MQP - DMS - 1101

Monitoring and Control Solution

For Electric Heat-Trace Systems

Major Qualifying Project

for Management Information Systems

By:

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Acknowledgments

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Abstract

This MQP utilizes MIS principles to provide our sponsor with a fully functional monitoring and control solution for heat trace systems. The solution collects real-time industrial measurements, displays the data via HMI screens, stores the data via an electronic database, and triggers out-of-range alarms. The MQP provides savings for clients through more efficient energy usage.

Authorship Statement

This MQP was conducted and written by me, Teodor Serbanescu. Roy Sjolander helped me build a test panel for the MQP module, and Richard Stearman helped me write portions of the HTML web page code.

Chapter 1 Introduction

1.1 What is Heat-Trace?

The purpose of this MQP is to develop an application that will monitor and control heat-trace systems. A ‘heat-trace’ is an electric thermal cable, which is installed directly onto, or around an object that is meant to be heated. When electricity is provided to the heat-trace cable, it will heat up. The quality and type of heat-trace cable will determine what temperature it will heat up to and a rough estimate of the cable’s life span, which can vary from just a few months, to several years. A ‘heat-trace system’ is a collection of heat-trace cables, which are installed in multiple locations, and all connect back to a central power source, which is usually a breaker box. A simple example of a heat-trace system is the installation of heat-trace cables onto a house roof, so that during the winter, the snow will not accumulate too much and add too much pressure to the structure. The heat-trace systems, for which we will be developing an application, are installed at natural gas power plants. These heat-trace cables are installed onto 'circuits' of pipes, which must not freeze, otherwise major damage will occur to the plant. See the glossary for definitions of the technical terms used in this MQP.

1.2 Request for Proposal

The 'problem' in the way that power plants are currently managing their heat-trace systems, which calls for this 'solution', is that they leave the heat-trace on all the time, and un-monitored, which causes them to lose money while risking potential malfunctions. Some power plants have their own in-house monitoring and control solution for their heat-trace system, but most do not. Instead, they manage it by turning the heat-trace on during the Fall, Winter, and Spring, then turning it off during the Summer. Due to the life span of the heat-trace, which in most cases cannot be accurately predicted, most plants will change their heat-trace long before they expire, which is very expensive. And some, however, will take the risk of running the heat-trace until it comes close to, or dies out. If the heat-trace stops working, the condensation from a steam pipe may freeze, and when the plant activates the pipe, new steam will evaporate that condensation with a high amount of pressure and cause the pipe to burst. This may cost the plant up to millions of dollars. Below, is a list of problems that these plants have, which will be solved by this MQP solution.

- **Energy & Operating Costs -** Without our proposed system, power plants will run every heat-trace circuit for three seasons per year. They will lose a lot of money on energy this way. Our system will turn on the circuits only when the temperature is below the set-point of that specific circuit. If a circuit is meant to be left off, it will not power that circuit, until the user turns the circuit on via our programmable logic controller's (PLC) interface.
- **Heat-Trace Life –** As mentioned, heat-trace cables have a life span, before they stop working. So, for example, if a heat-trace cable if left on continuously for two years, and then dies, this would mean that if the cable was turned off during the warm seasons, then during that time, it could last up to four years instead. Our system will utilize the run time of the heat-trace based on temperature set-points and increase the overall life of the cables.
- **Replacing Heat-Trace -** Without our system, the user will have to play a guessing game in deciding when to replace their heat-trace cables, which is very risky. Our system monitors the amperage and GFI of the heat-trace output, which will indicate when it is time to inspect or replace a heat-trace cable. For example, if a heat-trace cable usually outputs 13 amps, and then, over time, outputs 8-10 amps, this means that the cable is starting to 'burn out', and needs to be replaced soon. We will monitor these readings with the use of current transducers (CTs), which are relatively inexpensive.
- **Accidents –** There are many possible ways for heat-trace cables to be damaged, most of which are unpredictable, such as an inexperienced worker cutting one of them. Our solution will provide plant managers with a greater sense of security, knowing that, regardless of what causes the heat-trace to malfunction, our system will detect it and report it before it accumulates into a bigger problem.

1.3 Project Origination

The initial idea for this MQP came from Timothy R. Mullen, who has over 20 years of experience in the heat-trace business. He is our sponsor and project champion. Prior to entering this business, Tim had a successful career in managing industrial operations, specifically in the valve-systems industry. He then bought the company 'Diamond Technical Services', a well respected calibration firm, and also created a sub-division 'Diamond Thermal Systems', which became one of the top suppliers in the country for heat-trace systems. The idea of a wireless monitoring and control 'solution' for these heat-trace systems lingered in Tim's thoughts for a few years, as he became more and more aware of the deficiencies in how his customers managed their heat-trace systems.

During this past year, Tim decided to act upon his idea, and began designing an application for these heat-trace systems. I joined the company as an IT intern during this time to work on various office tasks, such as contact databases. Due to a fortunate turn of events, Tim discovered my ability to manage technical operations while understanding customer principles. And after considering the circumstances that I was close to completing my degree at WPI, the application was still in early development, and the scope of the project tied in perfectly with my academic major, Tim decided to transform his idea into my Master Qualifying Project and give me responsibility for all technical designs and implementations. From that point on, my paid IT internship had ended, and I was working solely on the MQP project, which was different from any of my previous work.

1.4 The Monitoring & Control Solution

This MQP will create a unique Programmable Logic Controller (PLC)/PC based application that will monitor and record wireless temperature readings on all circuit pipes, the amperage that each heat-trace cable is outputting, and the Ground Fault Interrupter (GFI) of each cable. The temperatures will be measured by Resistance Temperature Detectors (RTDs), directly attached to the pipes and our wireless transmitters. This data will be sent wirelessly to our gateway, which is then wired to our central PLC. The amperage and GFI of the heat-trace will be measured by our Current Transducers (CTs), which are directly wired to our PLC as well. The PLC also has the ability to 'control' the system, by turning on and off heat-trace circuits based on a user-inputted temperature set-point. If the actual temperature of the circuit is below the set-point, the PLC will turn the associated relay on, which turns the circuit on. Alarms are also created on the PLC, letting the user know if a temperature, amperage, or GFI reading is below or above a set-point. The 'PC' based component of this application is accomplished by the built-in web server of the PLC, which can create a webpage, and host it on the power-plant server. So essentially, the user may use their PC to view a 'real-time' monitoring screen. Lastly, the data is also logged and exported from the PLC, directly onto our server database, to allow users to view organized historic data.

1.5 Sponsor Deliverables

This section will outline the components of the project that will be directly delivered to our sponsor. Note that all of these components will also be included into the MQP report, but mostly located in the appendix section. Below is a list of deliverables:

1. **Cost-Benefit Analysis:** This document will contain cost savings estimations; including energy consumption, preventive maintenance costs, costs of downtime, repair costs, etc.
2. **Stress Testing Sheet:** This document will be initially created from the Patent Requirements, and then expanded as the project nears completion. It will include a series of test protocols for the solution, to ensure that it is working flawlessly in every possible circumstance. (Located in the confidential Appendix Folder)
3. **List of Materials:** This document will contain a full list of materials used for the solution, with specifications, such as measurement ranges, operation temperatures, size dimensions, etc. (Located in the confidential Appendix Folder)
4. **Bill of Materials:** This document will include the price and company names, from whom we purchased our materials. (Located in the confidential Appendix Folder)
5. **Diagram of Physical Infrastructure:** This will include detailed drawings of how the solution will be installed into a metal or plastic enclosure, where each individual component will be placed, and how they will be wired to one another. Wireless

communication will also be illustrated, as well as data flow. This will be done in CAD and possibly include 3D modeling as well. (Located in the confidential Appendix Folder)

6. **PLC Code:** The PLC is a mini-computer, which controls all of the operations of this solution. The code for it will be written in the language, Ladder Logic, with the software, VisiLogic. This code cannot be converted into any other type of file, so it will remain as a VisiLogic extension. (Located in the confidential Appendix Folder)
7. **Web Page Code:** The PLC has a built-in web server, which can import HTML code. The HTML file will contain the code for the web page design. The Web Page will be a real-time summary of all the data points, intended for users to monitor. (Located in the confidential Appendix Folder)
8. **Database Website:** The PLC also has the functionality of exporting its data to another location. In this case, the Dymocon Office will receive the exported data from the PLC, every six hours, and organize this data into a Unix Database. An interactive web site will be created to view the historic data.
9. **User Manual:** This document will be provided for the end user as an instruction sheet for using the solution. (Located in the confidential Appendix Folder)
10. **Possibilities & Limitations of Change:** This document will discuss what can be changed without additional programming, and what can be changed with additional programming. Large changes, such as the implantation of different measurement tools, will be estimated in terms of cost and time. This will help our sponsor approach the possibility of custom solutions in the future.
11. **Professional Demonstration:** A professional demonstration will be performed at the end of the project, for our sponsor, with testing gear, such as live heat-trace cables and light bulbs, to show the functionality of the solution.

Chapter 2 Literature Review

The Literature Review chapter of this MQP will discuss the components of a Heat Trace System and the Systems Development Life Cycle. This chapter will also discuss Gas Power Plants and Programmable Logic Controllers, which are both related to Heat Trace Systems.

2.1 Heat Trace System Components

2.1.1 Gas Power Plants

Power plans that utilize natural gas to produce energy are the main customers that this MQP will service. Natural gas is a gas that is primarily made of methane. It is very combustible, which makes it ideal for energy production. Deposits of natural gas are located deep beneath the earth, usually in close proximity with other fossil fuels, such as oil. Before natural gas can be used to produce energy, it must go through a complex process of by-product removal. Some of the by-products are useful, and can be sold directly to other companies, such as propane gas. The most common by-products to be removed from natural gas are oil, water, sulfur, and carbon dioxide.

Gas power plants use a series of pipes to transport the natural gas from each station of by-product removal, until ultimately the gas is ready to be converted into energy at a gas turbine. Sometimes, plants will use a 'combined-cycle', in which the heat exhaust from the gas turbine is then sent across pipes full of water, into a Heat Recovery Steam Generator (HRSG), which then uses the resulting steam to turn another turbine that produces electricity. The pipes that connect to and from the HRSG need to be kept above freezing; otherwise, condensation will freeze when the pipes are not active, and then expand and damage the pipes when they are turned on. If the pipe bursts due to this, it will cost the plant hundreds of thousands of dollars. The overall process of burning natural gas into energy emits fewer harmful chemicals into the air than oil, but also has a more complicated cycle of purifying.

Most natural gas plants will have an overwhelming amount of pipes. Instead of going through the trouble of monitoring them all, they will simply run their heat trace continuously, which is expensive and inefficient. Figure 1 shows a natural gas plant, illustrating how complex their pipe line system is (Processing Natural Gas, 2011) (*Energy Justice Network*, 2011).

Figure 1: Natural Gas Plant
Taken from (http://www.naturalgas.org/naturalgas/processing_ng.asp)

2.1.2 Background of Heat Trace

Heat Trace is a term used frequently in the industrial world, representing thermal cables. It is derived from the term 'heat tracing', which is the process of installing thermal cables onto an object to maintain a specific temperature. Heat trace cables were invented in the mid 1900s; the exact date is unknown, as various companies invented their own type of heat-trace. Today, there are various types of heat trace available.

The three main applications of heat trace are Freeze Protection, Roof & Gutter De-Icing, and Hot Water Maintenance. Freeze protection is the broadest of the applications, as it can include pipes, turbines, computer hardware, motors, etc. The most common is pipes, containing liquid or gas. Figure 2 is a diagram of a typical pipe structure.

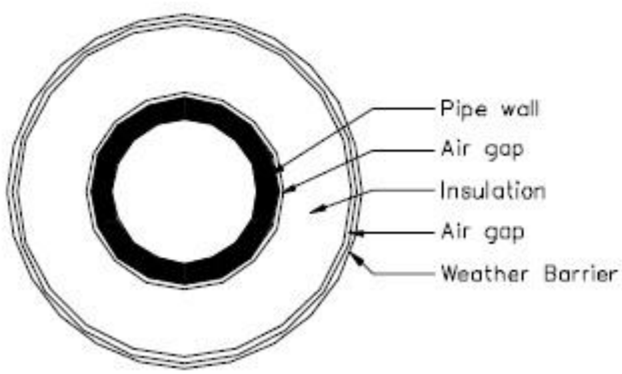

Figure 2: Pipe Structure

Most pipes come with a considerable amount of insulation to prevent heat loss, but during freezing ambient temperatures, the insulation is not enough to keep it at a desired temperature, especially if the pipe has to be shut off for a given period of time. Heat trace cables, like the one shown in Figure 3, are installed directly onto the pipe wall.

Figure 3: Heat Trace Cable

To install heat trace, a worker will have to access an opening, or create their own, through the weather barrier and insulation, to the inner pipe wall, and then feed the heat trace alongside the wall, for the length of the pipe. Roof and gutter de-icing consists of installing heat trace directly onto the surface of the roof and gutters, to create a melted path for water to escape. This prevents flooding, water damage, and weight induced damage to the roof. Hot water maintenance is similar to freeze protection; heat trace is installed onto water pipes to maintain a high water temperature.

There are three main types of heat trace cables: mineral insulated, constant wattage, and self regulating. Mineral insulated (MI) cables are the most common and most dependable type. These are the ones that our project primarily monitors and controls. They are constructed with a solid series resistor element on the outside, and magnesium oxide on the inside. When voltage is applied, the cable heats up. The heat to which the cable will rise depends on the way it is manufactured. Companies create various model numbers for cables with different temperature outputs. The cables run at a specific voltage input, which must be exact. While the cables are running, a certain amount of amperage is flowing through them, and by measuring this amperage amount, we can tell whether or not the cable is getting too old. The amperage increases over time, until the cable burns out, in which case the amperage drops to about zero. Also, as the cable gets old and the amperage increases, the actual temperature output decreases.

Constant wattage cables are similar, in the aspect that once you provide a power source, it functions, but they are more complex in the way they are constructed. The advantage of constant wattage cables is that if one section of the cable is damaged, it will continue to function at the parts that are not. The cost of these cables is higher than MI ones, which is why they are not as popular. Self regulating cables are the newest and most complex. They are built with a type of resistor that can act according to what the surrounding temperature is, thus providing a wide range of heat. The setback for these types of cables, aside from high costs, is that they are not as robust as the other two, and most customers will not risk their equipment by relying on them to function properly at all times.

A 'heat-trace system' is a collection of heat-trace cables, which are installed in multiple locations, all connect back to a central power source. A gas powered plant will have a series of pipes moving gas from one location to another. In this case, power lines will extend from the main breaker box, to the start locations of each heat trace, to provide power to them. Some power plants will go one step further and create their own monitoring system for their heat trace system, but most do not have the time, money, or experience (Heat Trace Products Training Manual, 1998) (Timothy R. Mullen, 2011).

2.1.3 Programmable Logic Controllers

A Programmable Logic Controller is a digital mini-computer that gathers inputs and controls outputs. The first PLCs appeared in the 1960s to improve the automobile industry by controlling the outputs of relays based on imbedded timers, located inside the PLC. Instead of somebody walking around the factory to switch relays on and off, the PLC would do it automatically. PLCs were initially preprogrammed using machine based-language, which was not easily changed or modified. During the 1980s, PLC operating systems were upgraded, allowing users to connect computers to the PLC, and download new programs. The language used in PLCs is ladder logic, which was supposed to replicate concepts of an electric circuit board design, allowing electric engineers to easily learn it. Now, due to the complexity of PLCs, even electric engineers will have to go through some training to program them. During the late

1980s, Human Machine Interface (HMI) screens were added to the PLCs, which gave users more options than just set patterns and procedures. Users could now adjust functions with the click of a button (History of the PLC, 2006).

The modern PLC is complex, and can perform a wide variety of functions. Some of these functions include web server hosting, data storage, data exporting, data importing, TCP/IP Ethernet communication, remote access utilities, intricate alarm functions, etc. There are multiple PLC manufacturers, the most common being Alan Bradley (ab.rockwellautomation.com) and Omega (omega.com). We have chosen to use Unitronics. The programming software is supplied for free by Unitronics, and is called VisiLogic. Unitronics also supplies a free remote access software, called Remote Operator, and a free data import software, called DataXport. The Remote Operator works by starting the software on a PC, establishing a connection between the PLC and the PC, either with physical wiring or through an Ethernet server, and then simply running the software. The program acts like the PLC HMI screen, allowing access to the PLC from a distance. For the PLC to export its data, a person must program this function into the PLC first, and then the DataXport software must be running on a PC, or “listening”, for the PLC to call the IP address, and export its data via excel format. Figure 4 is a picture of the PLC that we are using in this project: Unitronics V570. The HMI screen is a touch-screen (Vision570, 2011).

Figure 4: Modern PLC
Taken from (http://www.unitronics.com/Series.aspx?page=Vision570)

2.2 Systems Development Life Cycle (SDLC)

Our heat trace system solution is, essentially, an information system; we are collecting information, presenting the information, and controlling outputs based on information. The Systems Development Life Cycle (SDLC) is the cornerstone for developing a new information system. It contains four phases, which will guide the development of this project: Planning, Analysis, Design, and Implementation (Dennis, 2009).

2.2.1 Planning

The planning phase of a project is to determine why the information system should be built and how to build it. A system request is the first task to complete, usually involving a complete business value proposition. If the business will not profit from the system, then it should not be built. A feasibility analysis should be conducted next, consisting of three sections. Technical feasibility: can we build it? Economic feasibility: will it provide business value? Organizational feasibility: will the system be used efficiently if we build it? If the feasibility analysis is positive, and top management approves, then a work plan must be constructed. The work plan will assign responsibilities to the team, deadlines, and strategy. Planning provides the project with a strong foundation.

2.2.2 Analysis

The objective of the analysis phase is to produce a system proposal. This proposal will clearly distinguish who will use the system, where and when the system will be built, and what the system will do. During this phase, the current system will be analyzed for both weaknesses and strengths. Requirements gathering will also take place, typically involving interviews and questionnaires to find out exactly what the new system should do and not do. After this phase, the team should have a clear understanding of what the new system should produce.

2.2.3 Design

The design phase gathers all of the objectives determined in the analysis phase and decides how to implement them. It describes, in detail, how the software should be programmed and how the hardware should operate. It also describes how the network should communicate and how the data should be stored. The first step will be to determine whether to work from scratch or to work from a system that is already in place. Afterwards, each aspect of the system should be described, either in words or diagrams. The design phase should, essentially, be an instruction manual on how to implement the system.

2.2.4 Implementation

The final phase of the SDLC process is the implementation, where the system is physically built, programmed, and activated. This phase starts with construction, in which the system is built and tested for errors. Then, the system is installed, and the old system is de-activated. Finally, a support plan is implemented to ensure that the system is functioning properly and meets customer standards.

2.3 SDLC Development Options

There are multiple ways to approach the Systems Development Life Cycle, each of which has certain strengths and weaknesses, depending on the situation. The three most common approaches are Waterfall Development, Rapid Application Development, and Agile Development (Dennis, 2009). Waterfall Development is the most basic approach, in which each step of the SDLC is taken in sequential order. Going back to previous steps in this approach is very difficult, since each step has a lot of time and approvals already invested. The main advantage of this approach is its simplicity and organization in the aspect of following instructions and requirements set forth in the early stages of the project.

Agile Development splits objectives into individual processes, in which a lot of face-to-face communication is utilized to complete an entire system. Each objective is taken one step a time, to eventually create an information system. This approach involves a lot of customer interaction, which is good in some cases, but bad in others.

The last approach is Rapid Application Development, in which early stages of the project are rushed, for the purpose of creating a prototype system for the user to test and comment on. This approach is best for complex systems that users are not completely sure about yet. For example, if the user has no idea of how their HMI screens should look, then this is most likely the best approach.

In this project, we are using the Waterfall Development approach. We have invested much time and thought into the planning phase of this project. We have clear objectives and know exactly what should be produced by the project. We also know what tools and programming languages to use in accomplishing these goals. Agile Development would take too long to complete by requiring us to check with the customer after each individual step; we have already analyzed the customer and know what they will like to see. Rapid Application Design would have been too risky, since the program takes a long time to write; we could not afford to write an entire program and then go back to change if the customer did not approve.

The remainder of this MQP will be divided into the four sections of the SDLC: Planning, Analysis, Design, and Implementation. The principles learned from each section of the SDLC will be directly applied to the project and explained in detail. Appendices will be used for much of the final documentation and code. A conclusion section will end the project by assessing the overall work and discuss future enhancements.

Chapter 3 Planning

3.1 Business Value

If an information system is not profitable, then it is not worth making. In this section, we will discuss how power plants will profit from this project. This MQP will be given to our sponsor, and then used to service power plants. Thus, the project must be profitable to both our sponsor and his power plant customers. The sponsor's business value is simple since they are selling the solution; and this is, of course, to sell the solution for more money than production costs. Due to the privacy rights of the company, we cannot state exactly how much profit is being generated from this module.

Power plants will profit from this project in several ways. The first being energy costs. Weather is often unpredictable, so most power plants will run their heat trace for the entire seasons of Fall, Winter, and Spring. This will cost them a lot of money, depending on how much heat trace they have. A small natural gas power plant, with only one main combustion engine, or 'Unit', will consume 168 kilowatts per hour, on average, to power their heat trace. One kilowatt will cost the average plant $0.07. So, on an average day, a small plant will spend $282.24 to power their heat trace. Figure 5, below, is a chart of this information for a few sizes of power plants. Our solution will turn the heat trace on, only when the temperature drops beyond the set point. So, for example, at a small plant, if the temperature stays above the set point for roughly 120 days, during the Fall and Spring, then the plant will save $33,869 in energy bills that year. If the plant has more than one Unit, the savings will further increase.

		1 Unit	2 Units	3 Units
Ave # of circuits per panel	14			
Ave # of panels per unit	2			
Ave footage per circuit	50			
Ave wattage per cable	5			
# of units per plant	1			
# of units per plant	2			
# of units per plant	3			
Total wattage of heat trace / plant (Kw hours)		168.00		
Total wattage of heat trace / plant (Kw hours)			336.00	
Total wattage of heat trace / plant (Kw hours)				504.00
Nov 1 - March 31 = 151 days	151	% days operating	**60%**	90.6
Ave cost of Kilowatt hour	$ 0.07			
Ave cost to run heat trace per day (kwatt hours x cost of kwatt hour)		$ 282.24	$ 564.48	$ 846.72
Ave LOST PROFIT due to improper control of electric heat trace system		$ 25,570.94	$ 51,141.89	$ 76,712.83

Figure 5: Lost Profit of Running Heat Trace

Another way that power plants will profit from this solution, is that it is wireless. Most power plants have engineers and electricians that could potentially create an in-house wired solution to monitor their heat trace. But, the cost of just the wiring for such a solution is over $40,000 on average. Additionally, the wires and conduit would take up a lot of space and clutter the plant, which is a problem. Our solution is more complex, due to the wireless aspect, but cheaper to implement and takes up less space. Figure 6, below, is a comparison chart of the costs of a wired solution vs. a wireless solution.

Costs to Install Control & Monitoring System

	Wired		Dymocon Wireless	
Points of Control & Monitoring		20		20
Hardware Costs - System	$	27,200.00	$	36,866.00
RTD's (20 x $105)	$	2,100.00		included
RTD extension wire (3000 x $0.70)	$	2,100.00		N/A
configuration / programming (1 manhour x 20 x $100)	$	2,000.00		included
labor to install conduit to RTD's ($13.64 / ft ave x 3000 ft) ($13.64 for simple / $23.36 for difficult install)	$	40,920.00		N/A
labor to wire into Distribution Panel (16 manhours x $70)	$	1,120.00	$	1,120.00
Total Installed Cost	$	75,440.00	$	37,986.00

Figure 6: Wired vs. Wireless Costs

With this solution, power plants will be able to locate and diagnose heat trace cables, without having a maintenance electrician do it annually. There are two downsides to having a maintenance electrician come once per year and check the heat trace cables. Each year, it will cost the plant about $5,000. Also, if a heat trace cable malfunctions in between the visits, it could either slowly 'burn out' and draw more energy, or it could break and put their equipment at a very high risk.

Preserving the life of the heat trace itself is another value to plants. By running the heat trace only when it is needed, it will increase the life span of the cables, which can save the plant thousands of dollars. The application will monitor the amperage of the heat trace, thus notifying the plants when a cable is starting to burn out, so they can replace or fix it at the right time.

The most prominent business value that plants will receive from this solution is the sense of security that it provides. Plant operators will be alerted as soon as a heat trace cable malfunctions, so they can act before a freeze occurs. Even if no problems arise, the energy savings will pay for itself in two years. An average sized, 2-Unit plant, will lose a little over $52,000 due to power consumption. This application will cost the plant about $70,000. Therefore, the system will repay itself in 1.35 years on average.

3.2 Feasibility Analysis

A feasibility analysis was conducted to determine if the solution was possible with our current resources. It analyzes our familiarity with the application and tools, our staff, budget, and the amount of training, if necessary. The results are below:

Technical Feasibility: Can I build it? (Medium)

Familiarity with Application (High):

- I worked part time with Dymocon for one year, creating databases for customers and other tasks non-related to this MQP. About eight months ago, my employers and I discussed the possibility of creating a ‘Monitor & Control Solution’ and making it my senior project. Since that time, I have worked on the early-stage foundations of this project. This work was separate from my normal operation within the company, and specifically geared towards the MQP. During these early stages, I learned the programming language required for this MQP, which is Ladder Logic.

Familiarity with Technology (Medium):

- In addition to learning Ladder Logic, I attended seminars, paid for by the sponsor, and created test code for our lab PLC, ranging from simple to complex operations. This training was intended to prepare me to assess the feasibility of this project as my MQP.
- I have very limited experience with HTML code, which will be used for the web page of the solution. To mitigate this risk, the sponsor’s web consultant will help me develop sections of the webpage.

- I have no experience with Unix systems, but I do have experience with databases. The sponsor's web consultant will help me implement a Unix database, which will be used to store historic data from the PLC.
- I have a basic understanding of wiring schemes, and industrial equipment, such as relays, power supplies, gateways, and current transducers. It will be enough for me to design the layout, wiring scheme, and integrate the data into the PLC without any problems.

Project Size (Large):

- This size of the project would be overwhelming for an MQP, if I had no previous experience in the field. As mentioned previously, I spent time during the last eight months familiarizing myself with the programming language, and running test code on the PLC. The scope of the project is now manageable, due to my experience with the language.

Economic Feasibility: Should I build it? (High)

(Sponsor Economic Feasibility)

Tangible Costs and Benefits (High):

- Cost for the project will be $10,000 paid by the sponsor, to WPI.
- Materials for lab testing and demonstration equipment will be paid for by the sponsor, and cost $5,000.
- Materials for customer installation will be paid for by the sponsor and be discussed in the Bill of Materials appendix section.
- Sales profits will not be discussed due to privacy rights, but should exceed all costs, including R&D, after the fourth sale to an average power plant.

Intangible Costs and Benefits (High):

- The project will provide a foundation for future solutions.

(Power Plant Customer Economic Feasibility)

Tangible Costs and Benefits (High):

- For an average 2-Unit power plant, the cost of this module will be about $70,000.

- The return on investment will begin in the second year after installation. After the second year, the customer will save $51,000 on energy consumption per year, which would have been spent on running their heat trace cables inefficiently.

Intangible Costs and Benefits (High):

- The customer will be alerted of heat trace problems before they cause major damage to the plant.
- If a major disaster, such as a pipe freeze that causes an explosion, is prevented by this MQP, then the return on investment would be about 1,000 percent of the cost, for that year.

Organization Feasibility: Who will take part in the project? (High)

Project Champion:

- Timothy R. Mullen (Sponsor & CEO of Dymocon).

Project Engineer:

- Teodor Serbanescu (WPI Undergraduate)

Senior Management:

- Richard Stearman (Web Consultant) – help with HTML and Unix Database.

Users:

- Staff of Dymocon, and end user power plant customers.

Alignment with Business:

- The project will provide an application for our sponsor, to sell to power plant customers.
- The project will save power plants money, by deducing energy consumption, and preventing heat trace problems.

3.3 Work Plan

This project begun at the beginning of B term 2011 (October 25) and finished before the start of C term (January 11). Below is a rough time-line of waypoints and objectives for this MQP, followed by a Gantt Chart of the project work plan, Figure 7.

January - October

- **Planning Phase**: Learning software, identifying project deliverables & objectives, assessing business value, performing a feasibility analysis, developing a work plan, and familiarizing myself with the equipment.

October

- **Week 1**: Literature Review, Bill of Materials, Cost Savings Analysis.

November

- **Week 2**: Physical Infrastructure Design & CAD drawings.
- **Week 3**: PLC Code, design for web page & database.
- **Week 4**: PLC Code, design for web page & database.
- **Week 5**: PLC Code, design for web page & database.

December

- **Week 6**: PLC Code, design for web page & database.
- **Week 7**: PLC Code Testing, web page & database testing.
- **Week 8**: MQP Report, User Manual.
- **Week 9**: MQP Report.

January

- **Week 10**: Revisions, Demonstration, Final Submission.

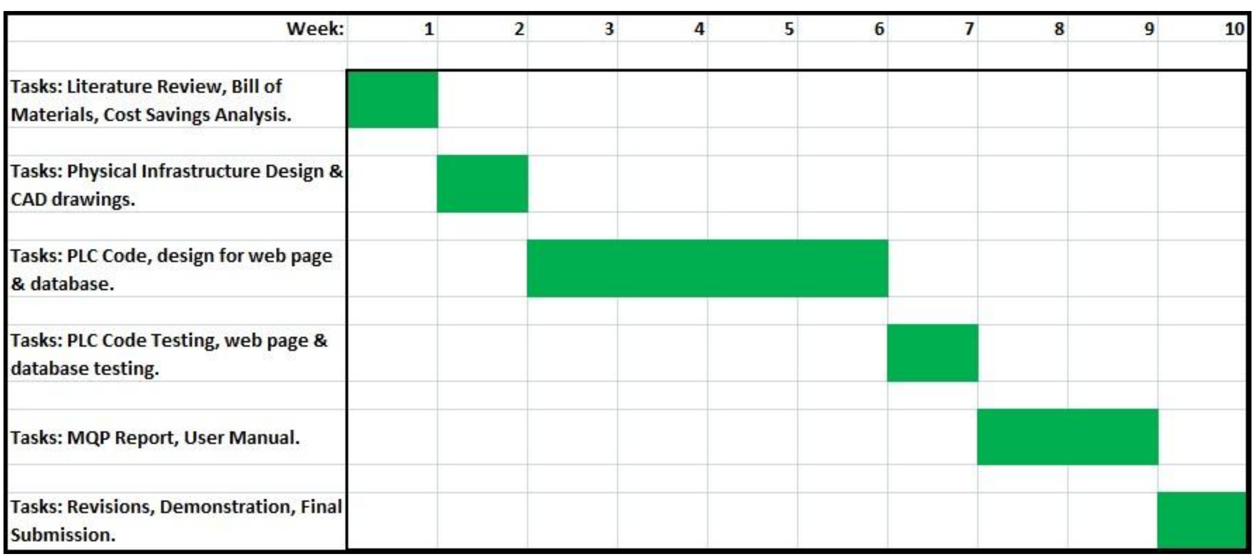

Figure 7: MQP Work Plan Gantt Chart

Chapter 4 Requirements Analysis

The 'Monitoring and Control Solution' was built and programmed at the laboratory of the sponsor, during the course of this MQP. The system was built inside a fiberglass enclosure and brought to WPI for a demonstration at the end of this project. There was no current system available to work from, so everything was assembled and programmed from scratch.

During the planning phase of this MQP, we decided to use a Unitronics PLC as the central device. We used various other instruments to collect data and report it back to the PLC. The PLC then displays the data, and create alarms based on user-defined set points. An organized Human-Machine Interface (HMI) Monitoring Screen is essential to the system, so they user may monitor their heat trace efficiently. The next section will outline all of the functions that this system must complete.

4.1 System Requirements

PLC HMI Monitoring Page

- The PLC collects & displays temperature readings of the power plant pipes, from the System Gateway.
- The PLC collects & displays battery strength of the System Wireless Transmitters, from the System Gateway.
- The PLC collects & displays signal condition of the System Wireless Transmitters, from the System Gateway.
- The PLC collects & displays amperage readings of the heat trace, from the Current Transducer Board.
- The PLC collects & displays GFI readings of the heat-trace, from the Current Transducer Board.

PLC HMI Configuration of Set-points & Alarms

- The PLC allows the user to name circuits as they please.

- The PLC allows the user to define the temperature set-point, which will turn the heat trace on or off, via the PLC output, based on what the actual temperature is.
- The PLC allows the user to define a low & high temperature alarm set-point.
- The PLC allows the user to define a low amperage alarm set-point.
- The PLC allows the user to define a low amperage set-point.
- The PLC allows the user to define a GFI alarm set-point.
- The PLC allows the user to disable or enable any specific circuit, which will forcefully stop the output of the PLC to that circuit.
- The PLC allows the user to clear inactive alarms from the HMI screen, including a GFI circuit trip, which will forcefully stop the PLC output if not cleared.

PLC Output

- The PLC will send a 24 volt output signal to our System Relays, which will turn on a specific heat trace circuit. This will happen only when the specific circuit is enabled by the user, and the temperature has dropped below the user defined temperature set-point.

PLC Alarms

- When an alarm occurs, a flashing red beacon will appear on the PLC HMI screen. The PLC will contain nine alarms in total.
    - <u>Probe Communication Failure</u> - indicates that a Wireless Transmitter connected to an RTD has lost connectivity with the System Gateway. When this alarm occurs, the temperature readings for that circuit will become 0, until communication is re-established.
    - <u>Gateway Communication Failure</u> - indicates that communication between the System Gateway and the PLC has failed. By default this alarm will turn all circuits to on.
    - <u>Battery Low</u> - batteries on a Wireless Transmitter are below 3 volts, and need to be changed to avoid a Communication Failure.
    - <u>GFI Warning</u> - generated if the milli-amp warning value (customer site defined) is exceeded.

- GFI Trip Alarm – generated if a milli-amp trip value (customer site defined) is exceeded. The circuit will be forcefully turned off if this occurs, to protect the heat trace. Once the issue is resolved, the user must clear the alarm via the PLC HMI.
- Circuit Amps Low - circuit is operating at amperage values below user defined amperage set-point.
- Temperature Low - generated when the temperature on one or more of the RTD probes drops to the user defined temperature set-point.
- Temperature High - generated when one or more RTD Probes reaches the user defined high temperature set-point.

- When an alarm occurs, the user will press the red beacon on the PLC HMI and be brought to an alarm description screen, where they may clear the alarm only if the cause of the alarm is resolved.

PLC Web Page

- The Unitronics PLC has a built-in web server, which may be accessed by anybody on the Ethernet network into which the PLC is wired.
- The PLC web page will be a non-interactive monitoring page, which will contain all of the information from the PLC Monitoring HMI Screen.

Historic Data Analysis

- The PLC will export its data every six hours, via Ethernet, to the sponsor's web server.
- The sponsor's server will organize the data into a Unix database, and also host a web site, which the user may access to view the PLC’s historic data.

Chapter 5 Design

5.1 Materials & Physical Infrastructure

The Monitoring & Control Solution MQP is centralized by the PLC, which is located inside a fiberglass enclosure. Most of the other system components are also located in this enclosure, which includes the PLC I/O, the Relays, the Current Transducer Boards, the Power Supply, the Gateway, and the Ethernet Switch. The only components that are not located inside the enclosure are the Wireless Transmitters, attached to the RTDs, and the sponsor's Database & Web Site, which collects the PLC data via internet. Below is a list of materials that the system uses, with descriptions. How the materials interact with one other is discussed after these descriptions.

- Fiberglass Enclosure: A weather proof enclosure where most of the materials are attached via din rail mounts.
- PLC: A programmable logic controller to gather all of the data via I/O, generate alarms for the user, and control heat trace output via I/O.
- Power Supply: A central power source to provide electric power to all of the materials inside the enclosure.
- Solid State Relay: A power switch, with is controlled by the PLC I/O, and may either provide power to the heat trace, or deprive power to the heat trace. Each relay can monitor a single heat trace circuit.
- Current Transducer Board: An electric board, which contains current transducers, which are looped around the wires connected to the Relays. They record amperage readings, then send those readings to the PLC I/O via a 4-20 milli-amp signal. Each board contains four CTs; each CT can monitor a single heat trace circuit.
- Ethernet Switch: A simple Ethernet hub which connects the PLC to the LAN network.
- RTD Probes: Resistance temperature detectors, which are drilled into a pipe that needs to be kept at a certain temperature. The RTD is wired directly to the Wireless Transmitter, and sends the temperature reading to it.

- Wireless Transmitter: A battery powered device which collects temperature readings from the attached RTD Probe and wirelessly sends the reading to the System Gateway.
- System Gateway: A device that collects data from its Wireless Transmitters every five minutes, and then over writes that data, when new readings arrive. It can manage up to 50 transmitters, and is wired directly to the PLC.

For the Monitoring & Control Solution to function as a system, all of the devices must work together. Four distinct diagrams have been created to illustrate how the system functions. The first diagram, shown below in Figure 8, is a traditional Data Flow Diagram, which summarizes the flow of data, and how it eventually reaches the customer.

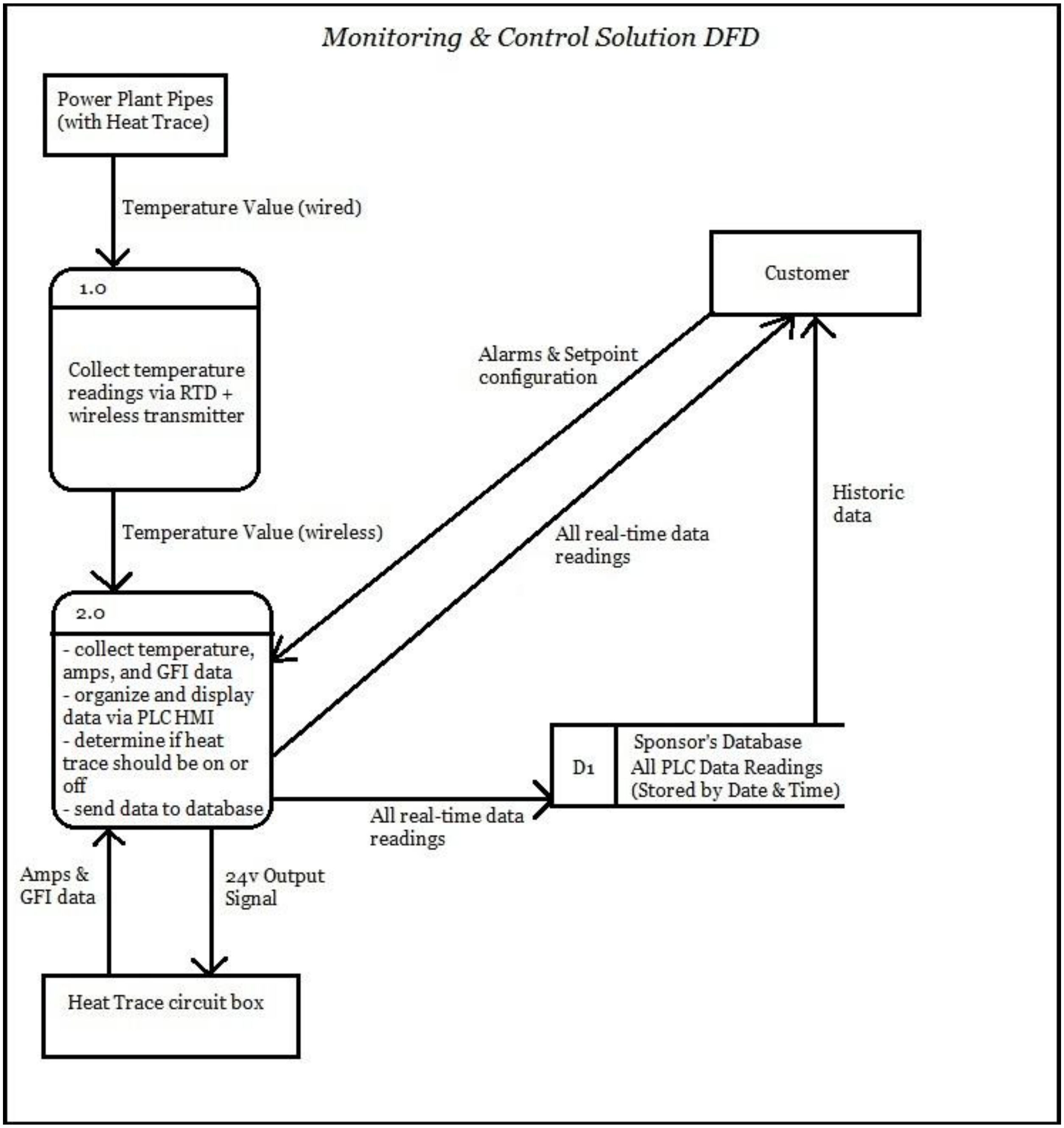

Figure 8: Data Flow Diagram of the Monitoring & Control System

The next diagram, figure 9, is a custom diagram that incorporates some elements from the traditional DFD-type structure, but also creates an overhead map-based view of how the system will function in a power plant setting.

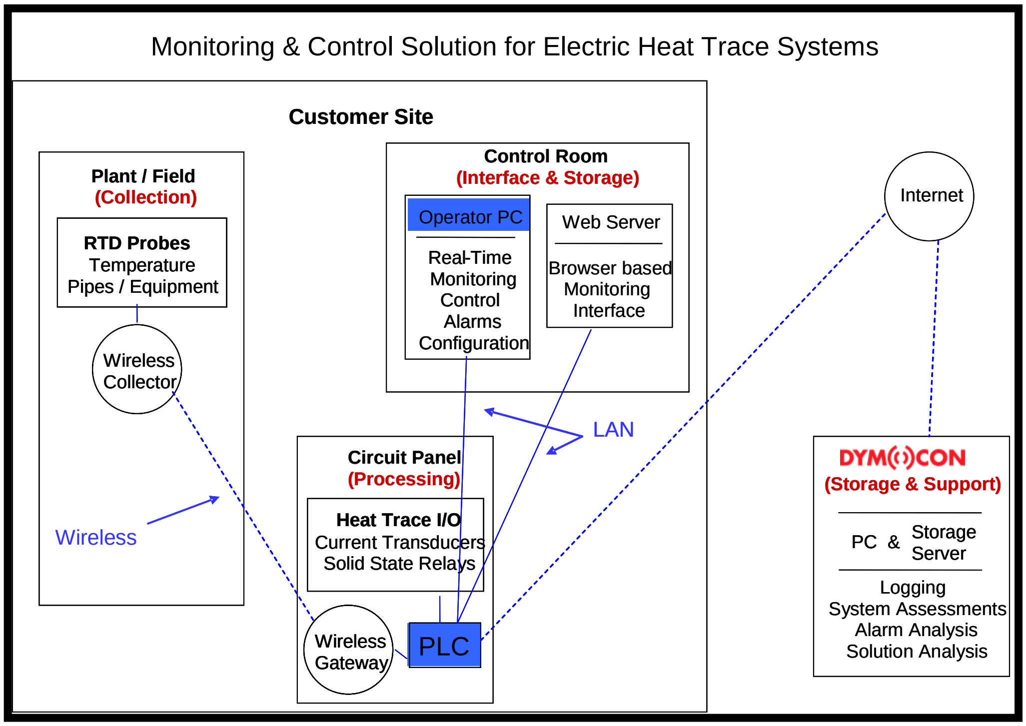

Figure 9: Map Diagram of the Monitoring & Control System

As the DFD and Map Diagram show, data moves to and from the PLC, and eventually to the customer. Wireless transmitters, located throughout various parts of the power plant, collect temperature readings from their attached RTDs, and send the readings to the Gateway, wirelessly. The Gateway then passes this data to the PLC via a wired connection, within the Panel Enclosure. The PLC also collects GFI and Amperage readings from the CTs, which are looped through the power connectors that attach to the Heat Trace Circuit Box; each looped wire represents the power coming from one Heat Trace Circuit. The PLC also collects alarm and output set-points from the customer, either through the PLC HMI screen, or through the Remote Operator Utility, which simply brings the PLC HMI screen to their PC Desktop. Based on the actual temperatures, and the associated set-points, the PLC will either turn the Heat Trace relays ON or OFF. The PLC will organize this data into its Web Server, which the customer can access on their PCs via the LAN. Finally, the PLC exports its data to the Sponsor's server every six hours, where it is organized into a database and hosted onto a web site for the Customer to browse.

Appendix B is the Panel Infrastructure Diagram, which lays out the actual design of the Panel Enclosure, in which the PLC is attached to the Gateway, CTs, Relays, Ethernet Switch, and its own I/O Units. Appendices C & D are the electrical ladder diagrams for the Panel Enclosure.

5.2 PLC Code

The PLC code is written in the Ladder Logic programming language, using the software Visilogic, which is made by the same company that builds the PLCs, Unitronics. The code must establish communication with the gateway, gather data from the gateway, gather data from the CT Boards, organize that data into real-time data tables, create 20 circuits that the user may navigate through, create and populate HMI screens, create set-points and alarms, control output, and export the data to the sponsor's server. The design of the PLC code is explained below.

5.2.1 Data Tables

The first step in designing the PLC code is to create data tables to hold data for each of the 20 circuits. The system may be used for fewer than 20 circuits, but not more. The reason to create the data tables first, is to establish a foundation for the code, where the data are stored, and then retrieved when necessary. The main data table will contain all of the real-time readings for all 20 circuits, and be called 'Circuit Probe Table'. Each row will represent a circuit, and each column will represent a specific data value. The 16 data values will be as follows: circuit name, amps expected, amps alarm set-point, amps actual, probe 1 name, probe 1 ID, probe 2 name, probe 2 ID, probe 3 name, probe 3 ID, GFI warning set-point, GFI trip set-point, GFI actual, temperature set-point, temperature low set-point, and temperature high set-point. Below, Figure 10, is a screenshot of this data table's construction.

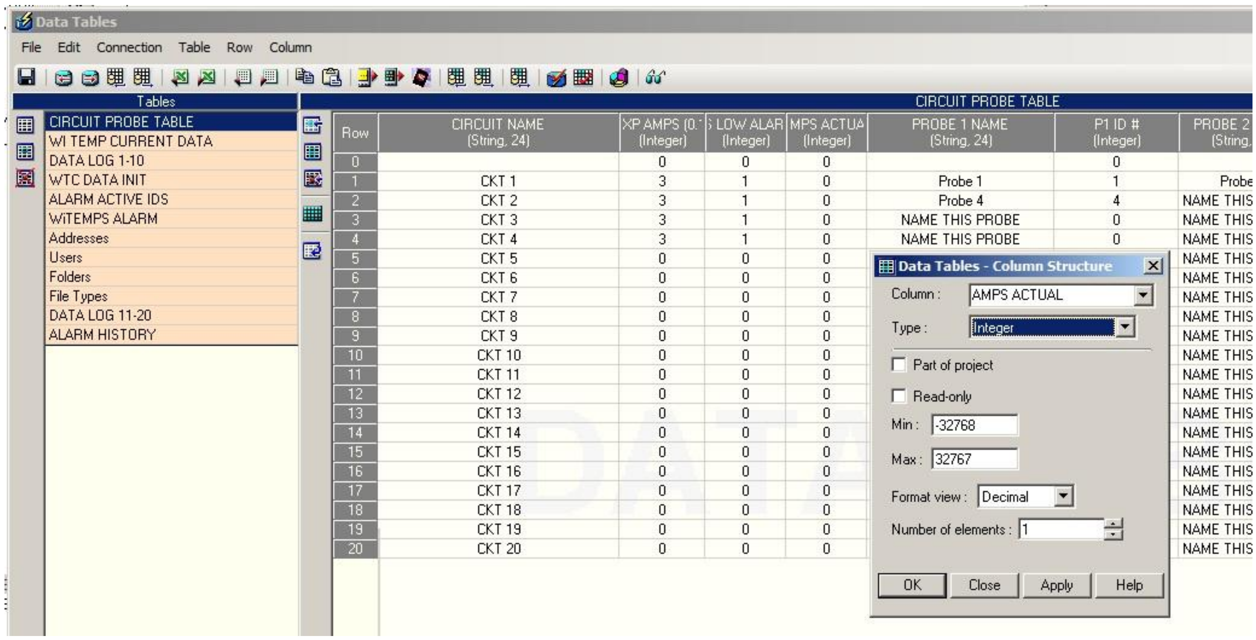

Figure 10: PLC Code - Circuit Probe Table

The next data table to be constructed is strictly for the wireless transmitters. This table will hold all of the real time temperatures, battery levels, and communication status, for up to 60 wireless transmitters. Eventually, these temperature readings are moved into the main 'Circuit Probe Table', but first, they are stored here. As the PLC scans through the Gateway's modbus registries, it gathers readings for each transmitter and assign those readings to the appropriate row of this table. Each row represents the transmitter ID, so if the PLC collects data for transmitter ID #6, it organizes the temperature, battery, and status directly into the 6th row.

Two alarm tables are programmed. One for the wireless transmitters and one for amperage, temperature, and GFI. The wireless transmitters alarm table will contain columns for the transmitter ID, battery alarm, and communication alarm. Each time an alarm is triggered, the associated row value will turn from 0 to 1, signifying that there is an alarm active for that transmitter. The same applies for the circuit based alarms, which include temperature high & low, GFI trip & warning, and amperage low.

The last tables are used for historic data readings. These tables are directly exported as .csv files, to the sponsor's server. The first table contains all data readings for circuits 1-10, while the second contains circuits 11-20, and the final table contains alarm history. Each row is organized by actual time & date, recorded by the PLC's internal clock. Each column is organized by circuit number. The code exports the data at midnight, 6AM, noon, and 6PM. The destination of the data tables is the IP Address of the sponsor.

5.2.2 Communication & Scan Sequence

The next phase of the code is to establish communication with, first, the PLC I/O units, which gather amperage and GFI readings from the CT Boards. Then, communication is established with the Gateway, which gathers transmitter readings. The type of communication parameter is called MODBUS TCP/IP, and is established through communication function blocks in the code. Once that is successful, memory locations must be assigned to the slots of the PLC I/O, which will store the real time amperage and GFI values in the PLC; they are updated continuously. A scan sequence must be created to gather the transmitter values. The code will create a vector of 60 addresses, with values from 1 to 60, and scan them one by one. Each time it scans an address, it will compare the value to those of the Probe IDs, which originate from the Circuit Probe Table. If the ID matches, then it will access the Gateway registries, and gather data from that specific ID. Once the data retrieval is done, it will continue scanning for the next Probe ID, and then repeat the process. All of the data is processed into memory locations, and organized into the data tables. Figure 11, is a screenshot of the code which retrieves the temperature reading and places it into a data table.

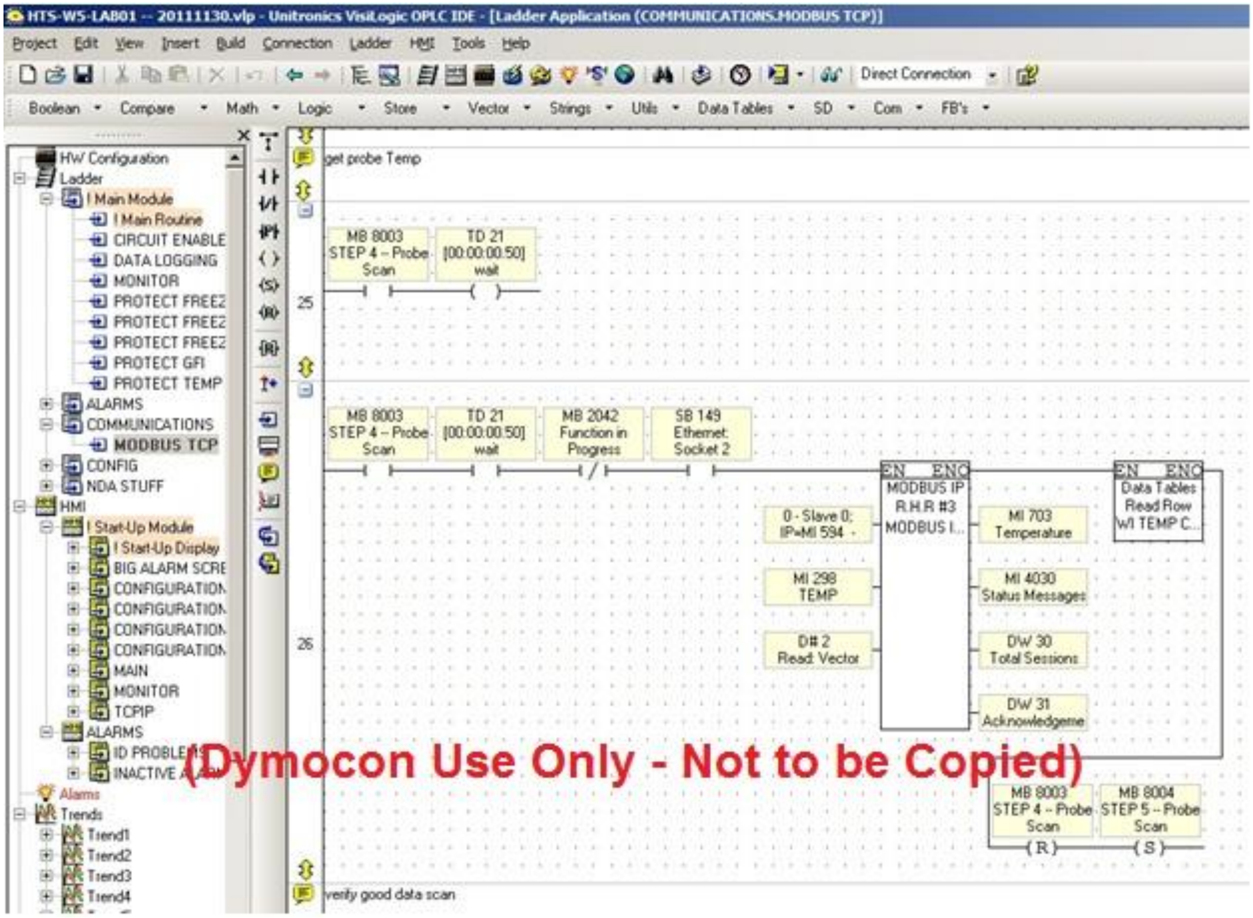

Figure 11: PLC Code - Scan Sequence

5.2.3 HMI Screens

At this point, it is time to start collecting user-defined set-points and displaying data via HMI screens. The two main screens will be the Monitor and Configuration screens. It is best to keep the general structure of these two screens the same, so they user may navigate through them easily. Both screens will display information for a single circuit, and have a navigational bar at the top, which may be used to move to the next or previous circuit. The Monitor screen will contain all of the information that we are collecting for the customer: temperatures, GFI, amperage, IDs, names, and two other indicators. The first indicator is the 'Circuit Enable/Disable' button, which is only able to be pushed by the user in the Configuration Screen. This button simply 'disables' a circuit, forcing the output and alarms to stay off for that specific circuit. This is useful if the plant is working on that circuit and does not want this system to interfere during the work. The second indicator is the 'Output On/Off' tab, which simply shows the user if PLC is sending output or not, to that specific circuit. Figure 12 shows the Monitor HMI screen in construction.

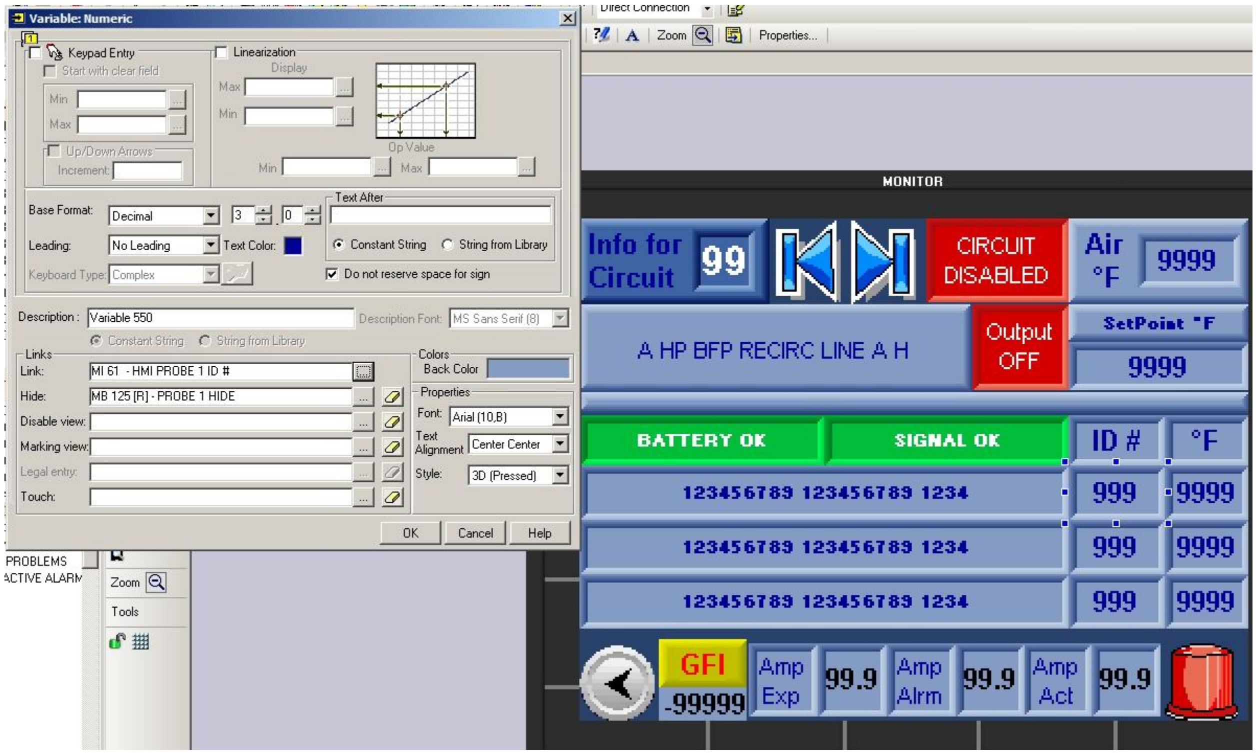

Figure 12: PLC Code - Monitor HMI Screen

The Configuration screen is divided into two screens. The first screen follows a similar format as the Monitor screen, but allows the user to change all of the set-point values, and Enable or Disable a circuit. The second Configuration screen allows the user to set the temperature and GFI set-points, which are not shown in the Monitor screen. The main HMI allows the user to choose between Monitor and Configure, and also adjust IP settings of the PLC, which are pre-configured for the user, but still available to be adjusted. The Configuration screen is also password protected, so when the user chooses to configure, from the main menu, they will be prompted with a small password screen first. In the Configuration screen, there is also a 'Save' button; the PLC will be programmed to save all of the set-points for any specific circuit when the Save button is pressed.

The last HMI screen is the Alarm Screen, which is pre-configured in Visilogic. Once an alarm trigger is programmed, the software allows the programmer to enter an 'alarm configuration' section, which, once filled, will create an alarm HMI screen. If an alarm is trigged, the user will see a read flashing beacon; once the user presses that beacon, they will be brought to an alarm screen, with a description of the alarm, and the option to clear the alarm, if it is no longer active. Figure 13 shows the alarm configuration page with data for an Amperage Low alarm.

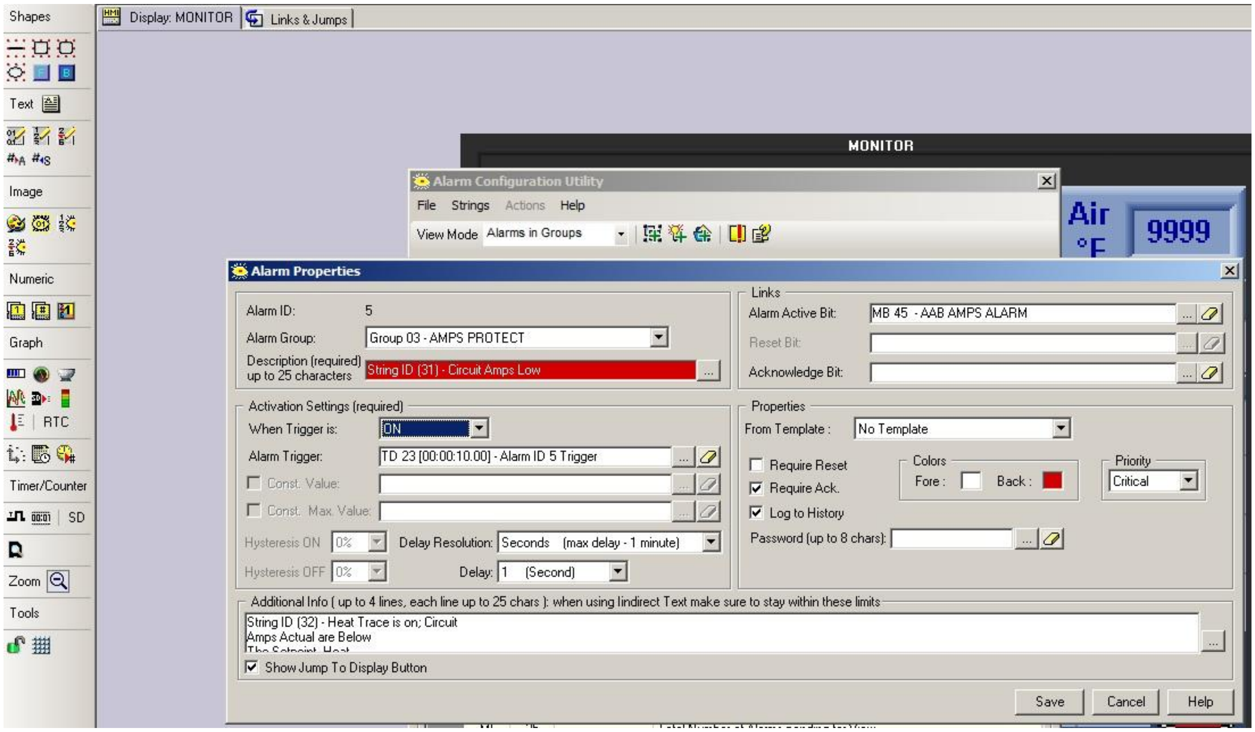

Figure 13: PLC Code - Alarm Configuration

5.2.4 Set-Points & Output

After a user inputs a series of set-points in the Configuration screen, then presses ‘Save’, the set-point values will be saved to memory integers of the PLC, and saved in the data tables. As the program collects data readings, such as amperage, it will compare the value to the set-point, and if the value is below the set-point (or above in some circumstances), it will trigger an alarm. For example, if the amperage low set-point is 5 amps, and the actual value is 4 amps, an amperage alarm will trigger.

The only set-point that controls the output of the PLC is the 'Temperature Set-point'. If any of the probe temperature readings of a specific circuit go below this set-point, the output for that circuit will be triggered, until the actual temperature has risen above it. Figure 14 is a screenshot of the code that controls the output for Circuit One. The output is turned on, only if all of the following conditions are met: the circuit is enabled, the temperature set-point is triggered, and there is no GFI trip active. Once the output is triggered, the amperage alarm system is also turned on for that circuit.

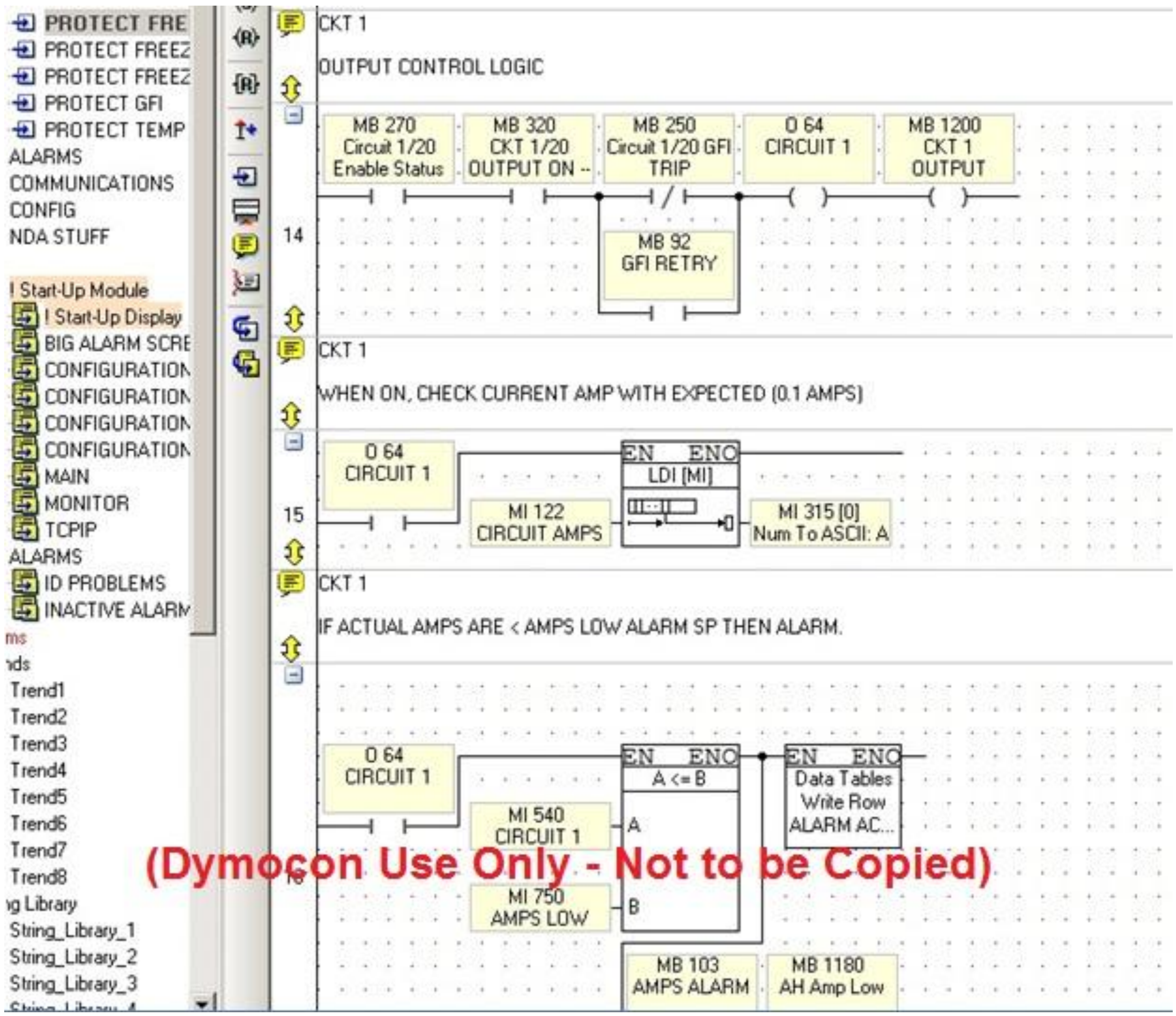

Figure 14: PLC Code - Output

5.3 Web Page Design

The PLC has an internal web server which may be used to create a web page. The web page itself is to be written in HTML code and then uploaded into the PLC directly. The objective of the web page is for the user to have a single monitoring page on their PC, which they may use to view the functionality of their plant's heat-trace system. The design will be a tabular view of all the circuits that they have enabled. The rows will represent each circuit, while the columns will represent data values. The columns, from left to right, will include: Circuit number, circuit status (enable/disable), circuit activity (on/off), circuit name, probe 1 temperature, probe 2 temperature, probe 3 temperature, temperature set-point, amps alarm set-point, amps actual, GFI status, communication status (of transmitters), and battery status (of transmitters). Values highlighted in red will represent that they have triggered an alarm. So, for example, if Circuit 5 has 3 amps below the set-point, it will show the actual amperage number highlighted in red.

5.4 Database & Historic Page Design

The PLC will export its data via data tables, every 6 hours. Meanwhile, the sponsor will run a program that accompanies Visilogic, called DataXport, which simply 'listens' for incoming calls from the PLC, and then collects the data tables It will reach the sponsor's server in a .csv format, and then be placed into a simple database. The ordering of the placement will be based on the first two columns, which are date and time. The database, which will be programmed in Unix, will be follow the same exact structure as the data tables, i.e. same columns, but with an unlimited amount of rows, representing data intervals every 5 minutes. The sponsor will then host a web site based on the database.

The Historic Web Site will allow the customer to view historic data and trending. The main tab will be 'Raw Data', which will simply ask the user for a time & date frame, and then display the data in a table for them. There will also be an additional three tabs which will show either temperature, amperage, or GFI for a specific circuit, for a given time range, and also create a line graph for the data. This will allow the user, for example, to see the amperage output for a specific circuit over a period of time, and perhaps trouble shoot an amperage problem.

Chapter 6 Implementation

The PLC Code, Web Page Code, User Manual, and Testing Results are located in the confidential Appendix Folder. Section 6.1 discusses the final end-user module, with associated screenshots.

6.1 HMI Navigation

The first screen of the PLC interface is the Main Options Screen shown in Figure 15. Each of the 3 tabs are reviewed in the following sections, as well as the alarm system, which is accessed by pressing the alarm light beacon on the lower left corner of the screen.

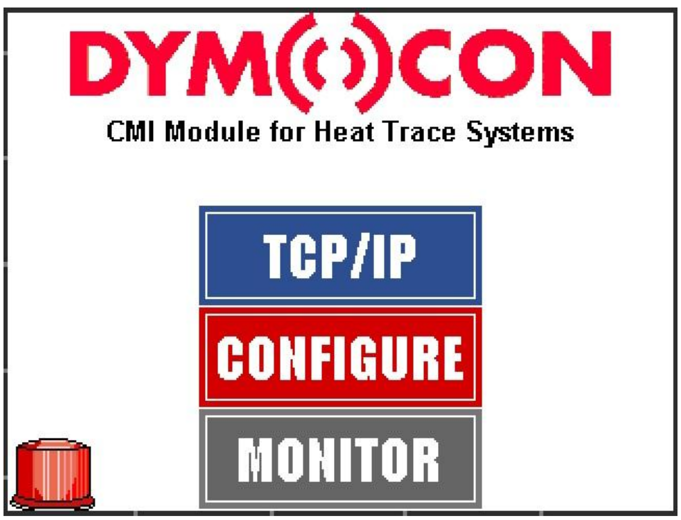

Figure 15: PLC Main Options Screen

6.1.1 TCP/IP

Selecting this tab takes the user to the IT Configuration Screen, shown in Figure 16. This information is Site specific and supplied by the Customer. These values are input at installation and should not be changed.

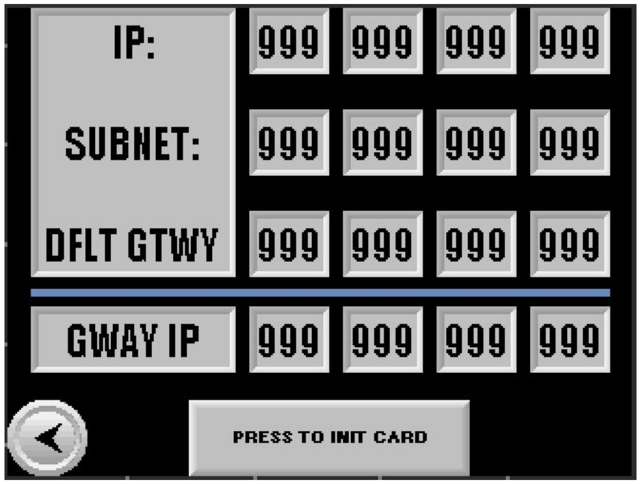

Figure 16: IT Configuration Screen

6.1.2 Configuration

The Configure Tab opens the screen shown in Figure 17. The User must enter a Password to access the Configuration Screens. Press on the Bar with 6 asterisks to access the Password keypad. The default Password is 0.

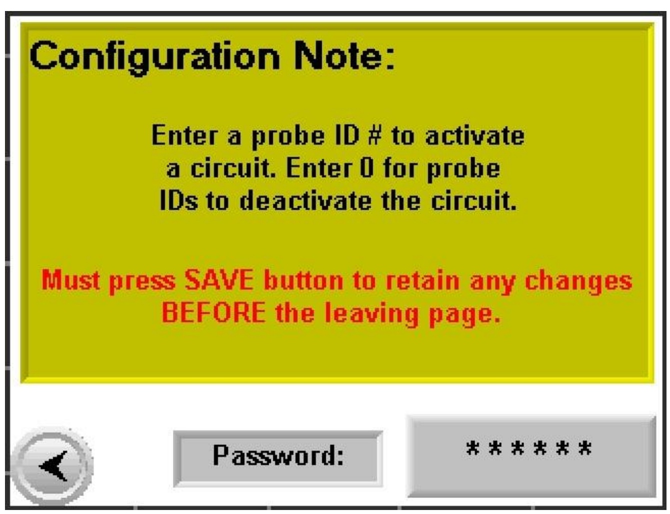

Figure 17: Password

There are 3 Configure Screens: Circuit Configuration, GFI and Set-point Configuration, and Password Reset. The first screen, Circuit Configuration, is shown in Figure 18, with surrounding commentary.

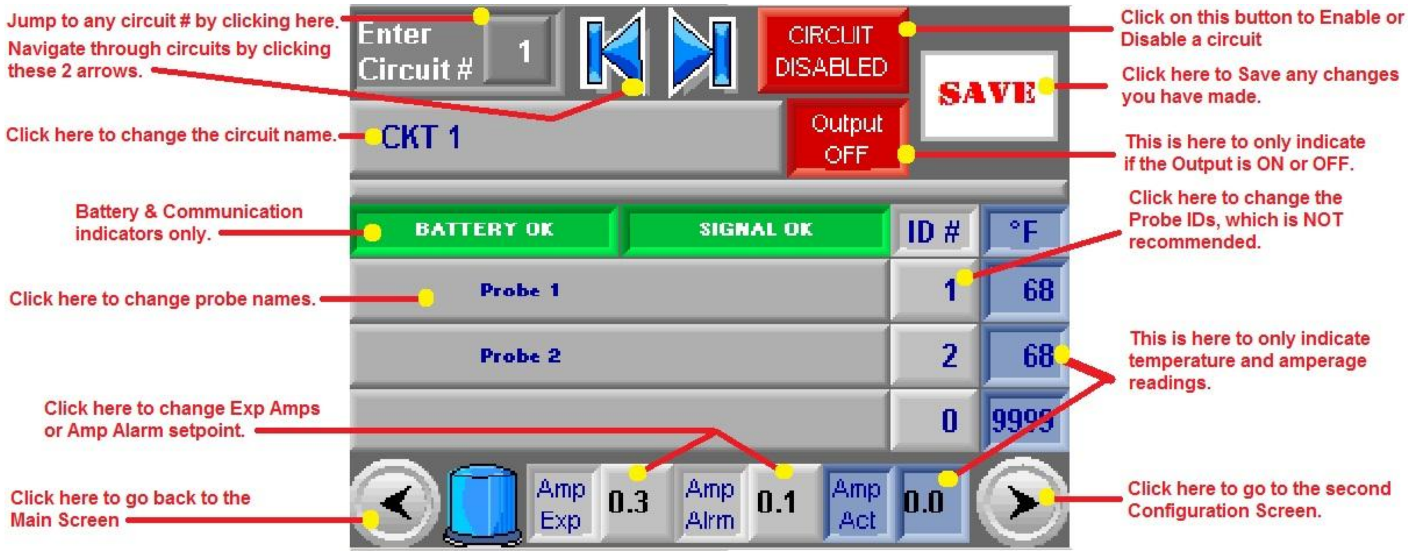

Figure 18: Circuit and Probe Configuration Screen

Note, when the CMI Module is deployed at a Customer Site, all Circuits being monitored will be pre-configured with the following information:

1 – Circuit Name (which will include the Site Circuit Number if it does not correspond to the Circuit Position Number in the *HMI Module*)

2 – RTD Sensor Name / Probe Name (up to 3 allowed per Circuit)

3 – RTD Sensor Device ID Number. Each RTD Sensor must have a unique ID for the wireless mesh network to operate correctly.

4 – Expected Amp reading for the Circuit. This is an estimated value based on the characteristics of the Heat Trace on the Circuit.

The Circuit Configuration Screen is used to make changes or additions to the User Defined Information about the Circuits being monitored by the CMI Module.

Enter Circuit # Tab – Shows the position number in the Solution of the Circuit to be configured. The CMI Module by default can work with up to 20 Circuits. These Circuits are pre-numbered in the solution. The first Configuration screen shown is always the Last Circuit configured or changed. If the actual circuit # at the Site does not correspond with the position number in the solution, the Site Circuit Number should be included in the Circuit Label or Name. If you press on the # window the screen will change to the Number Pad. Enter the Number of a Circuit and press Enter to go to that Circuit's Configuration Screen.

To the right of the Circuit # Tab are Left and Right scrolling tabs. These can be used to scroll to the Configuration Screens for the other Circuits being Monitored and Controlled by the Solution. To the right of that, is the Circuit Enabled / Disabled Tab.

The Circuit Disabled option is used to prevent the Heat Trace Circuit from being turned on when the Temperature sensor calls for heat. The Disabled option also prevents the GFI Warning, and Alarm, from being activated. This option is made available to prevent the Heat Trace from being turned on when maintenance is being performed on the equipment being protected.

The user can select the Number Tab and go to the Circuit Selection Screen which allows the user to select a Circuit by entering its number from the keyboard or through the number pad on the screen. Figure 19 is the keypad entry.

Figure 19: Circuit Selection Screen / Number Pad

The SAVE Tab in the upper right hand corner of the screen must be selected before leaving the configuration screen to retain any changes made to parameters being configured. A Circuit Name or Label must be given to each Circuit. Selecting the Label box will open an alpha-numeric key pad screen, shown in Figure 20, which is used to insert the Name or Label for the circuit.

Select letters or numbers from the key pad (1 – 25 characters) to insert the Name / Label desired. At the top of the screen information in a grey box will prompt you about the Name / Label being entered. For example, the screen below is for entering the Circuit Name / Label.

Figure 20: Alpha / Numeric Keypad

Each Circuit can have up to 3 RTD Probes. Each Probe being deployed should be given a Name or Label with a reference to its position along the Circuit. When selecting the Probe Label Box, an Alpha / Numeric Key Pad Screen as shown in Figure 2.3 will open so the Name / Label for the Probe can be entered. The Key Pad Screen for each Probe will show at the top the Probe Number it relates to. For example, "Probe 1 Name …" will show for Probe 1. The same will happen for Probes 2 and 3.

The Bottom of the Configuration Screen has an Active Alarms Beacon, and Amps Expected (Site User Defined), and Amps Actual windows. The *Amperage Actual* information is provided to help monitor the Status of the heat trace on each circuit and is provided by the CTs in the control panel for the CMI Module. When Amps Actual is below Amps Expected, the Solution will generate an alarm. If Amps Actual is 0, this indicates the heat trace is off.

Finally, the Bottom of the Configuration Screen has a Left Scroll Tab (<) which is used to go back to the Main Options Screen, Figure 0.1. The Right Scroll Tab (>) is used to go to the GFI and Set-point Configuration Screen, Figure 21.

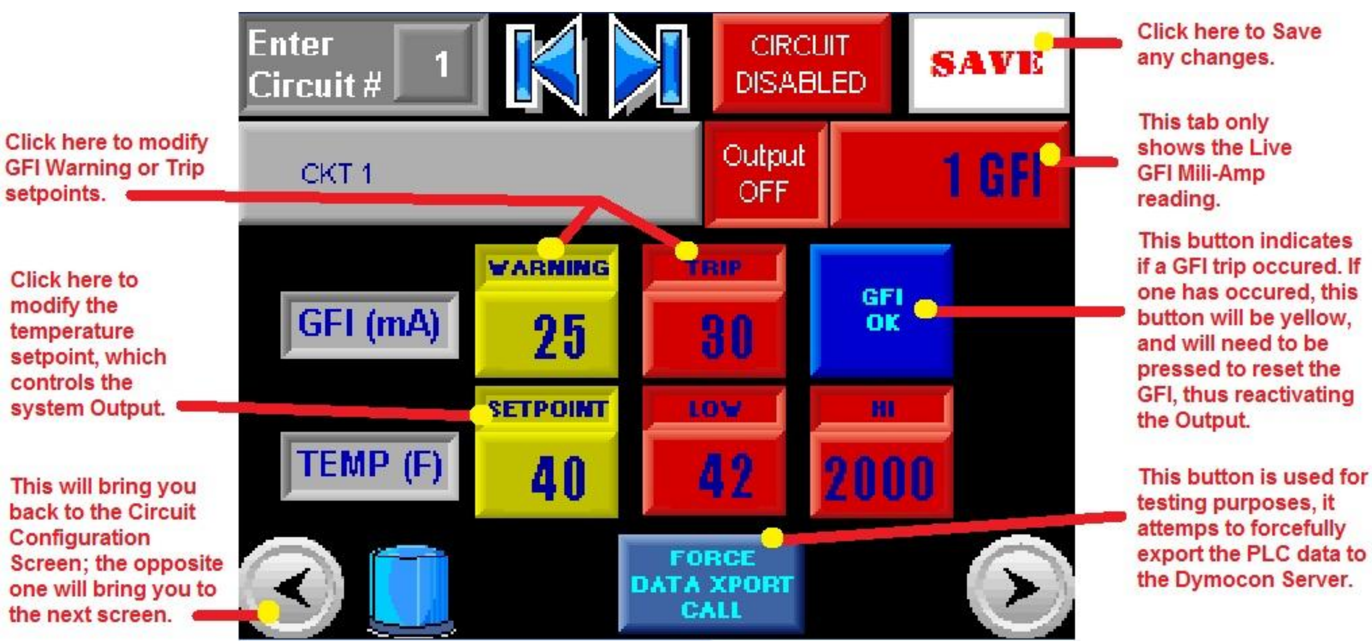

Figure 21: GFI and Set-point Configuration Screen

The following parameter information needs to be entered in this Screen for each Circuit being configured:

1 – **GFI Warning Value**. For a 30 mA circuit, this value will typically be set to 10. Any value from 0 to 999 can be entered here. A Warning is generated if the mA value defined is exceeded. This alarm is a Circuit level alarm.

2 – **GFI Trip Value**. For a 30 mA circuit, this value will typically be set to 30. Any value from 0 to 999 can be entered here. An Alarm is generated if the mA value defined is exceeded. This alarm is a circuit level alarm. In addition to an alarm, the system will shut the output off, for that circuit, until the user presses the 'GFI OK' button.

3 – **Temperature Set-point °F**. This is the temperature which must be maintained by the Heat Trace circuit during normal operation. All Probes on the Circuit will be reporting temperatures at or above the Set-point during normal Heat Trace operation. If the actual temperatures fall below the set point, the heat trace will turn on, unless the circuit is disabled.

4 – **Lo Set-point °F**. This is a temperature, below the Set-point temperature, which indicates that the Heat Trace is not working or is not maintaining temperature at, or above, the Set-point. An Alarm is generated when this temperature is recorded by one or more of the Probes on a circuit. This alarm is a circuit level alarm.

5 – **Hi Set-point °F**. This is a temperature, above the Temperature Set-point, which indicates that the Heat Trace is "On" and the temperature is above the Set-point. Above this temperature, damage to the Heat Trace may occur. An Alarm is generated when this temperature is recorded by one or more of the Probes on a circuit.

The GFI and Set-point Configuration Screen shows the Circuit Number (Enter Circuit #) and the Label of the Circuit. At the top of the screen are scroll Left / Right Tabs which can be used to scroll to this same window for other Circuits.

The Bottom of the Configuration Screen has a Left Scroll Tab (<) which is used to go back to the Circuit Configuration Screen shown in Figure 18. Also at the bottom of the screen is and Alarm Status Beacon; Red / Yellow when there is an Active Alarm Situation. When there is no Active Alarm this Beacon is Blue. The GFI Window in the Upper Right corner of the Screen provides a value generated, in real time, by the solution, measuring leakage to ground.

The Right Scroll Tab (>) is used to go to the Password Reset Screen (Figure 22). This screen is used to change the password required to enter the Configuration Tabs. The numeric pad that appears is the same as the others.

Figure 22: Password Reset Screen

6.1.3 Monitor

The Monitor Tab brings you to the Circuit Monitoring Screen, shown in Figure 23.

Figure 23: Circuit Monitoring Screen

The Circuit Monitoring Screen provides real-time status information about each circuit being monitored and controlled by the CMI Module. All information from wired sensors is real-time; all information from wireless sensors is based on updates at 5 minute intervals. Nothing in this screen is open to modification; to modify information or Enable/Disable Circuits, you must use the Configuration Screens. To the top right of the screen, 'Air °F' indicates the Outside Ambient Temperature at the Site being monitored; 66 °F in the Figure above.

Below the Circuit Number window is the Circuit Label Window, which in Figure 23 is showing "CKT 1". To the far right of the Label is the temperature Set-Point for the Circuit, which for CKT 1 is 40 °F. This is the temperature that will determine when the Heat Trace for this Circuit will turn on. At temperatures below the Set-Point the Heat Trace will remain on, and at temperatures above the Set-Point it will remain off, unless the circuit is disabled, which, in this case, would turn off the heat trace. There can be up to 3 Probes for each Circuit, and if one or more of the Probes reaches the Set-Point, the Heat Trace will be turned on.

The bottom of the screen has a Left Scroll Tab (<) which will take the User back to the PLC Main Options Screen. To the right of that, is a GFI indicator, with a GFI reading and color coded status. If the color is Yellow, it means that the GFI was tripped. A GFI Trip will turn the Heat Trace off for that Circuit, and will require the Operator to manually reset the Circuit by selecting the ‘GFI OK’ in the Configuration Screen. Finally, at the bottom of the Circuit Monitoring Screen are 3 windows with Amperage information for the Circuit: Amps Expected, Amps Alarm Set-point, and Actual Amp Reading.

In the lower right corner of the screen is the Alarms Beacon which in Figure 23 is showing Blue, indicating there are no Active Alarms on the System. This Icon is not specific to a Circuit or a screen. Any Alarm, on any Circuit, will change the Icon from Blue to Yellow / Red.

6.1.4 Alarms

By selecting the Alarms Beacon on any PLC screen, the Groups with Pending Alarms screen is accessed (Figure 24). This view shows the Alarms that are Active and have not been Acknowledged by the Operator, across all Circuits being monitored. After an Alarm has been Acknowledged and Resolved it will only be accessible through the Alarm History Tab of the CMI-Data Web Page, which is discussed later.

Figure 24: Groups with Pending Alarms

The Groups with Active Alarms Screen (Figure 24) shows 4 Rows of Pending Alarms information, one for each of the 4 Groups of Alarms. Each Row of information shows the Alarm Group ID, a Reset Tab, the number of Pending Alarms in the Group, the Alarm Group Name, and a Red Magnifying Glass Tab, which, if selected, will take the User to Figure 25, the Alarms in Group Screen. The Reset Tab in each Group ID row is used to clear Alarms that have been Acknowledged and Resolved.

The Refresh Tab at the lower left corner will refresh the view to add any new alarms in the groups shown or add other Groups with alarms that may have developed while monitoring this view. The ESC Tab in the upper right corner of the Screen will take the User back to the previous screen viewed.

The first Row of information in Figure 24 is for Alarm Group ID 01, the Serial Communication Alarm Group, and shows that there are 2 Pending Alarms. The Red Tab at the end of the row opens the Alarms in Group Screen, shown in Figure 25.

Figure 25: Alarms in Group Screen

There are 2 Rows of information in Figure 25, one for each Pending Alarm. Each row shows the Alarm ID, the Time it was Initiated (Time On), whether it has been Acknowledged, the Alarm Name, and a Red Magnifying Icon Tab, to drill down even further, into the Alarm Detail Screen. The alarm detail screen will show the time that the alarm occurred, and what specific alarm it was, i.e, amperage alarm.

6.2 Web Page

Figure 26 is a screenshot of the PLC Web Page. The web page consists of only one screen, with one pop up sub-screen, which will be discussed shortly**.** The page shows all circuits that have been configured for a given site.

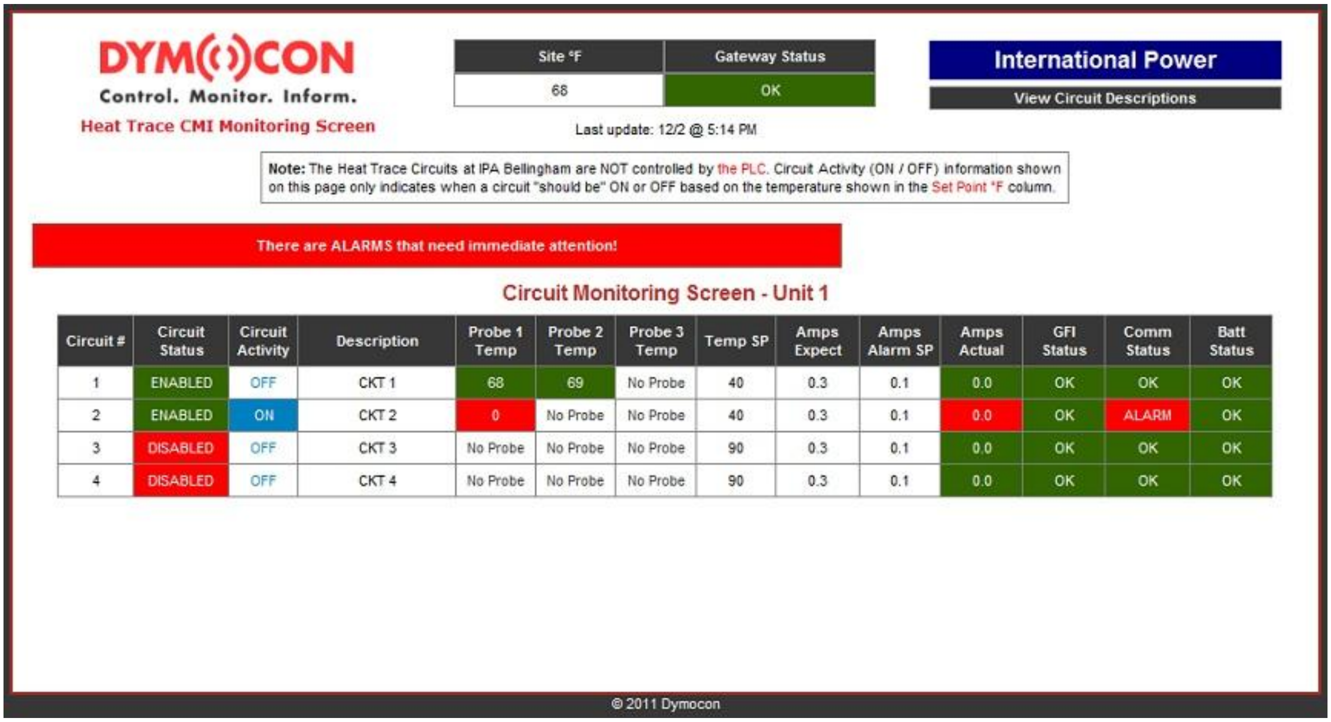

Figure 26: PLC Web Page

The screenshot demonstrates a 4-Circuit Unit, with some active alarms. Readings that are highlighted in Red signify an alarm. At the top, you will find basic information, starting with the logo on the left, then ambient temperature to the right, followed by the Gateway Status (whether or not the Gateway is communicating with the PLC), and then the pop-up sub-screen labeled "View Circuit Description". If you click on that box, a small screen will appear with a table of each circuit name and probe name. This pop up screen is intended to save the user some time, in case they forget the name of a specific probe. Moving down, you will find a small note reminding the user that the panel is not in control of the heat trace yet, by request. Below that, is a red alarm indication box; this box disappears when there are no active alarms.

Below the alarm box, you will find the monitoring screen table. The first column simply states the circuit number. The second column states whether the user has Enabled or Disabled a circuit; the user may disable a circuit to forcefully stop all of the output coming from that circuit (even if the conditions call for power), however, alarms will still be active during this time. The third column is called “Circuit Activity” and simply indicates if our *CMI Module* is trying to turn a heat trace circuit on (for example, in the screenshot above, Circuit 2 has a temperature below the set point, so it is calling for power to turn that heat trace ON, as opposed to Circuit 1, which has a temperature above the set point, and does not need to call for power to turn the heat trace on). The Circuit Description is simply the name of the circuit. The 3 ‘Probe Temperature’ columns either list the actual temperature, or will say “no probe” if there was nothing configured at that location. If a Probe Temperature cell is highlighted red, this means it is either below the ‘cold’ set point, or above the ‘high’ set point; note that if the reading is directly on the set point, it will still activate an alarm. Also, if a transmitter has lost communication, the reading will fall to 0 degrees, as demonstrated in the screenshot above, in Circuit 2. ‘Temperature Set-point’, ‘Amps Expected’, and ‘Amps alarm Set-point’ are self explanatory; note that ‘Amps Expected’ does not affect any alarm conditions and is there only for user comparisons. ‘Amps Actual’ will turn red into an alarm state when 2 conditions are BOTH met: Actual Amps are below (or equal) to Amps Alarm Set-point, AND the Circuit Activity is ON, meaning that the *CMI Module* is trying to power a specific heat trace circuit. GFI Status will remain OK until a GFI reading rises above the set point, which is defined by the user in the Configuration Screen of the PLC. ‘Comm’ and ‘Batt’ Status represent the communication and battery status for the wireless transmitter of each circuit. If the transmitter loses communication to the Gateway, an alarm will occur (as showed in Circuit 2, above), and if the Battery of the transmitter drops below 3 volts, its cell will turn red as well, signifying that the transmitter batteries need to be replaced. Note that the batteries are meant to last 5-7 years.

6.3 Historic Web Site

Customers are given a web address, user name, and password. They may log into the Historic Web Site and view data based on user-speficied time intervals. Each tab of the CMI-Data Web Page has a set of straight-forward instructions and is easy to navigate through. The first step is to click on “My Solutions” and choose from a drop down menu, the Plant for which you would like to see historic data. Once you have set that as your active solution, you may begin viewing your data. The most basic way to view your historic data is via the “Raw Data” page, shown in Figure 27.

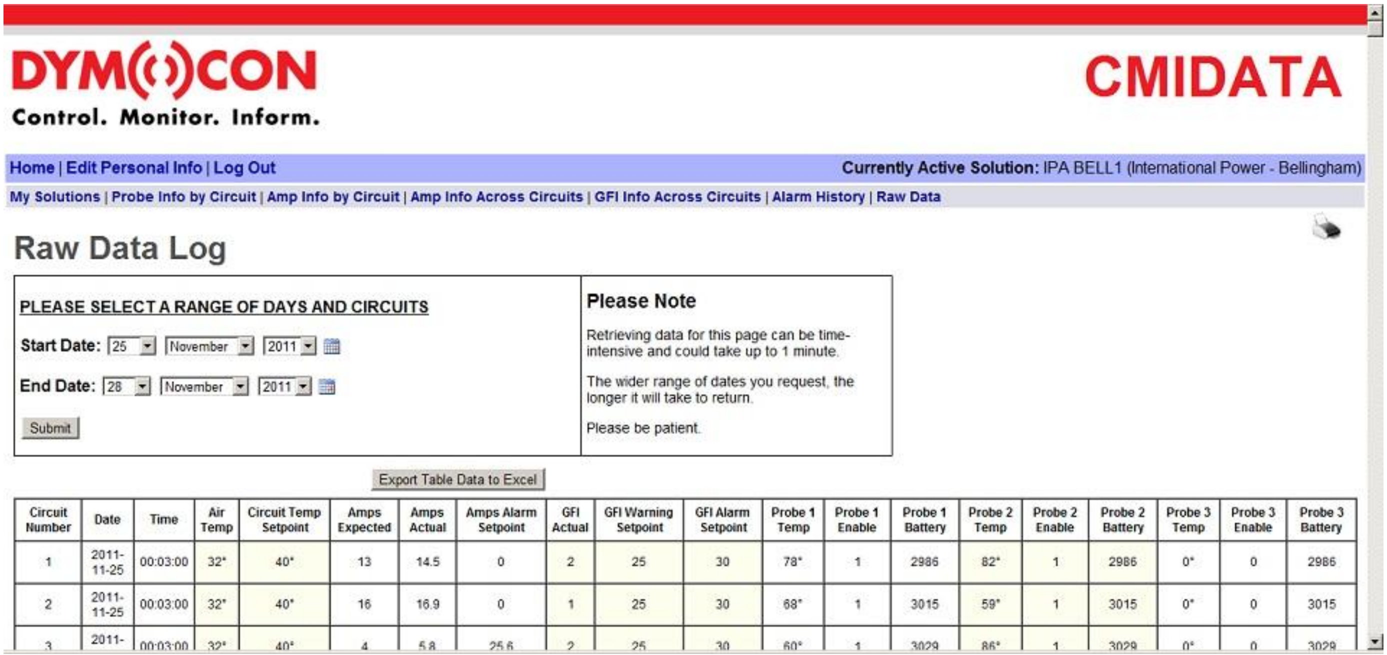

Figure 27: CMI-Data Raw Data Tab

In this tab, you simply select the date range you want to view, and then click "Submit" to view all of the data for that time period.

The Alarm History tab works in the same way as the Raw Data, in which you select a time interval, and it shows you what alarms occurred in that range, and on what circuit / probes they triggered, as shown in Figure 28.

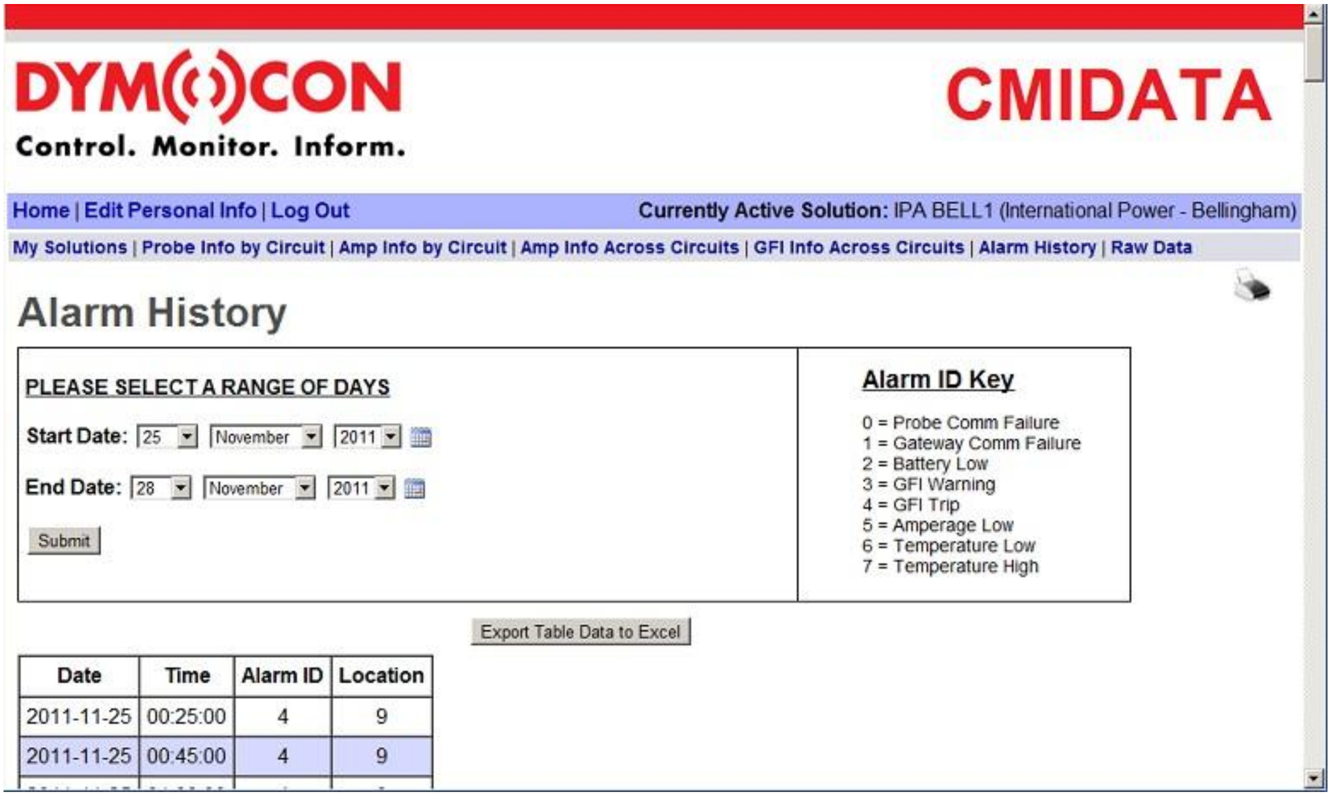

Figure 28: CMI-Data Alarm History

For every Battery or Probe Communication Alarm, the location will be the Probe ID of the first probe of that circuit. So, for example, if the battery was low on Circuit 2, the location of that alarm would be 4, since the first probe of Circuit 2 has the ID of 4. This was designed due to the nature of the mesh network. Every other alarm, aside from Battery and Probe Communication, will have an alarm location specific to its circuit.

The remaining tabs, Probe Info by Circuit, Amp Info by Circuit, Amp Info Across Circuits, and GFI Info Across Circuits, have the same data as the Raw Data tab, except they automatically create graphs of the data, which can be used for trending and analyzing. Just as the other tabs, the user inputs time ranges and then clicks submit.

6.4 Building a Test Environment

To accurately test this MQP module, we had help from the sponsor's electrician to build a test panel. This was a four circuit panel, with all of the components that would be present in an actual plant panel. The electrician built a device that attaches to the top of the enclosure, with four light bulbs, representing four heat trace lines. When the PLC was intended to turn a heat trace circuit on, it would turn on the associated light bulb. A GFI device was also created, to trip the GFI alarm of a specific circuit. The test enclosure weighs less than 50 pounds and is mobile, which is good for demonstrating purposes, as well as testing.

All of the stress test results were successful. Every alarm was triggered, and the outputs were activated properly. A complete log of the stress test is in Appendix G.

Chapter 7 Conclusion

The Monitoring & Control Solution MQP has successfully built an all-in-one module to manage heat trace systems. Power plant customers who install this module will benefit from decreased energy costs, as their heat trace will only be turned on when needed, which also equates to longer heat trace life. Customers will also be alerted immediately when their heat trace is not functioning properly, and can pin point the problem before it escalates. Customers will be able to monitor their entire heat trace system with a single, color-coded, web page. Furthermore, every data reading will be saved and logged into the sponsor's database, for the customer to analyze and trend at their convenience.

A test panel has been created, with real equipment and live readings. The module passed every stress test possible, which was designed to simulate on-site situations with real alarms. The same test panel was used for the MQP demonstration. Temperature, amperage, and GFI readings were all accurate, and the PLC output was triggered successfully. The panel was actively monitoring and controlling for over a week without any problems.

7.1 Possibilities & Limitations of Change

The Unitronics PLC that we are using now does have some limitations for future expansions. As of now, it monitors and controls 20 circuits. Most of the memory locations are being used with the current software. To expand the number of circuits, two PLCs would have to be used simultaneously. Another option would be to use a more expensive PLC, such as one from Alan Bradley, however, the cost would much higher, and the software would have to be re-written.

There are other types of industrial readings that this module may be able to monitor. Monitoring vibration can be useful, especially when monitoring important machinery. As stated before, due to the constraints of the current PLC, to add another variable such as vibration, the software would have to be modified and most likely delete one of the core readings, such as amperage, to free up space. Pressure is another possible reading that may be of value, for example, in oil tanks or under water vessels.

7.2 MQP Experience

This MQP gave me the opportunity to manage an Information Systems project, from start to finish. I learned the importance of retrieving and outlining customer specifications throughout the planning phase of the project. This helped me proceed to the design phase with a defined set of requirements and objectives. Communication with the customer and project sponsor was also critical during the early phases to avoid back-tracking later on. I also learned that software glitches are common in most new programs, and planning extra time for trouble-shooting is necessary for success.

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Glossary

Current Transducer (CT): A device that is installed around an electric wire, measuring the amount of amperage coming from it. It then sends out a 4-20 milliamp signal representing the amperage amount.

Enclosure: A protective box housing, made from plastic or metal, and usually weather proof.

Gateway: There are many different types of gateway, but for the purpose of this project, a gateway is a master device, which wirelessly communicates with a series of transmitters.

Ground Fault Interrupter (GFI): A device used to protect equipment from electric surges. It powers down the equipment when milliamp (mA) readings become too high. A 'GFI Reading' is simply a reading of the mA value. Through the use of CTs and PLC I/Os, this solution will have the functionality of a GFI, among other things.

Heat-Trace: A thermal cable that produces heat after receiving electric current. Heat-Trace is usually wrapped around an object to keep it from freezing, or to keep it at a desired temperature.

Heat-Trace System: A series of heat-trace cables, installed at various locations, which all connect back to one power source, or breaker box. Heat-Trace Systems are used at power plants, to keep various machines and pipes from freezing.

PLC Input/Output (I/O) Units: Physical devices, which are directly wired to the PLC, which can receive or send electric signals to outside devices.

Power Supply: A device which distributes electric current to multiple other devices.

Programmable Logic Controller (PLC): A mini computer with an attached touch screen that gathers inputs and controls outputs. Modern PLCs also have networking functions, discussed under Chapter 2.2.3

Relays: Devices that act as a power switch, between a power supply and another device. They can either allow power to reach the desired unit, or not allow power to reach it, based on the signal given to it, which in this case, comes from our PLC I/O Units.

Resistance Temperature Detectors (RTDs): Thermal devices that measure temperature and report it via attached wires, which do not require power.

Transmitter (or Node): A device which collects data, and wirelessly sends it to the gateway.