

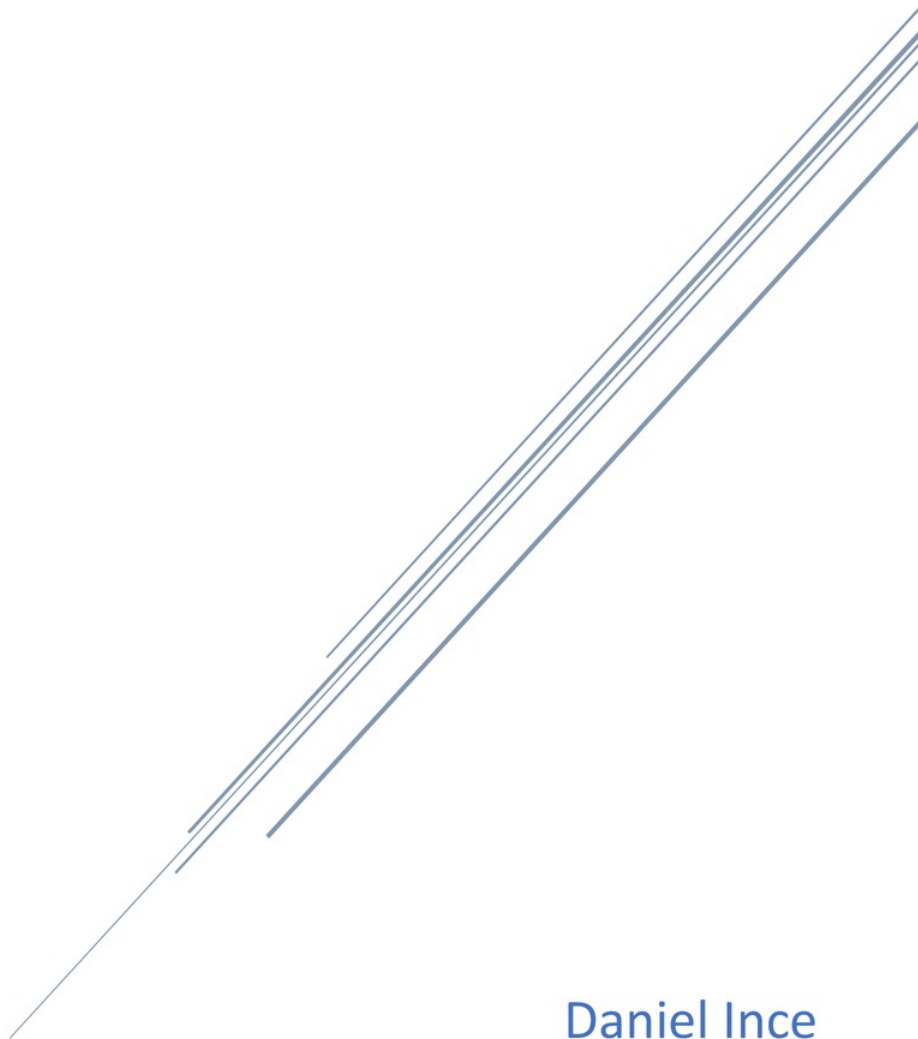
Daniel Ince - Final Report

by Daniel Ince

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PROJECT FINAL REPORT

PSDE5007 – R. Jenkins



Daniel Ince

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Very good list of contents

1. Project Proposal

1.1 Overview

The project in question is to centre on a control system. This system will involve a PLC with bespoke program written to provide the control aspect.

The outcome is to achieve an effective way of performing a valve sequence for a section of plant. A control aspect will be incorporated to regulate the sequence of events and keep it well within operating limits. This aspect will include a form of timing and sequential control to keep the process variable as close to the set point as possible. This set point will be able to be modified through interacting with a control panel installed through hardwiring and with the assistance of a HMI connected to the PLC.

The system is also to include a hardwired and software safety system in order to trip the system should it stray too far from the acceptable limits. The hardwired system will be an emergency stop to physically break the circuit and cut out the equipment should there be a failure of the software. A manual and automatic switch will be incorporated, along with a maintenance bypass to allow work to be carried out, such as live calibration, without the system needing to be shut down.

Investigation will be carried out in order to determine the most effective way of achieving this while being as cost effective as reasonably practicable. The different methods will be looked into through a variety of techniques, such as gant chart, direct comparison and SWOT analysis. These will aid in the decision of how to achieve the control system and make it clear which is most cost effective and includes the most layers of protection with regards to safety integrity.

The project work will be carried out predominantly at Valero, along with the use of resources during time spent at Coleg Sir Gar. Testing will be carried out using specialist test equipment found at Valero and calibration of any equipment will be completed there. The college software will be used to write and compile the program for the PLC.

The budget is to be £800 as the system will require use of a PLC, valves and sensing instrumentation.

Testing of the project will be done to determine whether or not the system conforms to the product design specification and thoroughly test all aspects of control within the system. Each instrument will be calibrated and loop checked to ensure adequate signal transmission and functionality. The program and software aspect will be set up and input/output configurations checked. This will include testing of the trip setting and adjustments to the set point to determine the optimum operation while remaining as safe as reasonably practicable. The safety system is important on the refinery as it is critical that the control measures are in place to prevent a process upset or dangerous occurrence.

The project will run from October 2017 to the 25th of April 2018 and will be planned throughout these dates with all information and activities being recorded in a log book.

1.2 Detailed Objective

The specified valve sequence will be the PSA (Pressure Swing Adsorption) skid on the HRU (Hydrogen Recovery Unit) of Pembroke Refinery. A system to control the systematic opening and closing of the many valves on the unit will need to be designed to suit accordingly to ensure correct unit operation.

Methods will be investigated and chosen until the most effective solution for controlling the system is determined. The method will need to be able to run the system flawlessly error free for at least 10 years with minimal maintenance on the control system itself.

2. Background Research

Research will be performed to gain an insight onto Pembroke Refinery, the HRU unit, the PSA skid and the existing control system.

2.1 Pembroke Refinery

Pembroke Refinery opened in 1964 and one of the largest refineries in Europe. Taken over by Valero in 2011, it processes 270,000 barrels of crude oil per day.

As stated on Valero's website:

- *Built in 1964 as a hydroskimmer, with cat-cracking capacity added in 1982*
- *Acquired from Chevron in 2011*
- *Occupies approximately 450 acres of a 1,275-acre site on the southern shore of the Milford Haven Waterway in Pembrokeshire, Wales*
- *Deep-water port and docks with capacity to handle very large ships, without reliance on third-party terminals or pipelines*
- *Total throughput capacity of 270,000 barrels per day, including 220,000 barrels per day of crude oil, plus 50,000 barrels per day of other feedstocks*
- *Approximately 10.5 million barrels of storage, about half used for feedstocks*
- *Large FCC and alkylation units providing significant volumetric production gains*
- *Nelson complexity rating of 11.6 ranking among the top refineries in Western Europe*
- *Refinery scale, flexibility, location and logistical advantages enhancing Valero's optimization and trading strategy in the Atlantic Basin*
- *Major national employer in Wales, including about 550 employees and 400 term contractors;*
- *50th anniversary of the refinery celebrated in 2014 by a visit from Their Royal Highness The Duke and Duchess of Cambridge*

(Valero, n.d.)

2.2 Hydrogen Recovery Unit

The HRU was implemented at Pembroke Refinery in order to recover hydrogen to supply additional reactors needed to reduce the sulphur levels of product. It uses gas feed from the CCR unit which passes through the LPGRU and then onto the HRU. This feed contains around 80% hydrogen content and is increased in pressure before being sent to the Pressure Swing Adsorption section and then the resultant pure hydrogen is sent to the hydrotreaters.

2.3 PSA Skid

The PSA skid consists of 4-bed adsorbers and is designed to remove impurities from the gas to produce high purity hydrogen. The process involves a cycle which varies the pressure of the feed and then regenerates the adsorbent of any impurities. Each cycle is staggered to ensure one adsorber is always online while the others are in the regeneration phase in order to provide a continuous flow. The PSA can also function using 3 beds if required but this is generally undesired as it can produce a lot of flaring if the resid gas purity drops. The adsorption phase timing can be increased to increase the purity of the hydrogen produced, and vice-versa depending on demand.

The entire cycle of each adsorber consists of four subcycles, adsorption, de-pressurisation, purging, and re-pressurisation ready for the cycle repeat.

Adsorption

The feed gas enters the adsorber at a pressure of 42.7kg/cm²g entering through 11-KV-0211 and flowing upwards into the vessel 02-F-201. As it passes over the bed, the adsorbent removes impurities from the gas through adsorbing them onto the bed surface. This subcycle is undergone for 135 seconds before moving on to the regeneration subcycle. The cycle time varies depending on flow rate and capacity and is controlled automatically by logic.

At the completion of adsorption on the first bed, the next bed begins the process to ensure continual flow.

Regeneration

The bed is now coated in impurities removed from the hydrogen and needs to be regenerated before the next cycle. The impurity concentration varies throughout the height of the vessel, with the lowest part containing the highest concentration with this decreasing as you move up the adsorber. The regeneration process is carried out in three stages.

These impurities are to be removed through desorption at low pressure, this is carried out by a two stage depressurisation of the adsorber through the top using co-current direction. This allows hydrogen to be recovered which is still in the bed before dumping the impurities. Initially the vessel is de-pressurised to the resid gas pressure and the hydrogen stored is used to pressurise and purge other adsorbers in the second and third stages of the regeneration cycle respectively.

Hydrogen from another adsorber is then used to purge the current one at a low pressure. The impurities are desorbed and removed through the bottom of the adsorber. The adsorber is then re-pressurised prior to adsorption using purified hydrogen from other adsorbers in regeneration to prepare it.

The stages are described in detail below.

Equalisation – This is a 30 second process which uses the high pressure hydrogen from adsorber 1 to partially repressurise adsorber 3. Valves 11-KCV-213 and 233 open in order to allow the flow from adsorber 1 to 3. The 30 second timer lasts to allow the pressure of adsorbers 1 and 3 to have equalised at 25.89kg/cm²g.

Purge providing – This is a 90 second step which uses the remaining hydrogen in adsorber 1 to purge adsorber 4. The gas exits the vessel through KCV-213 and then enters adsorber 4 through KCV-243. This process drops the pressure in the first adsorber to 14.39 kg/cm²g. This purge for adsorber 4 allows the remaining impurities to be forced out of the vessel downwards out of KCV-244.

Depressurisation dump – This is a 45 second step which reduces the pressure of adsorber 1 to 5.7 kg/cm²g through depressurising the gas downwards out of KCV-214. The opening of this valve is adjusted and used to control the rate of depressurisation within the allocated time.

Purge – Adsorber 1 is purged for 90 seconds from top to bottom using the hydrogen gas from adsorber 2. KCV-223 and 213 open to allow and control the purge gas flow to enter the vessel and desorb the impurities from the bed. The gas takes the impurities with it as it passes through KCV-214 which is fully open to maintain the low pressure in the system.

Re-pressurisation – The first adsorber then needs to be re-pressurised to prepare for the next cycle. To do this, two sources of hydrogen are used to pressure up the vessel, taken from the equalisation stage of adsorber 3 and pure hydrogen product through KCV-212. Once the pressure has equalised this first re-pressurisation stage ends and the next re-pressurisation begins using only purified hydrogen product. The maximum pressure reached is 42.7 kg/cm²g and allows the beginning of the next cycle.

The adsorber subcycle time can be modified depending on what is demanded. Using 4-beds and at 100% load, the subcycle is set at 135 seconds, should only 50% flow be required, the cycle time is set to 270 seconds. This is because the adsorbent can only remove a fixed amount of purities and so the larger the capacity of the adsorber, the shorter the subcycle time. The flow used for repressurisation is constant to maintain a stable product flow. The sequence is designed to have the adsorber complete the repressure stage at the end of the subcycle time, this is then switched to the adsorption stage and another adsorber begins repressurising.

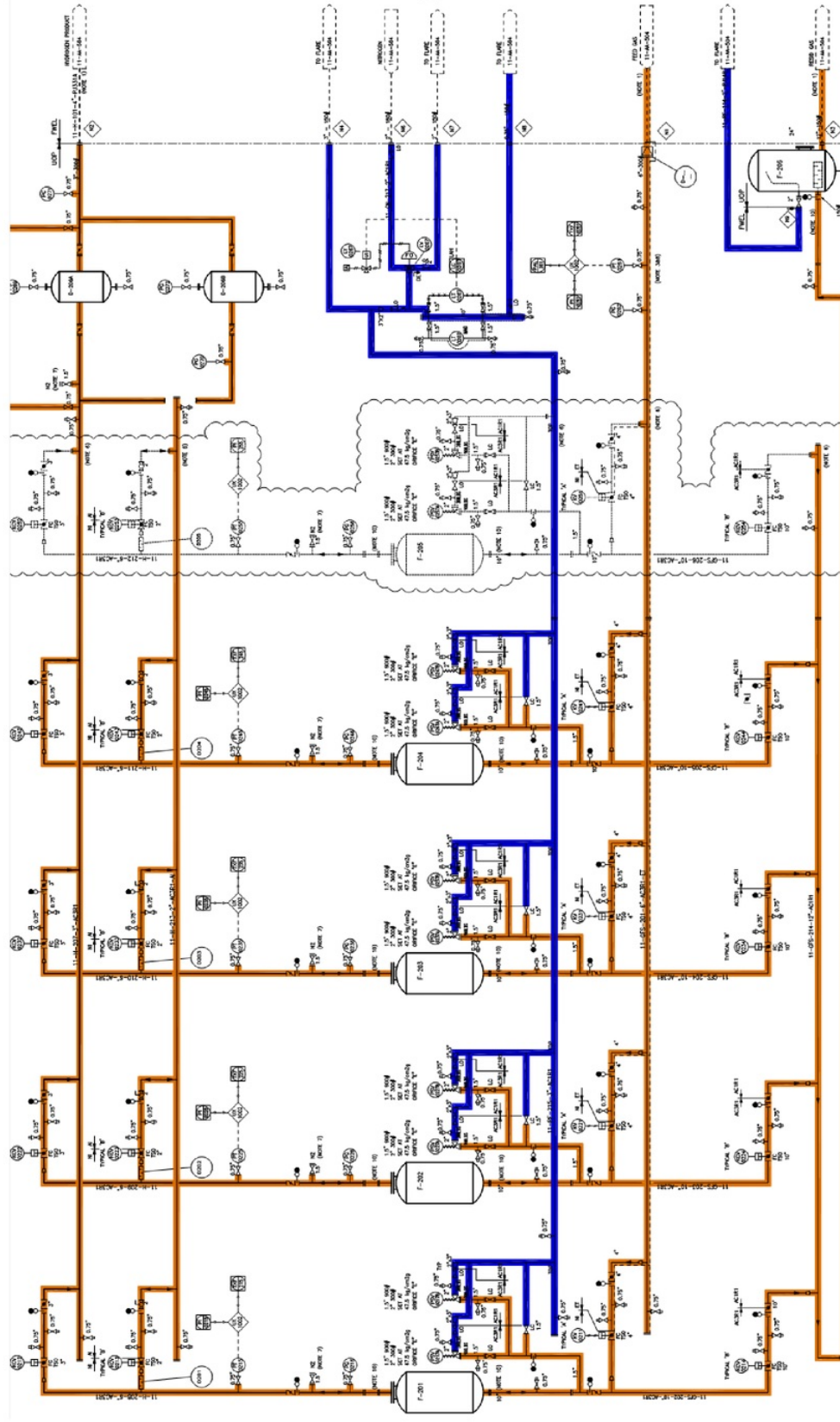


Figure 1: PSA Piping and instrument diagram

PSA feed

In order to provide a feed gas to the PSA skid, the reciprocating compressor 11-C-101 is used to increase the pressure of the feed gas from the LPGRU and CRU containing approximately 80% of hydrogen. The pressure is stepped up from 4.7 kg/cm²g to the 42.7 kg/cm²g required for the PSA skid. The unit is designed to process a maximum of 22000 sm³/h of gas and if this maximum flow is not met, then additional gas is taken from the LPGRU HP gas header to make up.

The compressor is designed to adjust its volumetric capacity to control the flow and this is done through a step-less control system known as Hydrocom. The loading on the compressor is controlled 11-FC-371 which sends a signal to the Hydrocom system. Upon start up, this output is set to 20% and can be increased from here in order to take in more LP feed gas. As this happens, the upstream pressure decreases as more gas is sent to the HRU and so the pressure controller 11-PV-391 closes off in response to maintain the upstream pressure and route the gas to the HRU. The ratio of feed gas between LP and HP gas is controlled through 11-PV-301A and 301B valves respectively, responding to the split pressure controller PC-301, in order to keep the feed gas to the compressor at 4.5 kg/cm²g. The controller opens 301A fully as the flow demand increases before opening the HP gas valve 301B to respond to any further increases. The compressor will trip upon a low suction pressure should the gas supply falter below 3.8 kg/cm²g.

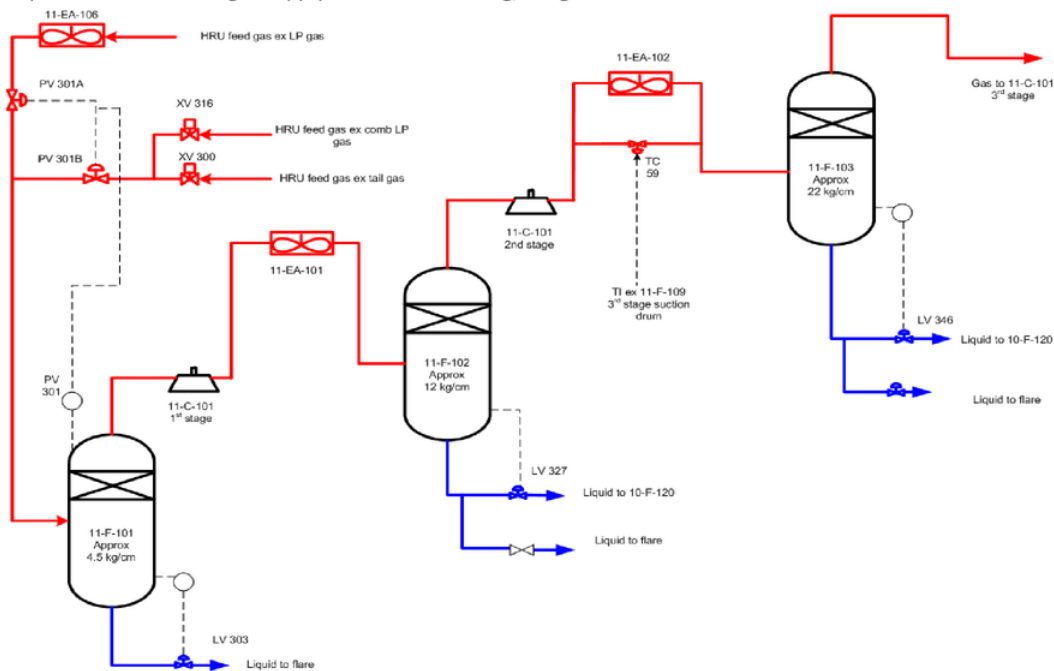


Figure 2: HRU overview

The compressor uses three stages to achieve the 42.7 kg/cm²g as shown in the above process diagram.

Stage 1 increases the pressure from 4.7 to 12.2 kg/cm²g, stage 2 then brings this up to 22.7 kg/cm²g and the final stage increases it to 42.7 kg/cm²g.

The loading is achieved through the use of the 22 Hydrocom suction valves and actuators. The valves are designed to spill back gas internally within the compressor. Depending on what load is needed, the suction valves open and allow a certain amount of gas to exit the cylinder before closing, leaving only some to be compressed during the compression stroke. The combination of these suction valves and the amount of time they are left open changes depending on the compressor loading chosen by the Hydrocom system.

Following the completion of the third compression stage, the high pressure gas is sent to 11-F-104A to allow any liquid butane to condense out and be removed from the system. This prevents the butane from entering the PSA skid and is instead exported to the butamer unit or spheres.

Should the PSA unit trip for any reason, the compressor can be used to send hydrogen of reduced purity (about 80%) to the hydrogen header at a reduced rate.

Product

The hydrogen product exits the PSA skid through a 4" line where it is sent to the LPGRU unit limits and then on to primarily Hydrotreater 1 and then Hydrotreater 2, depending on demand. If the PSA has tripped it can be bypassed and the compressor will send the mixed LP and HP gas directly into this line.

3. Specification

As The project is to be based on Pembroke refinery, it must follow the site-specific guidelines and regulations for projects on this refinery.

3.1 Detailed Design Specification

- The project must satisfy the ability to control the core features of the PSA unit.
- The adsorption stage must last for 135 seconds.
- A supply pressure of 4.2kg must be achieved for the hydrogen supply pressure, this is because the actual 42.7kg supply pressure used in the field is extremely high. For testing purposes and to satisfy health and safety, the pressure within the skid will be dropped by a factor of 10 for this equipment.
- The 4-bed system must operate continuously with staggered cycles. A manual ESD stop and start must be present. The stop button must vent out excess pressure and return the system to the start of the first cycle.
- The pressure of each vessel must be monitored by four pressure transmitters. Each pressure transmitter must act as indication and a trip system to prevent over-pressuring of the vessels.
- If a trip function is activated, the system will perform the same function of activating the ESD (Emergency Shutdown) button.
- Whilst a bed is in the adsorption stage, the other three beds must be performing the other sub-cycles of the process. (Equalisation, Providing Purge, Depressurising, Purging and Re-pressurising.
- The system must be able to control the sequence of opening and closing all 16 valves on the four vessels.
- Indication of the valve positions must be present to understand what current cycle the system is on.
- The system must be ergonomic enough to be functional within the workshop environment.

A good detailed spec

3.2 Timing and Budget

The project will need to be completed by April 2018 with all design, construction and testing finalised. The main bulk of the design will be research into how the system operates. Once this is determined, a method of achieving this operation will need to be chosen, details of this will be in the project plan section.

The budget has been set to £800 for the cost of all parts, including parts and equipment to be used but not time.

4. Testing Plan

Following project construction, the system will need to be tested against the Detailed Design Specification. Points that are conformed to will be noted and any failed points highlighted. From here, any improvements that could be made to achieve the complete DDS will be investigated. Any problems will become apparent during the test and an effort to rectify these will be made.

The first test will be to ensure that each vessel can make one complete cycle. At various stages during the cycle the valve positions will be checked against the valve position sheet to ensure correct functionality.

The second test will be to allow the system to run continuously for 10 cycles without faltering. Once this is complete, the ESD button will be pressed to ensure the system shuts down appropriately into what would be a safe condition.

The third test will include testing the high pressure trip settings on all four vessels. On activation of the trip, the vessel in question should vent all excess gas out the flare line.

Throughout the testing process, the indication and start functions will be checked and each cycle/subcycle timed to ensure it is correct. Failing to meet the correct valve timing will mean the pressure cannot be effectively 'swung' between vessels and results in a system failure.

5. Project Plan

In order to plan accordingly, a gant chart was made to show progress throughout the project. The chart is shown below with a key at the bottom for differentiating between the plan.

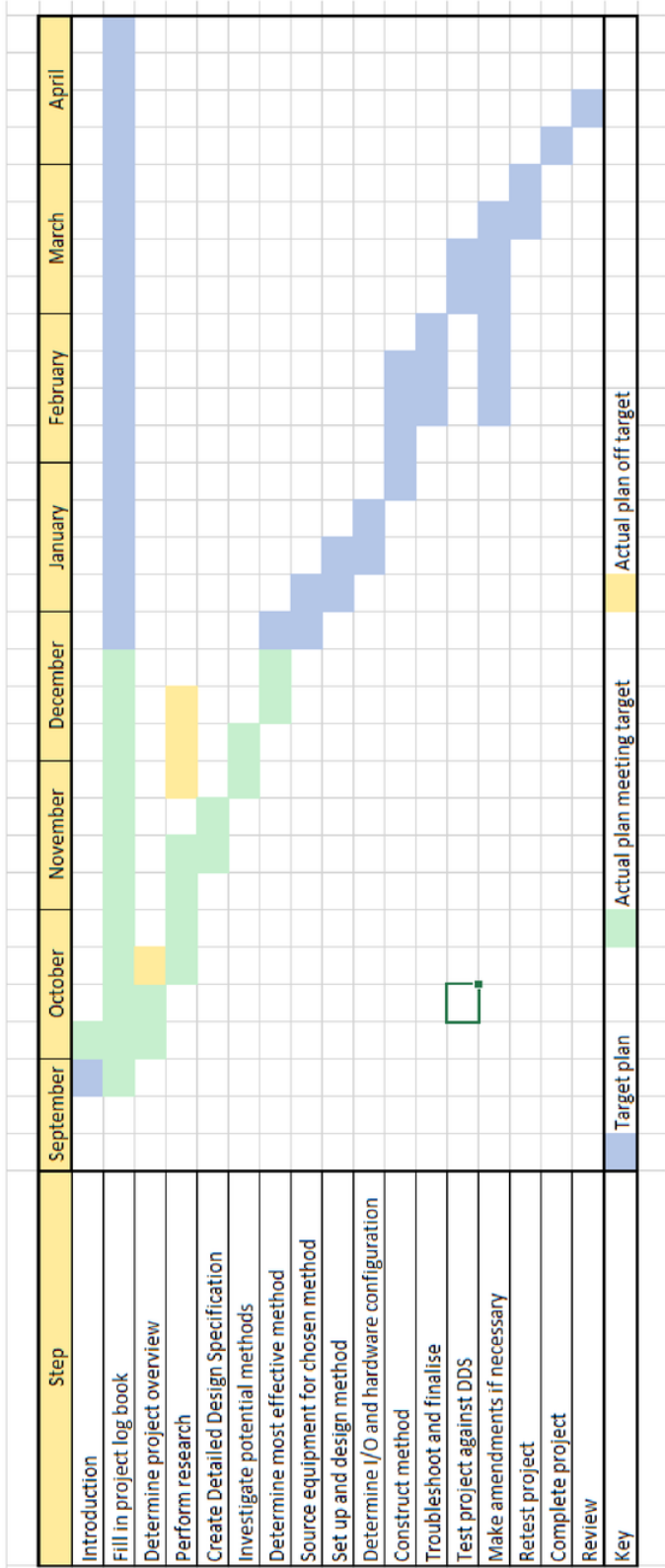


Figure 3: Project Gant chart

Very good use of Gant chart for project management comparison.

6. Potential Project Methods

6.1 Method One – Relay Logic

The first method is to carry out the control using relay logic. This will involve hardwiring the entire valve sequencing system, using timers and relays to cycle the adsorber beds through the different stages.

6.1.1 Advantages

The advantages of such a system as this is the ability to physically see the changes and the switching of the relays. It also gives an indication of what point in the sequence the valves are in as each state of the relay can physically be seen without the need of travelling into the field to look at each valve individually. This would typically be based with an array of relays and timers in the racking room.

Should any problems arise after system commissioning, the maintenance team would be able to individually swap out relays that fail. Identifying the faulty relay could be performed by referencing a relay state diagram, showing the switch state of each relay at every point during the cycle.

6.1.2 Disadvantages

Due to the nature of the system, all four beds require four valves each, with an open and close for each. This leads to 32 separate discrete input/outputs required. Multiple relays and timers will be needed for each one of those i/o to create the logic gates needed for the cycle. The complexity means a lot of physical hardwiring and the space that this will take up is far greater than the space available in the workshop.

The reliability of the system will become questionable due to the large number of components, if one fails, the complexity of the system would slow down fault finding and increase down time of the PSA skid. As the PSA skid provides 99.9% pure hydrogen to multiple other units on the refinery, failing to provide the gas greatly affects the overall refinery performance. A lower mean time between repair and higher downtime means this impact is more frequent and for longer periods of time.

6.1.3 SWOT Analysis

Strengths	Weaknesses
Visible indication of switching.	Very complex and occupies a lot of space.
	Lots of Hardwiring.
	Lots of components to fail.
Opportunities	Threats
Can be developed and expanded with more hardwiring.	A PLC performs the same task but better and in a much more compact form.

6.2 Method Two – PLC Ladder Logic

This method involves using a programmable logic controller to control the large amount of inputs and outputs required by this project. This will eliminate the need for relays and a lot of the hardwiring.

6.2.1 Advantages

A PLC is very small in comparison to a large array of relays and allows an entire program to be contained within a very small space, the only hard wiring is to the inputs and outputs. The PLC can also communicate with other controllers nearby and pass information to and from equipment such as a HMI (Human Machine Interface).

The PLC program is fully customisable and improvements can be made over time, security settings can also be placed to prevent it from being tampered with.

Trip amplifiers will not be needed as an analogue input card can be mounted.

6.2.2 Disadvantages

Using purely ladder logic to achieve the outcome means the program will be very complex and occupy a lot of memory within the PLC itself.

6.2.3 SWOT Analysis

Strengths	Weaknesses
Compact within the PLC.	If the PLC itself fails, the entire system fails.
Less hardwiring.	Very complex program.
Less components to fail.	
Opportunities	Threats
Ability to modify the program with ease.	Could be come outdated by better PLC systems.

6.3 Method Three – PLC Sequencer

This method is similar to method two as a PLC is used, however the programming will be done slightly differently and will be in the form of a sequencer. A table of inputs and outputs is sequenced through and translated into the physical inputs and outputs of the PLC. Different parameters and conditions can be set for each set in the sequence and it can allow for a timer between steps.

6.3.1 Advantages

Advantages are similar to that of method two, however the main benefit of this method is that the program is much smaller and less complex. This means that it takes up less memory and is easier to fault find if maintenance personnel are called to fault find an issue at a later date.

6.3.2 Disadvantages

If the PLC fails, the entire system fails.

6.3.3 SWOT Analysis

Strengths	Weaknesses
Compact program uses less memory.	If the PLC itself fails, the entire system fails.
Not as complex a program to fault find.	
Less hardwiring.	
Less components to Fail.	
Opportunities	Threats
Ability to modify the program with ease.	Could become outdated by better PLC systems.

Good analysis of method hypothesis.

6.4 Solution Conclusion

Overall, when reviewing the SWOT analysis, method three comes out on top as the most efficient, compact and long lasting option. Developing a PLC program to incorporate the best traits of ladder logic along with a sequencer provides versatility and efficiency. It also severely reduces the amount of logic gates needed within the program and makes it easier for fault finding.

This method will be chosen and the program will be designed to suit.

7. Final Solution and Implementation

7.1 PLC Sequencer

The final solution has been determined to be using a PLC program with a sequence function to achieve the project objective. In order to develop this, extensive research into the option of the 4-bed PSA skid must be performed.

Through referencing the operations manual, the 16 valve sequence has been worked out. To help visualise the sequence and each stage, the table on the next page has been developed (shown in figure 5).

The top table shows the stages that each vessel goes through and the overlapping points at which each stage affects any other. This can then be seen in the larger lower table which shows exactly what valves are opening and closing in relation to the stage. This table is crucial because many stages involve opening a link between vessels, here it can be seen when these links are open allowing the passage of gas between vessels.

The five second increment per cell is important as it allows this table to also represent the time at which the valves are open or closed for. These times are taken as instantaneous for the purpose of testing the program, Valve opening and closing times are not included.

Valve Tag	Vessel	Description
KCV-101	F-100	Feed gas supply
KCV-102	F-100	Pure hydrogen output
KCV-103	F-100	Common link between vessels
KCV-104	F-100	Vent to resid gas/flare
KCV-201	F-200	Feed gas supply
KCV-202	F-200	Pure hydrogen output
KCV-203	F-200	Common link between vessels
KCV-204	F-200	Vent to resid gas/flare
KCV-301	F-300	Feed gas supply
KCV-302	F-300	Pure hydrogen output
KCV-303	F-300	Common link between vessels
KCV-304	F-300	Vent to resid gas/flare
KCV-401	F-400	Feed gas supply
KCV-402	F-400	Pure hydrogen output
KCV-403	F-400	Common link between vessels
KCV-404	F-400	Vent to resid gas/flare

Figure 4: Valve tags and descriptions

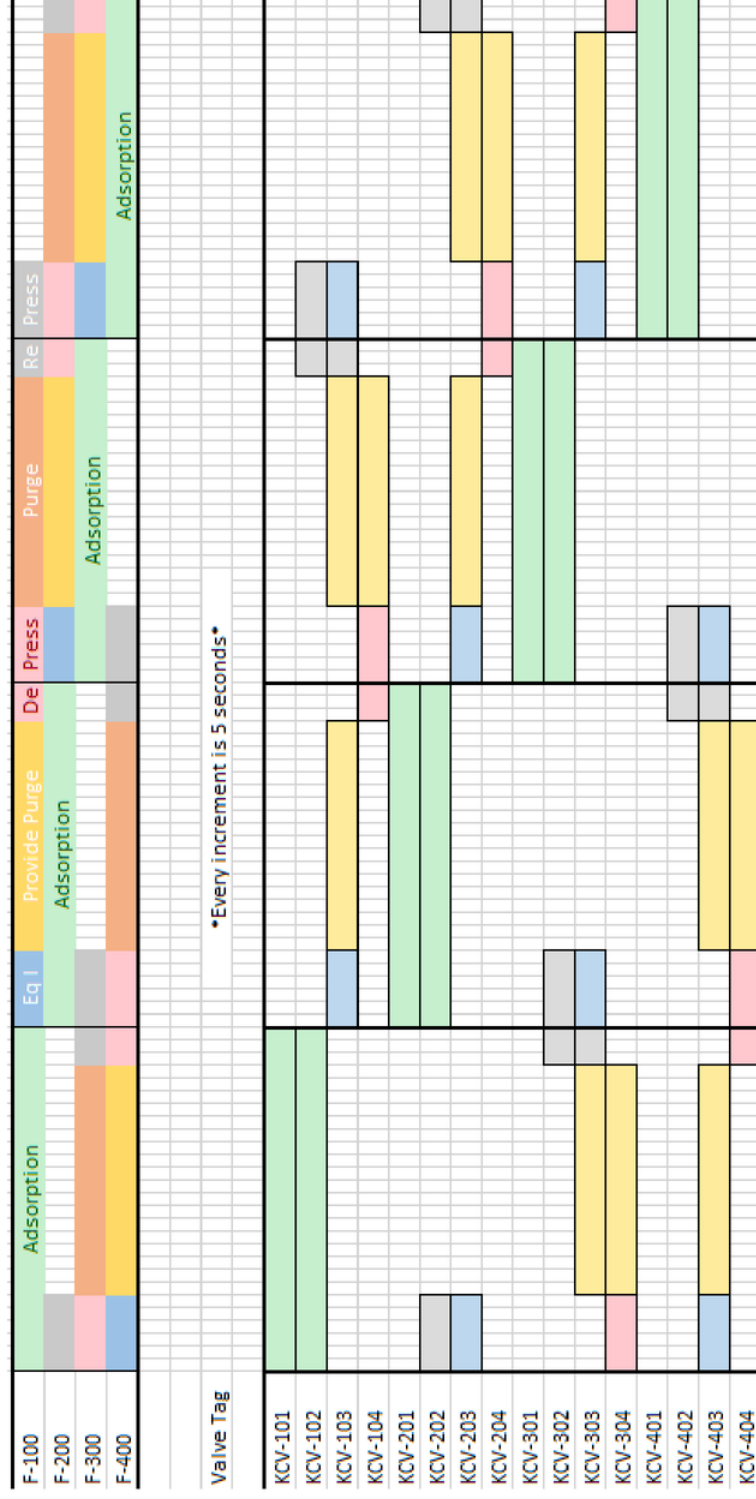


Figure 5: PSA valve position sequence

7.2 Equipment

Programmable Logic Controller

The equipment for this project must be suitable for this sequencing task, it must also comply with Valero's site standard for PLCs; Manufactured by Allen Bradley.

The PLC sourced and used is the Allen Bradley SLC500 with the 5/04 CPU, this allows programming to be performed with the electronics workshop programming laptop using the program RS Logix 500.



Figure 6: SLC 500

Figure 6 displays the Allen Bradley PLC which is a rack mounted unit. The cards were selected to allow analogue inputs and discrete relay outputs as required by the pressure transmitters and valves respectively. The CPU can be seen currently to be set in REMOTE mode, this allows the computer to automatically set the PLC to program or run mode as required when making changes to and downloading the program.

Slot	Part Number	Description
0	1747-L541C,D	5/04 CPU - 16K Mem. OS401 Series C
1	1746-IN16	16-Input (SINK) 24VAC/DC
2	1746-IN17	16-Input (SINK) 24VAC/DC
3	1746-NI8	Analogue 8 Channel Input - Class 3
4		
5	1746-OW16	16-Output (RLY) 240 VAC
6	1746-OW17	16-Output (RLY) 240 VAC

Figure 7: PLC card details

The order of cards shown in figure 7 ties in with the layout of the PLC rack in figure 6, slot 4 can be seen to be left blank, this will be a spare slot and is to have a protection cover on.

Pressure Transmitter

The PSA system is originally designed to be supplied with a feed gas pressure of 42.7kg/cm², for this system, this will be reduced by a factor of ten. This means the measuring elements must be capable of measuring a pressure in excess of 4.27kg/cm². The range of the transmitter will need to be calibrated to read from 0 to 10kg/cm² (gauge) pressure. This spectrum is enough to add in a trip point above that of the maximum supply pressure.

A trip point of 6kg/cm² is to be set, this is to include a dead-band of 0.5, bringing the healthy reset value down to 5.5kg/cm².

When selecting the transmitter, it must comply with the refinery's site standard and the ATEX hazardous area certification. To comply with this, the hazardous zone classification drawing must be consulted to determine the type of zone where the transmitters would be located, at the PSA skid on plant 11, the HRU.

The drawing 50-ZA-001-14 can be found in the Appendix.

Referencing the drawing shows that the location of the PSA is mainly a zone 2 area, meaning that a flammable atmosphere is only present for short periods of time and infrequently, being unlikely to be present. However, the type of gas being dealt with is hydrogen, a IIC gas, this means that the equipment must also be rated for dealing with this gas type.

The manufacturer site standard for pressure transmitters are Rosemount. One of these transmitters was sourced from the instrument stores and inspected, being checked against the ATEX initial inspection checklist. The transmitter obtained is shown in figure 8.



Figure 8: Rosemount pressure transmitter.

This transmitter will be used in the testing process to activate the trip setting and so must be set up accordingly. The output is 4 to 20 milliamps, based upon the calibrated range. This will also mean the raw analogue value will need to be scaled within the PLC program in order for the actual pressure to be interpreted.



Figure 9: Powered up with communicator connected.

The transmitter was powered up using the instrument workshop 24V power supply shown in figure 9, however an extra resistor was needed in series and so was soldered into the power leads. The 250 Ohm resistor is used to make the output at the Distributed Control System (DCS) a 1 to 5 Volts signal. Traditionally, this is done at the safe area side of the instrument loop. The reasoning behind it is due to the long distances of cabling at the refinery being subject to Voltage drop and noise. This will not affect the current signal as much and the 1 to 5 Volts is then used for communication purposes to the DeltaV DCS system.

$$V = I \times R \rightarrow [4mA \times 250 = 1V] \text{ and } [20mA \times 250 = 5V]$$

A HART (Highway Accessible Remote Transducer) communicator was used to set up the smart transmitter. The communicator test leads connect directly in parallel with the power leads and so there is not interruption of power when setting up. With communication established, the transmitter tag could be altered to '11-PT-101' and the device was now ready for calibration.

First the zero check was performed by opening up the high side vent to atmosphere and allowing the pressure to equalise across the cell. The zero was then adjusted electronically as shown in figure 10 on the next page.



Figure 10: Zeroing transmitter

The current transmitter range was set to 0 to 5kg/cm², therefore it needed to be adjusted to the required range of 0 to 10kg/cm². To do this, a pressure calibrator was connected up to the high side of the transmitter cell. Prior to transmitter calibration, it was checked that the test equipment was within calibration and the internal sensor was zeroed as shown in figure 11.



Figure 11: Sensor zero

The transmitter was set to a range of 0 to 10kg/cm² and then pressure tested using the calibrator. Figure 12 shows the range adjustment using the HART communicator.



Figure 12: Setting upper range value

With these values set, the transmitter could be pressure tested and loop checked throughout the range to ensure 0 kg/sqcm resulted in an output of 4mA and 10 output 20mA. Shown in figure 13.

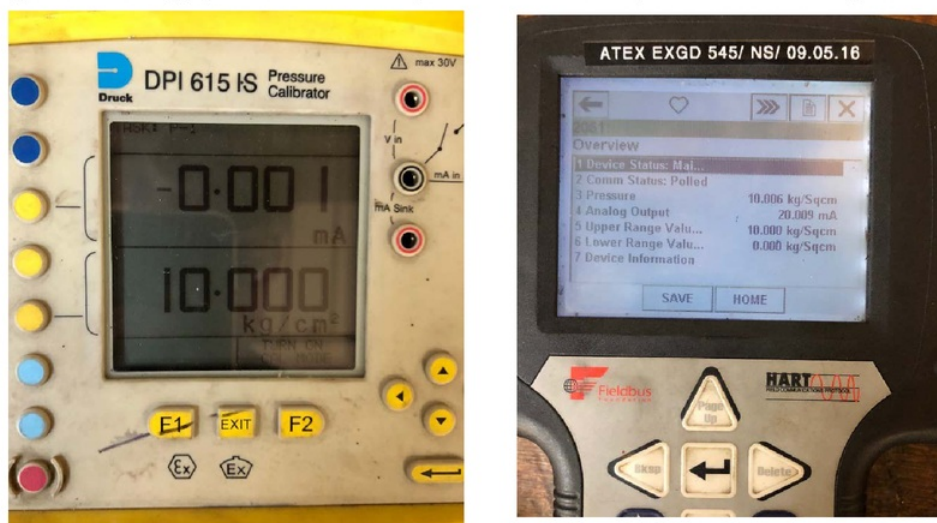


Figure 13: Full scale

At full scale, the current output is approximately 20mA, within the 2% tolerance for error.

7.3 Program Design

This project highly relies on the design of the program in order to operate the valve sequence effectively and meet the criteria of the detailed design specification.

To achieve this, the program RSLogix500 was opened and the PLC project created, The RS232 communication lead was connected to the PLC to allow the program to recognise what device was online and which cards were in the rack. Figure 14 shows the I/O configuration with the cards.

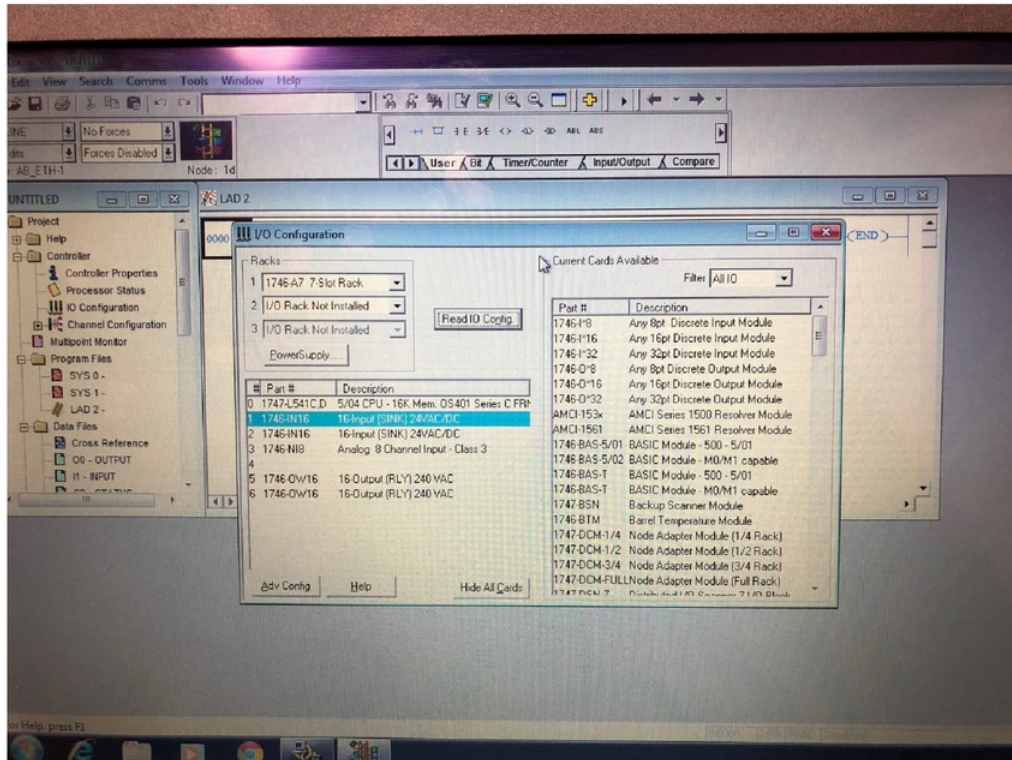


Figure 14: I/O configuration

Once the I/O was set up, the program needed to start the sequence. A traditional start-stop latch was added with a start flag to be used to initiate the sequence. The method to achieve this was through the use of a timer to trigger the shift in position of the sequence.

As the valve sequencing table shown in figure 5 shows an increment of 5 seconds between the steps, the entire sequence could be combined into sets of three 5 second intervals, making the total 15 seconds, this is to be used for the timer. To set this up, the start and stop bits were configured as inputs. START; I:0/0 and STOP; I:0/1. The START_FLAG was configured as a binary bit and occupied the internal memory B3:0/0.

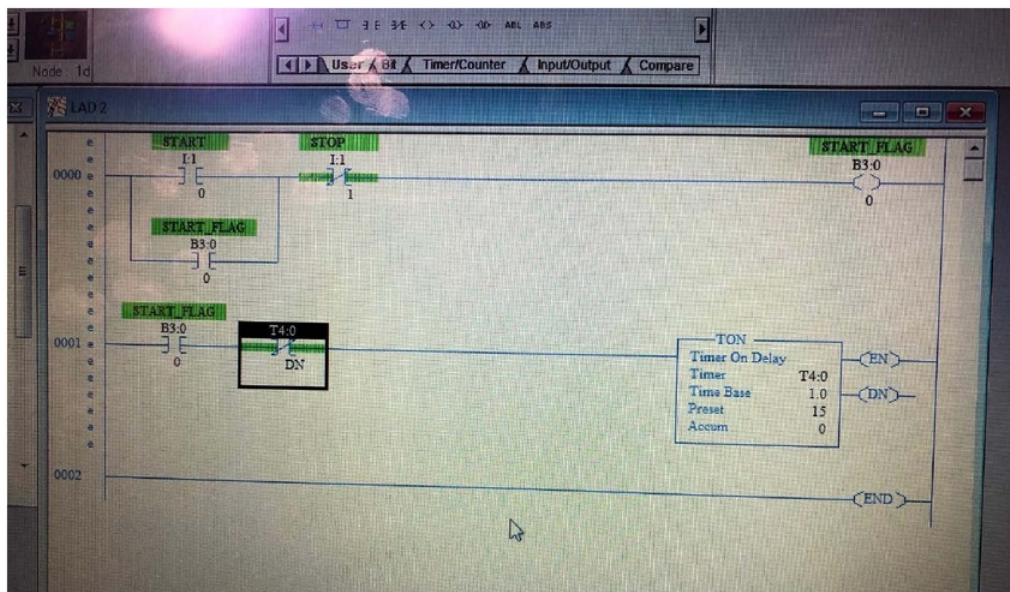


Figure 15: Timer configuration and start-stop latch

The timer T4:0 can be seen in figure 15, the preset time is set to 15 seconds and the start flag triggers the timer and 'Done' signal breaks the timer.

The data file B9 was used to house the sequencing data. As the maximum length of the sequence was 36 and there were 16 valves, the file was configured to suit and the values from the valve sequencing table were individually transferred and set to an output of 1 with intervals of 15 seconds, shown in figure 16.

Offset	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
B9:1	0	1	0	0	1	0	0	0	0	1	1	0	0	0	1	1
B9:2	0	1	0	0	1	1	0	0	0	0	0	0	0	0	1	1
B9:3	0	1	0	0	1	1	0	0	0	0	0	0	0	0	1	1
B9:4	0	1	0	0	1	1	0	0	0	0	0	0	0	0	1	1
B9:5	0	1	0	0	1	1	0	0	0	0	0	0	0	0	1	1
B9:6	0	1	0	0	1	1	0	0	0	0	0	0	0	0	1	1
B9:7	0	1	0	0	1	1	0	0	0	0	0	0	0	0	1	1
B9:8	1	0	0	0	0	1	1	0	0	0	0	0	0	0	1	1
B9:9	1	0	0	0	0	1	1	0	0	0	1	1	0	1	0	0
B9:10	1	0	0	0	0	1	1	0	0	0	1	1	0	0	0	0
B9:11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 16: Data table inputs

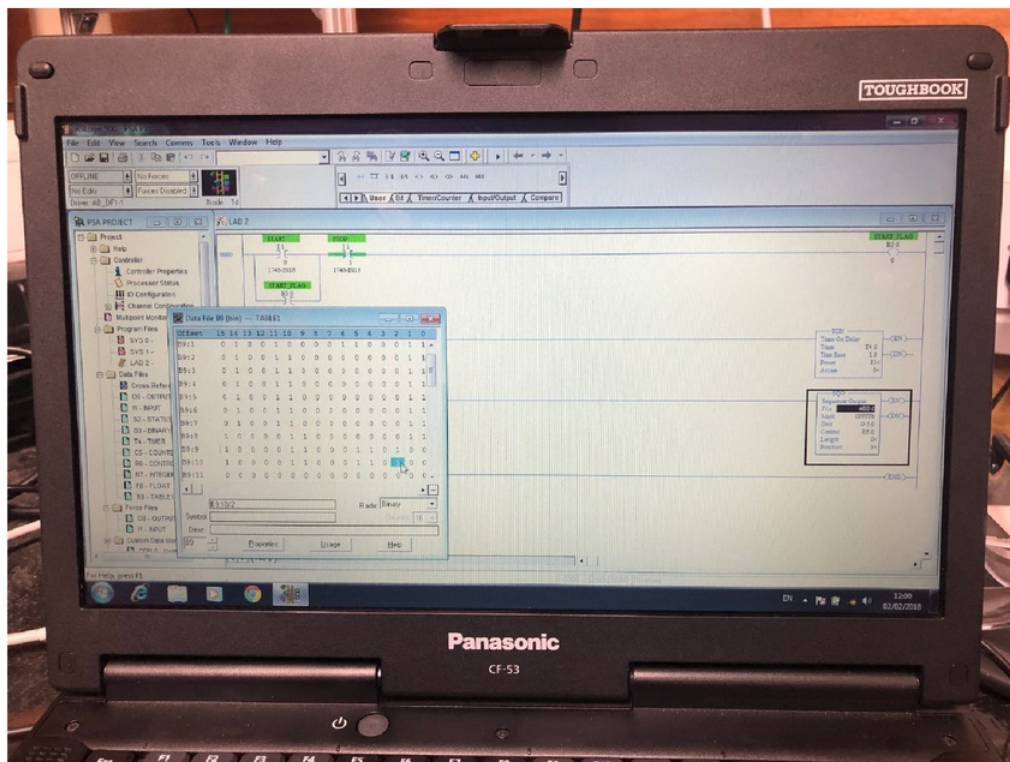


Figure 18: Sequencer Output

The sequencer output function was added and set up accordingly to pull data from the table B9 and write the values to the relay output card O:5.0. The length was set to 36 and the control file used was R6:0. The full sequencing table can be viewed in the program report in the Appendix.

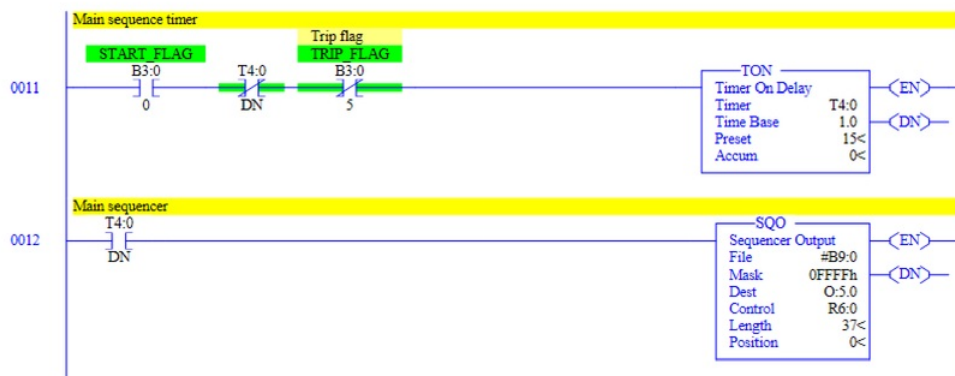


Figure 17: Main sequence

The ladder logic was designed to allow the timer completion signal to initiate a shift of the sequencer, as shown above in figure 18.

The next step is to add the analogue outputs and configure the scaling before adding the trip function.

Analogue Scaling and Trip Function

The scaling is required to convert the raw 4 to 20mA signal obtained from the four pressure transmitters into a scaled value of 0 to 10.

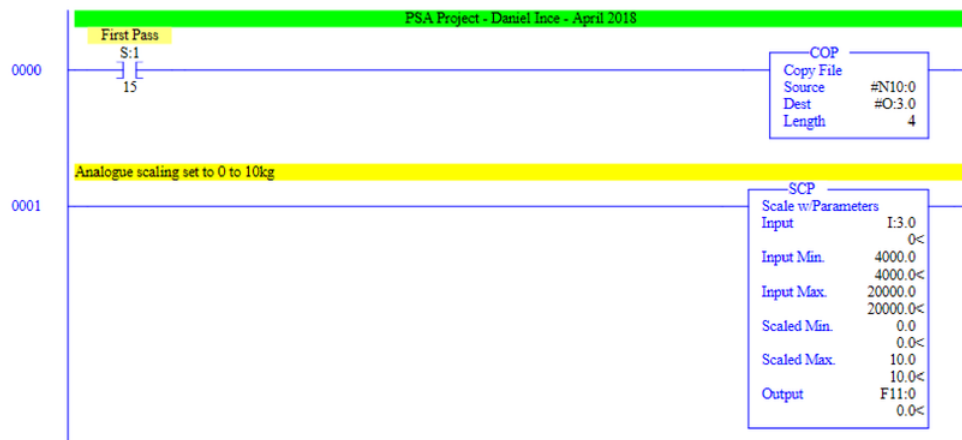


Figure 19: Analogue scaling

An example of the analogue scaling is shown in figure 19, the input minimum and maximum were set to 4000 and 20000 respectively. However prior to this, on the First pass [S:1/15] of the program, the analogue configuration [N10:0] was loaded into the destination O:3.0. This is the file which sets the range as 4 to 20 mA. The configuration in radix binary for this particular set up is:

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	1	0	1	1	0	1	0	0	0	1	0	1

The analogue scaling was repeated for all four pressure transmitters, however as a temporary measure, the other three values were set to a value of 0 to 1 for the scaled min and max as a result of performing online tests. In figure 13, it can be seen that the output of these values is F:11/0, this destination then allows a trip function to be added to look at the values.

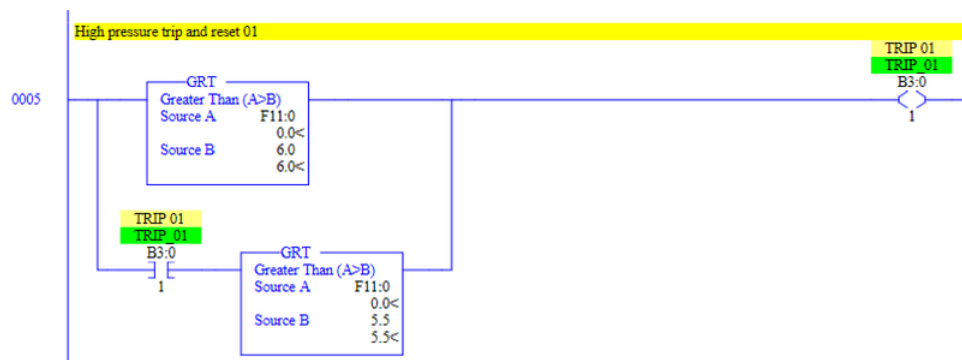


Figure 20: Trip function

The first high pressure trip is shown above in figure 20. A greater than function block was added to look at the scaled value for each pressure transmitter, in this case F11:0/0. Source A is set to the value in the destination and is compared against the user defined value for Source B. This is the trip set point set at 6kg/cm². Should this become true, the binary bit TRIP_01 [B3:0/1] becomes true. A latch is made to maintain the trip signal once triggered but another comparator is added to ensure the deadband is 0.5, resetting the signal once F11:0 falls below 5.5. This process was repeated for all four trip signals.

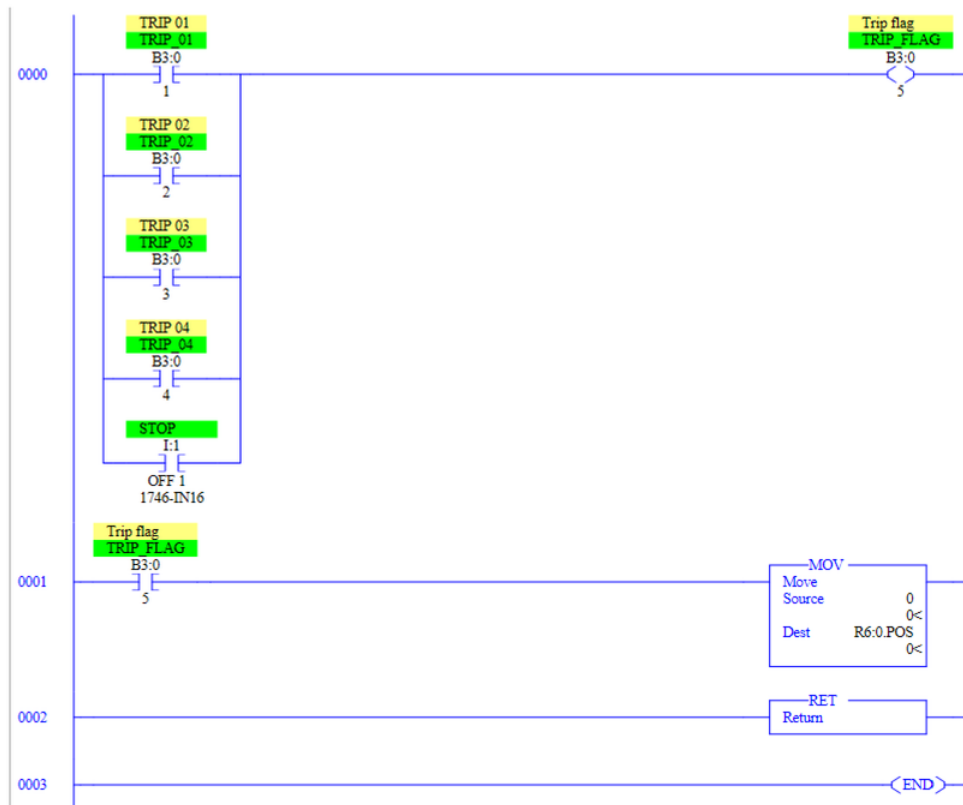


Figure 21: Trip Ladder

Following the trip rungs, the program is asked to jump to the sub routine shown in figure 21. This is a separate ladder which contains all four of the trip signals and combines them into a single trip flag [B3:0/5]. It can be seen that the stop bit is also included in the OR gate on rung 0. This allows the stop button to activate the same function as a trip, meeting the specification.

The trip flag resets the position of the main sequence by accessing the position section of the R6:0 control file for the sequencer and setting it to 0. This will ensure the sequence can begin again following a high pressure trip or stop button press. The sub-routine is then asked to return to the main program.

Purge sequence

The objective of triggering a trip upon high pressure is to allow this pressure to escape and safely shut down the equipment, therefore the trip flag must initiate an action to release this high pressure and stop the sequence.

After evaluating the method to achieve this, it was determined that another sequence should be started, known as the purge sequence. This sequence is to instantaneously open all vent valves [KCV##4] for all four vessels and also open up the link pipes [KCV##3] between vessels to allow for a faster equalisation of pressure.

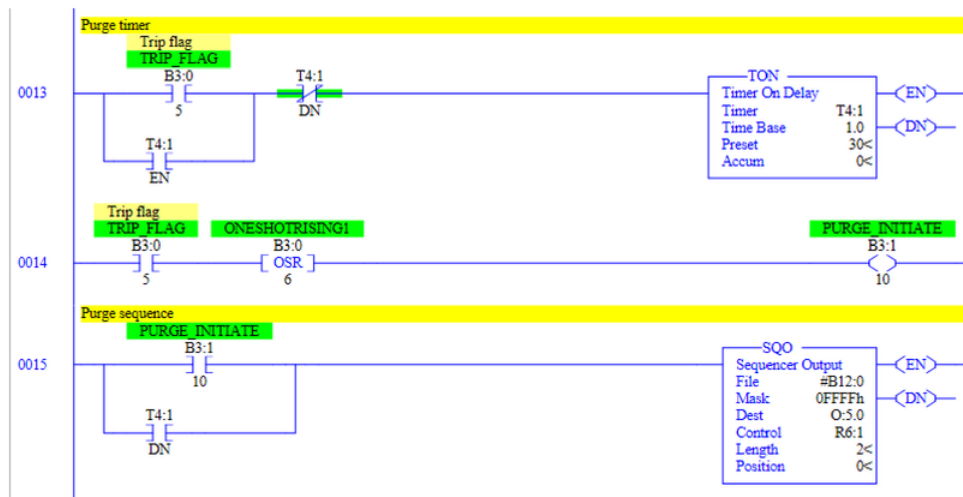


Figure 22: Purge rungs

Rung 13 in figure 22 shows the trip flag being used to activate the 30 second timer, this flag is also used to energise the Purge_Initiate output coil [B3:1/10]. This will then instantly switch the purge sequencer output position upon activation, seen on rung 15. The one-shot-rising bit was added after the results of online testing.

	Data File B12 (bin) -- PURGE -- Purge sequence data table																
Offset	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0	(Symbol) Description
B12:0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0	0	
B12:1	0	1	0	0	1	1	0	0	1	1	0	0	1	1	0	0	
B12:2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Figure 23: Purge data table

The purge sequencer output is loaded upon activation and overwrites the outputs to the valve, closing all valves except the link and the vent, as seen with the three sequence positions in figure 23. This allows a minute purge of the system before the final position in the sequence is achieved, leaving all valves in a closed state and requiring a safe condition and the start button to be hit again before the main sequence starts. This concludes the end of the program.

8. Testing

8.1 Preliminary

After initial development of the program, a preliminary test was carried out to check smooth operation of the program and iron out any runtime errors with online troubleshooting and corrective actions. The issues found are detailed below.

Preliminary test issues and outcomes

- When testing the sequence, PLC automatically switched on the sequencing outputs from the first position before the start button was pressed. Action: Data table B9 extended to a length of 37 and all values shifted along a position to leave position 0 with all outputs of 0. When loading program again, all valves remained closed until start button pressed. The sequencer output function was also extended to 37 to match that of the data table.
- Upon activation of the trip function, the purge sequence did nothing. Action: Added normally closed trip_flag contact on the start-stop latch for the main sequence, this allowed the start_flag to be cleared upon a trip and allowed the purge sequence to write to the outputs.
- Upon trip activation, purge sequence only switched position once, not being switched again after 30 seconds, therefore vent remained open continuously. Action: Added a One-shot-rising bit after the trip flag on rung 14. This meant a pulse was sent to the purge initiate once the trip flag was brought in, preventing the signal from being held on to the sequence.
- Main sequence did not run due to constantly being in a trip condition. Action: Adjusted scaled values of all analogue outputs to 0 min and 1 max for the purpose of testing the main sequence. The issue arose due to a 'default' analogue value of 16mA being apparent during online testing as there was nothing connected to the four analogue inputs during sequence testing. This was higher than the set point and so remained in a trip state. Reducing the scaled value to one that was below the trip set point allowed the sequence to be fully tested. When testing the trip function, the scaling values were reset back to 0 to 10, and a current source was used to simulate the analogue signal.
- When activating trip, purge sequence switched to first position and then did not progress any further. Action: Trip flag was holding steady and not switching position value for purge sequence. Oneshotrising bit was added in purge initiate rung in order to pulse the sequencer to change positions.

8.2 Start-stop and Main Sequence Testing

To thoroughly test the system, the main part of the program; the valve sequence must be started and compared against the valve sequencing table.

Test number	Test action (Sequence testing)	Expected result	Actual result	Pass/Fail
1	Operating the start should begin the sequence.	Start_Flag becomes true. Main sequence switches to position 1. T4:0 begins counting towards 15.	Start_Flag becomes true. Main sequence switches to position 1. T4:0 begins counting towards 15.	
2	Sequence should shift position every 15 seconds. Check position during online test. Compare against current outputs for each position and check against valve sequence diagram.	All 37 sequence position outputs relate to the same outputs on the valve sequence diagram.	Every sequence position tied in correctly.	
3	Leave sequence on.	Sequence should loop round and continue without human intervention.	Sequence continually loops.	
4	During the sequence, hit the stop button.	Start_flag output should de-energise. Sequence should stop and the current position should reset to 0. Purge sequence should begin.	Output de-energises and sequence stops. Purge sequence begins.	
5	Observe purge sequence.	For 30 seconds, with KCV##3 and ##4 outputs energised for all four vessels. Once time has elapsed, all valve outputs should de-energise and purge sequence end.	Purge performed successfully following stop button activation.	
6	Following the stop button press and purge sequence completion. Operate the start button.	Sequence should start from position 0 having been reset.	Sequence restarted from 0.	

8.2 Trip Functionality and Safety Testing

Interlocks and trip systems were also tested with an individual testing check sheet.

Test number	Test action (Trip testing)	Expected result	Actual result	Pass/Fail
1	Connect a 4-20mA current source directly to analogue input 0. Raise value slowly to the set point of 13.6mA [6kg = 60% so $(16 \times 0.6) + 4 = 13.6$ mA trip set point. Repeat for input 1, input 2 and input 3.	Trip should not initiate below the set point of 13.6mA. Trip initiates once set point is reached.	Trip initiated at the set point.	
2	Raise then lower the mA signal to the analogue input to top scale and then down to 12.8mA falling.	Once trip has initiated, ensure it remains active throughout the range above the set point. It must also remain active until it drops below 12.8mA which is the deadband lower setting.	Trip flag remained active until current signal dropped below set point.	
3	Activate then deactivate trip instantly, observe main sequence position, purge sequence position and valve outputs.	When trip activates, the main sequence position should reset to 0 and start flag clear. Purge sequence position shifts to 1. Purge timer begins counting towards 15. For 30 seconds, with KCV##3 and ##4 outputs energised for all four vessels.	All desired results achieved. Purge sequence carried out regardless of the fact that the trip pressure was only present briefly.	
4	Observe purge sequence until completion.	Completion of purge sequence should leave all valve outputs de-energised, leaving the system in a safe condition.	Outputs de-energised ready for start of main sequence.	
5	Activate trip and maintain a trip condition. Check purge sequence.	Purge sequence should run in an endless loop so long as trip is still in.	Purge sequence loops while trip condition is active.	
6	Repeat all trip tests for all four trips.	All trips perform exact same function.	Testing criteria met.	
7	Attempt to operate start button while a trip is in effect.	Start function does not work due to interlock.	Start was inoperable.	

8.3 Testing Method and Description

To test the program, the communication lead was connected between the laptop and the PLC. While the PLC was left in remote mode, the program was verified on the RSLogix500 software and downloaded to the PLC. The online mode was selected and forces were enabled, to allow bits to be altered for the purpose of testing.

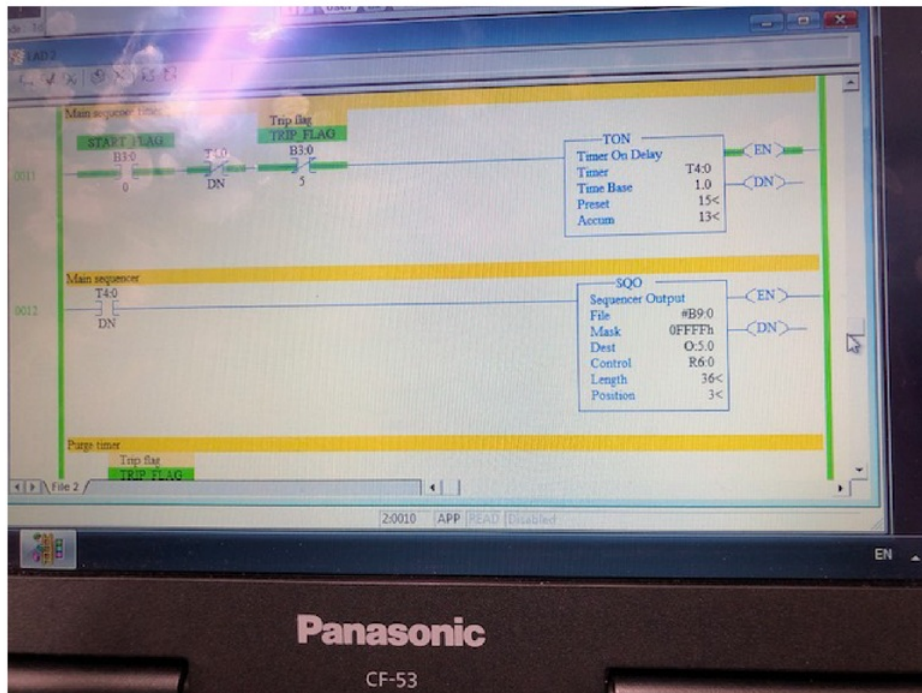


Figure 24: Online mode.

Whilst in online mode connections made and active can be seen to be highlighted green, allowing the logic to be analysed and troubleshooted if necessary. Figure 24 shows the sequence testing. The timer is active with the enable signal true, and the position of the sequencer can be currently seen at 3.



Figure 25: Sequence valve outputs

Figures 24 and 25 are of the same point in the sequence, it can be seen that outputs 0, 1, 10, 11, and 14 are enabled on relay output card 5. When comparing to the valve sequence diagram, these are the same valves which are requested to be open, proving this point in the sequence. This comparison was done for all 36 steps to ensure the sequence functioned perfectly with regards to valves.



Figure 26: Current source connected.

To test the trip points, a current signal source was obtained and connected to the analogue input positive and negative on card 3. The dial on the source allowed an exact percentage of the 4 to 20mA range to be achieved. This was effectively simulating the signal that the pressure transmitters would output directly to the PLC. Figure 26 shows the source connected directly to input 0 on card 3 [I3:0], to allow testing the analogue scaling and trip functionality for this input.

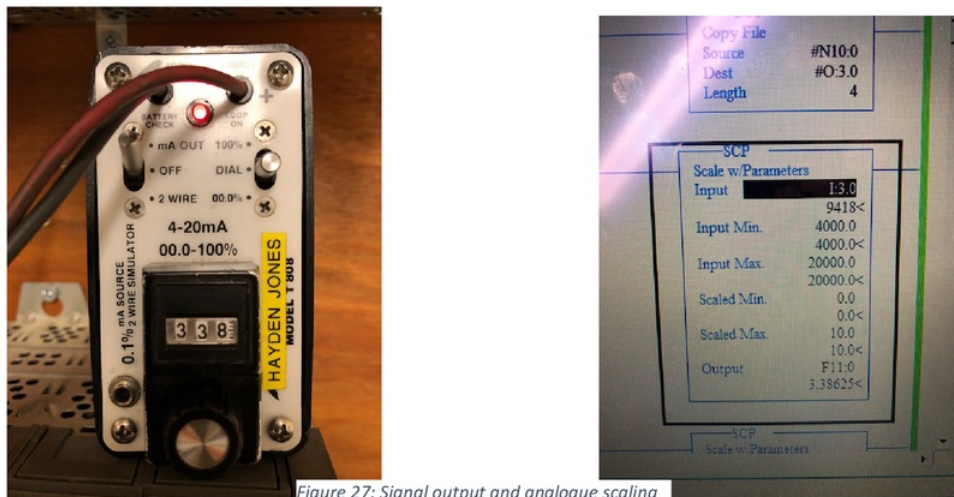


Figure 27: Signal output and analogue scaling

Figure 27 shows the source set to 33.8% of the range, this equates to 9.4mA and 3.38kg/cm², this is proven by observing the analogue scaling for this particular input at this time. This was proven for all four analogue inputs.

The trips were then tested individually. Figure 28 shows the output value raised to just below the set point, evident in the Greater than function blocks.

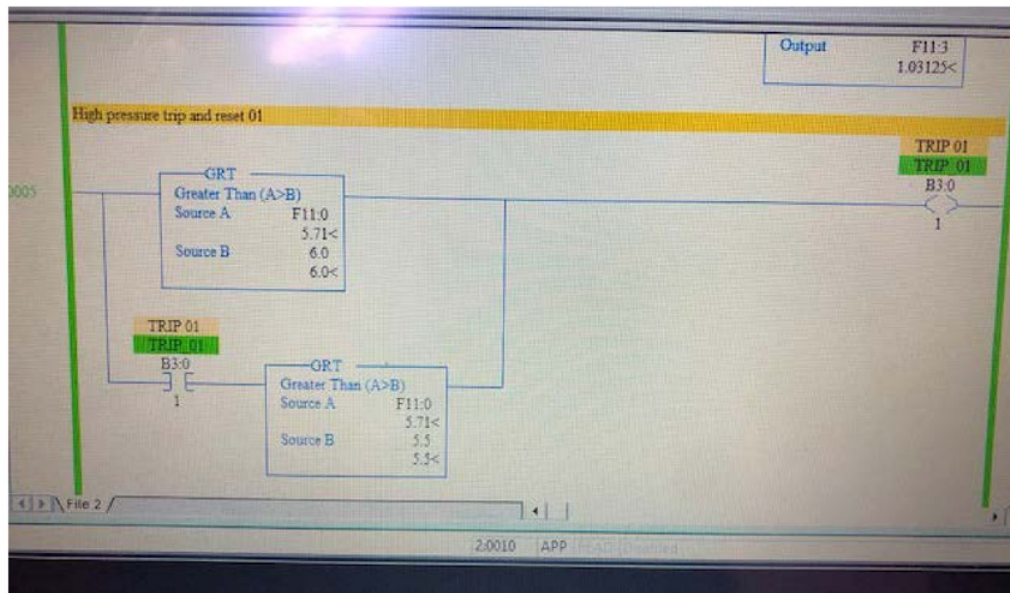


Figure 28: Prior to trip point

This performed as desired as it had not yet brought in the trip.

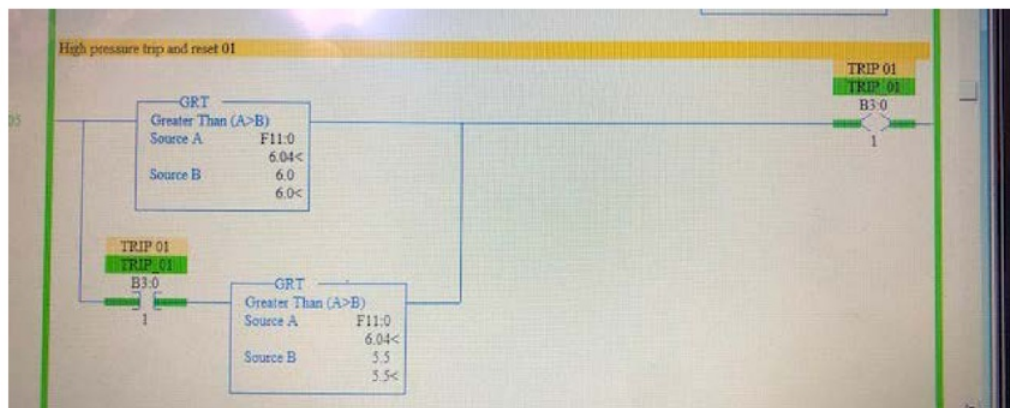


Figure 29: Trip set point reached.

Figure 29 shows the trip activated as the output has surpassed the set point. The trip_01 coil can be seen to be energised, proving this.

With the trip activated, figure 30 shows the initiation of the purge sequence, the position has shifted to 1, with the valves with outputs enabled being shown on the output card in figure 31.

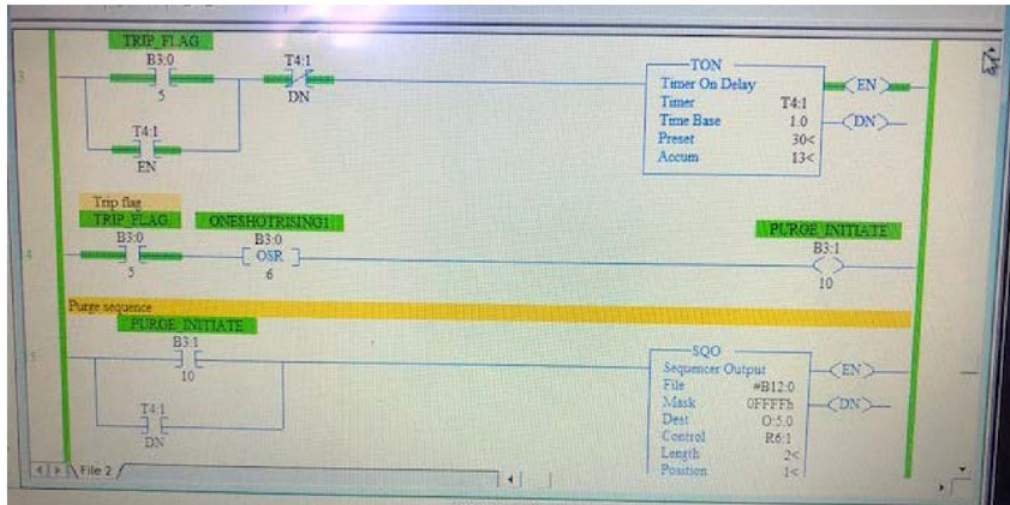


Figure 30: Trip and Purge

Figure 31 shows the valves open during the purging sequence. This lasted for 30 seconds.



Figure 31: Purge valve outputs

Following this, after the 30 second elapsed time, the sequence shifted to its final position and shut all the valves, leaving it in a safe state. This can be seen in figure 32.

All testing was checked against the valve sequence timing diagram and against the testing check sheets. Resulting in all tests completed successfully.



Figure 32: End of purge sequence

The test and analysis is very thorough and easy to understand. A good piece of work.

9. Project Plan Evaluation

The project involved planning out the different aspects of the task and setting a target to complete them by. A gant chart was made and regularly updated while also being reviewed to assess whether or not the project was falling behind target.

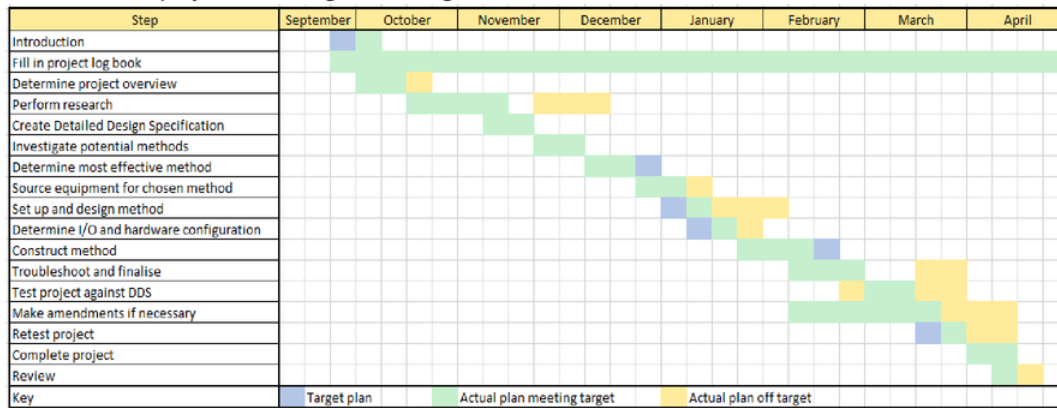


Figure 33: Final project gant chart

When evaluating the gant chart it is apparent that certain areas fell behind more than others. One of these subject areas in particular was the testing and troubleshooting. Due to the nature of the program, the system had to function reliably while also dealing with multiple sequencing data tables being enabled, reset and restarted. This meant a lot of testing and comparing was required to ensure the right timings were correct and that the correct valves were opening and closing when needed.

Overall, the project followed the plan pattern but more time was needed for troubleshooting and testing the project. A method to avoid this stray from the plan would be to plan more time for testing, or/also plan for more time designing the program itself. This would mean less time would be needed troubleshooting as it would be done earlier on in the design process. However, the project was finished on time and according to plan and so was successful.

10. Conclusions and Improvements

Overall, the project has been successful as it a functioning product has been developed which serves a purpose in the industrial environment. The greatest benefit of this type of project has been learning the equipment and software used as a site standard at this refinery. Skills with the PLC have been improved along with the ability to troubleshoot logic problems. The use of a sequencer is not a common solution and proved effective in this instance while also providing some challenging and broader potential options to achieve the same goal.

Below is the comparison to the detailed design specification. It can be seen that all but one was sufficiently achieved. The exception can be easily rectified and is not a functional failure of the program itself. The green text indicates criteria that has been passed fully.

- The project must satisfy the ability to control the core features of the PSA unit.
- The adsorption stage must last for 135 seconds.
- A supply pressure of 4.2kg must be achieved for the hydrogen supply pressure, this is because the actual 42.7kg supply pressure used in the field is extremely high. For testing purposes and to satisfy health and safety, the pressure within the skid will be dropped by a factor of 10 for this equipment.
- The 4-bed system must operate continuously with staggered cycles. A manual ESD stop and start must be present. The stop button must vent out excess pressure and return the system to the start of the first cycle.
- The pressure of each vessel must be monitored by four pressure transmitters. Each pressure transmitter must act as indication and a trip system to prevent over-pressuring of the vessels.
- If a trip function is activated, the system will perform the same function of activating the ESD (Emergency Shutdown) button.
- Whilst a bed is in the adsorption stage, the other three beds must be performing the other sub-cycles of the process. (Equalisation, Providing Purge, Depressurising, Purging and Re-pressurising.
- The system must be able to control the sequence of opening and closing all 16 valves on the four vessels.
- Indication of the valve positions must be present to understand what current cycle the system is on. *[This was not achieved as a local indication but the use of the PLC output card provided information on which valves were being operated purely within the workshop environment. To improve upon this, a HMI could be used with a process overview indicating the current state of all instrumentation on the skid.]*
- The system must be ergonomic enough to be functional within the workshop environment.

When looking to improve this system, the nature of the program allows for expansion and upgrades of features.

Three-bed mode: The sequence output file can be loaded using the sequence load file, allowing different data tables to be loaded into that main sequence output file. This would be useful to achieve the three bed PSA operation which is required when there is less demand for 99.9% pure hydrogen. A new table could just be loaded directly into the main sequence once a data table has been created for three bed (vessel) operation, upon 'three bed mode' being selected. In order to

perform the same function, the timer would also need to be changed for this instance or have another timer present.

Manual valve operation: Another improvement to the system could be added to allow the operator to manually operate all valves on demand. These manual controls would have interlocks on them to prevent them from being operated during the auto sequence and upon a trip signal activation. Control would need to be hardwired while also providing an indication in the form of a HMI.

Valve limits: To ensure all valves are fully opening and closing, limit switches can be added as discrete inputs to let the PLC know what state valves are in, open, closed or travelling between states. An interlock can be added to prevent the sequence from progressing if valve limits have not met, along with bringing in an alarm.

High pressure pre-trip Alarm: This alarm would activate shortly before a shutdown condition activates, at a slightly lower pressure to warn the operators that a trip is imminent if the pressure carries on rising.

To summarise, the project has been successful in producing a method of controlling the PSA skid on the hydrogen recovery unit. All sixteen valves are controlled within the timing sequence which operates flawlessly, looping round until the stop button is operated or there is a high pressure trip condition. An improvement to the design and planning process would reduce the amount of time spent testing and correcting errors found during this process. The system could also be designed with future expansion and upgrades in mind, with extra inputs and outputs already designated for alternate modes and extra controls.

The sequencer solution has satisfied the detailed design specification and is a much more efficient method for performing this task than the other two suggested methods. The sequencer can be editing and upgraded with ease, without the need for any changes to hardwiring which would be needed if relay logic was used. The timing and budget limits were achieved as the equipment sourced matched that of the £800 budget. A print out of the program and associated documentation with all data tables included and I/O can be seen in the appendix/log book.

*Good
conclusion
and
evaluation.*

11. References

11.1 Works Cited

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11.2 Reference List

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2. Valero P&ID 11-AA-506 Hydrogen Recovery Unit PSA Unit
3. Allen Bradley SLC 500 Digital I/O Modules – Installation instructions
4. Allen Bradley SLC 500 Analogue Input Module – User Manual

*The only negative
I find with the
report is the lack
of references to
support the
research, which is
extensive on the
specific project.*

12. Appendix

Daniel Ince - Final Report

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

71 /100

Instructor

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Text Comment. Very good list of contents

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Text Comment. A good detailed spec

PAGE 13

PAGE 14

Text Comment. Very good use of Gant chart for project management comparison.

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Text Comment. Good analysis of method hypothesis.

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Text Comment. Good testing procedure and explained very well

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Text Comment. A very detailed sequence test analysis carried out.

PAGE 32

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Text Comment. Good detailed test process

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Text Comment. The test and analysis is very thorough and easy to understand. A good piece of work.

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PAGE 42

Text Comment. Good conclusion and evaluation.

PAGE 43

Text Comment. The only negative I find with the report is the lack of references to support the research, which is extensive on the specific project.

PAGE 44

GRADING FORM: CSG-RUBIC

DANIEL INCE

0

RESEARCH-INFORMED LITERATURE



Research is extensive on the background specific to the project. Some research should have included a case study and would include some academic source for refs. Otherwise there is plenty of background here. Intro and background research - 7/10 References - 4/10

13/20

KNOWLEDGE AND UNDERSTANDING



Very good in this area and evidence of substantial effort. Specification is clearly defined and explained - 8.5/10 Solutions considered with evaluation -

17/20

ANALYSIS



Testing is substantial in the project and the evidence shows that. Some really good test procedures and results shown - 8.5/10 Conclusion is good with a good evaluation - 8.5/10

17/20

PRACTICAL APPLICATION AND DEP.



The solutions considered are explained and evaluated very well with good arguments put forward for the final solution. Solutions considered - 3.5/5 Final solution and implementation- 8.5/10 Quality of work is very good - 4/5

16/20

SKILLS FOR PROFESSIONAL PRAC.



Report is very good - 8/10 Presentation - ?

8/20