

The issue with Visual Basic is the continuous software updates that Microsoft sends out to the program. While the Microsoft software updates, the National Instruments hardware drivers may not. This ends up causing communication errors when the software updates. These communication errors should be eliminated by using software and hardware created by the same company, National Instruments.

In the RDAC lab, there are a total of four stations that are identical in set up. Each station has a 208 V power source supplied by PECO that connects to a 3-phase transformer. The transformer then connects to a distribution feeder box that contains a 9-bus radial power system. A drawing of the 9-bus power system can be seen in Figure 1.

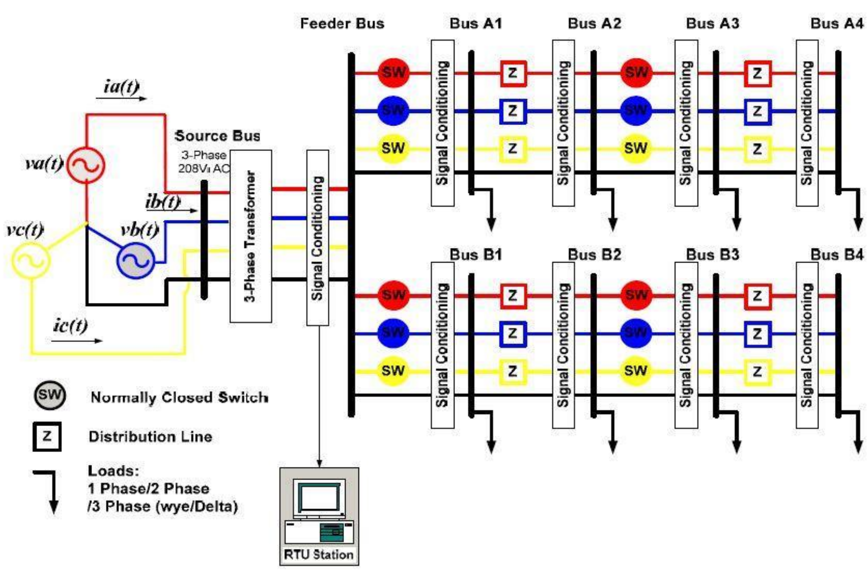


Figure 1. 9-bus radial system diagram.

Connected to the RDAC lab is the Interconnected Power Systems Laboratory (IPSL). In Figure 2 below, the set up in the RDAC lab can be seen. The RDAC lab consists of the following:

A: 208 V Power Supply
B: Distribution Feeder Box
C: Transfer Panel with Chassis

D: Load Bank (lightbulb banks)
E: IPSL/RDAC Interconnect Panel

The feeder box (B) is connected to the transfer panel (C) and a chassis that connects to the DAQ card inside of the computer terminal. The transfer panel is connected to a light bulb bank (D) that can act as a load for the power system. Below the transfer panel, there is a chassis that holds the signal conditioning boards and switch boards. Behind the computer terminal there is the singular solar transfer panel (E) that connects the solar panels from IPSL to the RDAC lab.

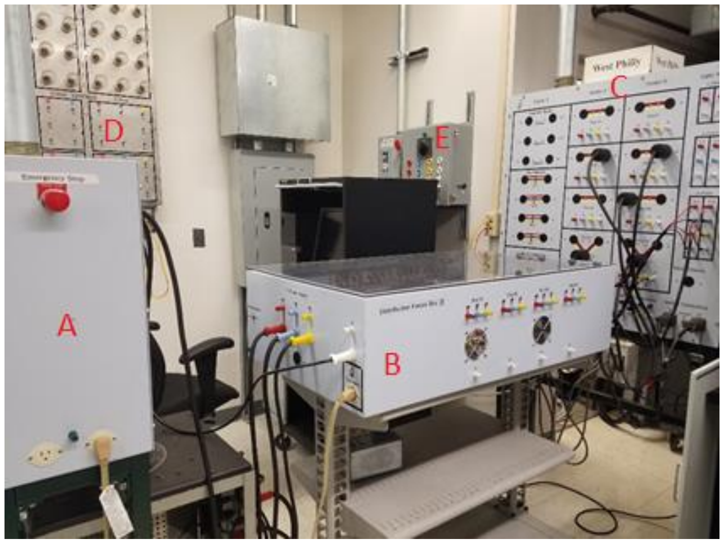


Figure 2. Overview of the RDAC Lab setup.

The objective for this design group is to improve on what was completed to develop a functional EMS, capable of receiving data from the RDAC lab and controlling the switches. The switches seen in Figure 1 are physically realized as the Crydom digital sectionalizing breakers seen in Figure 3.

Figure 3. Crydom 240 V AC Series 1 Solid State Relay.

A previous senior design group utilized the solar photovoltaic cells that were installed on the roof of the main building at Drexel University to connect the generation provided by the solar grid to the RDAC lab. The purpose of this was to connect the solar panels as a secondary power source. There exists a rudimentary interface in LabVIEW that displays the measurements of the current and voltage values of a varying power source through the NI Data Acquisition (DAQ) card. The varying power source could either be the solar panels connected via the IPSL/RDAC connection panel or a PECO, an Exelon Company supplied power.

Alongside the 1,600 W solar panel, backup power is being provided by a 24 V lithium ion battery equipped with a Battery Monitoring System (BMS), shown in Figure 4. With the data terminal for the battery not being in the RDAC lab, a Transmission Control Protocol / Internet Protocol (TCP/IP) connection must be created using the LabVIEW software to obtain the data.

Figure 4. Lithium Ion Battery, located in IPSL

In the RDAC lab, there exists a total of nine possible measurement points in the 9-bus radial power system. The maximum, at one time, amount of measurement points are four. For each of the measurement points, there is a corresponding signal conditioning board (SCB) that arranges the voltage and current data. Out of the 64 analog pins in the NI PCI-6071e DAQ card, 32 pins are used in the RDAC (8 pins for each of the four SCBs). For each of the SCBs, there are 4 pins for voltage and 4 pins for current measurements. Figure 5 shows the NI DAQ card that is being used in the RDAC lab. In Appendix J, there are the listed arrangements of the DAQ card pins.

Figure 5. National Instruments Data Acquisition Card.

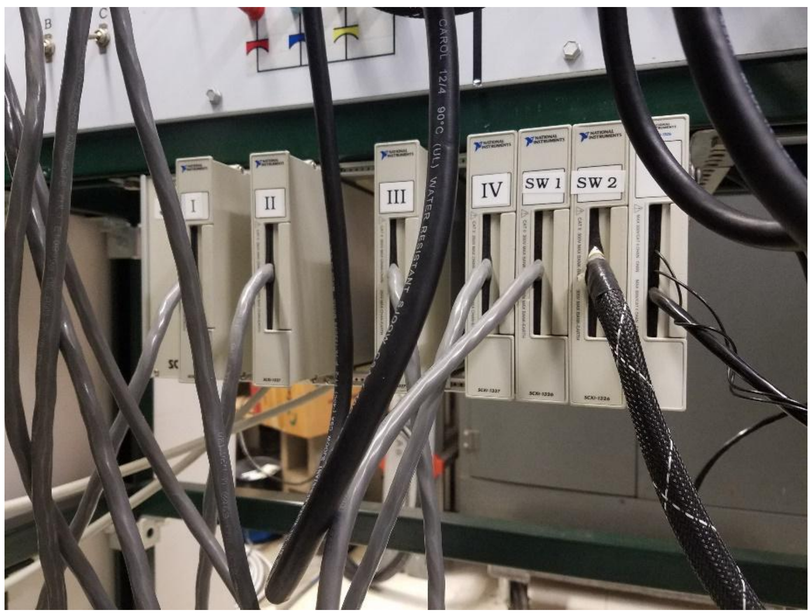


Figure 6. Chassis that holds the four SCBs and two Switch Boards (SW).

The SCXI-1326 SW1 board (seen in Figure 6) connects the distribution feeder box to the digital output connections of the DAQ card. The SW2 board connects to the transfer panel that contains tie line connection breakers and fault switches. The solid state relays in the feeder box are normally closed; the ones inside of the transfer panel are normally open. To flip the state of the relays, an 8-bit binary signal is sent from a LabVIEW Virtual Instrument (VI) through the DAQ Digital I/O channel. The 8-bit signal determines the state of each of the sectionalizing relays and after the DAQ Card reads the input, a 5 V injection is sent to the appropriate relay to flip it from a normally closed state to an open state.

3. Technical Steps for Solution

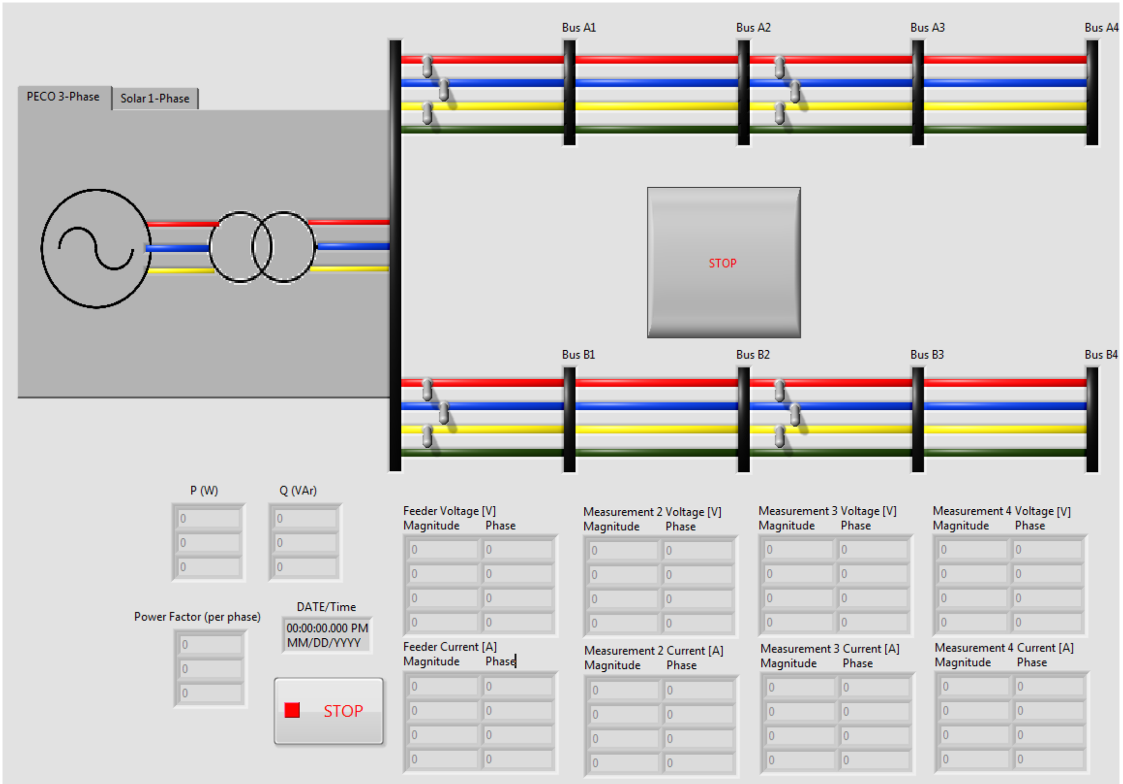


Figure 7. LabVIEW Front Panel view of RDAC GUI.

Figure 7 is the graphical user interface (GUI) that the lab group built within LabVIEW. The GUI is the beginning interface that allows the user to control the physical relays that are in the RDAC Lab. With this, the four measurement points that show the voltage and current measurements and calculations are displayed along with weather data and the battery monitoring system data. The navigation behind the EMS is an on-going progress and additional information such as the BMS and Weather data may be moved into separate tabs for users to access. The RDAC Lab can be supplied power by PECO and the solar panels. There exists a tab that will allow the user to select the type of source being applied to the power system. Due to the inaccessibility of direct solar power this feature is non-operational.

3.1.A. Measurements

Each signal conditioning board has its own physical properties that affect the measurement of the signal. This means that each measurement point has its own conditioning board that has specific AC voltage multiplier and DC offsets to consider when calculating the Root Mean Square (RMS) values of the signal. Table 1 shows the calculated values for each signal conditioning board. The gain value for each signal conditioning board was taken from the previous RDAC lab code. This code was developed under the existing Visual Basic program that uses the same signal conditioning boards. Under the transfer panel, there is a SCXI chassis that connects the four signal conditioning boards (SCBs) and the two switch boards (SWs).

Table 1. AC voltage multiplier and DC offset values for signal conditioning board

Measurement 1						Measurement 2				
AC Multiplier			**DC Offset**			**AC Multiplier**			**DC Offset**	
VA	*113.07*		***VA***	*-7.6040*		***VA***	*109.97*		***VA***	*-5.9945*
VB	*110.26*		***VB***	*-5.4698*		***VB***	*110.12*		***VB***	*-5.4019*
VC	*111.86*		***VC***	*-7.0963*		***VC***	*108.78*		***VC***	*-5.5619*
VN	*112.00*		***VN***	*-120.34*		***VN***	*112.00*		***VN***	*-119.73*
IA	*6.9345*		***IA***	*-0.3954*		***IA***	*6.9730*		***IA***	*-0.2939*
IB	*7.1342*		***IB***	*-0.3865*		***IB***	*7.1493*		***IB***	*-0.4323*
IC	*6.8649*		***IC***	*-0.1646*		***IC***	*7.0334*		***IC***	*-0.4311*
IN	*7.8465*		***IN***	*-0.4681*		***IN***	*14.627*		***IN***	*-0.3555*
Measurement 3						**Measurement 4**				
AC Multiplier			**DC Offset**			**AC Multiplier**			**DC Offset**	
VA	*107.99*		***VA***	*-3.2392*		***VA***	*109.29*		***VA***	*-4.9768*
VB	*110.64*		***VB***	*-6.2412*		***VB***	*109.49*		***VB***	*-5.0144*
VC	*107.10*		***VC***	*-2.3694*		***VC***	*110.37*		***VC***	*-5.9171*
VN	*112.00*		***VN***	*-125.28*		***VN***	*112.00*		***VN***	*-118.99*
IA	*7.0899*		***IA***	*-0.3535*		***IA***	*7.0128*		***IA***	*-0.3231*
IB	*6.9603*		***IB***	*-0.2359*		***IB***	*6.9767*		***IB***	*-0.2342*
IC	*6.7983*		***IC***	*-0.0393*		***IC***	*6.9881*		***IC***	*-0.2793*
IN	*14.447*		***IN***	*-0.2685*		***IN***	*15.032*		***IN***	*-0.2606*

Through empirical testing, the analog pins that read the proper measurements for each signal conditioning board were discovered. The procedure for testing this can be seen in the appendix. Table 2 shows the RDAC to NI DAQ Card pin connections for each measurement point.

Table 2. RDAC to NI DAQ Analog Channel Mapping Locations.

	Signal Conditioning Board I		**Signal Conditioning Board II**		**Signal Conditioning Board III**		**Signal Conditioning Board IV**	
	Voltage	**Current**	**Voltage**	**Current**	**Voltage**	**Current**	**Voltage**	**Current**
A-Phase	*ACH25*	*ACH29*	*ACH17*	*ACH21*	*ACH8*	*ACH12*	*ACH0*	*ACH4*
B-Phase	*ACH26*	*ACH30*	*ACH18*	*ACH22*	*ACH9*	*ACH13*	*ACH1*	*ACH5*
C-Phase	*ACH27*	*ACH31*	*ACH19*	*ACH23*	*ACH10*	*ACH14*	*ACH2*	*ACH6*
Neutral	*ACH28*	*ACH40*	*ACH20*	*ACH32*	*ACH11*	*ACH15*	*ACH3*	*ACH7*

3.1.B. Weather Data

Weather measurements that are supplied to an EMS may help the user with situational awareness and may prepare the dispatcher for the possible unbalancing of load and generation. In a power system, the maximum current carrying capability is reliant on its own ability to dissipate heat through I^2R losses. The weather can affect this capability. For example, a line's rating will be higher on a windy or cold winter day in comparison to a much warmer day. Though it does not apply to the 9-bus radial power system, the lack of real-time weather data will affect the reliability of a power system.

With this in mind, a secondary feature for the EMS was created with the ability to extract weather measurements and display this information within the LabVIEW VI. This information is obtained through online sources such as the National Oceanic and Atmospheric Administration (NOAA) and National Renewable Energy Laboratory (NREL). The VI can extract HTML code from these online sources and parse this information for display. Using the web socket functionality of the LabVIEW software, information can be displayed directly from the online source. This information is provided by nearby weather stations in the Philadelphia region, such as the Philadelphia International Airport and other various stations. Figure 8 shows the closer stations near Drexel University.

Figure 8. Weather Data Stations around the University City Area.

To obtain the weather measurements from online sources, an ActiveX Container must be created in the VI. This web browsing control is needed in order to control invoke nodes and the property nodes that are used to navigate the URL of the online sources. The property nodes converts the property of the document to HTML while the invoke node executes the arguments to display the web browser in the ActiveX Container. The programming behind this can be seen in Figure 9.

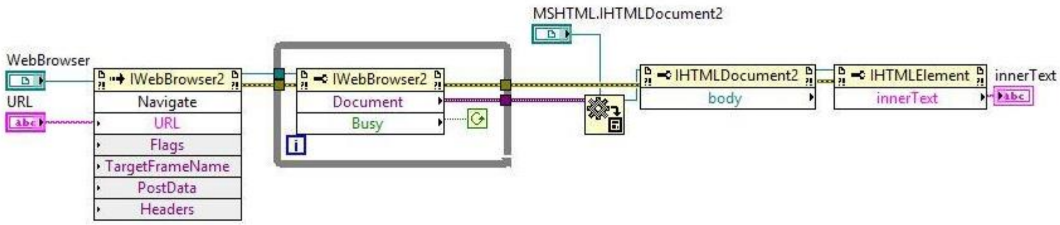


Figure 9. Code in LabVIEW, to display weather information.

3.1.C. Remote Data: Battery Monitoring System

The solar panel cells work in conjunction with the lithium ion battery banks. The batteries provide charge during the off hours of the solar cells. Specifically during the night when the photovoltaic cells are unable convert sunlight into energy, the batteries provide power. The BMS provides information on the status of the batteries such as pack voltage, average cell voltage, state of charge, Ampere hours remaining, and Ampere hours discharged. Appendix F lists all the information provided by the BMS. Like the solar panels installed on the top of the main building at Drexel University, the batteries for the solar system are not installed in the RDAC lab. To transfer the data provided by the BMS and any other outside data source, a TCP/IP connection is needed. Although the solar panels are no longer connected within IPSL, the TCP/IP connection will still function as a means to send data from the BMS or another outside source.

The data output type from the BMS is a tab delimited text file. This is a text document that separates the data elements by tab characters. Figure 10 displays an example of a tab delimited text file. This file is uploaded from the BMS to a computer terminal outside of RDAC that is TCP/IP connected to the RDAC station. The outside computer terminal also has LabVIEW software installed that imports the tab delimited files into a VI. This VI is read as the server side of the TCP/IP connection while the RDAC side holds the client side VI. The data from the BMS is imported into the server side as a table. The TCP/IP connection utilizes the server and client VIs to communicate between the two computer stations. The server VI, displayed in Figure 11, sends the tabulated data across an open port. The client side VI, displayed in Figure 12, opens the specified port and uses a specific IP address to allow the transmission of data between the two. Figure 13 displays the programming of the server VI behind the TCP/IP connection within LabVIEW.

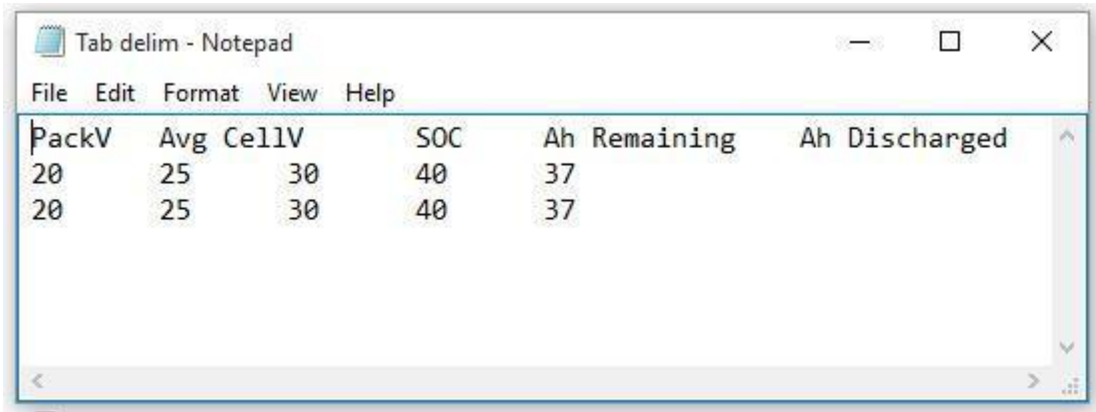


Figure 10. Example of a tab delimited text file.

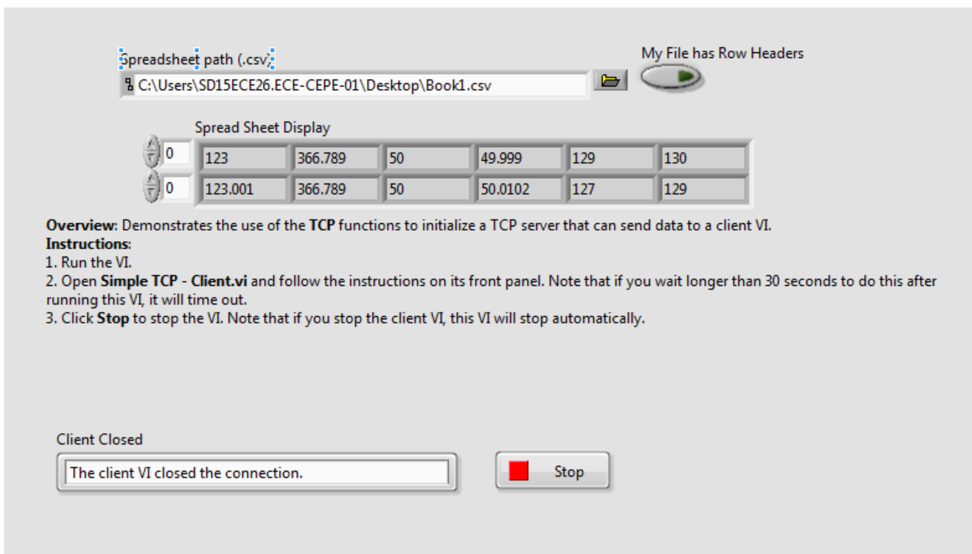


Figure 11. Server Side Virtual Instrument.

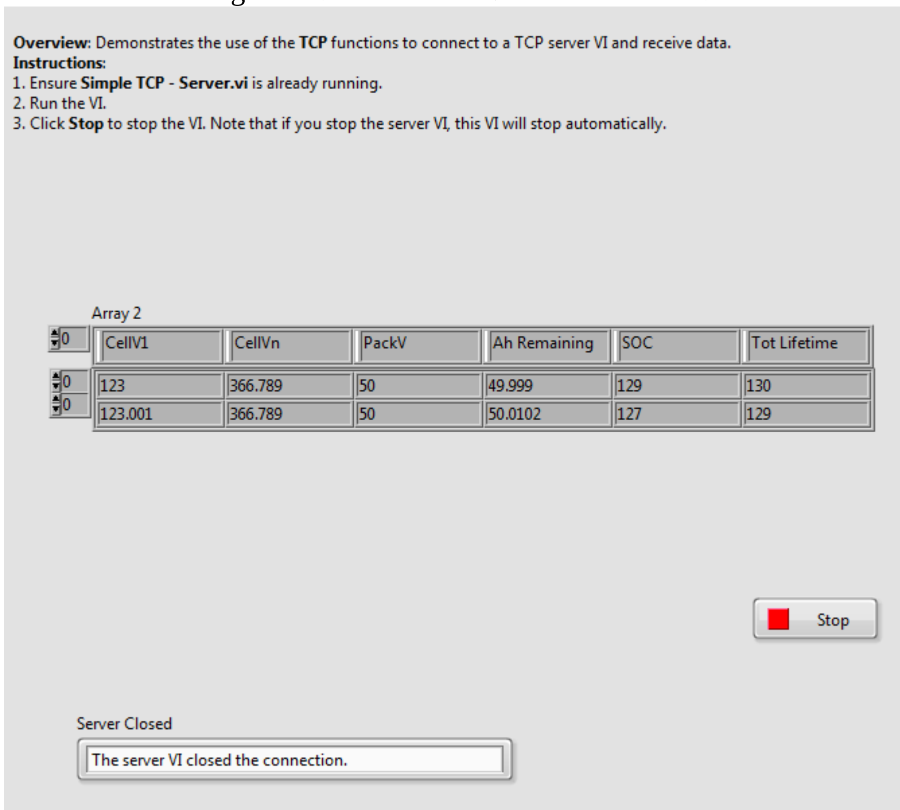


Figure 12. Client Side Virtual Instrument

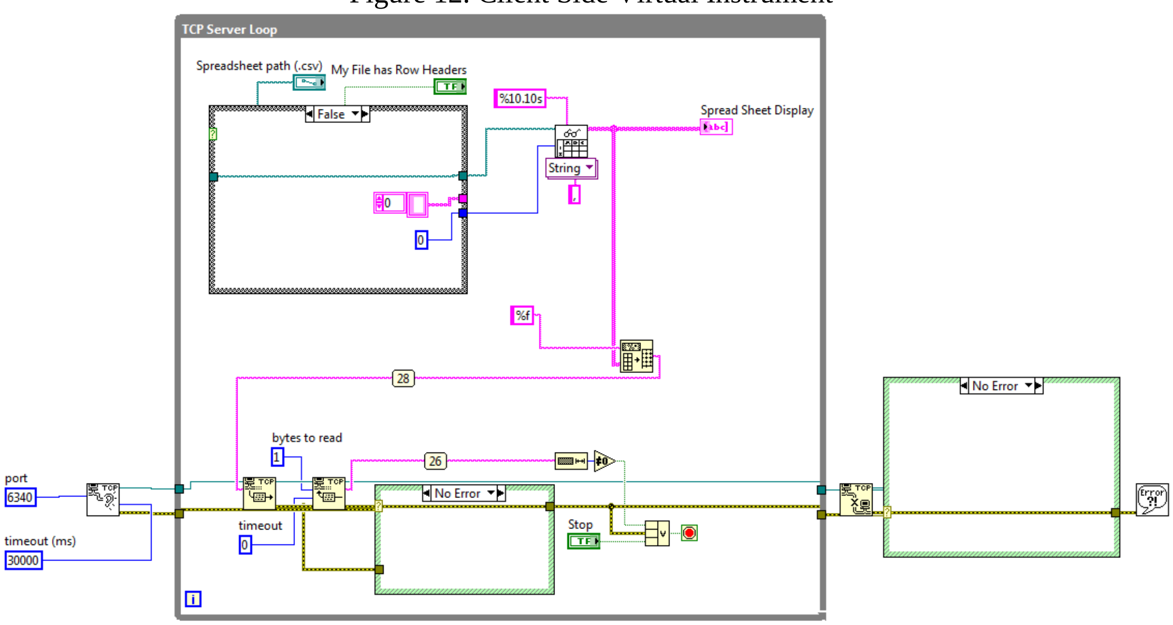


Figure 13. Programming for TCP/IP Connection (Server Side).

3.2 Control

The control of the CRYDOM sectionalizing relays is an objective of the EMS development senior design project. As mentioned earlier, the relays that are inside of the distribution feeder box of the RDAC lab are in a normally closed state. To flip the state of the relays from closed to open, a 5 V injection is needed. To send a signal to the power system to inject 5 V, a LabVIEW VI is needed.

Prior documentation of the RDAC lab shows that the SW boards are the connections between the power system relays and the DAQ card installed on the computer terminal. SW1 is connected to the distribution feeder box and SW2 is connected to the transfer panel.

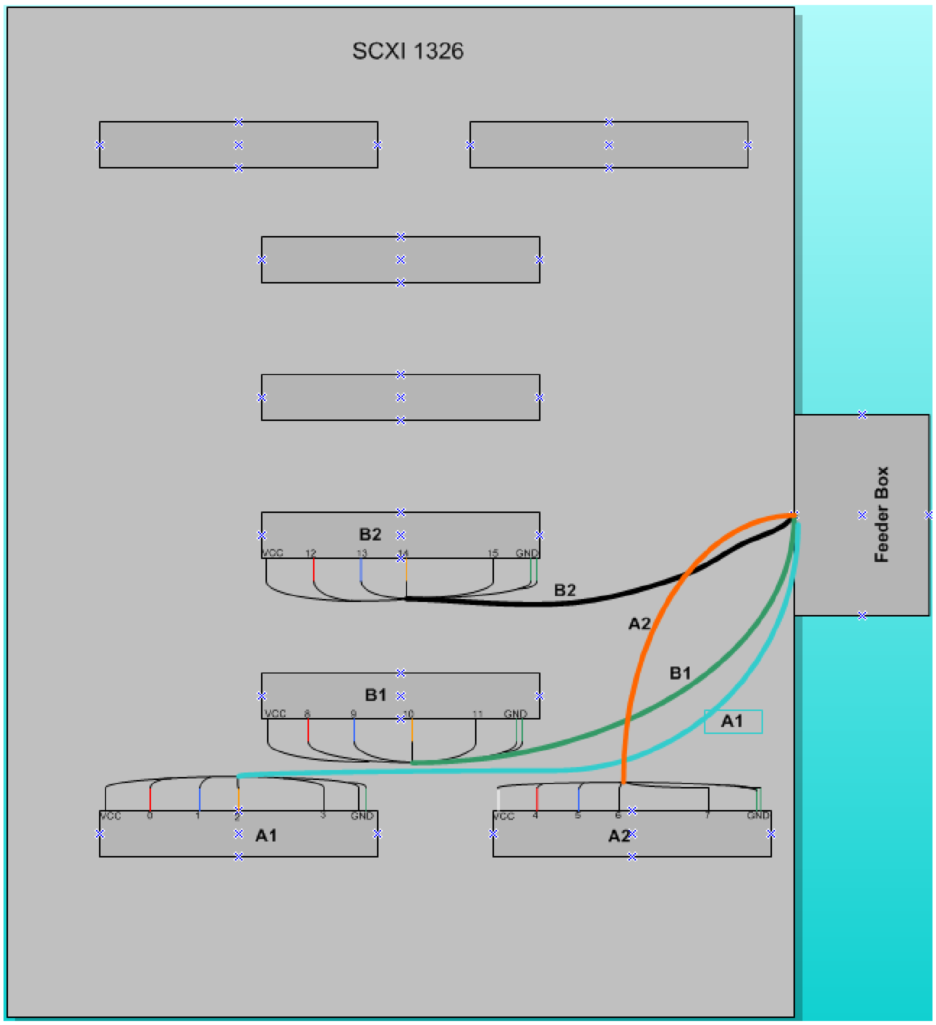


Figure 14. Diagram of connections inside of SW1 board.

The diagram in Figure 14, built using Microsoft Visio, displays the connections inside of the SW1 board. This board connects to the Crydom relays inside the distribution feeder box. In the figure, there are wired connections labeled A1, A2, B1, and B2 that correspond to the set of breakers for each phase at buses A1, A3, B1, and B3 respectively.

Installed with LabVIEW is a Measurement & Automation Explorer program (MAX). This program configures existing devices, can create NI-DAQmx Tasks inside LabVIEW, and troubleshoot signal issues. The NI MAX program interface can be seen in Figure 15. Using this explorer, the Digital Input/Output (DIO) port for the SW1 board was discovered to be DIO0 or Port 0 on the DIO. On Port 0, there are a total of 8 lines (0-7). These lines make up an 8-bit binary signal. This can be observed from MAX in the test panel window shown in Figure 16.

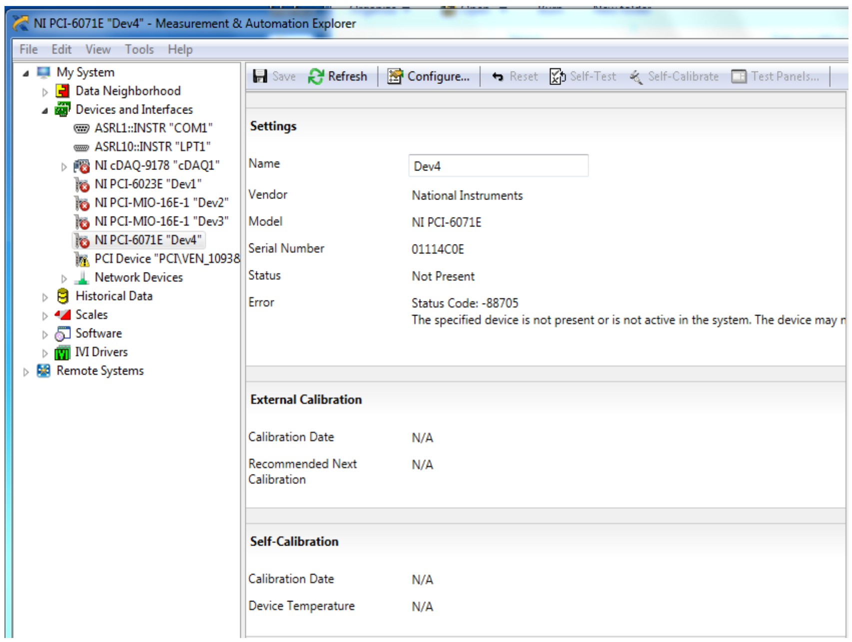


Figure 15. National Instruments MAX Front Window.

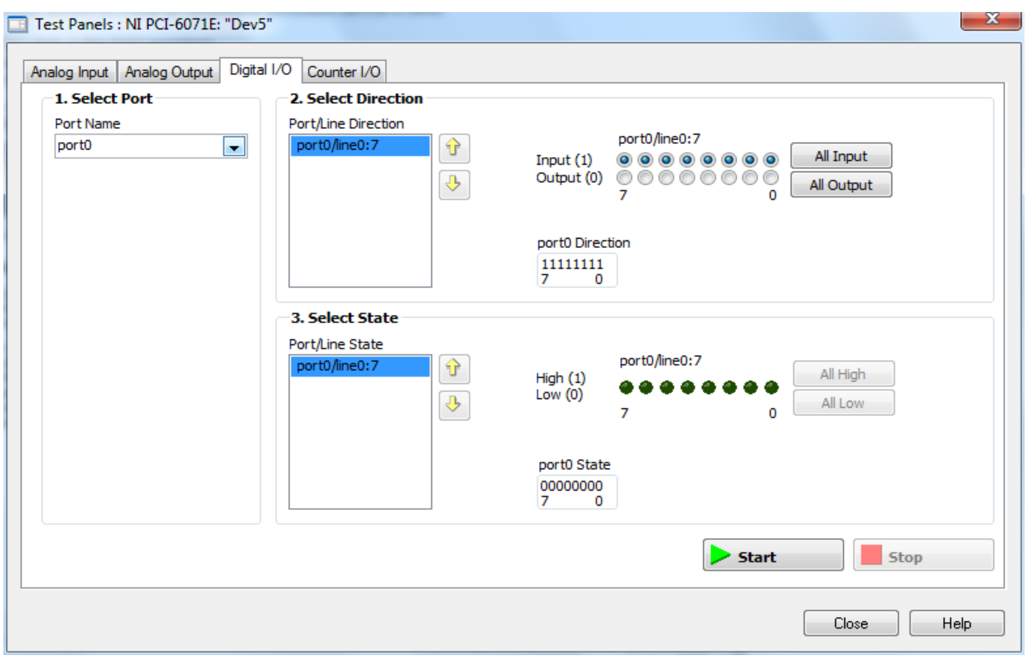


Figure 16. Digital Input/Output Test Panel.

Another method to test the use for control was to use the DAQ Assistant in LabVIEW, this uses MAX to create a virtual instrument to send an 8-bit binary signal through the DIO0 port. To control each separate breaker, an unique 8-bit signal must be sent through the DIO and into the SW board. The DAQ Assistant allows the user to send any arbitrary 8 bit signal through the DIO. Figures 17 and 18 show the steps of using DAQ Assistant in LabVIEW to create a virtual instrument.

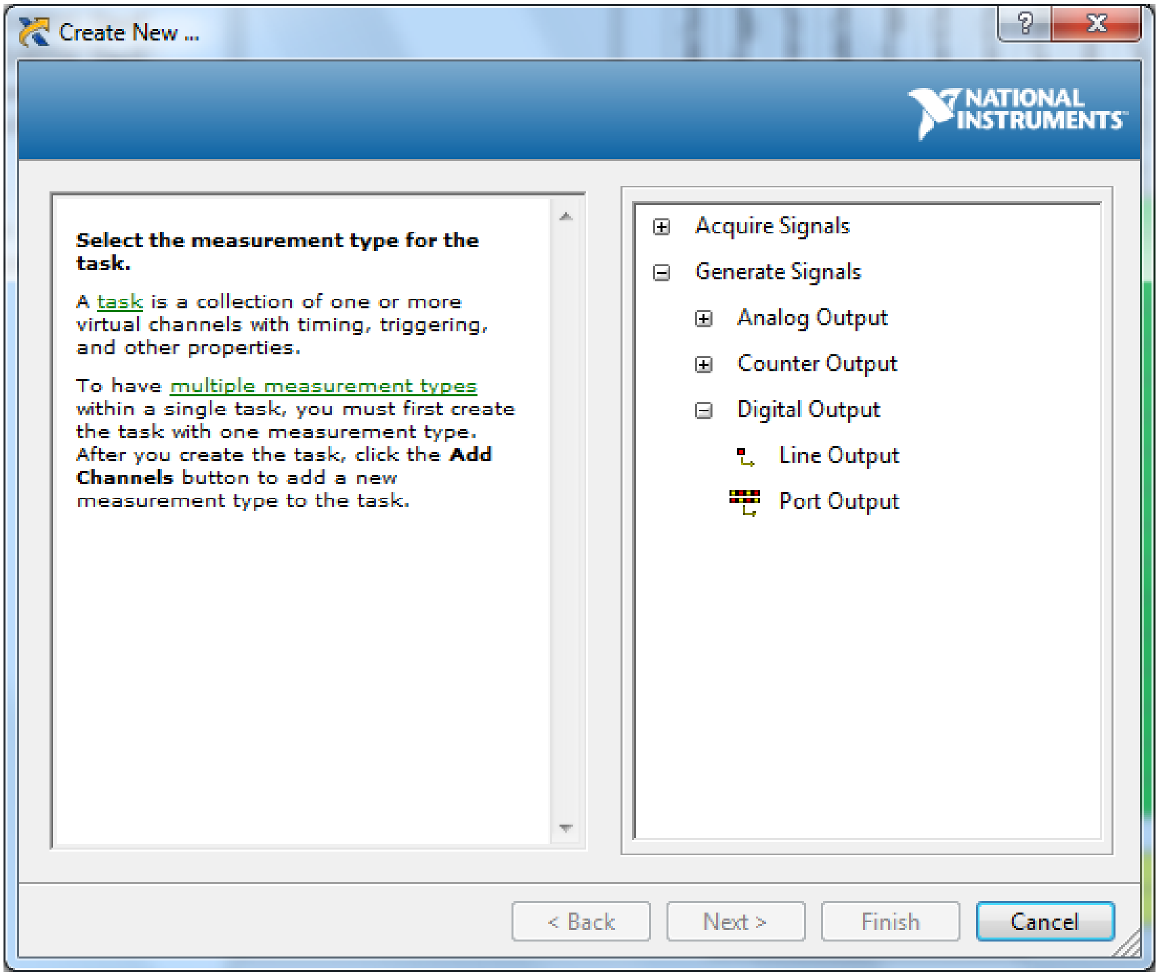


Figure 17. DAQ Assistant VI Creation Window.

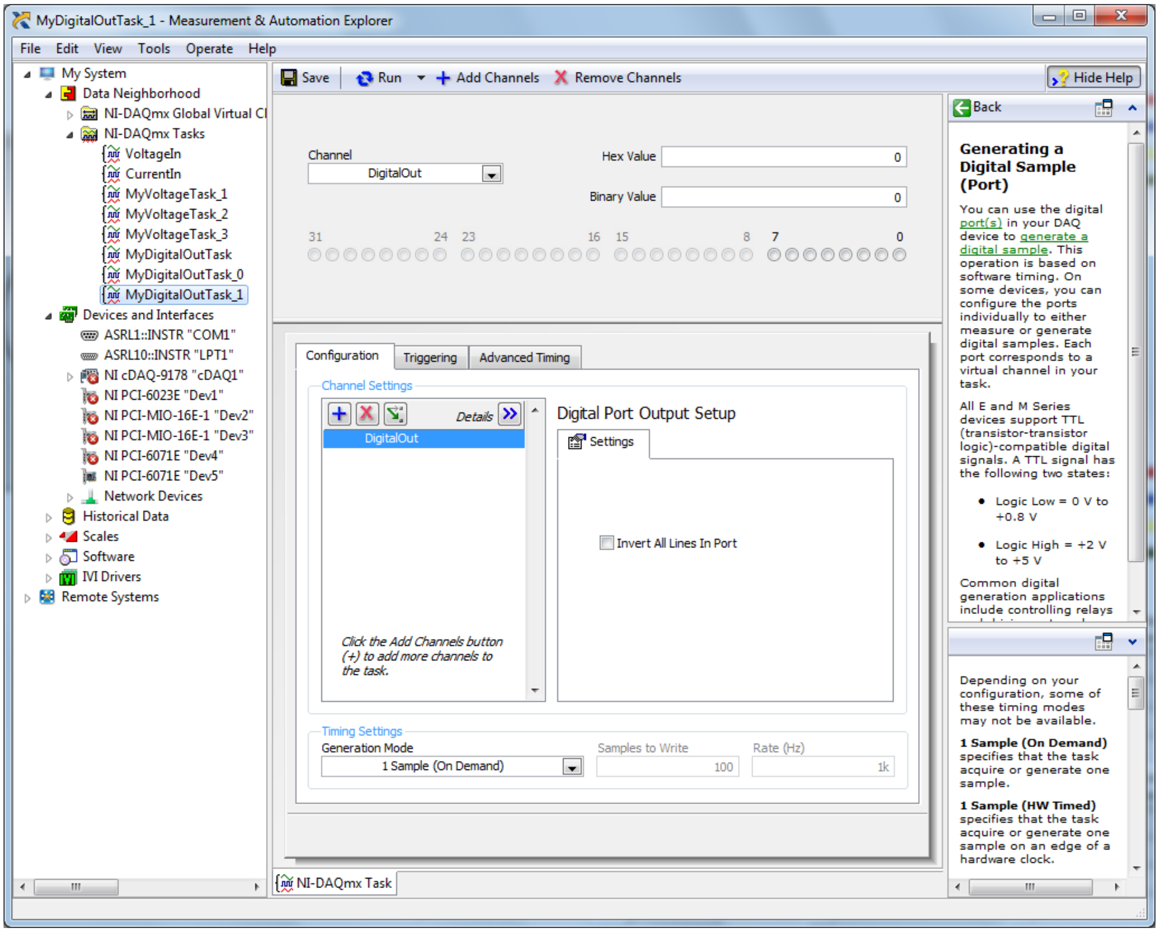
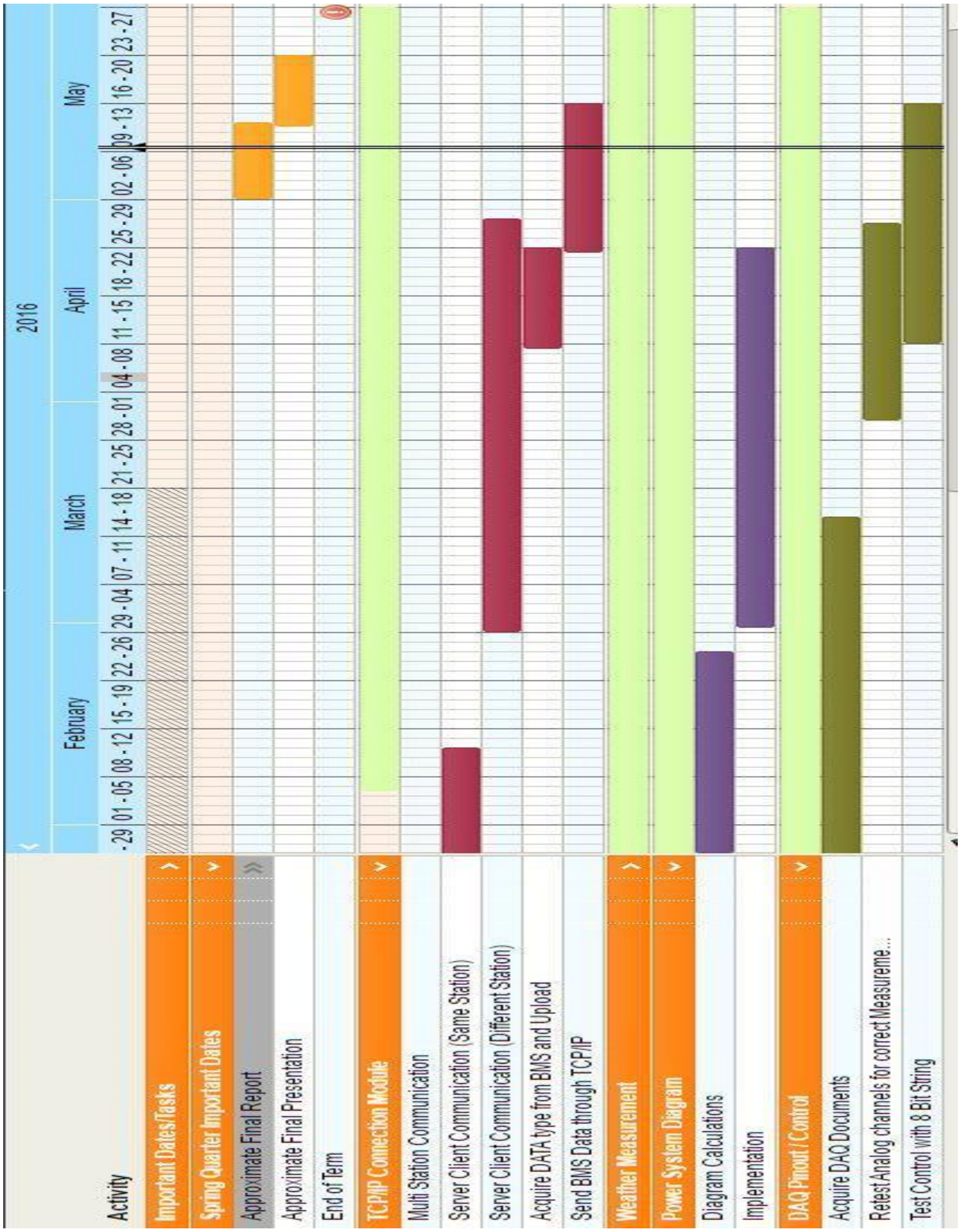


Figure 18. DAQ Digital Output Task.

4. Work Schedule /Gantt Chart



5. Industrial Budget

Table 3: Fall Term Budget

Fall Term

Project Title	Energy Management System for Solar Microgrid			
Names	Lang, Chris; Ngo, Jesse; Williams, Brett			
Team Number	ECE-26			
Labor		**rate/hr**	**Hours**	**Total**
	Electrical Engineer	$42.52	200	$8,504.00
	Electrical Engineer	$42.52	200	$8,504.00
	Electrical Engineer	$42.52	200	$8,504.00
Fringe Benefits			30%	$7,653.60
			Subtotal Labor	$33,165.60
Software Costs	**Part Number**			**Price**
	PCI-6071e DAQ Card*			$1,275.00
	LabVIEW System Design Software*			$2,999.00
			Subtotal:	**$4,274.00**
Out-of-Pocket Expenses	**Item**			**Price**
	N/A			$0.00
			Subtotal:	**$0.00**
			Project Total Without Overhead:	**$37,439.60**
			Overhead:	**$20,966.18**
			Project Total:	**$58,405.78**

*provided by ECE Dept.

Table 4: Winter Term Budget

Winter Term

Project Title	Energy Management System for Solar Microgrid			
Names	Lang, Chris; Ngo, Jesse; Williams, Brett			
Team Number	ECE-26			
Labor		**rate/hr**	**Hours**	**Total**
	Electrical Engineer	$42.52	250	$10,630.00
	Electrical Engineer	$42.52	250	$10,630.00
	Electrical Engineer	$42.52	250	$10,630.00
Fringe Benefits			30%	$9,567.00
			Subtotal Labor	$41,457.00
Software Costs	**Part Number**			**Price**
	PCI-6071e DAQ Card*			$1,275.00
	LabVIEW System Design Software*			$2,999.00
			Subtotal:	**$4,274.00**
Out-of-Pocket Expenses	**Item**			**Price**

	N/A	$0.00
	Subtotal:	**$0.00**
	Project Total Without Overhead:	**$45,731.00**
	Overhead:	**$25,609.36**
	Project Total:	**$71,340.36**

*provided by ECE Dept.

Table 5: Spring Term Budget

Spring Term

Project Title	Energy Management System for Solar Microgrid			
Names	Lang, Chris; Ngo, Jesse; Williams, Brett			
Team Number	ECE-26			
		rate/hr	**Hours**	**Total**
Labor	Electrical Engineer	$42.52	300	$12,756.00
	Electrical Engineer	$42.52	300	$12,756.00
	Electrical Engineer	$42.52	300	$12,756.00
Fringe Benefits			30%	$11,480.40
			Subtotal Labor	$49,748.40
Software Costs	**Part Number**			**Price**
	PCI-6071e DAQ Card*			$1,275.00
	LabVIEW System Design Software*			$2,999.00
			Subtotal:	**$4,274.00**
Out-of-Pocket Expenses	**Item**			**Price**
	N/A			$0.00
			Subtotal:	**$0.00**
			Project Total Without Overhead:	**$54,022.40**
			Overhead:	**$30,252.54**
			Project Total:	**$84,274.94**

*provided by ECE Dept.

6. Societal, Environmental, or Ethical Impacts

The EMS for the Solar Microgrid will involve the planning and operation of energy production and its consuming units. There are several beneficial impacts that an EMS can provide. An EMS can ease system constraints and reduce building costs of generation, transmission, and distribution units. The EMS will ultimately save customer energy costs. The ability to control a solar microgrid can provide relief during peak demand hours. This would reduce the environmental impact of the overall power grid by diminishing the use of fossil fuel plants. Furthermore, the correction of system disturbances and outages supported by an EMS can aid in the restoration of power. This includes the detection and isolation of faults and the automation of switching sequences. A functional EMS will also provide the ability to run simulations, without affecting real-time operations, in order to examine remedial actions and their effects of the power system.

The impacts that this system offers are conservation, climate protection, and cost savings. The EMS enables control of gathering, analyzing, documenting, and visualizing energy data to regulate and monitor energy consumption throughout the power grid. In today’s society, energy efficiency of the power grid is continuously improved through the use of systems like these.

7. Testing and Validation of Results

Throughout the Fall and Winter quarters of the project, different modules were created that were to be implemented into the Energy Management System. These modules are covered in the Technical Solutions section of the report.

1. Measurements
2. Weather Data
3. TCP/IP Connection
4. Control

The virtual instrument that displays the voltage and current RMS calculations was initially created by a previous senior design group. This virtual instrument allowed the user to designate which of the buses in the power system were set as measurement points. However, testing and analyzing the programming behind the virtual instrument lead the senior design team to discover that the incorrect AC voltage multipliers and DC offsets were used when calculating the RMS values from the signal conditioning board. Further testing lead to the discovery that the incorrect ACH of the DAQ cards were being used when calculating the signals. This led to the testing procedure in Appendix I being used to find the accurate ACH for each signal conditioning board.

The weather module was completed at the end of the Winter quarter and allows the user to either manually input a URL that will open up an internet browser so that the virtual instrument may receive and display weather data from any source like NOAA and NREL.

The TCP/IP connection tests involved a multitude of steps. The first step involves server and client VIs that can communicate (meaning the digital transfer of data) on the same computer station. Then the VIs were reprogrammed to communicate across separate stations. After concluding that the VIs were able to send and receive information, the design team focused on the BMS as a remote system to send data into the EMS. The data output type of the BMS was provided by previous documentation as a tab delimited file. Using this information a new VI uploaded a tab delimited file into a 2-Dimensional array. The TCP/IP connection was reprogrammed to compress the uploaded delimited file into a 2-D array and sent across to the server side. However, after compressing the 2-D array, the results yielded a long 1 Dimensional array. This is not the desired result of the TCP/IP connection and is still in progress.

8. References

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Appendix A: Design Constraints Summary

Team Number: ECE-26
Project Title: Energy Management System for a Solar Microgrid

Summary of the Design Aspects:

The project design, an Energy Management System for a Solar Microgrid, is used in the distribution system in Drexel University's Reconfigurable Distribution Automation and Control Laboratory (RDAC Lab). The LabVIEW software platform will create a user interface that connects to the measurement instruments already in the RDAC to run the test simulations with more functionality like control. Research about the distribution system and generation is the primary driving force behind developing an EMS.

Design Constraints:

Economic:

Solar Panels are not made with the same consistent materials. These materials are not inexpensive to the point where they can be regularly tested. The low maintenance is a beneficial factor that lowers costs. Since Drexel has solar panel installations on the roof, the design team will not be dealing with expenses mentioned above.

Manufacturability:

Solar panel installations for grid operation are increasing around the globe, with the renewable energy on the rise. Though the RDAC Lab is on a smaller scale than an actual generation power plant, the concepts and ideas behind an EMS remain the same.

Sustainability:

Photovoltaic systems have average lifetimes of 20-25 years. Maintenance is low and the cost to replace such systems are infrequent.

Environmental:

Photovoltaic systems have a very small carbon footprint and would put less pollutants in the air. However, a large amount of area is required to create a generation system large enough to affect the bulk electric system.

Ethical, health, and safety:

Similar to the environmental, usage of fossil fuel plants would decrease which would improve the quality of air. Photovoltaics do not require frequent maintenance this significantly reduces the chance of accidents. Furthermore, in remote parts of the world these panels can be used to create an energy infrastructure, enabling distant populations access to electricity.

Social:
Renewable energies are received well publicly as they are seen to play a key part in the sustainability of natural resources. However, solar panel facilities take up significant land and could be seen as visual pollution.

Political:
Government incentives for programs that support the implementation of a EMS system like this would increase interest, motivation, and productivity to further research in it.

Standards and Regulations:

- Standard for Interconnecting Distributed Resources with Electric Power Systems, IEEE Standard 1547, October 2003

- Guide For Monitoring, Information Exchange, and Control of Distributed Resources Interconnected with Electric Power Systems, IEEE Standard 1547.3, 2007

- Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems, IEEE Standards 1547.4, 2011

- Recommended Practice For Interconnecting Distributed Resources With Electric Power Systems Distribution Secondary Networks, IEEE Standards 1547.6 , September 2011

Appendix B: Resumes

Brett Williams

619 N. 34th Street
Philadelphia, PA 19104
856-404-7488
baw84@drexel.edu

Education

Drexel University — Philadelphia, PA
Bachelor of Science in Electrical Engineering — Anticipated Graduation - June 2016
Cumulative GPA: 3.03

Relevant Coursework

Electric Motor Control Principles
Nuclear Power Plant Design & Operation
Introduction to Renewable Energy
Theory of Nuclear Reactors
Solar Energy Engineering
Energy Management Principles

Engineering Experience

PJM Interconnection — Norristown, PA
Dispatch Co-op — September 2014 to March 2015

- Updated Excel spreadsheets daily for historical data preservation.
- Performed studies on EMS for transmission contingencies.
- Wrote monthly reports for State of System meetings.
- Constructed displays in PI ProcessBook for dispatchers in the Control Room.
- Completed data requests by NERC and FERC for regulatory purposes.
- Organized recorded phone calls for audits and specific events.

Metropolitan Acoustics, LLC — Philadelphia, PA
Acoustical Consulting Co-op — September 2013 to March 2014

- Designed room acoustics using Microsoft Excel and AutoCAD, to determine reverberation times and sound isolation.
- Modeled sound propagation through HVAC systems using Dynasonics.
- Drafted reports regarding room acoustics, sound isolation, and mechanical systems.
- Developed and enhanced modeling tools in Microsoft Excel.

Monitoring Analytics, LLC — Norristown, PA
Market Analyst — September 2012 to March 2013

- Managed and manipulated data regarding the electric power market, using SQL programming.
- Analyzed market participant conduct and market performance data to prevent monopolies and illegal trading.
- Developed database programming queries, data sets, and diagrams.

Additional Experience

PJM Interconnection Courses — Norristown, PA
Dispatch — September 2014 to March 2015

- Fundamentals of Transmission Operations
- System Dynamics
- PJM 101: The Basics
- NERC Standards Training
- Generation Operator Fundamentals
- System Resoration

Computer Skills

Software - Microsoft Word, Excel, and PowerPoint; AutoCad; Maple; SQL; Matlab; Dynasonics; SketchUp

Activities

Member, Acoustical Society of America, September 2013 to Present
Treasurer, Drexel University Ski and Snowboarding Club, September 2015 to Present
Member, Drexel University Ski and Snowboarding Club, September 2011 to Present

Christopher M. Lang

300 Beaver Drive
Lincoln University, PA 19352
(610) 348-2625
CL834@drexel.edu

Education

Drexel University, Philadelphia, PA
Bachelor of Science in Electrical Engineering, Anticipated Graduation: Spring 2016

Relevant Coursework

Intro to Renewable Energy	Electric Motor Principles	Nuclear Plant Design & Operation
Intro to Nuclear Engineering	Theory of Nuclear Reactors	Energy Management Principles

Relevant Experience

PECO, An Exelon Company, Philadelphia, PA
T&S Engineer, September 2012-April 2013

- Maintained and supported the Transmission and Substation Systems for PECO
- Examined equipment data through Computer-Aided analysis to identify and address system deficiencies
- Participated and restored 850,000 customers in the Hurricane Sandy restoration team, of the power delivery system

CDI Corporation, Ridley, PA
Engineering Technician , September 2013-March 2014

- Worked on Boeing 757, 777, and 787 Dreamliner commercial aircraft
- Performed stress analysis to validate and verify systems and components met requirements and specifications
- Applied Computer Aided analysis techniques and classical analysis techniques to ensure structural integrity and vehicle performance

PJM Interconnection, Audubon, PA
Dispatch, September 2014-March 2015

- Compiled daily reports with data from multiple resources and distributed them to proper recipients
- Performed studies on EMS for transmission contingencies
- Restructured operation manuals and control room displays
- Organized recorded phone calls for audits and specific events
- Maintained and gathered evidence for PJM compliance team
- Assisted PJM in their NERC audit

Additional Experience

PJM Interconnection Courses, Audubon, PA
Dispatch, September 2014-March 2015

- Fundamentals of Transmission Operations
- NERC Standards Training
- System Dynamics
- Generation Operator Fundamentals
- PJM 101: The Basics
- System Restoration

Computer Skills

Software: AutoCAD, MATLAB, Java, PSpice, Microsoft Word, Microsoft Excel, PowerPoint
Operating Systems: Windows 2000/XP/Vista, Mac OS

Activities

Institute of Electrical and Electronic Engineers, 2009-Present
American Society of Mechanical Engineers, 2010-Present
Sophomore Chair 2012-Present

Jesse Ngo
207 Oakford Avenue
Delanco, NJ 08075
609-500-3869
jln68@drexel.edu

Education

Drexel University — Philadelphia, PA
Bachelor of Science in Electrical Engineering — Graduation- June, 2016

Relevant Coursework

Dynamic System Stability
Power Systems I
Nuclear Power Plant Design & Operation
Energy Management Principles
Transform Methods, Signal Filtering I & II
Theory of Nuclear Reactors

Computer Skills

LabVIEW, Pro Engineer Wildfire 5.0, MatLab/Simulink, SAS, JAVA

Engineering Experience

PJM Interconnection — Norristown, PA
Reliability Engineering Co-op — September 2014 to March 2015

- Write and test Bulk Electric System Contingencies for The state analysis of the Energy Management System.
- Complete data requests for NERC and FERC for regulatory purposes.
- Program data management script for continuous updates of the Bulk Electric System.
- Create information displays of the Bulk Electric System to assist dispatchers and engineers

Arora Engineers - Corrpro Companies Inc. — West Chester, PA
Engineering Technician — September, 2013 to April, 2014

- Cooperated with the redesign of the Hugh L. Carey Tunnel (aka Brooklyn Battery Tunnel)
- Surveyed client projects to ensure CP system working effectively
- Worked lab experiments to determine environmental properties of soils

Monitoring Analytics — Eagleville, PA
Analyst — November, 2012 to April, 2013

- Programmed code templates to perform queries on large portions of data
- Researched multiple parent companies and affiliates for records
- Worked on large Cap and Trade projects

Additional Experience

PJM Interconnection Courses — Norristown, PA
Reliability Engineering — September 2014 to March 2015

- System Dynamics
- PJM 101: The Basics

Appendix C: Addressing Comments from the panel

The major comment that was presented to the design team were the grammatical errors within our winter progress report. In order to address this issue, the design team proofread the project report individually. Additionally, the design team's report was proofread by the advisor.

Appendix D: Individual contribution to the project

Chris Lang - Implemented weather measurements for the EMS interface.
Re-performed Multi-phase power flow experiment to check real-time data in LabVIEW. Assisted TCP/IP connection development.

Brett Williams - Developed TCP/IP connection to transfer data arrays from external sources to the RDAC station. Assisted in design and documentation of the 9-bus radial system diagram.

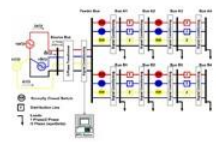
Jesse Ngo - Created a system diagram for the 9-bus radial power system. Constructed EMS interface to include power measurements along with additional capabilities. Assisted in programming WebsocketDisplay for weather measurement. Programmed parts of TCP/IP connection to transfer data from BMS.

Appendix E: Quad Chart

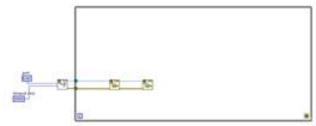
Energy Management System for a Solar Microgrid
ECE-26

Objective

- Design and develop an Energy Management System (EMS) to measure and control a distribution grid.
- Utilize National Instruments LabVIEW software.
- Testing will be performed in the Reconfigurable Distribution Automation and Control (RDAC) laboratory.
- The EMS data will be used to load shape as well as achieve a balance between generation and load.



Current 9-bus diagram constructed with multiple combinations.



Approach:

The decision method will be based primarily on specific elements:

- LabVIEW User Interface
  - Control Instrumentation
  - Weather Measurements
  - TCP/IP Connections
  - One-line Power System Diagram
- Stand-alone experiments
  - Implementation into the distribution grid
  - Control of sectionalizing switches on 9-bus array
- Aesthetics

Key Milestones

• 2015 LabVIEW software update	1/16
• 2nd LabVIEW station	1/16
• 9-bus radial array power system diagrams	2/16
• Multi-phase set up	2/16
• Control instrumentation	3/16
• TCP/IP Connections	3/16
• Functional weather measurement	4/16

2/16

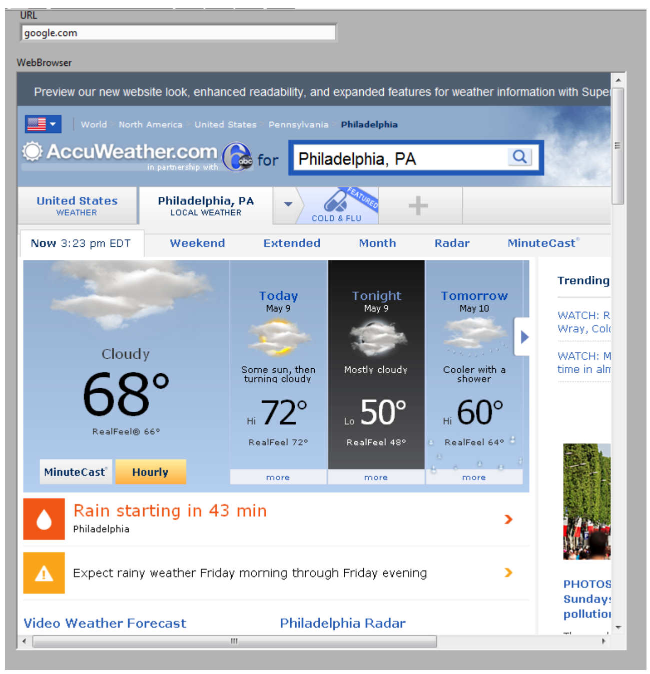
Appendix F: BMS Tab Delimited Data

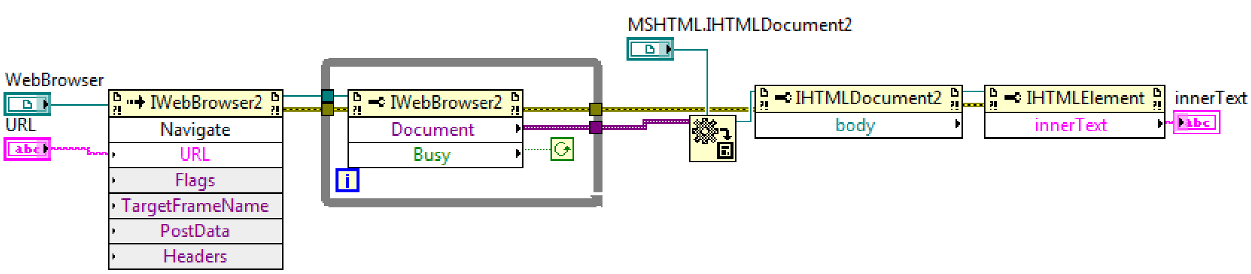
Log Data Element	**Description**
M1 through M3	This is the number of battery module containing the cells whose data follows. The uppermost battery module is M1, the middle is M2 and the bottom is M3.
Date/Time	The current date and time is displayed, in the following format: MM/DD/YY HH:MM:SS
Cell V1 thru Cell Vn	This is the voltage, in millivolts (mV), of the individual cells within the pack. V1 is the cell voltage at the negative end of the pack and Vn is the cell voltage at the positive end of the pack (where n represents the last cell in the pack). The output string for the cells voltage is: CELLV1 CELLV2 … CELLVn
PackV	This is the total pack voltage, displayed in millivolts (mV)
AvgCellV	This is the average voltage of all cells in the system, displayed in millivolts (mV)
CellT1 thru CellTn	This is the terminal temperature, in °C, of the individual cell within the pack. T1 is the cell's terminal temperature at the negative end of the pack and Tn is the cell's terminal temperature at the positive end of the pack (where n represents the last cell in the pack). The output string for the cell temperature is:
Balancing info	This is the state of the balancing of the cells within the battery module. This is a string of characters that represents the total number of cells within the system, where each character can be "N" for no balancing, "U" for charging the upper neighbor or "D" for balancing the lower neighbor. An example of what could be seen is: UNUNNDNN, where cell #1 would be transferring charge up to cell #2, and cell #6 would be transferring charge down to cell#5.
AmbientT	This is the ambient temperature, in °C, on the supervisory board.
AvgCurrent	This is the average battery current, in Amps, since the last data set.
Peak Current	This is the peak battery current, in Amps, since the last data set
Inst. Current	This is the battery current, in Amps, at the time when the cell voltages were captured for output in this data set.
SOC	This is the state of charge, in %, of the battery. 100% is fully charged.
Ah remaining	This is the approximate number of Ampere-hours remaining in the battery.
Ah discharged	This is the total number of Ampere-hours that have been drawn out of the battery since the last full charge.
Ah charged	This is the total number of Ampere-hours that have been put into the battery since the last full charge. If the battery has been charged and discharge several times without bringing it to a fully charged state, the number of Ampere-hours charged and discharged will grow to exceed the battery capacity. This is an indication that the state of charge (SOC) is becoming less accurate.
Ah lifetime	This is the total number of Ampere-hours that have been transferred through the battery since it was built.
Discharge Limit	This is the maximum discharge current limit, displayed in Amps.
Charge Limit	This is the maximum charge current limit, displayed in Amps.
Regen Limit	If regeneration were to be used, this would be the maximum allowed current from regeneration, displayed in Amps.
Leakage	If leakage current were to be used, this would display the amount being seen, in ohms/volt

Key Switch state	A “1” indicates that the key switch is “on”, and that the system is up and running. A “0” indicates that the key switch is “off” and that the system is not running.
Charger input state	A “1” means that a charger control signal “on” is enabled. A “0” means that the charge control signal is not enabled.
Contactor state	This displays the state of the contactor. If a “2” is displayed this means that the contactor is closed. If a “1” is displayed this means that the contactor is going to open. If a “0” is displayed this means that the contactor is open.
Charge Control State	This indicates whether or not the supervisor is controlling the charge, “1” means that the supervisor is in control of the charger and “0” means that the supervisor is not in control of the charger.
Faults for each string and Faults for supervisor	This displays any faults that might be present in the system. If no faults are present, “OK” is shown. Here is a list of possible faults: “OV” will be displayed if any cells voltage is over the safe voltage point, (for Lithium Iron Phosphate if voltage is at or above 3.8V and for Lithium Nickel Cobalt Manganese if voltage is at or above 4.25V) “UV” will be displayed if any cell is below the safe voltage point, (for Lithium Iron Phosphate if voltage is at or below 2.0V and for Lithium Nickel Cobalt Manganese if voltage is at or below 2.5V) “OT” will be displayed if any cell is over the safe temperature point, over 60°C. “OC” will be displayed if the current being discharged is too much. “COMM” will be displayed if communication is lost between the supervisor and the balancing board(s) “IS” will be displayed if there is an isolation fault “SHUNT” will be displayed if there is a problem with the current reading device.
<CR><LF>	Carriage return, linefeed characters that mark the end of the data set.

Appendix G: Weather Virtual Instrument

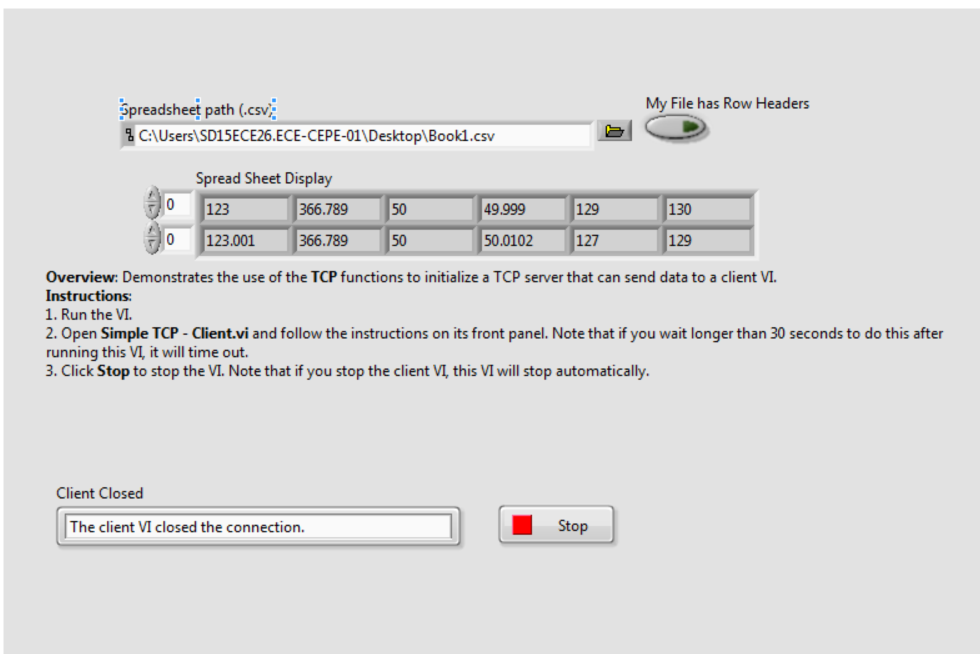
The Weather VI created in LabVIEW for the design project utilizes multiple property nodes, which automatically adapt to the class of the object that is being referenced, to pull text from a URL (weather data from NOAA, Accuweather, Weather Underground) into a string indicator on the front panel. It is important to note that the design team adapted their property nodes to specifically work with ActiveX properties. The design team deemed this as the best approach to display the weather data from the website. Beginning with the WebBrowser control, a property node is implemented to assign a URL. An additional property node was employed in order for the design team to have the capability to monitor the status (i.e. busy) of the assignment of the URL. After, LabVIEW passes the document to a Variant to Data VI, which is accepted as a HTML document, through the use of the document property. After implementing the document property, additional property nodes were again utilized to parse the body and the inner text. In the final step, the design team implemented the Automation Refnum control with HTML to reference the ActiveX object (i.e. website).

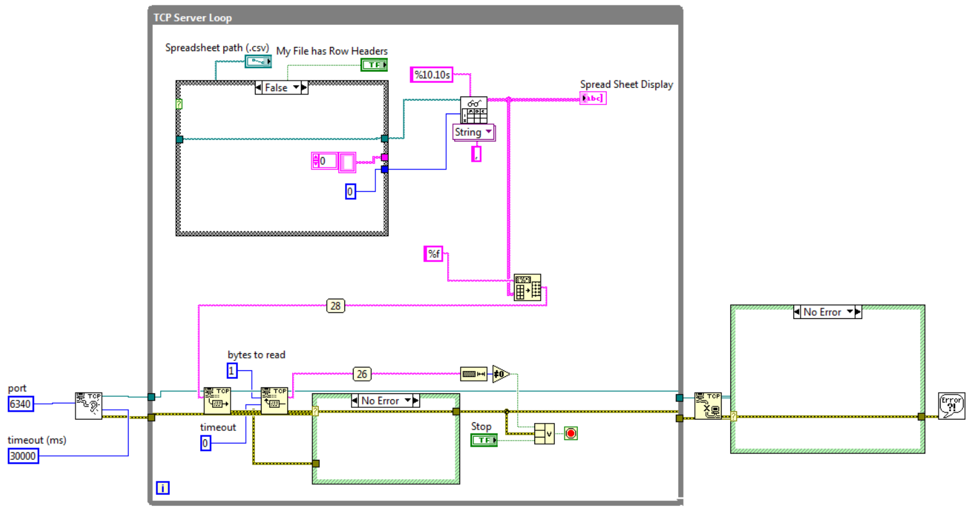




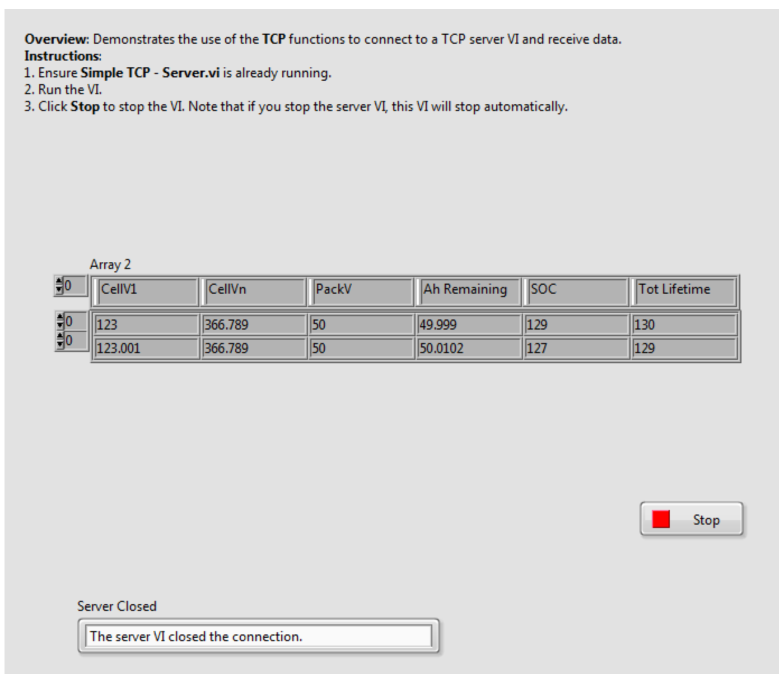
Appendix H: TCP/IP Server/Client Virtual Instruments

The TCP/IP connection of two computers was built in LabVIEW using a server VI and a client VI. TCP/IP connection was needed to send data from one computer to another. This data should be able to be displayed directly on the EMS GUI. The server VI is opened on the computer that has the data needed for transfer. The data in this case is the tab delimited text file obtained from the BMS. This file can be imported into the server VI by using the file radio button and finding the file within the computer's file explorer. Once uploaded, the tab delimited data will appear in the table named Spread Sheet Display. The next step is to run the Server VI in order to send the data to the client VI. Within the server VI, the data is changed from a 2 dimensional array into a 1 dimensional string. This is what is sent across the IP address. The client VI should then be opened on the computer which will receive the data. When ran, the server VI sends the data across the IP address of the network it is connected to. The port that the data is sent through can be determined by the user, however it must match the port in the client VI. This port number can be specified in the bottom left corner of the server VI and on the left side of the client VI. After this step the client VI can be ran. This VI searches for the specified port across the IP address. It then extracts the 1D string from the port and changes it back into a 2D array. The client VI then displays the array within the spread sheet display table on the front panel.

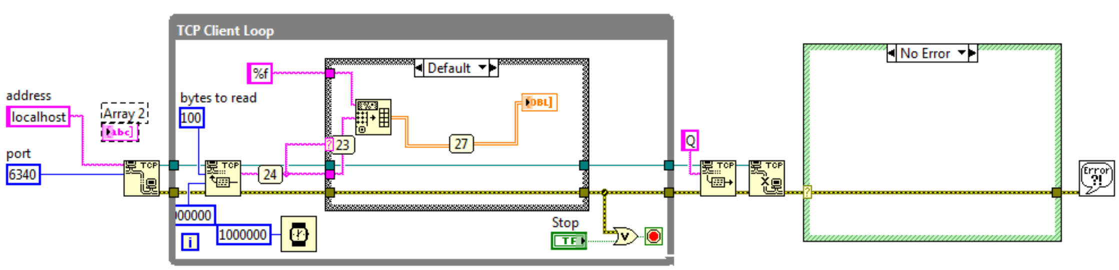




TCP Server Loop
Spreadsheet path (.csv)
My File has Row Headers
False
%10.10s
Spread Sheet Display
String
%f
28
bytes to read
26
port
6340
timeout (ms)
30000
timeout
No Error
Stop



Overview: Demonstrates the use of the TCP functions to connect to a TCP server VI and receive data.
Instructions:
1. Ensure Simple TCP - Server.vi is already running.
2. Run the VI.
3. Click Stop to stop the VI. Note that if you stop the server VI, this VI will stop automatically.
Array 2
CellV1 | CellVn | PackV | Ah Remaining | SOC | Tot Lifetime
123 | 366.789 | 50 | 49.999 | 129 | 130
123.001 | 366.789 | 50 | 50.0102 | 127 | 129
Stop
Server Closed
The server VI closed the connection.



TCP Client Loop
address
localhost
Array 2
port
6340
%f
bytes to read
100
Default
23
27
24
1000000
Stop
Q
No Error

Appendix I:

<u>Reconfigurable Distribution and Automation Control Lab Data Acquisition Test</u>

Purpose:

This document describes the general procedure for setting up, within the Reconfigurable Distribution and Automation Control (RDAC) lab, a power system that allows the testing of National Instrument's (NI) PCI-6071e Data Acquisition (DAQ) card.

General Test Setup:

In the RDAC lab, there is a 208 V AC power supply that connects to a 9-bus radial power system distribution box. The buses in the power system are connected to a total of four signal conditioning boards. This allows a total of four measurement points. The signal conditioning boards are then connected via DAQ card to a computer terminal in the RDAC lab. The transfer panel that exists above the conditioning boards will connect the distribution feeder box to a load bank that consists of light bulbs acting as a resistive load.

Required Equipment:

Computer Terminal with LabVIEW and Test Vis installed
Various cables
Handheld Voltmeter

Test Setup:

Step 1:

Connect the 208 V AC Power Supply to the transformer. Then connect each phase of the transformer to the appropriate phase of the distribution feeder box.

Step 2:

Ensure that the signal conditioning boards and switch boards are secured and connected to the correct terminals designated on the side of the distribution feeder box.

Step 3:

Connect load cables at buses A4 and B4. Of the four possible measurement points, the first is connected to the feeder bus. Connect the remaining measurement cables to buses A2, A3, and A4 on the transfer panel.

Step 4:

Connect the resistive light bulb bank as a 3-phase Y-connected load. Turn on a minimum of 3 bulbs per phase.

Step 5:

Turn on the voltmeter and connect it to the output of the power supply. (Feeder bus output)

Step 6:

With the physical portion of the lab set up, open of LabVIEW 2014 on the computer terminal and browse the directory for the virtual instrument labeled "EMS Interface". Open it.

Test:

Step 1:

Turn on the 208 V AC power supply and manually increase the voltage using the transformer until 75 V to 80 V is reached.

Step 2:

Record the voltmeter values for each phase of the feeder bus and the buses where the measurement points have been designated. (i.e. A2, A3, and A4).

Step 2a:

Remove load from a single phase on the same bus and note any large deltas in voltage. Repeat for all phases for each bus.

Step 3:

In the LabVIEW VI. Choose ACH0:ACH3 as your channel input. Record these values. Repeat Step 3 until an ACH matches with the readings recorded by the voltmeter for each bus.

Step 4:

Power down by cranking the transformer until it reaches 0 V. Then turn off the 208 V AC power supply.

Step 5:

Reconnect the measurement cables for buses that have not been covered (i.e. A2, A3, and A4 are done. What remains are buses A1, B1, B2, B3, and B4).

Step 6:

Repeat steps 1-4 until appropriate ACHs match the results measured by the voltmeter for each bus.

Concluding Activites:

1. Record all results into one conclusive document.
    a. There may be overlap due to an uneven amount of measurements that will cause repeats in recording data..
2. Remove any repetitive data.

Appendix J: DAQ Board Pin Outs