Barry-Wehmiller Design Group Co-Op: Control Systems Integration

A Work Experience Report

by

Dennis Binford
Department of Electrical and Computer Engineering
Texas A&M University
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Presented to

Dr. Aydin I. Karsilayan
Department of Electrical and Computer Engineering
Texas A&M University

Approved by

Michael Shaw
Director, Austin
Barry-Wehmiller Design Group, Inc.
8213A Shoal Creek Boulevard; Suite 201
Austin, Texas 78757
(738) 218-5750
Michael.Shaw@BWDesignGroup.com

ABSTRACT

This report discusses the technical skills I developed integrating control systems for a client in the battery cell manufacturing industry. I worked with control panels, control system platforms, and industrial automation devices. I ensured control panels were ready to be powered on in order for control system platforms to communicate with industrial automation devices. I tested hundreds of automation devices and troubleshot issues to successfully integrate two battery cell manufacturing control systems.

I. INTRODUCTION

Over the spring semester, I spent 14 weeks integrating the control systems of two battery cell manufacturing processes in Austin, Texas. I worked as a controls engineering contractor at Barry-Wehmiller Design Group for an Austin client. I gained valuable experience working in diverse teams of varying sizes, communicating completion rates within the team at Barry-Wehmiller Design Group and to the client. My primary task for both projects was to test each of thousands of input and output signals for hundreds of devices connected to control system platforms inside dozens of control panels. I learned valuable skills in powering on and operating control panels, working with control system platforms, and testing industrial automation devices. I made meaningful contributions to verifying the correct functionality of two battery cell manufacturing processes. I personally verified hundreds of devices.

II. CONTROL PANELS

Control panels are the central hubs housing control system platform hardware containing all input and output electrical signals for industrial automation devices. Control panels (as depicted internally and externally in Figures 1 and 2, respectively) must first be powered on to test the electrical input and output signals inside a control panel. Control panels follow a control panel power on procedure.

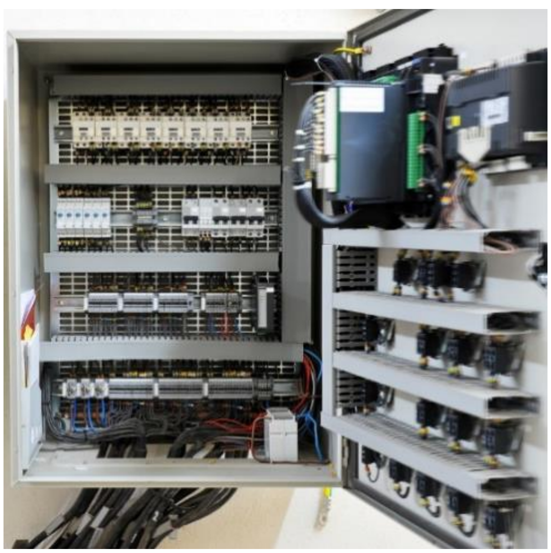

Fig. 1. Control Panel Interior

Fig. 2. Control Panel Exterior

PLC Panel Check List

Over all system cofiguration checks	Pass	Fail	Comments
System Name:			
Check Model, Quanity of the system modules against the record in BOM :			
Visual Inspection Checks			
Check the suitability of the testing area (staging area)			
Degree of Mechanical Protection			
The type test Certificate (as per IDS) including the electromagnetic Compatibility, tropicalisation etc.			
Check of instrument calibration (certificate for the instruments that will be used for the test)			
Cabinet type			
Check terminal strips functional separation			
check fusing and fuse rating			
check check of the wiring separation of various voltages			
check the filling ducts			
check of the space of future expansion			
safety grounding circuit check as per EN 61010-1 check of the safety ground insulation test			
Verify the control and signal cables			
Paintwork free from scratches, blemishes, deformities			
Eye bolts fitted			
All mechanical connections are secure and fit properly			
Doors and Lock/Keys are fitted securely			
Nuts / bolts / screws / fasteners are tight			
All Exterior cabinet namepltes are correctly located and squared to front and rear of cabinet for easy viewing			
All hazardous labels are fitted (voltage > 50 V)			
All device labels are fitted			

Fig. 3. Control Panel Checklist

A. Control Panel Power On Procedure

Control power on procedures follow a control panel checklist like Figure 3. “Several standards and regulations apply to [control panel] design, production, and installation” such as NFPA 70, UL 60947-4-1 and UL 508, and NFPA 79. Control panels “must comply with these standards to ensure safety and performance [1].” Checklists streamline communication between contractors and the client and document the status of a control panel. Control panels require proper mechanical installation and correct electrical wiring.

B. Mechanical Installation

Our team verified proper mechanical installation through visual inspection. Figure 3 shows specific checklist items for a visual inspection. I visually inspected a control panel’s exterior to ensure there are no gaps in the frame, firm installation of the control panel to the ground, and that the locking mechanism creates a tight seal. Next, I visually inspected the control panel’s interior to ensure that “the panel has enough space to accommodate all devices, with sufficient gaps between them when needed” and “that wire trays and ducts are sized appropriately, considering the amount and size of the cable to be run through them [1].”

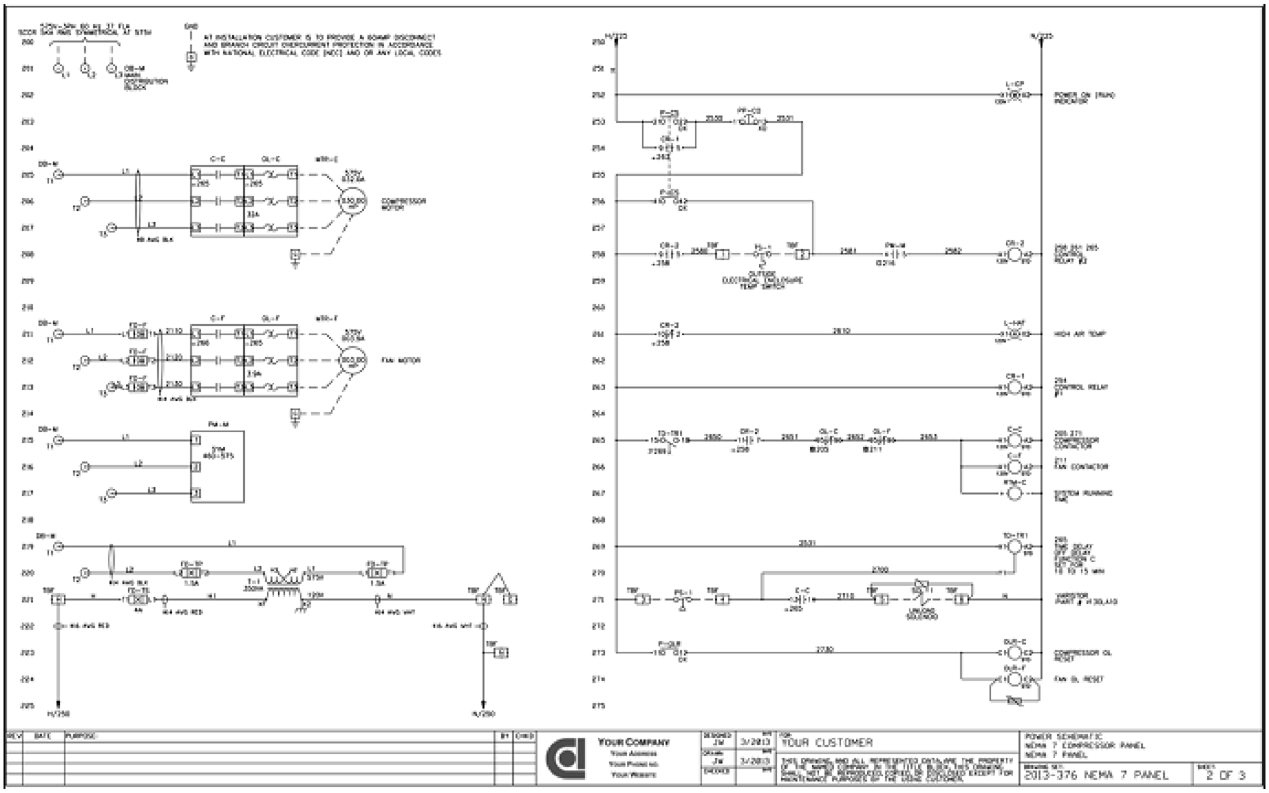

Fig. 4. Control Panel Wiring Diagram

C. Electrical Wiring

An operator references a control panel wiring diagram like Figure 4 to verify a control panel's electrical wiring. We checked each wiring connection to ensure that the wiring in the field matches the diagram. I used Bluebeam Revu 2.0 to access shared PDFs of control panel wiring diagrams for markups. Markups are crucial for documenting and communicating progress made on the electrical wiring of a control panel between contractors and the client. I highlighted wiring connections that were correct and made important comments on discrepancies. We also checked connections between power and ground to ensure that there were no short circuits. I checked that each of the control panel's interior devices were properly grounded. "Proper electrical grounding is critical" as "improper grounding is among the top causes of failure of control devices [1]." As shown in Figure 1, control panels have numerous wires behind wire trays which makes manually tracing each wire in a control panel unfeasible. For this reason, I performed continuity tests to verify correct electrical wiring.

D. Continuity Testing

Continuity testing is important to check and troubleshoot electrical wiring. In fact, I performed a continuity test inside of a control panel on my first day on site. "Continuity is the presence of a complete path for current flow [4]." A continuity test is "the testing of an electrical circuit to determine if the current can pass through it [3]." We completed continuity tests using multimeters that sends "a small voltage applied to the two points of the circuit that needs to be checked [3]." I primarily used the Fluke 789 Processmeter shown in Figure 5 to perform continuity tests.

Fig. 5. Fluke 789 Processmeter

I accessed continuity testing mode by turning the dial to Ω and then pressing the blue circular button to the top right of the dial. An audible beep indicated when the two probes had a connection between them [4]. Continuity tests also helped troubleshoot incorrect electrical wiring.

E. Troubleshooting Electrical Wiring

While subcontractors dealt with most wiring issues, troubleshooting was instrumental in my experience in fixing small wiring issues as well as gaining practical experience. I learned to wire connections that were not wired or rewire incorrect wiring connections inside control panels for simple short distance wiring issues. Rewiring required tracing the wire from a connection point to discover where it was incorrectly connected and then fixing the connection. For new wiring connections, I traced the wiring using a wiring spool through duct trays like in Figure 1 to determine the proper length. Then, I used wire strippers to cut both ends of the new wire cleanly. I stripped the insulation on both ends of the wire to apply wire ferrules. I crimped the wire ferrules which is important as “good crimping techniques will lead to a mechanically sound connection, which is a crucial part of the electrical installation process”. Not crimping a wire means that “the connection would be more susceptible to infiltration by [liquids] and corrosion [5].”

F. Power On

After I completed a control panel power on procedure, the control panel was powered on to test the industrial automation devices. There were three voltage levels present in the manufacturing plant: 24 V, 120 V, and 480 V. The client supplied power to 120 V and 480 V panels as working with those voltages is hazardous. However, for 24 V control panels (and devices inside higher voltage control panels that only require 24 V), we used power supplies to test faster. While not a traditional approach, we used power supplies to hit deadlines earlier than otherwise possible in a fast-paced environment. Similarly, we tested communication cable connections to find any issues in the networking of the hardware for control system platforms before they went online so subcontractors could fix faulty networking connections early.

G. Testing Communication Connections

A control system platform’s hardware inside control panels requires connection via communication cables. These connections use ethernet cables which we verified for both connection and functionality. Unlike with a wire, continuity testing is not sufficient as an ethernet cable may be wired correctly but unable to communicate due to damage. I verified connections using a specialized tester. I tested communication connections that used the EtherCAT which is a communication protocol commonly used in industrial applications “to communicate with industrial devices as close to real-time as reasonably possible [6].”

Fig. 6. Klein Tools Scout Pro 3

I used the Scout Pro 3 to test ethernet cables of any length through the detachable connector on the bottom below the ridge in Figure 6. The top of the tester has another connection point. Long-distance connections were necessary as ethernet cables between control panels could be in different rooms in the plant. Once both sides are connected, an EtherCAT cable passes when the numbers 1, 3, and 6 are visible and shows the word “Pass” on the top left of the screen. I used a network wiring diagram similar to the control panel wiring diagram in Figure 4 to see ethernet cable connection. Through this test, we discovered bad ethernet cables and missing ethernet connections before connecting the control system platforms hardware to the network.

III. CONTROL SYSTEM PLATFORMS

Control system platforms provide high level control over a manufacturing process. Control system platforms use hardware inside control panels to communicate industrial automation devices’ input and output electrical signals. Each control system platform has software providing programming control logic and remote access. Human machine interfaces are built on top of this software for intuitive operation of the manufacturing process. I worked with two types of control system platforms: programmable logic controllers and distributed control systems. Over the course of my co-op, I worked with Beckhoff TwinCAT, Siemens SIMATIC, and Emerson DeltaV. I learned how to work with the hardware, software, and human machine interfaces that encompass control system platforms to test correct functionality of industrial automation devices.

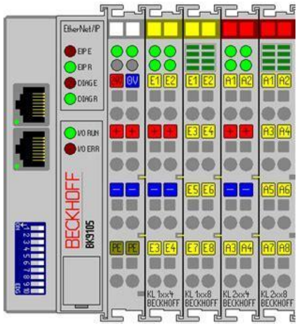

Fig. 7. Beckhoff Cards

Fig. 8. Emerson DeltaV

Fig. 9. Siemens SIMATIC Controllers

A. Hardware

Figures 7 through 9 show the hardware inside control panels of the three control system platforms I used to test industrial automation devices. The hardware consists of input and output modules connected to a controller. The lights on the input and output modules in Figures 7 through 9 display the status of industrial automation device's input and output electrical signals. Input and output modules take in discrete signals that are either low (0 V) or high (24 V) or analog signals that vary in current. A common range for analog current signals is 4-20 mA [7] and was the range used in both manufacturing processes. Beckhoff and Siemens use programmable logic controllers whereas Emerson's DeltaV is a distributed control system. Programmable logic controllers are faster, cheaper, and give more control than distributed control systems. A distributed control system provides a refined solution leading to easier implementation. For this reason, programmable logic controllers "are used to control a process or a machine" while a distributed control system "is used to control complex processes that require a lot of interaction between multiple controllers [8]." The ethernet ports on controllers connect the input and output signals to a software program giving insight into their values.

10_12 ▸ Wickler [CPU 1516F-3 PN/DP] ▸ Watch and force tables ▸ Forcetabelle

i	Name	Address	Display format	Monitor value	Monitor with trig...	Force value	F
F	"LM Motor 1":P	%Q0.0:P	Bool		Permanent	TRUE	☑
	"LM Motor 2":P	%Q0.1:P	Bool		Permanent		☐
F	"LM Motor 3":P	%Q0.2:P	Bool		Permanent	TRUE	☑
	"LM Motor 4":P	%Q0.3:P	Bool		Permanent		☐
	"LM Motor 5":P	%Q0.4:P	Bool		Permanent		☐
	"LM Motor 6":P	%Q0.5:P	Bool		Permanent		☐
	"LM Motor 7":P	%Q0.6:P	Bool		Permanent		☐
	"LM Motor 8":P	%Q0.7:P	Bool		Permanent		☐
F	"MS Motor 1":P	%I0.0:P	Bool	F TRUE	Permanent	TRUE	☑
F	"MS Motor 2":P	%I0.1:P	Bool	F TRUE	Permanent	TRUE	☑
F	"MS Motor 3":P	%I0.2:P	Bool	F TRUE	Permanent	TRUE	☑
	"MS Motor 4":P	%I0.3:P	Bool	TRUE	Permanent		☐

Fig. 10. Siemens Totally Integrated Automation Portal Watch and Force Table

B. Software

Each control system platform has software for viewing the raw values of the electrical signals in input and output ports and forcing values to send outputs to industrial automation devices. Discrete signals read either 1 (24 V) or 0 (0 V) while analog signals read a percentage where from 0-100% (4-20 mA). I used the force and watch tables in Figure 10 to view raw values and force output signals. I typed the port address of any industrial automation signals I wanted to view into the address column. If I wanted to send an output signal, I would enter a value into the force value column and check the force column checkbox on the right and finally hit the top left force button to update all values to their current force states. The other two software programs I used were Beckhoff TwinCAT and DeltaV Explorer which had different user interfaces, but a similar procedure for viewing raw values and sending output signals. While good for testing, raw values in this format are terrible for high level overview and operation of manufacturing systems. For that reason, human machine interfaces are built to integrate signals for more intuitive control over a manufacturing plant.

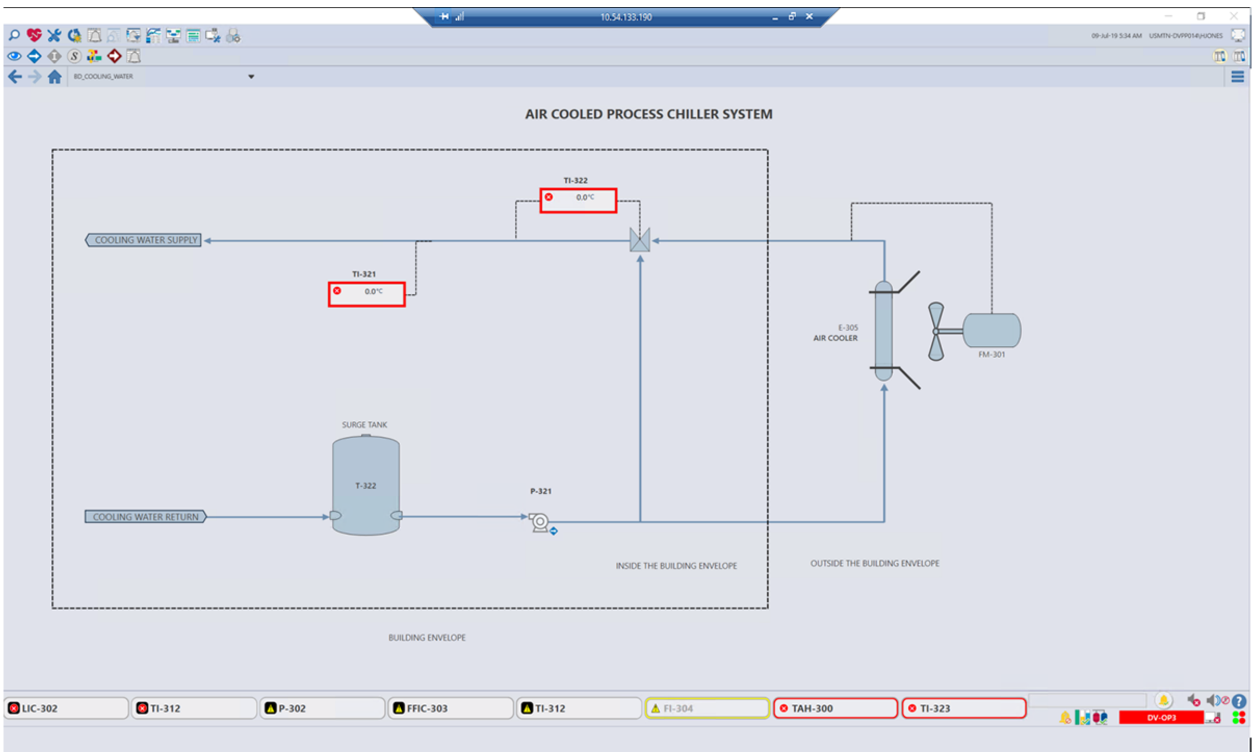

Fig. 11. DeltaV Live Human Machine Interface

C. Human Machine Interfaces

Human machine interfaces provide a high-level overview of a manufacturing process. Operators use these intuitive user interfaces to send commands and receive alerts for unusual behavior via alarms. Raw values are converted to readable discrete states or ranged values with engineering units. I used client provided human machine interfaces as well as DeltaV Live shown in Figure 11 to pass an industrial automation device fully. While an industrial automation device may be functioning correctly, it is also important that it displays its values correctly and that any commands sent from the human machine interfaces work as intended. In DeltaV Live, I used the search bar on the top left to search for the faceplate of a device tag to test an industrial automation device. A faceplate like Figure 12 shows the state of a device or what value a device is reading. Through this faceplate, I could determine whether the value matched the state or reading of an industrial automation device. I also used the faceplates to see if alarms would go off when expected. Client provided human machine interfaces had similar faceplates for conveying value and alarm states in a customized user interface. I interacted with faceplates to send command signals to and receive live feedback from industrial automation devices.

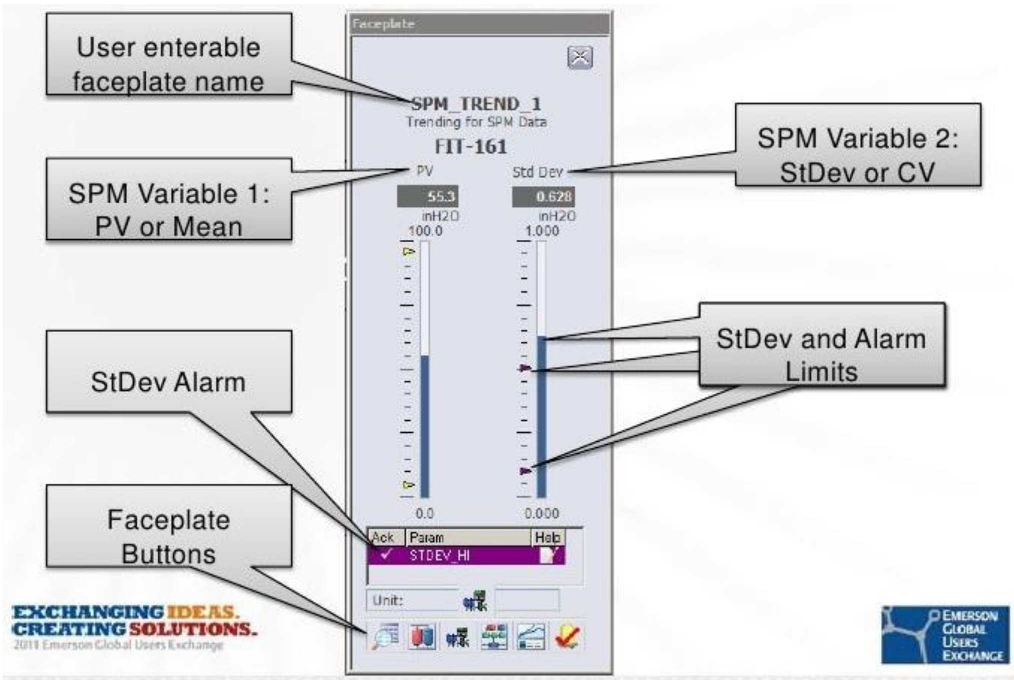

Fig. 12. DeltaV Live Faceplate

IV. Industrial Automation Devices

Industrial automation devices provide valuable data and control over an industrial manufacturing plant. I tested hundreds of industrial automation devices containing thousands of input and output signals using control system platforms to send commands and read feedback. As a part of this process, I located an industrial automation device in the field and either passed the device if it worked with the control system platform or troubleshot the cause of the failure. I worked with numerous types of industrial automation devices such as valves, transmitters, and buttons depicted in Figures 13 through 15.

Fig. 13. Valve

Fig. 14. Transmitter

Fig 15. Emergency Stop

A. Device Signals

Devices have input and output signals that are connected to the control system platform. Inputs are the feedback that a device sends to the control system platform indicating a device's current state or measured value. Outputs are the commands sent from the control system platform to the device to change states. Input and output signals are relative to the control system platform's perspective. Each device has at least one input signal due to the importance of tracking states and measured values. Devices such as the transmitter in Figure 14 and the emergency stop button in Figure 15 only have input values as they only send their state and measured value to the control system platform. However, many devices like the valve in Figure 13 use both input and output signals. Output signals are important for the control system platform to send commands for a device to change states such as commanding a valve to open or close. Depending on the type of device, devices send either discrete or analog signals. Devices with discrete states such as the valve in Figure 13 and emergency stop button in Figure 15 use discrete signals to communicate their states. Devices with a range of values such as the transmitter in Figure 14 communicate their measured value using analog signals.

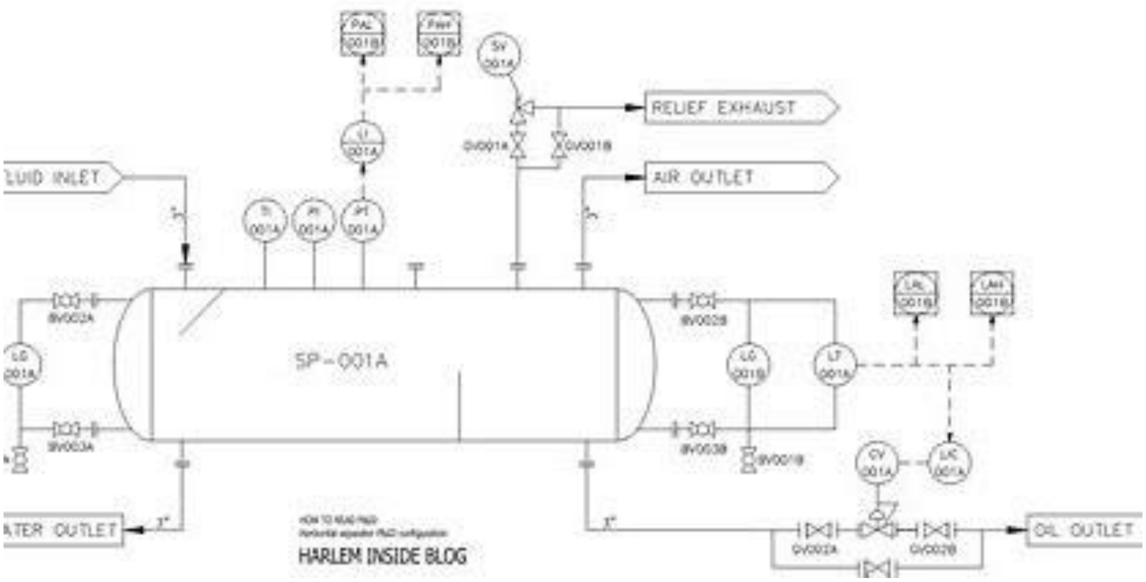

Fig. 16. Piping and Instrumentation Diagram

B. Piping and Instrumentation Diagram

In order to test a device, I located the device in the field and verified that the correct device was installed in the correct location. I used a piping and instrumentation diagram like the one depicted in Figure 16 to locate devices in the field. The circles inside a box signify the input and output signals connected to their corresponding device via dotted lines. I checked the labels on the device corresponding to the location in the piping and instrumentation device to ensure that it was the correct one. If there was no label or the label was different, I noted the discrepancy. I used BlueBeam Revu 2.0 to access the PDFs containing the piping and instrumentation diagrams. In Bluebeam Revu 2.0, the boxes can be highlighted and marked up with their status directly in the software. This was an easy way for the contractors and the client to track the general status of devices in a specific part of the plant. Excel and CxAlloy allowed us to track the progress of verifying the input and output signals for devices more meticulously.

C. Tracking Progress

Tracking progress is integral in communicating completion rates between contractors and clients. The client used CxAlloy to provide an overview of the progress of device checkout. I used CxAlloy to enter specific states and measure values and then pass or fail specific checklist items like the one in Figure 3 used for control panels for each device. I also used CxAlloy to assign issues to whomever was responsible for fixing the specific issue. I entered information into client provided Excel spreadsheets for both manufacturing processes. The Excel spreadsheets contained information for each device in one place and were used to track the status of wire and device labeling. The spreadsheets also provided valuable information on which control system platform was used, where the device's signals should connect to the control system platform's hardware expected states or values of a device. I made comments on the issues for failed devices and any notable information for devices that were passed. In one of the manufacturing processes, we used only Excel to track progress.

D. Testing

I used a device's respective control system platform to send commands and read feedback for devices that had input and output signals. For analog devices like the transmitter in Figure 14, I simulated currents to test the device. Many transmitters have a display with physical or laser-based buttons to navigate a menu which has an option for simulating current. Some devices without a screen have Bluetooth allowing us to connect an application and simulate current values using a similar menu as the ones with a display. However, some devices have neither a navigable menu in their display nor Bluetooth. In these cases, simulation required using a process meter to simulate current from the device's signal wires. I used the Fluke 789 Processmeter shown in Figure 5 to simulate currents. I attached probes in either the simulate or source positions on the bottom of the meter. I selected simulate for devices that had power supplied through the signal wiring and source for devices that had additional wiring supplying external powering separate from the signals wiring. I turned the dial to the first orange mA symbol to simulate currents. I pressed the MIN MAX button to increase in 4 mA increments and the button below to decrease in 4 mA increments. For each analog device, I simulated 4, 12, and 20 mA to confirm that the 0, 50, and 100% readings matched on the control system platform. I noted each of these values to put into the CxAlloy checklist for analog devices.

E. Calibration

I calibrated analog devices to the right range and units to ensure that the devices calibration matched the expected range on the human machine interface Without proper calibration, the control system platform would not reflect the actual readings that the transmitter was sending to the control system platform correctly. If the analog device had the wrong calibration, I would update the calibration to correspond with the low and high range values and engineering units in the spreadsheet. I used the menus in analog devices with navigable displays or Bluetooth to check and calibrate each device. Through these menus, I also updated the device tag if it had not yet been established using the client's naming convention for their devices. For devices with neither a navigable display nor Bluetooth, I used the Fluke 709H HART meter depicted in Figure 17 to communicate with the device.

Fig. 17. Fluke 709H Precision HART Loop Calibrator

I used the HART meter to connect to the device to read and write the lower and upper range values and the engineering units. I connected the probes on the top of the HART meter to the wiring on the control system platform side to create a closed loop with the devices signal wires. I turned the dial in the middle to navigate the menu and update the lower and upper range values, the process variable, and the device tag to match the client's chosen parameters for the device. I also used the HART meter like the process meter to simulate and note simulation values once calibrated.


Fig. 18. Harness

Fig. 19. SENCO PC1010N Air Compressor

F. Harnesses & Air Compressors

I tested many devices that were installed and wired, but some devices required air or scaffolding to reach or both. To stay on top of our assignments, we used air compressors and harnesses to externally supply air to devices requiring pneumatics such as valves and reach devices at high elevations. I was trained in operating a harness correctly according to OSHA standards. OSHA requires fall protection for elevations above "six feet in the construction industry [9]." I used a harness with two hooks like the one shown in Figure 18 to traverse high elevations. For pneumatic devices such as valves, I used the SENCO PC1010N air compressor shown in Figure 19 to hook up air to the device for testing. Just like using power supplies in control panels, air compressors and harnesses were non-traditional approaches used to exceed expectations in verifying devices for the client.

G. Device Failures

Device failures came in three main categories: mechanical, electrical, and controls. Mechanical issues involved physical issues with the installation of the device. Examples of mechanical issues include missing devices, incorrect installation or location of installation for a device, and mechanical problems in the device needing a part to be replaced. I marked the failure issue as mechanical with the specific issue in a comment and assigned it to the client's operations team to resolve the issue as it was beyond our scope. Electrical issues involved faulty electrical wiring or a device not receiving power. Controls issues involved discrepancies between the control system platform and the device due to incorrect configuration in the control system platform.

H. Troubleshooting

Most of my time was spent troubleshooting device failures. A device failure started with a discrepancy between the control system platform and the device. I had to determine the type of device failure. First, I inspected the device in the field to ensure that it was installed and wired correctly. I noted in the Excel spreadsheet if the device was not installed or there was a mechanical issue to be communicated up the chain. We assigned mechanical issues to the client's operations team in CxAlloy. If the device was not wired, I made a comment noting this as an electrical issue which was communicated with our electrician subcontractors. If the device was both mechanically installed and had wiring going into the device, I checked the wiring connection between the device and the control system platform. I performed a continuity test to determine if the wiring connection was correct. Due to the long distances between devices and the control system platform's hardware, wire nuts were used on one end to perform a continuity test to check the wiring connection. If there was not continuity, I used a wire tracer to determine where there was a break in the wire or determine if the wiring was in the wrong slot in the control system platform's hardware. I fixed simple wiring connections. For more complicated wiring issues, I made a comment specifying the issue to be relayed to our electrician subcontractors. If a device was properly installed and wired, a discrepancy between the control system platform meant that there was a control issue in the configuration of the control system platform's software or the human machine interface. I would determine the exact configuration issue and assign the issue to the client who had permission to change the configuration to remedy the problem.

V. CONCLUSION

This past spring, I ensured that control panels were ready to be powered on and worked with three control system platforms to test hundreds of industrial automation devices. Testing these industrial automation devices ensured that the control system was fully integrated. Most devices required troubleshooting and communicating progress in fixing issues to clients and contractors. Troubleshooting gave me incredible insight into real world problems in engineering and coming up with solutions in a fast-paced environment. Through these skills, I successfully integrated two control systems for a client in the battery cell manufacturing industry.

ACKNOWLEDGMENTS

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