Industrial Control Systems MQP

Sponsored by Babcock Power Services

Worcester Polytechnic Institute

Department of Electrical and Computer Engineering
Major Qualifying Project

A Major Qualifying Project
submitted to the Facility of
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ABSTRACT

The Industrial Control System MQP is sponsored by Babcock Power Services (BPS) and aims to create the logic and HMI screens used to control the burner management system of an industrial waste-to-energy boiler.

Main Project goals:

1.) Create & Standardize Burner Management System for Municipal Solid Waste (MSW) stoker. A complete system following National Fire Protection Association (NFPA) standards.

2.) Develop Boiler Control System using Rockwell Automation’s Logix Designer program.

3.) Design Human Machine Interface (HMI) screens using Rockwell’s Studio 5000 Design Software.

4.) A fully validated control system can be packaged for sale to industrial customers by BPS.

ACKNOWLEDGEMENTS

We would like to thank Babcock Power Services for sponsoring this MQP, Professor Gregory Noetscher for encouraging us to ask the right questions, the WPI IT team for all the troubleshooting and server repairs, and Diego Mier-Casares, Bob Pierson, and Vijay Parekh of Babcock Power Services for their knowledge and guidance in boiler control systems.

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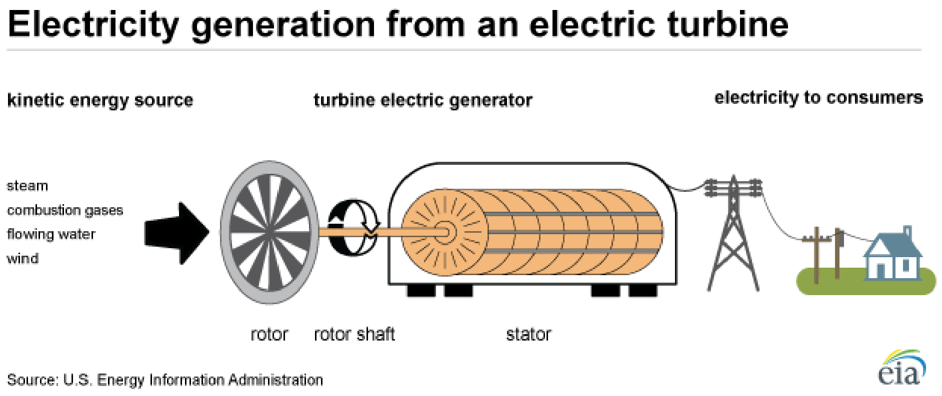
CHAPTER 1: Introduction

Do you know where your electricity is sourced? According to the U.S. Energy Information Administration (EIA), steam turbines accounted for ~42% of total U.S. electricity generation in 2022 [1]. Steam turbines are a critical aspect of the world's electricity generation and can utilize many different sources of energy to produce electricity. The most common setup includes a boiler that heats up water until it is turned to steam that would be used to push the blades of a rotor to turn the rotor shaft and generate electricity within the stator. A diagram from the EIA website showing this process can be found in Figure 1.



Source: U.S. Energy Information Administration

Figure 1: Electricity Generation from an Electric Turbine Diagram

The water-to- steam portion of this process involves a heat source and a boiler. Energy sources such as coal, natural gas, biomass, and more can be used as the main fuel for heating the water. An energy source of interest is the Municipal Solid Waste (MSW) Plant. MSW plants take garbage and other discarded materials to produce energy by burning them and heating up water to create the steam that will eventually move a turbine. Many different types of waste can be used in an MSW boiler; both biomass materials such as paper, food waste, and grass clippings and nonbiomass combustible materials like certain plastics. In 2022 there was a recorded 292 million tons of waste produced in the United States. Out of all this waste, only 12% is used for energy recovery processes while 50% is placed in a landfill [2]. There is room for expansion of these types of boilers in the US to eventually create mass amounts of power that must be handled following all safety standards.

The control system of any power plant is key to efficiently and safely handling the mass amounts of power generated by the system. The control system is operated by a certified controls operator, whose job is to start up the boiler, open and close specific valves based on sensor readings, and turn off the boiler. Sensors measure important information such as temperature, pressure, water levels, and fuel levels. If these measurements go above or below a certain threshold deemed unsafe, either the operator or the control system must take the necessary safety steps to eliminate a potential operating problem. This could be, for example, opening or closing a valve to halt the flow. If these safety measures are not taken, given the amount of electricity and power flowing through the system, the result could be dangerous for the operators and surrounding areas [3].

1.1 Project Objectives

A set of objectives for this Major Qualifying Project (MQP) was created and assigned to our team. Below is the list of objectives.

1. Develop & Standardize a Burner Management System (BMS) for NG or Oil (HFO & LFO) or Coal (PC) or MSW stoker or any combination fired boilers. A complete system following NFPA regulations.
2. Develop a Boiler Control System using Rockwell Automation's Studio 5000 Design Software. The Logix Designer allows for designing and configuring a Logix project. Logix Emulate allows running the Logix program in a virtual environment. View Designer also allows developing HMI screens.
3. Verify and Validate (V&V) existing control system.
4. Verify and Validate (V&V) controls design.
5. Develop non-real time, low-fidelity simulator to validate the control loops – to be run on the virtual platform offered by Studio 5000.
6. A fully validated control system can be packaged for sale to industrial customers. It can be branded and launched as a new product line from BPI.

1.2 Project Deliverables

Along with a set of objectives, Babcock Power also created a list of expected deliverables that highlights the process they wish to proceed with for the MQP. Below is the list of deliverables.

1. Identify and assign project – process (type of boiler, fuel system etc.).
2. Develop Pipping and Instrumentation Diagrams (P&ID) & Input and Output (I/O) List.
3. Develop Control Narrative.
4. Develop Logic Diagrams and assign I/O points.
5. Develop low-fidelity simulation program to facilitate checkout on virtual platform.
6. Commence Programmable Logic Controller (PLC) programming (for the process controls and the process simulation)
7. Develop HMI screens (for both the process controls and the simulation).
8. Download the PLC programs on the virtual controller.
9. Commence PLC configuration and loop checks.
10. Conduct internal control system check-out.
11. Conduct Factory Acceptance Test (FAT) with BPS and WPI – at this point it is a final product.

CHAPTER 2: Background

2.1 Babcock Power Services

Babcock Power Services (BPS) is one of the many sub-companies of Babcock Power Inc. (BPI) that work together to be the one source for many power system solutions. BPS is the leading service provider for utility and industrial power plants worldwide. Known for their comprehensive solutions in power generation and energy services, BPS is recognized for its expertise in natural circulation steam generation, low-NOx burner systems, and emissions control. Being a part of the Babcock Power Inc. family of companies, BPS has access to numerous manufacturing facilities throughout the USA that are certified by the American Society of Mechanical Engineers (ASME) and meet the latest code standards. Given BPS' 90 years of engineering expertise, they are prepared to assist with any manufacturing, construction, maintenance, or upgrade needs for all boiler and boiler-related equipment and service needs. Through its commitment to advancing technology and addressing the energy challenges of the 21st century, Babcock Power Services plays a vital role in shaping the future of power generation and ensuring a reliable and sustainable energy supply for customers around the globe [4].

2.2 Boilers

Boilers are an essential component of the greater power grid and produce 45% of all power generated in the United States [5]. Boilers produce energy by burning fuel, which generates the heat needed to boil water and make high-pressure steam. This steam is then piped to a turbine generator which spins, producing electricity. Most boilers operate in this way, however, there are many diverse types of boilers that burn different fuels in unique ways. The following sections go into greater detail on the inner workings of boilers as well as more specifics on municipal solid waste boilers and their control systems.

2.2.1 Boiler Fundamentals

As illustrated below in Figure 2, all boilers, no matter what fuel they burn or how they operate, are comprised of two key sections: the waterside and the fireside. The waterside of a boiler, shown as the top section in Figure 2, is responsible for piping water through and around the furnace, where the fuel is burned, to collect the heat energy given off by the burning fuel to convert the water to steam. The key input of the waterside is therefore water while the key outputs are steam as well as blowdown water. Blowdown water is water that has increased conductivity due to an increased concentration of minerals after repeated cycles through the system and repeated evaporation. Increased conductivity can lead to increased corrosion in pipes, so boiler systems blow out and replace water as needed.

The fireside, shown as the bottom section of Figure 2, is where fuel is mixed with air and burned in the furnace to produce heat. The fuel used can be anything from natural gas to solid waste. Fuel and air are the key inputs of the system's fireside which, when burned, produces the heat for the waterside, flue gas, and ash. Ash is carried out through the stack by the exiting flue gas and collected in ash hoppers and filters. As the flue gas moves out through the stack, various heat-exchanging components are utilized to harvest its heat to warm up incoming water and air. These heat exchangers, along with other components, increase the efficiency and operation of the boiler. Before exiting the boiler facility, flue gas moves through scrubbers and selective catalytic reduction devices to reduce the impact of the flue gas particulates on the environment [6].

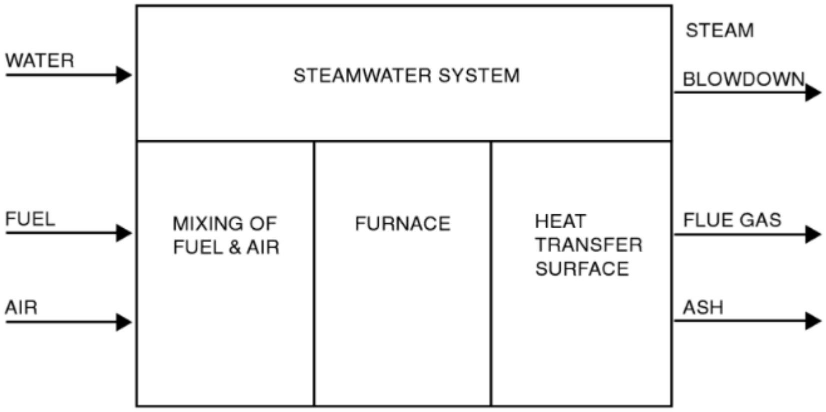


Figure 2: Fundamental Boiler Diagram [6]

In addition to the basic components of a boiler, there are secondary components added in the design to improve efficiency through heat transfer, such as superheaters and economizers. Superheaters provide additional heating to the steam to ensure no moisture is present within the steam. The removal of moisture from the steam ensures optimal steam flow to the turbine. Economizers are used to reduce the energy lost in the expulsion of hot flue gas by using this heat to raise the temperature of feed water.

2.2.2 Municipal Solid Waste Boilers

In municipal solid waste (MSW), or waste-to-energy, boilers, biomass such as trash/waste is burned to create the fireside heat necessary to generate steam. In this process, the waste is burned on the stoker which gradually shifts the waste like a conveyor belt towards the ash hopper, while giving the burning waste ample air and time to burn out. The volume of the waste is significantly reduced after burning, leaving behind only ash. In addition to the creation of electricity, the reduction in waste volume is one of the supplementary positives of MSW boilers for a community. [7]

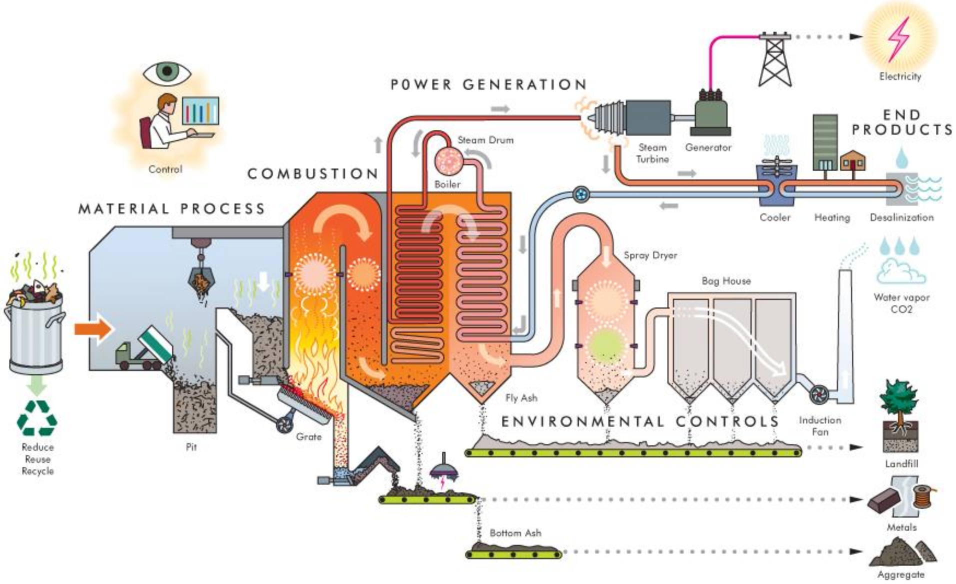


Figure 3: Municipal Solid Waste Boiler Diagram [8]

Figure Figure 3 displays the general process of MSW boilers. The recycled material goes through processing before combustion, which is where the steam is created, and then the steam is used for power generation by spinning a steam turbine connected to a generator. The steam, after it is used to create electricity, enters a condenser, and then recycles back into the boiler process. This entire system uses monitoring and controls to continuously check compliance with air quality standards and to optimize efficiency with the burners [9].

2.2.3 Burner Management Systems

A key component of all boilers is the burner. Without the burner, the system would be unable to ignite the fuel to begin the operation of creating steam and generating power. In the case of municipal solid waste boilers, the burner is still needed, however it is not what is used to primarily generate power. As seen in Figure 3, the furnace has two main parts, the stoker and the auxiliary burners. The auxiliary burners are used during startup to get the furnace to the optimal temperature for burning MSW. Once the furnace has reached its optimal temperature the stoker is used to burn the MSW and produce electricity while the auxiliary burners are kept on only to regulate the internal temperature of the furnace.

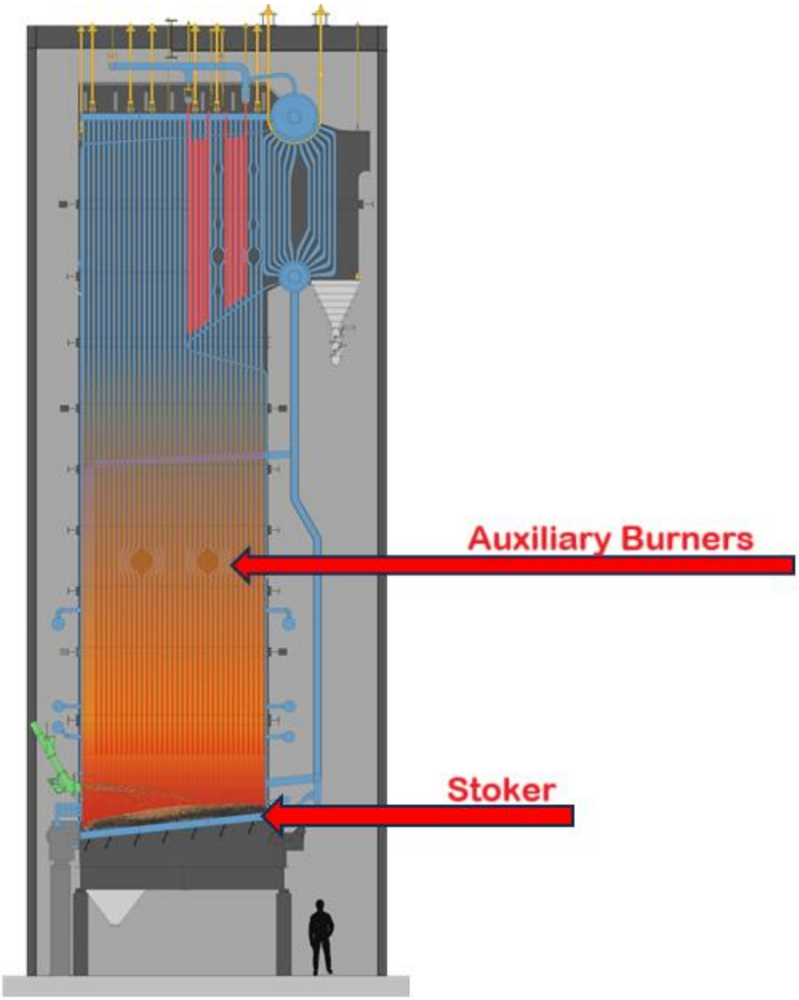


Figure 4: Municipal Solid Waste Furnace Diagram [10]

The Burner Management System (BMS) controls the operation of the auxiliary burners and ensures proper start-up and shutdown procedures and emergency trips. The BMS is therefore tied to the controls of the boiler and monitors relevant input and output conditions to maintain safe operation. This includes feed water flow rate, steam flow rate, fuel flow rate, air flow rate, final steam temperature, and final pressure. In addition to this, the BMS also must oversee the purging of the burners and flame detection to ensure seamless operation with no risk to boiler and operator safety. The BMS is also responsible for presenting all relevant data to the operator.

2.3 NFPA 85 - Boiler and Combustion Systems Hazard Controls

The National Fire Protection Association's codebook *NFPA 85 - Boiler and Combustion Systems Hazard Controls* is used as the standard for several diverse types of boilers and steam generators that have a fuel input rating of 3.7 MW or higher. NFPA 85 covers the design, installation, operation, and maintenance of these boilers to ensure safe operation for both the worker and the environment. The large scope of NFPA 85 means that the codebook is broken up into several different sections to make looking up standards easier for any type of boiler. [11]

For municipal solid waste boilers, chapters 4, 5, and 10 of NFPA 85 are particularly relevant. Chapter 4 of the NFPA discusses the fundamental operations of boilers in general. Within burner management logic is discussed with key standards on interlocks and alarms and standards for the control system itself, ensuring it is protected from unwanted exterior influences. Along with this, chapter 4 introduces proper combustion control systems requirements and important display information for operators. Chapter 5 dives further into the burner management systems and gives clear standards for potential system bypasses and the integration of boiler and burner control systems in one application. Chapter 10 builds off the previous chapters by going into greater detail on specifics for municipal solid waste boiler systems. This chapter goes over the processes employed by a municipal solid waste boiler including the various starting procedures, operation requirements, and shutdown occurrences.

2.4 Rockwell Automation's Studio 5000 Logix Designer

Rockwell Automation's Studio 5000 Logix Designer is a design software that allows for the construction and implementation of control systems.

2.4.1 PLC Programming

At the heart of all modern-day control systems are programmable logic controllers (PLCs). PLCs are the brains behind these control systems and allow them to function through user written logic. Studio 5000 allows for the programming of PLCs which can be done through a wide variety of languages, one such being the very popular ladder logic [12]. Ladder logic is a visually intuitive way to program PLCs as it is structured like a ladder with a series of rungs. Each of the ladder's rungs will have their own programmed function, with the left side being the input logic and the right side being the output logic. As the controller reads from left to right, it checks if it can pass a figurative "current" through the input logic to the right-side output. If the input gates allow for the "current" to pass, the output logic will be altered depending on the programmed outcome. Once the first rung is read, the rung directly below will be read and so on, going from the topmost rung to the bottom most rung. After the controller reads the bottom most rung it will go right back to the topmost rung and loop continuously.

Shown below in Figure 4 is a simple ladder logic program with press start and stop buttons that control a motor. The PLC program uses two different types of input gates, an output gate, and a branch within the rung. The first gate is an examine if closed [XIC] gate which is controlled by the variable "Start_PB". The variable "Start_PB" contains a Boolean tied to the start button which, when pressed, sends the Boolean high. When the Boolean is high, the XIC gate closes and allows for the "current" to pass through. The next input gate is an examine if open [XIO] which is the inverse to the XIC gate. This XIO is controlled by the Boolean variable "Stop_PB" which is tied to the stop button. When the stop button is pressed, the Boolean will go high and the XIO gate will open, stopping any "current" from passing through. Next is the output energize [OTE] gate, which controls the variable "MotorContactor". If current can move through the rung to the OTE gate, then the variable "MotorContactor" will go high. If not, the variable will go low. Finally, there is a branch parallel to the "Start_PB" XIC gate with the XIC gate controlled by the "MotorContactor" variable. Like electrical circuits, if either gate is closed then current will be able to pass through to the other side. Similarly, if both gates are open, no current will be able to pass through to the other side.

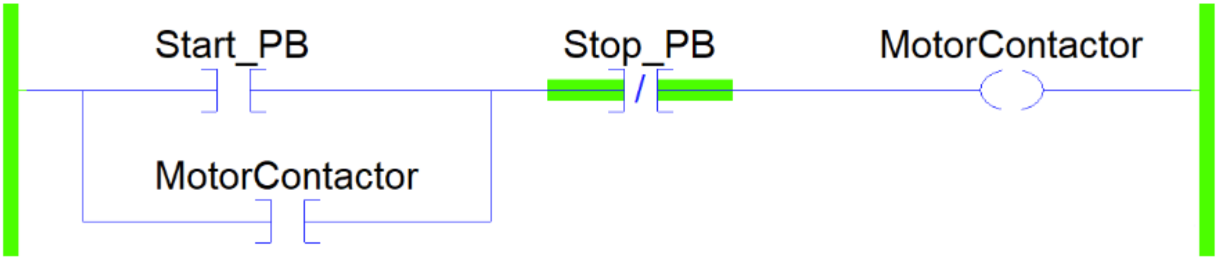


Figure 5: Ladder Logic Example [12]

As an example use case, consider the motor initially off and no buttons are pressed. Pressing the stop button will not affect the motor at this point but pressing just the start button will cause the XIC gate controlled by "Start_PB" to go high and current will be able to flow and cause the variable "MotorContactor" to go high along with its respective XIC and OTE gates. At this point, pressing the start button will not affect the motor running, and this motor will continue until the stop button is pressed. Once the stop button is pressed, the "Stop_PB" Boolean will go high and the XIO gate will close. With this, the variable "MotorContactor" will go low along with its respective XIC and OTE gates and the motor will stop.

2.4.2 Rockwell Automation's Studio 5000 View Designer

Along with Rockwell's Logix Designer, the View Designer is also included in Studio 5000. View Designer is used to create Human Machine Interfaces (HMI) that will be used by an operator to utilize the logic control systems created in the Logix Designer. [13] Having the ability to create both logic systems and the HMI screens from a single software program allows for seamless integration between the two designers and therefore is more efficient than using different software to accomplish the same goal. View Designer also includes a vast library of scalable graphics that can easily be used to create HMI screens along with a default set of screens that are editable to the user's preference. Using animated graphics, the operator can easily identify a change based on the data being read from the logic control system. View Designer can use tags created within Logix Designer to reference a specific data point quickly and easily on an HMI screen. This ensures that the data being displayed on an HMI screen is the desired data point being read by the control system and multiple tags are not used to read the same data point. [14]

2.4.2.1 Human Machine Interface Screen Design Considerations

One of the primary ways an operator interacts with a boiler is through a Human Machine Interface (HMI) screen. The interface's primary purpose is to allow the user to view relevant data and control the system based on the data. Since it is crucial for a power generation plant to operate without flaws, an easily understandable and straightforward HMI screen is critical for preventing any malfunction or operating mistake. When designing an HMI screen, there are a few key aspects to consider: color, layout, and labeling. [15] [16]

Color is used in HMI screens to quickly display information. The International Society of Automation (ISA) works to set standards for certain aspects of the automation industry to decrease confusion between systems. The ISA 101 standard states that HMI screens should maintain a mainly monochromatic color scheme with limited color use. Color should mainly be used for alarms or items that require immediate attention. This allows the operator to easily identify the areas that require attention since they will stick out due to the use of color. When designing HMI screens, one must be careful not to use too much color, as this may cause an operator to miss a crucial alarm buried in a busy and colorful screen. [17]

2.5 Acceptance Tests

2.5.1 Factory Acceptance Test

The Factory Acceptance Test (FAT) is a test that ensures the quality of a part or product and compliance with the customer's requirements, standards, and specifications. This test is normally done on newly manufactured equipment before delivery. In the case of control systems, the system is virtually tested against the desired boiler/system in all possible test conditions to ensure that it accomplishes its intended purpose. A FAT is done before the Site Acceptance Test (SAT), which is completed at the customer's site and ensures proper integration of the product. [18]

2.5.2 Site Acceptance Test

The Site Acceptance Test is completed after the FAT when the product reaches the site. This test is completed to ensure that the product is fully integrated and working properly for the customer. This last step is important as it requires calibration and training of the operators to use the product correctly. A misstep in this test could result in faulty equipment that the manufacturer could then be liable for due to incorrect installation. [19]

CHAPTER 3: Methodology

3.1 Gantt Chart

To ensure the completion of this project in the limited time allocated, the Gantt Chart presented in Appendix A was developed. This chart details the weekly goals that must be achieved to complete the project on time and the termly projected milestones.

3.2 Burner Management System P&ID Review and Operating Sequence

For the burner management system to be developed, the system's piping and instrument diagram (P&ID) and operating sequence must be reviewed. The P&ID establishes the base line of what the burner management system will be in control of, showing every relevant valve and sensor as well as their locations. The figure below is the P&ID of the pilot and burner natural gas headers. In this figure we can see that each header has both a safety shut off valve, shown as FV-4757 and FV-4759, and vent valve, shown as FV-4756 and FV-4758, so we know that those valves must be implemented into the final code along with their safety features. To properly implement what is present on the P&IDs, an operating sequence is needed. The operating sequence covers the entire scope of the burner management system, citing the various requirements for burner operation, the vast array of trips and alarms, and most importantly the start-up and shut down process of the burners and their pilots. With an understanding of the key components present in the P&ID as well as how they will operate with one another, the coding for the burner management system can be accomplished.

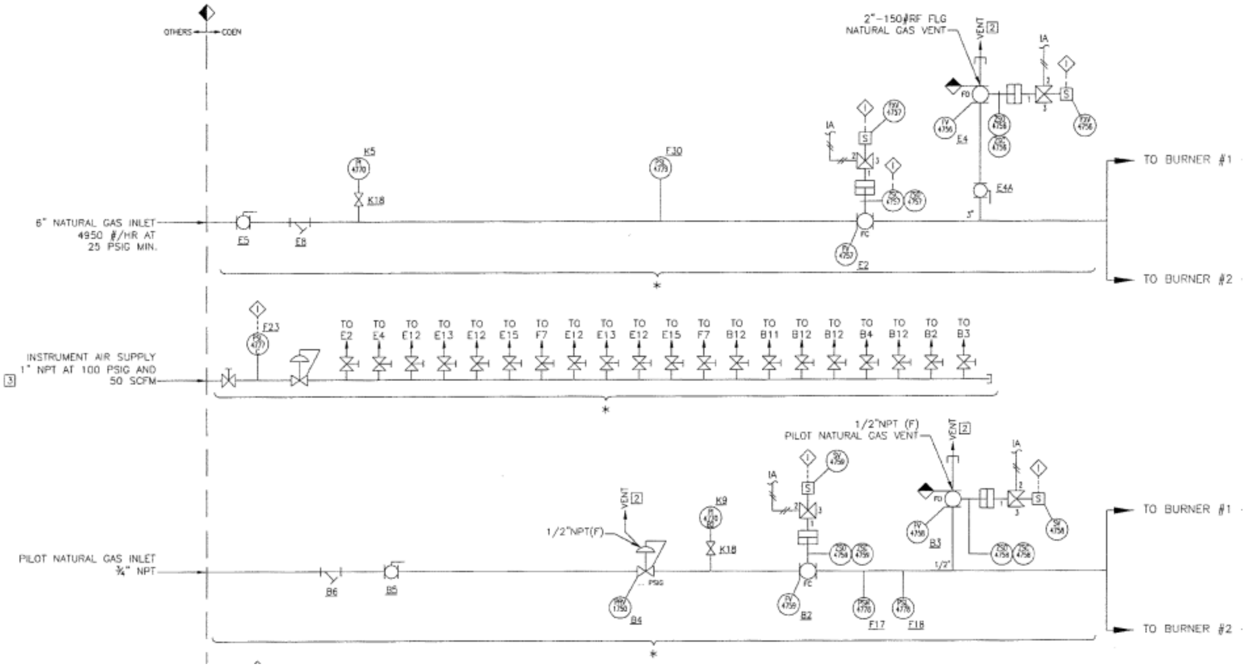


Figure 6: Burner and Pilot Natural Gas Headers P&ID

3.3 Studio 5000 Coding

3.3.1 Natural Gas Safety Shutoff and Vent Valve Implementation

As described above the first step to developing the burner management system is implementing the code for all the natural gas safety shutoff and vent valves. A review of the P&ID shows that each individual burner and pilot is fed by a main set of header valves. The header valves for the pilot and burner are oriented in the same way with first a safety shutoff valve followed by a vent valve. This can be seen in the figure below with the pilot header safety shutoff and vent valves denoted as FV-4759 and FV-4758, respectively, and the burner header safety shutoff and vent valves denoted as FV-4757 and FV-4756, respectively. Both the safety shut off and vent valves have a default state which occurs when they are not receiving a signal. The safety shut off valves for this system are all defaulted to close while the vent valves are all defaulted to open. Next, the individual pilot and burner valves can be denoted. As shown in the figure below, the individual pilot and burner pipes are identical with first a safety shutoff valve followed by a vent valve then followed by a final safety shut off valve. This too can be seen in the figure below with the individual pilot safety shutoff valves being denoted as FV-4760A1, A2, B1, and B2 and the individual pilot vent valves being denoted as FV-4760A2 and B2. The individual burner safety shut off and vent valves are similarly denoted but with the prefix FV-4705.

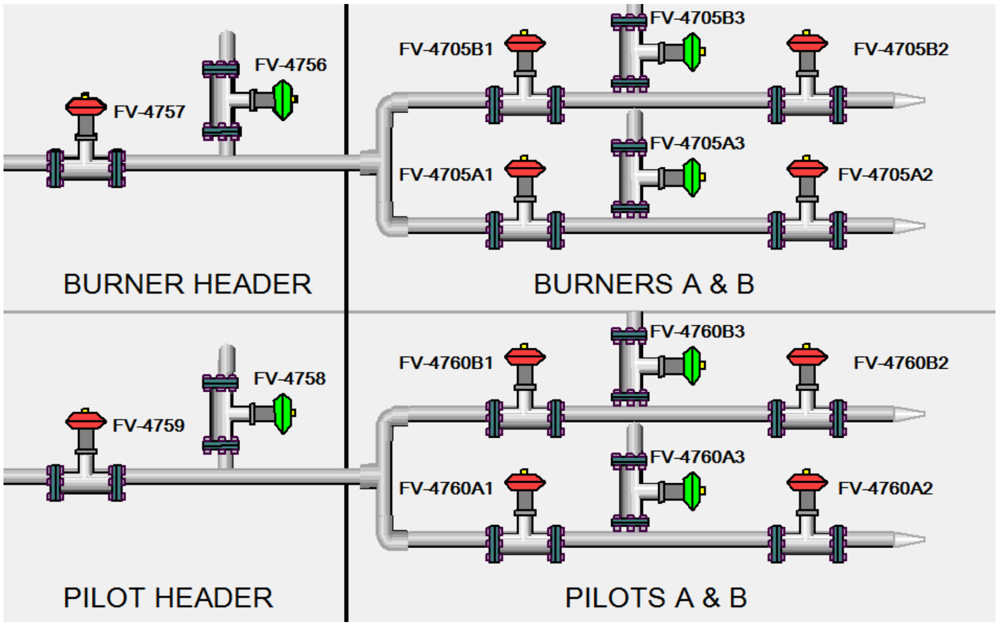


Figure 789: Pilot and Burner Natural Gas Piping Diagram

With the piping architecture described and each valve and its location understood, the valves can be coded into the program. For this, it is important to understand that vent valves and safety shut off valves differ in their default conditions. Safety shut off valves default to close while vent valves default to open meaning that the burner management system must signal to a safety shutoff valve to maintain open while it must signal to a vent valve to maintain closed. Without a signal from the burner management system, all valves will return to their default if applicable. The next step in implementing the valves is integrating their permits and trip conditions. For a valve to be controlled, the system must be running safely, and the valve should not be free to function if it is dangerous to the user. Shown in the figure below is a logic diagram for the basic valve permits required for a valve to operate. In the logic diagram, met conditions will generate a 1, while those not met will generate a 0. Additionally, circles in the logic diagram denote an inversion of the bit being output. If all permits return 1 to the AND gate, the valve can function. If at any point these conditions fail, the system will trip to ensure safety to the operator.

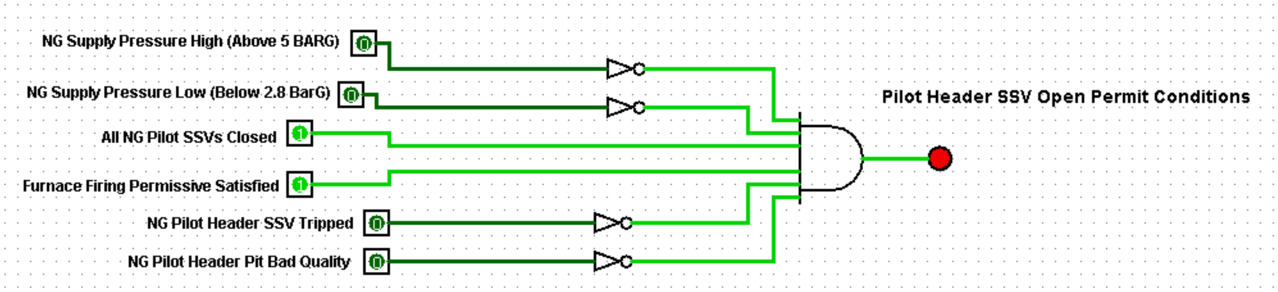


Figure 810: Pilot Header SSV Open Permit Conditions Logic Diagram

The next step in implementing valves is to ensure that the valves are operating properly beyond being permitted to function. Even when a valve can be opened or closed, a valve may fail to open or close due to an obstruction or system error. In these cases, the burner management system must detect the error and shut the system down to ensure safety. In this burner management system, whenever a valve is commanded to open or close, a ten second timer is started. If the valve fails to achieve the desired condition within this time, the system will trip. Additionally, in the case a valve signals it is both opened and closed, the system will also trip as this indicated another error.

Finally, it is important that all valves can return to their default condition in the case of a system trip or shutdown. As shown in the logic diagram in the figure below, if any such system trip occurs, a signal will be sent out. This signal commands all valves to return to their appropriate positions corresponding to the trip and is most important for ensuring the safety of the operator. The figure below shows the trips for the pilot header safety shutoff valve, but similar trips apply to all other valves.

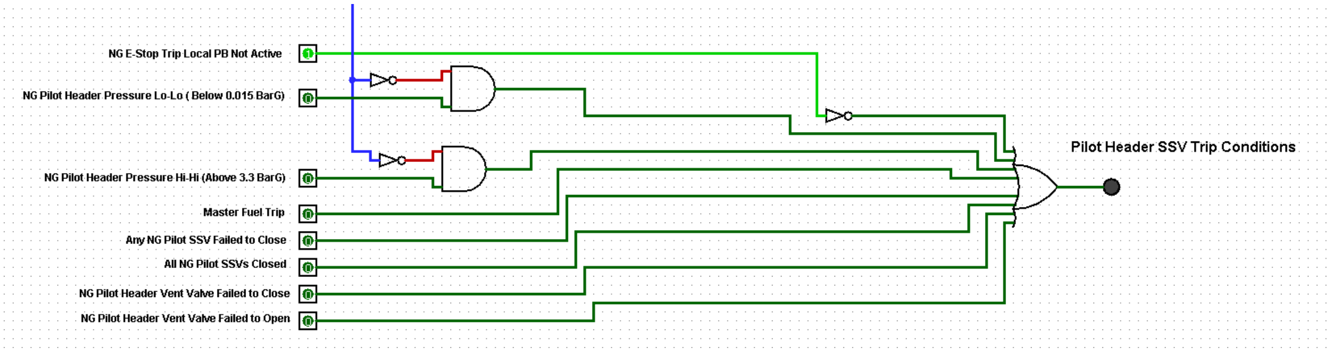


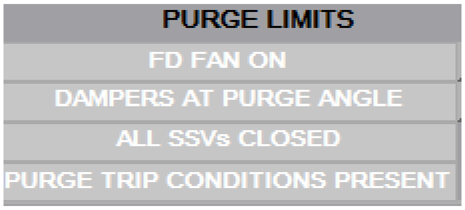
Figure 91112: Pilot Header SSV Trip Conditions Logic Diagram

3.3.2 Burner Management System Primary Burner Firing Sequence

With the pilot and burner valves integrated into the burner management system, the primary burner start-up sequence can be coded. To start up the first burner, the burner management system must go through three stages purging, pilot light-off and burner light-off.

3.3.2.1 Burner Management System Purging

The first stage in starting the primary burner is purging. To begin purging, the operator must press the “Start burner” pushbutton which will begin the purging sequence. Once the button is pressed, the purge limits shown in the figure below are verified by the burner management system. If the purge limits fail to meet following two minutes after the button is pressed, the purge will fail and the system will trip displaying “Purge Limits Failure.” If the purge limits are met within two minutes, the purge will begin and display “Purge in Progress.” The purge will last 90 seconds or until any purge limit is no longer met. In the case a purge limit fails during the 90 seconds, the purge will fail and signal “Purging Limits Failure.” If there are no purge limit failures during the 90 seconds, the purge will succeed and no longer display “Purge in Progress” but “Controls to Light-Off” as the primary pilot light-off sequence begins.

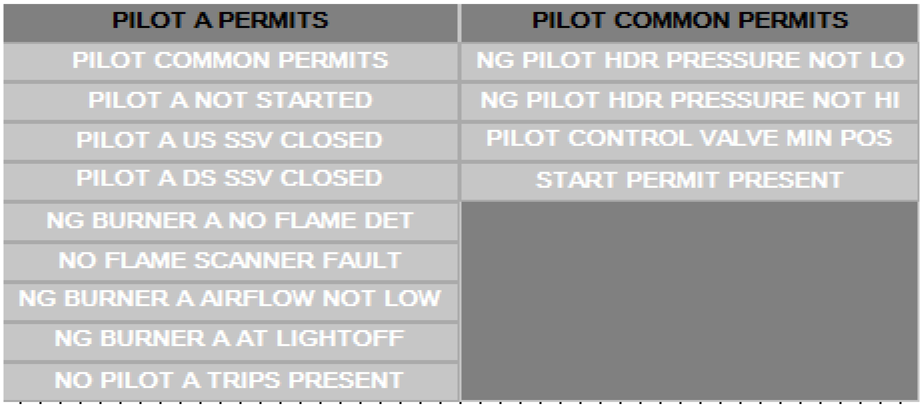


PURGE LIMITS
FD FAN ON
DAMPERS AT PURGE ANGLE
ALL SSVs CLOSED
PURGE TRIP CONDITIONS PRESENT

Figure 10: Purge Limits

3.3.2.2 Burner Management System Pilot Light-Off

Following purging, the primary burner firing sequence will enter the pilot firing mode. The burner management sequence will display “Controls to Light-Off” and the system will command the pilot header safety shutoff valve to open and vent valve to close. Once these valves are proven, a five second timer will start, after which the system will command the burner header safety shutoff valve to open and vent valve to close. With these valves proven, the burner management system will allow two minutes for all light-off limits to make. If the light-off limits fail to make in time or fail to be maintained prior to the primary burner being released to auto-modulation, the system will trip and display “Light-Off Limits Failure.” Shown in the figure below are the light-off limits expected by the system. If the light-off limits are made within two minutes the individual pilot safety shut off valves will be commanded to open, and the individual vent valve commanded to close. With these proven “Pilot Ignition in Progress” will be displayed to the operator.



PILOT A PERMITS	PILOT COMMON PERMITS
PILOT COMMON PERMITS	NG PILOT HDR PRESSURE NOT LO
PILOT A NOT STARTED	NG PILOT HDR PRESSURE NOT HI
PILOT A US SSV CLOSED	PILOT CONTROL VALVE MIN POS
PILOT A DS SSV CLOSED	START PERMIT PRESENT
NG BURNER A NO FLAME DET	
NO FLAME SCANNER FAULT	
NG BURNER A AIRFLOW NOT LOW	
NG BURNER A AT LIGHTOFF	
NO PILOT A TRIPS PRESENT	

Figure 11: Light-Off Limits

With “Pilot Ignition in Progress” displayed, the ignition transformer for the primary pilot will be energized for ten seconds. After the ten second ignition trial, the ignition transformer will de-energize and a five second timer will be run and the display will show “Pilot Proving Delay.” If the pilot flame fails to be seen by the flame scanner during this five second period, the system will enter flame failure shutdown. If the flame is still seen, the individual primary burner safety shut off valves will be commanded to open, and the individual vent valve commanded to close. With these proven, “Main Ignition in Progress” will be displayed to the operator and the burner light-off stage will begin.

3.3.2.3 Burner Management System Burner Light-Off

With “Main Ignition in Progress” displayed, a ten second timer will begin to prove main burner light-off. Following this timer, all pilot safety shut off valves will be commanded to close, and all pilot vent valves commanded to open, allowing for the burner to produce a flame without the need of the pilot. Following this, a fifteen second timer will begin, and the display will show “Burner Stabilizing.” If during these fifteen seconds the flame scanner fails to detect a flame, the system will enter flame failure shutdown. If the burner flame is still seen at the end of the fifteen seconds, the primary burner will enter auto modulation and display “Auto Modulation.” With the primary burner sequence complete, the system will display “Release to Modulation” allowing for the secondary burner sequence to begin.

3.3.3 Secondary Burner Firing Sequence

With the “Release to Modulation” displayed, the secondary burner firing sequence can begin. Unlike the primary burner firing sequence, the secondary has only two stages, pilot light-off and burner light-off. The purging stage is skipped for the secondary firing as it was already performed during the primary burner sequence. Beyond this, the secondary firing sequence is identical to the primary burner firing sequence, but with limits corresponding to its own individual pilot and burner valves.

3.3.5 Trips and Alarms

Trips and alarms are essential to the burner management system and must be implemented properly for the system to operate safely. During the stages of starting and operating an individual burner, different limits are needed at various times. If any of these limits are not met when required, the system will trip. System trips can also occur if the “Emergency Pushbutton” or “Emergency Stop” pushbuttons are pushed. In these cases, the individual burner that is tripped will close all safety shutoff valves and the conditions that caused the trip will be displayed with the message “Reset Required.” To restart the system, the “System Stop/Reset” button must be depressed for the individual tripped burner and the post purge will run. The post purge will be set for thirty seconds, after which the system can be operated again if the limits are proven.

Alarms occur in the instance of any trip or alarm condition being met. Alarm conditions can occur when the system is operating off normal conditions but not in a way that is dangerous unlike when trip conditions occur. An alarm sounds if either alarm or trip conditions are present and the “Alarm Acknowledge” pushbutton must be pressed to clear the alarm. This will not remove the condition that caused the alarm or trip condition - this process must be done by the operator.

3.4 Rockwell View Manager Studio Implementation

For the burner management system to best assist the operator, an interface must be created to handle user input as well as convey important system outputs, such as warning and trip conditions. Rockwell view manager studio was used for this in conjunction with Echo Logix to connect this program with Studio 5000. Screens corresponding to the various system stages will be made with displays of various pilot and burner conditions, trips, and the purge processes. On top of these screens, there are additional screens that will display alarms and system information for the operator.

CHAPTER 4: Results

To verify the functionality of the burner management system, several tests were performed to ensure proper and safe operation. This includes not just tests on the typical operations of the system but also forcing system trips to ensure safe and proper shutdowns.

4.1 Basic Operations

On system startup, the main screen will be displayed as shown in figure 13, providing the status of all pilot and burner valves along with the current date and time. At the bottom of the screen are several directory buttons which take the operator to the corresponding screen as well as indicate to the operator important system steps. These buttons are programed to flash certain colors at points in burner operation. If a button is highlighted in solid green, it means that the step of burner operation is complete. If a button is highlighted in orange, it means that that screen's main process is running. Finally, if a button is highlighted in flashing green it means that that step of the burner operation is waiting to be started by the operator. Beyond the directory button at the bottom of this screen, and all other screens, is the emergency stop button. When the emergency stop button is pressed, the entire system will trip and attempt to shutdown correctly. Now, with the main system started and no trip conditions present, the main screen will indicate the operator to start the boiler purge by highlighting the "Boiler Purge" button in flashing green.

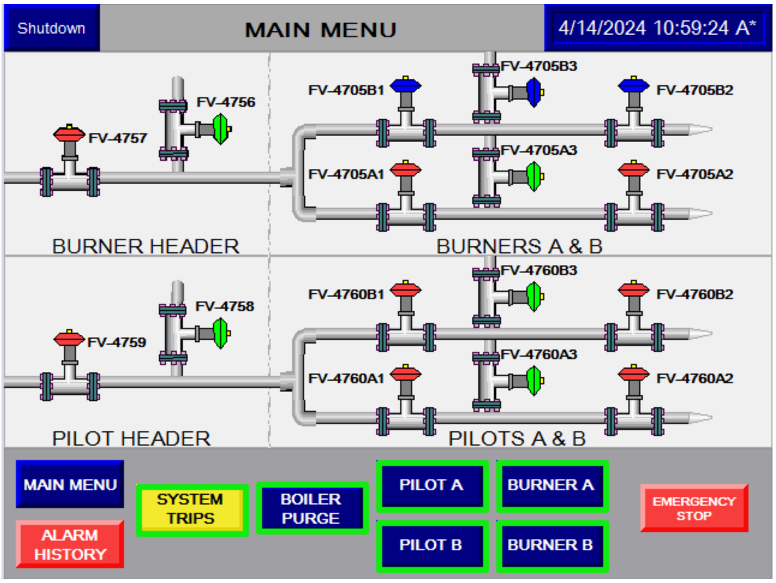


Figure 12: BMS Main Screen

Shown in figure 14 is the boiler purge screen. This screen allows for the forced draft (FD) fan to be turned on and off along while allowing the operator to start the purge process. This screen also indicates the purge limits needed for the boiler purge to begin and timers for purge limit proving and purging the boiler. Once the boiler purge is started and completed without any system trips, the screen will indicate that the boiler purge is completed by highlighting the "Boiler Purge" button in solid green and highlighting the "Pilot A" and "Pilot B" pushbuttons in flashing green, indicating they are ready to be started by the operator.

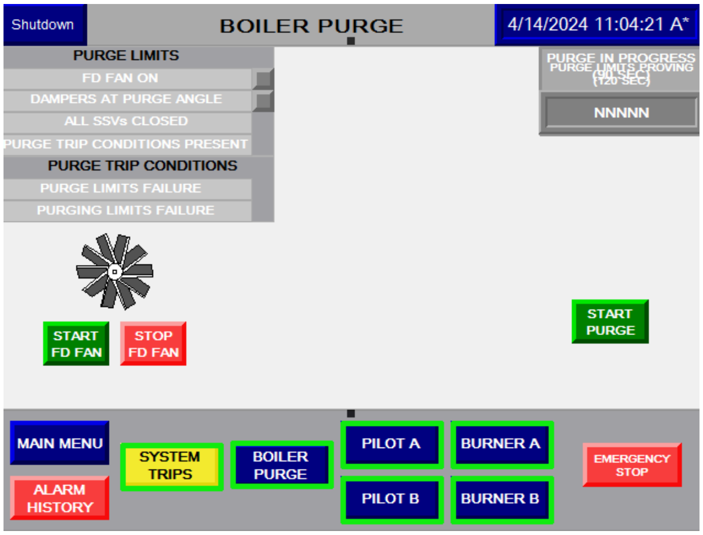


Figure 13: BMS Boiler Purge Screen

Following boiler purge, the operator will see the message “Controls to Light-Off” displayed and can choose whether to start burner A or burner B by beginning the light-off process for their corresponding pilot. The pilot screen for pilot A is displayed in the figure below and is nearly identical to the pilot B screen, however, the pilot B screen displays its corresponding valves, trips, and other such exclusively relevant features. The screen for pilot A displays its valves and their statuses along with the pilot header valves and statuses. Along with this, the pilot A screen displays the common and individual pilot permits needed for pilot A to begin firing alongside pilot A’s start pushbutton. With all permits proven and no trip conditions, pilot A can be started by the operator pressing the “Start” pushbutton, which will begin the pilot A light-off process. Beyond this being indicated to the operator by the display showing the processes of the pilot light-off, the “Pilot A” directory button will change from being highlighted in flashing green to solid orange while the “Pilot B” directory button will stop being highlighted as it can no longer be started at this point in the burner firing sequence.

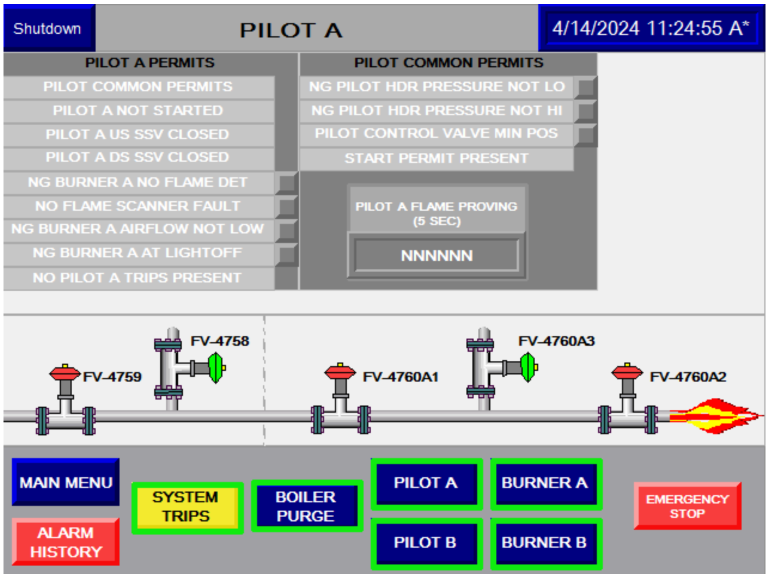


Figure 14: BMS Pilot A Screen

Once pilot A can successfully light without experiencing trips, the “Pilot A” button will turn solid green, and the “Burner A” directory button will begin flashing green. The burner A screen is displayed in the figure below and is nearly identical to the burner B screen, however, the burner B screen displays its corresponding valves, trips, and other such exclusively relevant features. For burner A’s screen, its valves, and their statuses along with pilot A’s valves and statuses are displayed for the operator. Along with this the burner A screen displays the relevant trips which could occur during operation alongside relevant timers for burner operation. With pilot A started burner A will begin proving, displaying relevant timers and process directly to the operator. Once burner A can successfully fire without the assistance of pilot A, burner A will enter auto modulation and the “Burner A” directory button will go from solid orange to solid green. Once burner A enters auto modulation, burner B can then be started which is indicated by the “Pilot B” directory button flashing green.

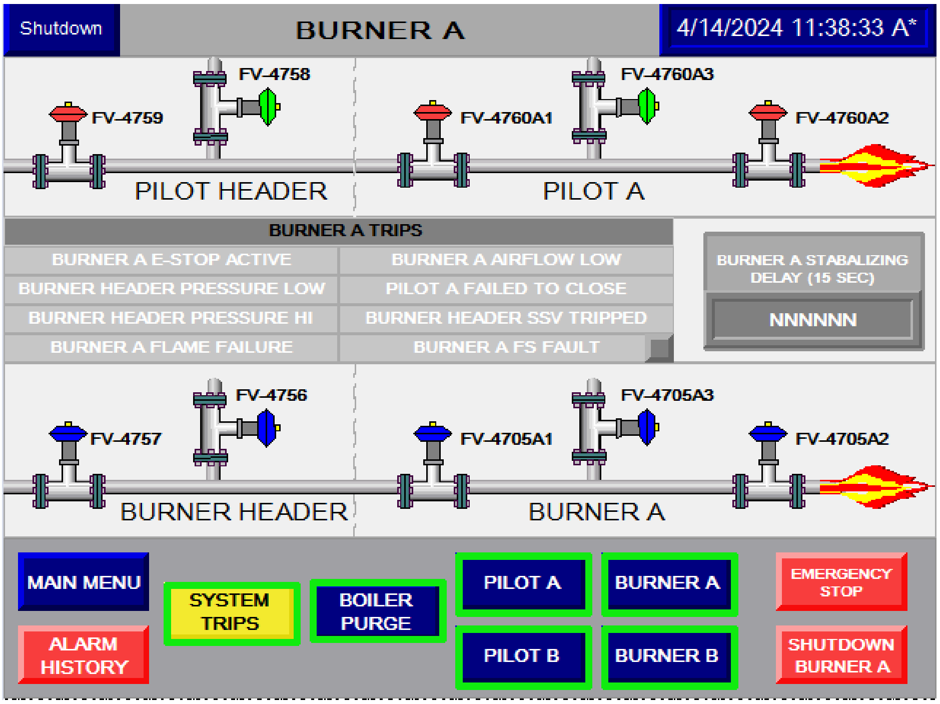


Figure 15: BMS Burner A Screen

The startup for burner B is identical to the startup of burner A, with the operator being indicated to start pilot B which will flow into burner B starting. Either burner can be started first, however, once one burner is put into its light-off sequence, the operator will be unable to start the other burner during this light-off without completely resetting the system by pressing the “Emergency Stop” button or shutting down the corresponding burner with its shutdown button. Once the burner exits its light-off sequence by entering auto modulation the other burner can be started.

4.2 Basic System Trips

During system operation, many trips can occur, whether it be during purging, pilot A or B light-off, or burner A or B light-off. In the case any trip is present, the system will shut down all valves and indicate the operator to enter the system trips screen by highlighting the “System Trips” button in flashing yellow. Along with doing this, the display will indicate the trip which caused the system to fail.

The system trips screen is displayed in the figure below and shows all relevant system trips. If a system trip is present, the corresponding panel will be illuminated in red and will stay illuminated until the trip is resolved. To continue operation, all trips must be cleared, and the “System Stop/Reset” button must be pressed. Once pressed, a final purge will occur and the system will return to normal operations, indicating for the operator to begin the primary purge before starting either burner.

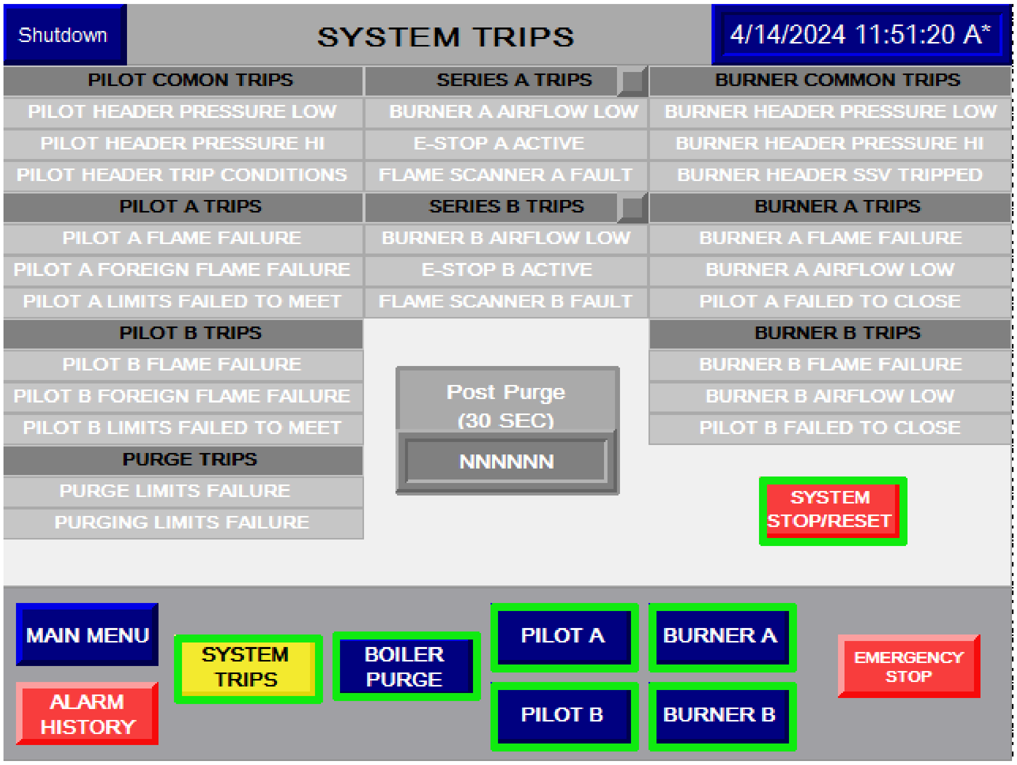


Figure 16: BMS System Trips Screen

4.3 Burner Shutdown

In addition to the “Emergency Stop” button, both burner screens have a burner shutdown button corresponding to their burner. Unlike the emergency stop pushbutton, the shutdown burner button only stops the operation of the corresponding burner. Once pressed, that burner will shut all relevant valves and the relevant burner pilot directory button will flash green indicating it can be started if the operator chooses. The opposite pilot directory button will also flash green if that burner is not already started. Shutting down both burners will allow for either pilot light-off sequence to be started again.

4.4 Emergency Stop

In the case of emergencies, the “Emergency Stop” push button can be pressed by the operator. When this button is pressed, the system trips and all safety shut off valves are forced to close as well as all vent valves being forced to open. With the emergency stop button pressed, no sequence can be started without the operator going to the system trips screen and running the post purge. Additionally, any off conditions that may have occurred due to the emergency stop button will be displayed on the system trips screen and must be cleared prior to resuming operation.

4.5 Flame Failures

Like all other trips, if a flame failure is to occur at any point during system operation, say when a fire is detected when it should not be, or a flame is not detected when it should be, the entire system will shut down. System shutdown will cause all safety shut off valves to close and all vent valves to open as well as any current operations to be halted. The system will also display to the operator the cause of the flame failure. The flame failure can be cleared the same way as all other system trips, by pressing the “System Stop/Reset” button in the system trips screen.

CHAPTER 5: Conclusion & Recommendations

Our team has been able to successfully create the ladder logic dictating the default conditions and alarm trip conditions for the Pilot Header safety shutoff valves and vent valves, the burner management system firing sequence and alarm trip conditions for the primary and secondary burners. Using ladder logic for each sequence, we created an HMI screen system displaying the status of all pilot and burner valves with a working directory to engage in boiler purge, pilot or burner data, alarm history or an emergency stop. From our experience using Rockwell Studio 5000's Design Software to create the ladder logic code and HMI screens for this system, we have a few recommendations for the rest of the coding required.

Further development with Rockwell Automation should not be done through a remote server and desktop. One of the main difficulties we faced was the program randomly crashing and losing files. We unfortunately had to run the Rockwell Automation Software through a remote desktop using a WPI server. This ensured every team member could access the project through the Rockwell software. The team believes that the factors causing these issues could be a combination of hardware and software setup issues.

Another recommendation would be to continue the project by implementing the software on a physical burner management system. At the start of this project, Babcock Power planned for this to be a packaged system sold to customers for their boiler's burner management system. Babcock Power can continue with this idea of selling a packaged system to future customers.

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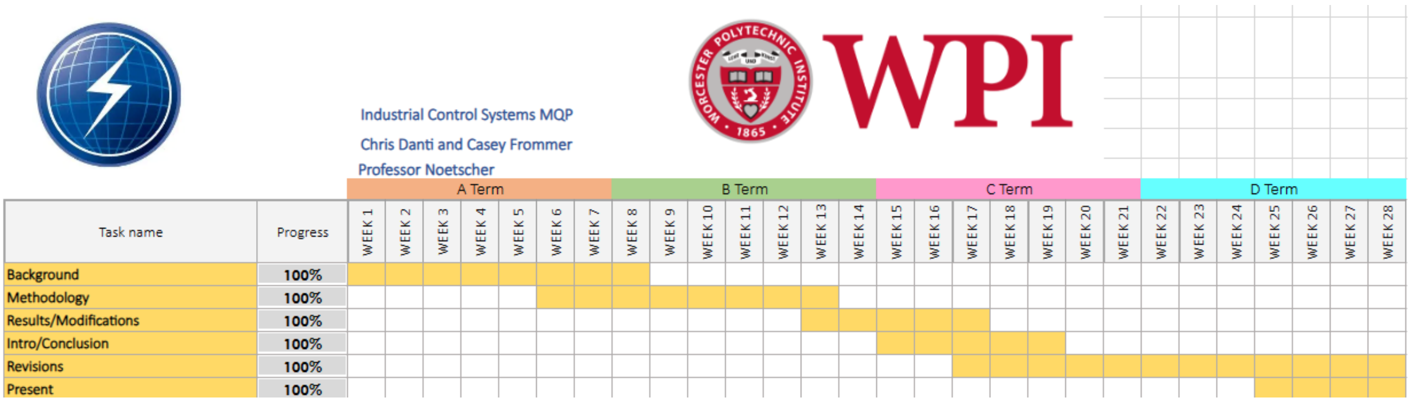
Appendix A

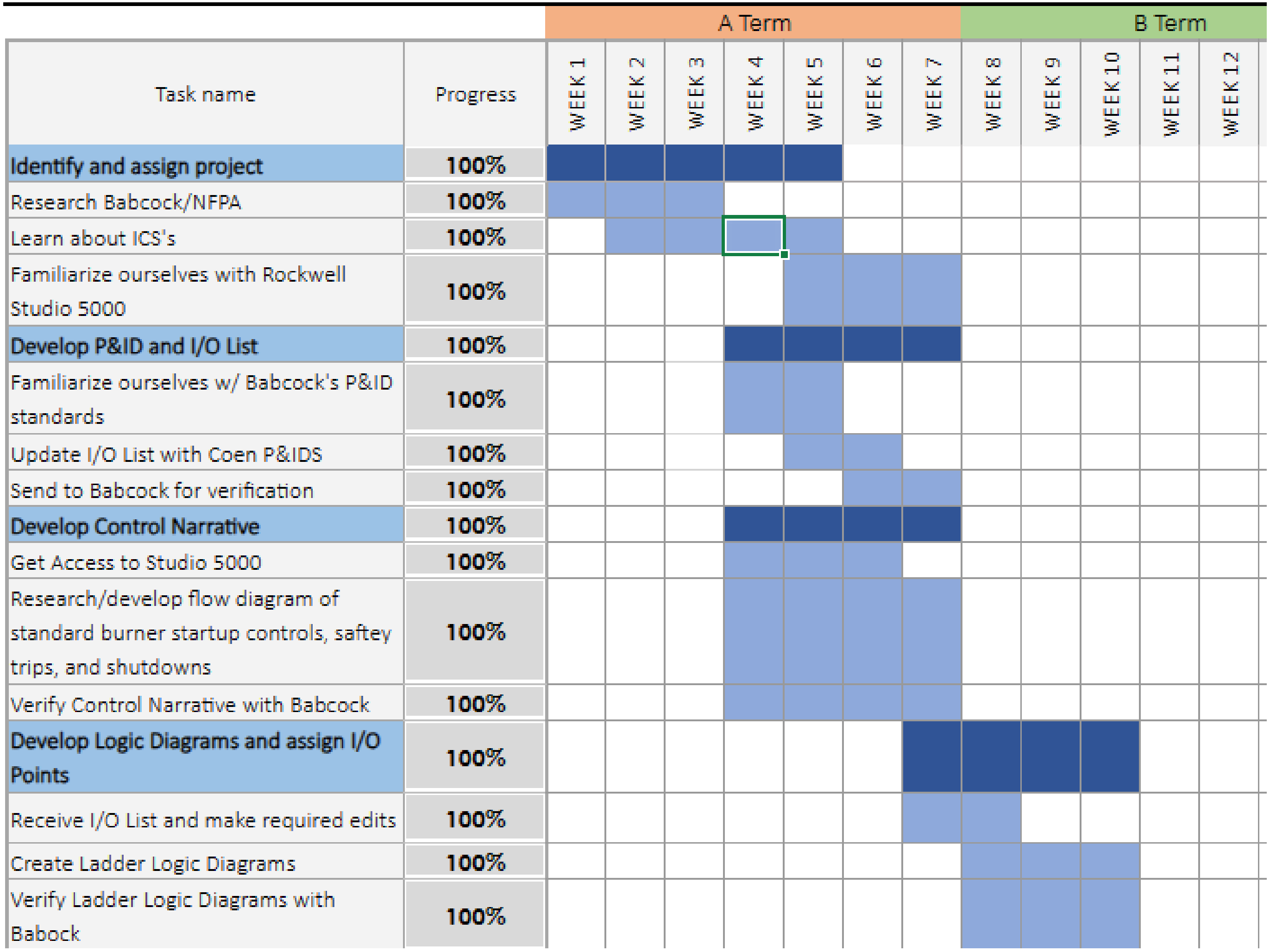


Industrial Control Systems MQP

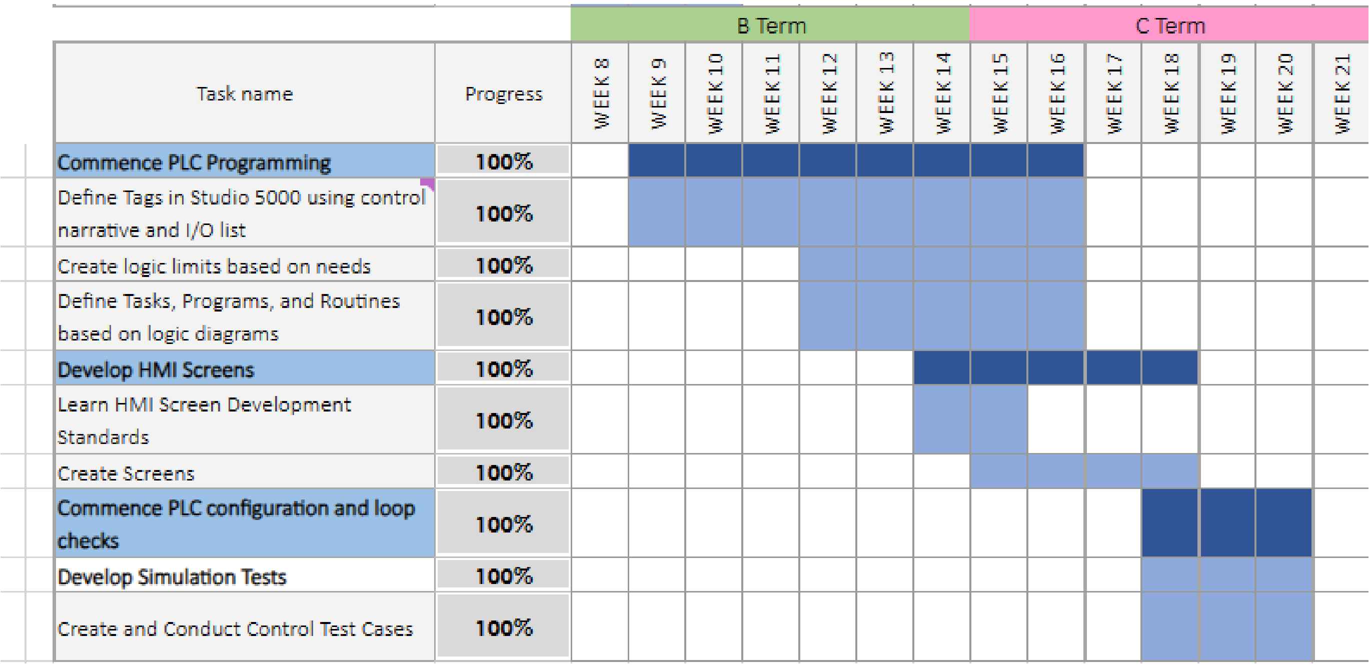
Chris Danti and Casey Frommer

Professor Noetscher

		A Term							B Term							C Term							D Term						
Task name	Progress	WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5	WEEK 6	WEEK 7	WEEK 8	WEEK 9	WEEK 10	WEEK 11	WEEK 12	WEEK 13	WEEK 14	WEEK 15	WEEK 16	WEEK 17	WEEK 18	WEEK 19	WEEK 20	WEEK 21	WEEK 22	WEEK 23	WEEK 24	WEEK 25	WEEK 26	WEEK 27	WEEK 28
Background	100%	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨																				
Methodology	100%						🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨															
Results/Modifications	100%													🟨	🟨	🟨	🟨	🟨											
Intro/Conclusion	100%															🟨	🟨	🟨	🟨	🟨									
Revisions	100%																	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
Present	100%																									🟨	🟨	🟨	🟨



		A Term							B Term				
Task name	Progress	WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5	WEEK 6	WEEK 7	WEEK 8	WEEK 9	WEEK 10	WEEK 11	WEEK 12
Identify and assign project	100%	■	■	■	■	■							
Research Babcock/NFPA	100%	▨	▨	▨									
Learn about ICS's	100%		▨	▨	▨	▨							
Familiarize ourselves with Rockwell Studio 5000	100%					▨	▨	▨					
Develop P&ID and I/O List	100%				■	■	■	■					
Familiarize ourselves w/ Babcock's P&ID standards	100%				▨	▨							
Update I/O List with Coen P&IDS	100%					▨	▨						
Send to Babcock for verification	100%						▨	▨					
Develop Control Narrative	100%				■	■	■	■					
Get Access to Studio 5000	100%				▨	▨	▨						
Research/develop flow diagram of standard burner startup controls, saftey trips, and shutdowns	100%				▨	▨	▨	▨					
Verify Control Narrative with Babcock	100%				▨	▨	▨	▨					
Develop Logic Diagrams and assign I/O Points	100%							■	■	■	■		
Receive I/O List and make required edits	100%							▨	▨				
Create Ladder Logic Diagrams	100%								▨	▨	▨		
Verify Ladder Logic Diagrams with Babock	100%								▨	▨	▨		



		B Term							C Term						
Task name	Progress	WEEK 8	WEEK 9	WEEK 10	WEEK 11	WEEK 12	WEEK 13	WEEK 14	WEEK 15	WEEK 16	WEEK 17	WEEK 18	WEEK 19	WEEK 20	WEEK 21
Commence PLC Programming	**100%**		■	■	■	■	■	■	■	■					
Define Tags in Studio 5000 using control narrative and I/O list	**100%**		▨	▨	▨	▨	▨	▨	▨	▨					
Create logic limits based on needs	**100%**					▨	▨	▨	▨	▨					
Define Tasks, Programs, and Routines based on logic diagrams	**100%**					▨	▨	▨	▨	▨					
Develop HMI Screens	**100%**							■	■	■	■	■			
Learn HMI Screen Development Standards	**100%**							▨	▨						
Create Screens	**100%**								▨	▨	▨	▨			
Commence PLC configuration and loop checks	**100%**											■	■	■	
Develop Simulation Tests	**100%**											▨	▨	▨	
Create and Conduct Control Test Cases	**100%**											▨	▨	▨	