5-2017

Peak Power Demand from Centrifugal Chillers Used to Comfort Condition the John C. Hodges Library

Summer F. Fabus
University of Tennessee, Knoxville, schurch1@vols.utk.edu

Jared A. Baxter
University of Tennessee, Knoxville, jbaxte24@vols.utk.edu

Kyle Jackson Goodrick
University of Tennessee, Knoxville

Divyani Rao
University of Tennessee, Knoxville

Kevin Chiang
University of Tennessee, Knoxville

Final Project Report

Peak Power Demand from Centrifugal Chillers Used to Comfort Condition the John C. Hodges Library

ECE/COSC 402

<u>Team #12:</u>
Divyani Rao
Summer Fabus
Kevin Chiang
Kyle Goodrick
Jared Baxter

Customer: Dr. William Miller,

Joint Faculty MABE, Oak Ridge National Laboratory

May 8th, 2017

Table of Contents

Executive Summary

The University of Tennessee uses a network of chillers and brine to cool many of the facilities on campus. For the John C. Hodges Library, this task is accomplished with two separate centrifugal chiller units. The majority of the demand for these centrifugal chillers occurs during late afternoon summer cooling, and their usage generates large peak electricity charges for the university. The mechanical engineering department is currently looking to reduce these charges by using a redox flow battery to perform load balancing for the library. In order to gather more data to support their plans, we were asked to install several power sensors on the chillers and other auxiliary pumps used by the library for climate control purposes. Our role in the project was to help plan out the installation and program the hardware that collects the data. The data acquisition system (DAS) will acquire total power usage by the library, as well as the power consumed by the heating, ventilation and air-conditioning (HVAC) plant operating in the basement of the Hodges Library. The team will establish ongoing collection of field measures and will provide MABE students training in the setup of the DAS system for continuation of the field study for one full year. The acquired measurements will be used to show economic justification for installing a vanadium redox flow battery to help curb summer and winter peak demand charges. We were also asked to program the software that transforms the data into the format required by our customer.

During the semester, our team was able to design the measurement system, resolve network issues, prepare equipment, and provide all materials to UT Facilities Services. As students, we were not allowed to install the equipment ourselves due to safety standards. Although the equipment, schematics, and installation instructions were given to UT Facilities Services, they were unable to install the equipment this semester due to other job priorities. As a result, other people will need to complete the final testing once the system is set up in the future.

To demonstrate the concept and simulate the project once the equipment is installed in Hodges library, data will be collected from an already installed data logger located in a remote facility. The data will then be displayed and analyzed in the same way the data from Hodges library would. While this demonstration will unfortunately not be on live data received from the library, it will still be developed on the same software platform as intended for the library. This will act as an example for teams or research groups that continue with this work in the future. They will likely be able to use much of the example demonstration and bring the functionality over to the library data with only minimal effort required to port the software.

Requirements

1. Platform
   1.1. The web application must function on all modern browsers.
2. Hardware
   2.1. The hardware must include a Campbell Scientific CR6 data logger.
      2.1.1. The data logger must be housed in a NEMA enclosure.
   2.2. The data logger must be equipped with Wi-Fi capability so data can be easily downloaded by students and/or UTK personnel.
   2.3. The hardware must interface with the existing General Electric Multilin Multifunction Power Quality Meter (PQM II-T20-C-A) from main library feed #1.
   2.4. The hardware must interface with the existing General Electric Multilin Multifunction Power Quality Meter (PQM II-T20-C-A) from main library feed #2.
   2.5. WNC-3D-480-MB WattNode transducers must be connected to Hodge's cooling equipment equipment that includes two centrifugal chillers, 8 water pumps, 2 reheat pumps and 3 cooling tower fans..
      2.5.1. The WattNode transducers must be placed in enclosure boxes.
      2.5.2. A WattNode transducer must be connected to Hodge's centrifugal chiller #1.
         2.5.2.1. The WattNode connected to Hodge's centrifugal chiller #1 must have three 600 amp current transformers (model ACT-1250-600) installed.
            2.5.2.1.1. There must be one 600 amp current transformer installed on phase A.
            2.5.2.1.2. There must be one 600 amp current transformer installed on phase B.
            2.5.2.1.3. There must be one 600 amp current transformer installed on phase C.
      2.5.3. A WattNode transducer must be connected to Hodge's centrifugal chiller #2.
         2.5.3.1. The WattNode connected to Hodge's centrifugal chiller #2 must have three 600 amp current transformers (model ACT-1250-600) installed.
            2.5.3.1.1. There must be one 600 amp current transformer installed on phase A.

2.5.3.1.2. There must be one 600 amp current transformer installed on phase B.

2.5.3.1.3. There must be one 600 amp current transformer installed on phase C.

2.5.4. A WattNode transducer must be connected to four water pumps feeding chilled water to the evaporative air handler unit.

2.5.4.1. Three 20 amp current transformers (model ACT-0750-020) per air handler unit pump motor must be installed.

2.5.4.1.1. There must be one 20 amp current transformer installed on phase A.

2.5.4.1.2. There must be one 20 amp current transformer installed on phase B.

2.5.4.1.3. There must be one 20 amp current transformer installed on phase C.

2.5.5. A WattNode transducer must be connected to the pumps feeding condenser water to the chillers and also to the cooling tower on the roof of Hodges.

2.5.5.1. Three 50 amp current transformers (model ACT-0750-020) per pump motor must be installed.

2.5.5.1.1. There must be one 50 amp current transformer installed on phase A.

2.5.5.1.2. There must be one 50 amp current transformer installed on phase B.

2.5.5.1.3. There must be one 50 amp current transformer installed on phase C.

2.5.6. A WattNode transducer must be connected to two cooling tower fans used to cool condenser water.

2.5.6.1. Three 20 amp current transformers (model ACT-0750-020) per fan motor must be installed.

2.5.6.1.1. Three 20 amp current transformer must be installed on cooling tower #1.

2.5.6.1.1.1. There must be one 20 amp current transformer installed on phase A.

2.5.6.1.1.2. There must be one 20 amp current transformer installed on phase B.

2.5.6.1.1.3. There must be one 20 amp current transformer installed on phase C.

2.5.6.1.2. Three 20 amp current transformers must be installed on cooling tower #2.

2.5.6.1.2.1. There must be one 20 amp current transformer installed on phase A.

2.5.6.1.2.2. There must be one 20 amp current transformer installed on phase B.

2.5.6.1.2.3. There must be one 20 amp current transformer installed on phase C.

3. Software
   3.1. The user must be able to view the data collected by data logger on LoggerNet software using real time monitoring control.
   3.2. The system must be able to access the data collected by using CRBasic code.
   3.3. The data must be stored in a database on the network.
   3.4. The data logger must allow the user to connect from outside of the local network.
4. Security and Privacy
   4.1. The system must have configurable security options.
   4.2. The system must have configurable privacy options.
      4.2.1. The system must allow multiple users with different access levels.
5. Setup
   5.1. The system must be capable of being setup and configured from the website.

Changelog

- February 2017: To collect the data, a computer/server will be continuously on and running the LoggerNet software, since there is no viable solution to directly push data from the data logger to a server on the UT network.

- March 2017: For requirement 3.3.3, the data no longer has to be stored in a database on the network. The customer has asked that the data be stored in CSV files and then uploaded to the web server after a given amount of time.

- April 18th, 2017: Due to an issue in library manpower, the hardware will not be installed in time in Hodges Library. An alternate demonstration will be completed using data from a remote data logger.

- April 2017: Due to the delay in installation of the equipment, interfacing with the General Electric Multilin Multifunction Power Quality Meter must be completed at a later time.

Design Process

In our system, there is a network of chillers, pumps, fans, and cooling towers that are used to provide climate control for Hodges Library. This network of cooling infrastructure takes brine from UT's central brine network and cools it with a pair of centrifugal chillers. This chilled brine is then pumped to one of two air handler units, and chiller air is distributed throughout the building. Chiller water is also pumped to many terminal unit heat exchangers spread throughout the building. To aid the chillers in cooling this brine, there is also a water loop that pumps condenser water from the chillers to a cooling tower that is on the roof of Hodges Library. This water is cooled by the combination of the cooling tower and three separate fans using an evaporative cooling process. This network processes a significant amount of brine and, therefore, requires a considerable amount of energy to function. This is the primary reason for our senior design project - to monitor and track this energy usage.

As part of the system, the cooling tower and the associated fans are located on the roof of Hodges Library. As they are quite large, loud, and heavy, the chillers are located away from the occupied areas of the library in the basement. This physical distance creates a problem for our system. We must have a way to connect the sensors that measure the voltage, current, and power on each part of the system to a central data logger. For the two centrifugal chillers, the four water pumps, and the four brine pumps, this is a relatively straight-forward task. All of this equipment is located in the basement where the central data logger will be placed. UT facility services can connect the current transformers and voltage probes to the equipment to be measured and also to the WattNode transducers, model number WNC-3D-480-MB. These WattNode transducers can then be connected to the data logger in a daisy chain configuration. This daisy chain configuration allows a single pair of wires to go from the data logger to all of the measurement devices. However, the fans on the roof present a challenge because there is no way to include these WattNodes in the daisy chain, as there is no way to run the cables from the roof to the basement.

As we investigate potential solutions in the coming sections, there are a number of important details to keep in mind. The first is that our data logger, a CR-6 Series Campbell Scientific Model, has an Ethernet port and network capabilities. These network capabilities are rather important for other parts of our project, so it is certain that the data logger will be connected to the network. It has also been tested and confirmed by the Department of Mechanical, Aerospace, and Biomedical Engineering that there is a good Wi-Fi signal in both the basement and on the roof. These connections are available, but their stability and reliability have yet to be determined. As part of our available components, we also have Wi-Fi adapters that will allow the Campbell Scientific data logger to connect to Wi-Fi and also to a wireless adapter for the WattNode transducer that will be on the roof. While this does not suggest that we must use Wi-Fi, it does allow us to consider it without need for additional financial concern.

For transferring data, we first considered Ethernet. We researched that Ethernet can reach speeds up to 1 Gbps. These high speeds allow for large quantities of data to be rapidly sent from the chillers and cooling tower to the data logger. The range of Ethernet is around 100 meters, and this would not be enough for the size of our library. However, there are Ethernet range extenders available that can be installed to increase the range of Ethernet. Additionally, Ethernet would be more reliable in our case. Because the equipment would be connected by wire, there is no loss of signal, and the data collected would be of better quality. The University of Tennessee Office of Information Technology's website states that they can install 10 Mbps, 100 Mbps, and 1000 Mbps Ethernet data ports. However, according to the UT facility services, the cost to install these Ethernet ports with conduit in the library is above nine thousand dollars, and that exceeds the budget of our project. So, we decided to look into other research options.

Wi-Fi is the other communication protocol that was investigated that could be used. The Wi-Fi is already installed in the library. The range of Wi-Fi extends from the basement to the roof and, therefore, it is possible to communicate between chillers and cooling towers with the data logger. According to the Office of Information Technology at UT, the main campus has the 802.11n wireless network standard with 300 Mbps throughout. The network offers 2 network names: ut-open and eduroam. The main difference between the two networks is that eduroam is encrypted from the device on the network to the core of the network, while ut-open does not support encryption over the air. This is a key difference for our application because we will be transferring sensitive information about the power usage of Hodges Library.

To solve the network issue, two network drops without conduit were requested and granted in the library: one in the basement and one on the roof. Without a conduit, the Ethernet connection was much less expensive. Thus, we could use a MOXA device to connect the power transducers and current transformers on the roof to the Internet, where we can then use the Campbell Scientific data logger to retrieve the data from the MOXA device and place it with the data for the other current transducers.

To ensure the network connection between all of the devices would work, a sample box consisting of current transducers, WattNodes, a MOXA switch, and a NEMA enclosure was created. This box was then registered with OIT in order for the CR6 data logger to see it. The sample box was then rewired to allow it to be placed on the library roof, where it would then be registered to the network again in the Hodges Library subspace.

In order to complete the project, it was decomposed into manageable responsibilities. Computer science majors Kevin Chiang and Divyani Rao configured devices to the UT network, resolved network issues, modified the data logger's CRBasic code to measure data from all WattNodes, and determined how to display and store collected data. Electrical engineering majors Kyle Goodrick, Jared Baxter, and Summer Fabus determined how to wire all of the components and created the following schematic to give to UT Facilities Services. All team members organized and labeled the equipment to make the installation process simpler. In addition, a test bench was used to ensure the data logger and the WattNodes would work correctly via a direct connection or a MOXA switch. The requirements were met for the design phase of the project, but we were unable to execute them in actual installation, testing, and evaluation due to the limitations described in the executive summary.

Figure 1 shows a high level overview of how the system will be connected.

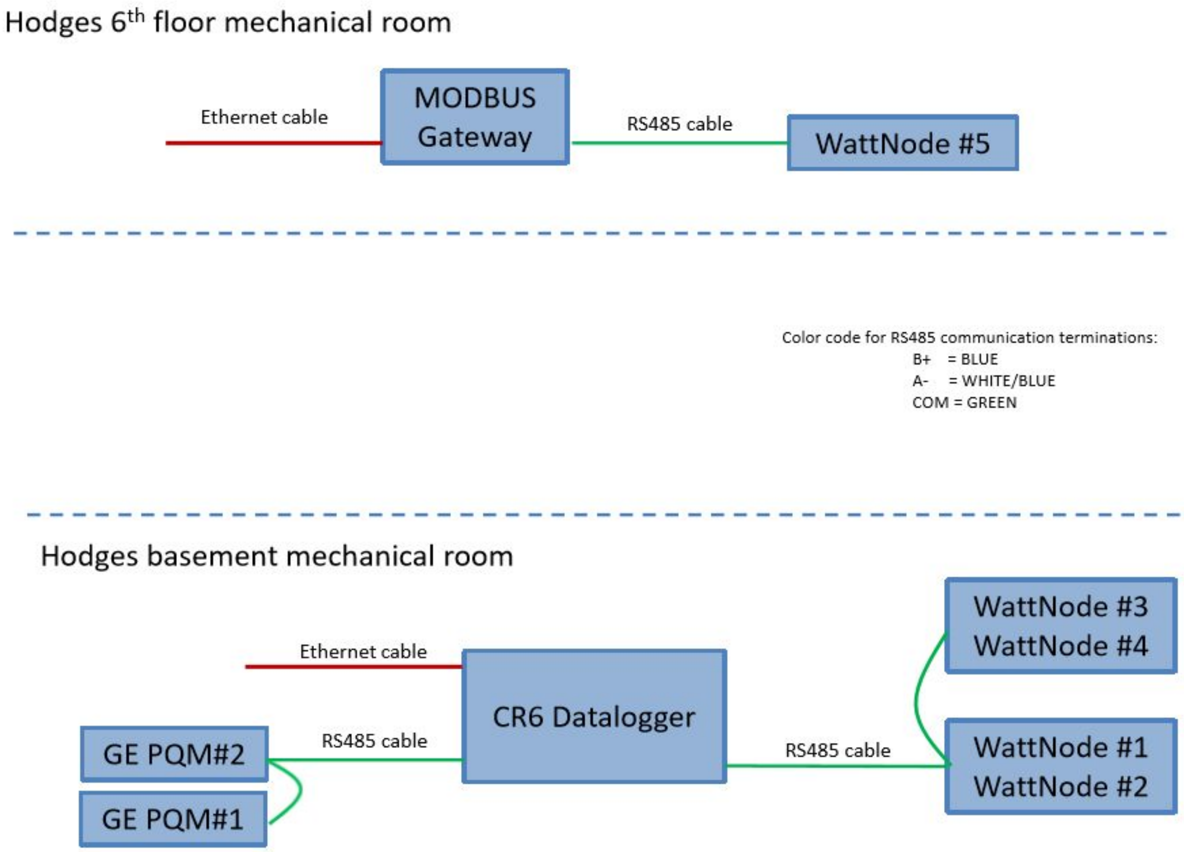


Figure 1

Table 1 shows all components involved to measure energy data from the library's cooling system.

Name	Description	Model #	Serial #	Location	Enclosure #	Voltage	CT amp size	# of CTs	Program CT size	MB Address	Connection Type
WN1_comp1	Centrifugal chiller 1	WNC-3D-480-MB		Basement	1	480 VAC, 3ph	600	3	600	1	serial cable
WN2_comp2	Centrifugal chiller 2	WNC-3D-480-MB		Basement	1	480 VAC, 3ph	600	3	600	2	serial cable
WN3_4evals	Air handler unit, 4 chilled water pumps	WNC-3D-480-MB		Basement	3	480 VAC, 3ph	20	12	80	3	serial cable
WN4_2conds	Condenser, 4 water pumps to cooling towers	WNC-3D-480-MB		Basement	3	480 VAC, 3ph	50	12	200	4	serial cable
WN5_roof	Cooling tower, 3 fans	WNC-3D-480-MB		7th floor	2	480 VAC, 3ph	20	9	60	5	serial to MGATE

MGATE	MOXA MODBUS TCP gateway	MGATE W5108-T	TAFBB1019364	7th floor	2	24 VDC					wired IP
MGATE_PS	MGATE power supply			7th floor	2	120 VAC					
CR6	data logger	CR6		basement	4	120 VAC					wired IP
GE_PQM_1	Hodges Main Feed #1	PQM-II-T20-C-A		basement	5	480 VAC, 3ph	?	3		11	serial cable
GE_PQM_2	Hodges Main Feed #2	PQM-II-T20-C-A		basement	6	480 VAC, 3ph	?	3		12	serial cable

Table 1

Figures 2 and 3 show a schematic, which maps out the wiring of all of the equipment that will be installed in the library.

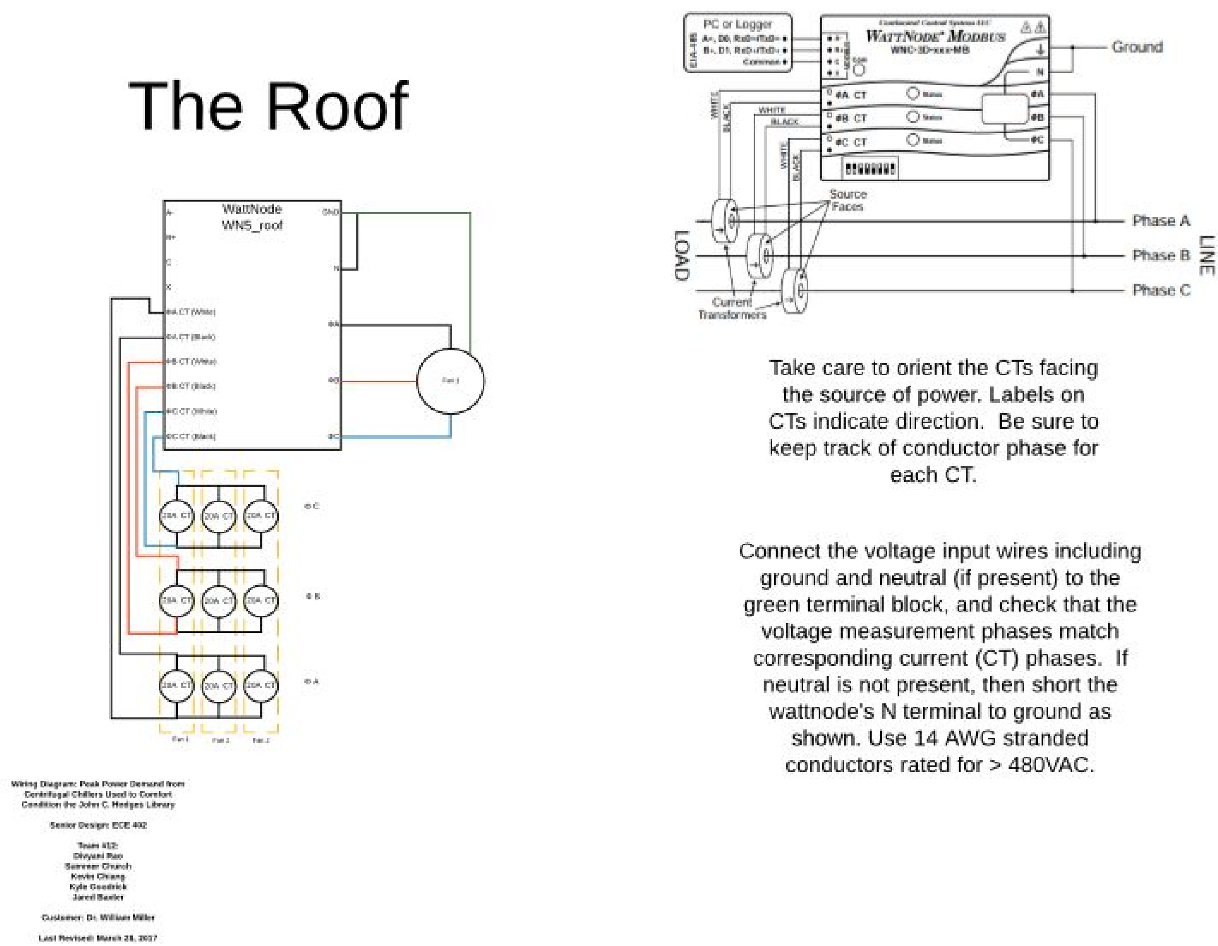
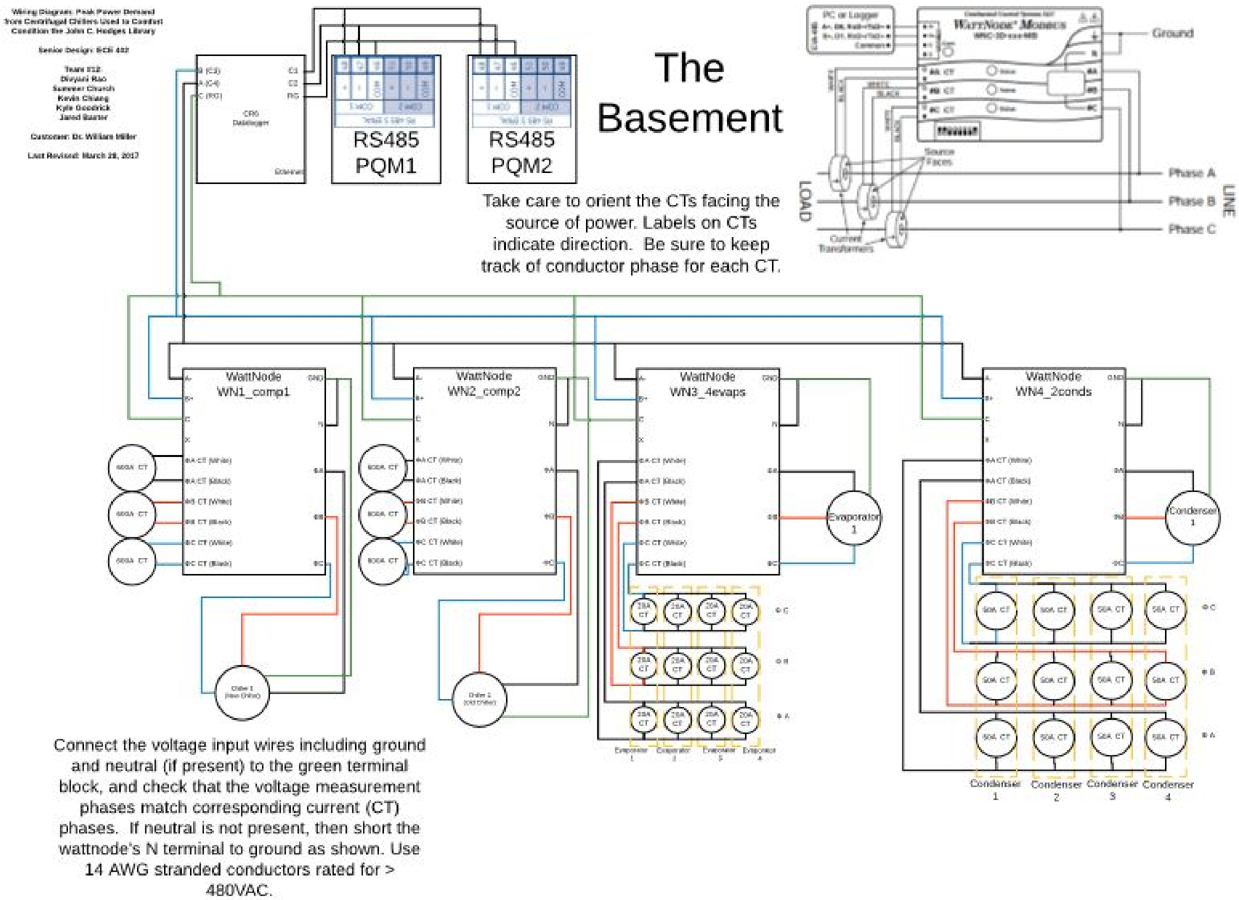


Figure 2



The Basement
RS485
PQM1
RS485
PQM2
Take care to orient the CTs facing the source of power. Labels on CTs indicate direction. Be sure to keep track of conductor phase for each CT.
Ground
Phase A
Phase B
Phase C
LOAD
LINE
WattNode
WN1_comp1
WattNode
WN2_comp2
WattNode
WN3_4evaps
WattNode
WN4_2conds
Evaporator 1
Condenser 1
Connect the voltage input wires including ground and neutral (if present) to the green terminal block, and check that the voltage measurement phases match corresponding current (CT) phases. If neutral is not present, then short the wattnode's N terminal to ground as shown. Use 14 AWG stranded conductors rated for > 480VAC.

Figure 3

Lessons Learned

During our project this semester, we had several unexpected events that took place. At the beginning of the semester, we were deciding how we could connect our devices from the basement of the library to the roof of the library. When we asked UT Facilities Services how much it would cost to install Ethernet in the Hodges library, they quoted us $9,000 for installation of a conduit. After realizing that it would cost us $9,000, we were surprised and decided to find other alternative solutions for connecting our devices from the basement of the library to the roof of the library. We decided to go with Wi-Fi. However, this would mean that all our devices would need to be configured with the UT network. After trying to work with UT's OIT, we realized that it might be easier to install Ethernet without conduits. The team quickly changed gears and started working on our new solution, which would work easily in the library. After we finished setting up all our devices and sent UT Facilities Services our schematic, our customer pushed for the devices to be installed. However, UT Facilities Services told us a week before the presentation day that they would not be able to install it before the end of semester. The team handled this situation by trying to get data from a similar installation at a home or by setting up a test bench. In future, we should use written confirmation/approval about getting installations into any building at UT.

Another valuable lesson learned is the importance of communication in a group project. Often one member's work depended on the other's, and if there was not proper discussion, the work would not progress. This situation was prevented if there was an exchange of information among all the group members. We realized that apart from having a group chat, we should also set times to make progress on our project every week. Our team lead considered each team member's obligations and set aside time for all of us to meet. We also decided to meet with our customer once a week to give him updates on our progress and to get feedback. We also took notes during the meetings so that if any of the team members missed out on anything, they could easily be updated by reading the notes. To be able to share our reports and other documents with each other, we used Google Docs, which helped us all work simultaneously on them. When it came to sharing code, we used Github. We updated our edits to the code on Github so everyone was able to access them. We also learned from using Github that it can consume time in the beginning to learn a tool, but at the end it helps a lot with group communication and eventually makes the team more efficient.

Communicating with individuals that were working on the project but were outside the team was also a learning curve. Our team worked extensively with Tony Gehl at ORNL, a personal connection of Dr. Miller's, who is very experienced in similar projects. He helped determine what parts the team needed, as well as how to get many components of the system working together. It was challenging handling the correspondence between our customer, Dr. Miller; Mr. Gehl; the library staff; and the team. Most conversations were through specific email threads, which can be very difficult to decipher later on. Perhaps a good solution to this would be to create a group chat using an Internet-based Live Meeting system such as Blue Jeans, etc. Most information was pertinent to everybody on the team, but many emails had to be forwarded individually.

Additionally, we also developed a more efficient system for turning in completed assignments on time. This was especially important, considering that senior design has a significant number of group assignments, such as bi-weekly MBOs, group reports, presentations, and other group papers. During the semester, we decided that it would be best to separate past and upcoming assignments in a shared Google Drive folder so that it would be clear what was to be done next. Even though we had developed a great system to keep up with current and past assignments in the Google Drive, there are still a few more practices that we could have implemented. For example, since we used Google's services for keeping up with our documents and reports, we should have made a Google Calendar for the team. At times, it seems all we were discussing in our group chats was when a meeting was going to be and if it was cancelled. However, had we used Google Calendar, one person could just change the calendar, and it would immediately update everyone's personal Google Calendar. Also, we could have put assignment due dates in the calendar. Certain people in the group were also designated to turn in final assignments once they were agreed upon as complete by the entire group. Our team also began to have short weekly meetings, right after our customer meeting, to briefly discuss upcoming assignments and responsibilities for the week. This systematic approach helped us to successfully finish the tasks requested by our customer, along with the senior design assignments.

During our project, we used our knowledge from various classes. Computer Organization class helped us make the schematic using combinational and sequential circuits, Electric Energy System Components assisted us in analyzing the power consumption of the library, and Software Engineering helped us to use Github to complete this project. Additionally, general knowledge about AC (alternating current) and DC (direct current) electric circuits and magnetic fields was used in the system design. These topics were covered in Circuits I, Circuits II, Physics Electricity and Magnetism, and Fields.

Were the team to redo this project from the beginning, there are a number of things that we would consider doing differently. As detailed above, we were unable to see our system installed due to lack of resources available from UT Facilities Services. With what we know

now, we would have ensured from the beginning that this was a project that the university intended to support throughout the process and gotten this assurance in writing. With this assurance we would have made certain to include a detailed timeline of events and deliverables so that all parties involved had the same expectations for necessary contributions and deadlines. While it is easy to say looking back that these things would have been beneficial, it is uncertain to say that even with the intention of doing things differently that the results would have been different. There were many uncertainties in the project that could not be known in the beginning and could have only been discovered through the process that we went through. It is likely that projects of this scale, requiring the assistance of the UT Facilities Services infrastructure are somewhat ambitious for completion by a team in only one semester. These types of projects are likely best handled by teams looking to complete a single project over the two semesters of ECE/COSC 401 and 402. This would allow for the necessary time to coordinate with UT Facilities Services and the other UT entities involved in the process.

Team Member Contributions

The responsibilities of each team member are given. Each team member's contribution to what has been accomplished so far is described under the Implementation section. If the project would have been able to advance further, each member's roles in testing and evaluation are also provided.

- Summer Fabus
    - Major: Electrical Engineering
    - Role: Writer & Presenter / Solutions Architect
    - Implementation
        - Summer assisted with installing the WattNodes in the enclosures and also helped to draw the wiring schematic. While equipment is being installed in Hodges library, she may shadow some of the electricians to better understand the system as a whole and ensure that components are installed properly.
    - Testing
        - Once data is acquired, Summer will check that the current and voltage of each phase of every device is being measured accurately.
    - Evaluation
        - After a reasonable amount of data has been collected, Summer will evaluate the energy consumption by various parts of the cooling system. This analysis will be useful to the mechanical engineering team who is researching the possible implementation of a vanadium redox flow battery in the system.

- Kevin Chiang
    - Major: Computer Science
    - Role: Team Leader/ Designer & Implementer
    - Implementation
        - Kevin is responsible for planning meetings with the customer and others who assist in the project. In addition, he is responsible for the functionality of the software on the data logger. Once the data logger is installed in the library, Kevin will be writing code to retrieve data from data logger. Given the delay in the library installation, Kevin will be working on the visualizations for data retrieved by the remote data logger.

- Testing
    - A testing setup was created in Min Kao Engineering, where we have the data logger, MOXA, WattNodes, and current transducers to be placed in the library were tested. After installation, Kevin will be testing the code to be written.
- Evaluation
    - Kevin will set up the data logger for retrieval of needed values. The data will then be represented in comma delimited format form for easy access by others.

- Divyani Rao
  - Major: Computer Science
  - Role: Lead Report Writer / Lead Tester
  - Implementation
    - Divyani is responsible for analyzing the data collected from the data logger and compiling the input from other team members. In addition, she is to also help Kevin with the data logger software setup and writing code to retrieve data from the data logger.
  - Testing
    - Divyani will make sure that the UT electricians are installing the data logger correctly in the Hodges library.
  - Evaluation
    - Divyani will represent the data collected by the data logger in the form of graphs and charts. The conclusions from the graphs and charts will then be sent to the mechanical engineering team by Divyani.

- Kyle Goodrick
  - Major: Electrical Engineering
  - Role: Librarian / Researcher
  - Implementation
    - Kyle was responsible for researching the General Electric PQM meters that the library uses to measure the overall energy usage of the library and asses their suitability for use with the Campbell Scientific data logger. He also worked on the schematic document and assisted with construction of the WattNode Enclosures.

- Testing
    - Kyle will make sure the GE PQM meters measurement function as necessary and will help UT electricians debug the installation if needed.
- Evaluation
    - Kyle will use the PQM meters to compare the total energy usage of Hodges with the energy usage of the HVAC equipment. He will also assist in the design of the LoggerNet interface that will show a live stream of the data.

- Jared Baxter
    - Major: Electrical Engineering
    - Role: Lead Presenter / Reviewer
    - Implementation
        - Jared is responsible for the inventory of all of the equipment that will be installed in the John C. Hodges Library. He also assisted in making a schematic for all of the components of the system, building of enclosures, and will potentially shadow electricians as they station the equipment in the library to ensure everything is installed properly.
    - Testing
        - Jared will assist with the analysis of data once the data logger and all measurement equipment is installed in the Hodges Library. He will also be on hand in case any problem occurs in the installation of the data logging equipment.
    - Evaluation
        - Jared will ensure that all equipment has been installed correctly in the Hodges Library. He will also conduct analysis and draw conclusions based on the data measured and along with other team members, inform the mechanical engineering team of its findings for the purpose of installing a vanadium redox flow battery.

Conclusion

This semester's project has been an interesting journey, and we learned many lessons about how to work as a team and how to interface with large institutions. While the initial goal of our project was not achieved, we were still able to demonstrate how the system would work once it is installed.

Literature Cited

https://s.campbellsci.com/documents/sp/manuals/cr6.pdf
https://ctlsys.com/wp-content/uploads/site-images/WNC-Modbus-Manual-V18.pd

Acknowledgments

The team would like to thank Dr. William Miller for his project idea and guidance, Tony Gehl for his technical support, Cesar Penalba and UT Facilities Services for their help with installation, and Dr. Mark Dean for instructing this class.