SGEL6000 Independent Project 2020-2021

DOUBLE MARKING SHEET AND COMBINED STUDENT FEEDBACK

Assessment 3 of 4

Assignment 2: Project Design, implementation and evaluation

Agreed mark **68**

Student Name: Daniel Ince **Student Number** 1602836

Generic Assessment Criteria	Marks available	Ist Marker (RD)	2nd Marker (MH)	Agreed Mark
1. Engagement with Literature Skills.				
Section 3: Judicial use and critical evaluation of technical literature in the design of the project: Evidence of use of technical literature throughout from manufacturers. No evaluation of the literature was evident as it mainly consisted of company documentation.	5	3	2	3
Section 4: Extent of reading, range of credible sources and use of Harvard method: A small range of sources consulted, Harvard referencing correctly applied. Range of sources was very small for such a complex project and primarily consisted of company documentation. Legal regulations, component datasheets and wider issues such as H&S and ethical engineering were not listed.	5	1	1	1
Total	10	4	3	4
2. Knowledge and Understanding Skills				
Section 3: Advanced knowledge and critical understanding demonstrated in the design of the project: Report shows an advanced level of understanding in the project design process. A high level of technical knowledge and critical understanding of all aspects of the project were clearly demonstrated throughout the report.	10	7	8	7
Total	10	7	8	7
3. Cognitive and Intellectual Skills				
Section 5: Testing and analysis of result: Clear evidence of thorough testing of the final system. Testing was carried out on each part of the system separately using a test schedule, these could have included more specific success metrics and tolerances. e.g. how is `prompt` defined? The comments column didn't expand on failed tests.	10	8	7	7
Section 5: Critical evaluation of the project outcomes: A detailed evaluation of all aspects of the project was undertaken. The FDS was mentioned generically, but not each of the requirements and how successful the project was in satisfying them.	10	8	6	7
Section 6: Conclusions and recommendations: Clear conclusions and recommendations presented.	10	7	6	7

The conclusions contained some unsubstantiated claims, such as `*proven to be the optimum long term solution*`. Recommendations included improvements to management of the project rather than a technical improvement.				
Total	30	**23**	**19**	**21**
4. Practical Application Skills				
Section 3: Formulation of innovative and creative design solution to the project problem: The solution was the most appropriate for the given circumstances which involved integration into the company's existing system. The chosen solution satisfied all aspects of the FDS, there was little mention of any ethical considerations in the design solution.	10	**7**	**7**	**7**
Section 4: Deployment method, use of material, tools, equipment and techniques in the construction of the project: Very good methods employed appropriate to the company's standards. Practical deployment was clearly shown by the extensive range of images included in the appendix.	5	**3**	**4**	**3**
Section 4: Quality of the final product or system: The end product was mainly software with a clear way forward in the full implementation using the hardware. The final product is to be used in the oil industry, so quality cannot be in doubt.	10	**7**	**8**	**7**
Section 5: Use of test equipment and presentation of results of the project: Good use of testing and clear presentation of results. Test equipment is primarily computer-based monitoring, although some direct observations were evident. Results were presented both within the test schedule and as a huge collection of screenshots which would have benefited from consolidation.	5	**4**	**3**	**4**
Sections 3 and 5: Management of the design process: The process was well managed given the difficult circumstances A detailed Gantt chart was used and updated throughout the project's timeframe. A S-curve was produced to track man hours and a spreadsheet showing expenditure was included.	5	**4**	**4**	**4**
Total	35	**25**	**26**	**25**
5. Transferable Skills for Life and Professional Practice				
Sections 1 and 2: Executive summary, acknowledgements and introduction: Briefly stated but no acknowledgements given. The Executive Summary was brief and lacked specific detail, the introduction was good, but switched tenses. No acknowledgements were evident.	5	**3**	**3**	**3**
All Sections: Quality of the report: High quality report, well structured and presented. However, there are far too many images and diagrams in the main report which belong either in an appendix or a log book. However, the report has been written in a monotonous way, your reader is presented with fact after fact but the overall picture is lost in the detail. Much of what you have said belongs in a log book. This is not a very interesting read! All calculations should be in the appendix with the results summarised in a table in the main report The body of the report was well written and presented in a logical order. A 54 page appendix was excessively large.	5	**3**	**3**	**3**

Word count: Exceeded but not more than 10%	5	5	5	5
Total	15	11	11	11
Grand Total	**100**	**70**	**67**	**68**

1602836 Assignment 2 Dan Ince Final Project Report

by Daniel Ince

FILE	14401_DANIEL_INCE_1602836_ASSIGNMENT_2_DAN_INCE_FINAL_PROJECT_REPORT_178864_1283880417.PDF (12.64M)		
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Course: BSc (Hons) Electrical & Electronic Engineering

Module: SGEL6000 Independent Project

Assignment: 2. Project Design, Implementation and Evaluation

Name: Daniel Ince

University Number: 1602836

Date Submitted: 30/04/2021

Word Count: 6519

Positive comments:

1. Report contain detailed information about the design, implementation and testing of the project (RD)
2. Good structure and presentation (RD)

Negative comments:

1. Report contains too many diagrams and images which belong in the appendix. (RD)
2. All calculations should be in the appendix with the results summarised in a table in the main report. (RD)
3. The report has been written in a monotonous way, your reader is presented with fact after fact but the overall picture is lost in the detail. Much of what you have said belongs in a log book. This is not a very interesting read! (RD)

Good Structure

Where is your acknowledgements section?

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1. Executive Summary

Contained within this report is the design and work scope of implementing the Vapour Recovery Unit (VRU) Compressor Control System Upgrade project. The aim of this project was to address target problems with the set point control, relay logic and compressor loading sequences, whilst also future proofing and increasing the reliability of the system. This is achieved through migrating the existing system onto the Distributed Control System (DCS) and executing as per the plan and budget. Following project completion, all aspects of the project were tested as per the Functional Design Specification (FDS), to which it met the criteria and passed the test successfully.

An evaluation of the project management and implementation was carried out to identify deviations and planning accuracy. A point of weakness was discovered in time management, where restrictions and company commitments were detrimental to the critical path.

Brief and to the point (RD)

You should have made it clear that the overall aim was to produce a demonstration rig to prove the concept. (RD)

2. Introduction

The project detailed in this report is to be implemented to improve a problematic Vapour Recovery Unit compressor control system on an industrial site. The finalised build will be tested and subject to a Site Acceptance Test to prove functionality. A DCS based solution was chosen through previous analysis to achieve this objective with a maximum material budget of £20,000.

The report will contain the design of the initial system and preliminary logic, along with the project implementation and execution. Following completion, the project is due to be tested against the specification and any abnormalities or failures recorded.

An evaluation will be carried out of the whole project and management process to assess the execution versus the design and plan, to review any differences encountered. Finally, the process will be summarised and any target areas for improvement suggested.

You could have explained that the overall aim was to produce a demonstration rig to prove the concept (RD)

How much did the project change since the specification was approved? (RD)

3. Design and Implementation

3.1 Design

3.1.1 Logic

To install the VRU upgrade, replacement control logic will be built into the DeltaV control system, therefore the desired compressor operation must be determined to assist with designing preliminary logic.

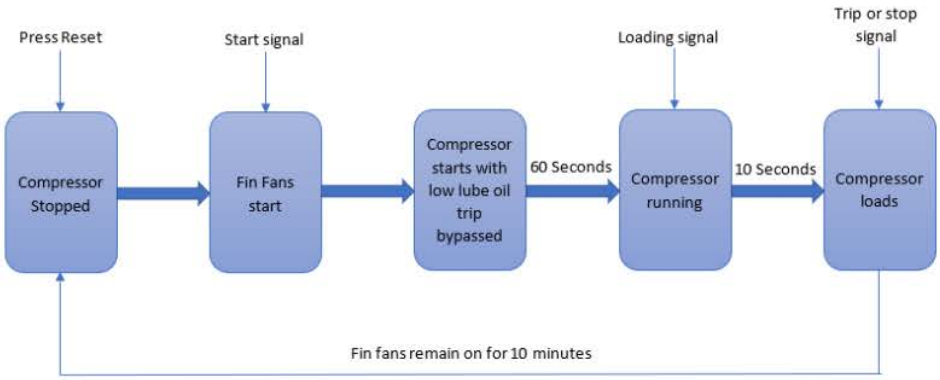


Figure 1: Operation flow diagram

The flow diagram shown in figure 1 details the process steps that must be built into the logic for successful running. Current logic drawings are based upon the existing hardwired relay installation and so new logic must be designed around the capabilities of the DeltaV system. This predominantly uses a function block design which is modifiable through internal programming language.

Figure 2 displays a conditional logic flow diagram for the compressor start and stop sequence, this expands upon the process flow in the context of logic.

This is a good flowchart (RD)

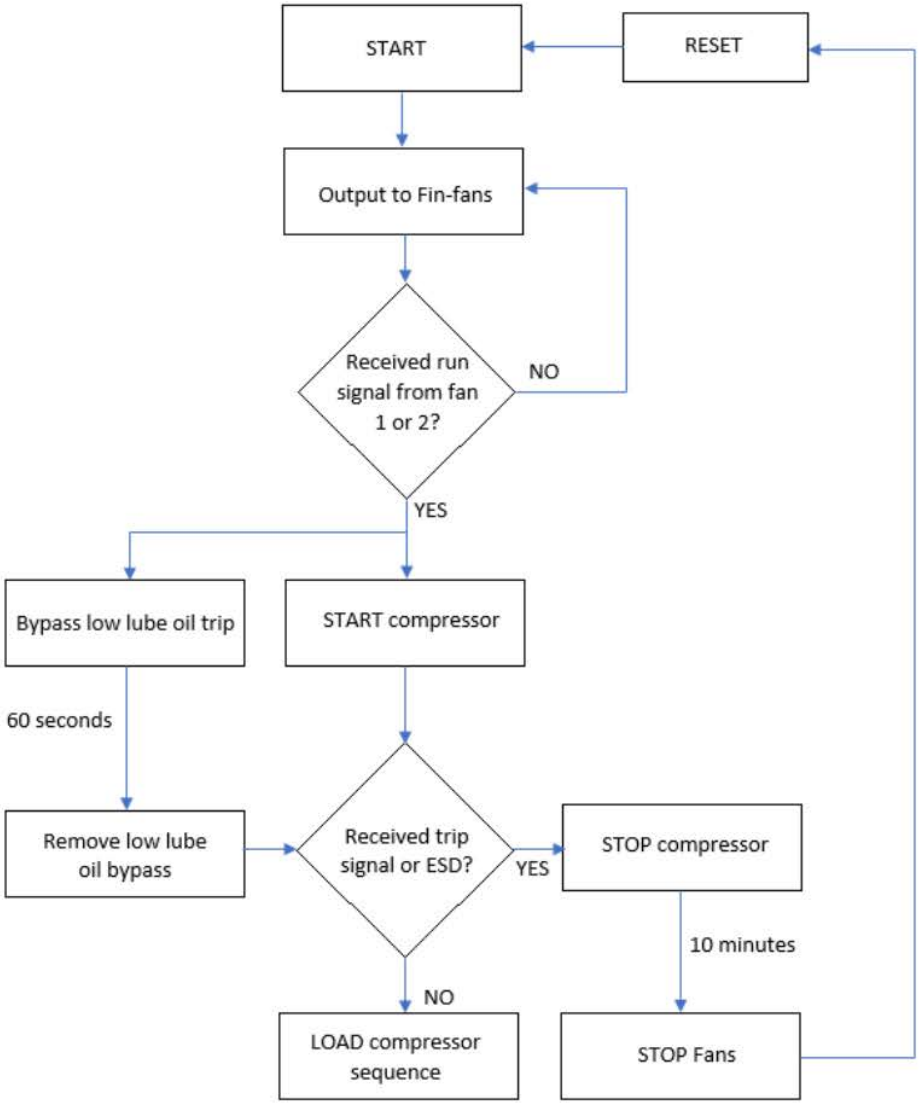


Figure 2: Logic flow diagram

The existing relay logic will be reviewed, and the best fit replacement planned for the migration to DCS logic.

This drawing belongs in the appendix (RD)

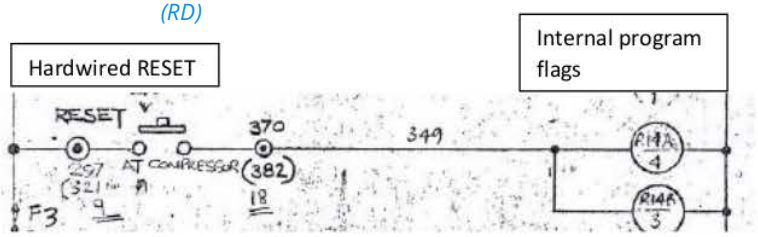


Figure 3: Logic replacement example.

The trip logic foundations will remain the same, except performed with internal flags and not relays. The physical switches in the field remain and provide the main input into DeltaV for trips, these switches will be wired directly into DI Charms with power being supplied from the CIOC rail.

The set up for vibration will alter slightly, these will be done through a relay output on a Bently Nevada 3500 rack. Therefore, only one NC vibe trip per compressor will be required for these. The flag from the reset above latches these rungs when the trips are healthy, and the reset is pressed.

The start logic kicks in when the now electronic pressure transmitter reaches the first value of 4.42kg/cm2, this starts the compressor fully unloaded. For 60 seconds, the low lube oil trip is bypassed to allow it to get the pressure above the trip point. (This is done through R13 on the low oil pressure rung), DeltaV will need to do this through timers.

Loading	Switch Point Rising *(Falling)*	Pressure Switch VRU1 *(VRU2)*	Loading SOVs Energised VRU1 *(VRU2)*	Cylinders Active
0%	6.5psi *(3.5psi)*	PS-1577A *(1677A)*		
25%	6.5psi **10sec delay** *(3.5psi)*	PS-1577A *(1677A)*	SOV-1578 *(1678)*	1 & 5
50%	10psi (7.8*psi)*	PS-1577B *(1677B)*	SOV-1578 *(1678)* SOV-1580 *(1680)*	1 & 5 2 & 6
75%	12.3psi (10.3*psi)*	PS-1577C *(1677C)*	SOV-1578 *(1678)* SOV-1579 *(1679)*	1 & 5 3 & 7 and 4 & 8
100%	15psi (13*psi)*	PS-1577D *(1677D)*	SOV-1578 *(1678)* SOV-1579 *(1679)* SOV-1580 *(1680)*	1 & 5 3 & 7 and 4 & 8 2 & 6

Table 1: Loading and unloading design

Table 1 displays how the compressors load and unload, based on the pneumatic controller output and pressure switches, there is hysteresis for this system. Calculations were then performed to determine the current output and pressure reading for these loading points with the new electronic transmitter.

These calculations belong in the appendix with a summary table included in the main report (RD)

Pressure values and old percentage calculations for loading with 4.3 to 4.7kg/cm^2 range:

0 & 25%: $\frac{(6.5-3)}{12} = (0.292 \times 0.4) + 4.3 = 4.42 \rightarrow \frac{0.12}{0.4} = 30\%$

50%: $\frac{(10-3)}{12} = (0.583 \times 0.4) + 4.3 = 4.53 \rightarrow \frac{0.23}{0.4} = 57.5\%$

75%: $\frac{(12.3-3)}{12} = (0.775 \times 0.4) + 4.3 = 4.61 \rightarrow \frac{0.31}{0.4} = 77.5\%$

50%: $\frac{(15-3)}{12} = (1.0 \times 0.4) + 4.3 = 4.7 \rightarrow \frac{0.4}{0.4} = 100\%$

New percentage and current loading values with 0 to 6kg/cm^2 range:

0 & 25%: $\frac{4.42}{6} \times 100 = 73.67\% \rightarrow 15.787mA$

50%: $\frac{4.53}{6} \times 100 = 75.5\% \rightarrow 16.08mA$

75%: $\frac{4.61}{6} \times 100 = 76.83\% \rightarrow 16.293mA$

100%: $\frac{4.7}{6} \times 100 = 78.3\% \rightarrow 16.528mA$

The same was performed for unloading to provide:

0 & 25%: $\frac{(3.5-3)}{12} = (0.042 \times 0.4) + 4.3 = 4.317$

50%: $\frac{(7.8-3)}{12} = (0.4 \times 0.4) + 4.3 = 4.46$

75%: $\frac{(10.3-3)}{12} = (0.608 \times 0.4) + 4.3 = 4.543$

100%: $\frac{(13-3)}{12} = (0.83 \times 0.4) + 4.3 = 4.63$

The new unloading range percentage and current values were then determined:

0 & 25%: $\frac{4.317}{6} \times 100 = 72\% \rightarrow 15.512mA$

50%: $\frac{4.46}{6} \times 100 = 74.33\% \rightarrow 15.893mA$

75%: $\frac{4.543}{6} \times 100 = 75.72\% \rightarrow 16.115mA$

100%: $\frac{4.63}{6} \times 100 = 77.2\% \rightarrow 16.352mA$

Table 2 was formulated to account for the replacement to the electronic transmitter, all loading is delayed for 10 seconds after starting up. DeltaV is required to output to the same SOVs as detailed in table 1. The SOVs will be wired from DO Charms and the transmitters into AI.

	New loading values [Tx range 0 to 6kg/cm2]		
	Pressure (kg/cm2)	Current (mA)	% Range
0%	4.42	15.787	73.67
25%	10 second delay 4.42	15.787	73.67
50%	4.53	16.08	75.5
75%	4.61	16.293	76.83
100%	4.7	16.528	78.3

Table 2: Loading range and current values.

Table 3 shows the figures for when the compressor unloads, along with there is a dead band on the loading SOVs. These tables display the exact current, pressure and range percentages that are to be programmed onto DeltaV.

	New Unloading values [Tx range 0 to 6kg/cm2]		
	Pressure (kg/cm2)	Current (mA)	% Range
0%	4.317	15.512	72
25%	4.317	15.512	74.33
50%	4.46	15.893	74.33
75%	4.543	16.115	75.72
100%	4.633	16.352	77.2

Table 3: Unloading range and current values.

3.1.2 Electrical

The current supply to the field instruments in the B&S racking room is a 110V AC supply, this will be utilised to power the twin 24V 10A Emerson power supplies.

The total power rating of the supply is: $10A \times 24 = 240W$

The Rosemount 2051 transmitter will be specified with NAMUR alarm and saturation levels, therefore the maximum current draw will be $22.3mA \times 24 = 0.5352W$. Which when accounting for both VRU systems gives a maximum current draw of: $1.07W$. To ensure compliance with site standards, the accuracy of the pressure transmitters must be determined.

$Accuracy = \mp\left(0.025 + 0.005\left(\frac{6[URV]}{6[Span]}\right)\right) = 0.03\%$ Span. Therefore $= \mp 0.002 kg/cm^2$.

$Stability = \mp 0.1\%\ of\ URV\ for\ 2\ years. Therefore: \mp 0.006\% kg/cm^2$

Referencing the company drawing 50-ZA-003, the hazardous area is a Zone 2 Gas Group IIC, to comply with ATEX regulations, the transmitter rating must meet or exceed this. The Rosemount 2051 will be ATEX rated to Ex ia IIC T4 to meet the company standard for new installations; intrinsically safe where possible, whilst also complying with the zone and temperature requirements.

To sense the switching input, the DI IS NAMUR Charm requires a current above 2.1mA. Therefore 10mA will be selected and a 2.4kΩ resistor will be used. The switch power draw will be $10mA \times 24 = 0.24W$ each, making a total of 3.12W per VRU (6.24W total). Each Charm will draw a maximum current of 28mA and so 8.736W per VRU (17.472W total).

The Asco solenoid valve outputs draw 1.2W of power each, of which there are 6.

The nearby Bently Nevada 3500 rack is also supplied by the 110V AC supply, this means no extra power is required and only a short run of wiring is needed between the CIOC box and the rack. The relay outputs from the rack will feed directly into the normally open digital input Charm on the DeltaV CIOC. These will act as replacements for the vibration switches currently fitted.

3.1.3 Wiring

3.1.3.1 Cabinet specification

To implement the control system, the existing relays and wiring need to be removed from the B&S racking room 1 shutdown panel and field instrument terminals connected directly to the CHARM installation. As the control system manufacturer is Emerson, a specification for the hardware will be determined and equipment built as per the desired requirements.

The cabinet is to be sized at 915mm width by 1070mm height, with a depth of 325mm. These dimensions fit within the B&S marshalling cabinet on the back wall.

The 110V AC relay supply will be disconnected and cut-over to supply the dual Emerson power supplies located within the cabinet during the final site implementation. These were specified to contain a dual redundancy feature for instrument protection.

Reviewing hazardous area drawings, the field equipment is mounted within a zone 2 area, gas group IIC. To adhere to ATEX regulations, the equipment needs to be intrinsically safe, therefore 24V energy limiting IS CHARMs were specified. It is also ensured that this IS wiring is kept separate from the 110V supply by at least 2 inches. This is in accordance with regulations as stated by Ind Ex "*Conductors of intrinsically safe circuits are permitted where they are separated from nonintrinsically safe circuit conductors by a space of not less than 50 mm.*" (2017)

This diagram belongs in the appendix and a key to each item included (RD)

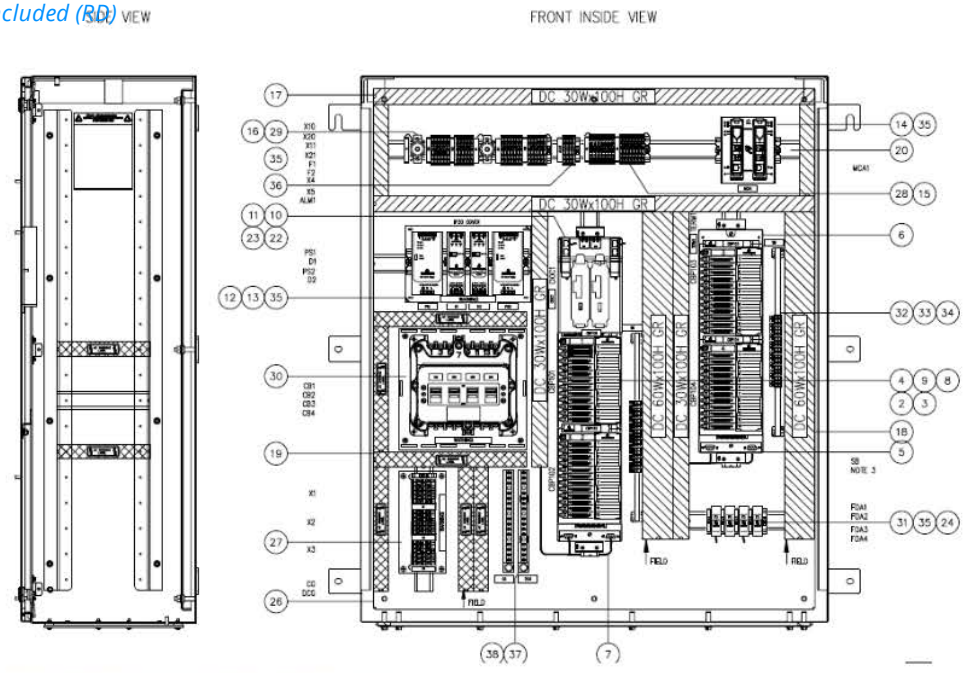


Figure 4: Emerson CHARM cabinet. (Emerson, 2020)

Figure 4 shows the manufacturer drawing for the Emerson cabinet. As per the Emerson quote, a pre-fabricated CIOC box will be installed within the cabinet to house the controllers and CHARMs.

3.1.3.2 Input connections

The terminal block diagram for the input connections are shown in figure 5. The field instruments are wired using white (positive) and blue (negative) insulated wires on the hazardous side to meet the site requirements for IS instrumentation. The block will be housed in the B&S shutdown cabinet. The drawing has been completed using the company standards and tagging codes.

Inputs have been assigned to the 12 slot charm rails and are tagged based on the enclosure and CIOC section.

diagram belongs in the appendix (RD)

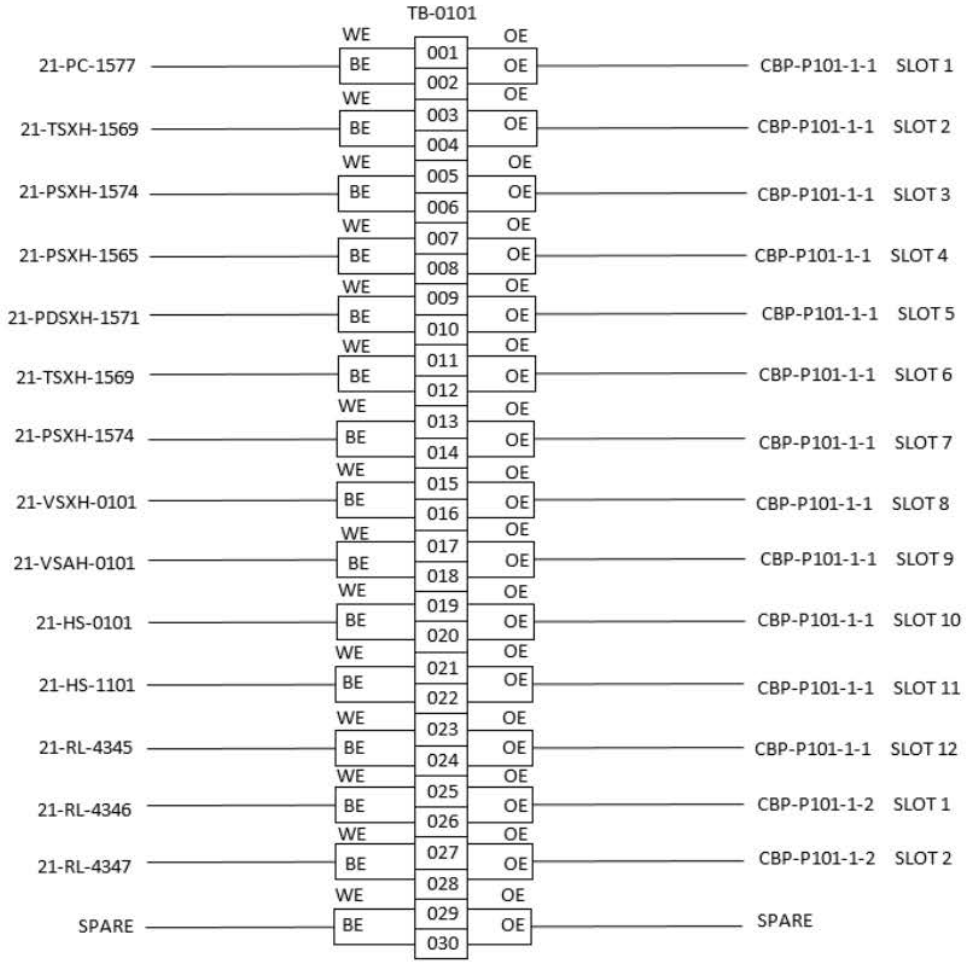


Figure 5: Input terminal wiring.

3.1.3.3 Output connections

A drawing for the VRU1 output connections is shown in figure 6. These are taken from the output CIOC and wired into the secondary terminal block.

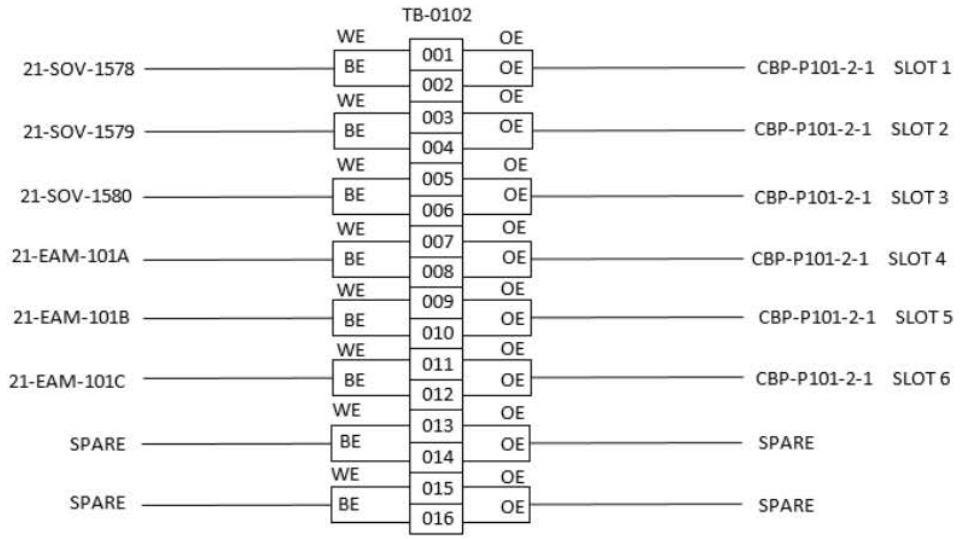


Figure 6: Output terminal wiring.

3.2 Implementation

3.2.1 DeltaV controller set up and initial logic programming

To build the background control system logic, the configuration software DeltaV Explorer was used, this connects to the main DeltaV server and can download directly to the controllers based on site.

A new area was configured 'VRU', and assigned to the PROPLUS network, when in service, this area can be assigned to the required control panel. Within this node, the controller and CIOC CHARM modules can be configured as shown in figure 7 and appendix 1 & 2.

screen shots like this belong in the appendix (RD)

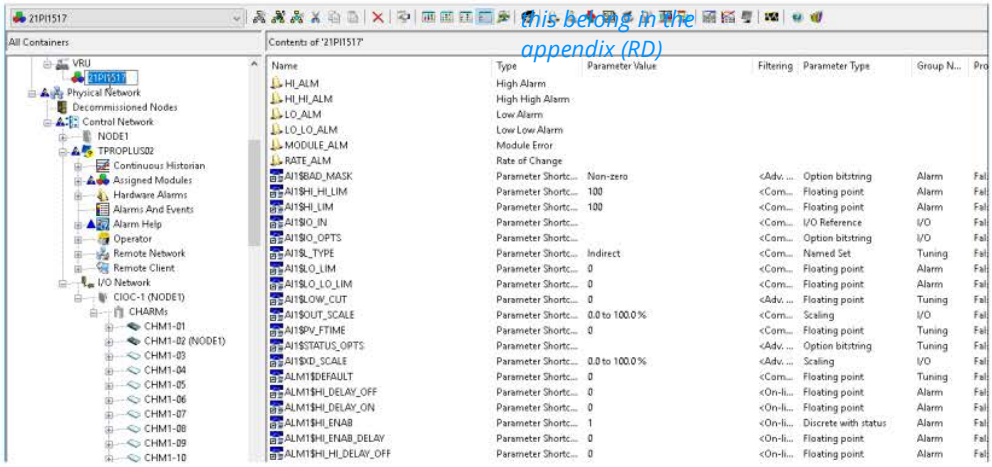


Figure 7: Setting up the main pressure controller.

The compressor loading controller 21PI1577 was built to the first CHARM, with the parameters set as a 4-20mA HART protocol, for smart capabilities. This was converted to a class-based module and the modules V_AI_52_DT and V_AI_52_FP assigned to provide the 'detail' and 'faceplate' respectively. The contents of the charm allows configuration of NAMUR alarm saturation points and also provides provision for different alarm points.

The VRU area was then downloaded to the database to allow configuration of the analogue input module. Here the AI1 block parameters were adjusted so that the block writes from tag 21PI1577, as it was now visible on the database, shown in appendix 8. The input was configured to the required 0 to 6 kg/cm^2 across the 4-20mA range and 'L_Type' set to indirect, this ensured the faceplate displayed scientific units and not a raw current value. The module was opened on the Control Studio online simulation to briefly test the faceplate and tag detail facilities, here the range was tested by inputting a signal of 4.5kg/cm^2, detailed in appendix 6.

The three loading solenoid output tags (21SOV1578, 1579 & 1580) are relay 'DO' signals and so were configured as 'DO_52' modules with the appropriate tags and assigned to CHARMs. Appendix 3 & 5 display the build and download.

With all three SOVs added, they were downloaded to the server and each module opened for configuration. Parameters were set within the DO module, as this is where the I/O is driven from, shown in appendix 7.

The contents of DO1 was set to output directly to 21-SOV-1578, the tag was taken from the database and assigned to the block, shown in appendix 7. This process was repeated for 21-SOV-1579 and 1580 and these blocks can now be used as outputs within the logic. Appendix 9 shows the internals of the solenoid output modules.

3.2.2 Loading configuration

The nature of the compressor loading means a form of hysteresis will be required to be built within the logic. Using the tables formulated during the design stage, the pressure set points with a 0 to 6kg/cm^2 are to be implemented using the DeltaV block design, shown in appendix 8.

Output blocks for the three solenoids were created and placed within the threshold section for 02-PI-1577. Here the individual action thresholds could be configured and mapped to the solenoids in different combinations as per the loading table. To allow any loading to occur, a 10 second on delay timer was implemented to elapse on start up. Each threshold was built with logic as per the dead band tables 2 and 3 to provide 25%, 50%, 75% and 100% loading.

A compressor module was built to accept inputs from the loading thresholds, this will provide the foundation for compressor control. Here a start output can be written or tripped based off thresholds and interlock parameters. This is detailed in Appendix 10.

Within the compressor block, the start force was configured to be written from the 21-PI-1577 input. The permissive block for the compressor was opened up and set point force logic was entered to instruct the output variable to change to a 1 if either input is set to 1. Figure 8 and appendix 11 & 12 display the logic that takes the first loading start stage input and uses it to start the machine.

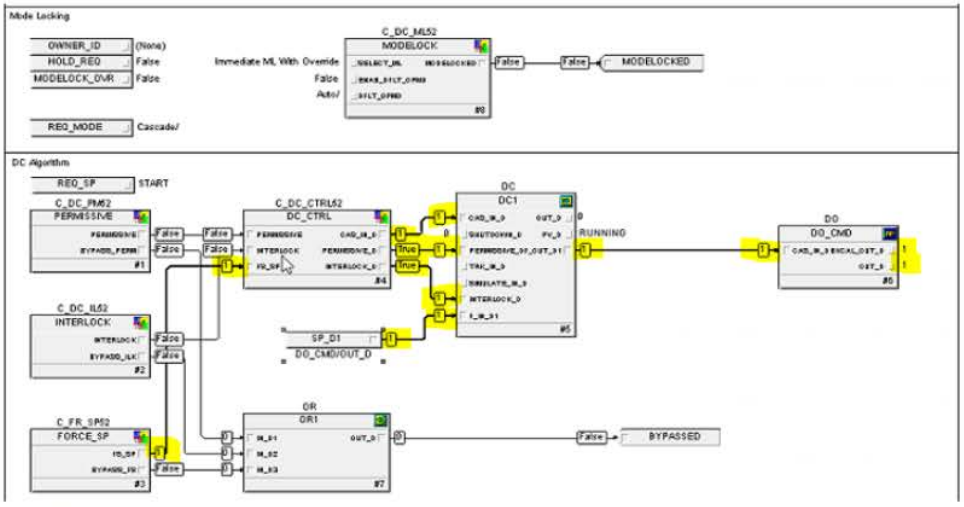


Figure 8: Force logic test

A quick test was performed using a simulated value of 5kg/cm^2, a healthy output of 1 is showing from the DO block as the requirements for the set point force is healthy. The system has been set up to act as an internal run light as at this point there is no feedback through the DI Charm.

3.2.3 Interlock and start procedure configuration

The low lube oil pressure switch module 21-PSXL-1571 was created and configured for a faceplate. As this input is required to trip the compressor by also hold out for 60 seconds, an on-delay block was added to the main compressor module. The timer was then configured into the first interlock logic, in combination with the pressure switch output.

Appendix 14 shows the logic that is used to only permit the compressor to run providing the low lube oil pressure is healthy. The time delay bypass logic will be built upon this foundation. The interlock composite module shown in Appendix 16 was configured and added to include this logic

The low lube oil bypass logic needed to be configured to override the trip for the first 60 seconds of operation. Initially the start/stop faceplate in appendix 18 was built to the DC1 block for driving output 'OUT_D' from faceplate. This allows the set point to be written via the operation of the faceplate and will manually override the loading automatic starting if desired.

Within the overall interlock module, CND8 logic was configured to time the initial bypass. The expression shown in appendix 19 must become true to allow a healthy output. Therefore, when the start is pressed, the logic recognises that the lube oil pressure is low. The timer will only be counting whilst the expression is true, therefore once the pressure is healthy it resets back to zero. If the timer reaches 60 seconds with the low state still active, the compressor trips.

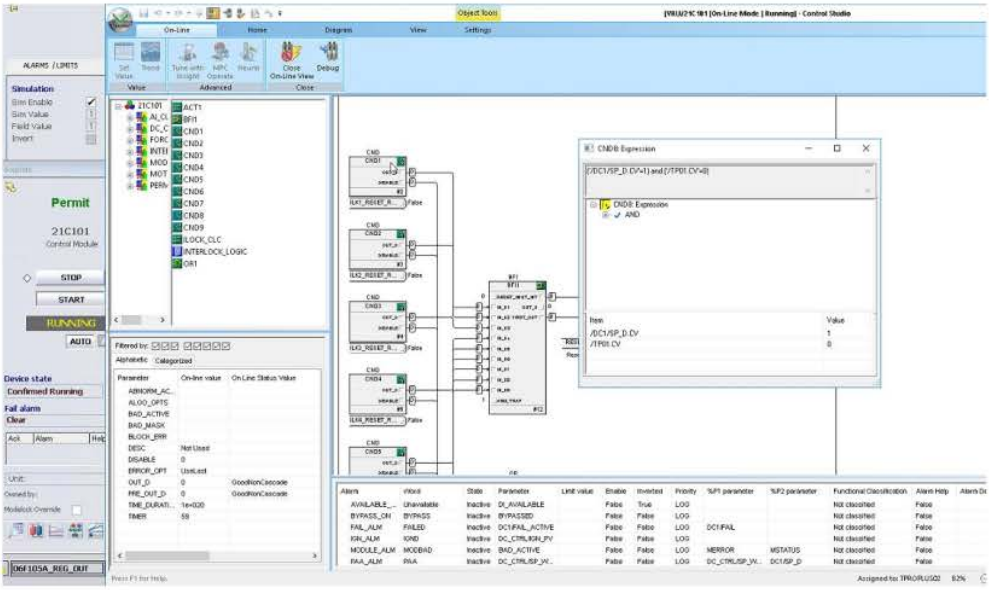


Figure 9: 60 second delay test.

A simulation test was performed to show compressor running, whilst lube oil pressure is still low as shown in figure 9 and appendix 20. This allows the compressor to start whilst pressure is low, as

pressure is created by the internal oil pump. Appendix 17 shows the miscellaneous logic expression within the compressor block updated to create a latch, where TP01 is used to hold out and reset timer latch allowing consecutive uses.

The main interlock logic expression was also updated to include TP01 to trip compressor if TP01 and lube oil pressure is still low, this also generates an interlock which would shut down compressor and prevent restart. A brief test was conducted in appendix 22, here the elapsed time is 59 seconds and the compressor is still in the running state with low lube oil pressure. The timer then counts to 61 seconds, at which point the compressor trips on low lube oil pressure as shown in appendix 23. The trip condition was then simulated healthy and retest performed where the timer reset to zero and compressor remained running as shown in appendix 24.

3.2.4 Shutdown and bypass inputs

All shutdown blocks were configured and assigned to Charms, as shown in appendix 25. Each one of these was defined to an individual CND interlock on the main compressor logic block.

Each individual interlock was checked and used to inhibit manual or automatic compressor starting. Appendix 26 shows an example of this test, with the compressor tripped and buttons greyed out, preventing operation. The interlock blocks were further modified to be discounted when a bypass became active. The logic expression in appendix 27 was used for each bypass and the respective interlock trip function.

The miscellaneous logic block was also modified to include the bypass logic. Appendix 28 displays the control module test outputting a true signal for the bypass. Here CND3 is bypassed and so a 1 is input to the OR gate, this outputs to the common bypass active alarm. The effect of removing the override can be seen in appendix 27, where the interlock becomes true again.

Appendix 29 and figure 10 display a test showing how the bypass has removed the start inhibit from the faceplate, despite a low suction pressure trip being active. The bypass logic expression can be found in the appendix.

An additional check was carrid out to ensure the override suitably affected the 60 second start up bypass, this is shown in appendix 31. The timer has elapsed and reset despite there being a low lube oil pressure trip in, allowing the compressor to continue running.

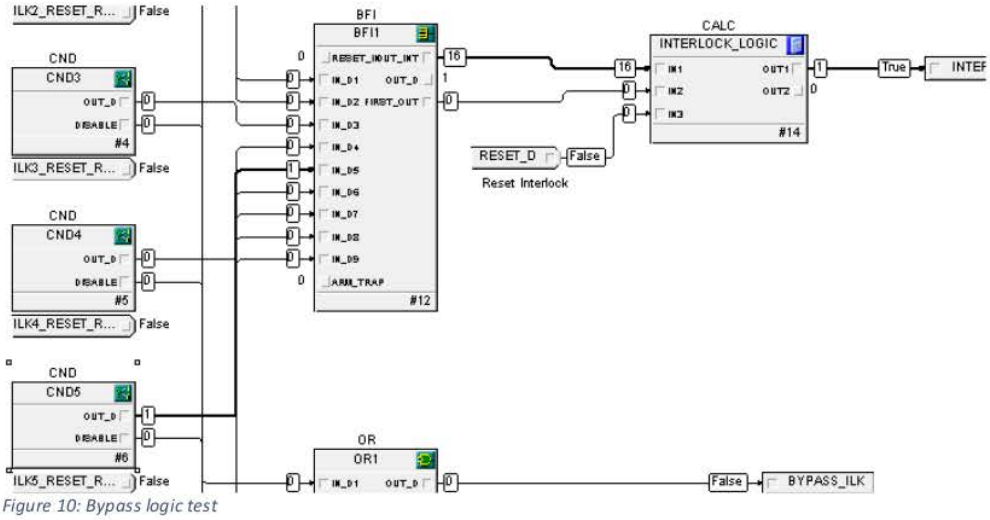


Figure 10: Bypass logic test

A non-latching reset button shown in appendix 33 was built and configured to return to normal once the trip has been cleared and reset pressed, the logic expression can be found in appendix 32. Within the miscellaneous logic block, TP10 is used to hold out on any interlocks becoming healthy, such as TP2 in appendix 34, therefore the reset actuates TP10, which clears the trip.

3.2.5 Alarm and graphic configuration

A graphic screen was built within the Blending and Shipping DeltaV sector, this included the compressors and fin fans along with a basic process layout. Indication for PI1577 and compressor loading was added as a permanent feature.

The graphic dynamos were configured to look at points within the logic, this also allowed icons to function as buttons to bring up faceplates when operated. This function is also assigned to allow the start, stop and reset buttons to be utilised. Animations were added to the blocks to change colour when the equipment is operating, this is fed from the running lights and requests to start. White indicates offline, whereas a solid fill represents running, the start request will thicken the outline of the graphic briefly. This can be seen in appendix 36 and 37.

The graphic requirement also specified trip and bypass indication. This was first configured through a first up alarm driven by the compressor function block to write to the animated text. The first out block shown in appendix 38 will output different values based on the initial trip alarm. The text data table was built up to reference these points shown in appendix 39. Appendix 41 displays an example of the first up alarm triggered when the high suction separator level alarm is active. The output from BF1 in appendix 38 is '2', which corresponds to the data table and therefore that text is displayed. The first up alarm was also configured to clear only after a compressor reset has been pressed. This was done through utilising TP10 reset output to be tracked and the alarm to only clear if this is healthy, the logic can be found in the appendix. Appendix 40 displays a separate trip flagging up the first up alarm.

Bypass and shutdown alarms were also configured and animated to ensure colour and state change upon operation. The graphics have been configured as per Valero DCS standard with the text layout as shown in figures appendix 42 and 43. The text and alarm lights are tied into the reset and so will only clear after the master reset has been operated. Figure 11 shows the completed graphic with the compressors running at 100% and no standing alarms.

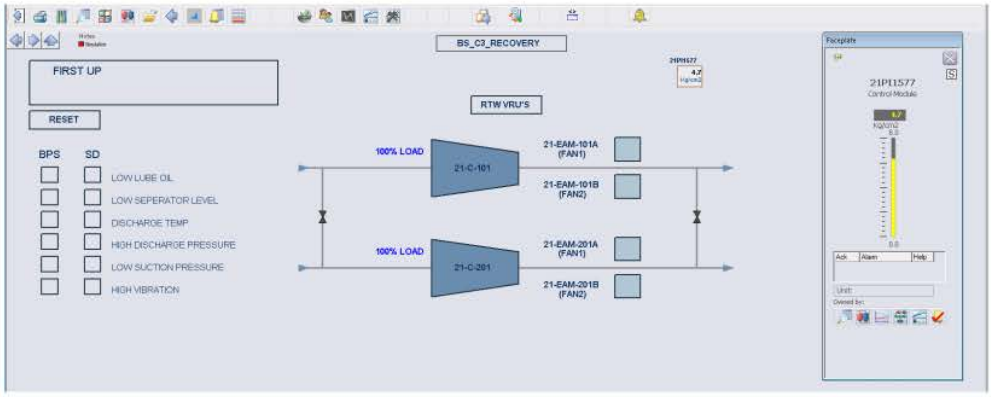


Figure 11: Completed graphic with both compressors running.

3.2.6 Bently Nevada logic programming

The Bently Nevada 3500 rack needed to be configured for the new probes and trip logic for the VRU compressors. The Bently Nevada 3500 rack configuration software was launched, and the PC connected to the rack through COM port 2. The Rack address is selected as 2 (as set on the dip switches on the front of the rack), and the baud rate is set at 9600.

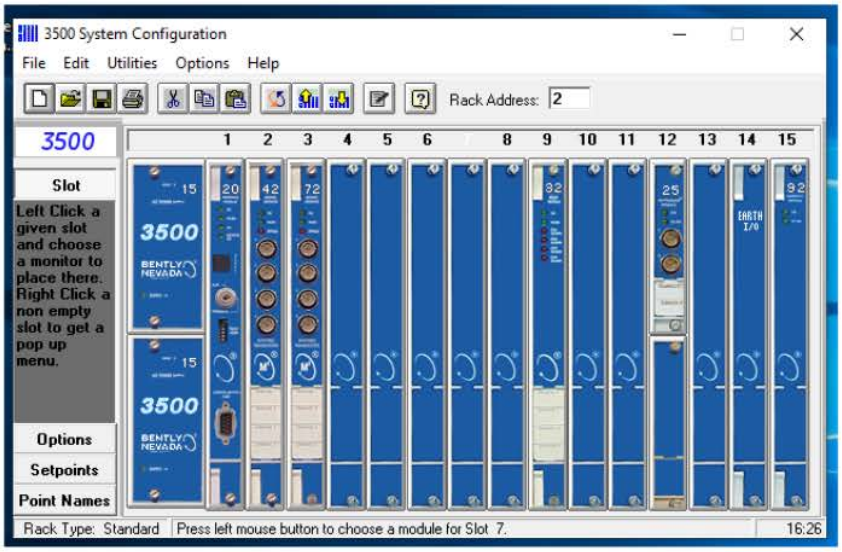


Figure 12: Configuration downloaded

The module configuration was uploaded from the rack to allow setting up, the block can now be seen in figure 12 populated with the correct modules. Slot 2 module was selected as it has four channels for the fin-fan proximitors, one channel per fin-fan, two channels per compressor as shown in appendix 48. The probe type has been set as radial vibration and channels activated due to the location of the probes, these were tagged up accordingly. Each module needed to be configured for the correct probe type, as shown in appendix 49. The radial transducer type was selected, in this case a 3300 8mm probe, no external barriers are connected to this probe as the rack itself is intrinsically safe. Direct Frequency Response was left default for this probe type.

Variable and alarm configuration for VT-101 was carried out as shown in appendix 51. Range values were set at 10 thou" and -24V for distance and gap voltage respectively. Regarding alarm values, a three second delay was chosen for the alert to reduce the chance of spurious alarms during start-up. The danger alarm will feature a higher set point and voting system; therefore, one second will suffice. These are set as latching and so will only clear after a rack reset.

This process was repeated for all four channels as they are identical, evidence of this can be found in the appendix.

Alarm settings were configured in figure 13, starting with VT-101, this included setting the gap voltage and distance alarm points for the alert. The danger was set at 7.5 thou' (75%) of the maximum range, this was repeated for all four probes.

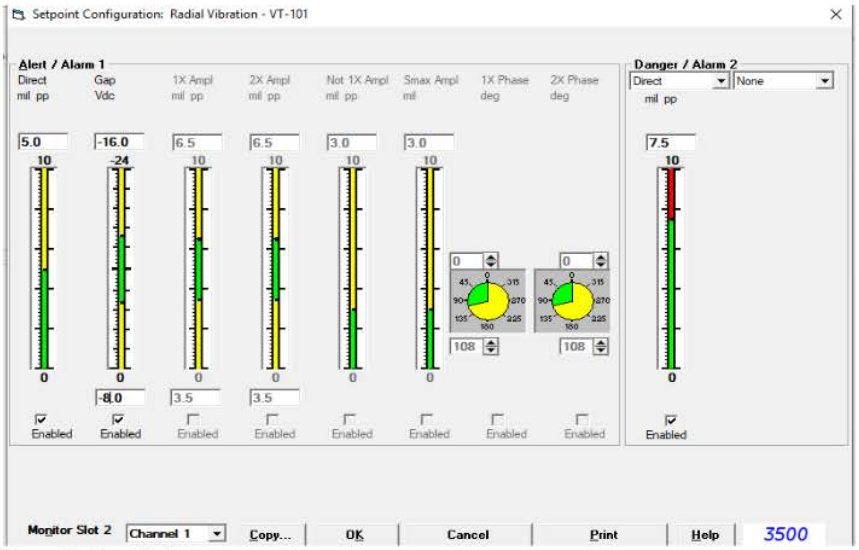


Figure 13: Alarm limits

Appendix 53 displays the output configuration for channel 1, the Boolean logic was set so an alert on either slot 1 or 2 will trigger the channel 1 alarm. [(Slot 2, Channel 1, Alarm 1) OR (Slot 2, Channel 2, Alarm 1)]. This was done to provide a rack alarm if either machine vibrations spike to the lower limit, however they will not prompt a trip. Channel 2 on the relay output module was also set as an OR gate for channels 3 and 4 (VRU 2) on the proximitor card as shown in the appendix.

For the VRU 1 trip, the logic was set as an AND gate for the two probes, this is because the VRU can only function if at least one fin-fan is running. The system then trips if both fin-fans show faults, a 2-out-of-2 voting system is also the company standard for radial proximitors, as shown in appendix 54. The same voting system was configured for VRU 2, probe channels 3 and 4. The danger level set point has been used for all trips.

Once completed, the configured modules were selected and downloaded to the rack, as shown in appendix 55.

3.2.7 Installation and testing setup

The DeltaV programming had been completed and so needed to be downloaded, installed and tested from the field side. The DeltaV test rig was built up and specified with the appropriate number of charms. The rig base was already set so the required controllers and power supplies were dropped into the mounting slots as shown in figure 14. These controller power supplies are dual redundancy with a failure alarm configured on DeltaV.



Figure 14: DeltaV controllers and CIOCs installed.

Once installed and illuminated as healthy, the charm blocks could be populated with DO, DI and AI HART charms. The CIOC and controllers are connected to each other and the local DeltaV server through an ethernet port. This allowed the VRU program to be assigned to that area as carried out at the start of the implementation.

The Rosemount 2051 SIL transmitter was obtained from the stores, connected to the AI 1577 charm and set up using the HART communicator. To comply with standards, the NAMUR alarm failure and saturation limit configuration was chosen, along with range values of 0 to 6kg/cm^2 as shown in appendix 58.

The adjacent Operator workstation was logged onto and connected to the DeltaV server via Ethernet port. The VRU area could be accessed and interface displayed on the computer, allowing live operation of the I/O as shown in appendix 57.

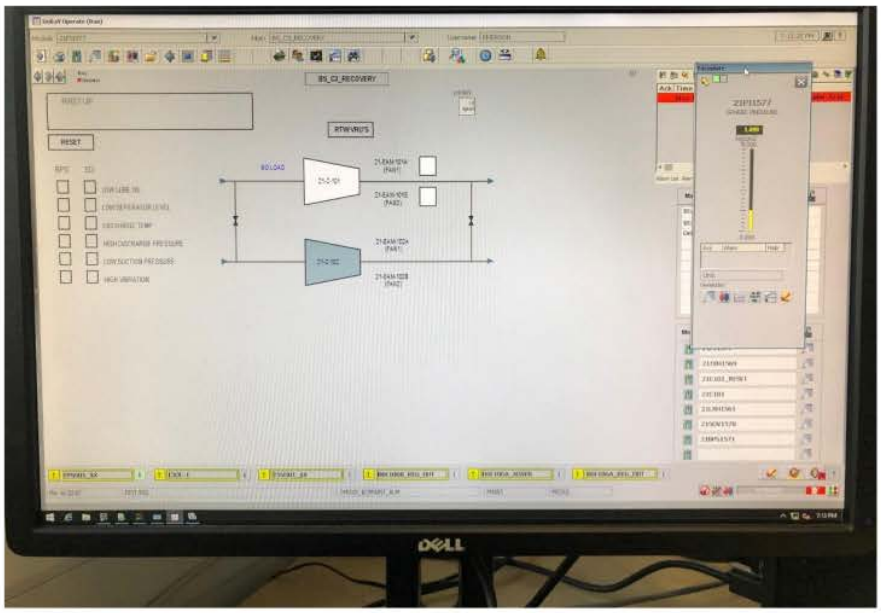


Figure 15: Interface

4 Testing and Results

The test rig was used to check all aspects of the project as per the testing table found in section 4.4. To prove suitability for the plan, a full function check was required of the compressor operation, safety features and protection.

4.1 Control logic testing

The control logic was tested by increasing the current output from the pressure transmitter PI1577, varying this output ensured the automatic starting, loading sequence and stopping could be checked accurately.

A testing table should give the expected range of results together with the actual results. Your reader should be able to decide if the test was successful. This table does not allow for that. (RD)

Current Output (mA)	Pressure value (kg/sqcm)	Compressor status	Pass (Y/N)
8.0	1.499	Offline	Y
15.85	4.420	Online, 0% loading for 10 seconds, then 25%	Y
16.10	4.533	Online, 50% loading	Y
16.45	4.645	Online, 75% loading	Y
16.55	4.702	Online, 100% loading	Y
16.40	4.646	Online, 100% unloading	Y
16.25	4.589	Online, 75% unloading	Y
16.05	4.514	Online, 50% unloading	Y
15.9	4.458	Online, 25% unloading	Y
15.6	4.346	Online, 25% unloading	Y
15.5	4.308	Offline	Y

Table 4: Loading hysteresis test.

How can your reader agree with you that the test was passed? (RD)

Table 4 displays the checks carried out for the control software, the images of which can be found in sequence in the Testing section of the Appendix, references 59 to 78. These checks show a successful loading hysteresis as per the design requirements. When a fault occurs on the pressure controller, the faceplate shows bad point and fails to -25%.

As part of the start sequence, the fin fans must be started prior to compressor running, this was confirmed by the testing and fin fan run lights. The low lube oil trip was also successfully bypassed for 60 seconds. The images from these tests can be found in the Appendix references 68 to 70.

4.2 Trip function and bypass testing

All trip inputs were tested consecutively by closing and opening the input to the DI charm. The bypass was also enabled and disabled via the software, to ensure trip alarms still come in, however the compressor remains running whilst trip active. Failure actions and interlocks were also tested, these results can be found in the appendix references 79 to 88.

The Bently Nevada configuration and alarms were also checked to ensure the indication and trips functioned as desired. The rack has a dual redundancy AC power supplies that are supplied via 110V, this means if one fails, the secondary supply takes over and no process shutdown or loss in information occurs.

The 8mm probes were connected to the -24V terminals from the back of the probe module and the VRU 1 probes were then verified with the gap voltage set at -10V and wobulators set up to measure vibration. Probe VT-101 vibration was increased to above the alert set point, this can be seen on the rack card and on the live screen. Probe VT-102 was also brought into alert, bringing in the channel 1 alarm relay card. Channel 2 was brought into danger as shown on the screen; however, the trip output did not energise due to the voting being 1-out-of-2.

VT-101 was also brought to the danger limit, this brought in the trip alarm output channel 2 on the relay card, proving the voting logic. Both proximitors were then made healthy, the danger alarms cleared however the trip remained active on the rack until the reset was pressed. This process was repeated for VT-201 and 202 probes. These tests can be found in the appendix, references 89 to 103.

These tests proved the relay output to DeltaV by flagging up the trip and first up alarm on the HMI, the alert 1 out of 2 voting alarm remains a rack indication only and can be cleared through manual operation of the reset.

4.3 Results

The testing results table can be seen in table 5, all tests were completed and the outcomes acceptable.

Reviewing the outcomes, two testing criteria were not fully met and did not directly match the expected output. These tests are still marked as successful, however a BSU (Before Start-Up) or ASU (After Start-up) action will be assigned to rectify either the equipment or supporting documentation.

The Punch List is shown in table 5.

Test	Query	Pass?	Rectification	BSU/ASU
4.1.1.5	Manual starting of compressor will always start fin fans. Unable to inhibit fans and force compressor output without entering control studio. From studio, either compressor or fans can be forced. However, compressor will not start without fans from faceplate.	Y	Verify operations user area unable to access control studio.	BSU
4.1.2.3	No loading bypass present on DeltaV.	Y	Manually lock out loading solenoids in the field to prevent loading and test when compressor operational. This ensures field operator presence when bypassing loading.	ASU

Table 5: Punch list

To conclude the testing, the project has passed the site acceptance test with a couple of action items to be completed as part of the final commissioning.

This belongs in the appendix

This is a better testing table because it shows expected and actual results. (RD)

FDS item	Test	Expected result	Actual result	Pass (Y/N)	Amendment required/Notes
4.1.1.2, 4.1.2.4	Simulate an open circuit trip condition during healthy VRU1 compressor operation for TSHH-1569. Repeat for all VRU1 trips.	Output to VRU1 compressor immediately de-energises to shutdown equipment. VRU1 loading SOV outputs de-energise. Compressor will not start until trip made healthy again.	VRU1 Compressor shuts down when trip active, first up alarm displays the initial trip. Compressor will not restart until trip clear and reset pressed.	Y (RD?)	Vibration trips activate on Bently rack and provide visual indication to channel. The relay output is direct to DeltaV where the operator interface provides alarm and trip information.
	PSHH-1574	Indication for each alarm and trip must operate			
	PSLL-1571				
	PDSLL-1571				
	FAN-1 Vibration				
	LSHH-1561				
	Simulate an open circuit trip condition during healthy VRU2 compressor operation for TSHH-1669. Repeat for all VRU2 trips.	Output to VRU2 compressor immediately de-energises to shutdown equipment. VRU2 loading SOV outputs de-energise. Compressor will not start until trip made healthy again.	VRU2 Compressor shuts down when trip active, first up alarm displays the initial trip. Compressor will not restart until trip clear and reset pressed.		Vibration trips activate on Bently rack and provide visual indication to channel. The relay output is direct to DeltaV where the operator interface provides alarm and trip information.
	PSHH-1674	Indication for each alarm and trip must operate.			
	PSLL-1671				
	PDSLL-1671				
	FAN-2 Vibration				
	LSHH-1661				
4.1.1.3	Increase pressure of VRU1 set point controller to 4.4kg/cm2 whilst all states healthy and compressor offline.	VRU1 compressor should promptly cut in following start sequence.	VRU1 compressor cuts in at desired pressure and loads accordingly.		Compressor loading follows hysteresis for unloading at correct pressures.
	Increase pressure of VRU2 set point controller to 4.4kg/cm2 whilst all states healthy and compressor offline.	VRU2 compressor should promptly cut in following start sequence.	VRU2 compressor cuts in at desired pressure and loads accordingly.		Compressor loading follows hysteresis for unloading at correct pressures.
4.1.1.4	Begin VRU1 compressor start sequence.	Fin-fans EAM-101A&B outputs should cut in instantly.	Fin-Fan outputs energise.		Running indication also provided.
	Begin VRU2 compressor start sequence.	Fin-fans EAM-102A&B outputs should cut in instantly.	Fin-Fan outputs energise.		Running indication also provided.
4.1.1.5	Force VRU1 fin-fan outputs open and attempt to begin start sequence on VRU1.	VRU2 compressor output should not energise.	Compressor will not start unless interlock is overriden.		Lock out manual output forcing for operations log on. Point forcing only to be unlocked for engineer users.
	Force VRU2 fin-fan outputs open and attempt to begin start sequence on VRU2.	VRU2 compressor output should not energise.	Compressor will not start unless interlock is overriden.		Lock out manual output forcing for operations log on. Point forcing only to be unlocked for engineer users.
4.1.1.6	Increase VRU1 controller pressure throughout range.	VRU1 loading SOVs should trigger as per loading table.	Correct loading as per tables.		
	Increase VRU2 controller pressure throughout range.	VRU2 loading SOVs should trigger as per loading table.	Correct loading as per tables.		
4.1.1.7, 4.1.1.9	Begin VRU1 compressor start sequence.	VRU1 must not load until 10 seconds after start. Lube oil trip must be bypassed for 60 seconds after start.	Lube oil low trip bypassed for 60 seconds or until healthy pressure is established.		
	Begin VRU2 compressor start sequence.	VRU2 must not load until 10 seconds after start. Lube oil trip must be bypassed for 60 seconds after start.	Lube oil low trip bypassed for 60 seconds or until healthy pressure is established.		
4.1.2.1	Test ESD buttons during compressor operation	Corresponding compressor must shutdown and not restart while latched.	Compressors shutdown.		
4.1.2.2	Test compressor resets.	Corresponding compressor alarms and trips should clear and compressor start when reset operated if all trips are healthy and pressure above set point.	Compressor trips and first up alarms only clear when reset operated.		Vibration trips must be reset on the Bently Nevada 3500 rack adjacent to control panel, before they can be reset on the DCS software.
4.1.2.3	Operate loading bypasses.	Compressors must not load when bypass is engaged.	No loading bypass implemented on control system.		Manual loading of cylinders can be manually operated in field if desired. No requirement for these to be software.
4.4.1.1	Disconnect one power supply.	System should still maintain power from redundant supply.	System still operational.		System can also run with a single controller.
4.4.2.5	Check full range of electronic pressure transmitters.	Range should output 4-20mA as per specification.	0 to 6 kg/sqcm full range accurate to analogue output.		
4.4.1.2	Check power supply output voltage.	Output should be 24V.	Correct voltage.		
4.1.1.2, 4.1.1.3	Test Bently Nevada 3500 Voting for vibration alarms and trips.	Alert alarm should trigger when either of the two probe readings is above the the threshold. Danger trip alarm should trigger when both probe values increase above the threshold.	Voting logic correct and analogue value viewable through Bently Rack.		

Table 6: Testing spreadsheet

5 Evaluation and Wider Issues

5.1 FDS conformity and completion

Did the specification have to change also? (RD)

Reviewing the FDS shows that the project was an overall success, as all areas within the specification were met. The conformity was proved through use of the testing table, of which extra tests were added in line with the program development. The tests concluded with a couple of minor action items.

The final design was carried out as per the risk assessment and EMOC actions to ensure compliancy within the industrial application. As a completed project, the installation onto site is easily achievable through the modular design of the DeltaV hardware. The Emerson cabinet will require I/O cut-over from the old relays, directly into the Charm terminal blocks and supply from the 110V. The addition of the Bently Nevada rack output will replace the traditional vibration switch wiring, simply requiring the relay outputs to be wired from the card to the Charm terminals, across the adjacent cabinet. The rack is mounted within 1m of the DeltaV control panel in the B&S control room, allowing for alarm indication and reset of the rack without having to leave the panel. This satisfies the ergonomic criteria 4.2.3.1 of the FDS detailed in Assignment 1 (Ince, 2020)

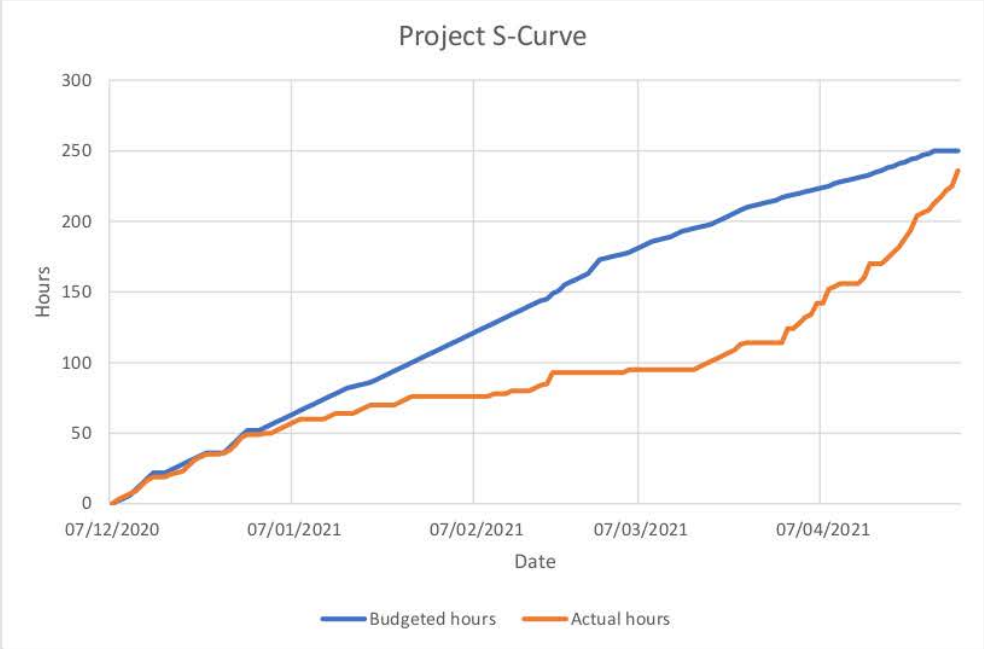
The project meets the design criteria for being an operational demonstration rig ready for site implementation. The integrated control software and hardware will reduce maintenance costs, environmental fines, and improve safety of the Vapour Recovery Unit for the company.

The fact that it was to be a demonstration rig should have been clearly stated in the introduction. (RD)

5.2 Time management and costing

To manage time and plan the project accordingly, a preliminary Gantt chart was developed, detailed in appendix 104. This initial chart failed to account for unforeseen project setbacks and so design and implementation planning did not extend into the company planned outage.

Due to COVID-19 restrictions, the project timeline shifted well into the TAR (turnaround), during this period the company priority was the commitment to TAR and so project work was put on hold. This shift in priority and extended working hours meant a new plan had to be developed for the forecasted hours.



It could be argued that the TAR period should have been considered at the outset and contingencies built into the plan (RD)

Figure 16 Project S-Curve

The S-curve for the project man hours seen in figure 16 was developed to keep track of the project design and execution hours across the full work scope. Initially the project remained on target until mid-January. The company TAR started from January 14th 2021 onwards and this is reflected by the curve as the actual hours deviate hugely from the planned, plateauing until the beginning of April, this is also shown in the Gantt chart. A slight shift in company priority from the end of March allowed more allocation of time to project work, this is when a large amount of the implementation was completed, often exceeding the planned hours for that period. This means that the project timeline is very back loaded, with larger amounts of work being completed in short periods and reduced productivity in between. This form of completion was less desirable as the project did not progress steadily or according to plan.

The deviation from the plan during the execution stage meant that the monthly budget had to be shifted from the original to track the change in labour costs. The overall costing spreadsheet in table 7 details how these changes differ from the original plan. The ordering of materials earlier meant that the bulk of the budget was used before 2021. The labour hours are well below the original budget during January to March, however the hours in April required more budget allocation. Overall, the final labour costs are £1140 under budget.

Description	MWO No.	Original Budget	Current Budget	Current Forecast	2020 Sep-20	Oct-20	Nov-20	Dec-20	Jan-21	Feb-21	Mar-21	2021 Apr-21	May-21
Construction Total	Various	£0											
			£0										
				£0									
Manhour Costs Total	Various	£6,000				600	750	750	750	1,050	1,050	1,050	
			£6,000			600	750	1,050	1,050	1,050	750	750	
				£4,860		600	750	735	375	255	315	1,830	
Materials Total	Various	£20,000						15,000	5,000				
			£17,800					15,000	2,800				
				£19,880					15,000	4,880			
Overall Total		£26,000			0	600	750	15,750	5,750	1,050	1,050	1,050	0
			£23,800		0	600	750	16,050	3,850	1,050	750	750	0
				£24,740	0	600	750	735	15,375	5,135	315	1,830	0
Accumulative Total					0	600	1,350	17,100	22,850	23,900	24,950	26,000	26,000
					0	600	1,350	17,400	21,250	22,300	23,050	23,800	23,800
					0	600	1,350	2,085	17,460	22,595	22,910	24,740	24,740

	Sep-20	Oct-20	Nov-20	Dec-20	Jan-21	Feb-21	Mar-21	Apr-21	May-21
Original Commitment	0	600	1,350	17,100	22,850	23,900	24,950	26,000	26,000
Current Commitment	0	600	1,350	17,400	21,250	22,300	23,050	23,800	23,800
Actuals Commitment	0	600	1,350	2,085	17,460	22,595	22,910	24,740	24,740
Frozen Forecast Commitment	0	600	1,350	2,085	17,460	22,595	22,910	24,740	24,740

Table 7: Monthly costing

The materials costing table has been updated with the final prices, this also includes the pressure transmitter obtained from the instrument stores as surplus and as a result has no effect on the total. The extra project scope materials have been added on whilst the overall total remains under the £20,000 budget.

Item	Manufacturer	Vendor	Price each	Quantity	Total
48 CHARM CIOC Controller enclosure	Emerson	Emerson	£15,000	1	£15,000
DI CHARM	Emerson	Emerson	£100	10	£1,000
DO CHARM	Emerson	Emerson	£100	12	£1,200
AI CHARM	Emerson	Emerson	£300	2	£600
Rosemount 2051 (Instrument Surplus)	Emerson	Emerson	£2,100	2	N/A
Bently Nevada 3500 8mm probe	Bently Nevada	Bently Nevada	£220.00	4	£880
Bently Nevada 3500 Proximitor	Bently Nevada	Bently Nevada	£300.00	4	£1,200
				Total:	£19,880

Table 8: Materials costing

5.3 Project execution and plan

The project build was carried out through utilising the plan to separate out the individual tasks and milestones throughout. Due to constraints previously discussed, many milestones were not met according to plan. However, some milestones were unaffected by this and yet still overran, for example, the logic design and implementation, as seen on the finalised Gantt chart in the Appendix. The plan begins initially on track; however, the logic programming stage and further took many weeks longer due to the difficulties encountered and a shift in company priorities towards turnaround work.

The logic design although planned using existing logic diagrams, had to be designed as ongoing with the project build as the ladder logic cannot be directly mapped across to the DeltaV system, this was due to the technician's inexperience with the control software. To pre-empt this, less time could be allocated to designing the logic, and more time to building and implementing it. In future however, the knowledge gained from the project would allow planning to be more thorough to prevent milestone dates overrunning. As shown in the appendix 104 Gantt chart, the overrunning time (red) mostly occurred during the logic programming period. Despite these issues, the project was completed ahead of the planned project end, 30th of April.

A minor change to the project design was made during the build, this involved utilising the existing Bently Nevada 3500 rack within the control room to control the vibration trips on the fin-fans. Utilising unused I/O slots on this equipment to output relay state changes to the DeltaV improved indication and alarm management for the system and ultimately control ergonomics. The labour hours allocated to the execution required no increase for this change whilst also keeping material costs below the maximum budget.

During the implementation, no improvement areas for safety were identified. The bulk of the execution involved logic and control system programming, the largest areas for concern being posture when operating a workstation. Correct breaks and seating position ensured no injuries were sustained throughout.

As documented in the EMOC Risk Assessment form *PP-PEM-FRM-0077* (Valero, 2020), the action items required for the upgrade to be allowed have been incorporated into the system. This ensures the equipment meets the safety requirements for the site.

The materials used in the project have been sourced as ethically as reasonably possible. Where available, parts have been signed out of the company stores and surplus. This has reduced excess packaging as when replenishing stock, the company will order a large batch. Therefore, less packaging is required than when ordering individual items on a smaller scale. Regarding surplus stock, this is not re-ordered and therefore is utilising materials that would otherwise go to waste, effectively saving money whilst also benefitting the environment.

6 Conclusions and Recommendations

Overall, the project has been completed to a standard that meets the initial criteria detailed whilst also in accordance with the company and industry standards. The success of the project depended on addressing the three target issues of the previous system. The new system solves these and so will improve performance and reliability of the refinery and ultimately reduce running costs and operating emissions. The finalised testing rig for the project is ready for site implementation, to fully implement on site, the existing I/O and supply will be required to be cut over directly to the charms and supply in the Emerson cabinet. The DeltaV system will then be able to access and manipulate the I/O with the designed control software. Operability has been proven through thorough testing of each function, repeated tests were carried out through each development of the design and a finalised test following completion. Regarding the operability standpoint, the project is a success and has achieved the desired outcome.

The delivery of the project plan met many issues that greatly shifted the track away from the plan, the impact of this was reduced in a partial respect by starting the project earlier than originally planned. However, time management still became an issue and resulted in disjointed progress, reflected in the S-curve (figure 16). The budget of the project required micromanaging monthly in line with the labour hours, however remained under budget whilst including a minor design addition.

The DCS choice has proven to be the optimum long-term solution of the three initial choices, the system is future proofed through being integral to the control system upgrade that has only recently been fully rolled out across site. Control and trip functionality have been jointly carried out by the DCS, external logic has also been included into the standalone Bently Rack. The integration of the Bently rack allows for future expansion, such as a speed probe or machinery diagnostic project and compressor upgrade. It has also enabled the project to benefit from modern existing infrastructure, saving costs.

Recommendations for future projects are associated with improving the project planning process. Despite implementing multiple contingencies, this project deviated by a large amount from the plan. Difficulties posed by COVID-19 restrictions initially denied access to work locations and equipment, this delayed the project further into the TAR, an extremely time intensive period with delays of its own. These irregular conditions impeded progress but are however not a common occurrence. In future, for a work-based project to be carried out alongside normal working hours, the work scope must be planned across a far larger amount of time. Doing so will reduce daily demand and will allow the flexibility for separate work commitments.

In conclusion, the project overcame the challenges encountered throughout, and despite moving off plan, managed to stay within budget whilst being an operational and environmental success.

7 Citation List

Emerson, 2020. *AC Powered Field Enclosure for 48 CHARM I/O; For Zone 2 Locations (EU-FE-48-AC-CIOC-HA-DEMO),* s.l.: s.n.

Ince, D., 2020. *Major Project Assignment 1,* s.l.: s.n.

Ind Ex, 2017. *Wiring requirements in hazardous locations.* [Online]
Available at: https://www.atexdb.eu/atex_article/wiring-requirements-in-hazardous-locations
[Accessed 15 February 2021].

Valero, 1988. *JA08/4585/Z VRU Relay Logic*. s.l.:s.n.

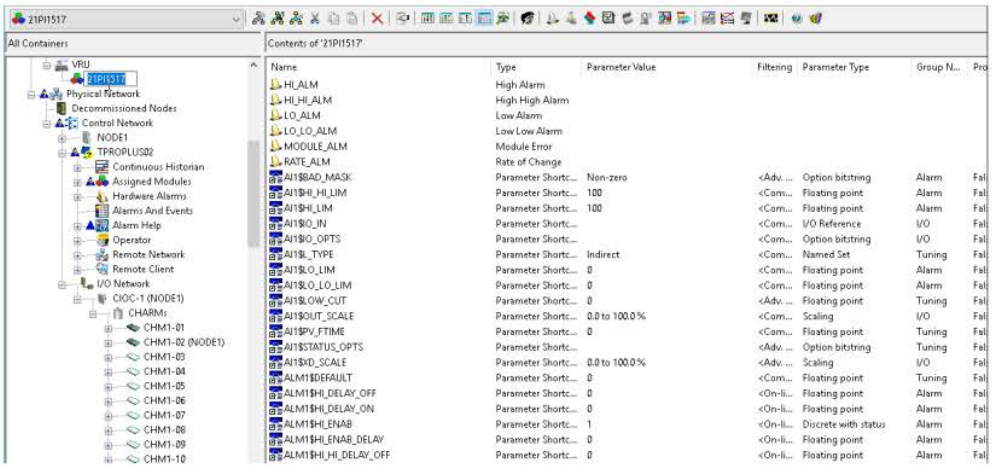
Valero, 2020. *MOC Risk Assessment PP-PEM-FRM-0027 ,* s.l.: s.n.

Valero, 2020. *Risk Matrix PP-HES-GUI-0009 ,* s.l.: s.n.

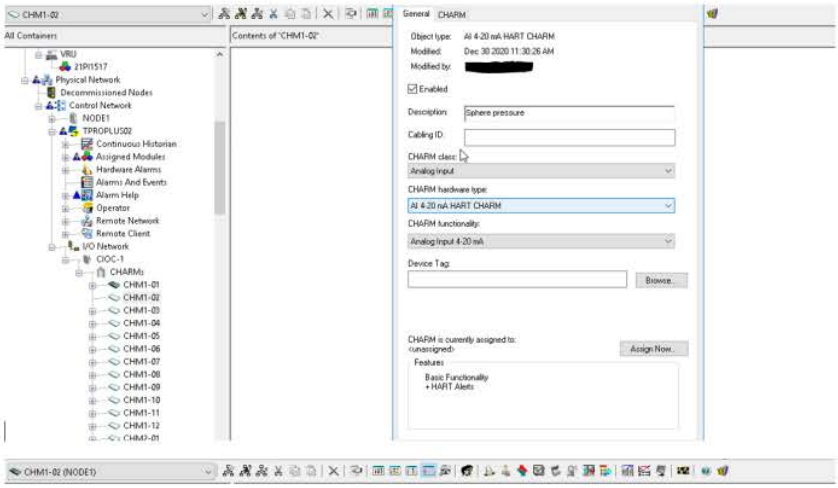
This list is far too small for a major independent report, at least two or three pages of references should be included at this level. (RD)

8 Appendix

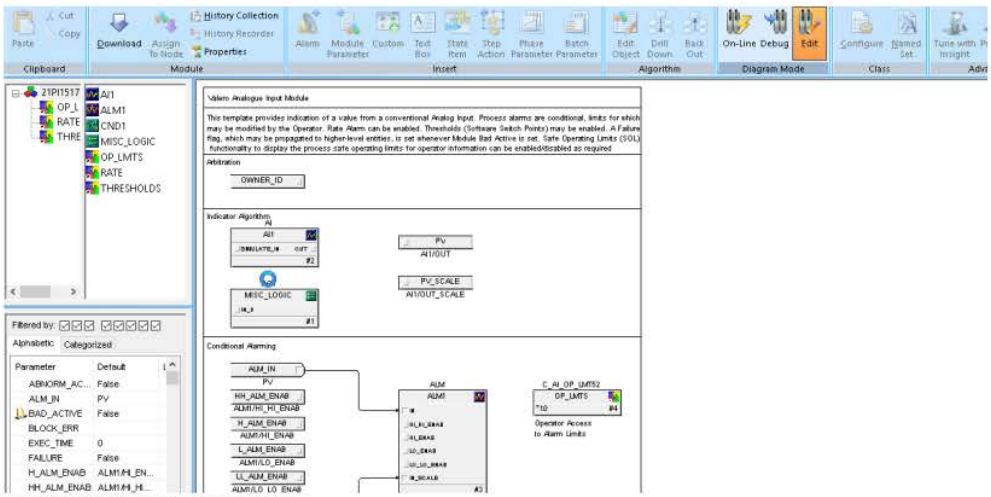
8.1 Implementation Evidence



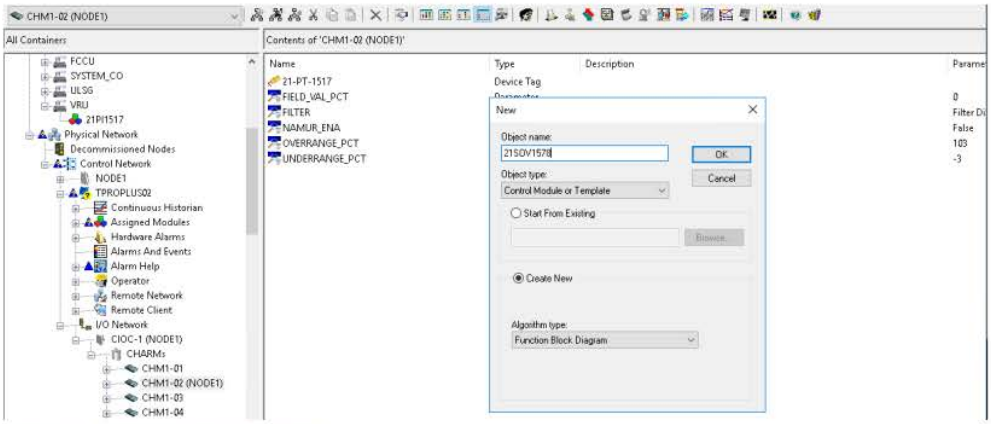
Appendix 1: Setting up the main pressure controller.



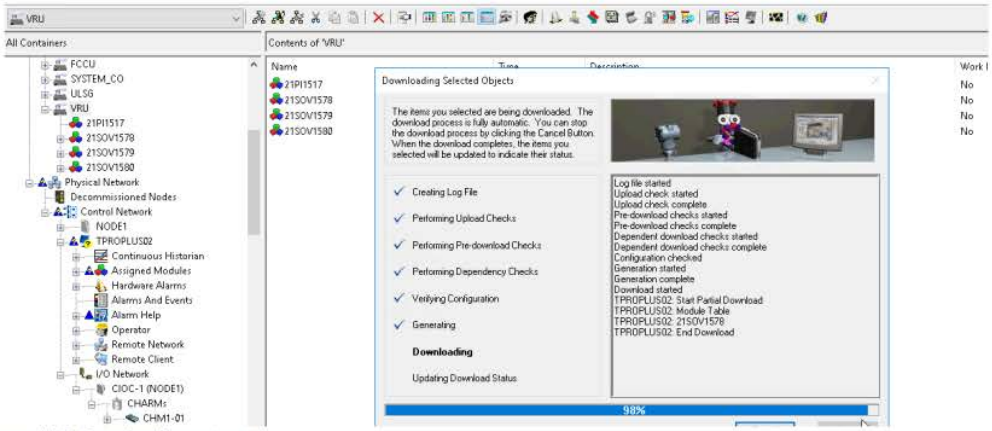
Appendix 2: Network area configuration.



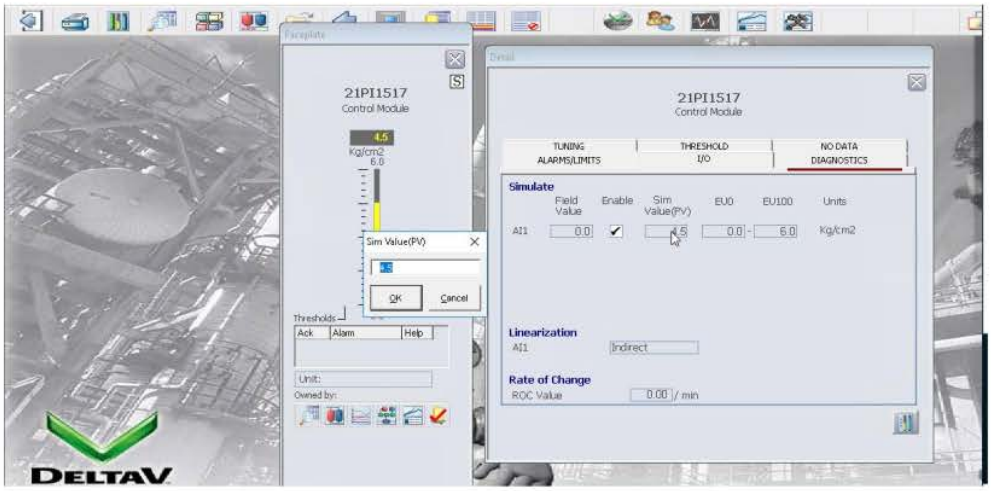
Appendix 3:AI controller internal blocks.



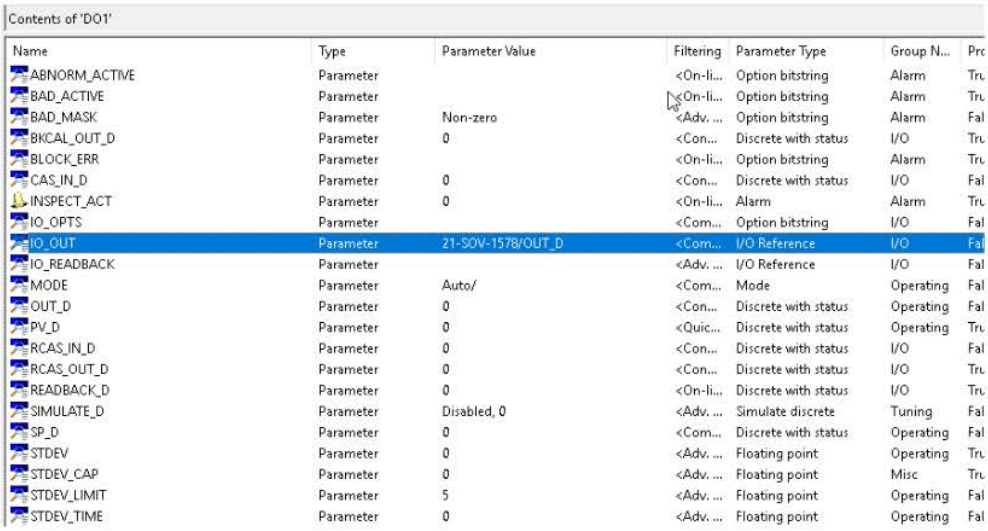
Appendix 4: Solenoid outputs configured.



Appendix 5: Downloading outputs.



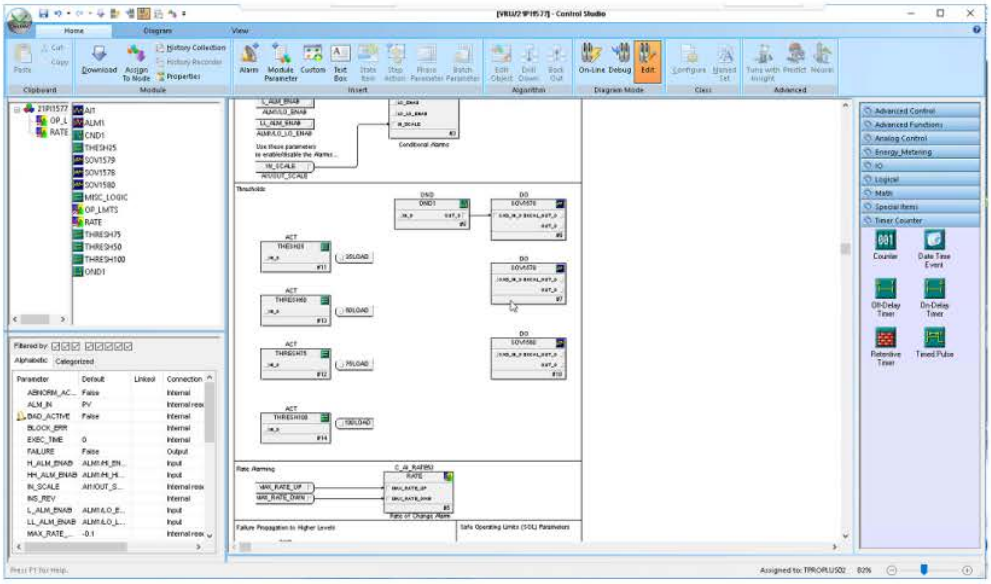
Appendix 6: Faceplate configuration and test.



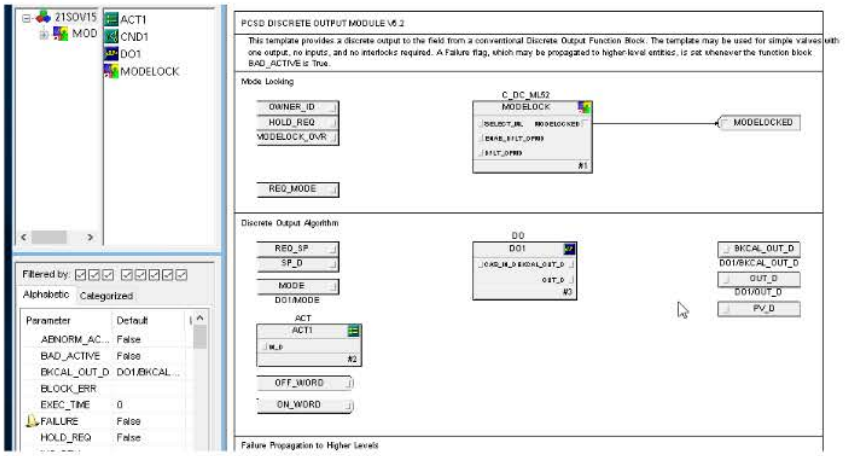
Contents of 'DO1'

Name	Type	Parameter Value	Filtering	Parameter Type	Group N...	Pro
ABNORM_ACTIVE	Parameter		<On-li...	Option bitstring	Alarm	Tru
BAD_ACTIVE	Parameter		<On-li...	Option bitstring	Alarm	Tru
BAD_MASK	Parameter	Non-zero	<Adv. ...	Option bitstring	Alarm	Fal
BKCAL_OUT_D	Parameter	0	<Con...	Discrete with status	I/O	Tru
BLOCK_ERR	Parameter		<On-li...	Option bitstring	Alarm	Tru
CAS_IN_D	Parameter	0	<Con...	Discrete with status	I/O	Fal
INSPECT_ACT	Parameter	0	<On-li...	Alarm	Alarm	Tru
IO_OPTS	Parameter		<Com...	Option bitstring	I/O	Fal
IO_OUT	Parameter	21-SOV-1578/OUT_D	<Com...	I/O Reference	I/O	Fal
IO_READBACK	Parameter		<Adv. ...	I/O Reference	I/O	Fal
MODE	Parameter	Auto/	<Com...	Mode	Operating	Fal
OUT_D	Parameter	0	<Con...	Discrete with status	Operating	Fal
PV_D	Parameter	0	<Quic...	Discrete with status	Operating	Tru
RCAS_IN_D	Parameter	0	<Con...	Discrete with status	I/O	Fal
RCAS_OUT_D	Parameter	0	<Con...	Discrete with status	I/O	Tru
READBACK_D	Parameter	0	<On-li...	Discrete with status	I/O	Tru
SIMULATE_D	Parameter	Disabled, 0	<Adv. ...	Simulate discrete	Tuning	Fal
SP_D	Parameter	0	<Com...	Discrete with status	Operating	Fal
STDEV	Parameter	0	<Adv. ...	Floating point	Operating	Tru
STDEV_CAP	Parameter	0	<Adv. ...	Floating point	Misc	Tru
STDEV_LIMIT	Parameter	5	<Adv. ...	Floating point	Operating	Fal
STDEV_TIME	Parameter	0	<Adv. ...	Floating point	Operating	Fal

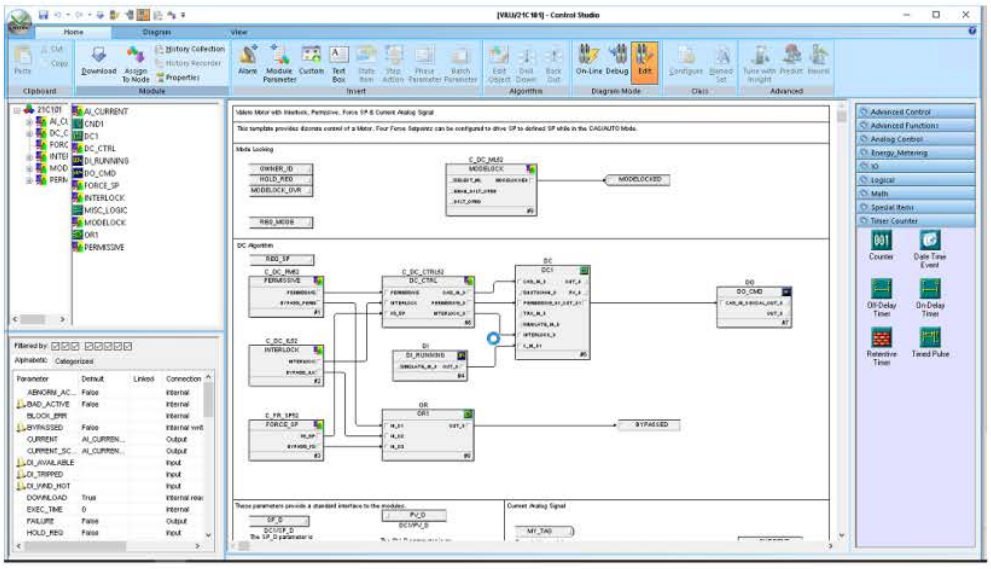
Appendix 7: Output reference assigned.



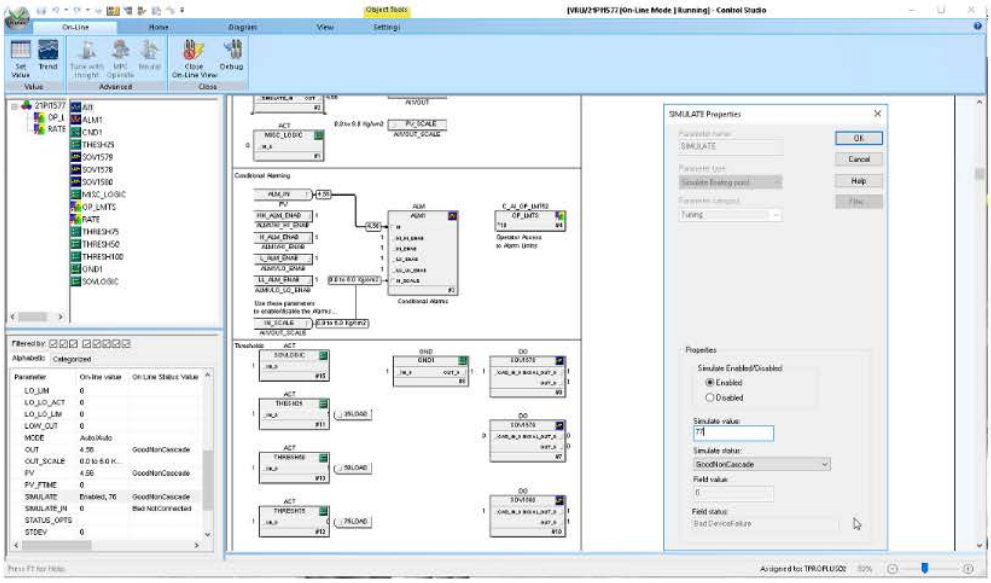
Appendix 8: Loading module design



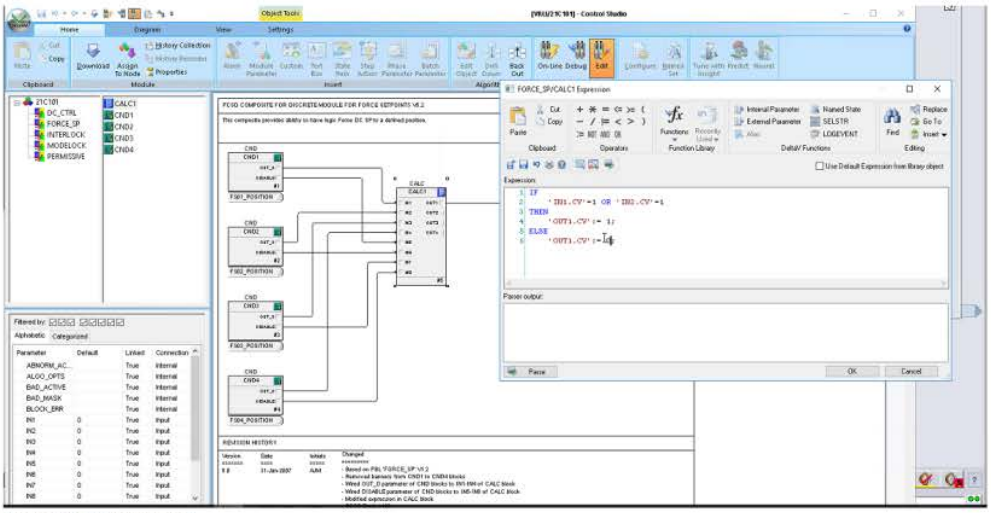
Appendix 9: SOV module internal blocks.



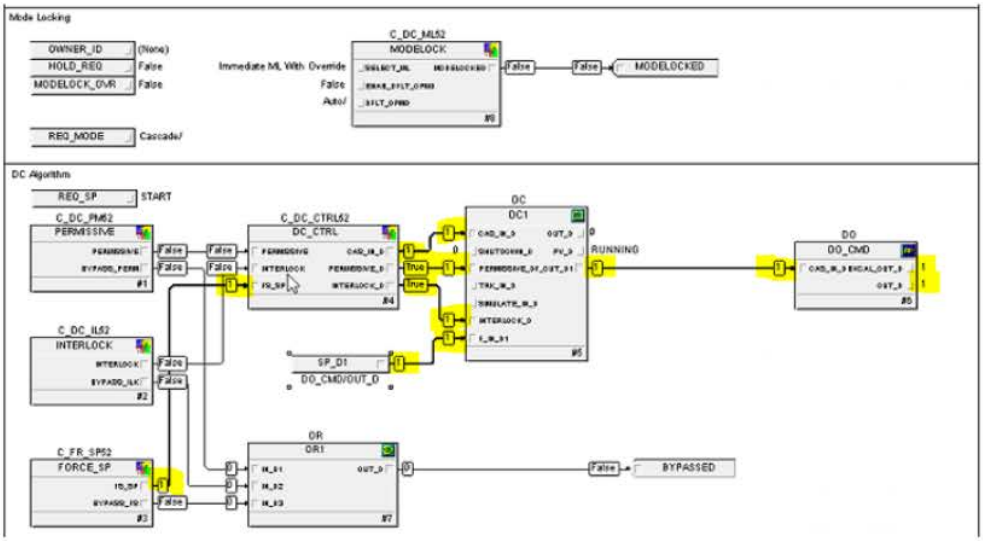
Appendix 10: Compressor module.



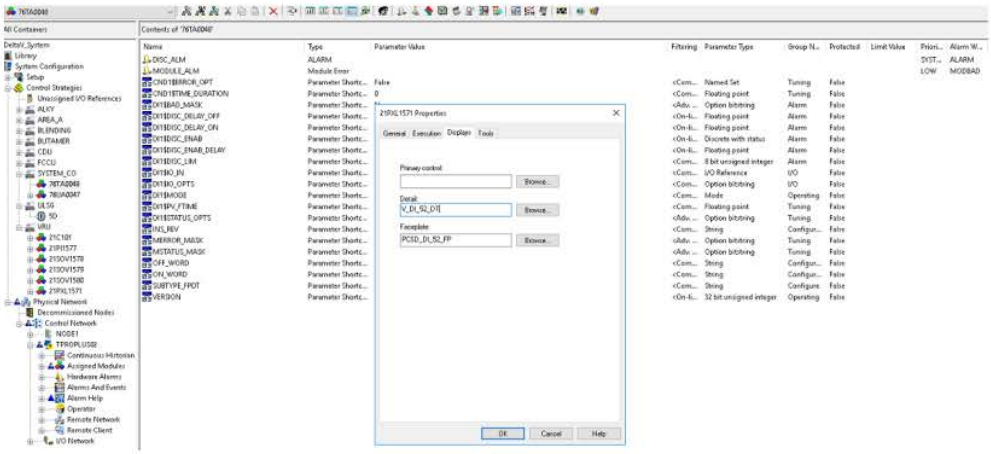
Appendix 11: Simulation force and test.



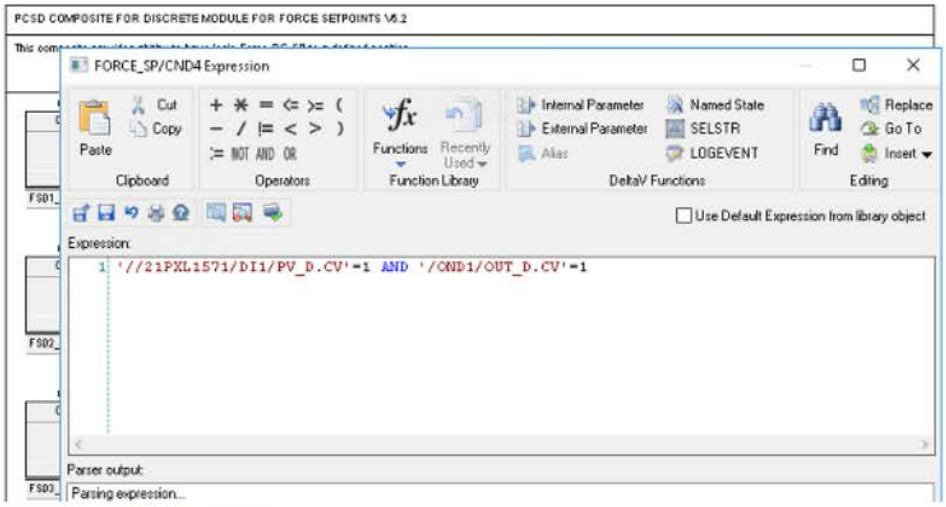
Appendix 12: Force logic.



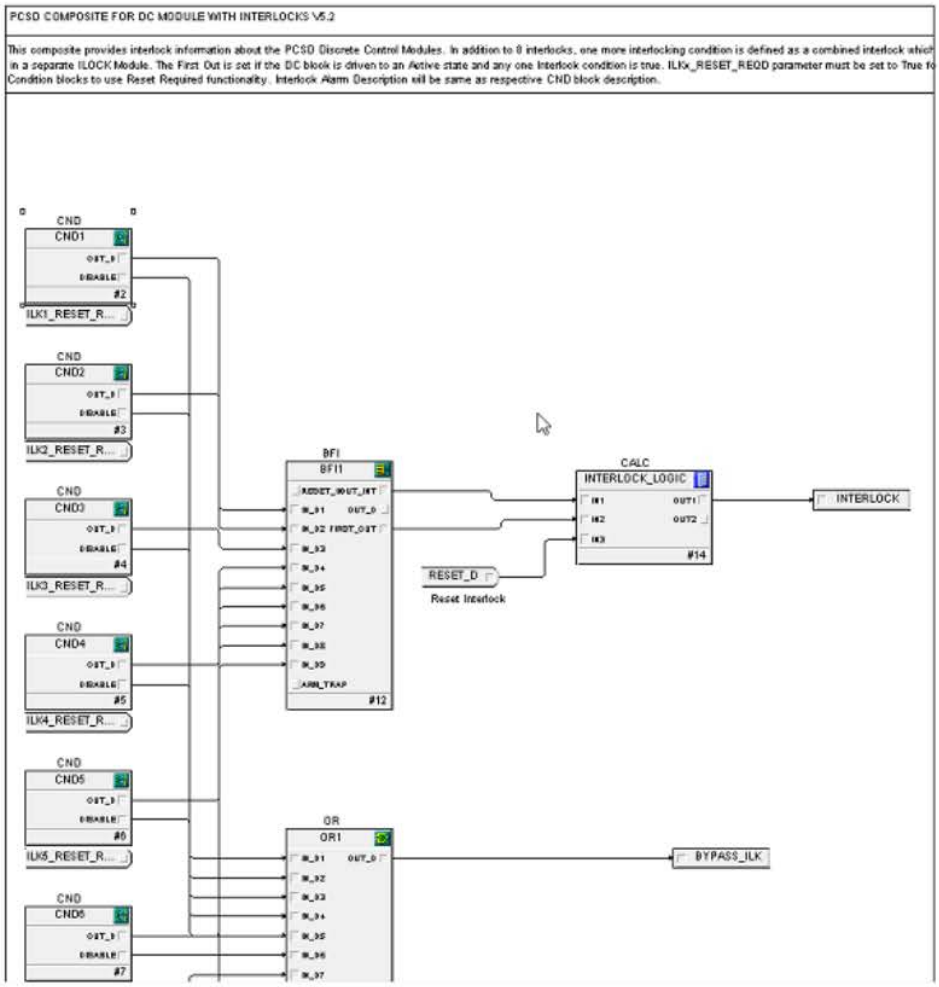
Appendix 13: Force logic test.



Appendix 14: Low lube oil module.

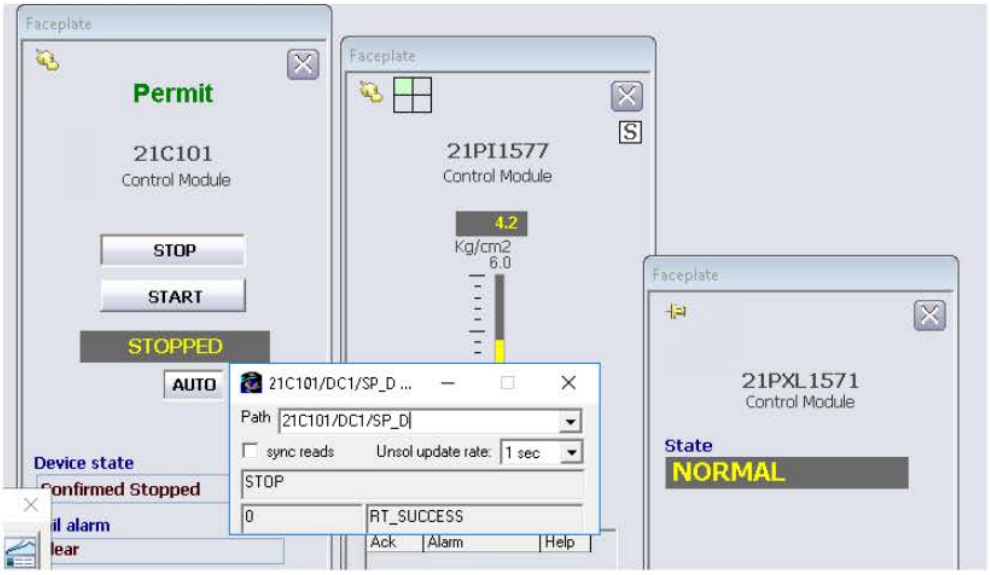


Appendix 15: Low lube oil trip logic.

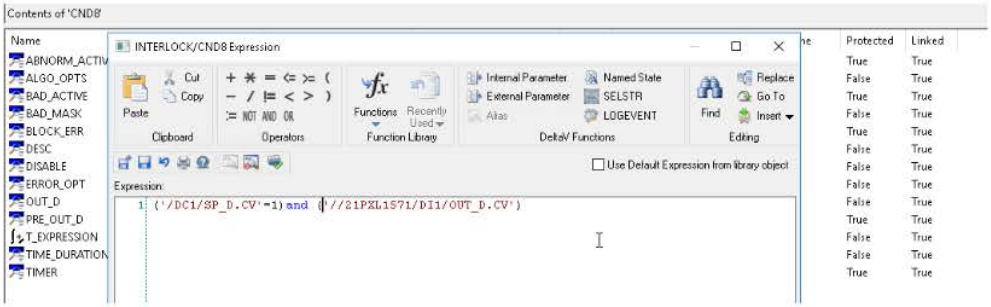


Appendix 16: DC Interlock module.

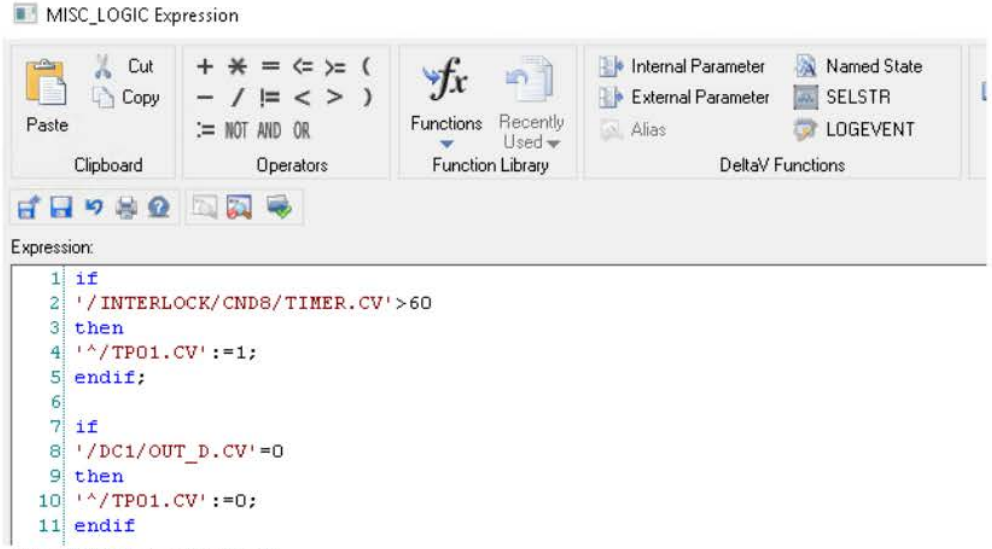
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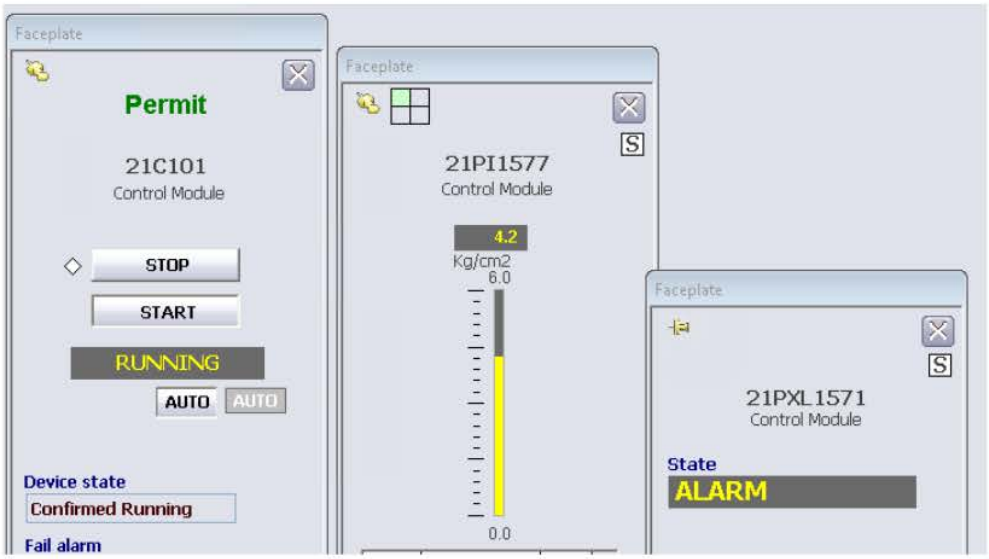
Appendix 18: Start testing.



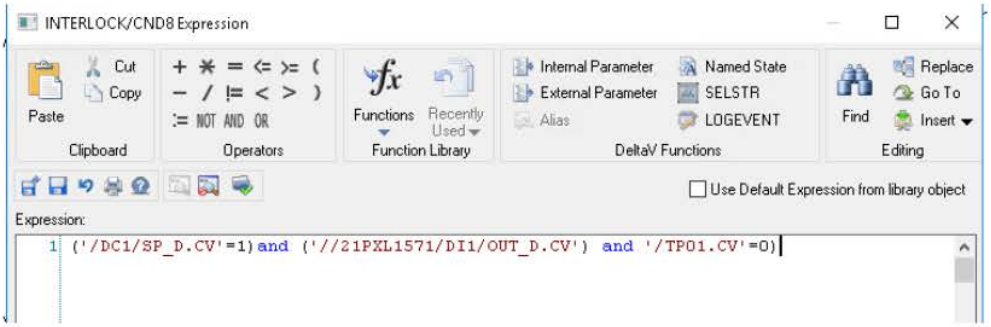
Appendix 19: Interlock expression.



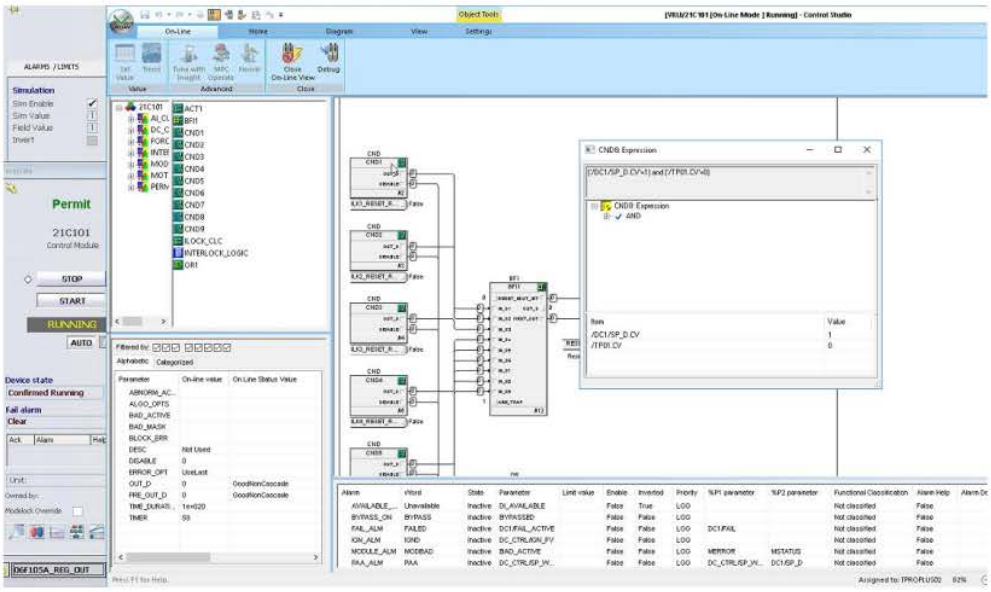
Appendix 17: Updated timer logic.



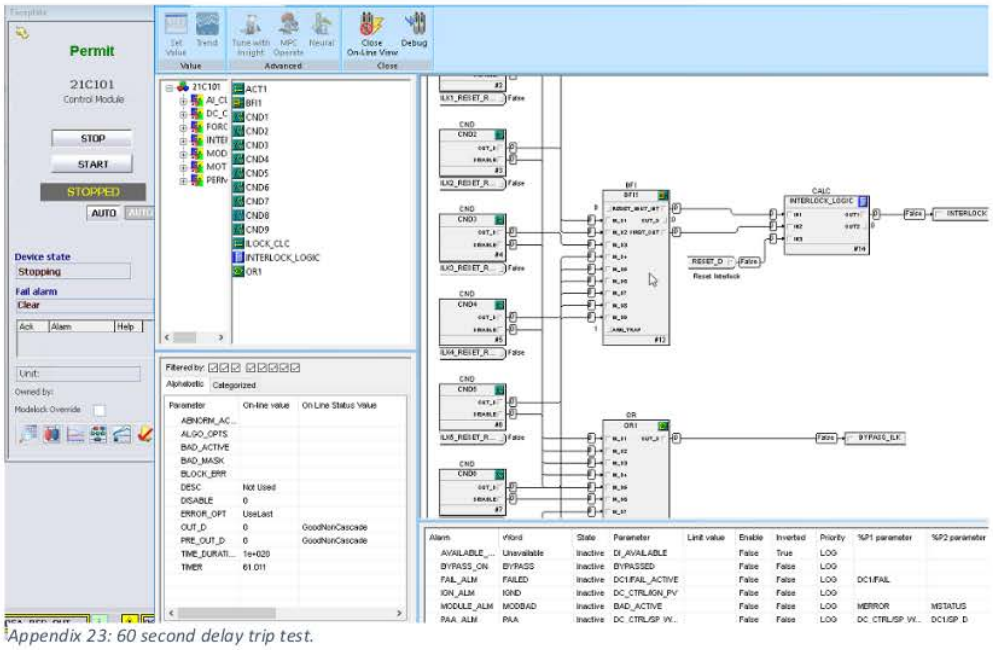
Appendix 20: Lube oil trip bypass trip test.



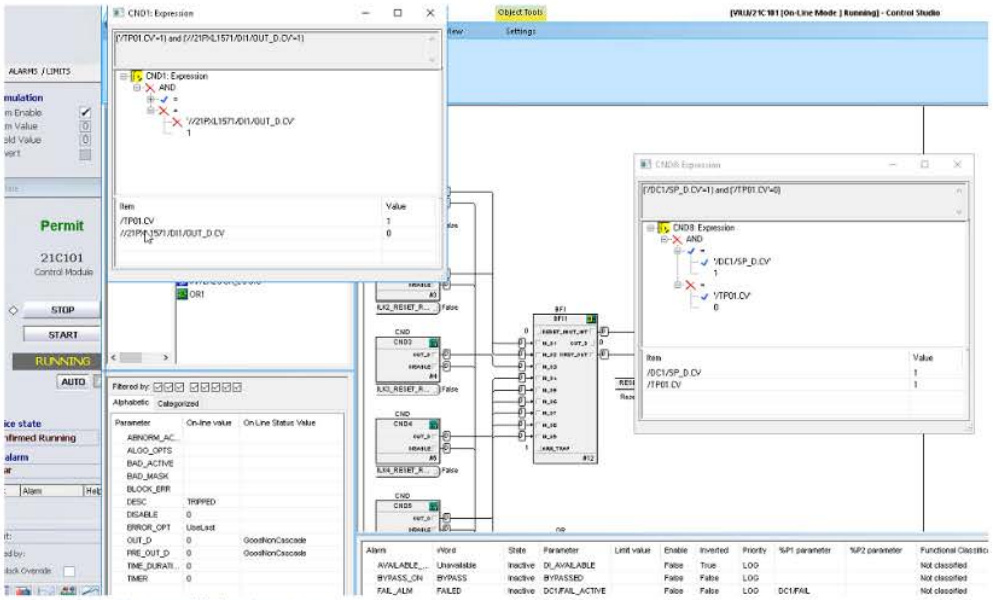
Appendix 21: Interlock expression update.



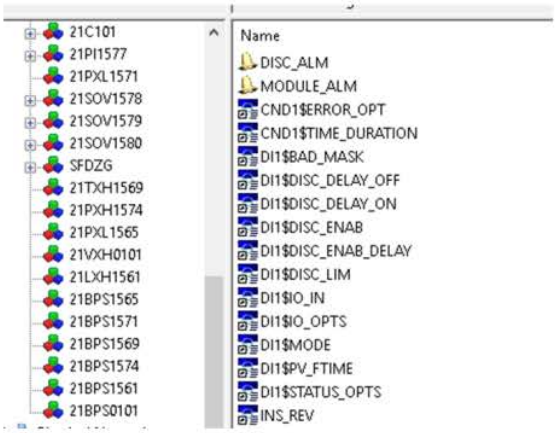
Appendix 22: 60 second delay test.



Appendix 23: 60 second delay trip test.



Appendix 24: 60 second delay timer reset.



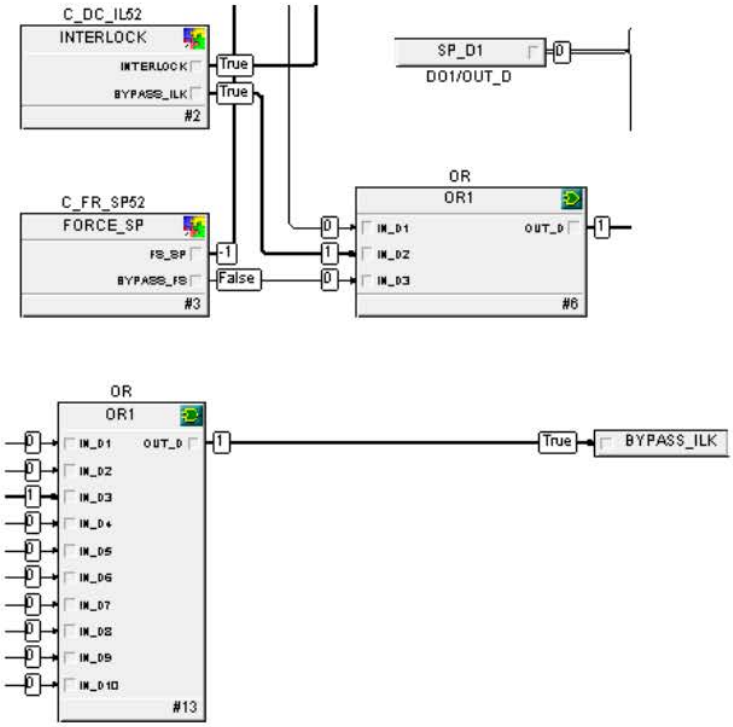
Appendix 25: Shutdown DI blocks.



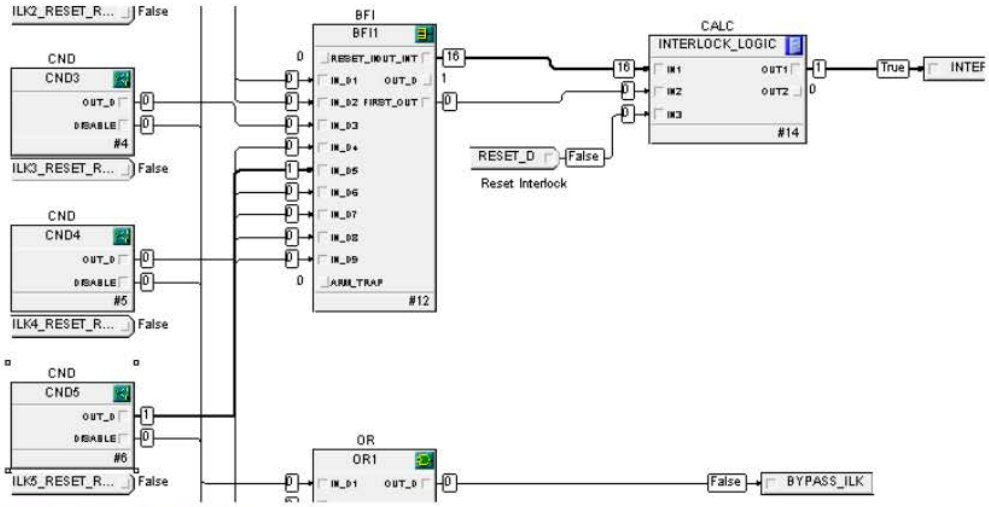
Appendix 26: Inhibit start test.

```
13 IF
14 '//21BPS1565/DI1/OUT_D.CV'=1
15 THEN
16 '^/INTERLOCK/CND3/DISABLE.CV':=1;
```

Appendix 27: Single bypass logic.



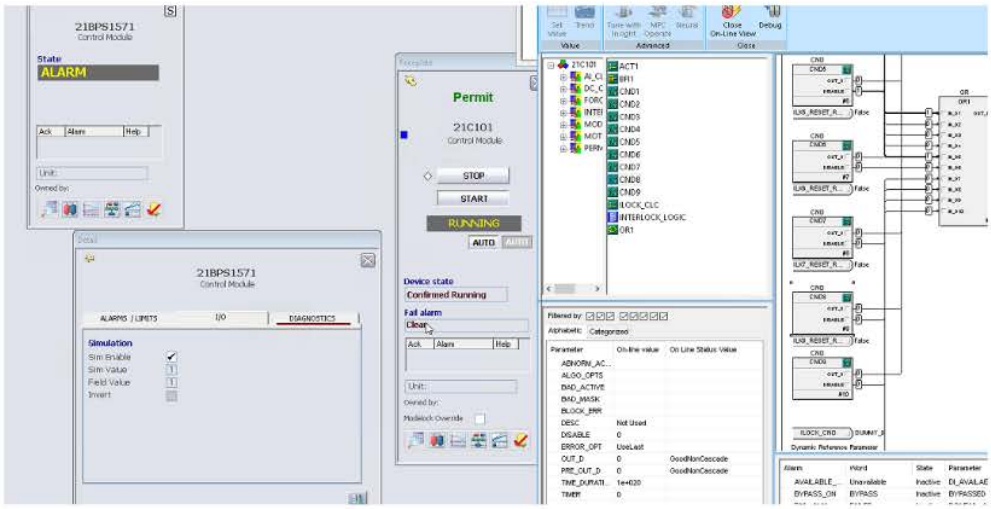
Appendix 28: Bypass logic test.



Appendix 29: Bypass logic test 2.



Appendix 30: Bypass allowing start.



Appendix 31: Start up bypass test.

```
IF
'//21BPS1561/DI1/OUT_D.CV'=1
THEN
'^/INTERLOCK/CND2/DISABLE.CV':=1;
ELSE
'^/INTERLOCK/CND2/DISABLE.CV':=0;
ENDIF;

IF
'//21BPS1569/DI1/OUT_D.CV'=1
THEN
'^/INTERLOCK/CND3/DISABLE.CV':=1;
ELSE
'^/INTERLOCK/CND3/DISABLE.CV':=0;
ENDIF;

IF
'//21BPS1574/DI1/OUT_D.CV'=1
THEN
'^/INTERLOCK/CND4/DISABLE.CV':=1;
ELSE
'^/INTERLOCK/CND4/DISABLE.CV':=0;
ENDIF;

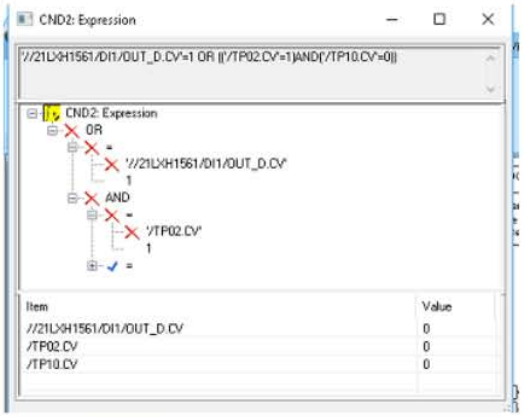
IF
'//21BPS1565/DI1/OUT_D.CV'=1
THEN
'^/INTERLOCK/CND5/DISABLE.CV':=1;
ELSE
'^/INTERLOCK/CND5/DISABLE.CV':=0;
ENDIF;

IF
'//21BPS0101/DI1/OUT_D.CV'=1
THEN
'^/INTERLOCK/CND6/DISABLE.CV':=1;
ELSE
'^/INTERLOCK/CND6/DISABLE.CV':=0;
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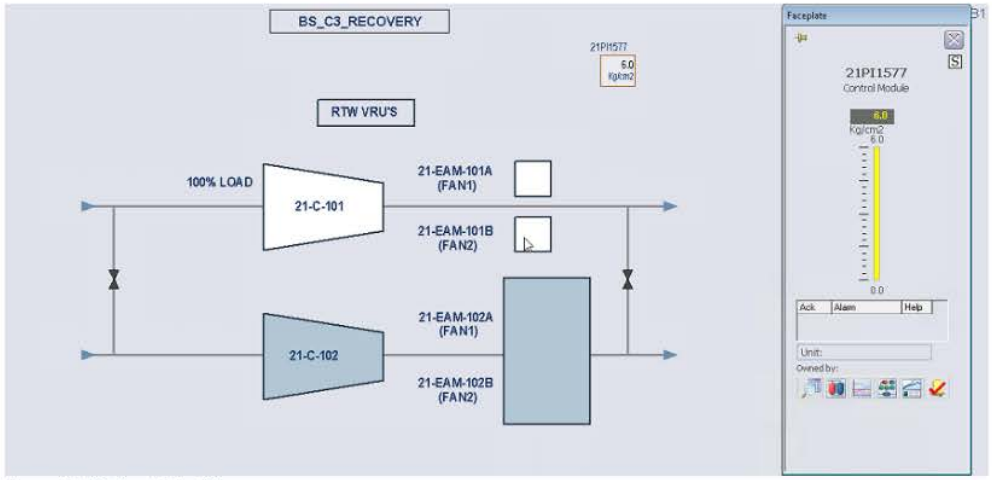
Appendix 32: Further bypass logic.

Appendix 33: Rest button faceplate.

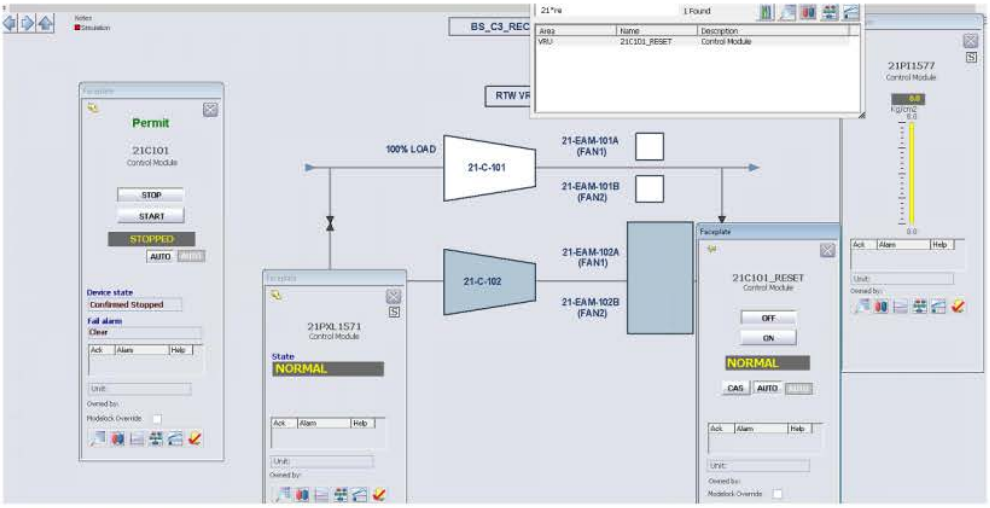




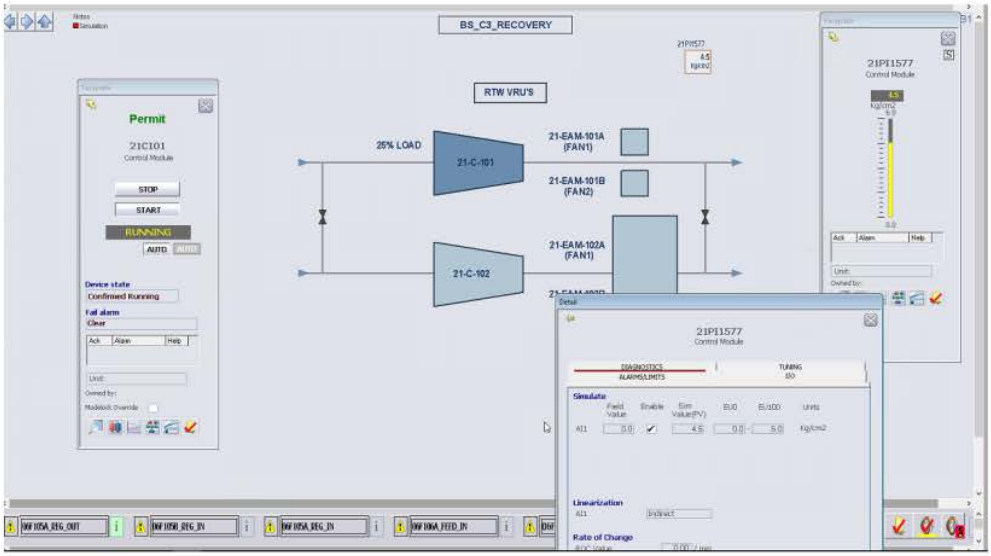
Appendix 34: TP10 is clear.



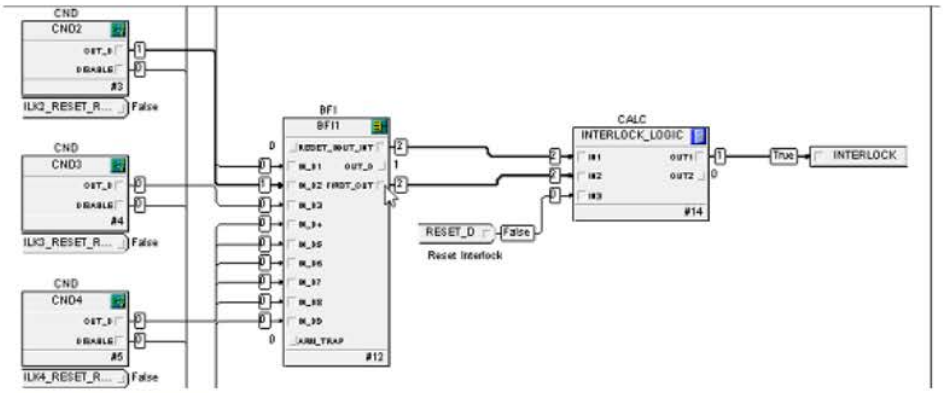
Appendix 35: Graphic build.



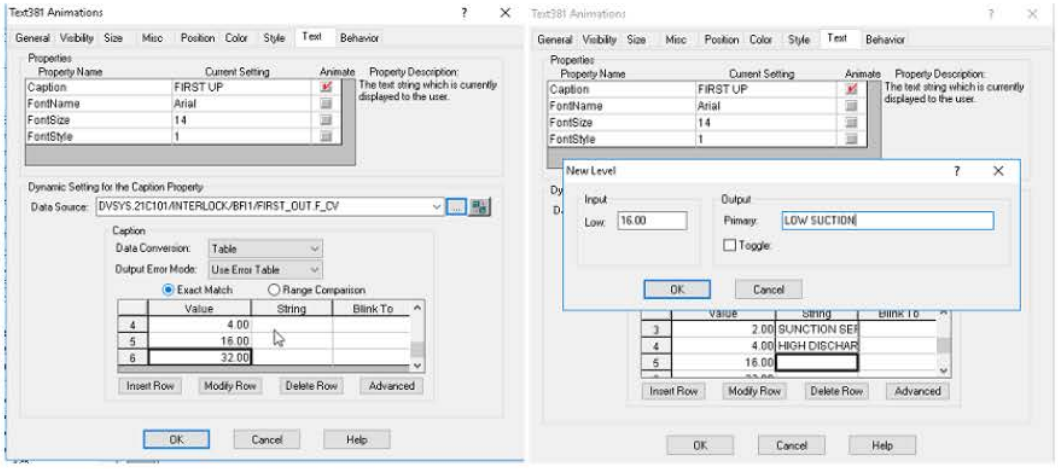
Appendix 36: Graphic and faceplates.



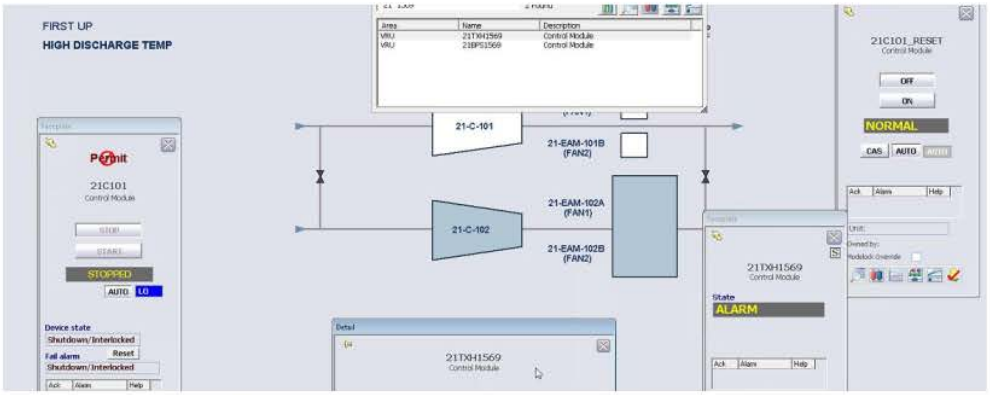
Appendix 37: Running graphic.



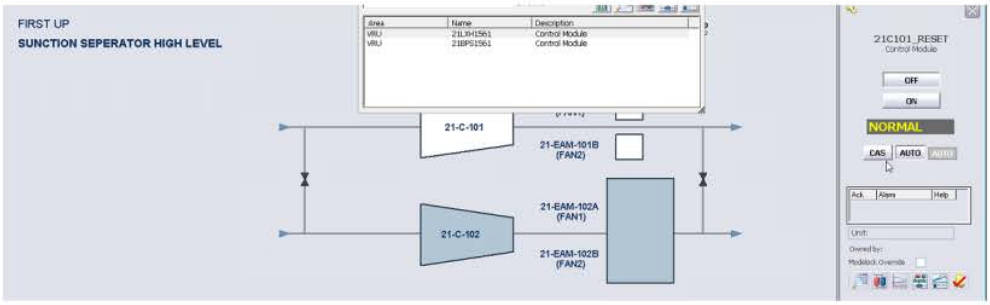
Appendix 38: First up logic.



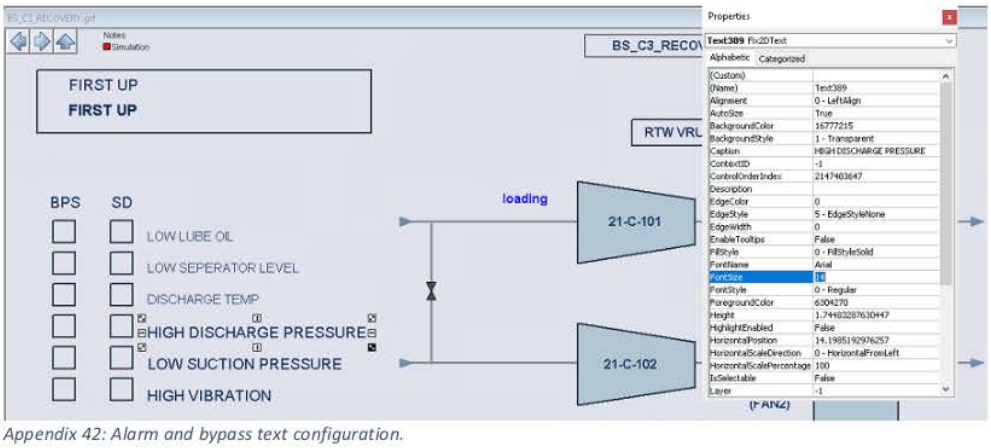
Appendix 39: First up animated text configuration.



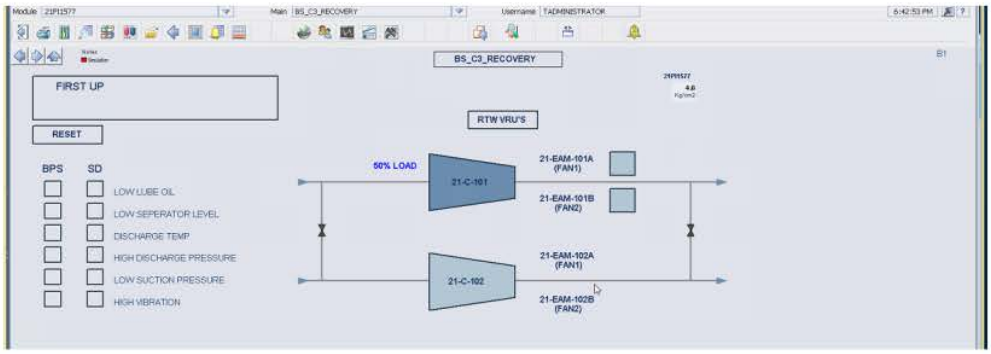
Appendix 40: Shutdown and first up.



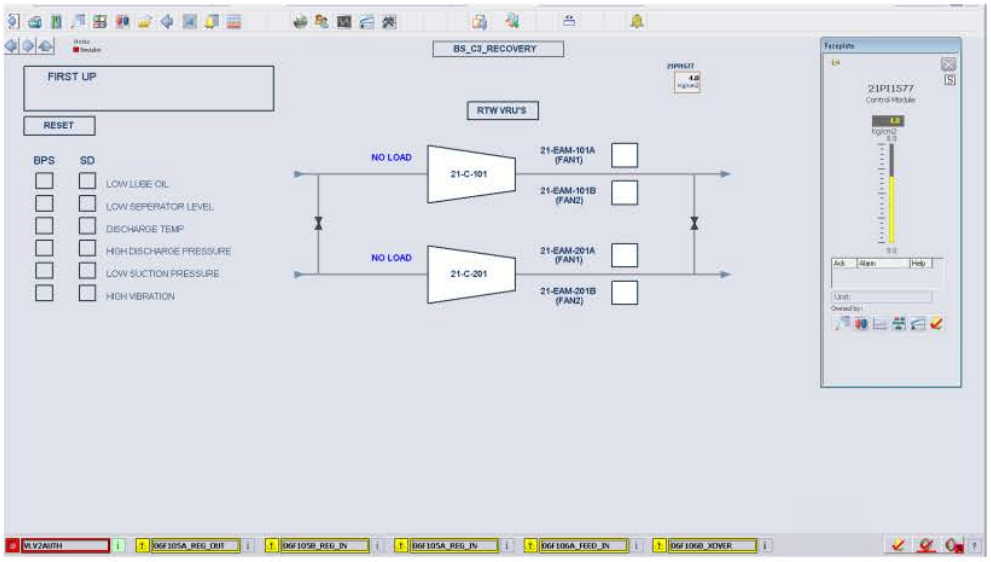
Appendix 41: First up test.



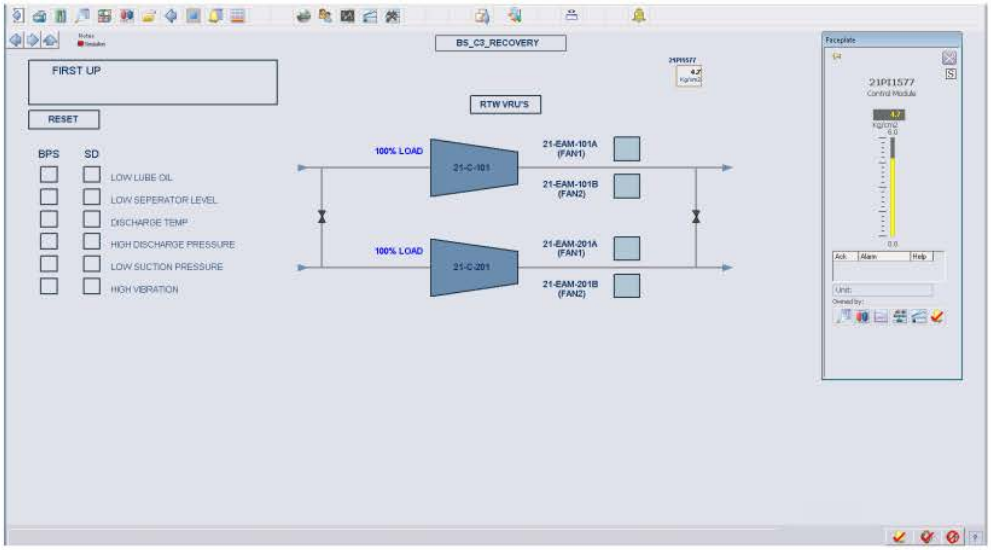
Appendix 42: Alarm and bypass text configuration.



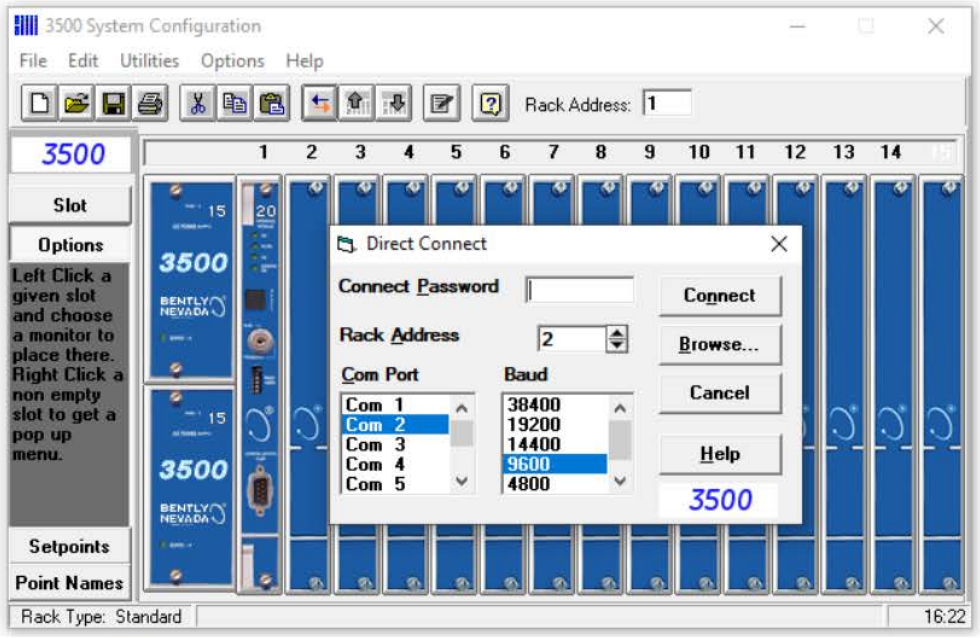
Appendix 43: VRU1 graphic complete.



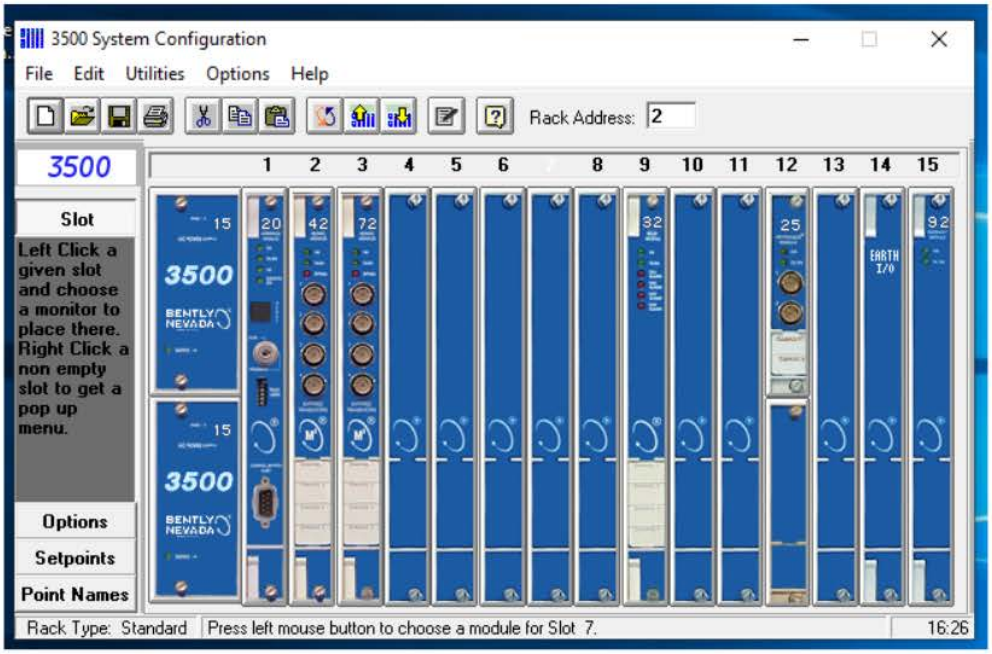
Appendix 44: VRU1 & 2 graphic complete with compressors offline.



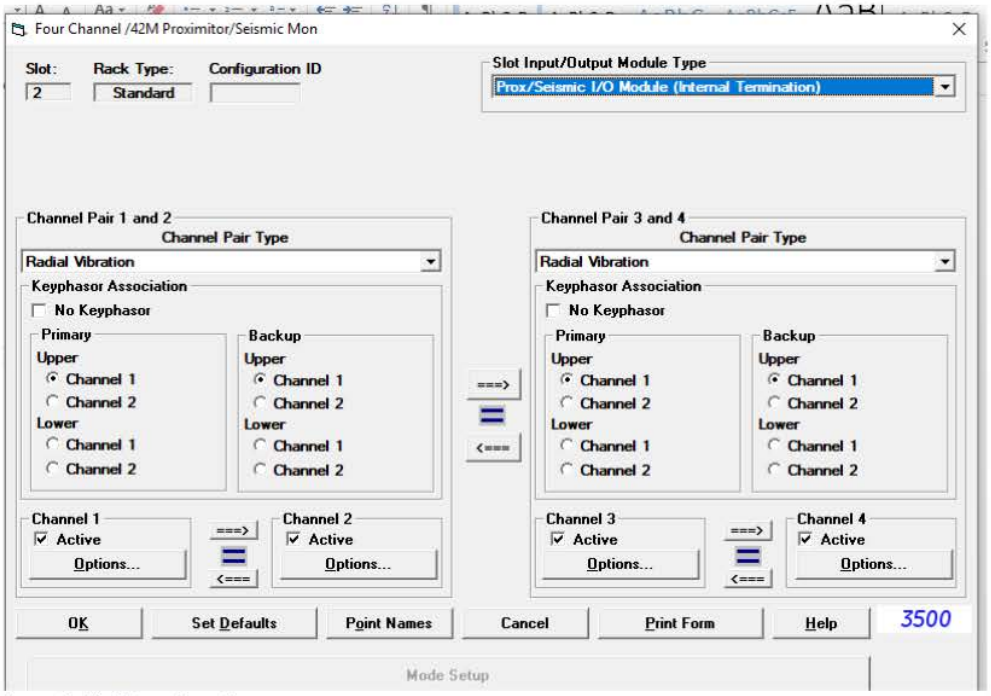
Appendix 45: VRU graphic with compressors online.



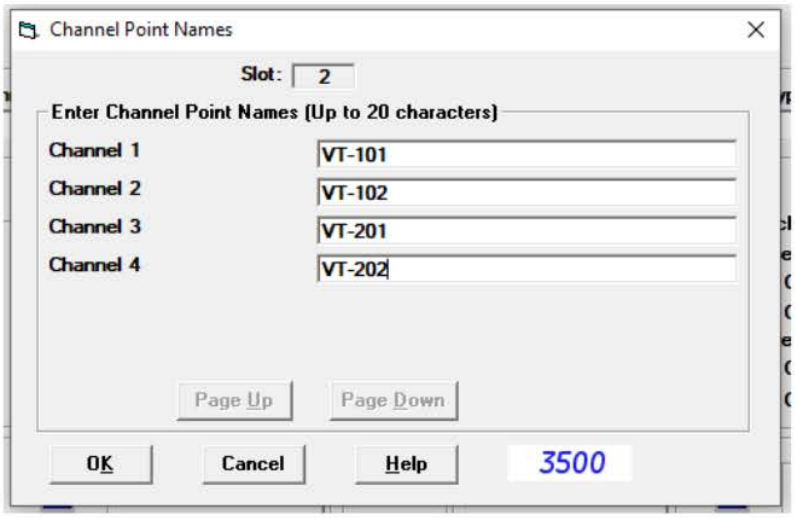
Appendix 46: 3500 rack configuration.



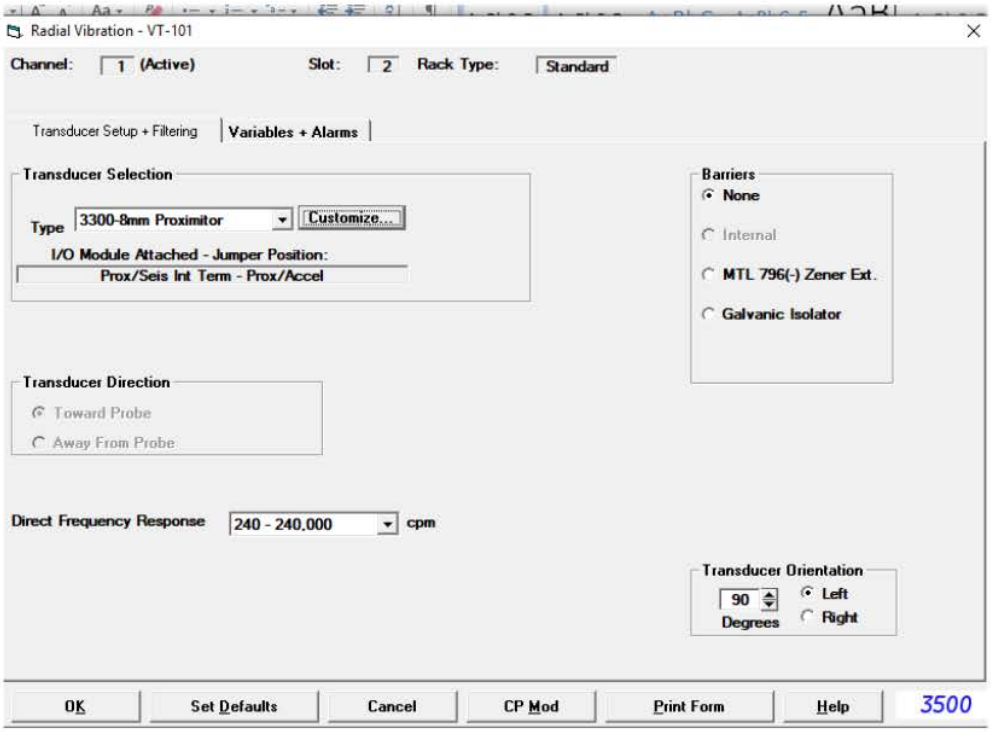
Appendix 47: Configuration downloaded.



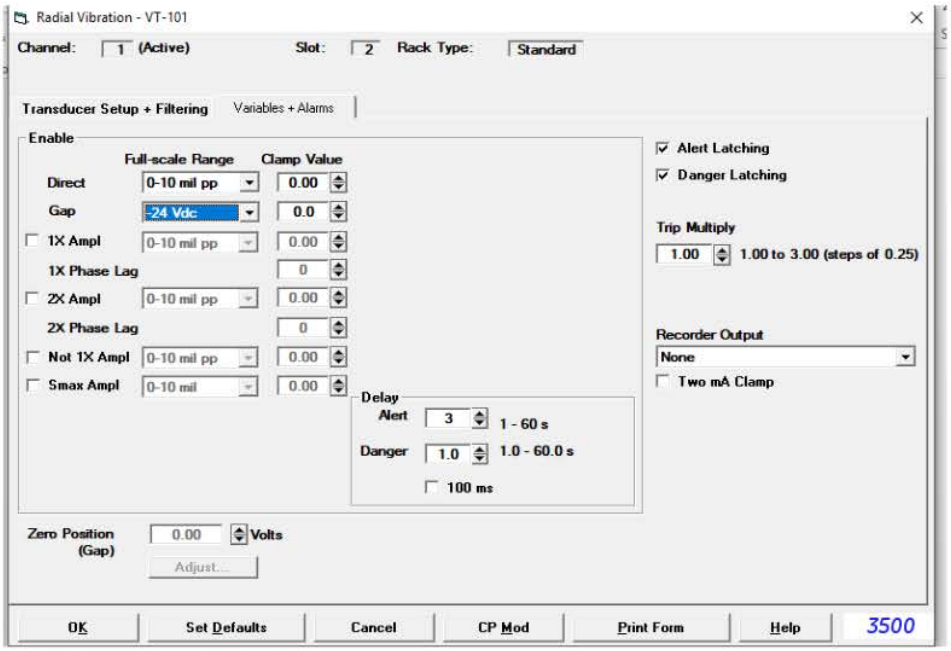
Appendix 48: Slot configuration.



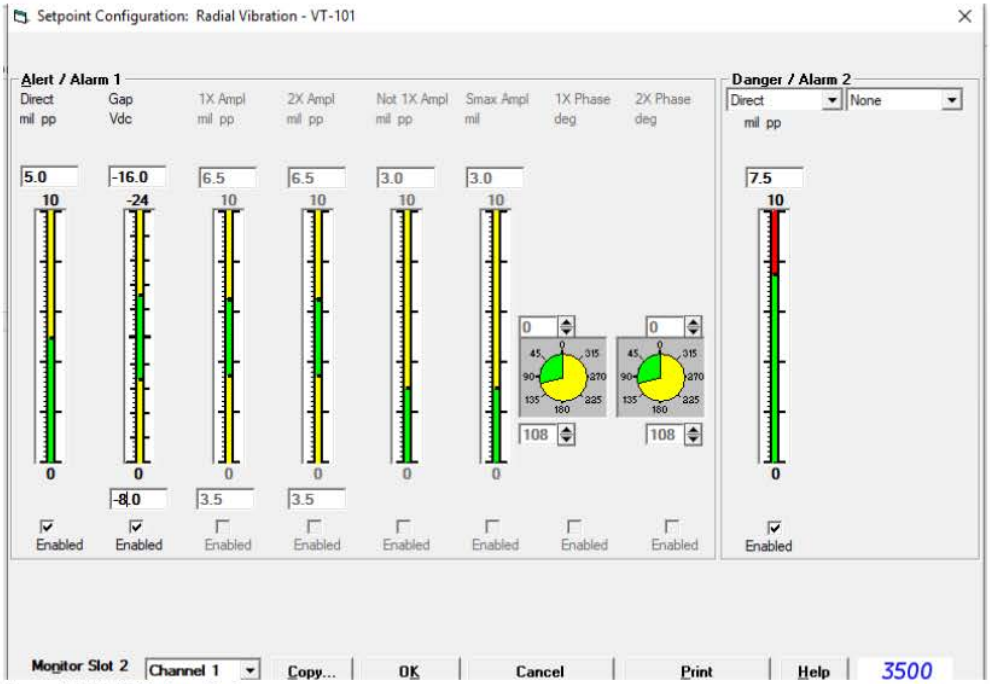
Appendix 50: Probe tagging.



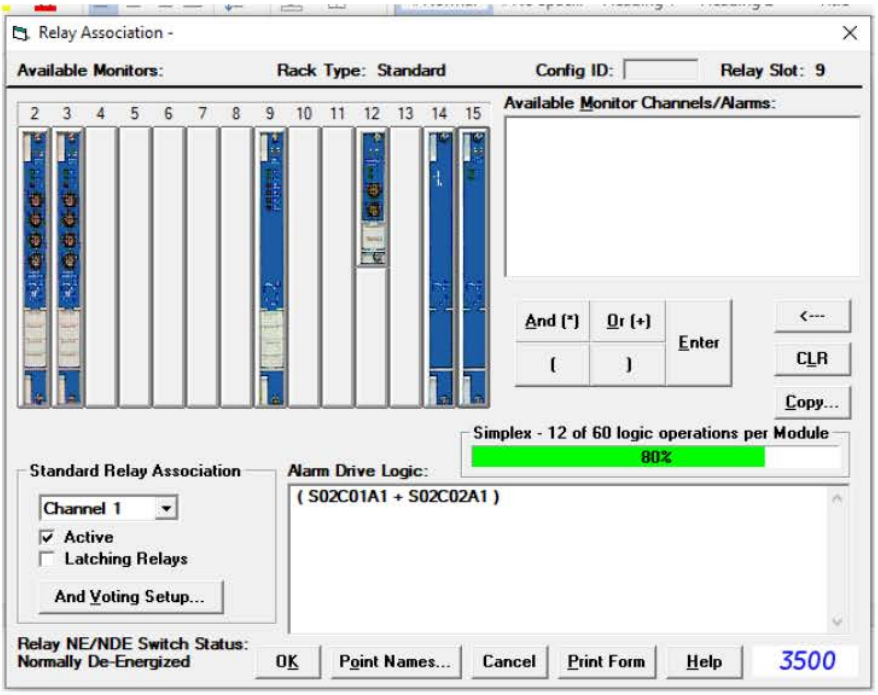
Appendix 49: Probe settings.



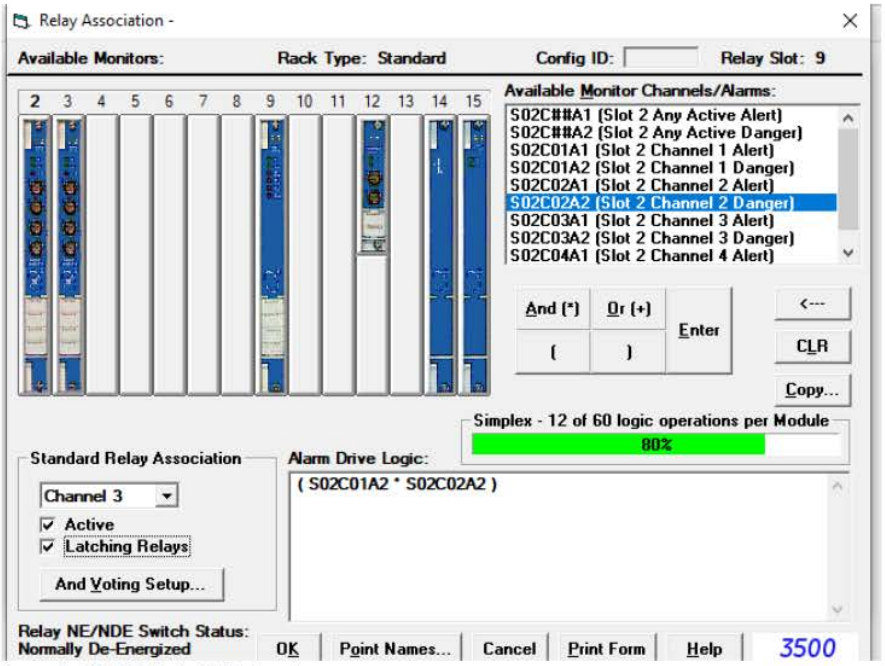
Appendix 51: Probe and alarm parameters.



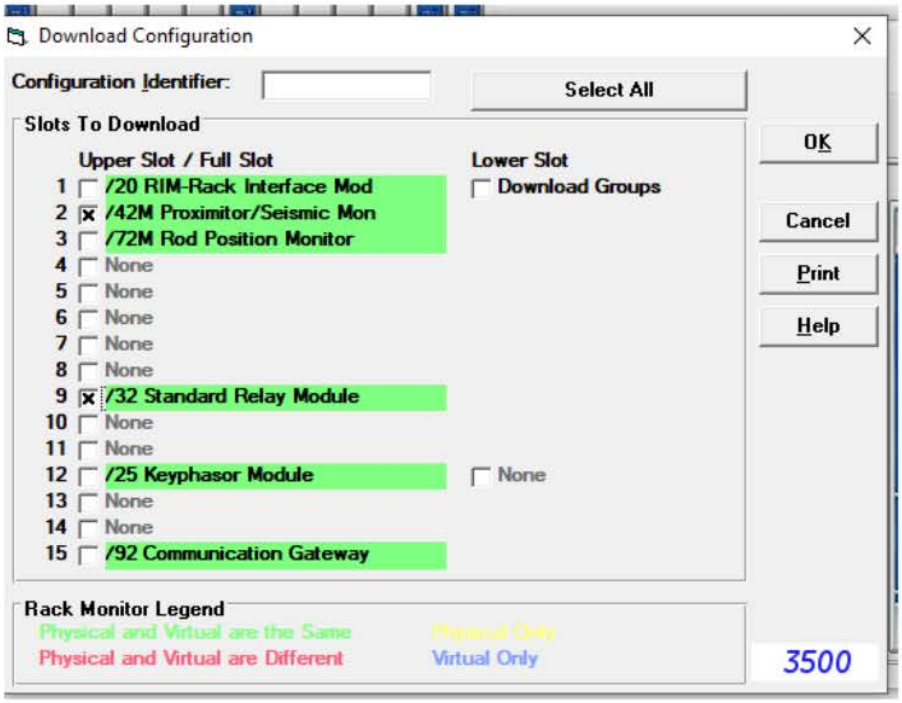
Appendix 52: 3500 alarm limits.



Appendix 53: 3500 logic OR gate.



Appendix 54: 3500 logic AND trip gate.



Appendix 55: Card download to 3500 rack.

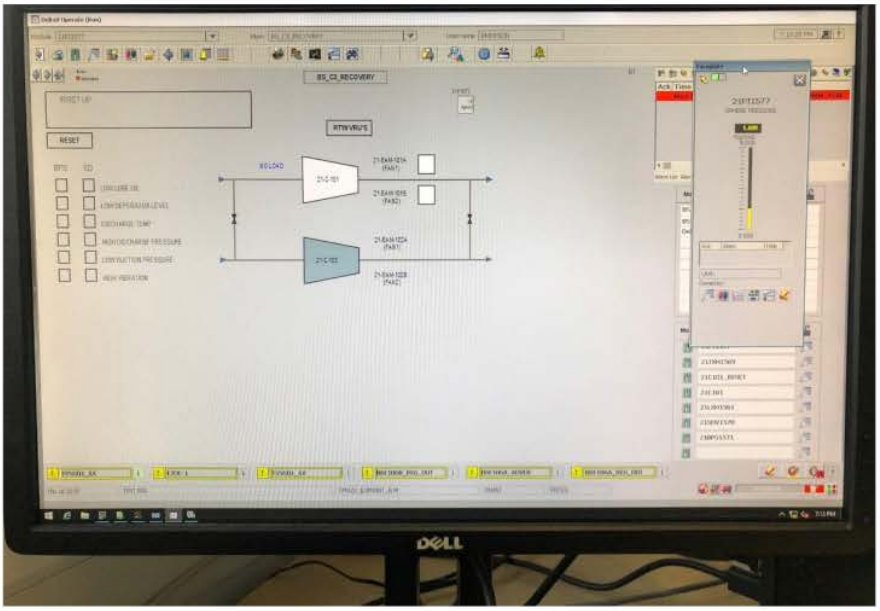




Appendix 56: DeltaV controllers and CIOCs installed.

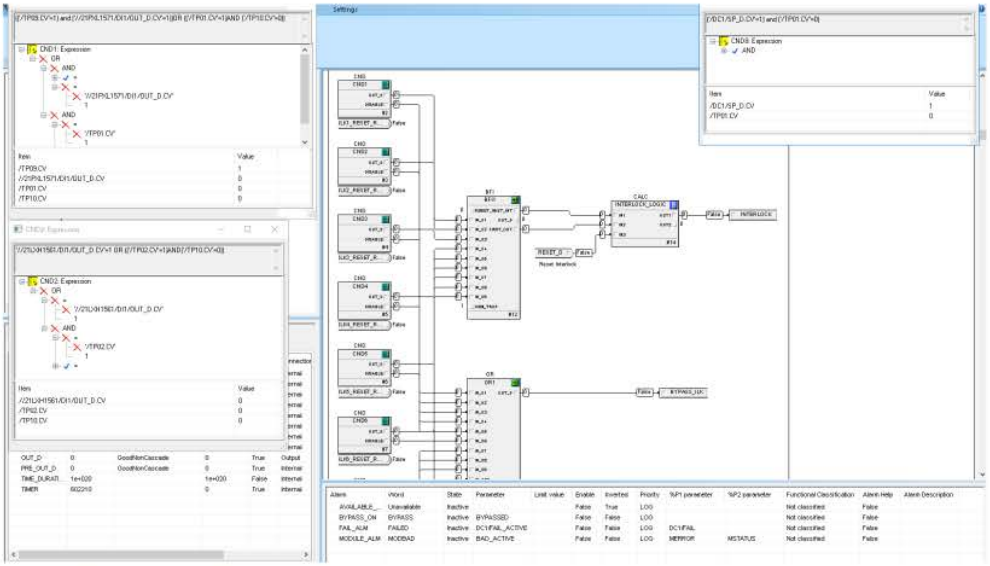


Appendix 58: Pressure transmitter set up.

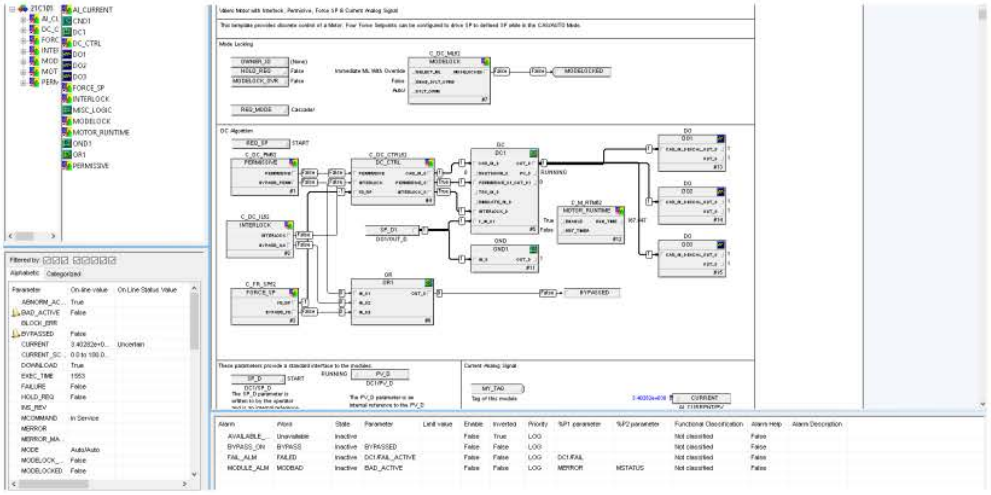


Appendix 57: Operator interface console.

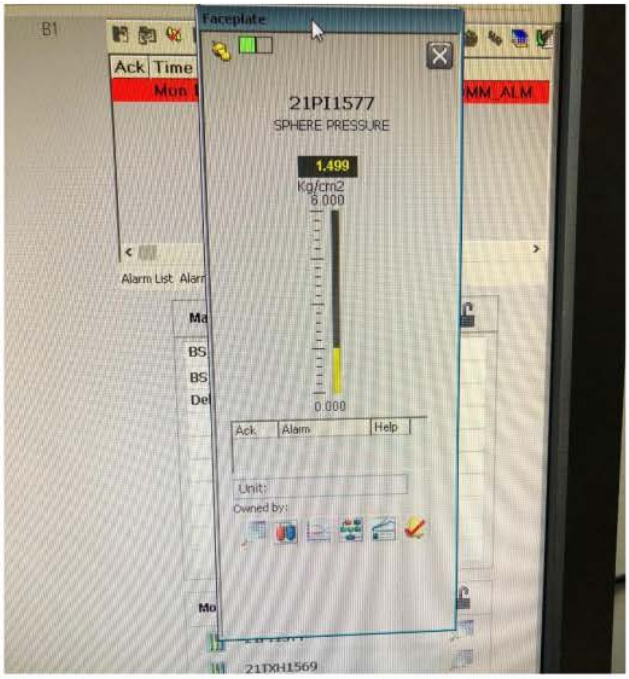
8.2 Testing Evidence



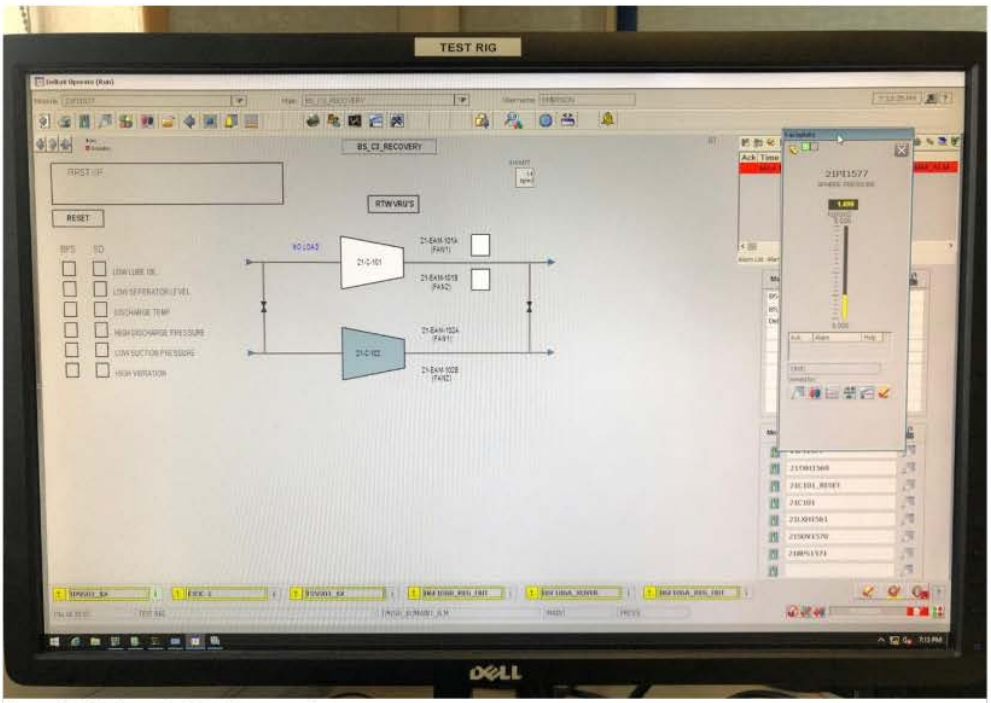
Appendix 59: Final interlock logic.



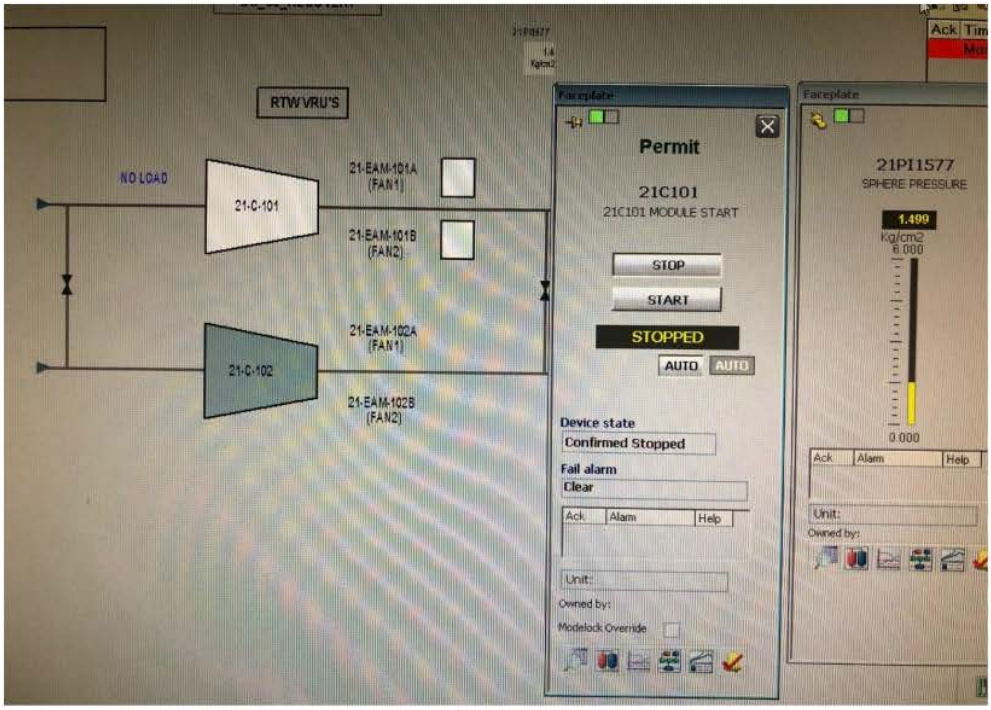
Appendix 60: Final compressor module logic.



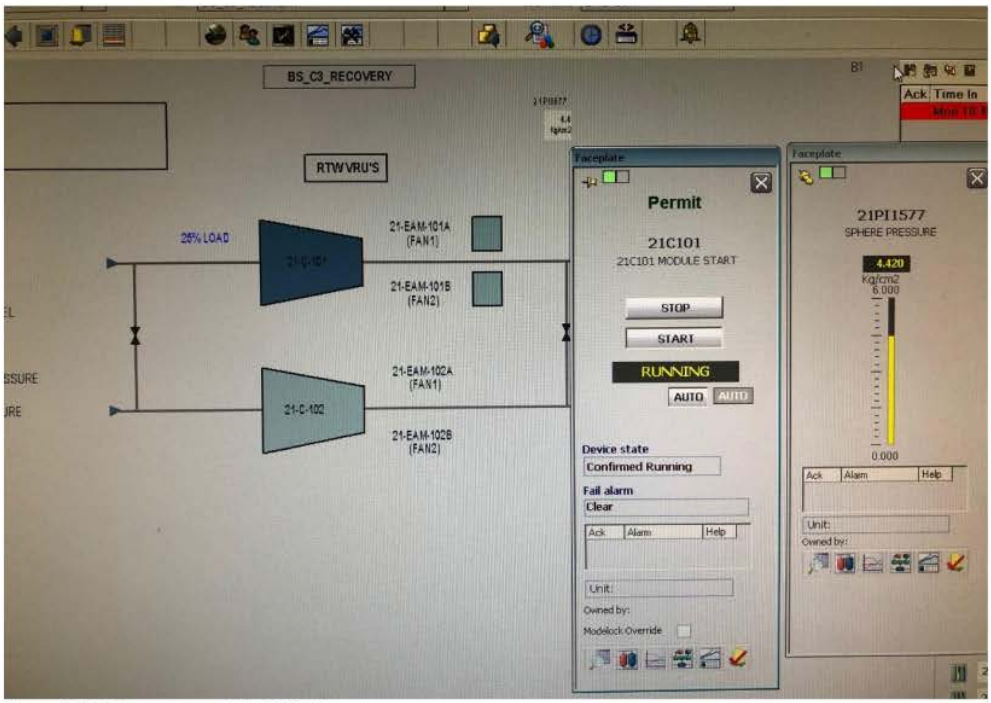
Appendix 61: 25% pressure.



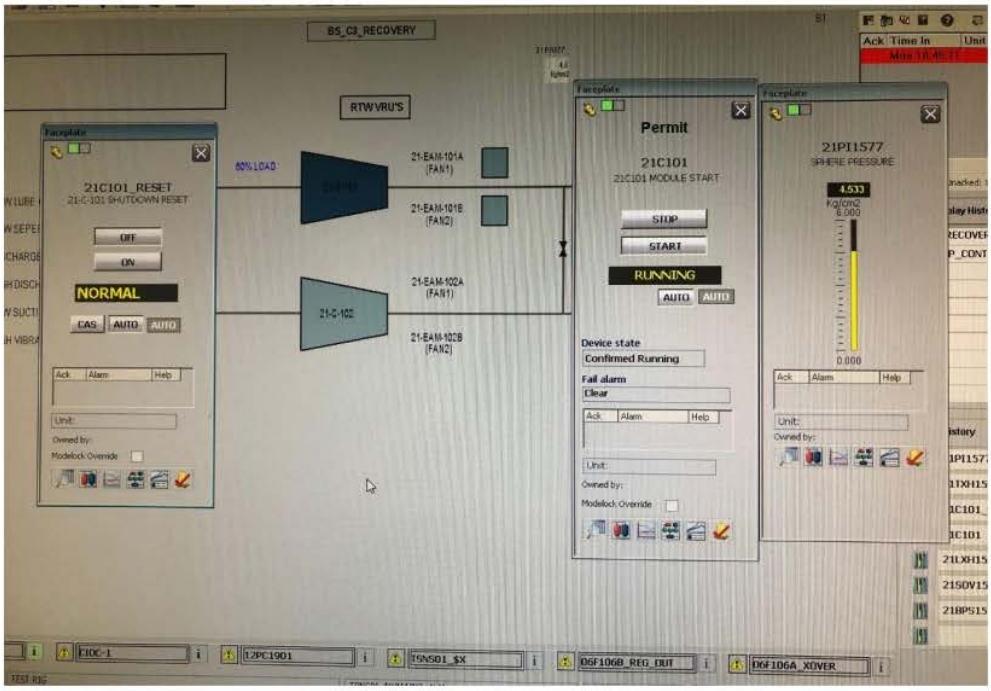
Appendix 62: Operator interface console.



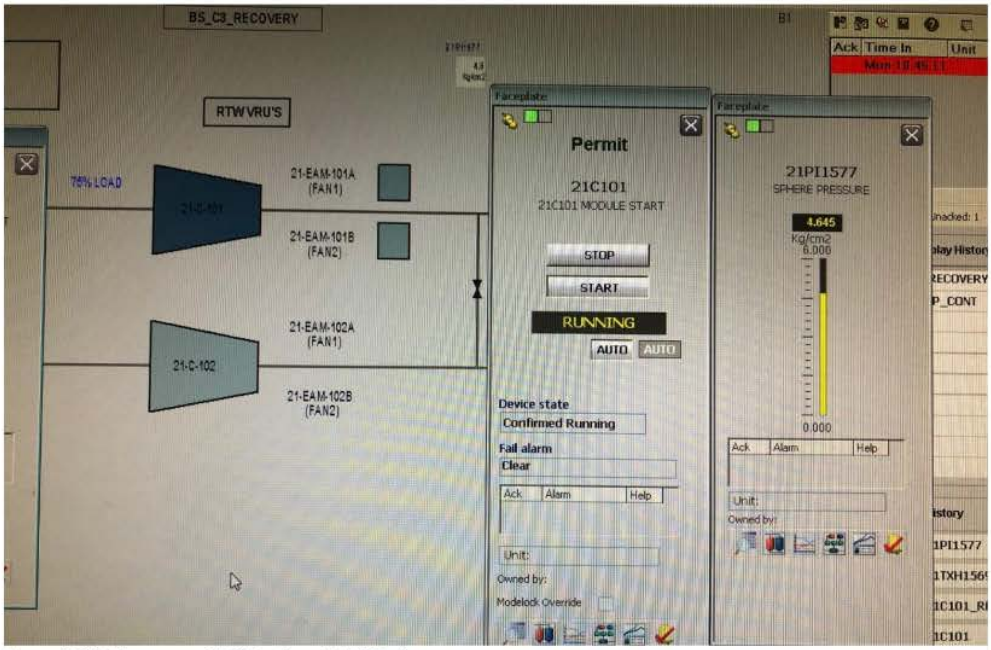
Appendix 63: Auto below set point.



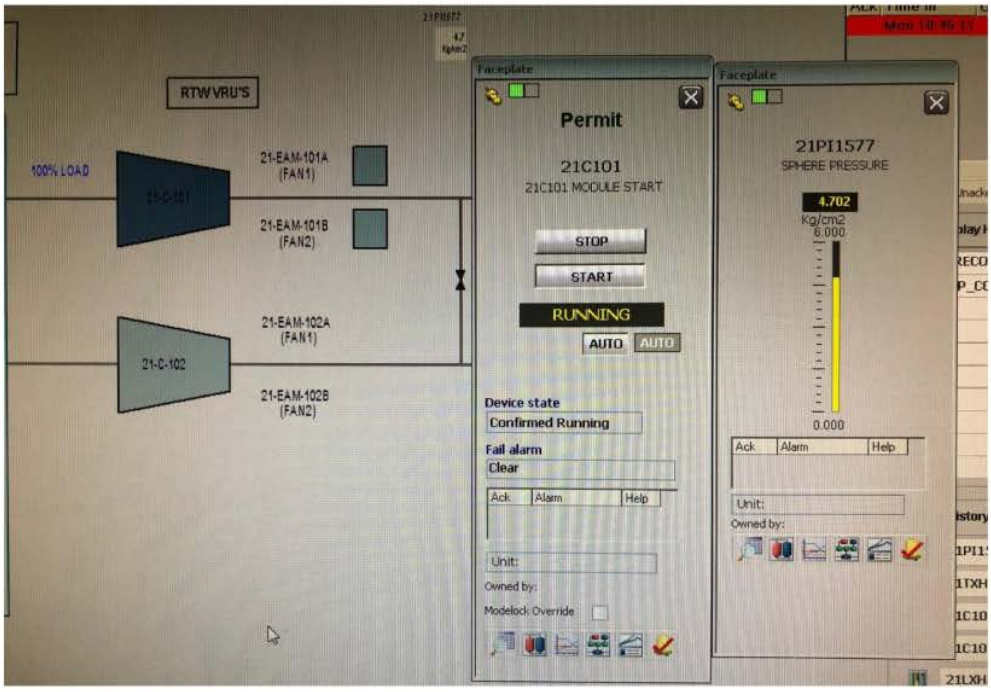
Appendix 64: Compressor cut in 4.42kg/sqcm.



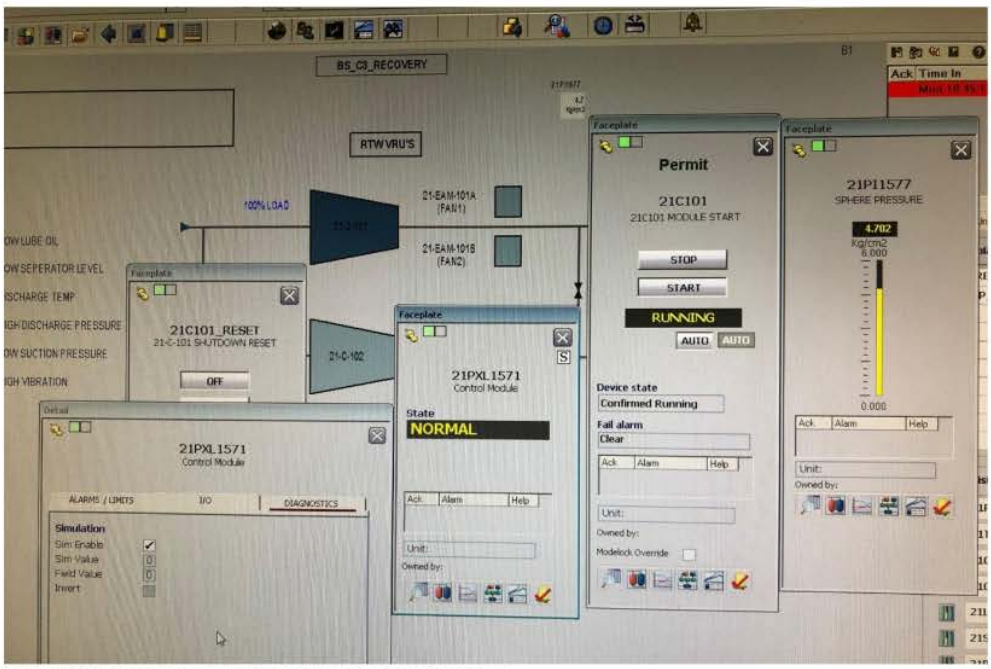
Appendix 65: Compressor 50% loading at 4.533kg/sqcm.



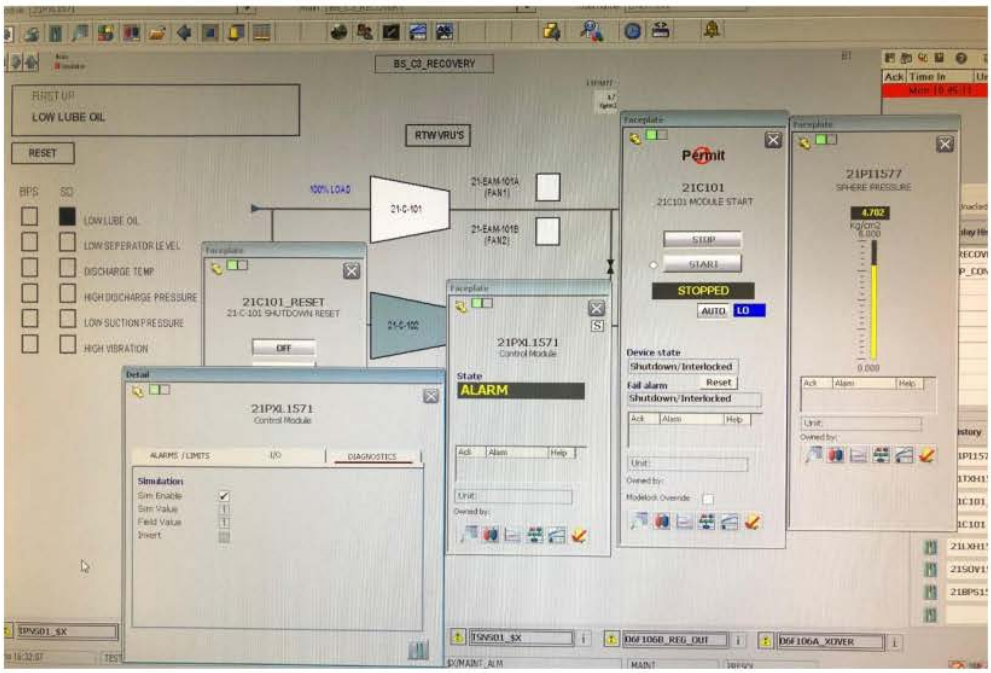
Appendix 66: Compressor 75% loading at 4.645kg/sqcm.



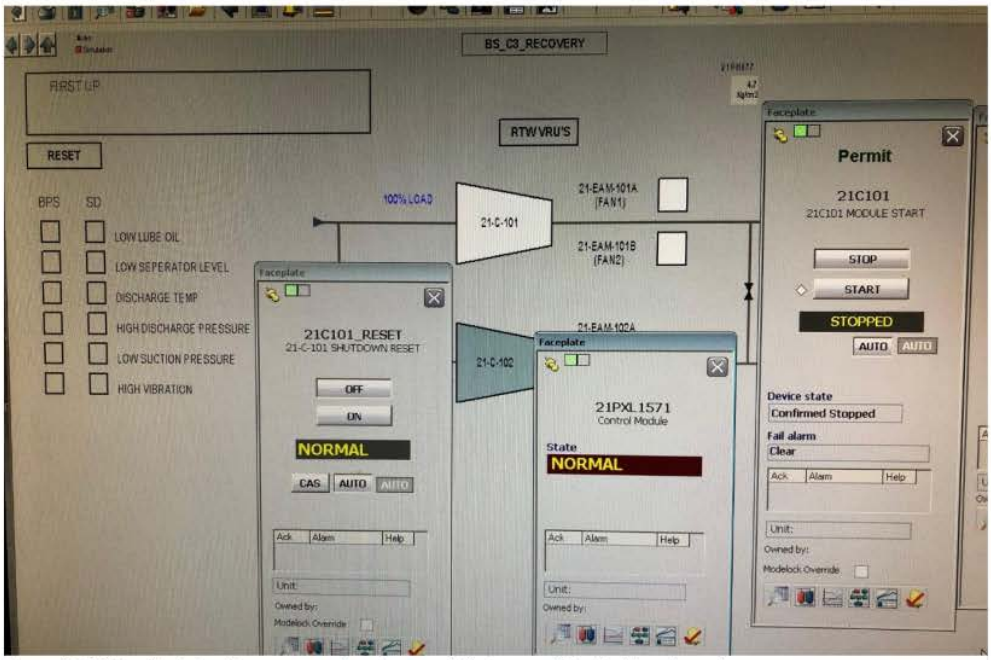
Appendix 67: Compressor 100% loading at 4.702kg/sqcm.



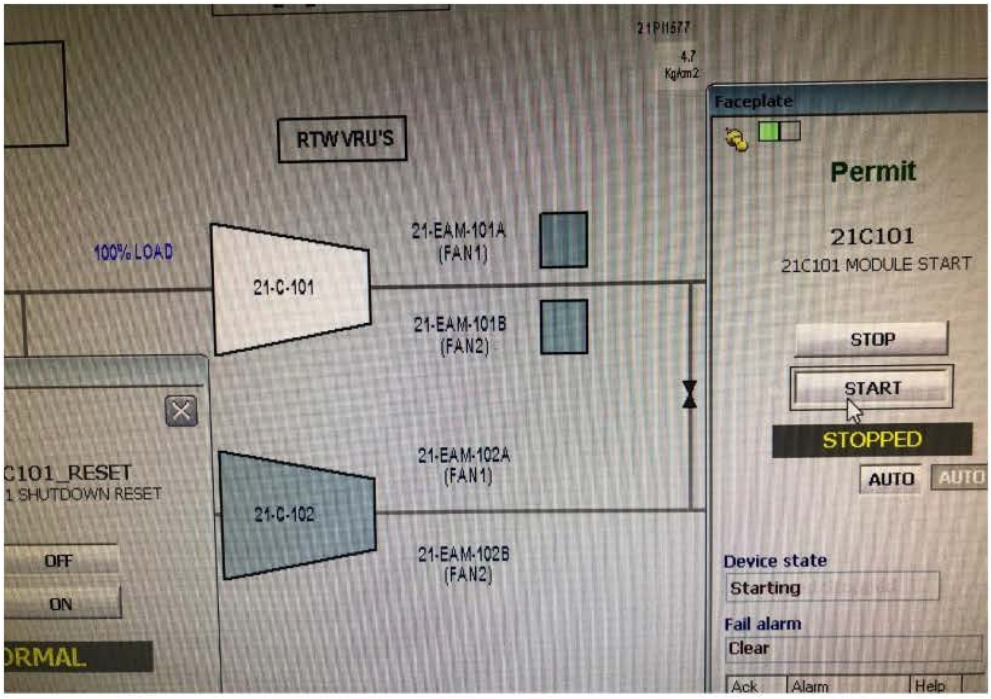
Appendix 68: Compressor running with healthy lube oil pressure.



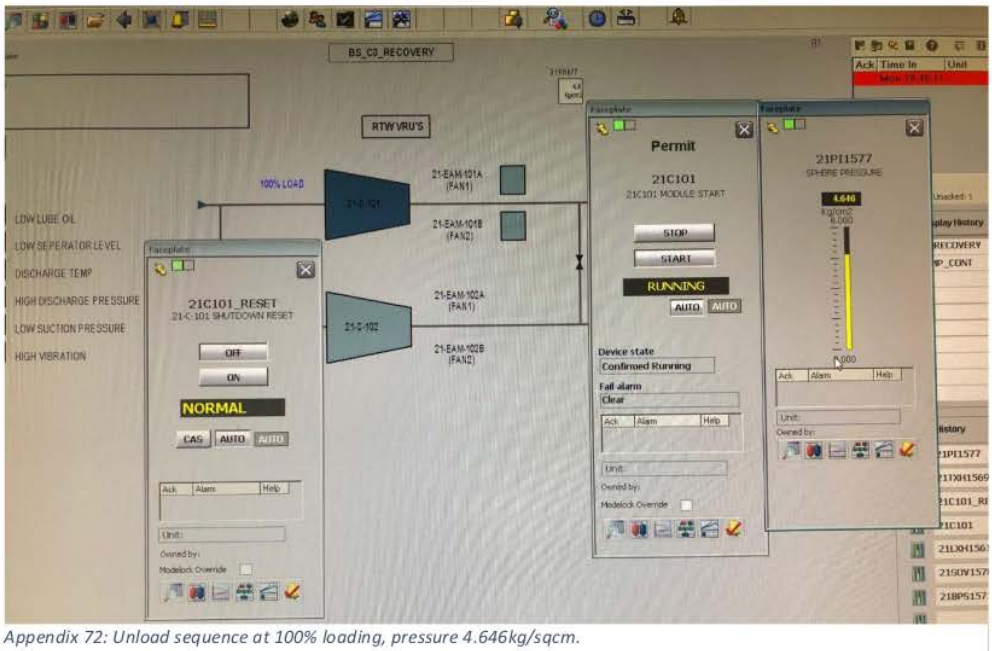
Appendix 69: Low lube oil tripped compressor and interlock active preventing restart. First up alarm active.



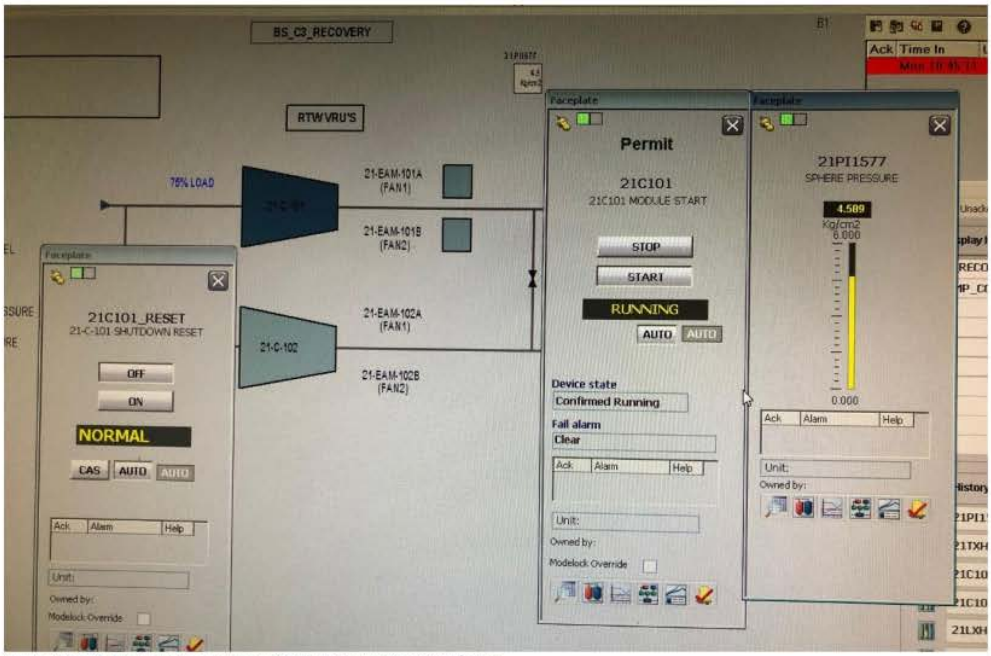
Appendix 70: Healthy lube oil pressure and reset pressed. First up and interlock has cleared.



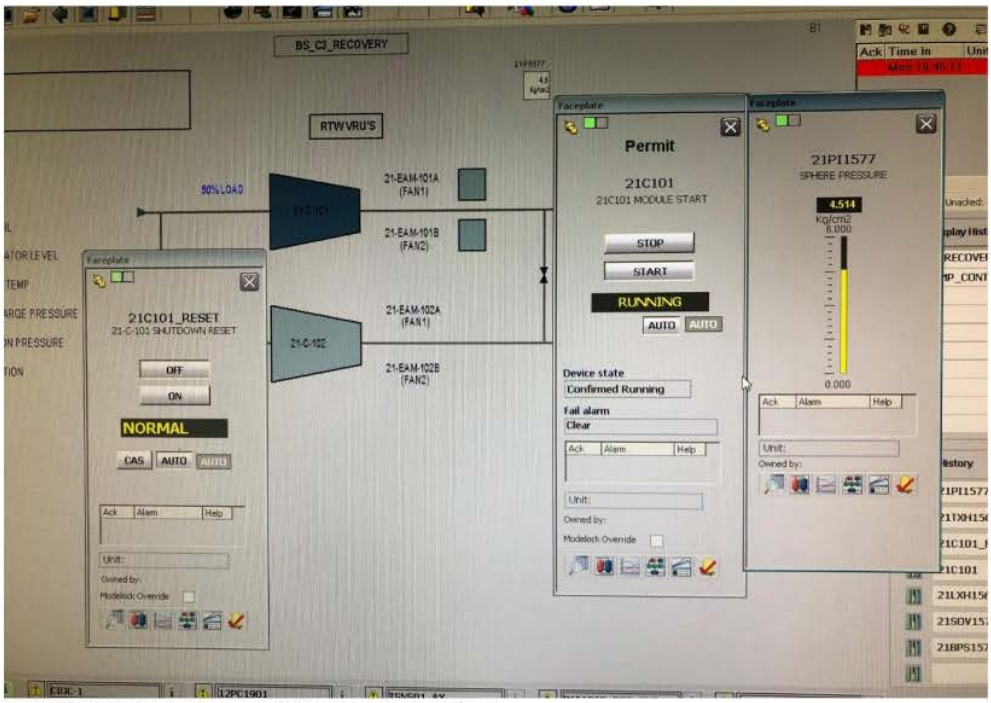
Appendix 71: Start initiated, fin fans have started before compressor. Set point means compressor will attempt to load to 100% once running.



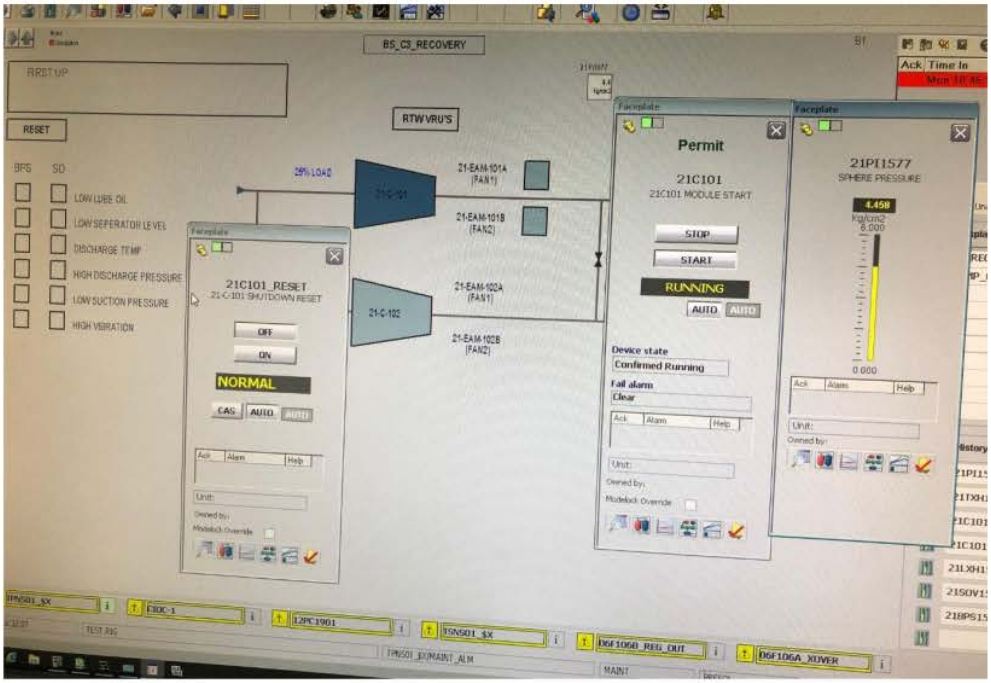
Appendix 72: Unload sequence at 100% loading, pressure 4.646kg/sqcm.



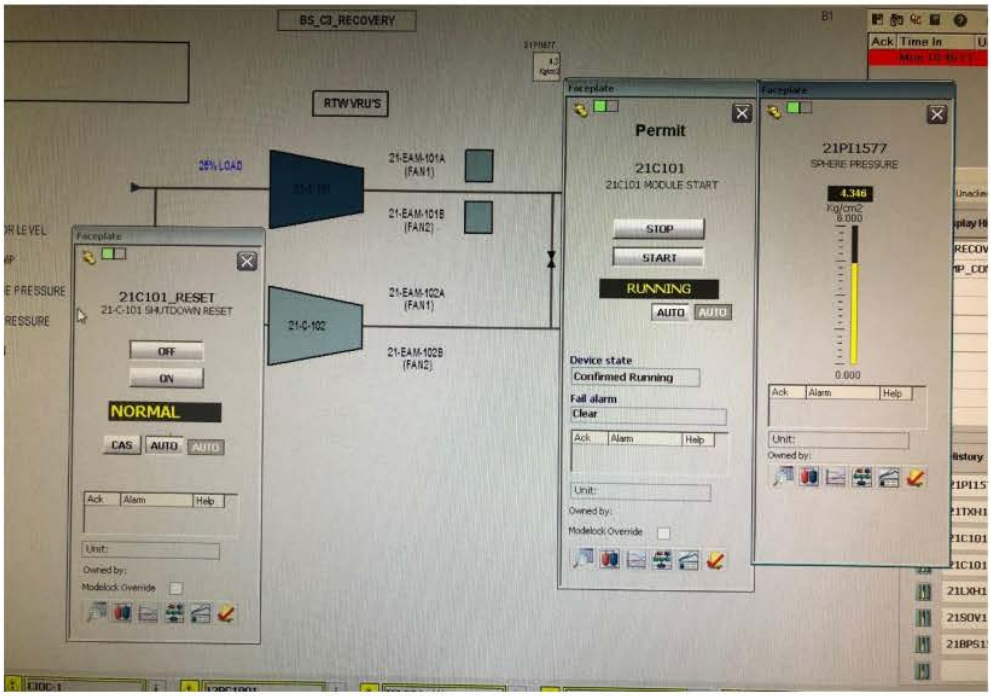
Appendix 73: Unload sequence at 75%, pressure 4.589kg/sqcm.



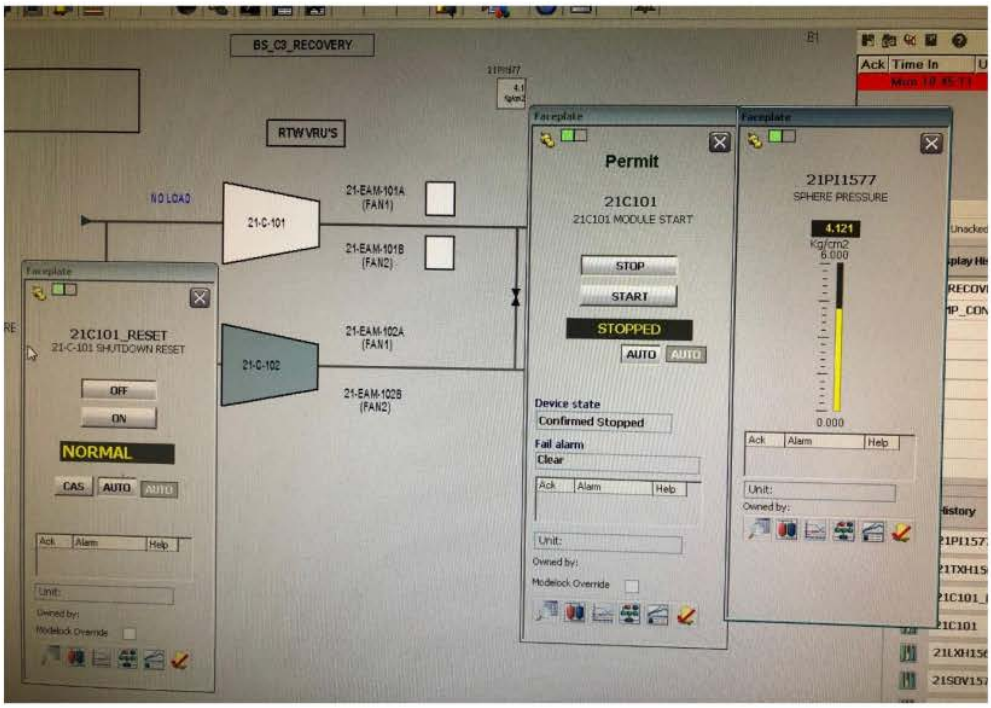
Appendix 74: Unload sequence at 50%, pressure 4.514kg/sqcm.



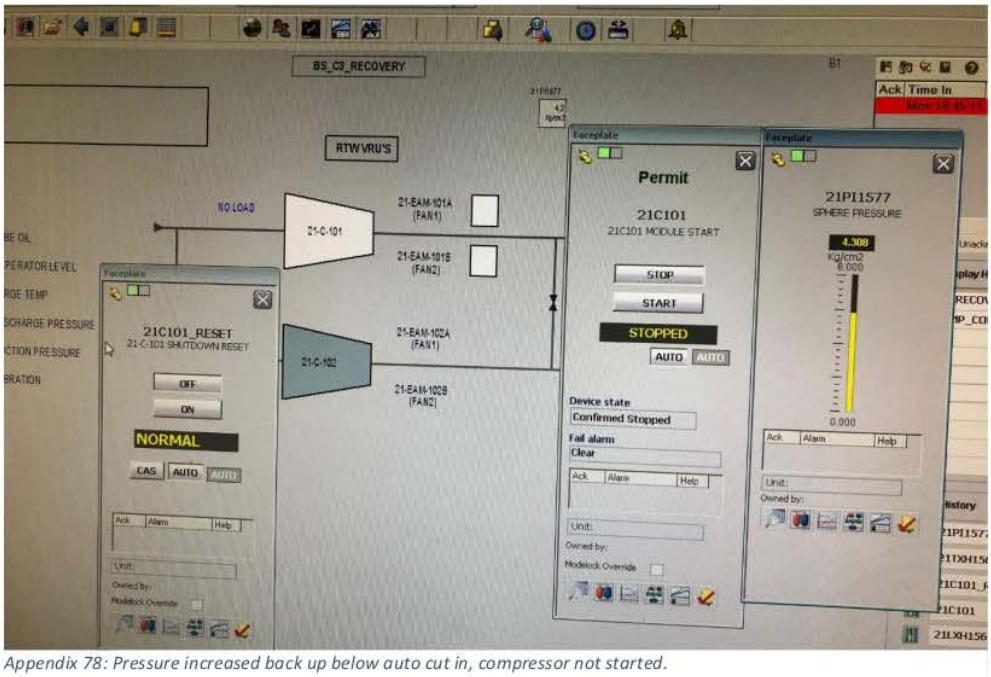
Appendix 75: Unload sequence at 25%, pressure 4.458kg/sqcm.



Appendix 76: Unload sequence still at 25%, pressure 4.346kg/sqcm.



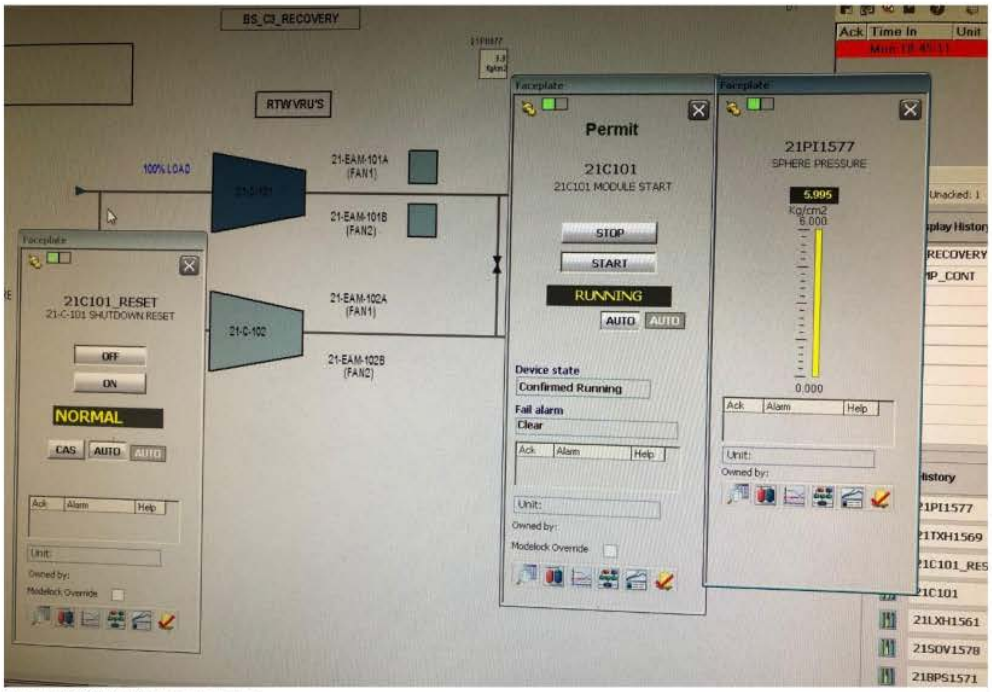
Appendix 77: Compressor offline and unloaded automatically as pressure below set point.



Appendix 78: Pressure increased back up below auto cut in, compressor not started.



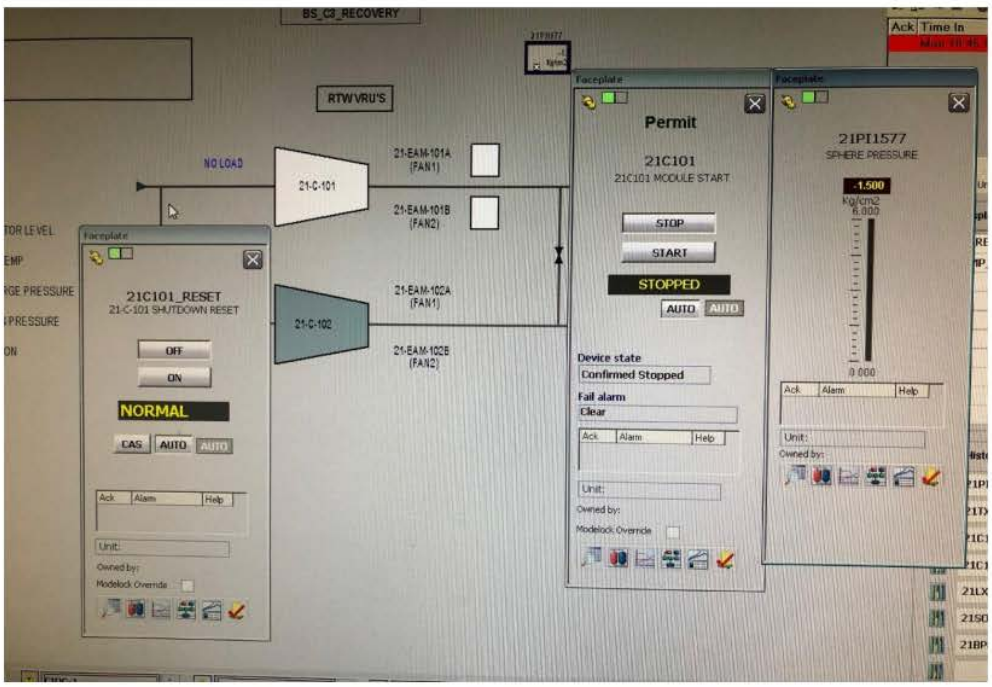
Appendix 79: Pressure full range loop check.



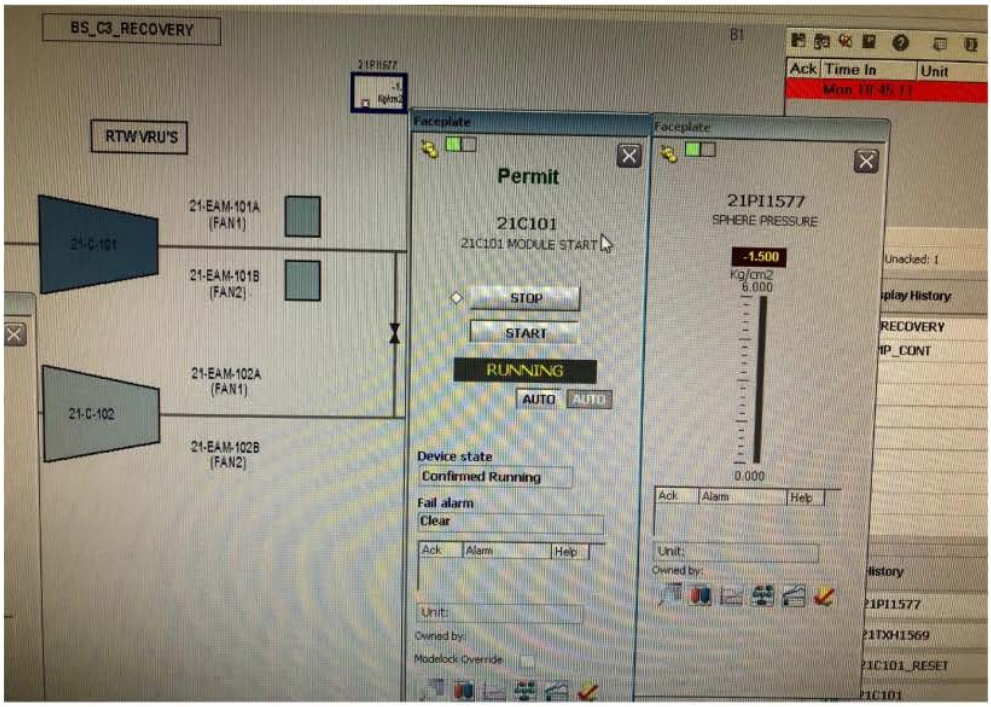
Appendix 80: Full pressure range.



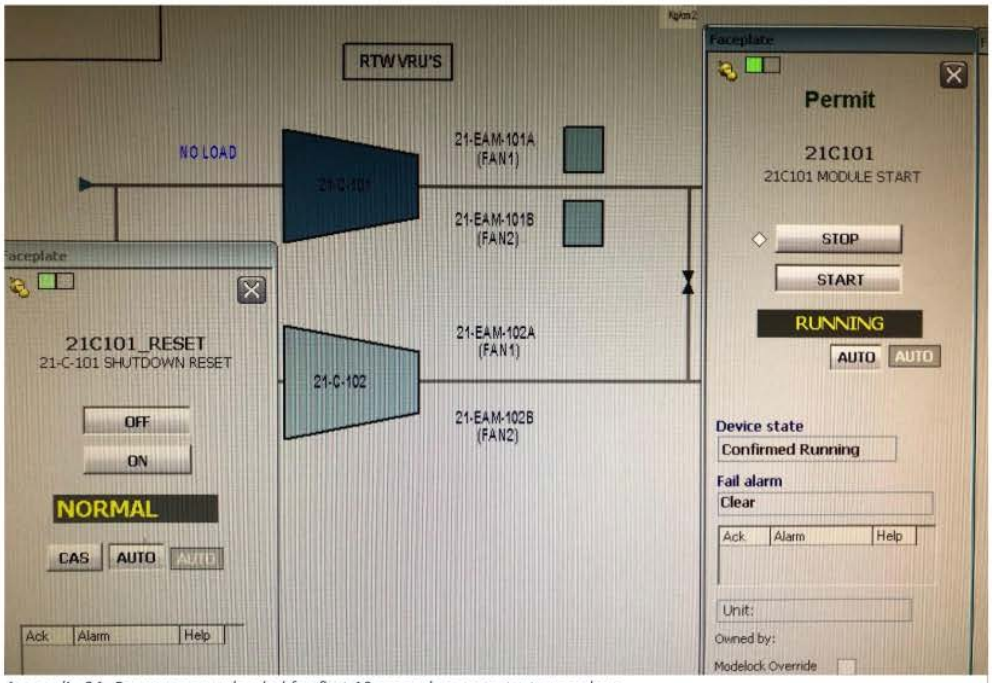
Appendix 81: Charm disconnection/Isolation test.



Appendix 82: Pressure AI failed to -1.5kg/sqcm. This prevents compressor auto cut in if transmitter fails. MODBAD highlight box/alarm present on top graphic indication. BAD PV indicator also active.



Appendix 83: Manual starting of compressor still functional when indication failed.



Appendix 84: Compressor unloaded for first 10 seconds as per start procedure.



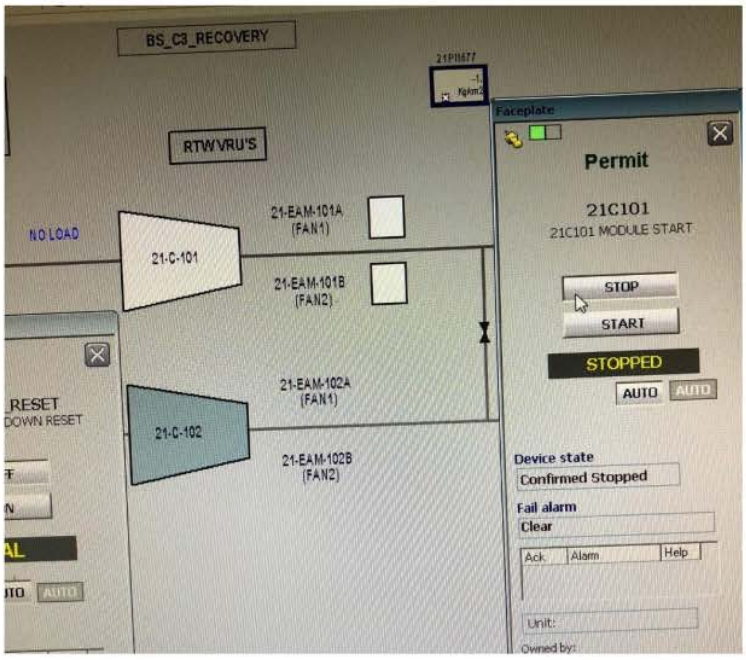
Appendix 85: Line fault highlights Charm analogue input alarm.



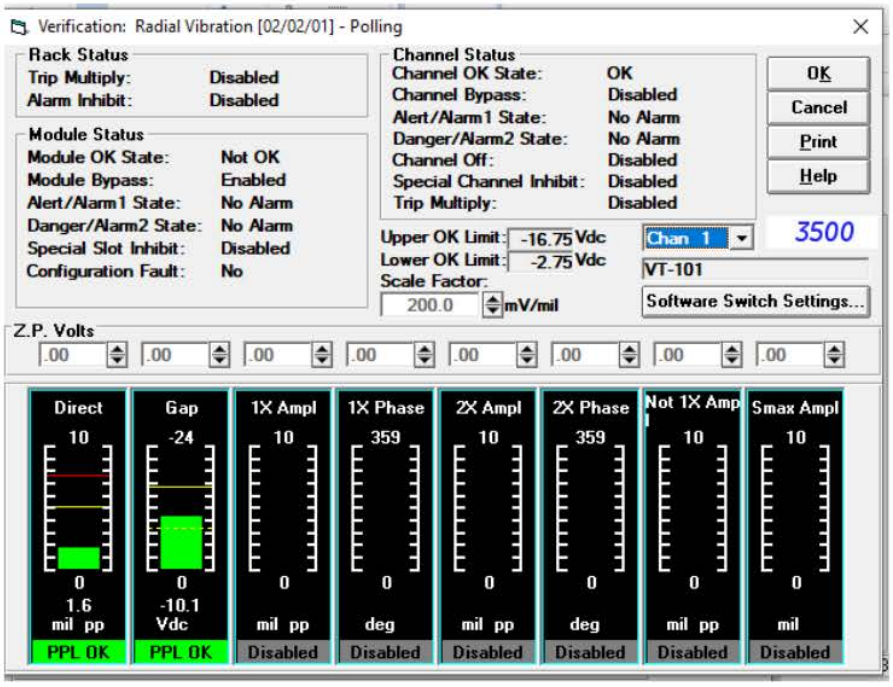
Appendix 86: Dual redundancy controllers and power supplies. Currently left hand in service.



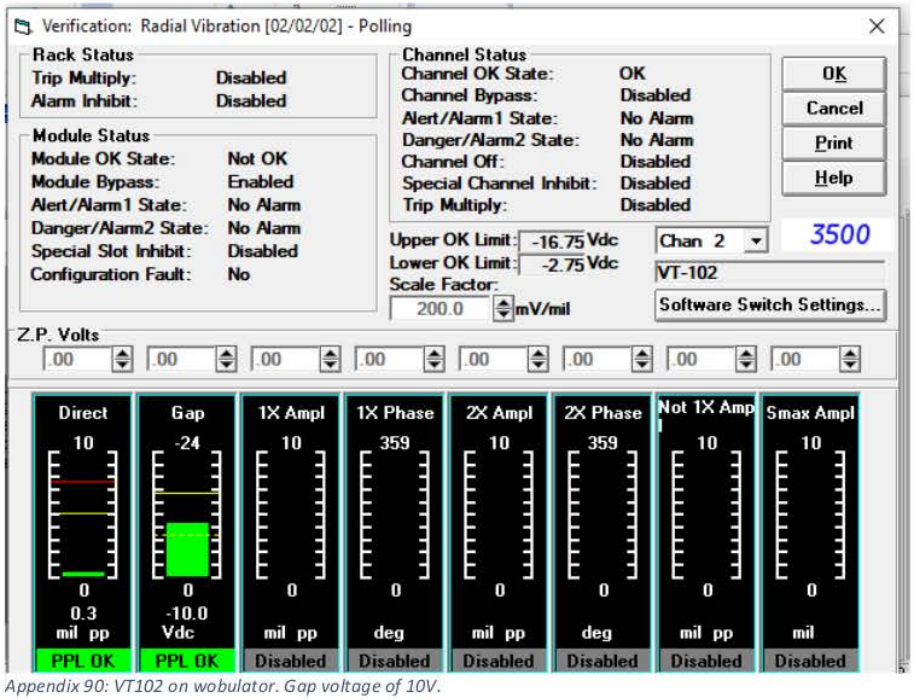
Appendix 87: DeltaV test rig.



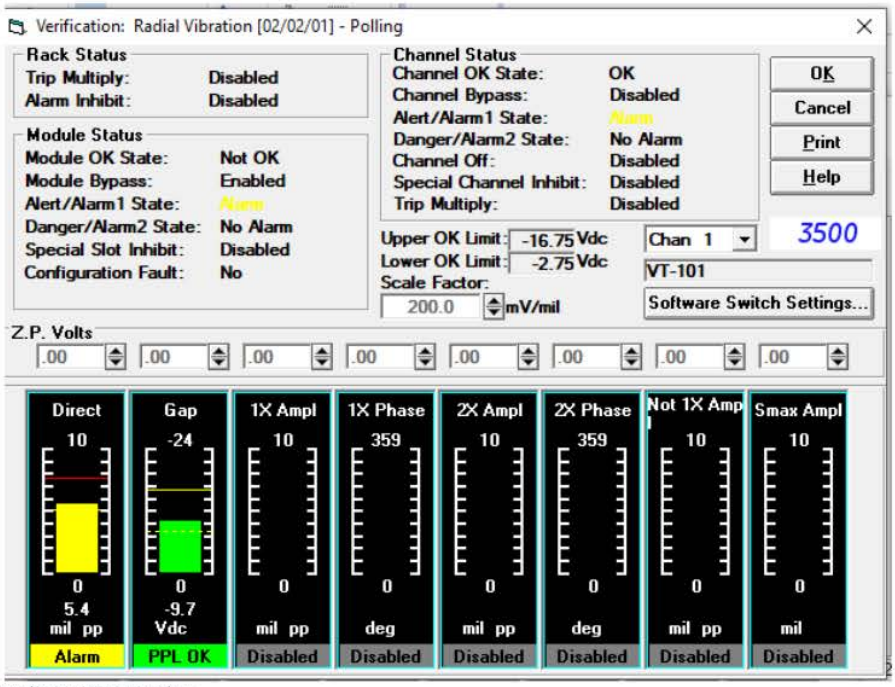
Appendix 88: Compressor manual stop test.



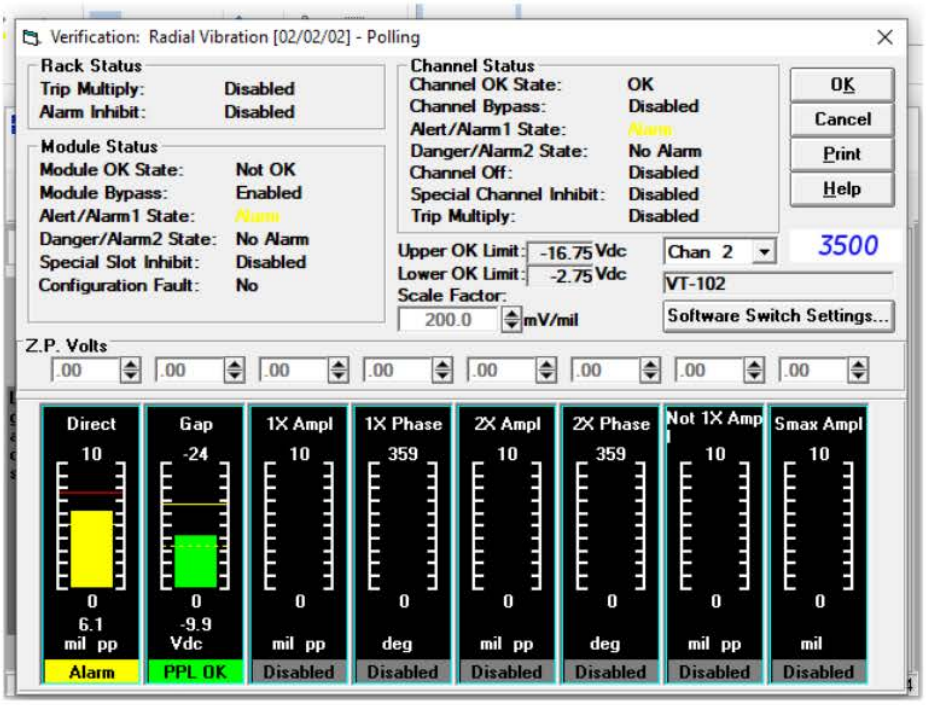
Appendix 89: VT101 probe on wobulator. gap voltage of 10V.



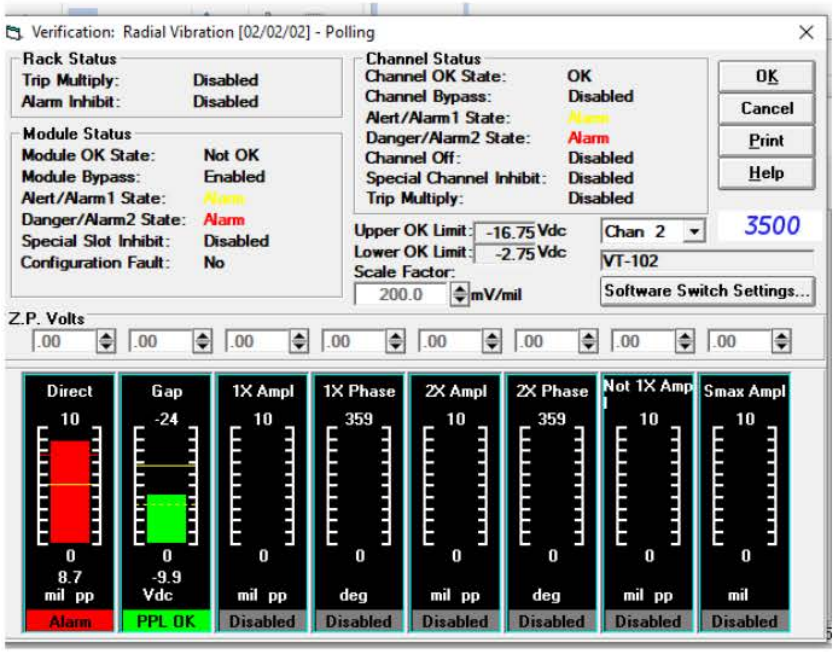
Appendix 90: VT102 on wobulator. Gap voltage of 10V.



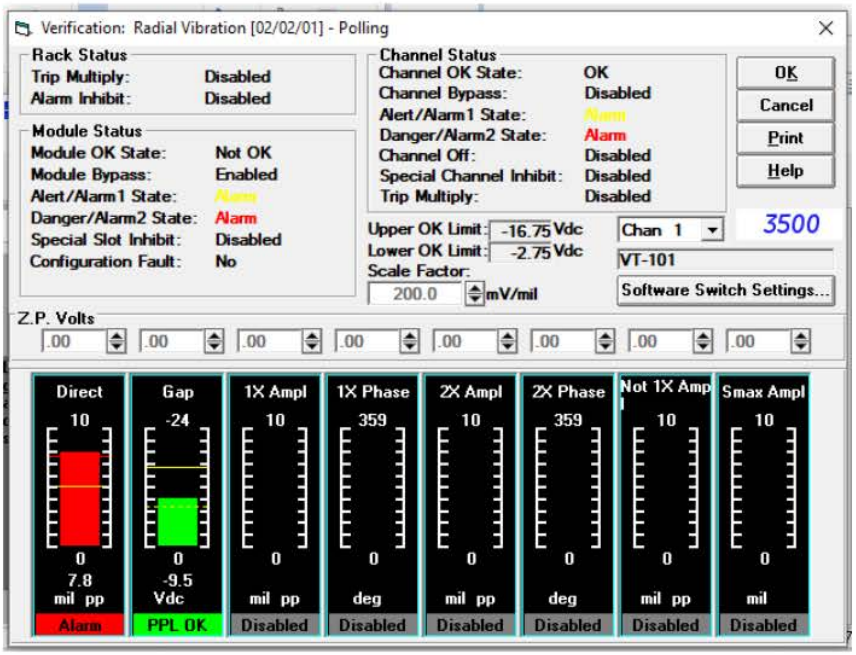
Appendix 91: VT101 in Alert.



Appendix 92: VT102 in Alert.



Appendix 93: VT102 in Danger.



Appendix 94: VT101 in Danger.



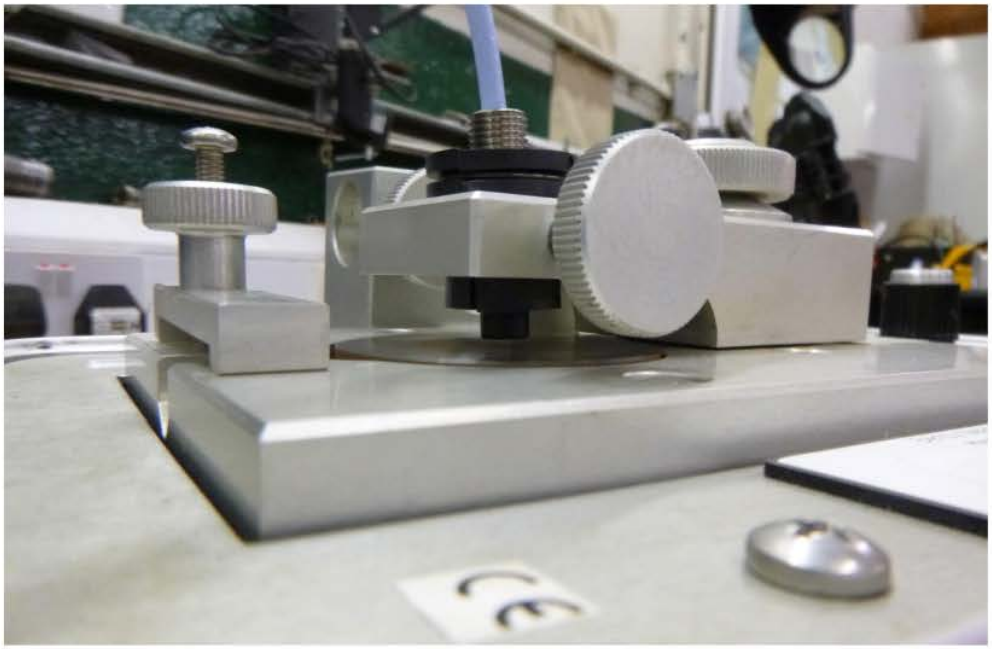
Appendix 95: 3500 rack.



Appendix 96: 3500 proximitor and extension for probes.



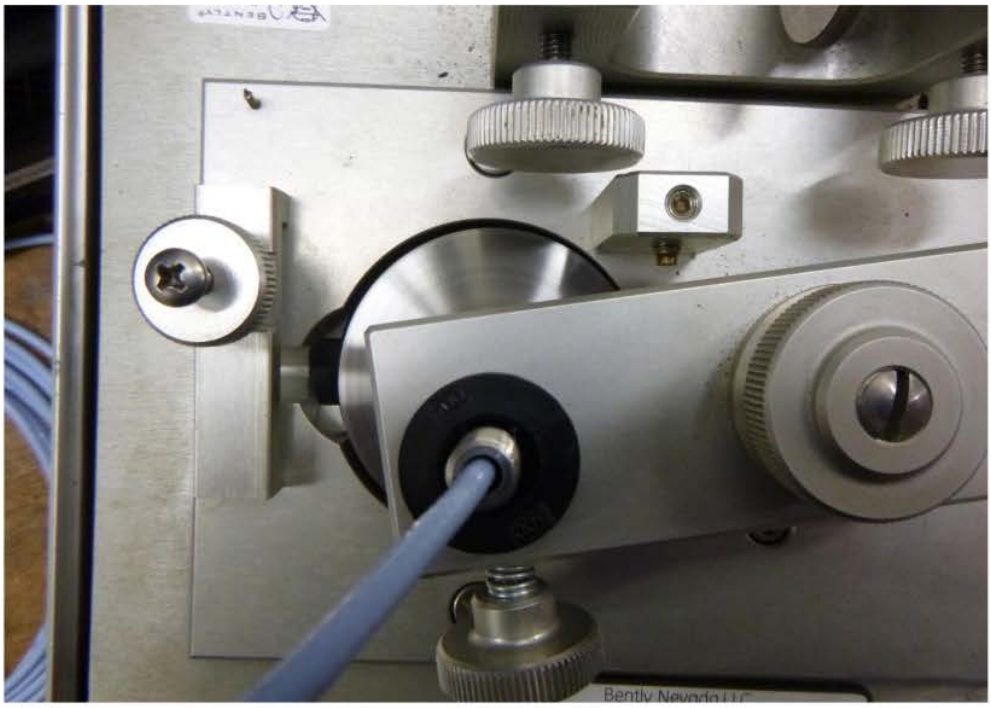
Appendix 97: Wobulator set up with probe positioned central.



Appendix 98: Gap voltage set to 10V.



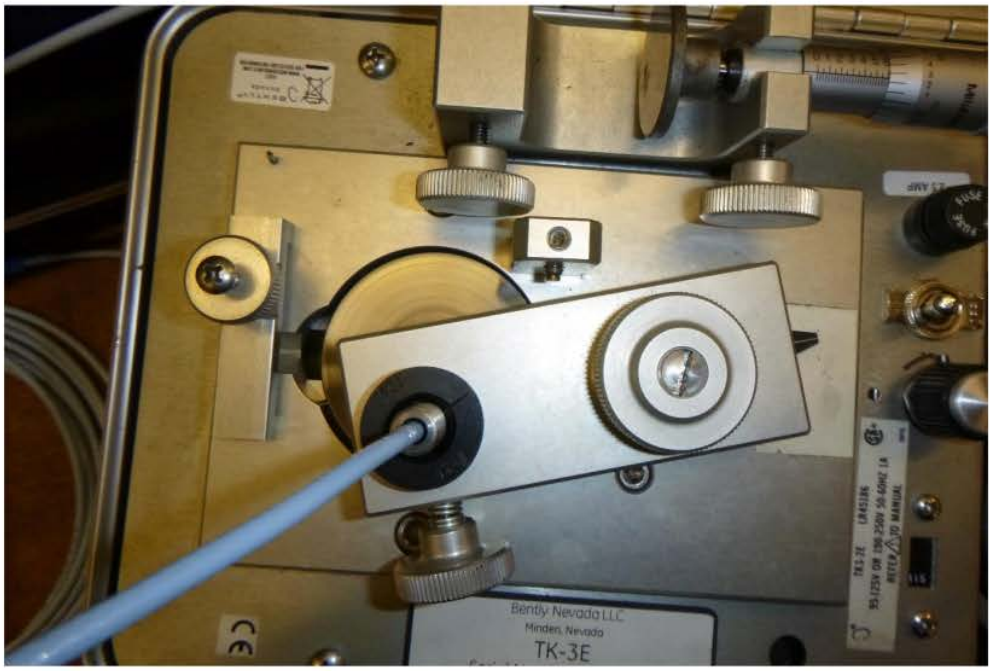
Appendix 99: With both probes below alarm limits, no alarms present on rack.



Appendix 100: Shift in vibration levels to Alert.



Appendix 101: Relay card output active, Alert OR logic condition has been met.



Appendix 102: Vibration levels increased to Danger for both VT101 and VT102.



Appendix 103: Voting AND criteria met for Danger trip condition. Relay card shutdown output active.

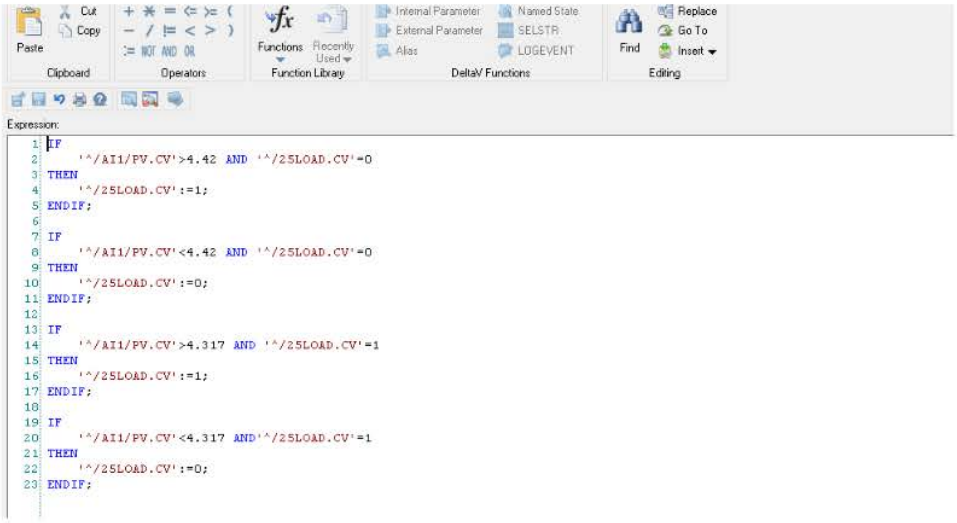
8.3 Plan and Evaluation



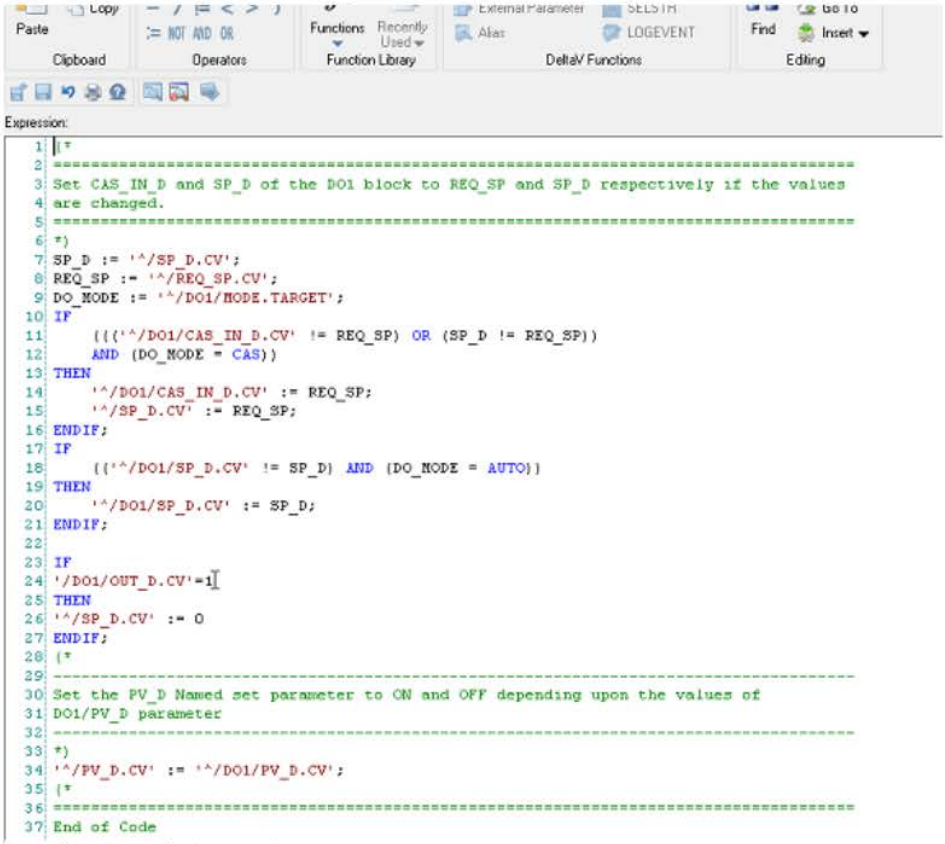
Appendix 104: Project Gantt chart.

A detailed plan but how can your reader distinguish between the original plan timing and the actual implemented timing? (RD)

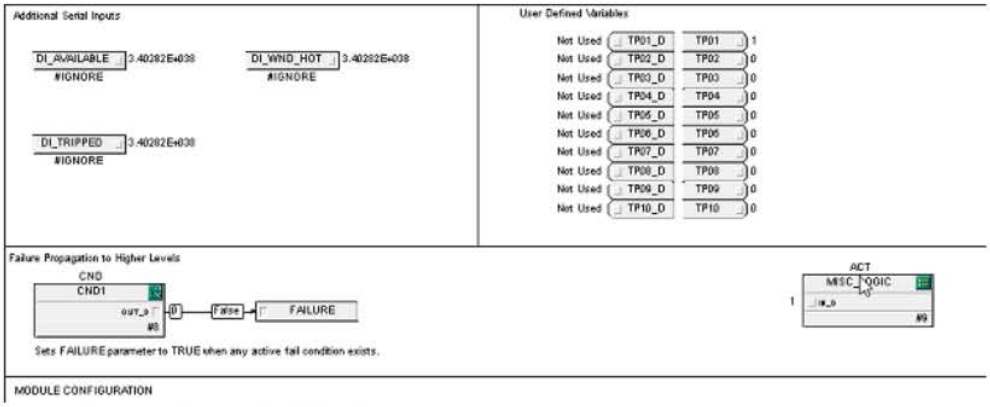
8.4 Miscellaneous



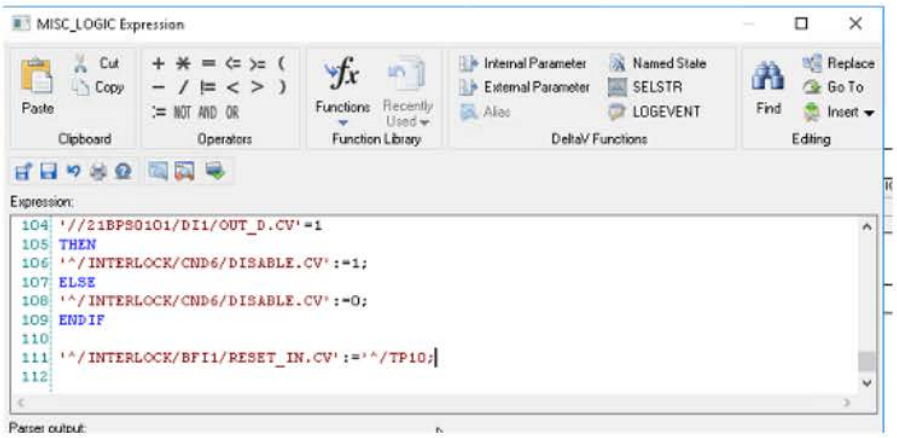
Appendix 105: Initial 25% loading logic.



Appendix 106: ACT1 logic expression.



Appendix 107: Failure and Misc logic location.



Appendix 108: TP10 expression.

1602836 Assignment 2 Dan Ince Final Project Report

GRADEMARK REPORT

FINAL GRADE

68/100

GENERAL COMMENTS

Instructor

PAGE 1

Text Comment. Positive comments:

Text Comment. 1. Report contain detailed information about the design, implementation and testing of the project (RD)

Text Comment. 2. Good structure and presentation (RD)

Text Comment. Negative comments:

Text Comment. 1. Report contains too many diagrams and images which belong in the appendix. (RD)

Text Comment. 2. All calculations should be in the appendix with the results summarised in a table in the main report. (RD)

Text Comment. 3. The report has been written in a monotonous way, your reader is presented with fact after fact but the overall picture is lost in the detail. Much of what you have said belongs in a log book. This is not a very interesting read! (RD)

PAGE 2

QM

Good Structure

Report is structured exactly as stated in the assignment brief.

Text Comment. Where is your acknowledgements section?

PAGE 3

PAGE 4

PAGE 5

PAGE 6

Text Comment. Brief and to the point (RD)

Text Comment. You should have made it clear that the overall aim was to produce a demonstration rig to prove the concept. (RD)

PAGE 7

Text Comment. You could have explained that the overall aim was to produce a demonstration rig to prove the concept (RD)

Text Comment. How much did the project change since the specification was approved? (RD)

PAGE 8

PAGE 9

Text Comment. This is a good flowchart (RD)

PAGE 10

Text Comment. This drawing belongs in the appendix (RD)

PAGE 11

Text Comment. These calculations belong in the appendix with a summary table included in the main report (RD)

PAGE 12

PAGE 13

PAGE 14

Text Comment. This diagram belongs in the appendix and a key to each item included (RD)

PAGE 15

PAGE 16

Text Comment. diagram belongs in the appendix (RD)

PAGE 17

PAGE 18

Text Comment. screen shots like this belong in the appendix (RD)

PAGE 19

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Text Comment. A testing table should give the expected range of results together with the actual results. Your reader should be able to decide if the test was successful. This table does not allow for that. (RD)

Text Comment. How can your reader agree with you that the test was passed? (RD)

PAGE 30

PAGE 31

PAGE 32

Text Comment. This belongs in the appendix

Text Comment. This is a better testing table because it shows expected and actual results. (RD)

Text Comment. Y or N ?

Text Comment. (RD)

PAGE 33

Text Comment. Did the specification have to change also? (RD)

Text Comment. The fact that it was to be a demonstration rig should have been clearly stated in the introduction. (RD)

PAGE 34

Text Comment. It could be argued that the TAR period should have been considered at the outset and contingencies built into the plan (RD)

PAGE 35

PAGE 36

PAGE 37

PAGE 38

Text Comment. This list is far too small for a major independent report, at least two or three pages of references should be included at this level. (RD)

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Text Comment. key for colours would be helpful (RD)

Text Comment. A detailed plan but how can your reader distinguish between the original plan timing and the actual implemented timing? (RD)

PAGE 91

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GRADING FORM: NEW CSG-RUBRIC

DANIEL INCE **68**

1. ENGAGEMENT WITH LITERATURE

Section 3: Judicial use and critical evaluation of technical literature in the design of the project: Evidence of use of technical literature throughout from manufacturers. No evaluation of the literature was evident as it mainly consisted of company documentation. Section 4: Extent of reading, range of credible sources and use of Harvard method: A small range of sources consulted, Harvard referencing correctly applied. Range of sources was very small for such a complex project and primarily consisted of company documentation. Legal regulations, component datasheets and wider issues such as H&S and ethical engineering were not listed. (4/10)

4

2. KNOWLEDGE AND UNDERSTANDING

Section 3: Advanced knowledge and critical understanding demonstrated in the design of the project: Report shows an advanced level of understanding in the project design process. A high level of technical knowledge and critical understanding of all aspects of the project were clearly demonstrated throughout the report. (7/10)

7

3. COGNITIVE AND INTELLECTUAL

Section 5: Testing and analysis of result: Clear evidence of thorough testing of the final system. Testing was carried out on each part of the system separately using a test schedule, these could have included more specific success metrics and

21

tolerances. e.g. how is `prompt` defined? The comments column didn't expand on failed tests. Section 5: Critical evaluation of the project outcomes: A detailed evaluation of all aspects of the project was undertaken. The FDS was mentioned generically, but not each of the requirements and how successful the project was in satisfying them. Section 6: Conclusions and recommendations: Clear conclusions and recommendations presented. The conclusions contained some unsubstantiated claims, such as `proven to be the optimum long term solution`. Recommendations included improvements to management of the project rather than a technical improvement. (21/30)

4. PRACTICAL APPLICATION



Section 3: The solution was the most appropriate for the given circumstances which involved integration into the company's existing system. The chosen solution satisfied all aspects of the FDS, there was little mention of any ethical considerations in the design solution.. Section 4: Very good methods employed appropriate to the company's standards. Practical deployment was clearly shown by the extensive range of images included in the appendix. Section 4: The end product was mainly software with a clear way forward in the full implementation using the hardware. The final product is to be used in the oil industry, so quality cannot be in doubt. Section 5: Good use of testing and clear presentation of results. Results were presented both within the test schedule and as a huge collection of

25

screenshots which would have benefited from consolidation. The process was well managed. (25/35)

5. TRANSFERABLE SKILLS

Sections 1 and 2: Executive summary, acknowledgements and introduction: Briefly stated but no acknowledgements given. The Executive Summary was brief and lacked specific detail, the introduction was good, but switched tenses. No acknowledgements were evident. All Sections: Quality of the report: High quality report, well structured and presented. However, there are far too many images and diagrams in the main report which belong either in an appendix or a log book. However, the report has been written in a monotonous way, your reader is presented with fact after fact but the overall picture is lost in the detail. Much of what you have said belongs in a log book. This is not a very interesting read! All calculations should be in the appendix with the results summarised in a table in the main report The body of the report was well written and presented in a logical order. A 54 page appendix was excessively large. Word count: Exceeded but not more than 10% (11/15)

11

SECOND MARKER - MH

Course: BSc (Hons) Electrical & Electronic Engineering

Module: SGEL6000 Independent Project

Assignment: 2. Project Design, Implementation and Evaluation

Name: Daniel Ince

University Number: 1602836

Date Submitted: 30/04/2021

Word Count: 6519

(1) WIDER READING SEEMED LIMITED FOR SUCH A COMPLEX PROJECT. CITATION LIST WAS CORRECTLY FORMATTED, BUT DIDN'T COVER SUCH ASPECTS AS ETHICAL ENGINEERING.

(2) KNOWLEDGE DEMONSTRATED BY THIS PROJECT IS EVIDENTLY EXTENSIVE.

(3) TESTING WAS COMPREHENSIVE WITH AN EXTENSIVE RESULTS IN THE APPENDIX. THE ACTUAL TEST SCHEDULE WAS NOT INCLUDED OR REFERENCED.
CONCLUSIONS AND RECOMMENDATIONS WERE GENERIC AND COULD HAVE BEEN MORE SPECIFIC.

(4) PRACTICAL DEPLOYMENT WAS CLEARLY TO A HIGH LEVEL OF COMPETANCE (AS EXPECTED IN THE OIL INDUSTRY).
TIME MANAGEMENT TECHNIQUES WERE NOT UPDATED DURING THE PROJECT TO REFLECT CHANGES AND MISSED DEADLINES.

(5) EXECUTIVE SUMMARY WAS SHORT AND DIDN'T GIVE A THOROUGH OVERVIEW OF THE PROJECT. APPENDIX IS HUGE

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1. Executive Summary

Contained within this report is the design and work scope of implementing the Vapour Recovery Unit (VRU) Compressor Control System Upgrade project. The aim of this project was to address target problems with the set point control, relay logic and compressor loading sequences, whilst also future proofing and increasing the reliability of the system. This is achieved through migrating the existing system onto the Distributed Control System (DCS) and executing as per the plan and budget. Following project completion, all aspects of the project were tested as per the Functional Design Specification (FDS), to which it met the criteria and passed the test successfully.

An evaluation of the project management and implementation was carried out to identify deviations and planning accuracy. A point of weakness was discovered in time management, where restrictions and company commitments were detrimental to the critical path.

THIS COULD HAVE BEEN MORE DETAILED. THE READER SHOULD BE ABLE TO UNDERSTAND THE PROJECT'S MAIN FEATURES, SUCCESSES / FAILURES AND OUTCOMES JUST BY READING THE ES.

2. Introduction

The project detailed in this report is to be implemented to improve a problematic Vapour Recovery Unit compressor control system on an industrial site. The finalised build will be tested and subject to a Site Acceptance Test to prove functionality. A DCS based solution was chosen through previous analysis to achieve this objective with a maximum material budget of £20,000.

The report will contain the design of the initial system and preliminary logic, along with the project implementation and execution. Following completion, the project is due to be tested against the specification and any abnormalities or failures recorded.

An evaluation will be carried out of the whole project and management process to assess the execution versus the design and plan, to review any differences encountered. Finally, the process will be summarised and any target areas for improvement suggested.

3. Design and Implementation

3.1 Design

3.1.1 Logic

To install the VRU upgrade, replacement control logic will be built into the DeltaV control system, therefore the desired compressor operation must be determined to assist with designing preliminary logic.

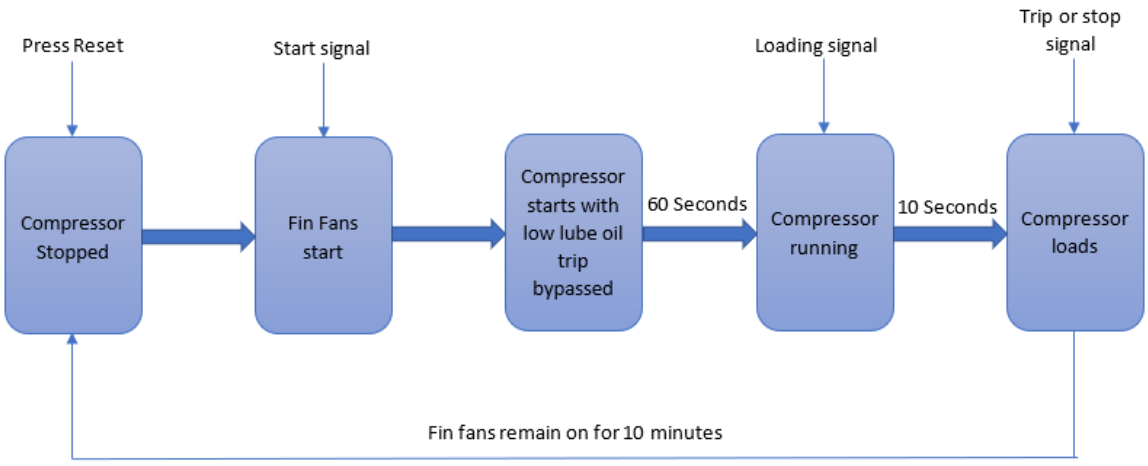


Figure 1: Operation flow diagram

The flow diagram shown in figure 1 details the process steps that must be built into the logic for successful running. Current logic drawings are based upon the existing hardwired relay installation and so new logic must be designed around the capabilities of the DeltaV system. This predominantly uses a function block design which is modifiable through internal programming language.

Figure 2 displays a conditional logic flow diagram for the compressor start and stop sequence, this expands upon the process flow in the context of logic.

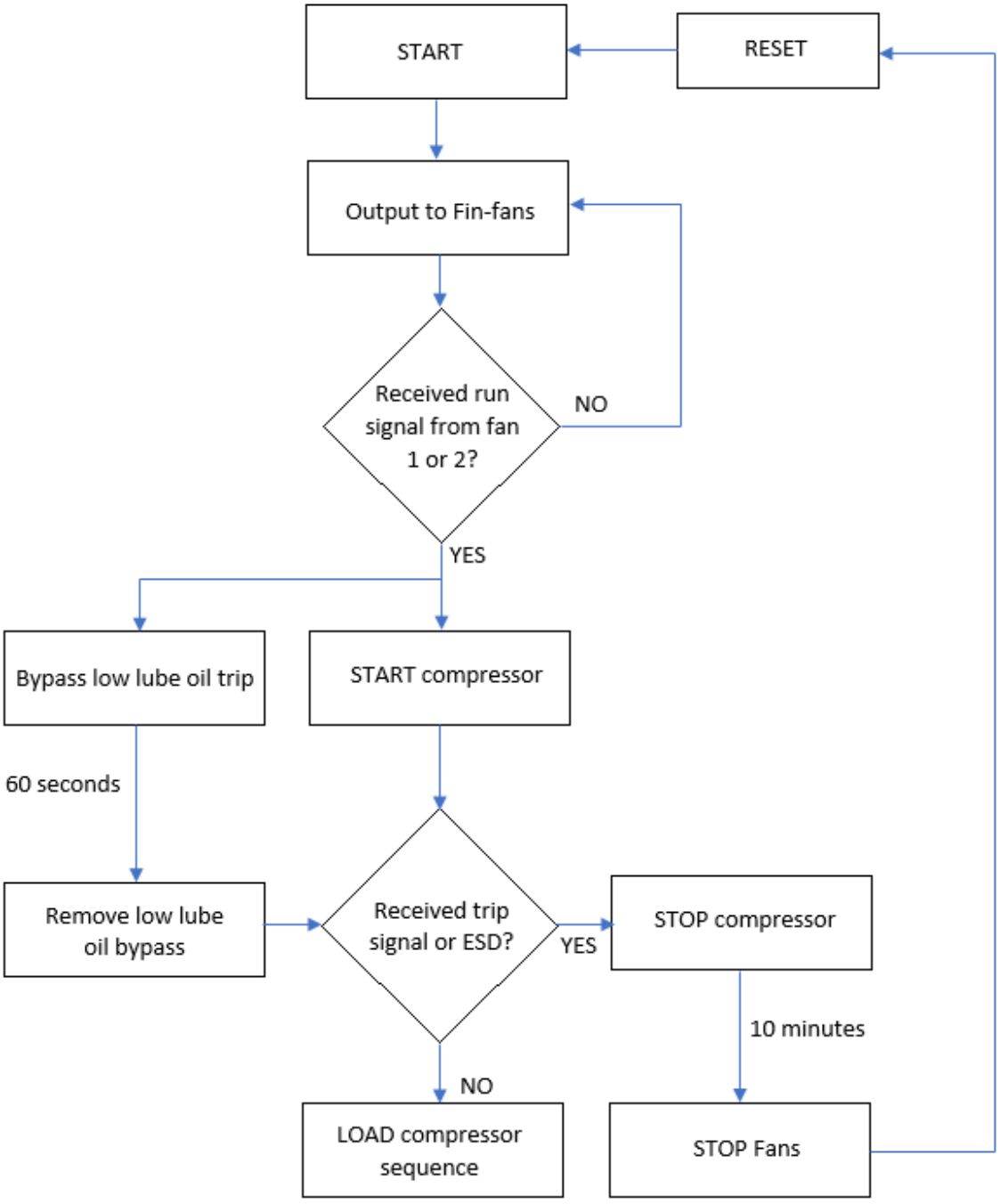


Figure 2: Logic flow diagram

The existing relay logic will be reviewed, and the best fit replacement planned for the migration to DCS logic.

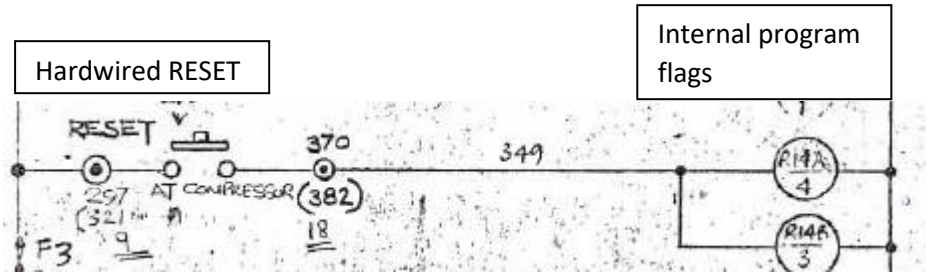


Figure 3: Logic replacement example.

The trip logic foundations will remain the same, except performed with internal flags and not relays. The physical switches in the field remain and provide the main input into DeltaV for trips, these switches will be wired directly into DI Charms with power being supplied from the CIOC rail.

The set up for vibration will alter slightly, these will be done through a relay output on a Bently Nevada 3500 rack. Therefore, only one NC vibe trip per compressor will be required for these. The flag from the reset above latches these rungs when the trips are healthy, and the reset is pressed.

The start logic kicks in when the now electronic pressure transmitter reaches the first value of 4.42kg/cm2, this starts the compressor fully unloaded. For 60 seconds, the low lube oil trip is bypassed to allow it to get the pressure above the trip point. (This is done through R13 on the low oil pressure rung), DeltaV will need to do this through timers.

Loading	Switch Point Rising *(Falling)*	Pressure Switch VRU1 *(VRU2)*	Loading SOVs Energised VRU1 *(VRU2)*	Cylinders Active
0%	6.5psi (*3.5psi)*	PS-1577A (*1677A)*		
25%	6.5psi **10sec delay** (*3.5psi)*	PS-1577A (*1677A)*	SOV-1578 (*1678)*	1 & 5
50%	10psi (7.8*psi)*	PS-1577B (*1677B)*	SOV-1578 (*1678)* SOV-1580 (*1680)*	1 & 5 2 & 6
75%	12.3psi (10.3*psi)*	PS-1577C (*1677C)*	SOV-1578 (*1678)* SOV-1579 (*1679)*	1 & 5 3 & 7 and 4 & 8
100%	15psi (13*psi)*	PS-1577D (*1677D)*	SOV-1578 (*1678)* SOV-1579 (*1679)* SOV-1580 (*1680)*	1 & 5 3 & 7 and 4 & 8 2 & 6

Table 1: Loading and unloading design

Table 1 displays how the compressors load and unload, based on the pneumatic controller output and pressure switches, there is hysteresis for this system. Calculations were then performed to determine the current output and pressure reading for these loading points with the new electronic transmitter.

Pressure values and old percentage calculations for loading with 4.3 to 4.7kg/cm^2 range:

0 & 25%: $\frac{(6.5-3)}{12} = (0.292 \times 0.4) + 4.3 = 4.42 \rightarrow \frac{0.12}{0.4} = 30\%$

50%: $\frac{(10-3)}{12} = (0.583 \times 0.4) + 4.3 = 4.53 \rightarrow \frac{0.23}{0.4} = 57.5\%$

75%: $\frac{(12.3-3)}{12} = (0.775 \times 0.4) + 4.3 = 4.61 \rightarrow \frac{0.31}{0.4} = 77.5\%$

50%: $\frac{(15-3)}{12} = (1.0 \times 0.4) + 4.3 = 4.7 \rightarrow \frac{0.4}{0.4} = 100\%$

New percentage and current loading values with 0 to 6kg/cm^2 range:

0 & 25%: $\frac{4.42}{6} \times 100 = 73.67\% \rightarrow 15.787mA$

50%: $\frac{4.53}{6} \times 100 = 75.5\% \rightarrow 16.08mA$

75%: $\frac{4.61}{6} \times 100 = 76.83\% \rightarrow 16.293mA$

100%: $\frac{4.7}{6} \times 100 = 78.3\% \rightarrow 16.528mA$

The same was performed for unloading to provide:

0 & 25%: $\frac{(3.5-3)}{12} = (0.042 \times 0.4) + 4.3 = 4.317$

50%: $\frac{(7.8-3)}{12} = (0.4 \times 0.4) + 4.3 = 4.46$

75%: $\frac{(10.3-3)}{12} = (0.608 \times 0.4) + 4.3 = 4.543$

100%: $\frac{(13-3)}{12} = (0.83 \times 0.4) + 4.3 = 4.63$

The new unloading range percentage and current values were then determined:

0 & 25%: $\frac{4.317}{6} \times 100 = 72\% \rightarrow 15.512mA$

50%: $\frac{4.46}{6} \times 100 = 74.33\% \rightarrow 15.893mA$

75%: $\frac{4.543}{6} \times 100 = 75.72\% \rightarrow 16.115mA$

100%: $\frac{4.63}{6} \times 100 = 77.2\% \rightarrow 16.352mA$

Table 2 was formulated to account for the replacement to the electronic transmitter, all loading is delayed for 10 seconds after starting up. DeltaV is required to output to the same SOVs as detailed in table 1. The SOVs will be wired from DO Charms and the transmitters into AI.

	New loading values [Tx range 0 to 6kg/cm2]		
	Pressure (kg/cm2)	Current (mA)	% Range
0%	4.42	15.787	73.67
25%	10 second delay 4.42	15.787	73.67
50%	4.53	16.08	75.5
75%	4.61	16.293	76.83
100%	4.7	16.528	78.3

Table 2: Loading range and current values.

Table 3 shows the figures for when the compressor unloads, along with there is a dead band on the loading SOVs. These tables display the exact current, pressure and range percentages that are to be programmed onto DeltaV.

	New Unloading values [Tx range 0 to 6kg/cm2]		
	Pressure (kg/cm2)	Current (mA)	% Range
0%	4.317	15.512	72
25%	4.317	15.512	74.33
50%	4.46	15.893	74.33
75%	4.543	16.115	75.72
100%	4.633	16.352	77.2

Table 3: Unloading range and current values.

3.1.2 Electrical

The current supply to the field instruments in the B&S racking room is a 110V AC supply, this will be utilised to power the twin 24V 10A Emerson power supplies.

The total power rating of the supply is: $10A \times 24 = 240W$

The Rosemount 2051 transmitter will be specified with NAMUR alarm and saturation levels, therefore the maximum current draw will be $22.3mA \times 24 = 0.5352W$. Which when accounting for both VRU systems gives a maximum current draw of: $1.07W$. To ensure compliance with site standards, the accuracy of the pressure transmitters must be determined.

$Accuracy = \mp\left(0.025 + 0.005\left(\frac{6[URV]}{6[Span]}\right)\right) = 0.03\%$ Span. Therefore $= \mp 0.002 kg/cm^2$.

$Stability = \mp 0.1\% \; of \; URV \; for \; 2 \; years. Therefore: \; \mp \; 0.006\% kg/cm^2$

Referencing the company drawing 50-ZA-003, the hazardous area is a Zone 2 Gas Group IIC, to comply with ATEX regulations, the transmitter rating must meet or exceed this. The Rosemount 2051 will be ATEX rated to Ex ia IIC T4 to meet the company standard for new installations; intrinsically safe where possible, whilst also complying with the zone and temperature requirements.

To sense the switching input, the DI IS NAMUR Charm requires a current above 2.1mA. Therefore 10mA will be selected and a 2.4kΩ resistor will be used. The switch power draw will be $10mA \times 24 = 0.24W$ each, making a total of 3.12W per VRU (6.24W total). Each Charm will draw a maximum current of 28mA and so 8.736W per VRU (17.472W total).

The Asco solenoid valve outputs draw 1.2W of power each, of which there are 6.

The nearby Bently Nevada 3500 rack is also supplied by the 110V AC supply, this means no extra power is required and only a short run of wiring is needed between the CIOC box and the rack. The relay outputs from the rack will feed directly into the normally open digital input Charm on the DeltaV CIOC. These will act as replacements for the vibration switches currently fitted.

ARE ALL THESE CALCULATIONS REQUIRED FOR TESTING AND IF SO WERE THEY OBTAINED SUCCESSFULLY?

3.1.3 Wiring

3.1.3.1 Cabinet specification

To implement the control system, the existing relays and wiring need to be removed from the B&S racking room 1 shutdown panel and field instrument terminals connected directly to the CHARM installation. As the control system manufacturer is Emerson, a specification for the hardware will be determined and equipment built as per the desired requirements.

The cabinet is to be sized at 915mm width by 1070mm height, with a depth of 325mm. These dimensions fit within the B&S marshalling cabinet on the back wall.

The 110V AC relay supply will be disconnected and cut-over to supply the dual Emerson power supplies located within the cabinet during the final site implementation. These were specified to contain a dual redundancy feature for instrument protection.

Reviewing hazardous area drawings, the field equipment is mounted within a zone 2 area, gas group IIC. To adhere to ATEX regulations, the equipment needs to be intrinsically safe, therefore 24V energy limiting IS CHARMs were specified. It is also ensured that this IS wiring is kept separate from the 110V supply by at least 2 inches. This is in accordance with regulations as stated by Ind Ex "*Conductors of intrinsically safe circuits are permitted where they are separated from nonintrinsically safe circuit conductors by a space of not less than 50 mm*." (2017)

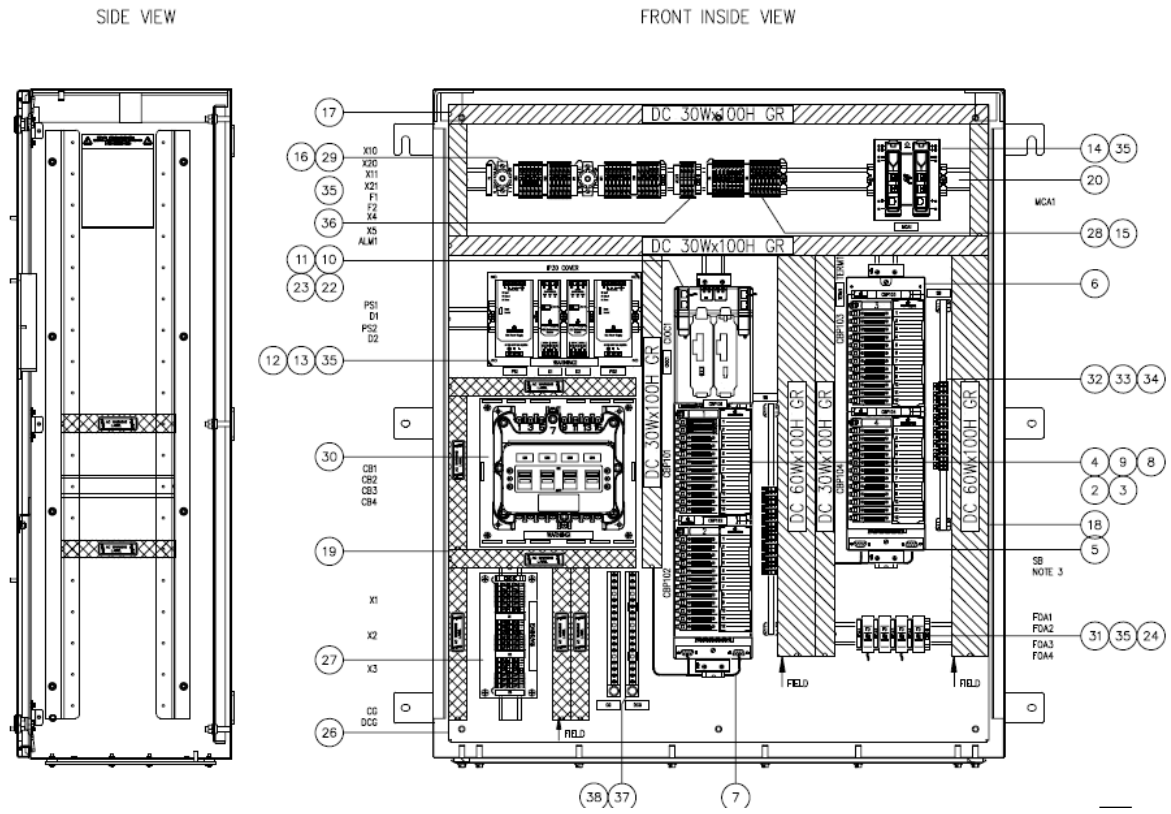


Figure 4: Emerson CHARM cabinet. (Emerson, 2020)

Figure 4 shows the manufacturer drawing for the Emerson cabinet. As per the Emerson quote, a pre-fabricated CIOC box will be installed within the cabinet to house the controllers and CHARMs.

3.1.3.2 Input connections

The terminal block diagram for the input connections are shown in figure 5. The field instruments are wired using white (positive) and blue (negative) insulated wires on the hazardous side to meet the site requirements for IS instrumentation. The block will be housed in the B&S shutdown cabinet. The drawing has been completed using the company standards and tagging codes.

Inputs have been assigned to the 12 slot charm rails and are tagged based on the enclosure and CIOC section.

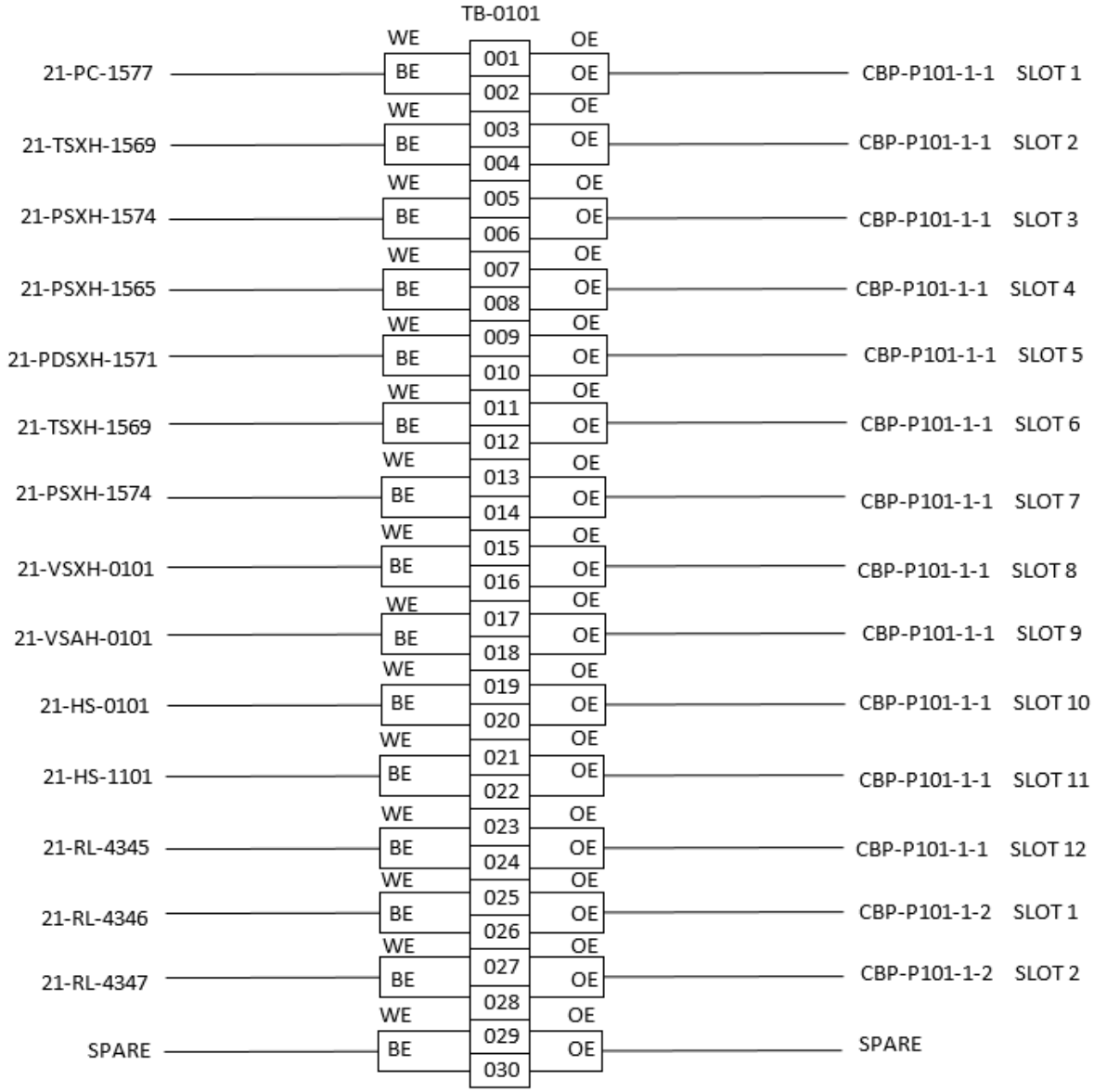


Figure 5: Input terminal wiring.

3.1.3.3 Output connections

A drawing for the VRU1 output connections is shown in figure 6. These are taken from the output CIOC and wired into the secondary terminal block.

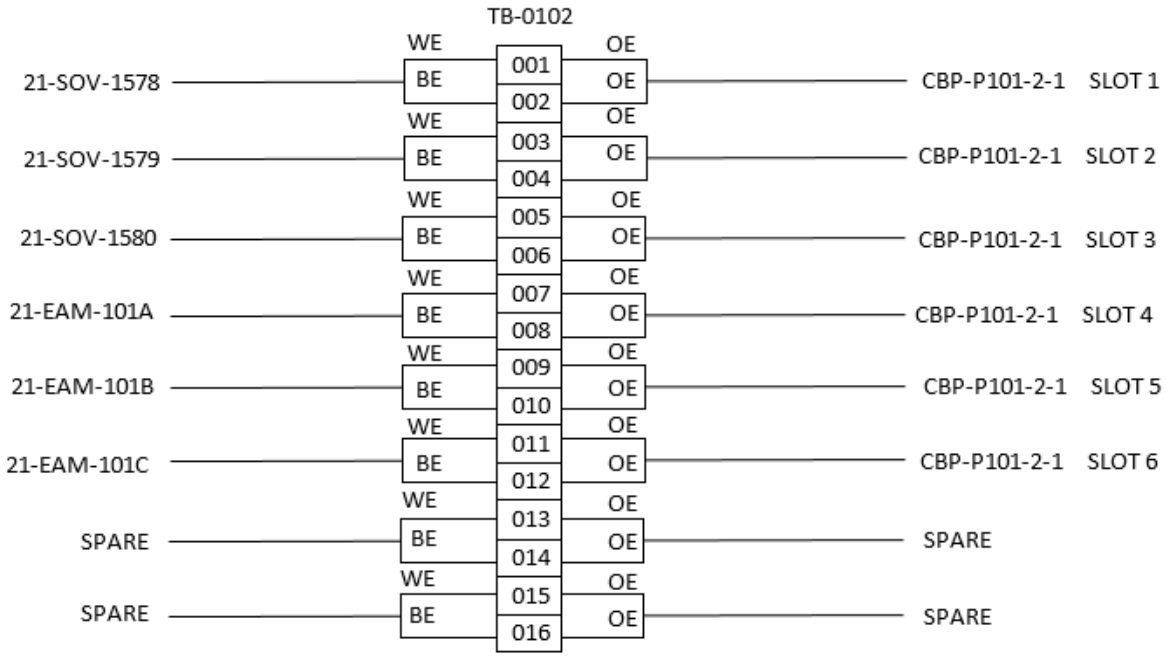


Figure 6: Output terminal wiring.

3.2 Implementation

3.2.1 DeltaV controller set up and initial logic programming

To build the background control system logic, the configuration software DeltaV Explorer was used, this connects to the main DeltaV server and can download directly to the controllers based on site.

A new area was configured ‘VRU’, and assigned to the PROPLUS network, when in service, this area can be assigned to the required control panel. Within this node, the controller and CIOC CHARM modules can be configured as shown in figure 7 and appendix 1 & 2.

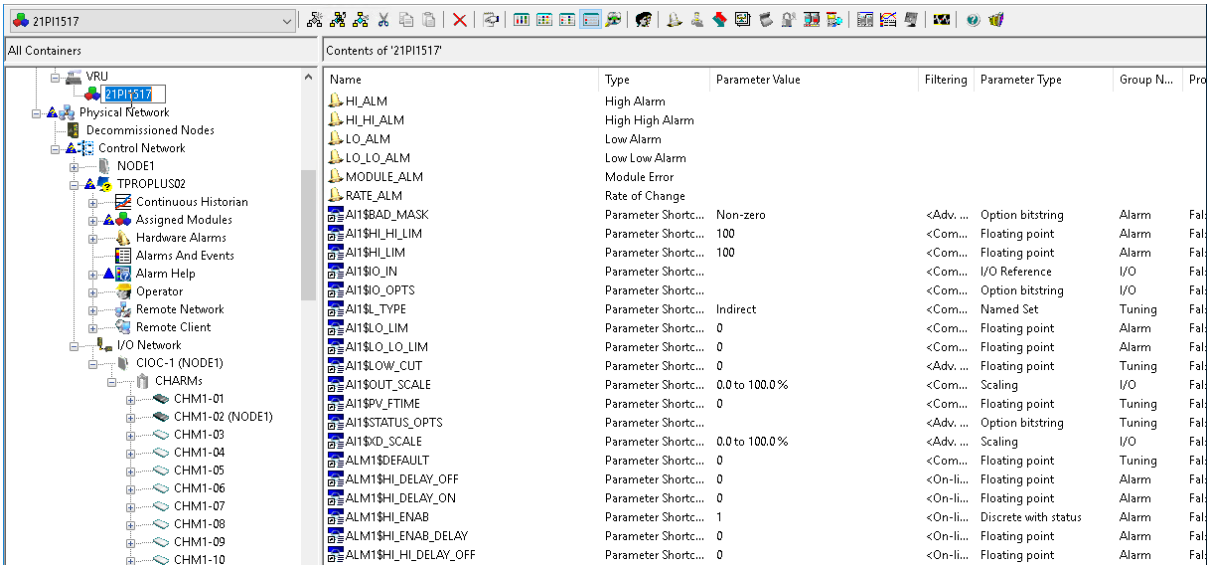


Figure 7: Setting up the main pressure controller.

The compressor loading controller 21PI1577 was built to the first CHARM, with the parameters set as a 4-20mA HART protocol, for smart capabilities. This was converted to a class-based module and the modules V_AI_52_DT and V_AI_52_FP assigned to provide the ‘detail’ and ‘faceplate’ respectively. The contents of the charm allows configuration of NAMUR alarm saturation points and also provides provision for different alarm points.

The VRU area was then downloaded to the database to allow configuration of the analogue input module. Here the AI1 block parameters were adjusted so that the block writes from tag 21PI1577, as it was now visible on the database, shown in appendix 8. The input was configured to the required 0 to 6 kg/cm^2 across the 4-20mA range and ‘L_Type’ set to indirect, this ensured the faceplate displayed scientific units and not a raw current value. The module was opened on the Control Studio online simulation to briefly test the faceplate and tag detail facilities, here the range was tested by inputting a signal of 4.5kg/cm^2, detailed in appendix 6.

The three loading solenoid output tags (21SOV1578, 1579 & 1580) are relay ‘DO’ signals and so were configured as ‘DO_52’ modules with the appropriate tags and assigned to CHARMs. Appendix 3 & 5 display the build and download.

With all three SOVs added, they were downloaded to the server and each module opened for configuration. Parameters were set within the DO module, as this is where the I/O is driven from, shown in appendix 7.

The contents of DO1 was set to output directly to 21-SOV-1578, the tag was taken from the database and assigned to the block, shown in appendix 7. This process was repeated for 21-SOV-1579 and 1580 and these blocks can now be used as outputs within the logic. Appendix 9 shows the internals of the solenoid output modules.

3.2.2 Loading configuration

The nature of the compressor loading means a form of hysteresis will be required to be built within the logic. Using the tables formulated during the design stage, the pressure set points with a 0 to 6kg/cm^2 are to be implemented using the DeltaV block design, shown in appendix 8.

Output blocks for the three solenoids were created and placed within the threshold section for 02-PI-1577. Here the individual action thresholds could be configured and mapped to the solenoids in different combinations as per the loading table. To allow any loading to occur, a 10 second on delay timer was implemented to elapse on start up. Each threshold was built with logic as per the dead band tables 2 and 3 to provide 25%, 50%, 75% and 100% loading.

A compressor module was built to accept inputs from the loading thresholds, this will provide the foundation for compressor control. Here a start output can be written or tripped based off thresholds and interlock parameters. This is detailed in Appendix 10.

Within the compressor block, the start force was configured to be written from the 21-PI-1577 input. The permissive block for the compressor was opened up and set point force logic was entered to instruct the output variable to change to a 1 if either input is set to 1. Figure 8 and appendix 11 & 12 display the logic that takes the first loading start stage input and uses it to start the machine.

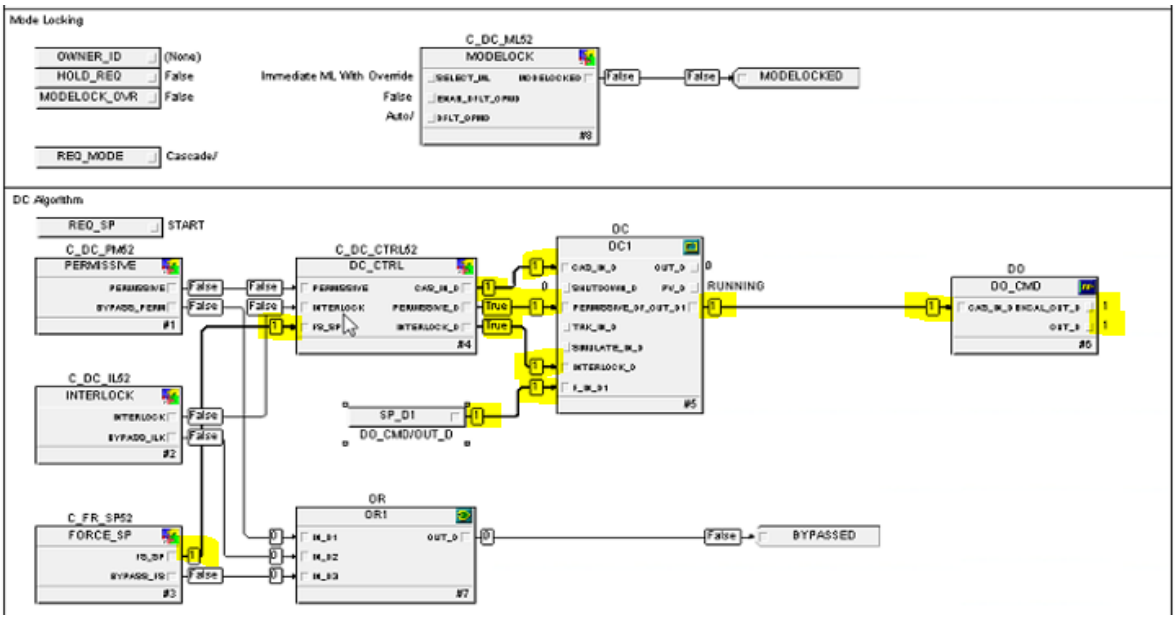


Figure 8: Force logic test

A quick test was performed using a simulated value of 5kg/cm^2, a healthy output of 1 is showing from the DO block as the requirements for the set point force is healthy. The system has been set up to act as an internal run light as at this point there is no feedback through the DI Charm.

3.2.3 Interlock and start procedure configuration

The low lube oil pressure switch module 21-PSXL-1571 was created and configured for a faceplate. As this input is required to trip the compressor by also hold out for 60 seconds, an on-delay block was added to the main compressor module. The timer was then configured into the first interlock logic, in combination with the pressure switch output.

Appendix 14 shows the logic that is used to only permit the compressor to run providing the low lube oil pressure is healthy. The time delay bypass logic will be built upon this foundation. The interlock composite module shown in Appendix 16 was configured and added to include this logic

The low lube oil bypass logic needed to be configured to override the trip for the first 60 seconds of operation. Initially the start/stop faceplate in appendix 18 was built to the DC1 block for driving output 'OUT_D' from faceplate. This allows the set point to be written via the operation of the faceplate and will manually override the loading automatic starting if desired.

Within the overall interlock module, CND8 logic was configured to time the initial bypass. The expression shown in appendix 19 must become true to allow a healthy output. Therefore, when the start is pressed, the logic recognises that the lube oil pressure is low. The timer will only be counting whilst the expression is true, therefore once the pressure is healthy it resets back to zero. If the timer reaches 60 seconds with the low state still active, the compressor trips.

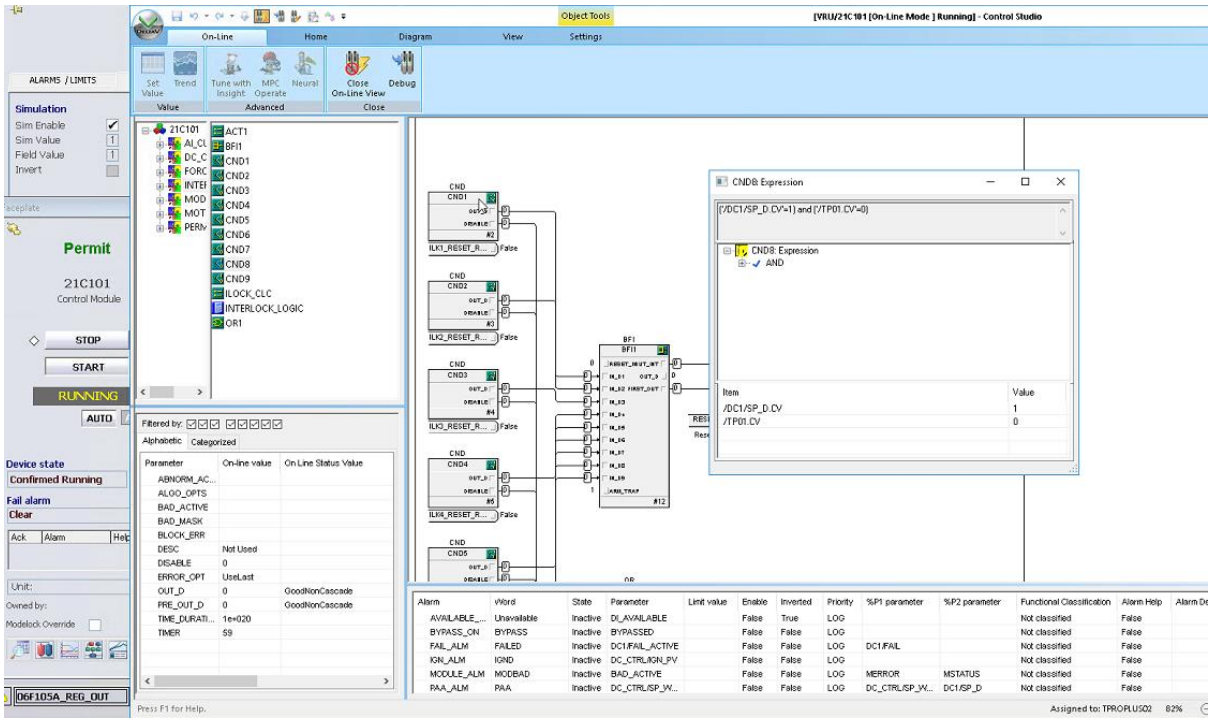


Figure 9: 60 second delay test.

A simulation test was performed to show compressor running, whilst lube oil pressure is still low as shown in figure 9 and appendix 20. This allows the compressor to start whilst pressure is low, as

pressure is created by the internal oil pump. Appendix 17 shows the miscellaneous logic expression within the compressor block updated to create a latch, where TP01 is used to hold out and reset timer latch allowing consecutive uses.

The main interlock logic expression was also updated to include TP01 to trip compressor if TP01 and lube oil pressure is still low, this also generates an interlock which would shut down compressor and prevent restart. A brief test was conducted in appendix 22, here the elapsed time is 59 seconds and the compressor is still in the running state with low lube oil pressure. The timer then counts to 61 seconds, at which point the compressor trips on low lube oil pressure as shown in appendix 23. The trip condition was then simulated healthy and retest performed where the timer reset to zero and compressor remained running as shown in appendix 24.

3.2.4 Shutdown and bypass inputs

All shutdown blocks were configured and assigned to Charms, as shown in appendix 25. Each one of these was defined to an individual CND interlock on the main compressor logic block.

Each individual interlock was checked and used to inhibit manual or automatic compressor starting. Appendix 26 shows an example of this test, with the compressor tripped and buttons greyed out, preventing operation. The interlock blocks were further modified to be discounted when a bypass became active. The logic expression in appendix 27 was used for each bypass and the respective interlock trip function.

The miscellaneous logic block was also modified to include the bypass logic. Appendix 28 displays the control module test outputting a true signal for the bypass. Here CND3 is bypassed and so a 1 is input to the OR gate, this outputs to the common bypass active alarm. The effect of removing the override can be seen in appendix 27, where the interlock becomes true again.

Appendix 29 and figure 10 display a test showing how the bypass has removed the start inhibit from the faceplate, despite a low suction pressure trip being active. The bypass logic expression can be found in the appendix.

An additional check was carrid out to ensure the override suitably affected the 60 second start up bypass, this is shown in appendix 31. The timer has elapsed and reset despite there being a low lube oil pressure trip in, allowing the compressor to continue running.

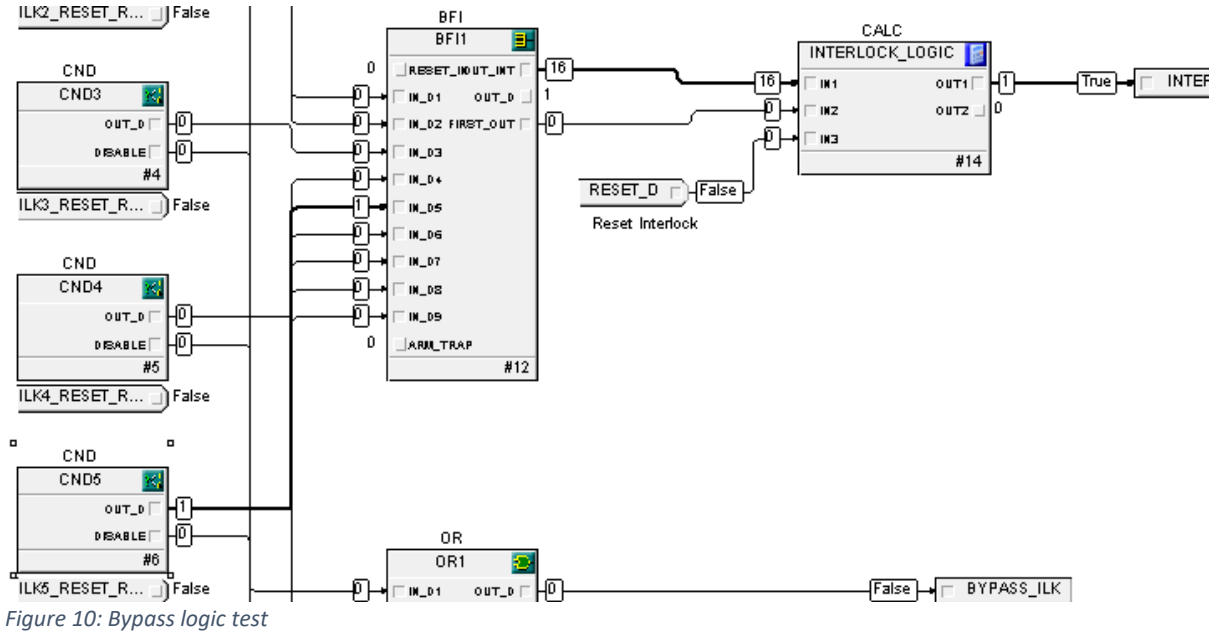


Figure 10: Bypass logic test

A non-latching reset button shown in appendix 33 was built and configured to return to normal once the trip has been cleared and reset pressed, the logic expression can be found in appendix 32. Within the miscellaneous logic block, TP10 is used to hold out on any interlocks becoming healthy, such as TP2 in appendix 34, therefore the reset actuates TP10, which clears the trip.

3.2.5 Alarm and graphic configuration

A graphic screen was built within the Blending and Shipping DeltaV sector, this included the compressors and fin fans along with a basic process layout. Indication for PI1577 and compressor loading was added as a permanent feature.

The graphic dynamos were configured to look at points within the logic, this also allowed icons to function as buttons to bring up faceplates when operated. This function is also assigned to allow the start, stop and reset buttons to be utilised. Animations were added to the blocks to change colour when the equipment is operating, this is fed from the running lights and requests to start. White indicates offline, whereas a solid fill represents running, the start request will thicken the outline of the graphic briefly. This can be seen in appendix 36 and 37.

The graphic requirement also specified trip and bypass indication. This was first configured through a first up alarm driven by the compressor function block to write to the animated text. The first out block shown in appendix 38 will output different values based on the initial trip alarm. The text data table was built up to reference these points shown in appendix 39. Appendix 41 displays an example of the first up alarm triggered when the high suction separator level alarm is active. The output from BF1 in appendix 38 is '2', which corresponds to the data table and therefore that text is displayed. The first up alarm was also configured to clear only after a compressor reset has been pressed. This was done through utilising TP10 reset output to be tracked and the alarm to only clear if this is healthy, the logic can be found in the appendix. Appendix 40 displays a separate trip flagging up the first up alarm.

Bypass and shutdown alarms were also configured and animated to ensure colour and state change upon operation. The graphics have been configured as per Valero DCS standard with the text layout as shown in figures appendix 42 and 43. The text and alarm lights are tied into the reset and so will only clear after the master reset has been operated. Figure 11 shows the completed graphic with the compressors running at 100% and no standing alarms.

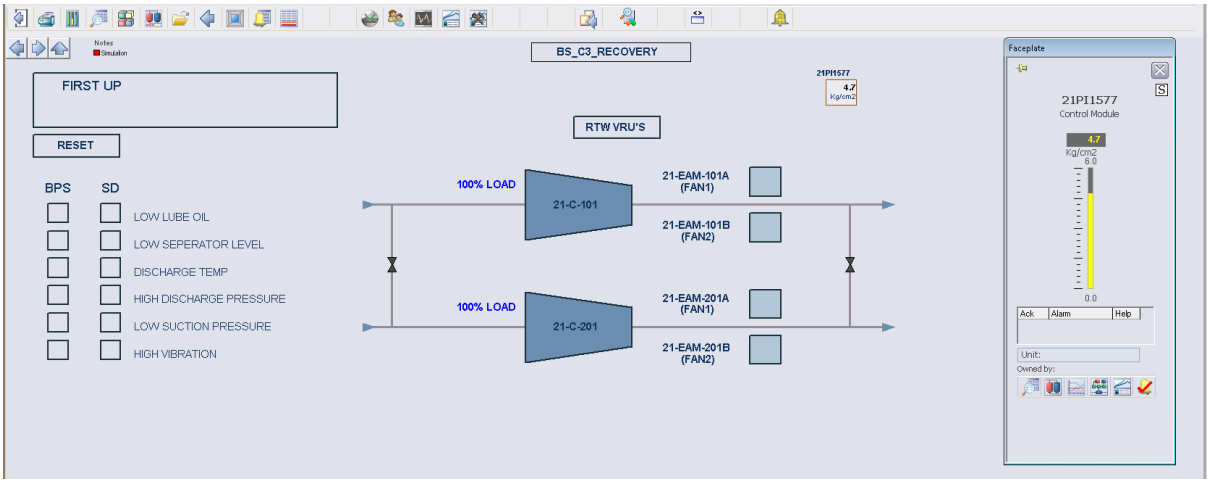


Figure 11: Completed graphic with both compressors running.

3.2.6 Bently Nevada logic programming

The Bently Nevada 3500 rack needed to be configured for the new probes and trip logic for the VRU compressors. The Bently Nevada 3500 rack configuration software was launched, and the PC connected to the rack through COM port 2. The Rack address is selected as 2 (as set on the dip switches on the front of the rack), and the baud rate is set at 9600.

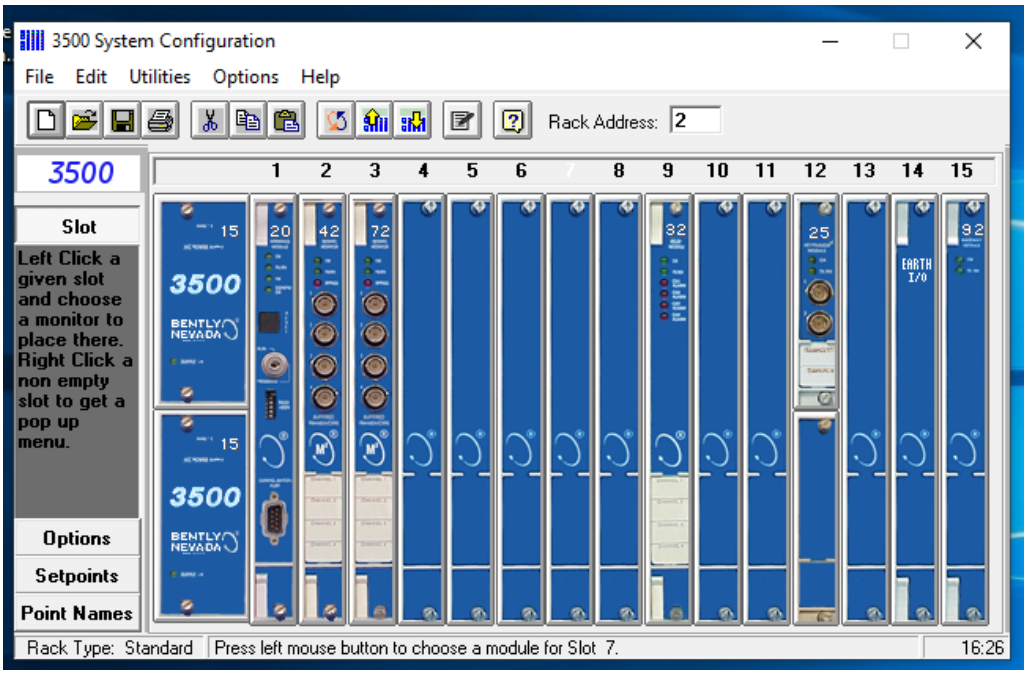


Figure 12: Configuration downloaded

The module configuration was uploaded from the rack to allow setting up, the block can now be seen in figure 12 populated with the correct modules. Slot 2 module was selected as it has four channels for the fin-fan proximitors, one channel per fin-fan, two channels per compressor as shown in appendix 48. The probe type has been set as radial vibration and channels activated due to the location of the probes, these were tagged up accordingly. Each module needed to be configured for the correct probe type, as shown in appendix 49. The radial transducer type was selected, in this case a 3300 8mm probe, no external barriers are connected to this probe as the rack itself is intrinsically safe. Direct Frequency Response was left default for this probe type.

Variable and alarm configuration for VT-101 was carried out as shown in appendix 51. Range values were set at 10 thou" and -24V for distance and gap voltage respectively. Regarding alarm values, a three second delay was chosen for the alert to reduce the chance of spurious alarms during start-up. The danger alarm will feature a higher set point and voting system; therefore, one second will suffice. These are set as latching and so will only clear after a rack reset.

This process was repeated for all four channels as they are identical, evidence of this can be found in the appendix.

Alarm settings were configured in figure 13, starting with VT-101, this included setting the gap voltage and distance alarm points for the alert. The danger was set at 7.5 thou' (75%) of the maximum range, this was repeated for all four probes.

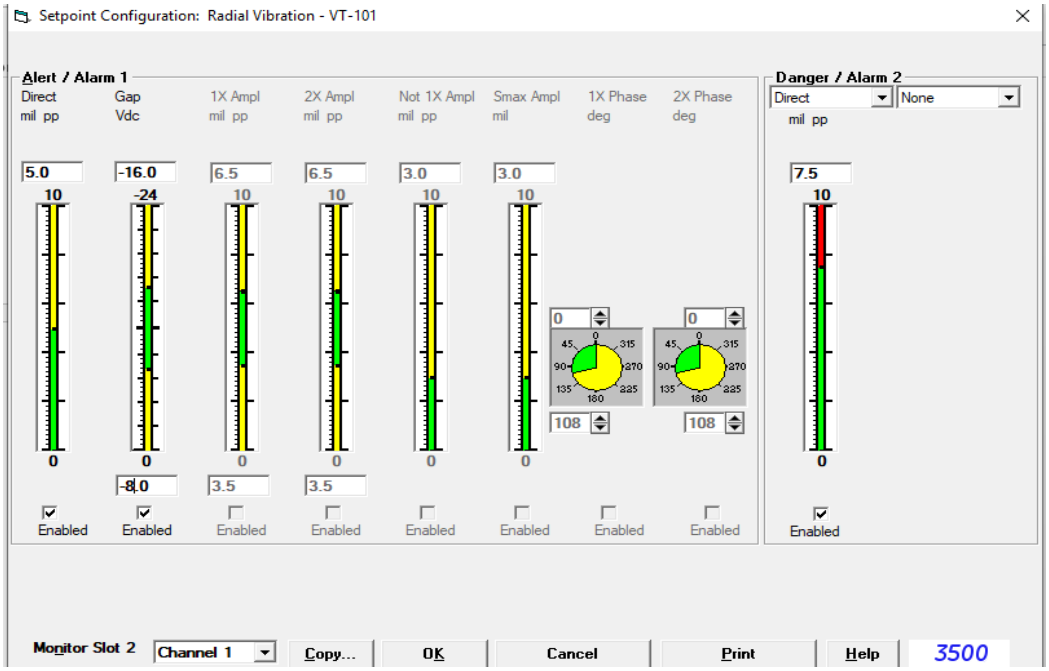


Figure 13: Alarm limits

Appendix 53 displays the output configuration for channel 1, the Boolean logic was set so an alert on either slot 1 or 2 will trigger the channel 1 alarm. [(Slot 2, Channel 1, Alarm 1) OR (Slot 2, Channel 2, Alarm 1)]. This was done to provide a rack alarm if either machine vibrations spike to the lower limit, however they will not prompt a trip. Channel 2 on the relay output module was also set as an OR gate for channels 3 and 4 (VRU 2) on the proximitor card as shown in the appendix.

For the VRU 1 trip, the logic was set as an AND gate for the two probes, this is because the VRU can only function if at least one fin-fan is running. The system then trips if both fin-fans show faults, a 2-out-of-2 voting system is also the company standard for radial proximitors, as shown in appendix 54. The same voting system was configured for VRU 2, probe channels 3 and 4. The danger level set point has been used for all trips.

Once completed, the configured modules were selected and downloaded to the rack, as shown in appendix 55.

3.2.7 Installation and testing setup

The DeltaV programming had been completed and so needed to be downloaded, installed and tested from the field side. The DeltaV test rig was built up and specified with the appropriate number of charms. The rig base was already set so the required controllers and power supplies were dropped into the mounting slots as shown in figure 14. These controller power supplies are dual redundancy with a failure alarm configured on DeltaV.



Figure 14: DeltaV controllers and CIOCs installed.

Once installed and illuminated as healthy, the charm blocks could be populated with DO, DI and AI HART charms. The CIOC and controllers are connected to each other and the local DeltaV server through an ethernet port. This allowed the VRU program to be assigned to that area as carried out at the start of the implementation.

The Rosemount 2051 SIL transmitter was obtained from the stores, connected to the AI 1577 charm and set up using the HART communicator. To comply with standards, the NAMUR alarm failure and saturation limit configuration was chosen, along with range values of 0 to 6kg/cm^2 as shown in appendix 58.

The adjacent Operator workstation was logged onto and connected to the DeltaV server via Ethernet port. The VRU area could be accessed and interface displayed on the computer, allowing live operation of the I/O as shown in appendix 57.

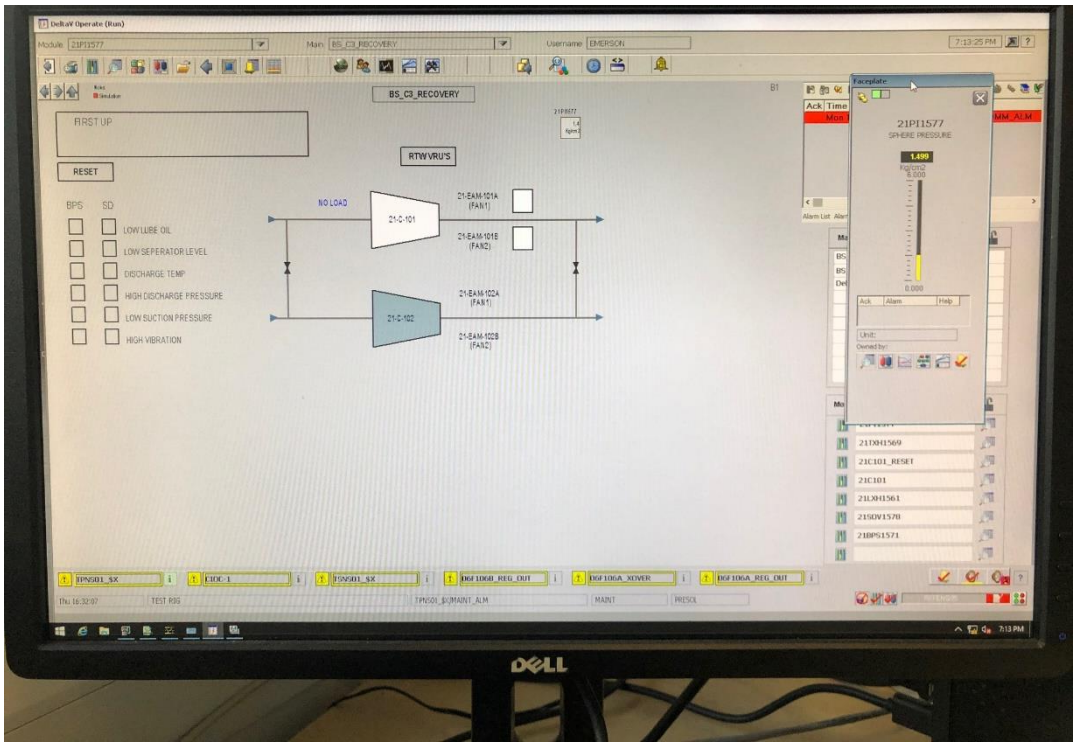


Figure 15: Interface

WHAT TEST SCHEDULE WAS USED. EITHER INCLUDE IT DIRECTLY OR REFERENCE IT IF IS TOO LARGE. ALSO, HOW WILL THE SYSTEM BE TESTED AS PART OF THE REGULAR PREVENTATIVE MAINTENANCE REGIME?

4 Testing and Results

The test rig was used to check all aspects of the project as per the testing table found in section 4.4. To prove suitability for the plan, a full function check was required of the compressor operation, safety features and protection.

4.1 Control logic testing

The control logic was tested by increasing the current output from the pressure transmitter PI1577, varying this output ensured the automatic starting, loading sequence and stopping could be checked accurately.

Current Output (mA)	Pressure value (kg/sqcm)	Compressor status	Pass (Y/N)
8.0	1.499	Offline	Y
15.85	4.420	Online, 0% loading for 10 seconds, then 25%	Y
16.10	4.533	Online, 50% loading	Y
16.45	4.645	Online, 75% loading	Y
16.55	4.702	Online, 100% loading	Y
16.40	4.646	Online, 100% unloading	Y
16.25	4.589	Online, 75% unloading	Y
16.05	4.514	Online, 50% unloading	Y
15.9	4.458	Online, 25% unloading	Y
15.6	4.346	Online, 25% unloading	Y
15.5	4.308	Offline	Y

Table 4: Loading hysteresis test.

Table 4 displays the checks carried out for the control software, the images of which can be found in sequence in the Testing section of the Appendix, references 59 to 78. These checks show a successful loading hysteresis as per the design requirements. When a fault occurs on the pressure controller, the faceplate shows bad point and fails to -25%.

As part of the start sequence, the fin fans must be started prior to compressor running, this was confirmed by the testing and fin fan run lights. The low lube oil trip was also successfully bypassed for 60 seconds. The images from these tests can be found in the Appendix references 68 to 70.

4.2 Trip function and bypass testing

All trip inputs were tested consecutively by closing and opening the input to the DI charm. The bypass was also enabled and disabled via the software, to ensure trip alarms still come in, however the compressor remains running whilst trip active. Failure actions and interlocks were also tested, these results can be found in the appendix references 79 to 88.

The Bently Nevada configuration and alarms were also checked to ensure the indication and trips functioned as desired. The rack has a dual redundancy AC power supplies that are supplied via 110V, this means if one fails, the secondary supply takes over and no process shutdown or loss in information occurs.

The 8mm probes were connected to the -24V terminals from the back of the probe module and the VRU 1 probes were then verified with the gap voltage set at -10V and wobulators set up to measure vibration. Probe VT-101 vibration was increased to above the alert set point, this can be seen on the rack card and on the live screen. Probe VT-102 was also brought into alert, bringing in the channel 1 alarm relay card. Channel 2 was brought into danger as shown on the screen; however, the trip output did not energise due to the voting being 1-out-of-2.

VT-101 was also brought to the danger limit, this brought in the trip alarm output channel 2 on the relay card, proving the voting logic. Both proximitors were then made healthy, the danger alarms cleared however the trip remained active on the rack until the reset was pressed. This process was repeated for VT-201 and 202 probes. These tests can be found in the appendix, references 89 to 103.

These tests proved the relay output to DeltaV by flagging up the trip and first up alarm on the HMI, the alert 1 out of 2 voting alarm remains a rack indication only and can be cleared through manual operation of the reset.

4.3 Results

The testing results table can be seen in table 5, all tests were completed and the outcomes acceptable.

Reviewing the outcomes, two testing criteria were not fully met and did not directly match the expected output. These tests are still marked as successful, however a BSU (Before Start-Up) or ASU (After Start-up) action will be assigned to rectify either the equipment or supporting documentation.

The Punch List is shown in table 5.

Test	Query	Pass?	Rectification	BSU/ASU
4.1.1.5	Manual starting of compressor will always start fin fans. Unable to inhibit fans and force compressor output without entering control studio. From studio, either compressor or fans can be forced. However, compressor will not start without fans from faceplate.	Y	Verify operations user area unable to access control studio.	BSU
4.1.2.3	No loading bypass present on DeltaV.	Y	Manually lock out loading solenoids in the field to prevent loading and test when compressor operational. This ensures field operator presence when bypassing loading.	ASU

Table 5: Punch list

To conclude the testing, the project has passed the site acceptance test with a couple of action items to be completed as part of the final commissioning.

FDS item	Test	Expected result	Actual result	Pass (Y/N)	Amendment required/Notes
4.1.1.2, 4.1.2.4	Simulate an open circuit trip condition during healthy VRU1 compressor operation for TSHH-1569. Repeat for all VRU1 trips.	Output to VRU1 compressor immediately de-energises to shutdown equipment. VRU1 loading SOV outputs de-energise. Compressor will not start until trip made healthy again. Indication for each alarm and trip must operate	VRU1 Compressor shuts down when trip active, first up alarm displays the initial trip. Compressor will not restart until trip clear and reset pressed.		Vibration trips activate on Bently rack and provide visual indication to channel. The relay output is direct to DeltaV where the operator interface provides alarm and trip information.
	PSHH-1574				
	PSLL-1571				
	PDSLL-1571				
	FAN-1 Vibration				
	LSHH-1561				
	Simulate an open circuit trip condition during healthy VRU2 compressor operation for TSHH-1669. Repeat for all VRU2 trips.	Output to VRU2 compressor immediately de-energises to shutdown equipment. VRU2 loading SOV outputs de-energise. Compressor will not start until trip made healthy again. Indication for each alarm and trip must operate.	VRU2 Compressor shuts down when trip active, first up alarm displays the initial trip. Compressor will not restart until trip clear and reset pressed.		Vibration trips activate on Bently rack and provide visual indication to channel. The relay output is direct to DeltaV where the operator interface provides alarm and trip information.
	PSHH-1674				
	PSLL-1671				
	PDSLL-1671				
	FAN-2 Vibration				
	LSHH-1661				
4.1.1.3	Increase pressure of VRU1 set point controller to 4.4kg/cm2 whilst all states healthy and compressor offline.	VRU1 compressor should promptly cut in following start sequence.	VRU1 compressor cuts in at desired pressure and loads accordingly.		Compressor loading follows hysteresis for unloading at correct pressures.
	Increase pressure of VRU2 set point controller to 4.4kg/cm2 whilst all states healthy and compressor offline.	VRU2 compressor should promptly cut in following start sequence.	VRU2 compressor cuts in at desired pressure and loads accordingly.		Compressor loading follows hysteresis for unloading at correct pressures.
4.1.1.4	Begin VRU1 compressor start sequence.	Fin-fans EAM-101A&B outputs should cut in instantly.	Fin-Fan outputs energise.		Running indication also provided.
	Begin VRU2 compressor start sequence.	Fin-fans EAM-102A&B outputs should cut in instantly.	Fin-Fan outputs energise.		Running indication also provided.
4.1.1.5	Force VRU1 fin-fan outputs open and attempt to begin start sequence on VRU1.	VRU2 compressor output should not energise.	Compressor will not start unless interlock is overriden.		Lock out manual output forcing for operations log on. Point forcing only to be unlocked for engineer users.
	Force VRU2 fin-fan outputs open and attempt to begin start sequence on VRU2.	VRU2 compressor output should not energise.	Compressor will not start unless interlock is overriden.		Lock out manual output forcing for operations log on. Point forcing only to be unlocked for engineer users.
4.1.1.6	Increase VRU1 controller pressure throughout range.	VRU1 loading SOVs should trigger as per loading table.	Correct loading as per tables.		
	Increase VRU2 controller pressure throughout range.	VRU2 loading SOVs should trigger as per loading table.	Correct loading as per tables.		
4.1.1.7, 4.1.1.9	Begin VRU1 compressor start sequence.	VRU1 must not load until 10 seconds after start. Lube oil trip must be bypassed for 60 seconds after start.	Lube oil low trip bypassed for 60 seconds or until healthly pressure is established.		GREEN = PASS ? YELLOW = FAIL
	Begin VRU2 compressor start sequence.	VRU2 must not load until 10 seconds after start. Lube oil trip must be bypassed for 60 seconds after start.	Lube oil low trip bypassed for 60 seconds or until healthly pressure is established.		
4.1.2.1	Test ESD buttons during compressor operation	Corresponding compressor must shutdown and not restart while latched.	Compressors shutdown.		
4.1.2.2	Test compressor resets.	Corresponding compressor alarms and trips should clear and compressor start when reset operated if all trips are healthy and pressure above set point.	Compressor trips and first up alarms only clear when reset operated.		Vibration trips must be reset on the Bently Nevada 3500 rack adjacent to control panel, before they can be reset on the DCS software.
4.1.2.3	Operate loading bypasses.	Compressors must not load when bypass is engaged.	No loading bypass implemented on control system.		Manual loading of cylinders can be manually operated in field if desired. No requirement for these to be software.
4.4.1.1	Disconnect one power supply.	System should still maintain power from redundant supply.	System still operational.		System can also run with a single controller.
4.4.2.5	Check full range of electronic pressure transmitters.	Range should output 4-20mA as per specification.	0 to 6 kg/sqcm full range accurate to analogue output.		
4.4.1.2	Check power supply output voltage.	Output should be 24V.	Correct voltage.		
4.1.1.2, 4.1.1.3	Test Bently Nevada 3500 Voting for vibration alarms and trips.	Alert alarm should trigger when either of the two probe readings is above the the threshold. Danger trip alarm should trigger when both probe values increase above the threshold.	Voting logic correct and analogue value viewable through Bently Rack.		

Table 6: Testing spreadsheet

5 Evaluation and Wider Issues

5.1 FDS conformity and completion

Reviewing the FDS shows that the project was an overall success, as all areas within the specification were met. The conformity was proved through use of the testing table, of which extra tests were added in line with the program development. The tests concluded with a couple of minor action items.

The final design was carried out as per the risk assessment and EMOC actions to ensure compliancy within the industrial application. As a completed project, the installation onto site is easily achievable through the modular design of the DeltaV hardware. The Emerson cabinet will require I/O cut-over from the old relays, directly into the Charm terminal blocks and supply from the 110V. The addition of the Bently Nevada rack output will replace the traditional vibration switch wiring, simply requiring the relay outputs to be wired from the card to the Charm terminals, across the adjacent cabinet. The rack is mounted within 1m of the DeltaV control panel in the B&S control room, allowing for alarm indication and reset of the rack without having to leave the panel. This satisfies the ergonomic criteria 4.2.3.1 of the FDS detailed in Assignment 1 (Ince, 2020)

The project meets the design criteria for being an operational demonstration rig ready for site implementation. The integrated control software and hardware will reduce maintenance costs, environmental fines, and improve safety of the Vapour Recovery Unit for the company.

You could have reviewed each FDS point and presented evidence to show each has been met. And what criteria was used.

5.2 Time management and costing

To manage time and plan the project accordingly, a preliminary Gantt chart was developed, detailed in appendix 104. This initial chart failed to account for unforeseen project setbacks and so design and implementation planning did not extend into the company planned outage.

Due to COVID-19 restrictions, the project timeline shifted well into the TAR (turnaround), during this period the company priority was the commitment to TAR and so project work was put on hold. This shift in priority and extended working hours meant a new plan had to be developed for the forecasted hours.

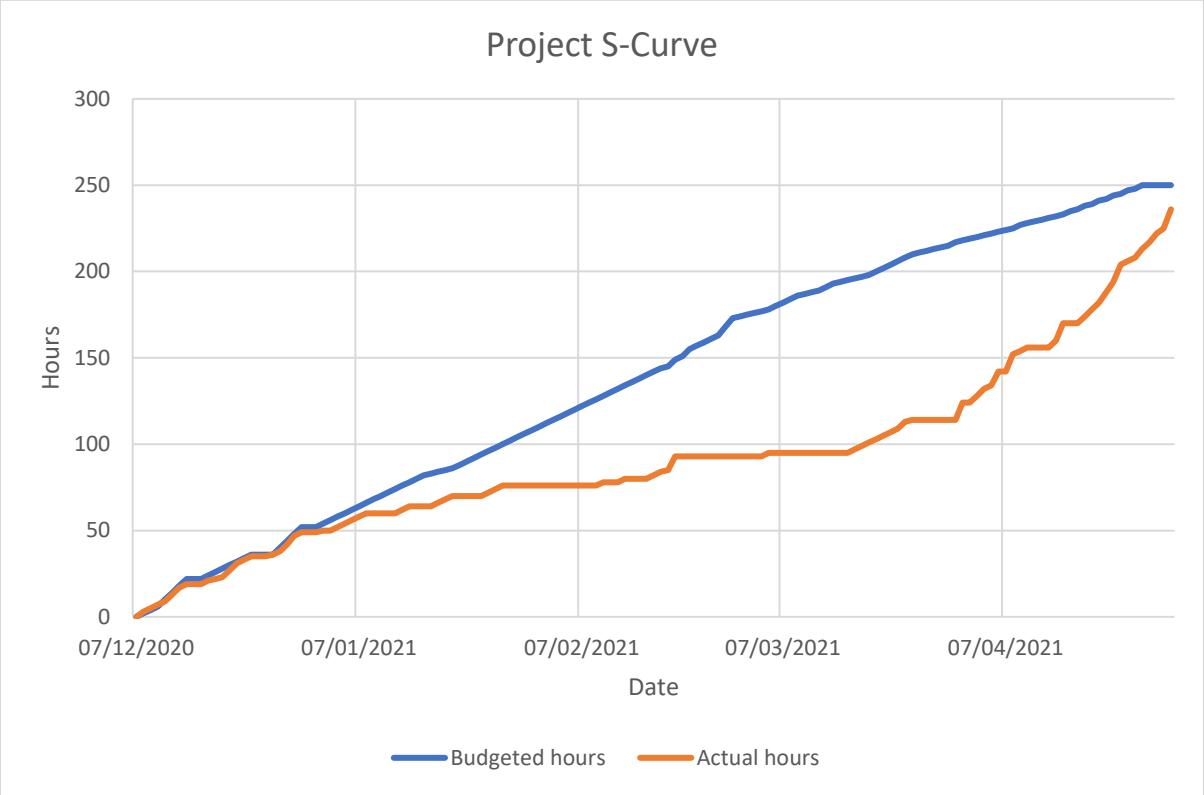


Figure 16: Project S-Curve.

The S-curve for the project man hours seen in figure 16 was developed to keep track of the project design and execution hours across the full work scope. Initially the project remained on target until mid-January. The company TAR started from January 14th 2021 onwards and this is reflected by the curve as the actual hours deviate hugely from the planned, plateauing until the beginning of April, this is also shown in the Gantt chart. A slight shift in company priority from the end of March allowed more allocation of time to project work, this is when a large amount of the implementation was completed, often exceeding the planned hours for that period. This means that the project timeline is very back loaded, with larger amounts of work being completed in short periods and reduced productivity in between. This form of completion was less desirable as the project did not progress steadily or according to plan.

The deviation from the plan during the execution stage meant that the monthly budget had to be shifted from the original to track the change in labour costs. The overall costing spreadsheet in table 7 details how these changes differ from the original plan. The ordering of materials earlier meant that the bulk of the budget was used before 2021. The labour hours are well below the original budget during January to March, however the hours in April required more budget allocation. Overall, the final labour costs are £1140 under budget.

Description	MWO No.	Original Budget	Current Budget	Current Forecast	2020 Sep-20	Oct-20	Nov-20	Dec-20	2021 Jan-21	Feb-21	Mar-21	Apr-21	May-21
Construction Total	Various	£0											
			£0										
				£0									
Manhour Costs Total	Various	£6,000				600	750	750	750	1,050	1,050	1,050	
			£6,000			600	750	1,050	1,050	1,050	750	750	
				£4,860		600	750	735	375	255	315	1,830	
Materials Total	Various	£20,000						15,000	5,000				
			£17,800					15,000	2,800				
				£19,880					15,000	4,880			
Overall Total		£26,000			0	600	750	15,750	5,750	1,050	1,050	1,050	0
			£23,800		0	600	750	16,050	3,850	1,050	750	750	0
				£24,740	0	600	750	735	15,375	5,135	315	1,830	0
Accumulative Total					0	600	1,350	17,100	22,850	23,900	24,950	26,000	26,000
					0	600	1,350	17,400	21,250	22,300	23,050	23,800	23,800
					0	600	1,350	2,085	17,460	22,595	22,910	24,740	24,740

	Sep-20	Oct-20	Nov-20	Dec-20	Jan-21	Feb-21	Mar-21	Apr-21	May-21
Original Commitment	0	600	1,350	17,100	22,850	23,900	24,950	26,000	26,000
Current Commitment	0	600	1,350	17,400	21,250	22,300	23,050	23,800	23,800
Actuals Commitment	0	600	1,350	2,085	17,460	22,595	22,910	24,740	24,740
Frozen Forecast Commitment	0	600	1,350	2,085	17,460	22,595	22,910	24,740	24,740

Table 7: Monthly costing

The materials costing table has been updated with the final prices, this also includes the pressure transmitter obtained from the instrument stores as surplus and as a result has no effect on the total. The extra project scope materials have been added on whilst the overall total remains under the £20,000 budget.

Item	Manufacturer	Vendor	Price each	Quantity	Total
48 CHARM CIOC Controller enclosure	Emerson	Emerson	£15,000	1	£15,000
DI CHARM	Emerson	Emerson	£100	10	£1,000
DO CHARM	Emerson	Emerson	£100	12	£1,200
AI CHARM	Emerson	Emerson	£300	2	£600
Rosemount 2051 (Instrument Surplus)	Emerson	Emerson	£2,100	2	N/A
Bently Nevada 3500 8mm probe	Bently Nevada	Bently Nevada	£220.00	4	£880
Bently Nevada 3500 Proximitor	Bently Nevada	Bently Nevada	£300.00	4	£1,200
				Total:	£19,880

Table 8: Materials costing

5.3 Project execution and plan

The project build was carried out through utilising the plan to separate out the individual tasks and milestones throughout. Due to constraints previously discussed, many milestones were not met according to plan. However, some milestones were unaffected by this and yet still overran, for example, the logic design and implementation, as seen on the finalised Gantt chart in the Appendix. The plan begins initially on track; however, the logic programming stage and further took many weeks longer due to the difficulties encountered and a shift in company priorities towards turnaround work.

The logic design although planned using existing logic diagrams, had to be designed as ongoing with the project build as the ladder logic cannot be directly mapped across to the DeltaV system, this was due to the technician's inexperience with the control software. To pre-empt this, less time could be allocated to designing the logic, and more time to building and implementing it. In future however, the knowledge gained from the project would allow planning to be more thorough to prevent milestone dates overrunning. As shown in the appendix 104 Gantt chart, the overrunning time (red) mostly occurred during the logic programming period. Despite these issues, the project was completed ahead of the planned project end, 30th of April.

A minor change to the project design was made during the build, this involved utilising the existing Bently Nevada 3500 rack within the control room to control the vibration trips on the fin-fans. Utilising unused I/O slots on this equipment to output relay state changes to the DeltaV improved indication and alarm management for the system and ultimately control ergonomics. The labour hours allocated to the execution required no increase for this change whilst also keeping material costs below the maximum budget.

During the implementation, no improvement areas for safety were identified. The bulk of the execution involved logic and control system programming, the largest areas for concern being posture when operating a workstation. Correct breaks and seating position ensured no injuries were sustained throughout.

As documented in the EMOC Risk Assessment form *PP-PEM-FRM-0077* (Valero, 2020), the action items required for the upgrade to be allowed have been incorporated into the system. This ensures the equipment meets the safety requirements for the site.

The materials used in the project have been sourced as ethically as reasonably possible. Where available, parts have been signed out of the company stores and surplus. This has reduced excess packaging as when replenishing stock, the company will order a large batch. Therefore, less packaging is required than when ordering individual items on a smaller scale. Regarding surplus stock, this is not re-ordered and therefore is utilising materials that would otherwise go to waste, effectively saving money whilst also benefitting the environment.

6 Conclusions and Recommendations

Overall, the project has been completed to a standard that meets the initial criteria detailed whilst also in accordance with the company and industry standards. The success of the project depended on addressing the three target issues of the previous system. The new system solves these and so will improve performance and reliability of the refinery and ultimately reduce running costs and operating emissions. The finalised testing rig for the project is ready for site implementation, to fully implement on site, the existing I/O and supply will be required to be cut over directly to the charms and supply in the Emerson cabinet. The DeltaV system will then be able to access and manipulate the I/O with the designed control software. Operability has been proven through thorough testing of each function, repeated tests were carried out through each development of the design and a finalised test following completion. Regarding the operability standpoint, the project is a success and has achieved the desired outcome.

WHAT METRIC ARE BASING THIS ON?

The delivery of the project plan met many issues that greatly shifted the track away from the plan, the impact of this was reduced in a partial respect by starting the project earlier than originally planned. However, time management still became an issue and resulted in disjointed progress, reflected in the S-curve (figure 16). The budget of the project required micromanaging monthly in line with the labour hours, however remained under budget whilst including a minor design addition.

CAN YOU STATE THIS AFTER A SHORT PERIOD OF IMPLEMENTATION.

The DCS choice has proven to be the optimum long-term solution of the three initial choices, the system is future proofed through being integral to the control system upgrade that has only recently been fully rolled out across site. Control and trip functionality have been jointly carried out by the DCS, external logic has also been included into the standalone Bently Rack. The integration of the Bently rack allows for future expansion, such as a speed probe or machinery diagnostic project and compressor upgrade. It has also enabled the project to benefit from modern existing infrastructure, saving costs.

Recommendations for future projects are associated with improving the project planning process. Despite implementing multiple contingencies, this project deviated by a large amount from the plan. Difficulties posed by COVID-19 restrictions initially denied access to work locations and equipment, this delayed the project further into the TAR, an extremely time intensive period with delays of its own. These irregular conditions impeded progress but are however not a common occurrence. In future, for a work-based project to be carried out alongside normal working hours, the work scope must be planned across a far larger amount of time. Doing so will reduce daily demand and will allow the flexibility for separate work commitments.

In conclusion, the project overcame the challenges encountered throughout, and despite moving off plan, managed to stay within budget whilst being an operational and environmental success.

7 Citation List

Emerson, 2020. *AC Powered Field Enclosure for 48 CHARM I/O; For Zone 2 Locations (EU-FE-48-AC-CIOC-HA-DEMO),* s.l.: s.n.

Ince, D., 2020. *Major Project Assignment 1,* s.l.: s.n.

Ind Ex, 2017. *Wiring requirements in hazardous locations.* [Online]
Available at: https://www.atexdb.eu/atex_article/wiring-requirements-in-hazardous-locations
[Accessed 15 February 2021].

Valero, 1988. *JA08/4585/Z VRU Relay Logic.* s.l.:s.n.

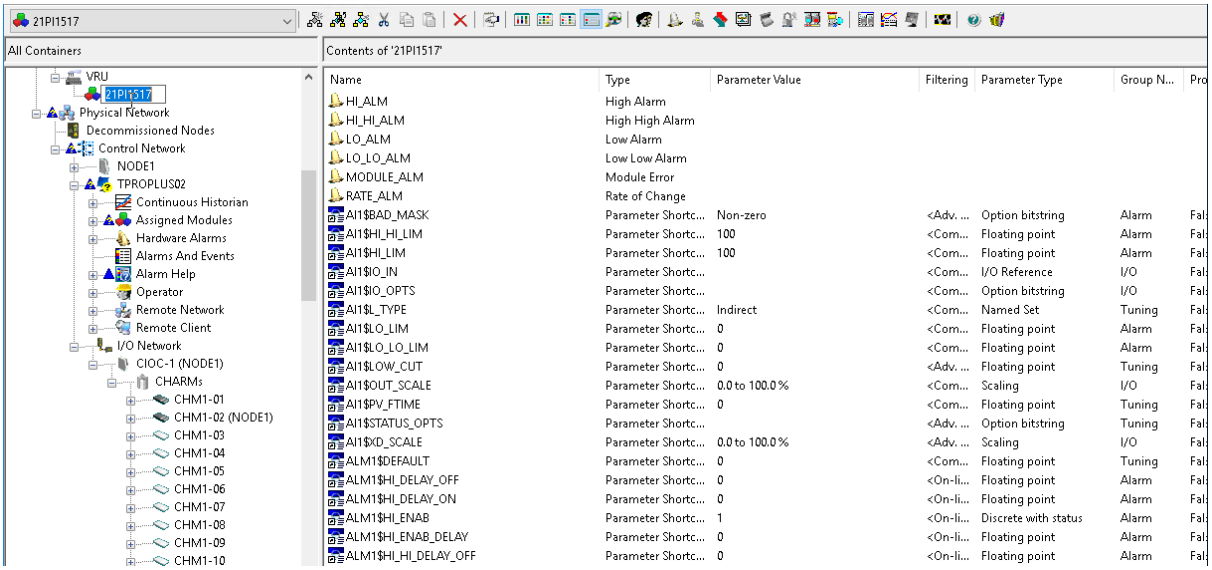
Valero, 2020. *MOC Risk Assessment PP-PEM-FRM-0027 ,* s.l.: s.n.

Valero, 2020. *Risk Matrix PP-HES-GUI-0009 ,* s.l.: s.n.

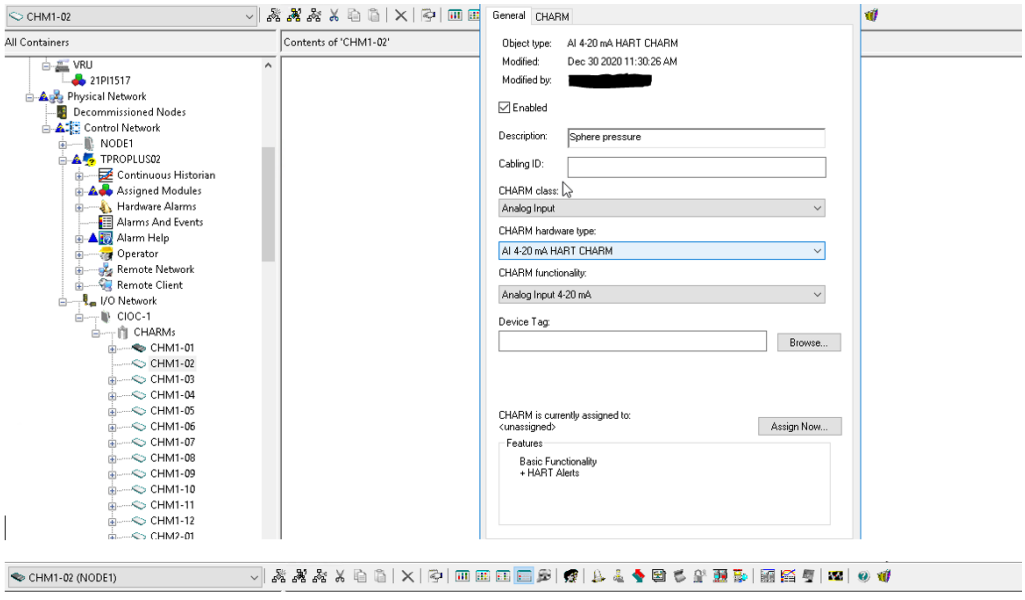
RANGE OF SOURCES SEEMS SMALL. LOOK ABOUT WIDER ISSUES SUCH AS H+S, SUSTAINABILITY AND ETHICAL ENGINEERING.

8 Appendix

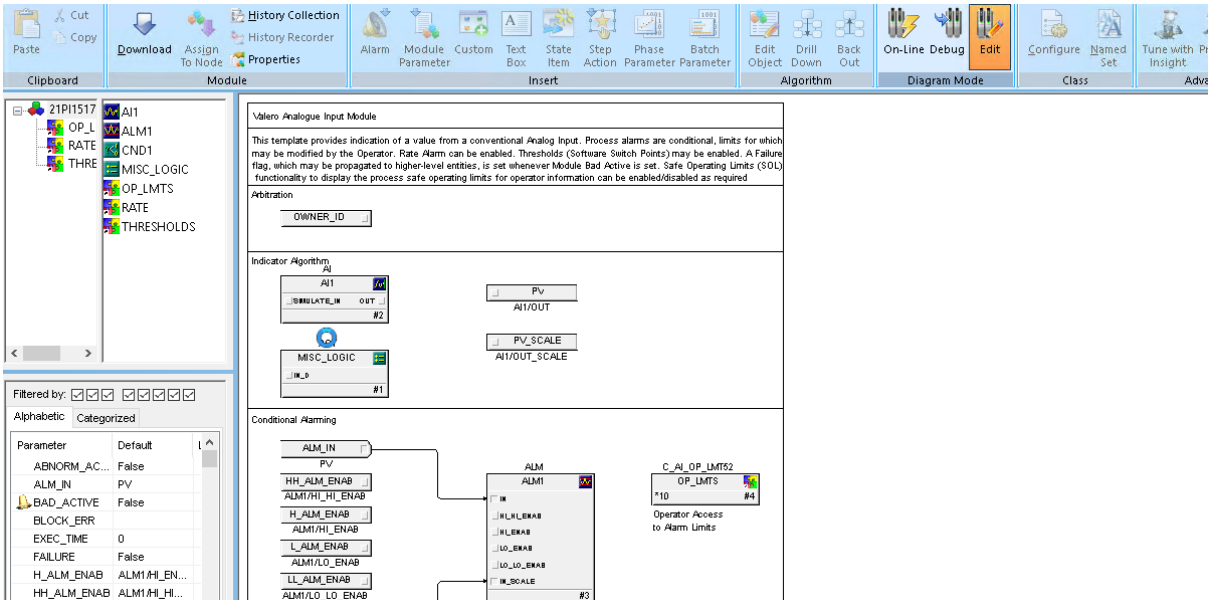
8.1 Implementation Evidence



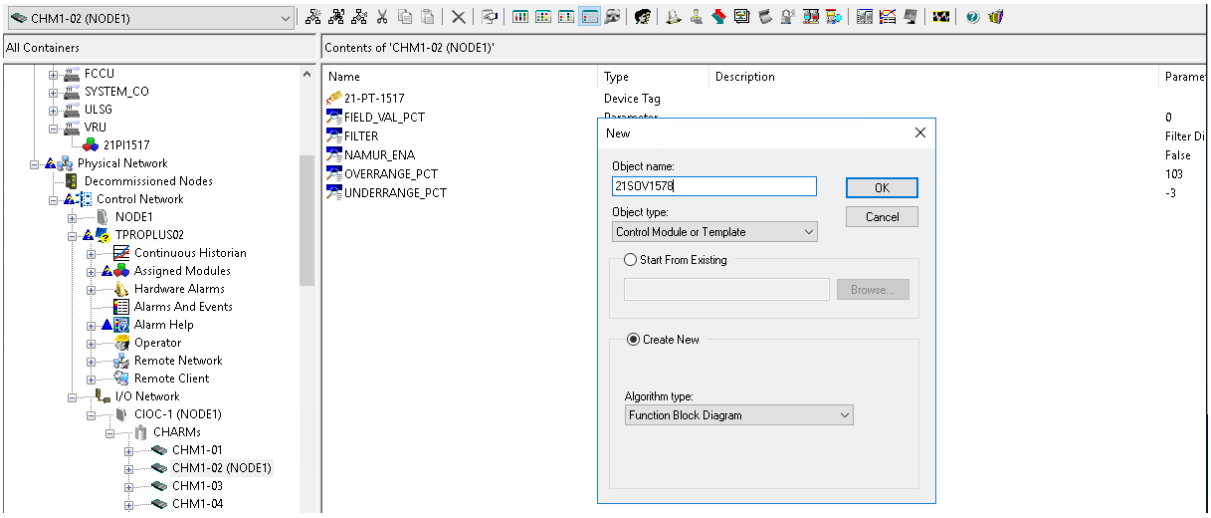
Appendix 1: Setting up the main pressure controller.



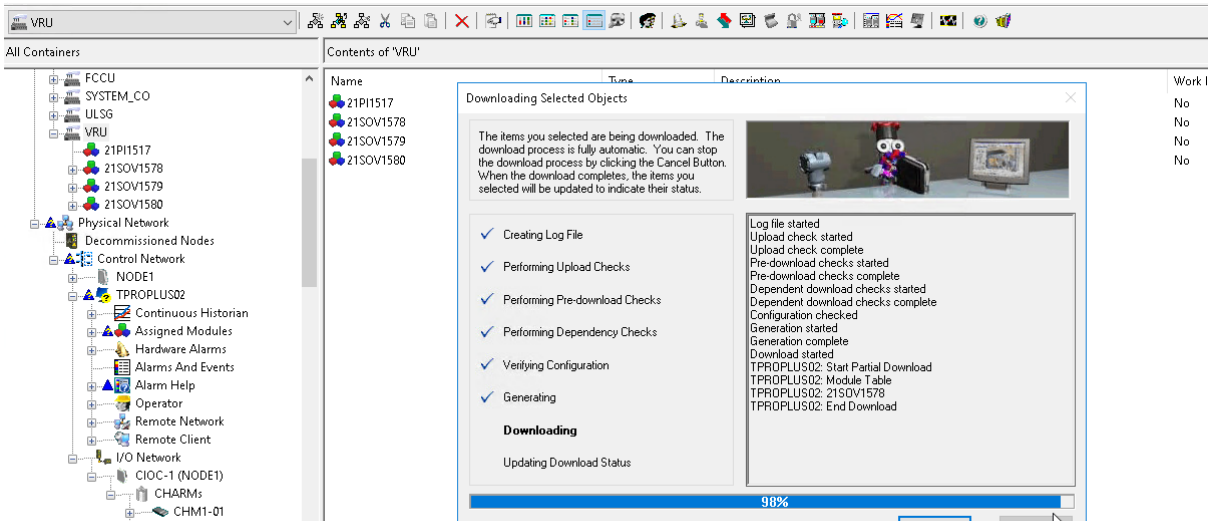
Appendix 2: Network area configuration.



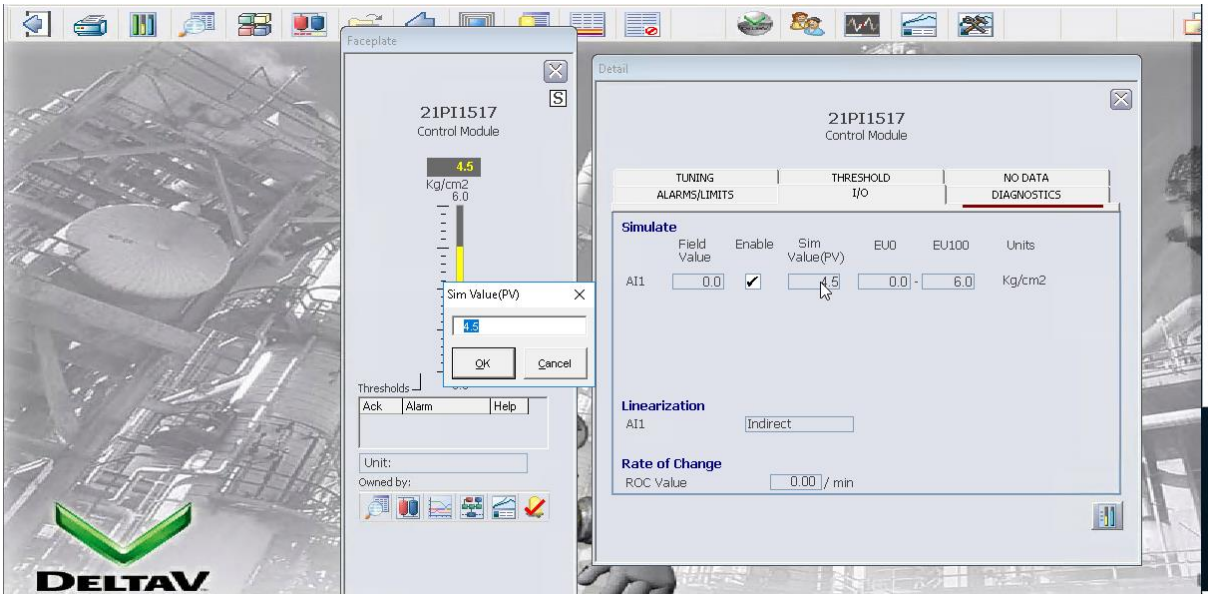
Appendix 3:AI controller internal blocks.



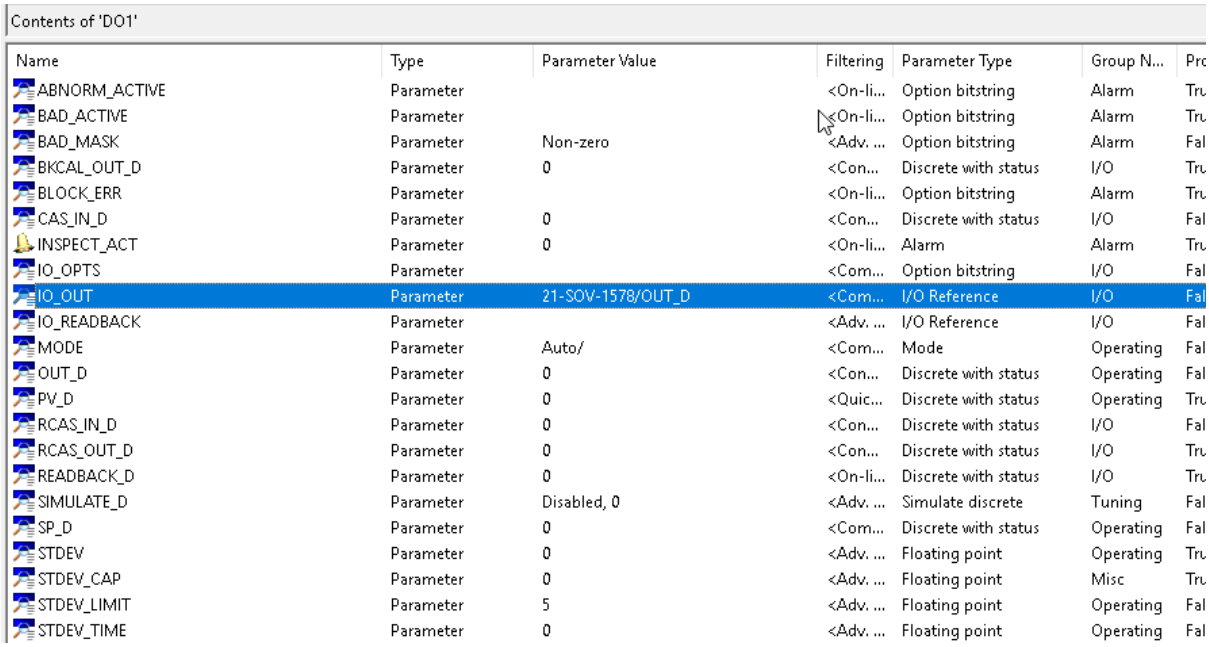
Appendix 4: Solenoid outputs configured.



Appendix 5: Downloading outputs.



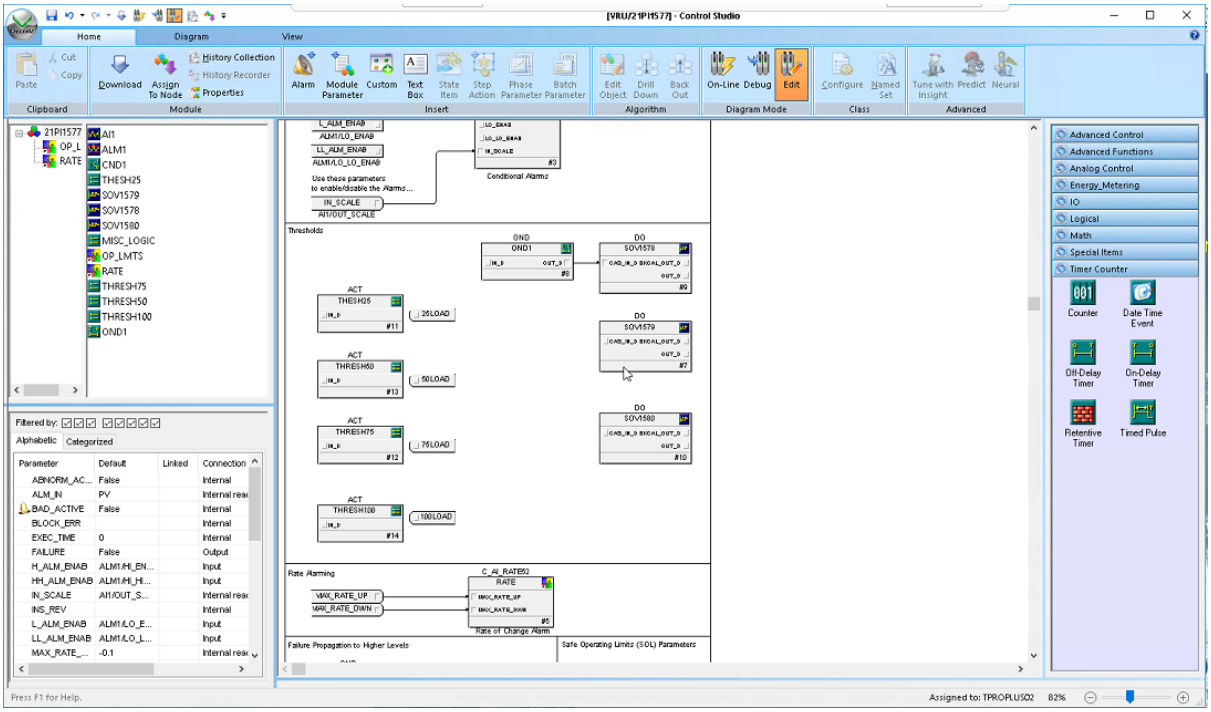
Appendix 6: Faceplate configuration and test.



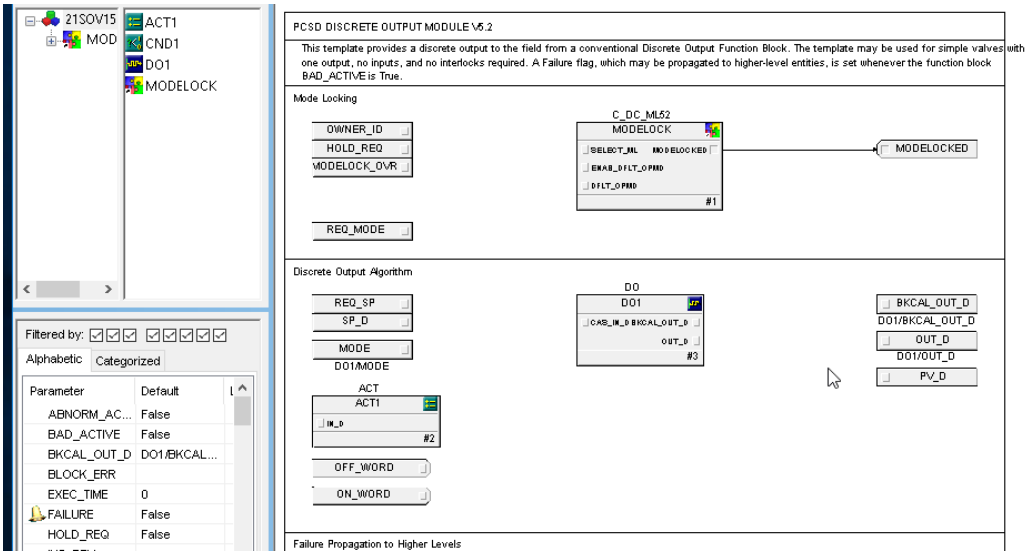
Contents of 'DO1'

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ABNORM_ACTIVE	Parameter		<On-li...	Option bitstring	Alarm	Tru
BAD_ACTIVE	Parameter		<On-li...	Option bitstring	Alarm	Tru
BAD_MASK	Parameter	Non-zero	<Adv. ...	Option bitstring	Alarm	Fal
BKCAL_OUT_D	Parameter	0	<Con...	Discrete with status	I/O	Tru
BLOCK_ERR	Parameter		<On-li...	Option bitstring	Alarm	Tru
CAS_IN_D	Parameter	0	<Con...	Discrete with status	I/O	Fal
INSPECT_ACT	Parameter	0	<On-li...	Alarm	Alarm	Tru
IO_OPTS	Parameter		<Com...	Option bitstring	I/O	Fal
IO_OUT	Parameter	21-SOV-1578/OUT_D	<Com...	I/O Reference	I/O	Fal
IO_READBACK	Parameter		<Adv. ...	I/O Reference	I/O	Fal
MODE	Parameter	Auto/	<Com...	Mode	Operating	Fal
OUT_D	Parameter	0	<Con...	Discrete with status	Operating	Fal
PV_D	Parameter	0	<Quic...	Discrete with status	Operating	Tru
RCAS_IN_D	Parameter	0	<Con...	Discrete with status	I/O	Fal
RCAS_OUT_D	Parameter	0	<Con...	Discrete with status	I/O	Tru
READBACK_D	Parameter	0	<On-li...	Discrete with status	I/O	Tru
SIMULATE_D	Parameter	Disabled, 0	<Adv. ...	Simulate discrete	Tuning	Fal
SP_D	Parameter	0	<Com...	Discrete with status	Operating	Fal
STDEV	Parameter	0	<Adv. ...	Floating point	Operating	Tru
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STDEV_TIME	Parameter	0	<Adv. ...	Floating point	Operating	Fal

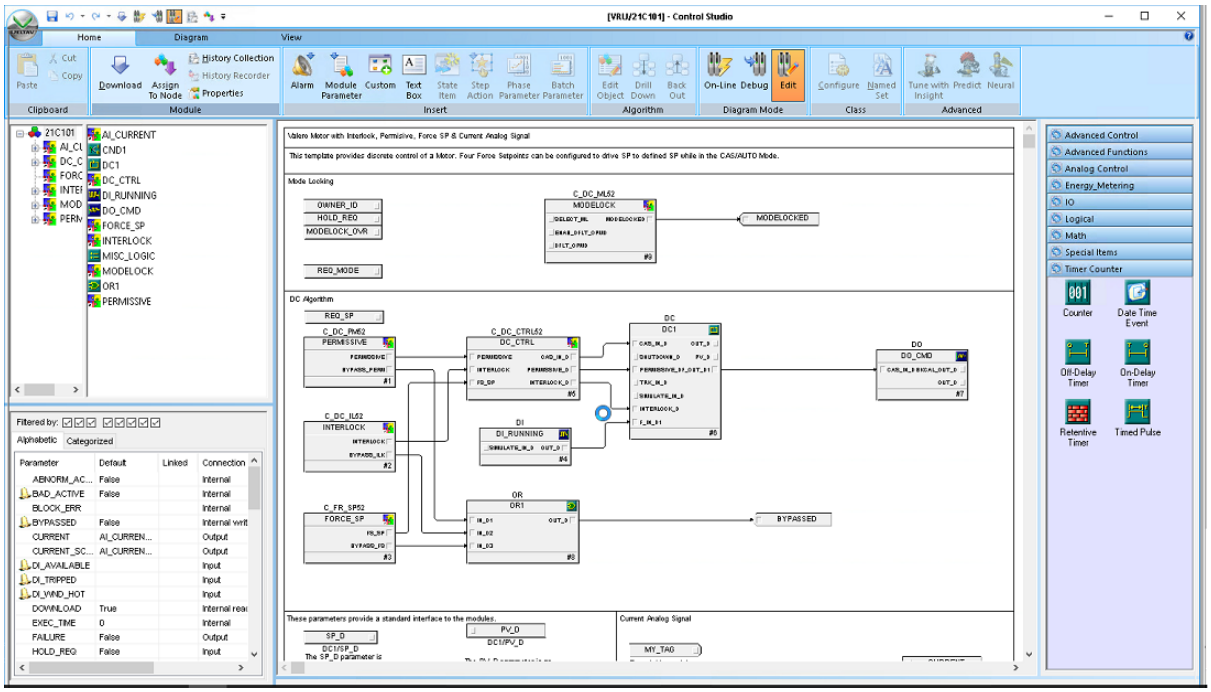
Appendix 7: Output reference assigned.



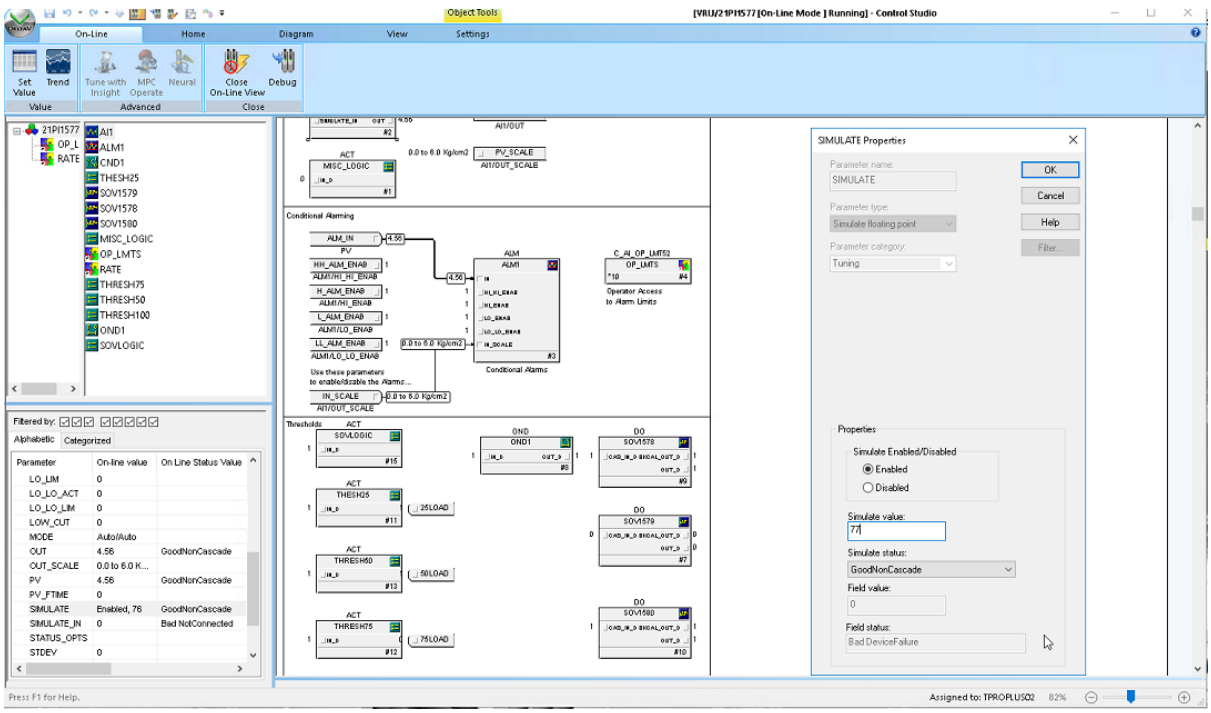
Appendix 8: Loading module design



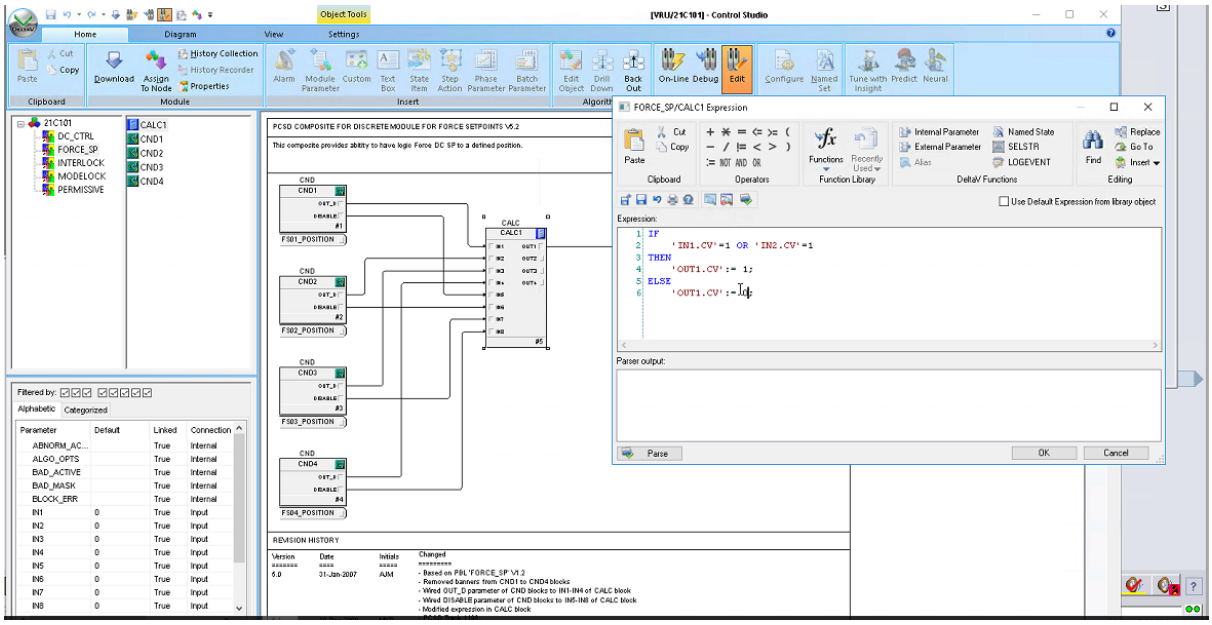
Appendix 9: SOV module internal blocks.



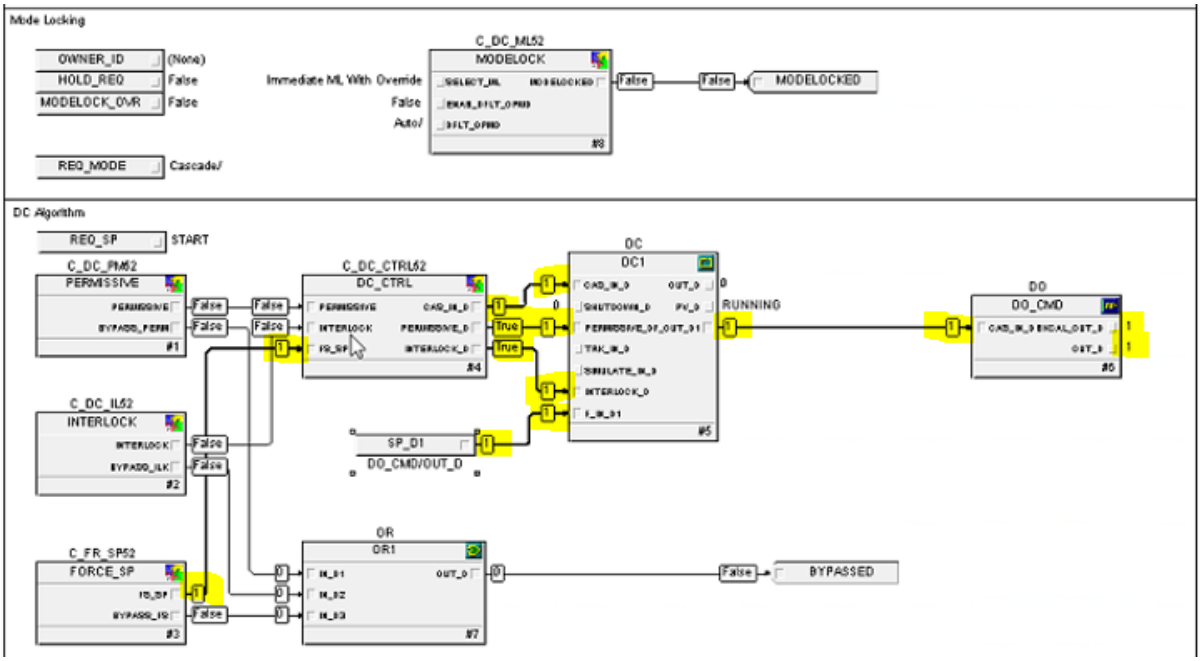
Appendix 10: Compressor module.



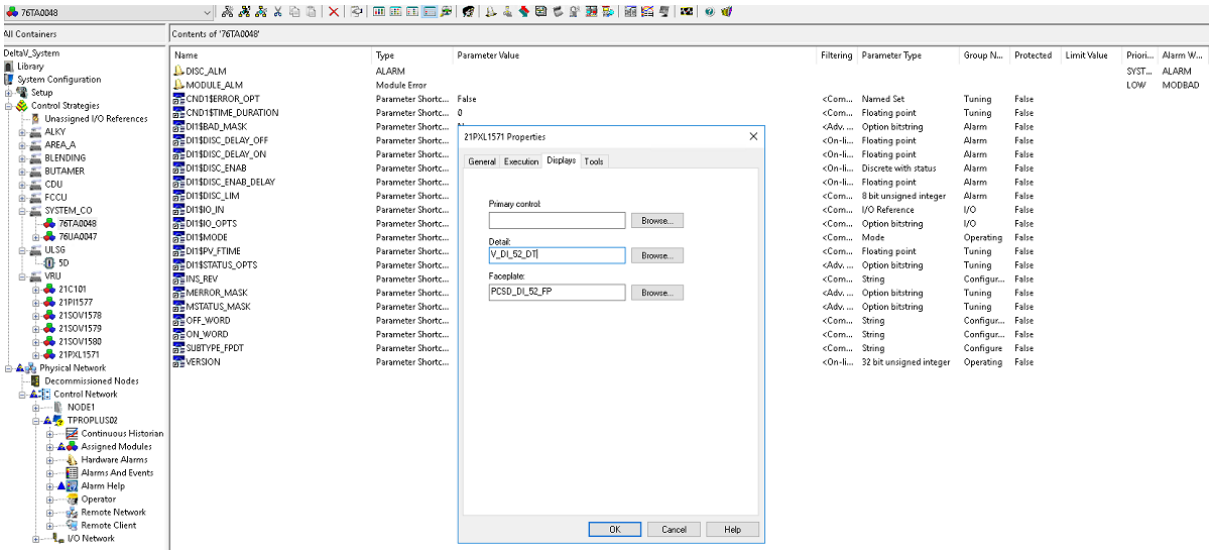
Appendix 11: Simulation force and test.



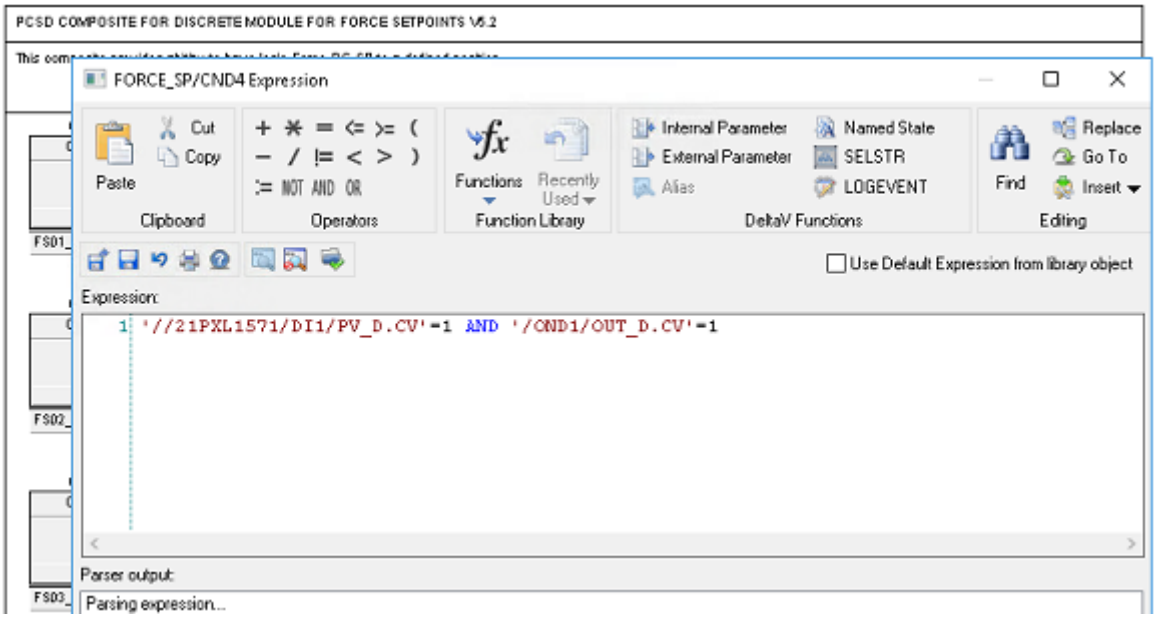
Appendix 12: Force logic.



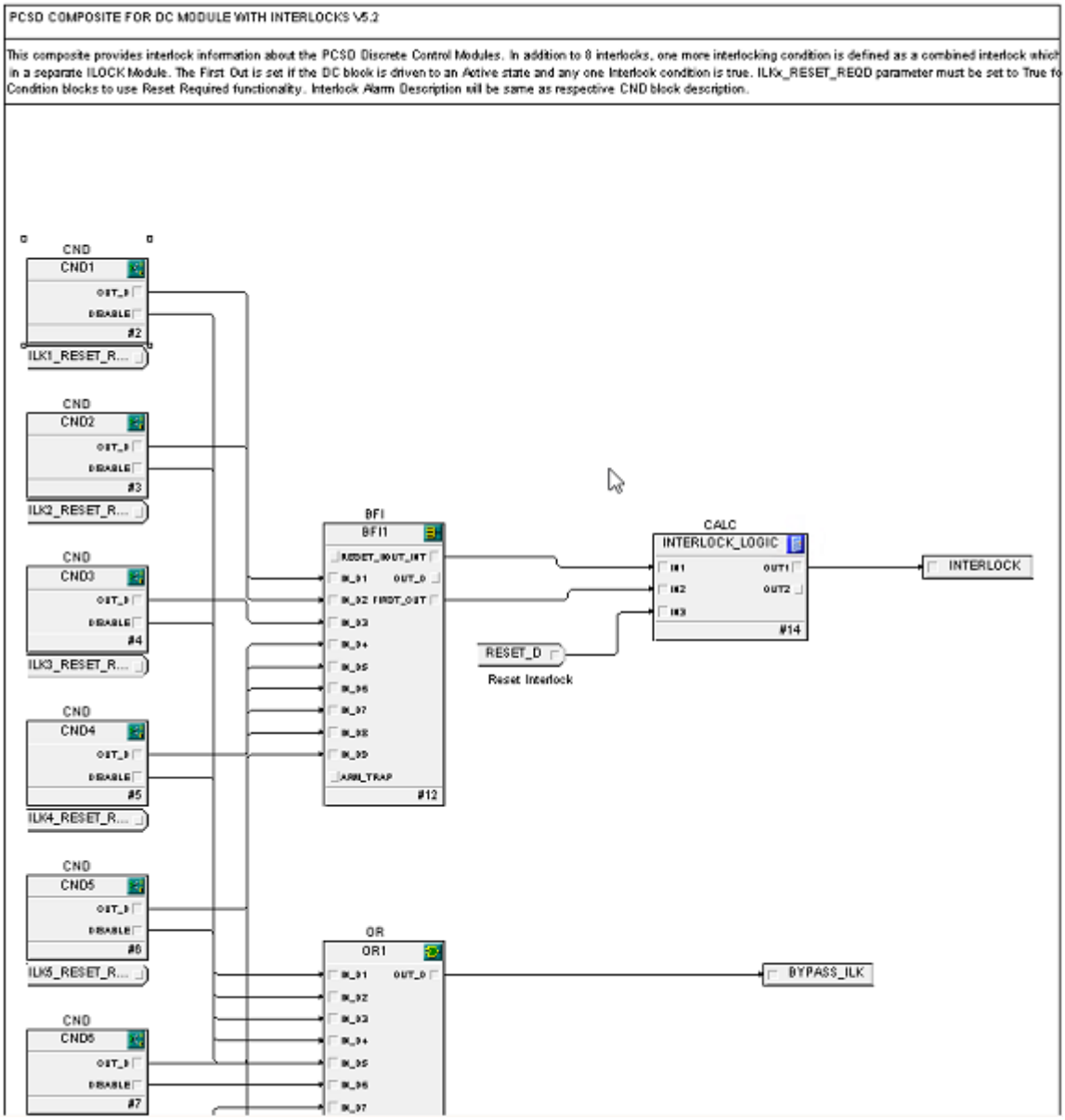
Appendix 13: Force logic test.



Appendix 14: Low lube oil module.

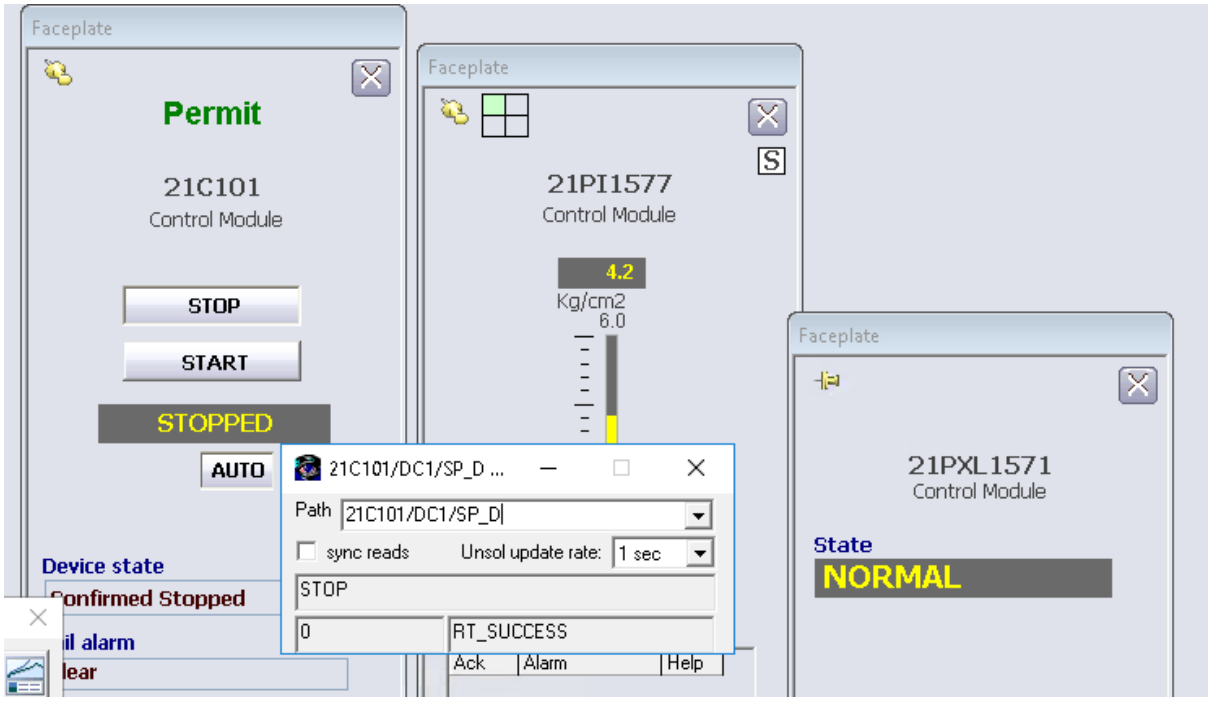


Appendix 15: Low lube oil trip logic.

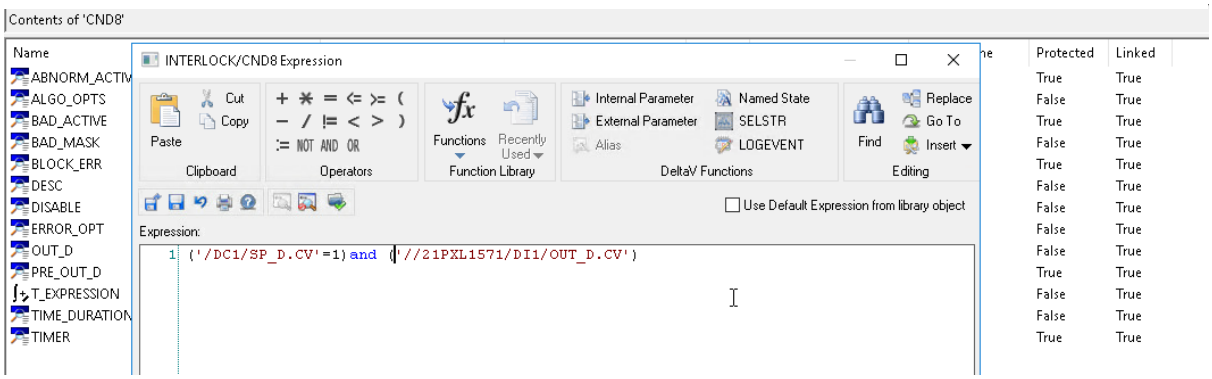


Appendix 16: DC Interlock module.

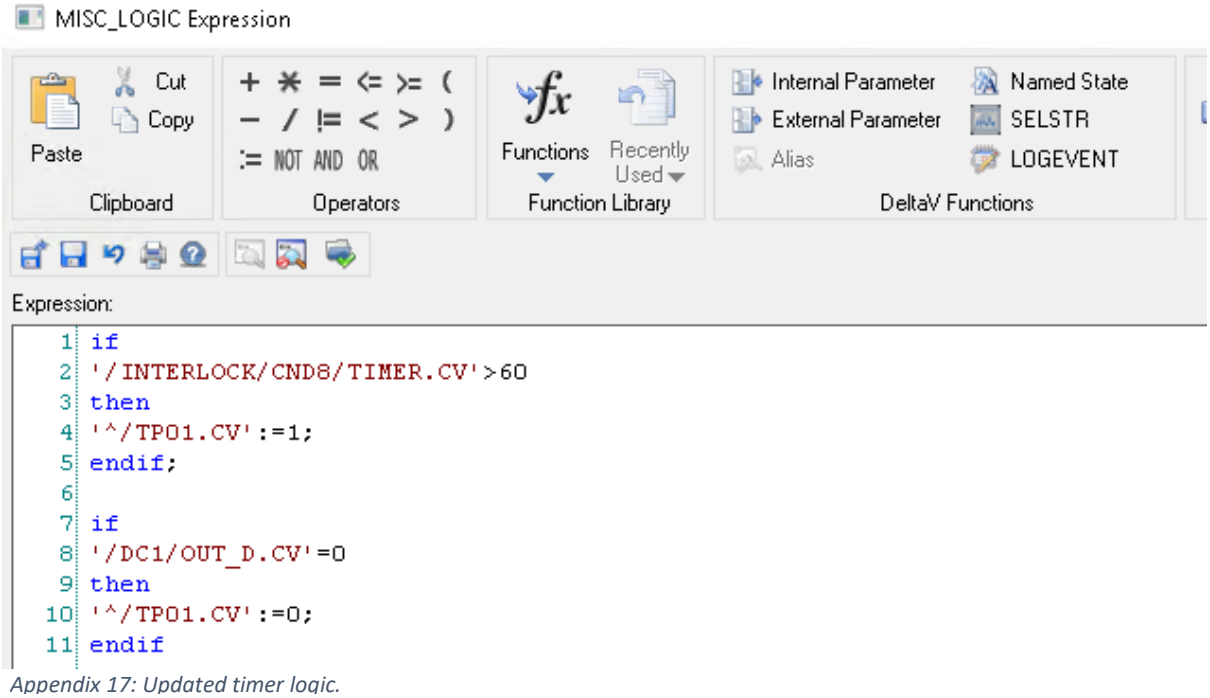
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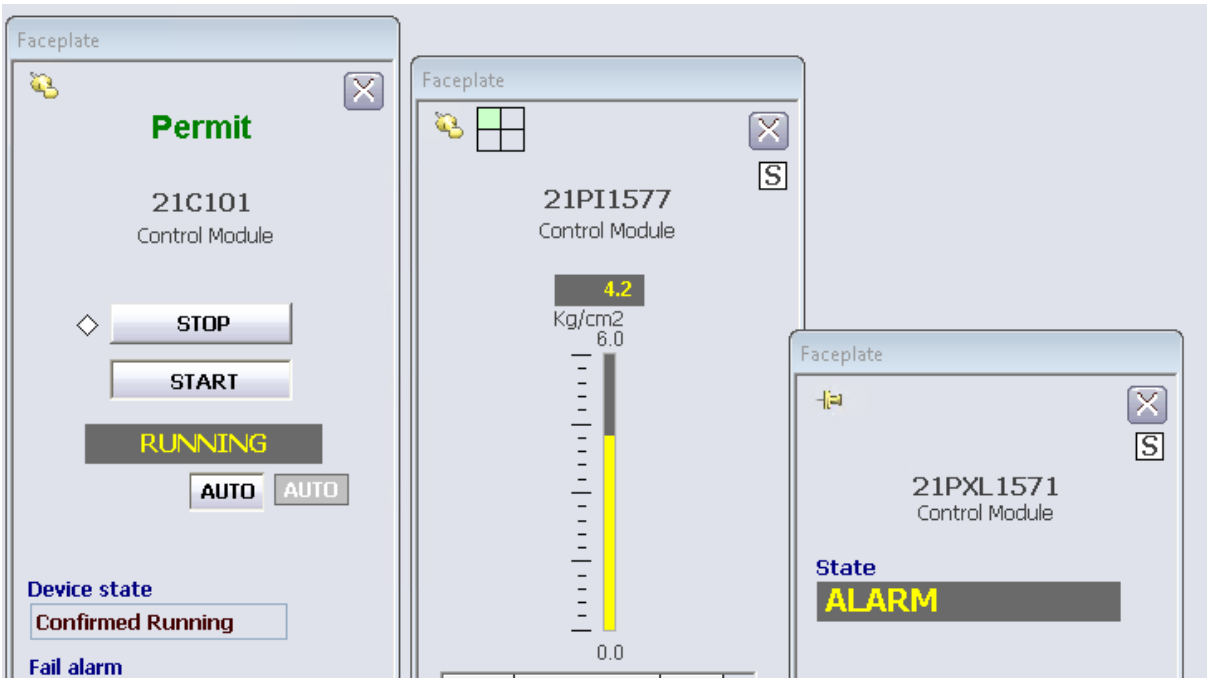
Appendix 18: Start testing.



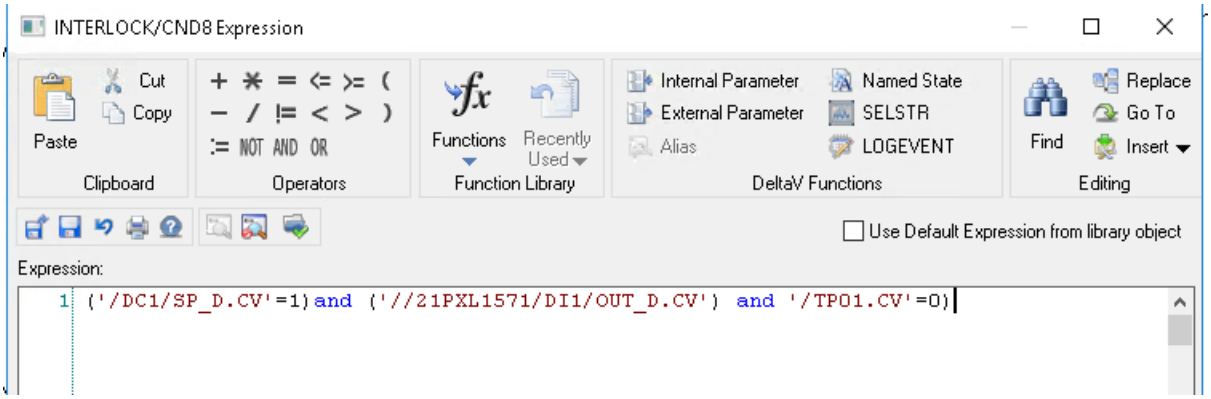
Appendix 19: Interlock expression.



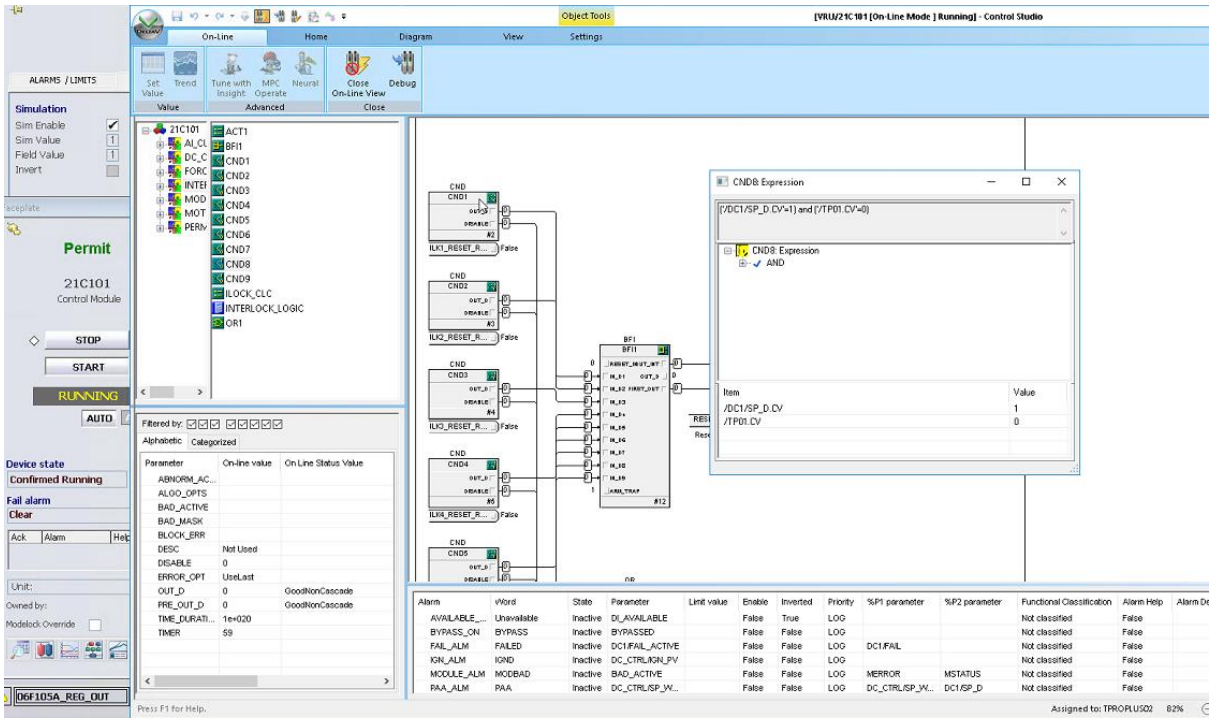
Appendix 17: Updated timer logic.



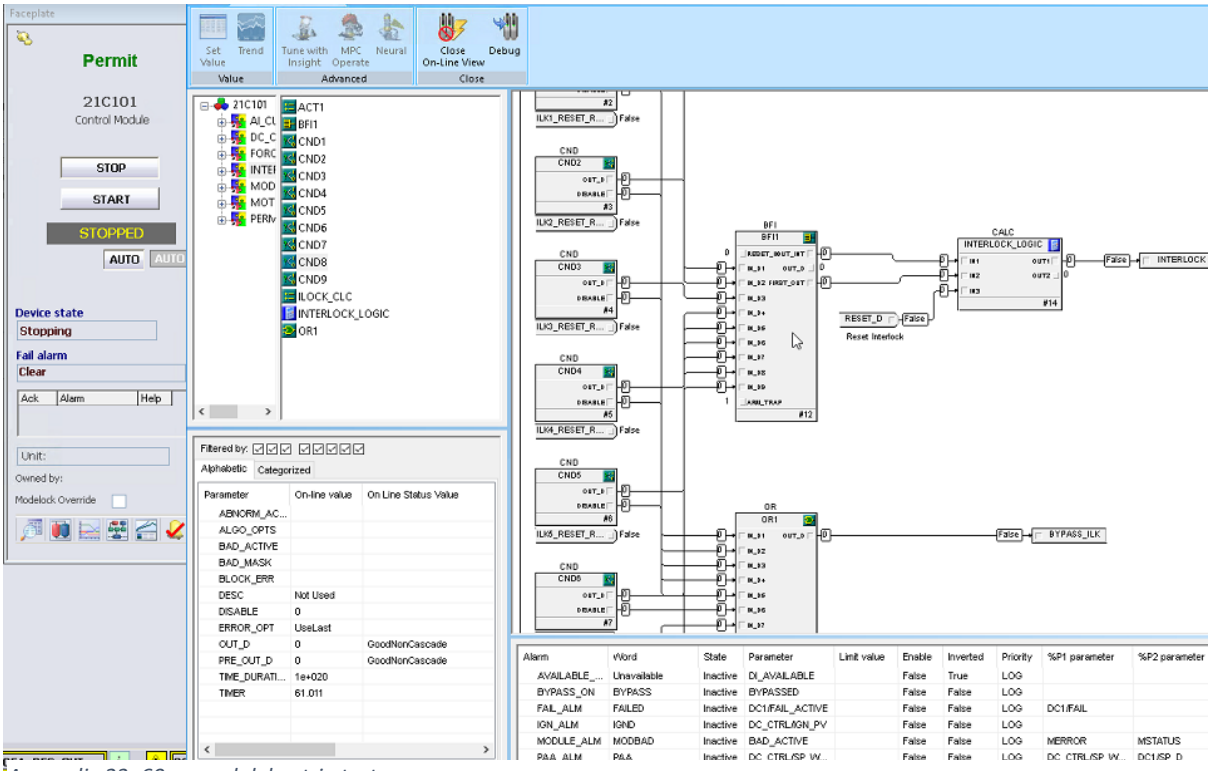
Appendix 20: Lube oil trip bypass trip test.



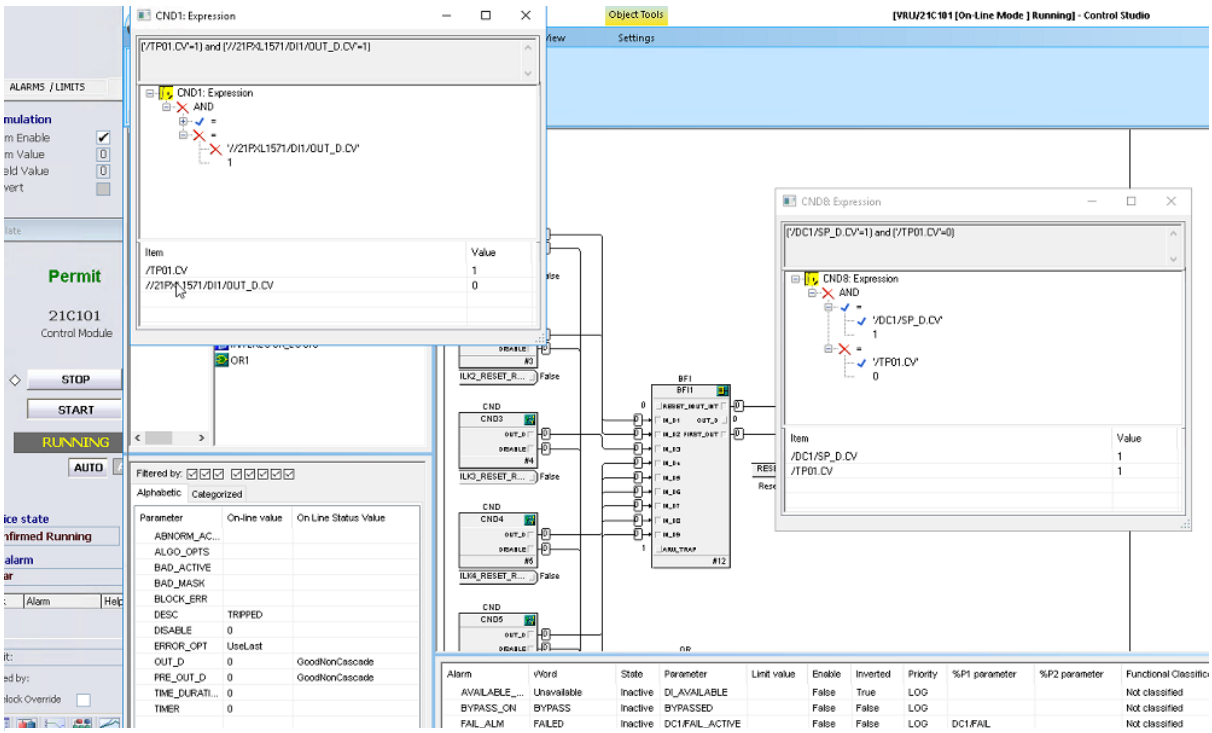
Appendix 21: Interlock expression update.



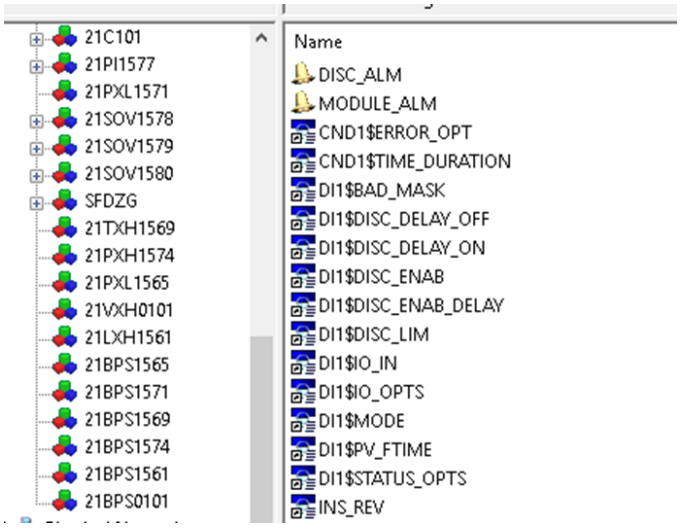
Appendix 22: 60 second delay test.



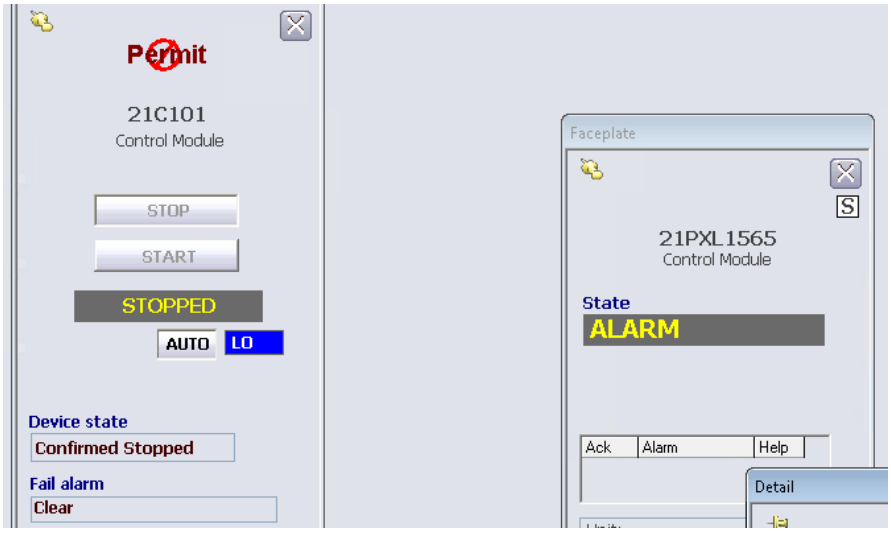
Appendix 23: 60 second delay trip test.



Appendix 24: 60 second delay timer reset.



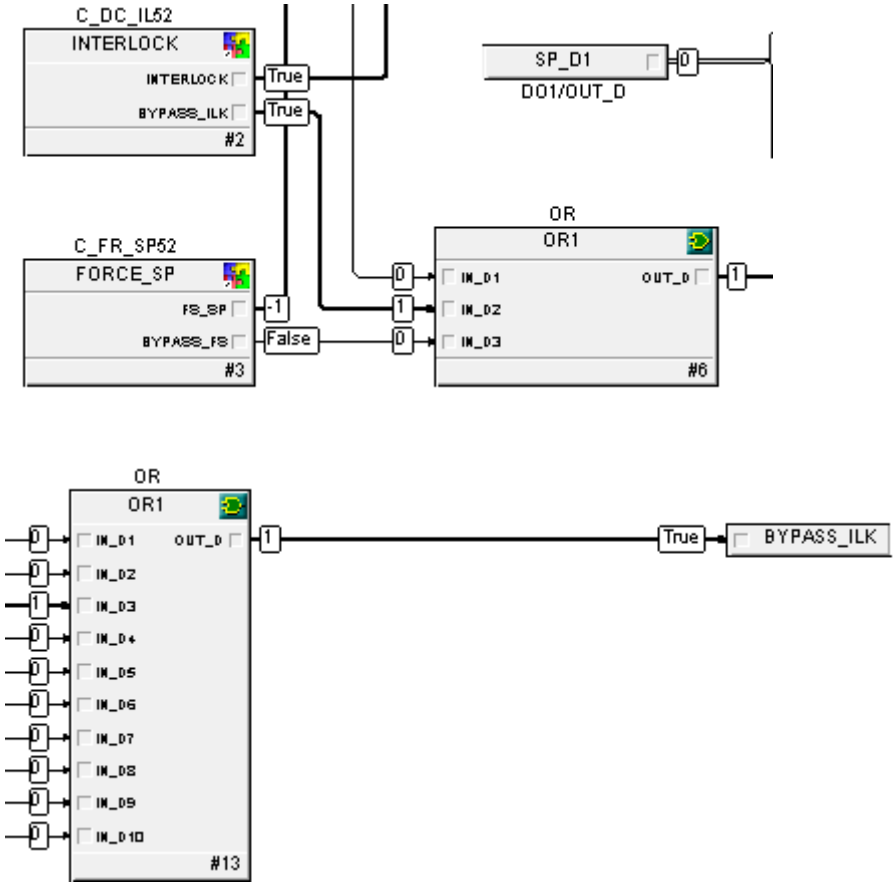
Appendix 25: Shutdown DI blocks.



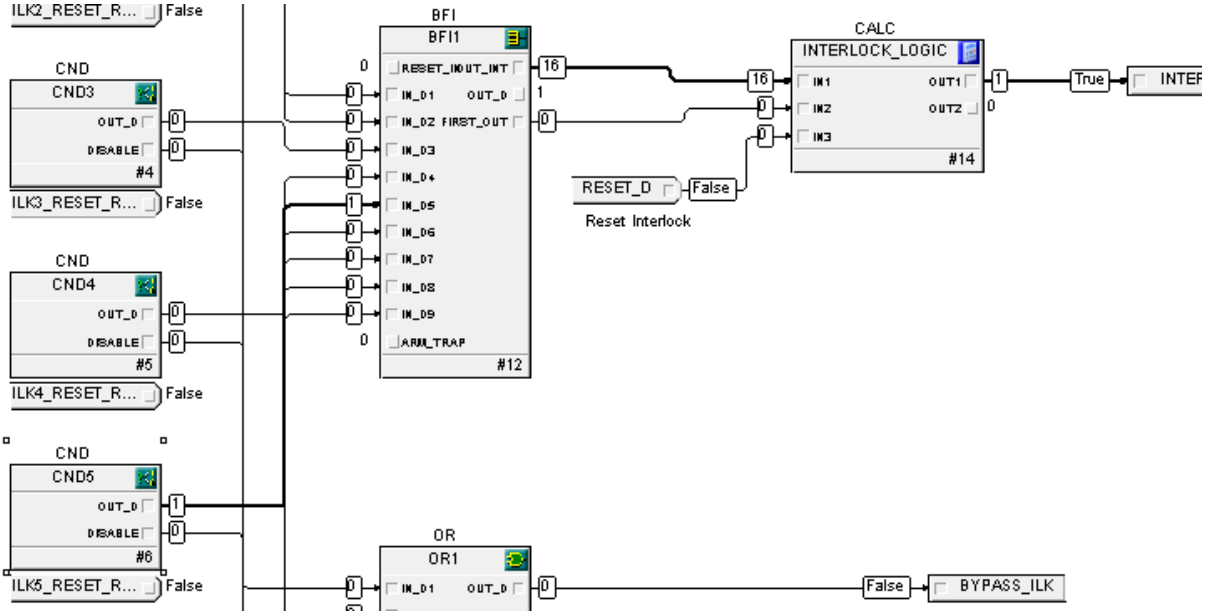
Appendix 26: Inhibit start test.

```
13 IF
14 '//21BPS1565/DI1/OUT_D.CV'=1
15 THEN
16 '^/INTERLOCK/CND3/DISABLE.CV':=1;
```

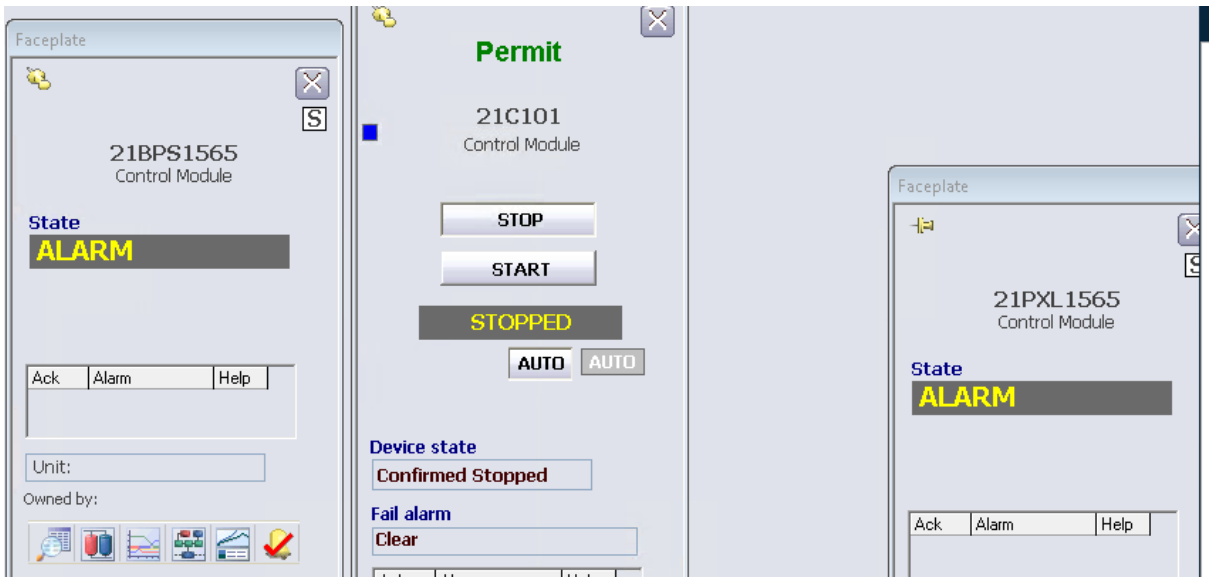
Appendix 27: Single bypass logic.



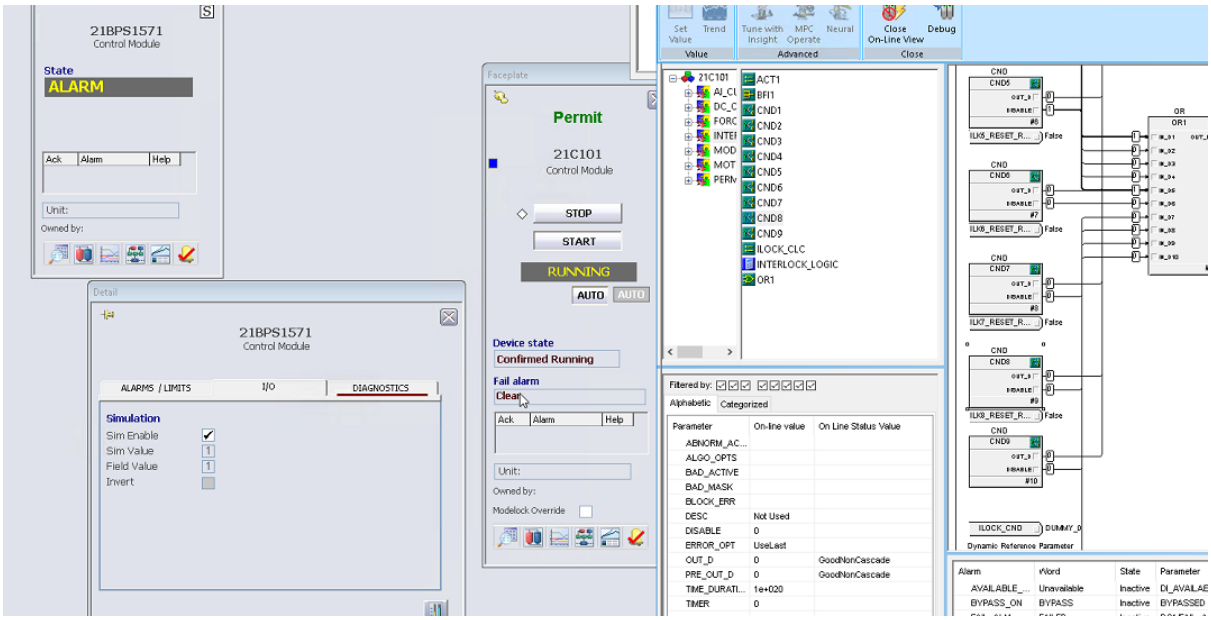
Appendix 28: Bypass logic test.



Appendix 29: Bypass logic test 2.



Appendix 30: Bypass allowing start.



Appendix 31: Start up bypass test.

```
IF
'//21BPS1561/DI1/OUT_D.CV'=1
THEN
'^/INTERLOCK/CND2/DISABLE.CV':=1;
ELSE
'^/INTERLOCK/CND2/DISABLE.CV':=0;
ENDIF;

IF
'//21BPS1569/DI1/OUT_D.CV'=1
THEN
'^/INTERLOCK/CND3/DISABLE.CV':=1;
ELSE
'^/INTERLOCK/CND3/DISABLE.CV':=0;
ENDIF;

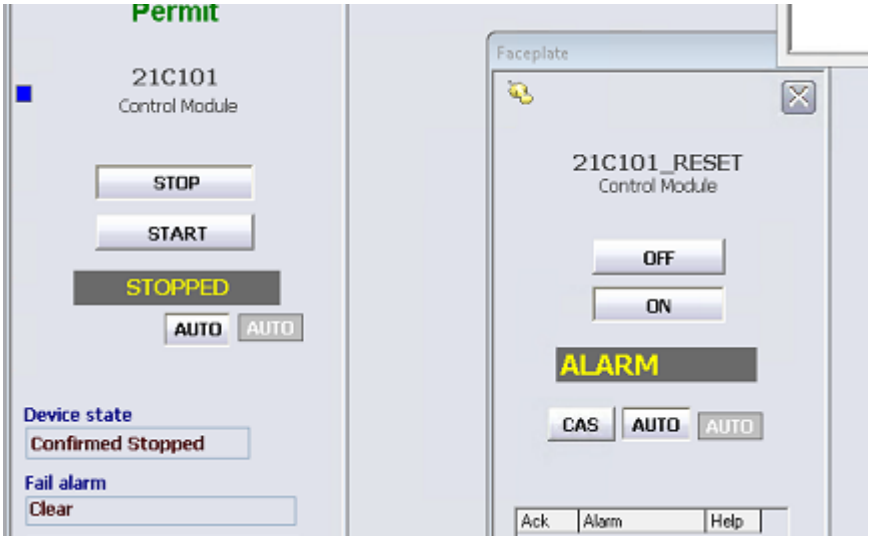
IF
'//21BPS1574/DI1/OUT_D.CV'=1
THEN
'^/INTERLOCK/CND4/DISABLE.CV':=1;
ELSE
'^/INTERLOCK/CND4/DISABLE.CV':=0;
ENDIF;

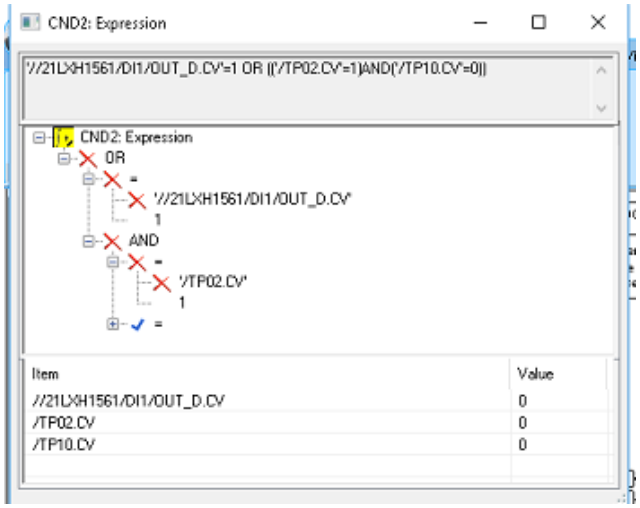
IF
'//21BPS1565/DI1/OUT_D.CV'=1
THEN
'^/INTERLOCK/CND5/DISABLE.CV':=1;
ELSE
'^/INTERLOCK/CND5/DISABLE.CV':=0;
ENDIF;

IF
'//21BPSO101/DI1/OUT_D.CV'=1
THEN
'^/INTERLOCK/CND6/DISABLE.CV':=1;
ELSE
'^/INTERLOCK/CND6/DISABLE.CV':=0;
```

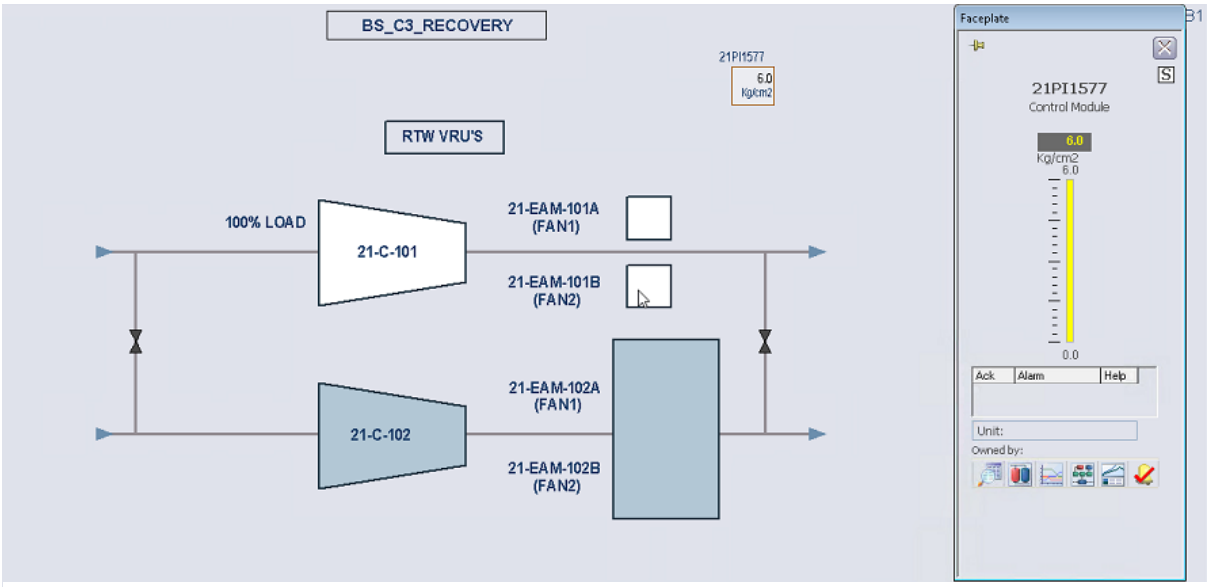
Appendix 32: Further bypass logic.

Appendix 33: Rest button faceplate.

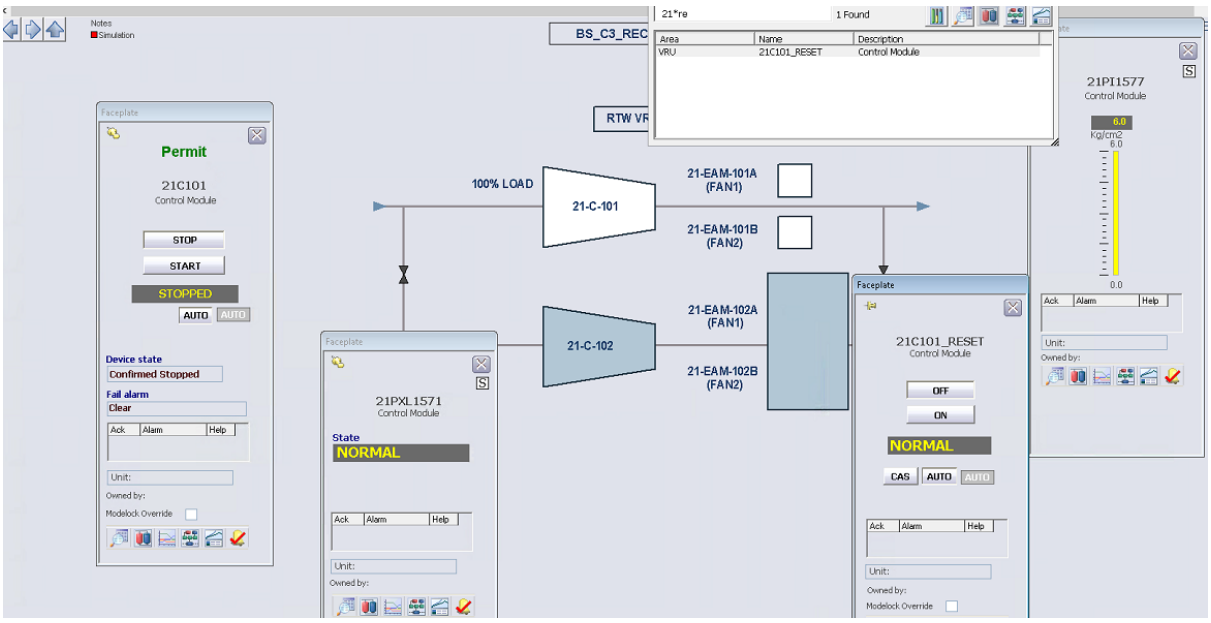




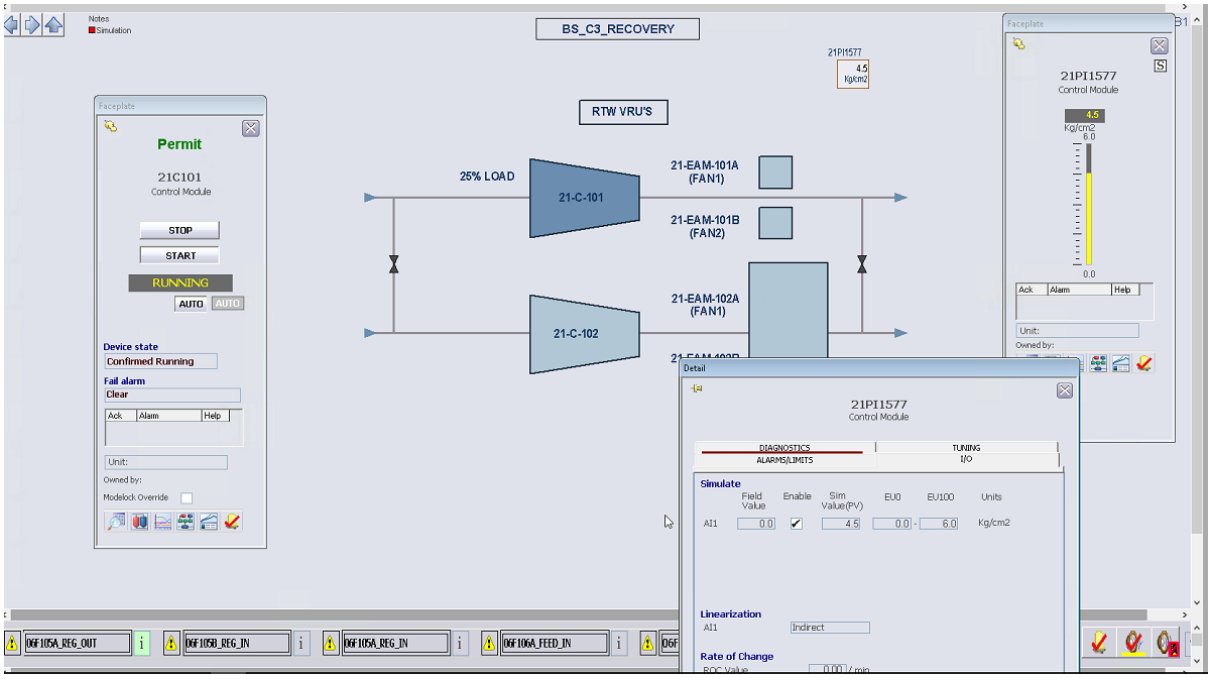
Appendix 34: TP10 is clear.



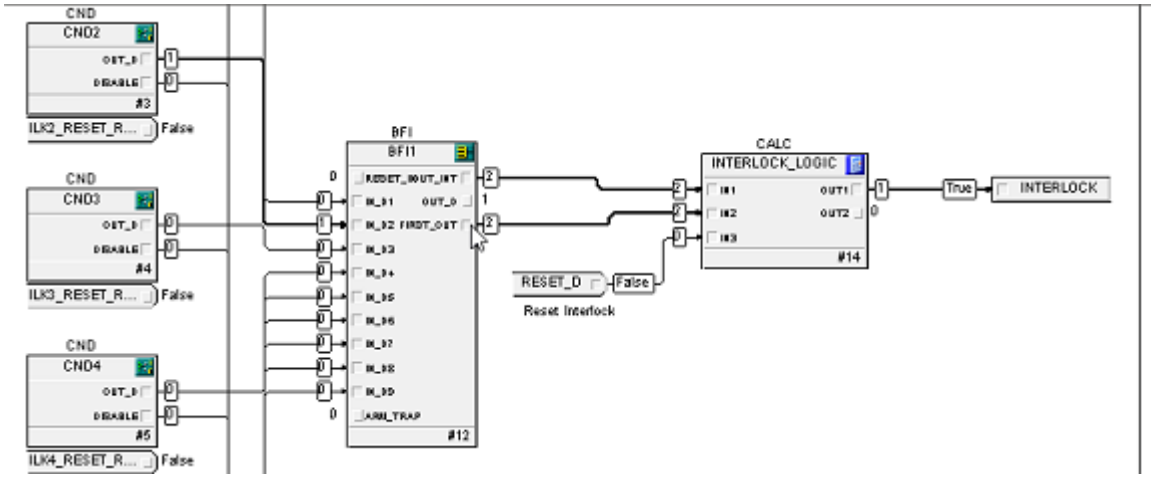
Appendix 35: Graphic build.



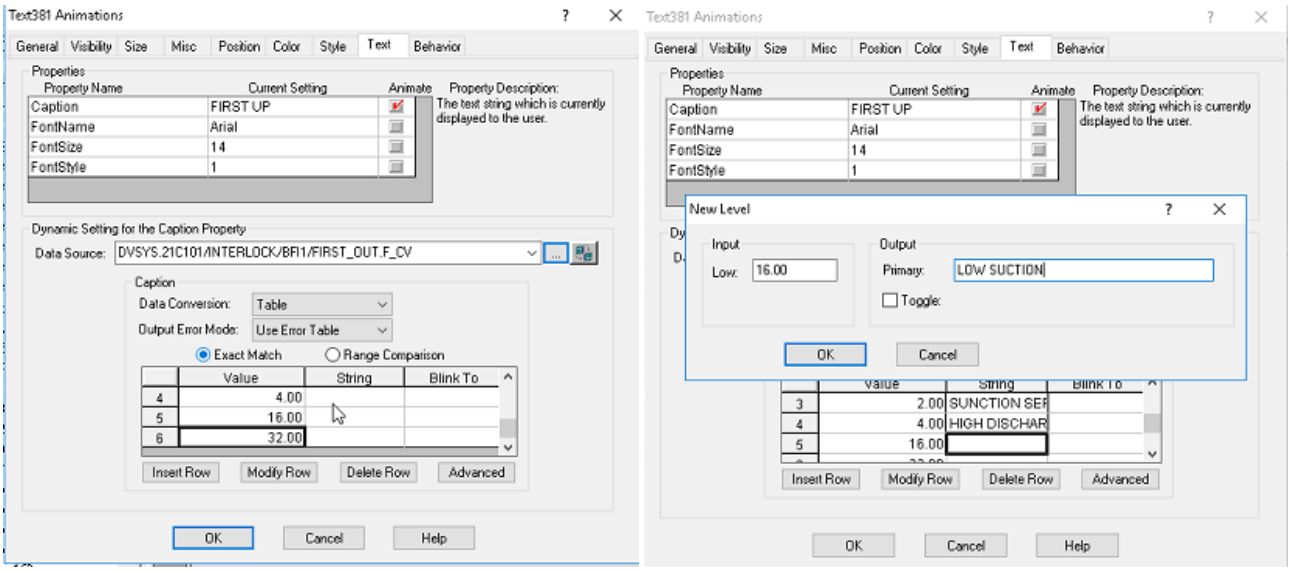
Appendix 36: Graphic and faceplates.



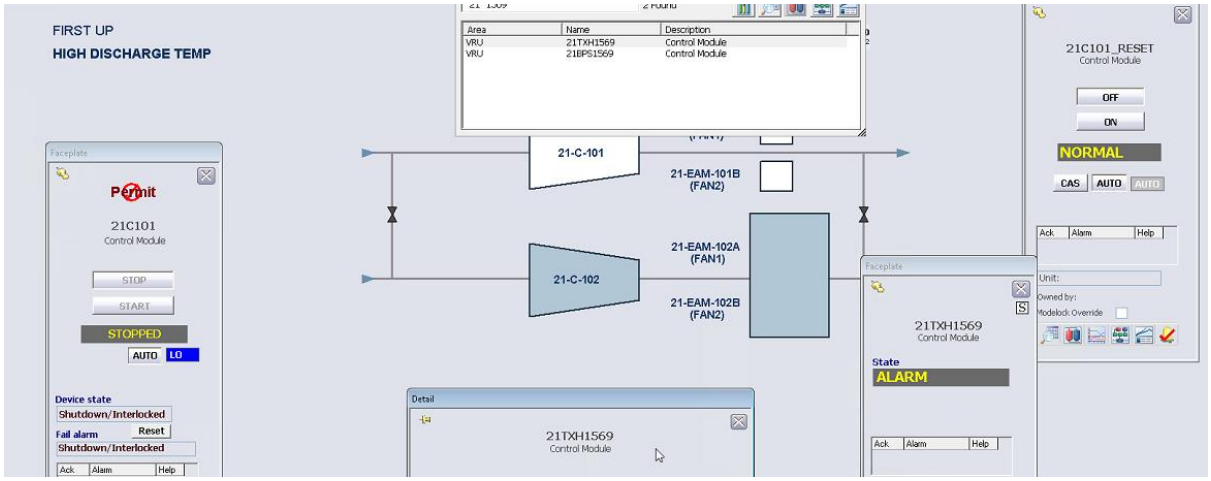
Appendix 37: Running graphic.



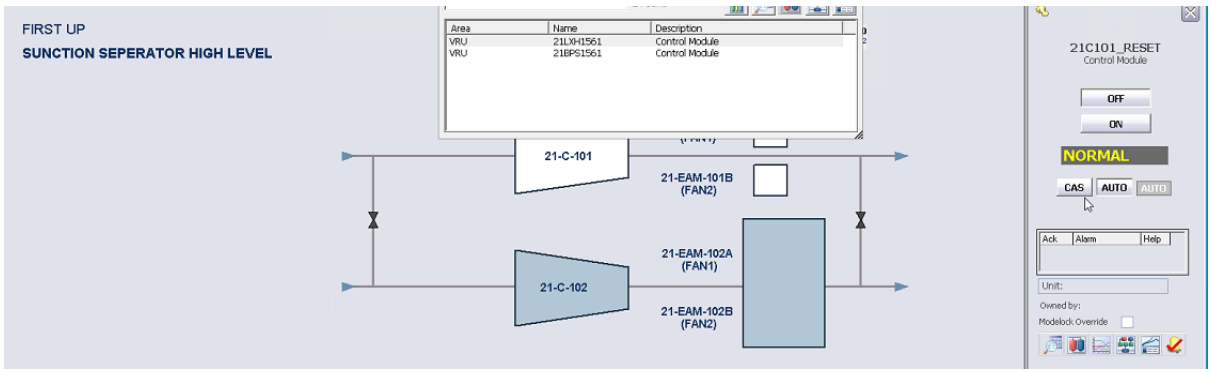
Appendix 38: First up logic.



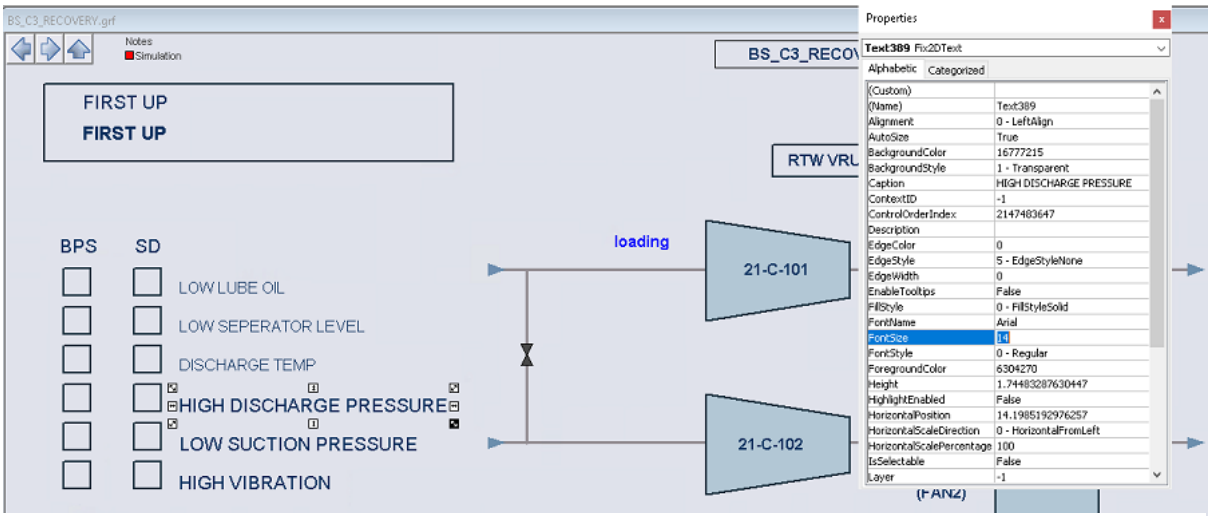
Appendix 39: First up animated text configuration.



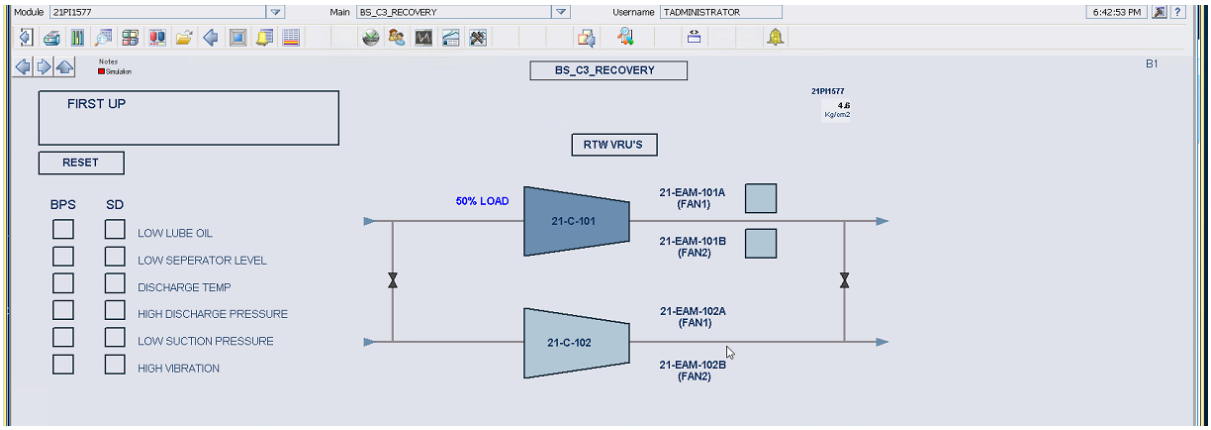
Appendix 40: Shutdown and first up.



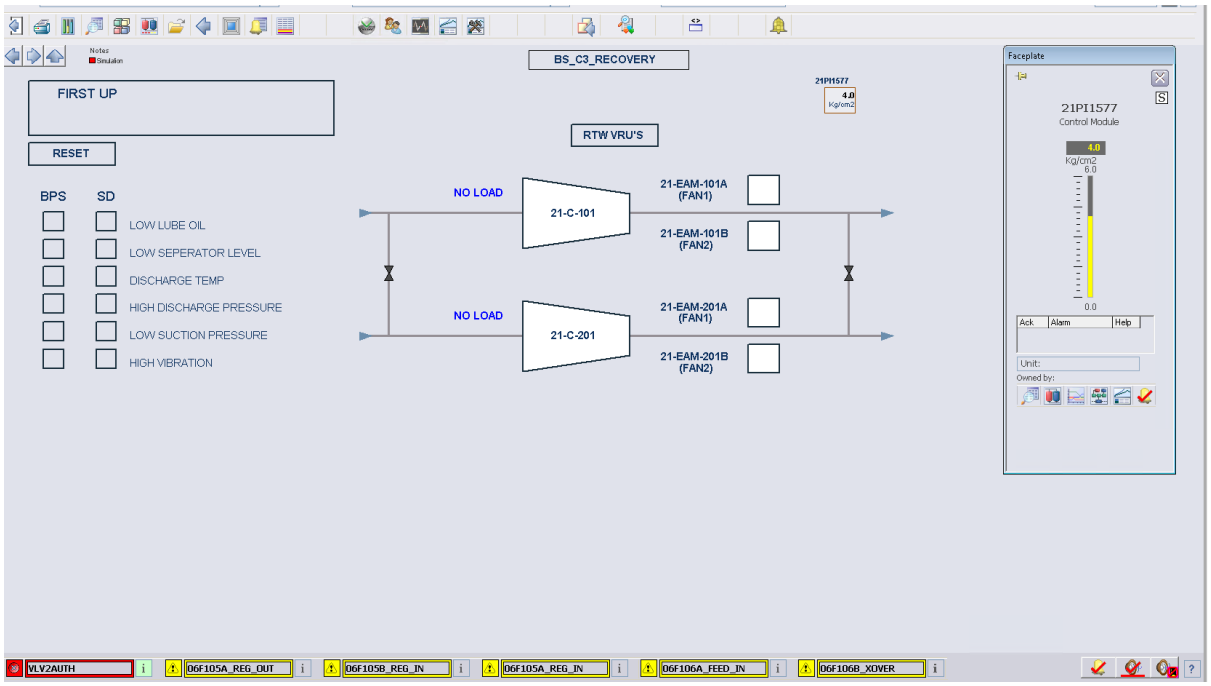
Appendix 41: First up test.



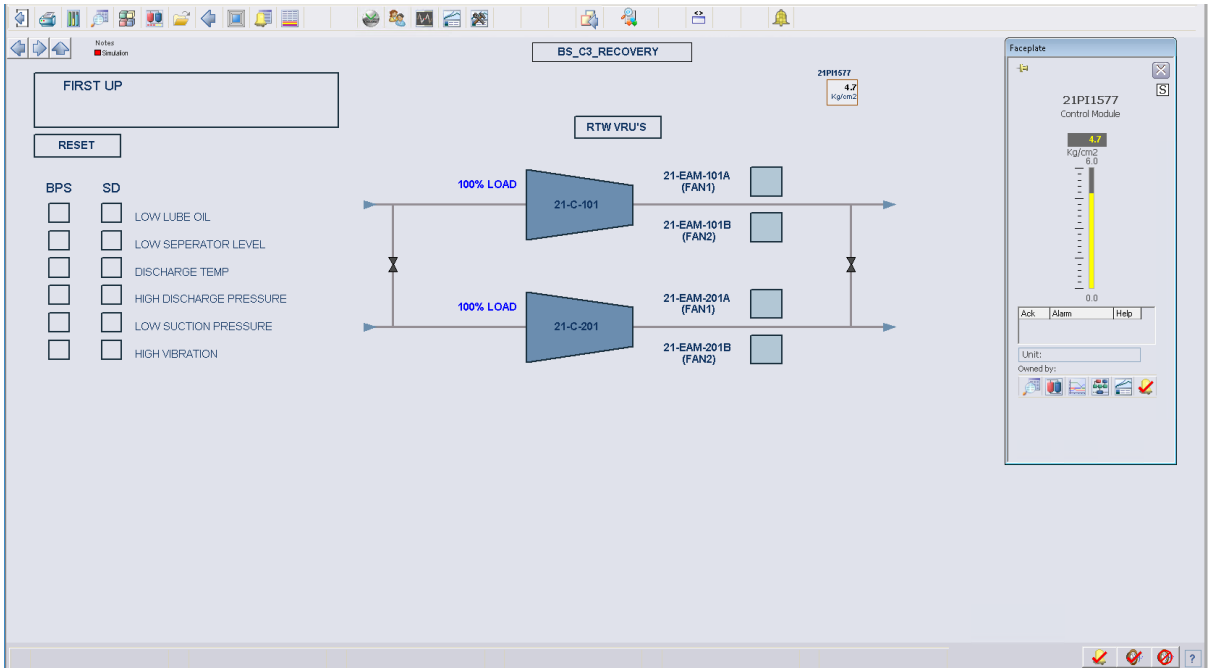
Appendix 42: Alarm and bypass text configuration.



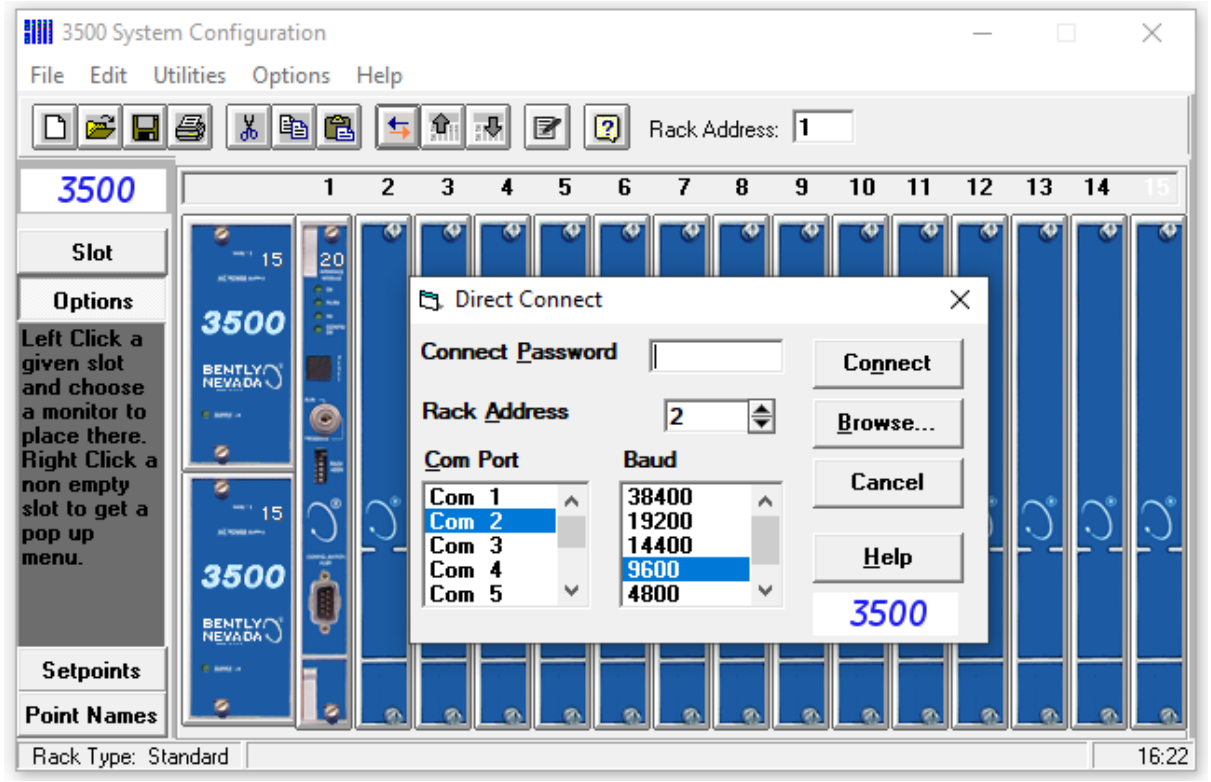
Appendix 43: VRU1 graphic complete.



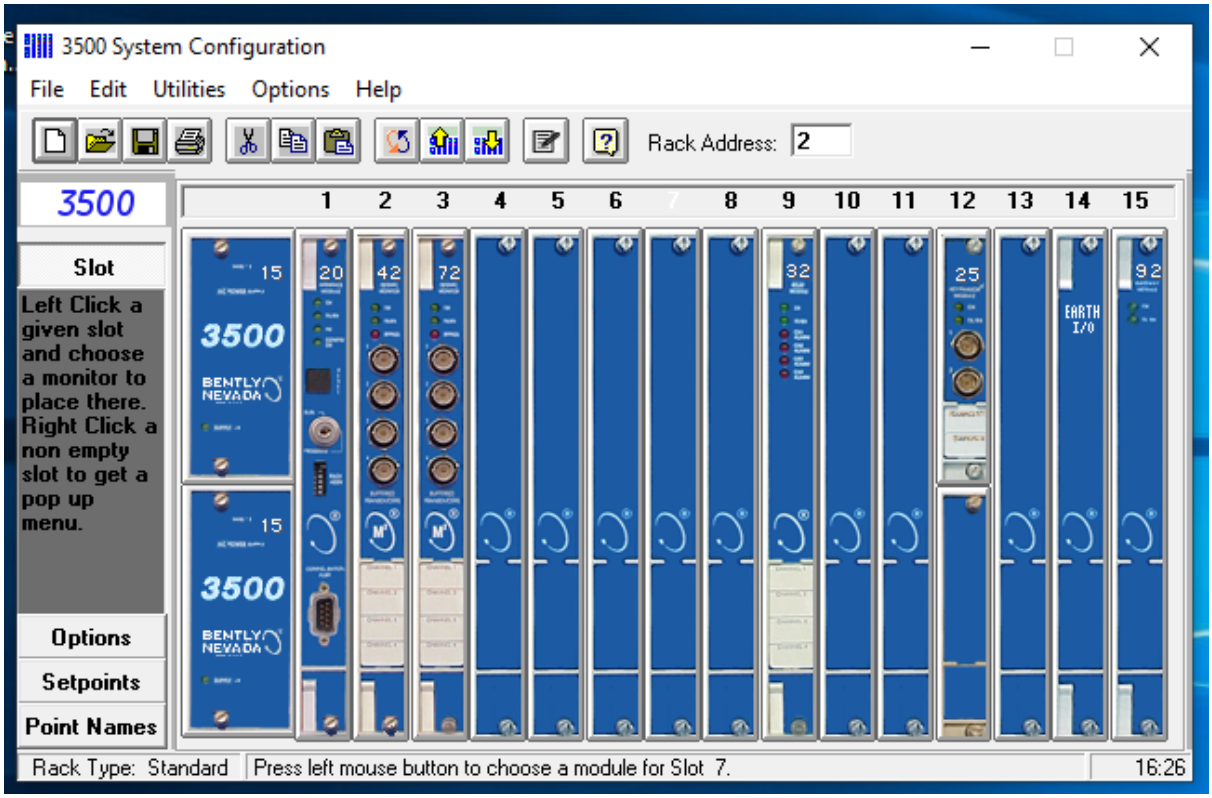
Appendix 44: VRU1 & 2 graphic complete with compressors offline.



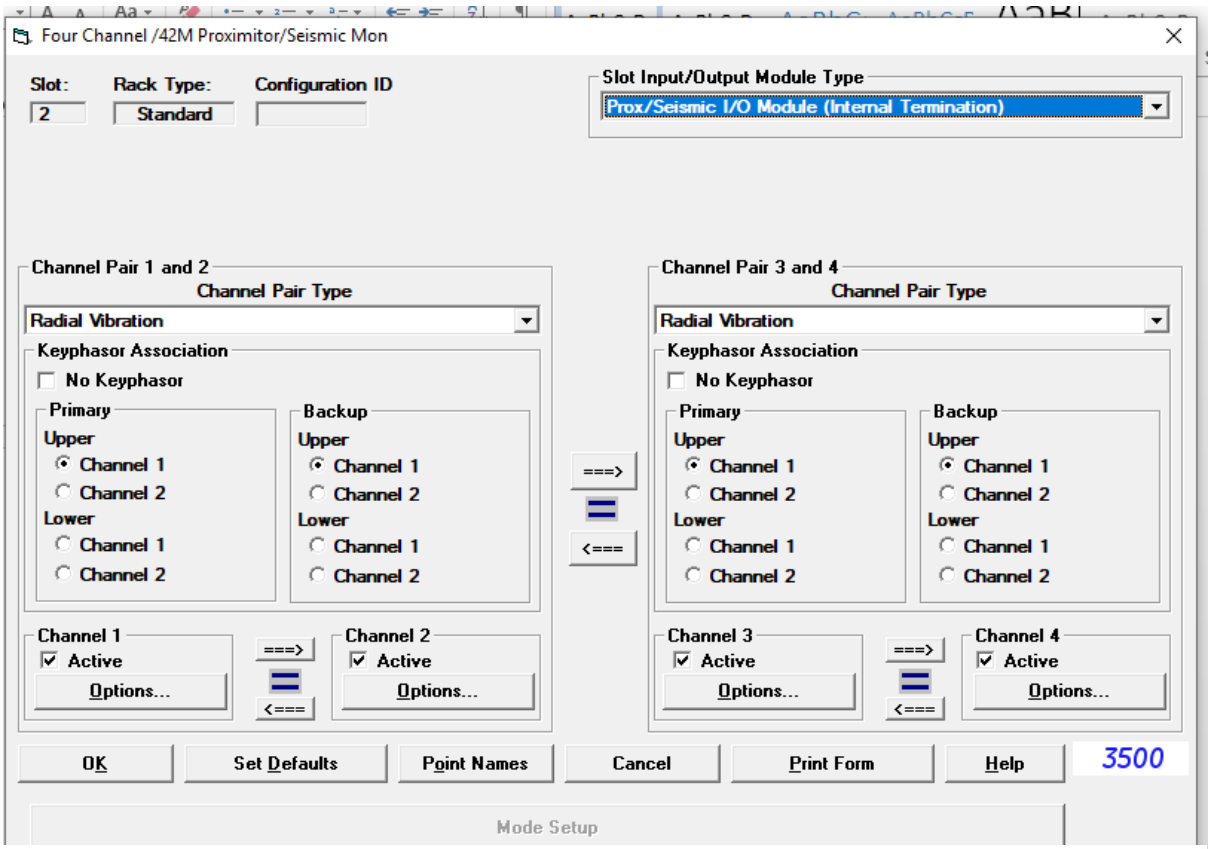
Appendix 45: VRU graphic with compressors online.



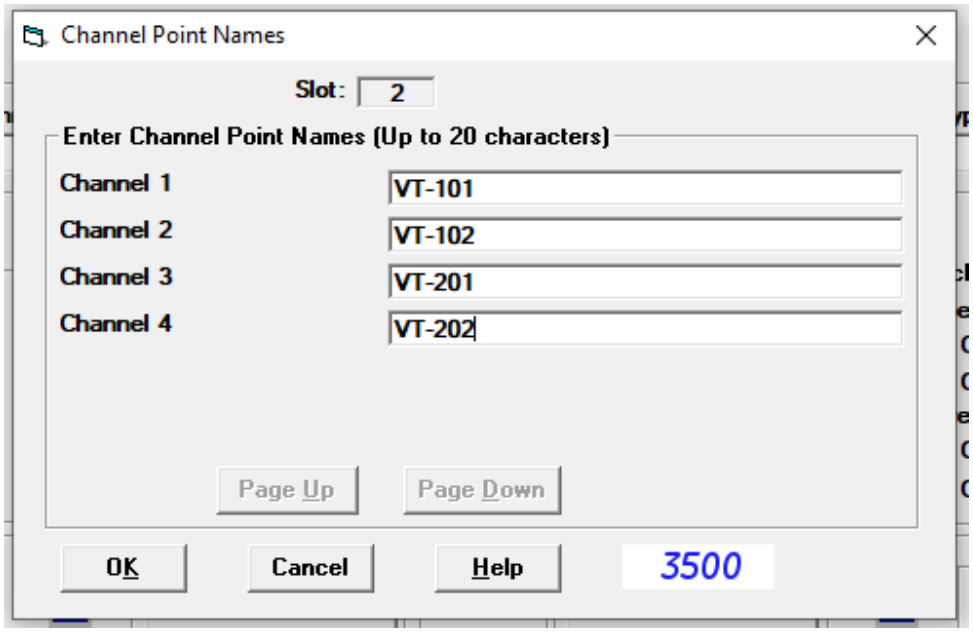
Appendix 46: 3500 rack configuration.



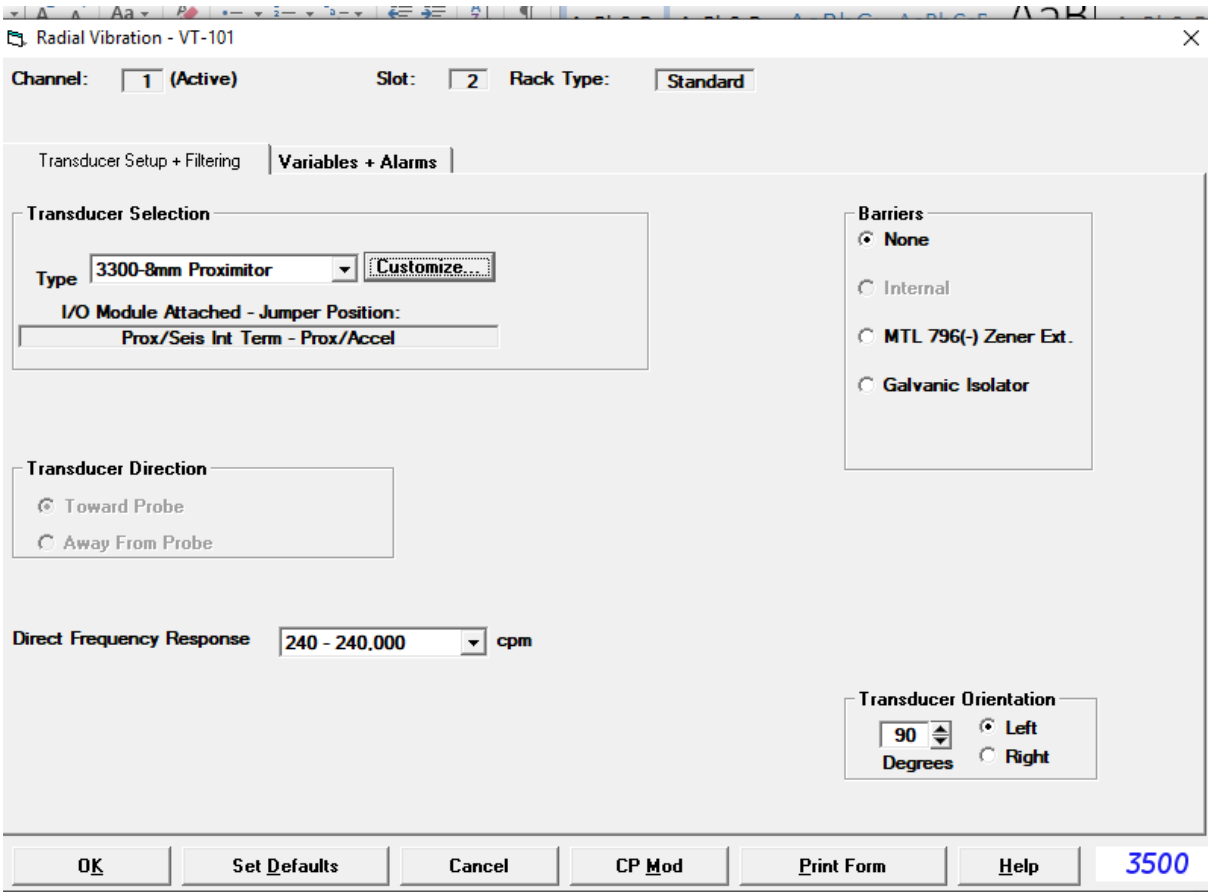
Appendix 47: Configuration downloaded.



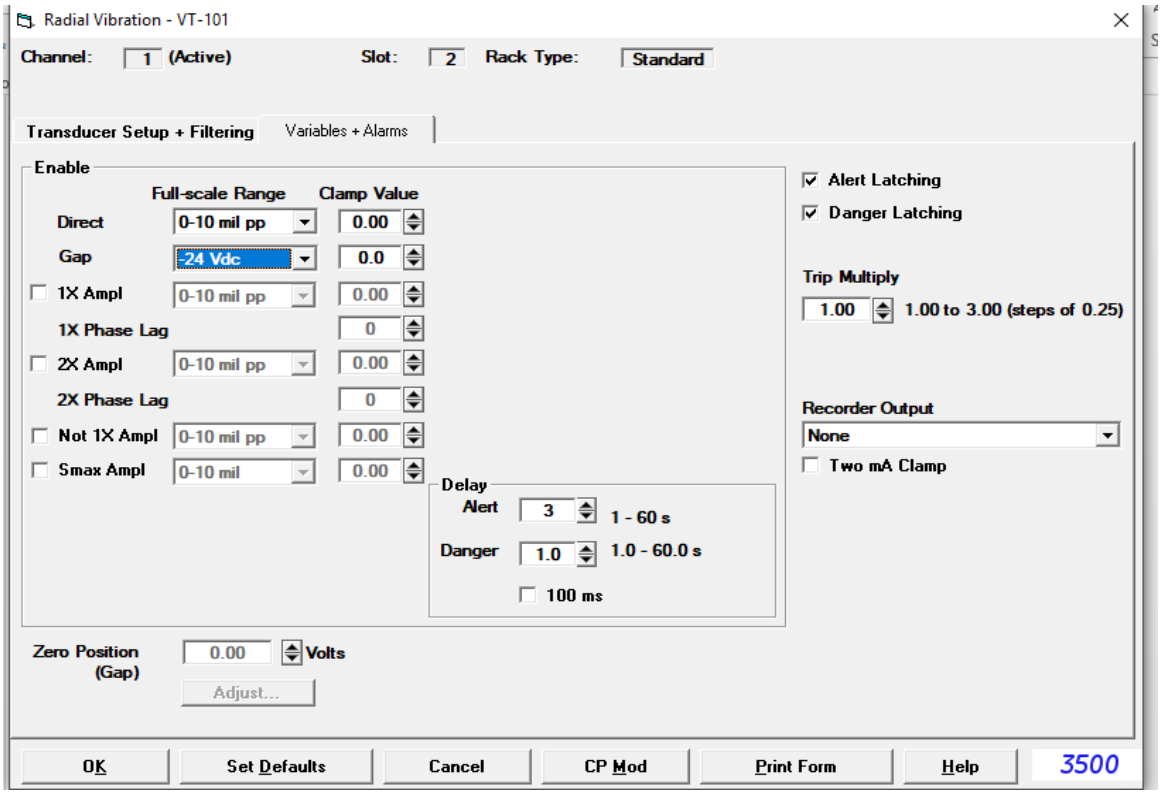
Appendix 48: Slot configuration.



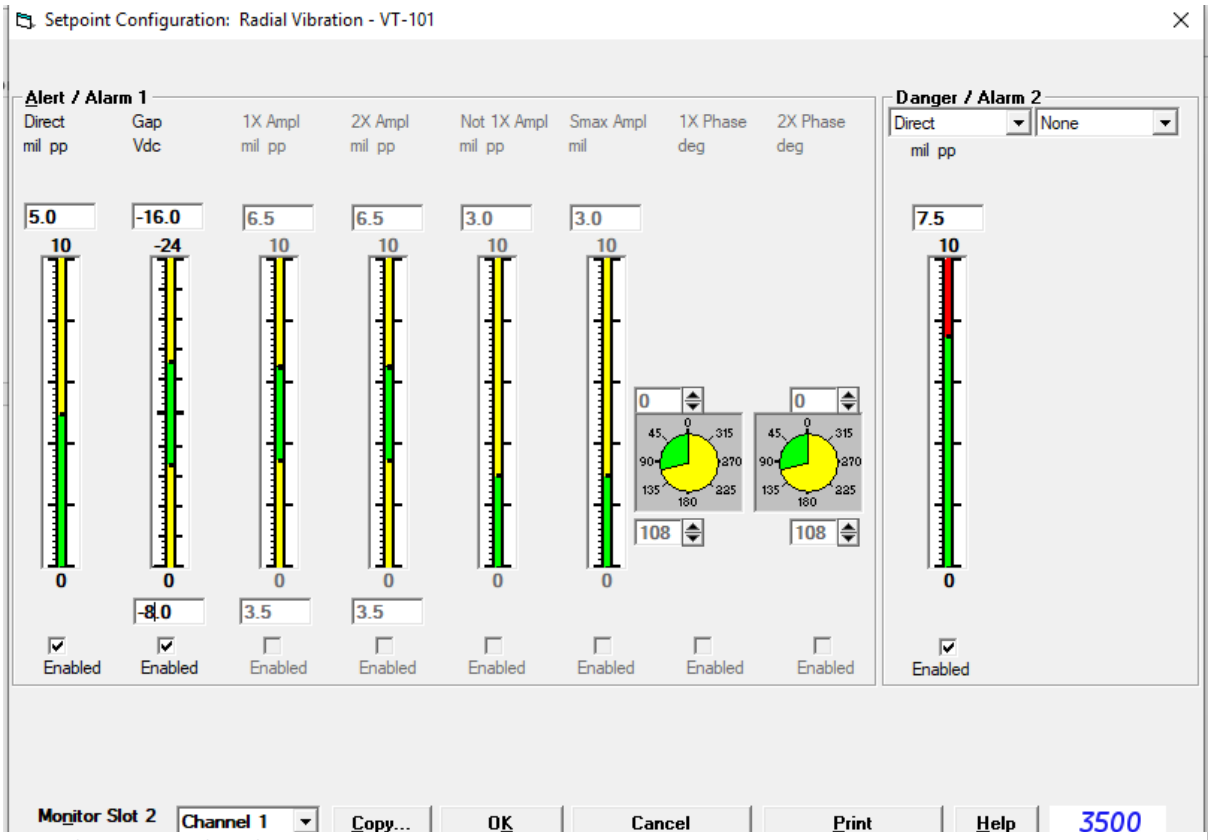
Appendix 50: Probe tagging.



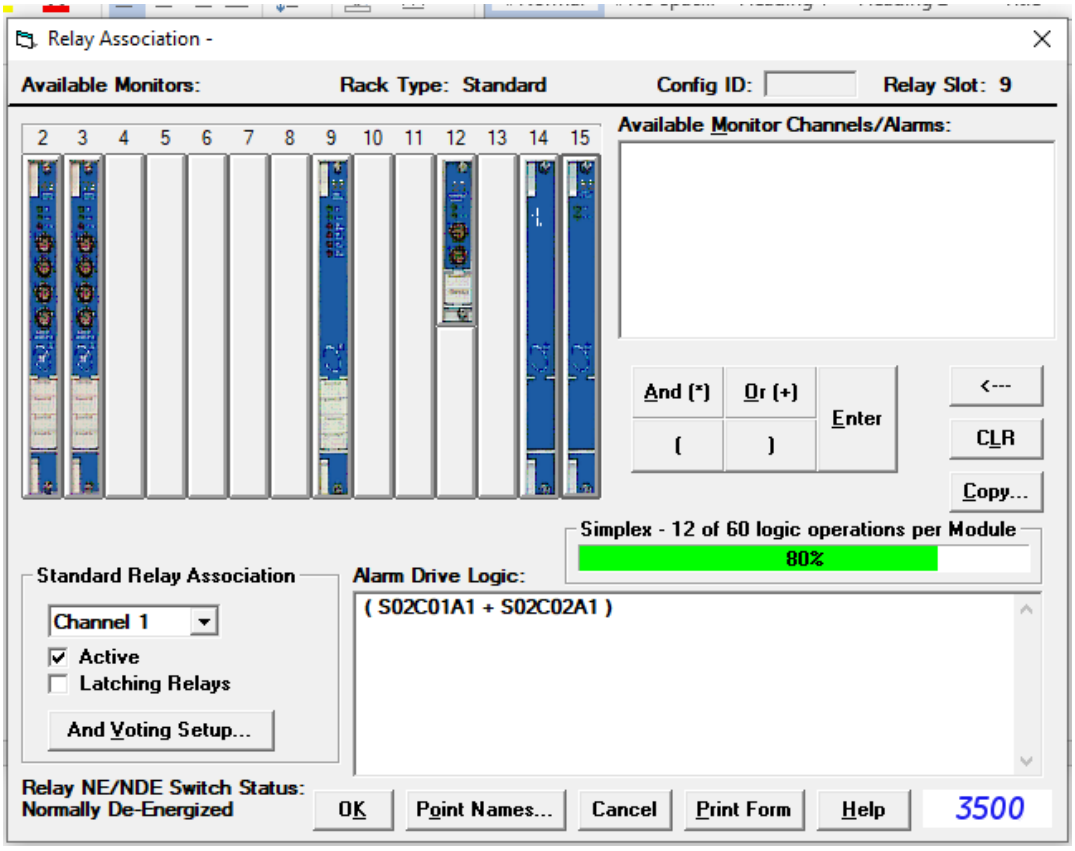
Appendix 49: Probe settings.



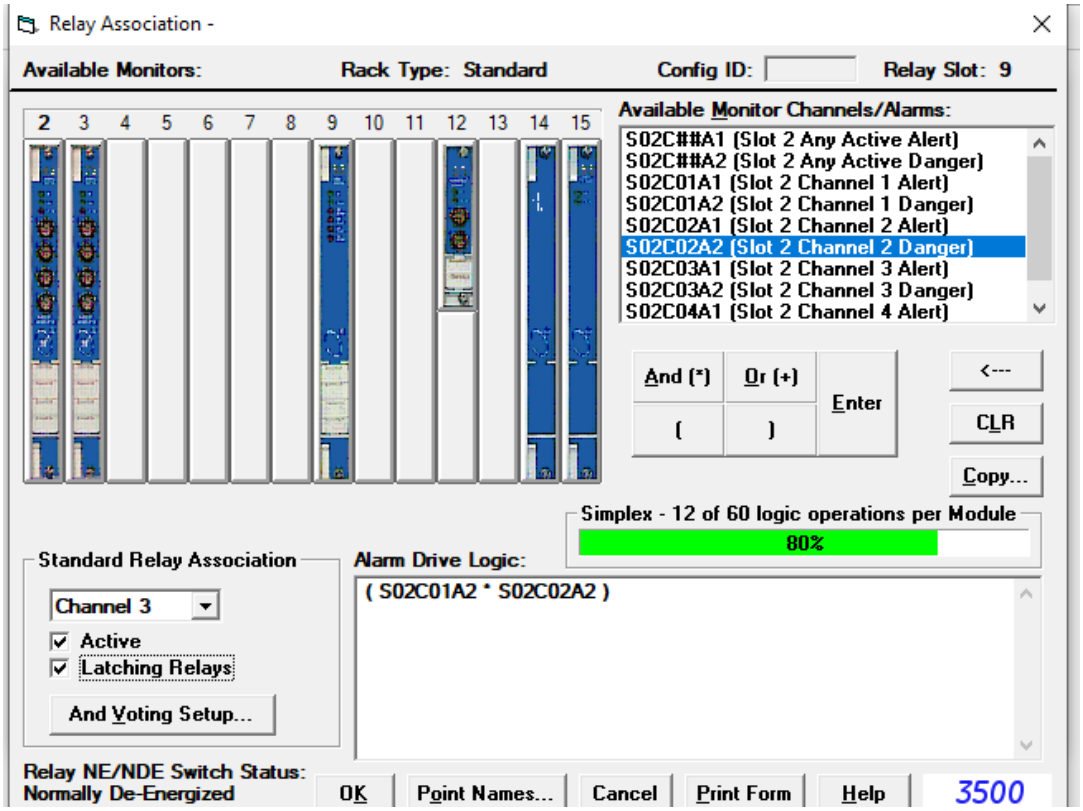
Appendix 51: Probe and alarm parameters.



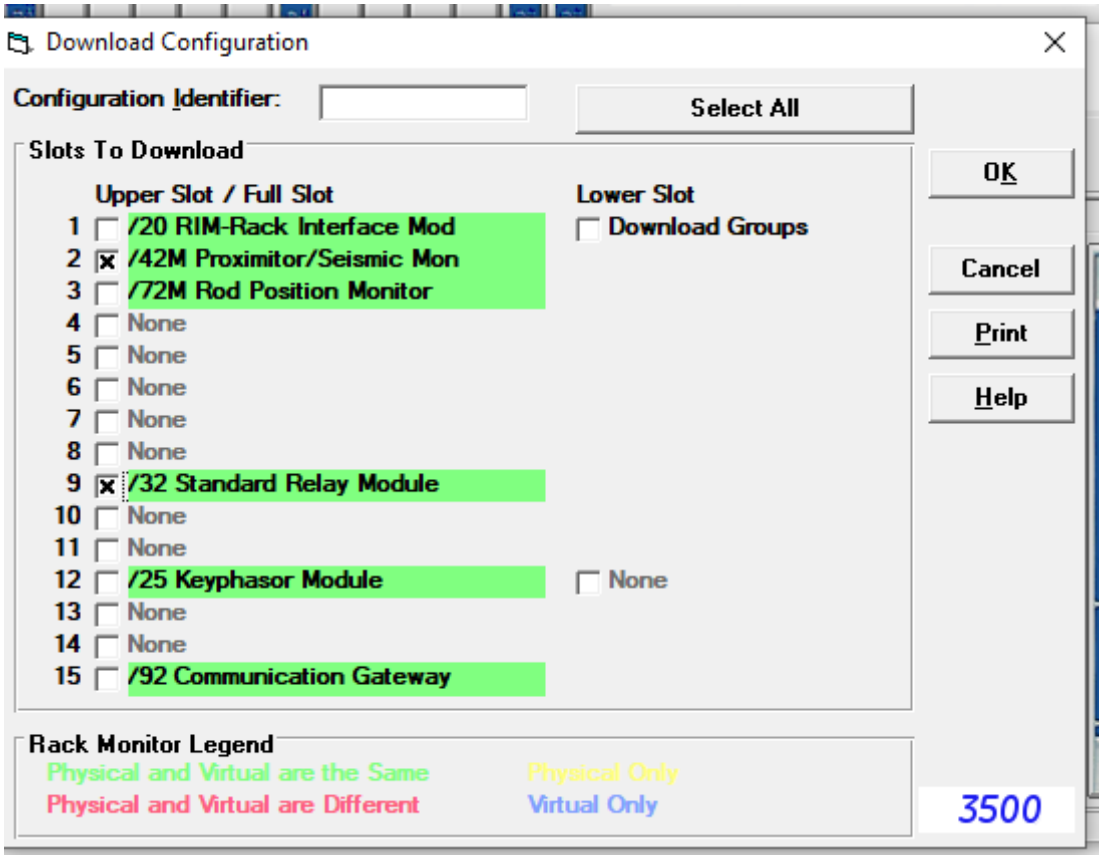
Appendix 52: 3500 alarm limits.



Appendix 53: 3500 logic OR gate.



Appendix 54: 3500 logic AND trip gate.

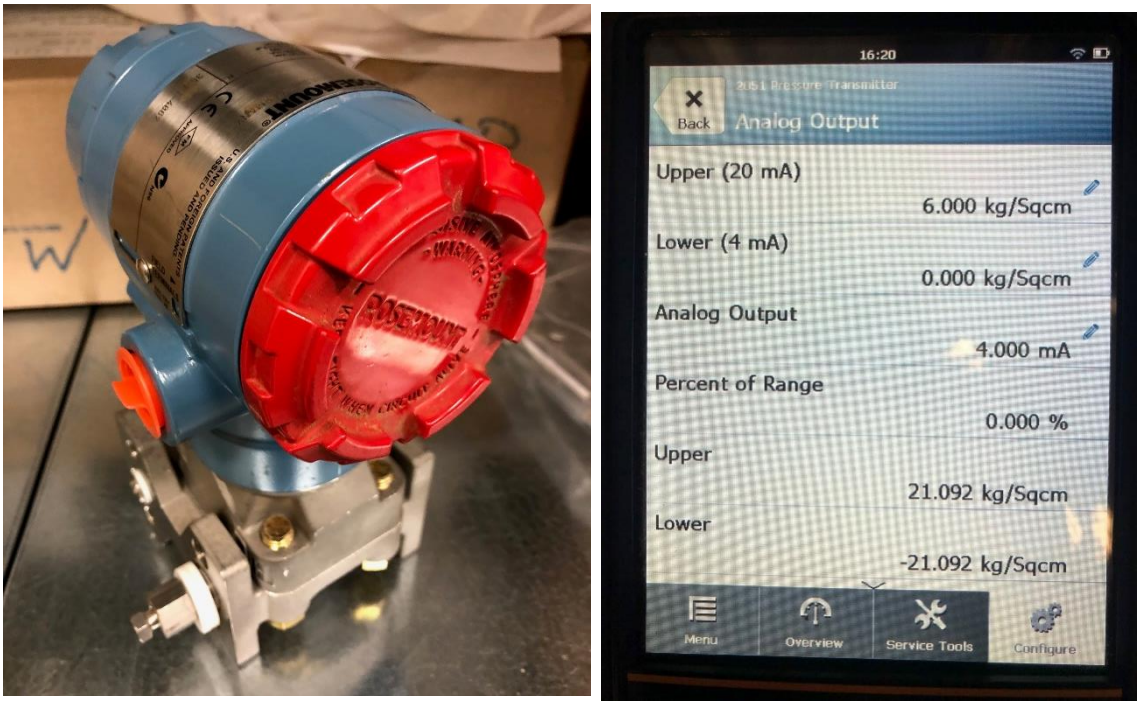


Appendix 55: Card download to 3500 rack.

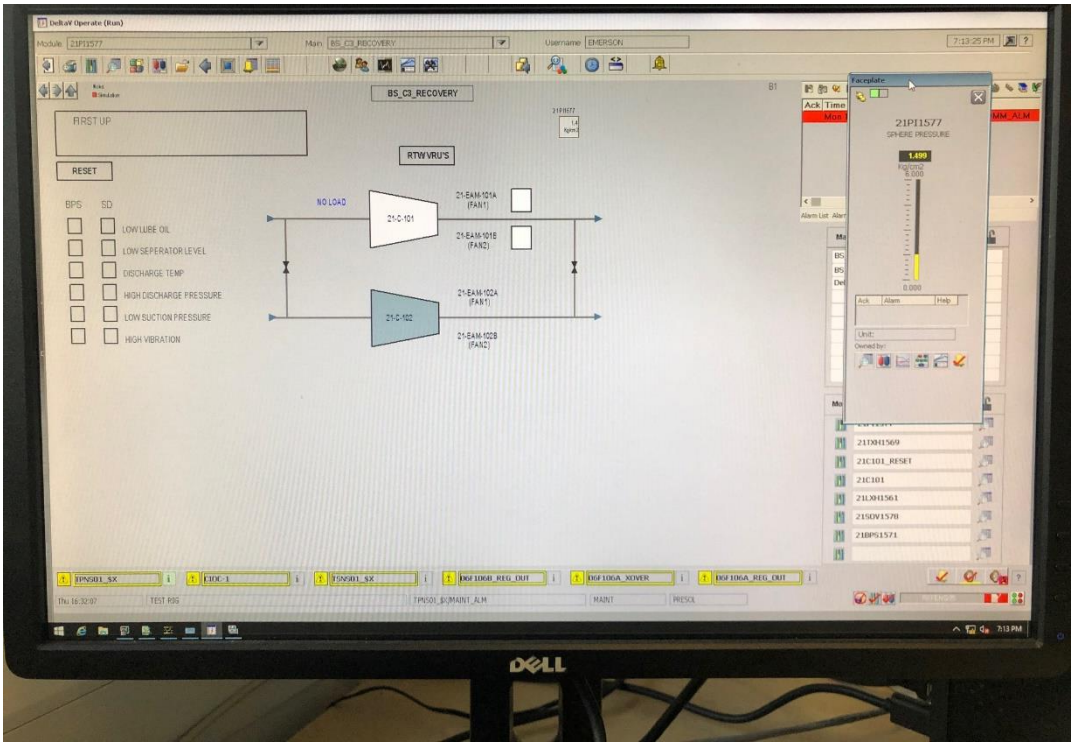




Appendix 56: DeltaV controllers and CIOCs installed.

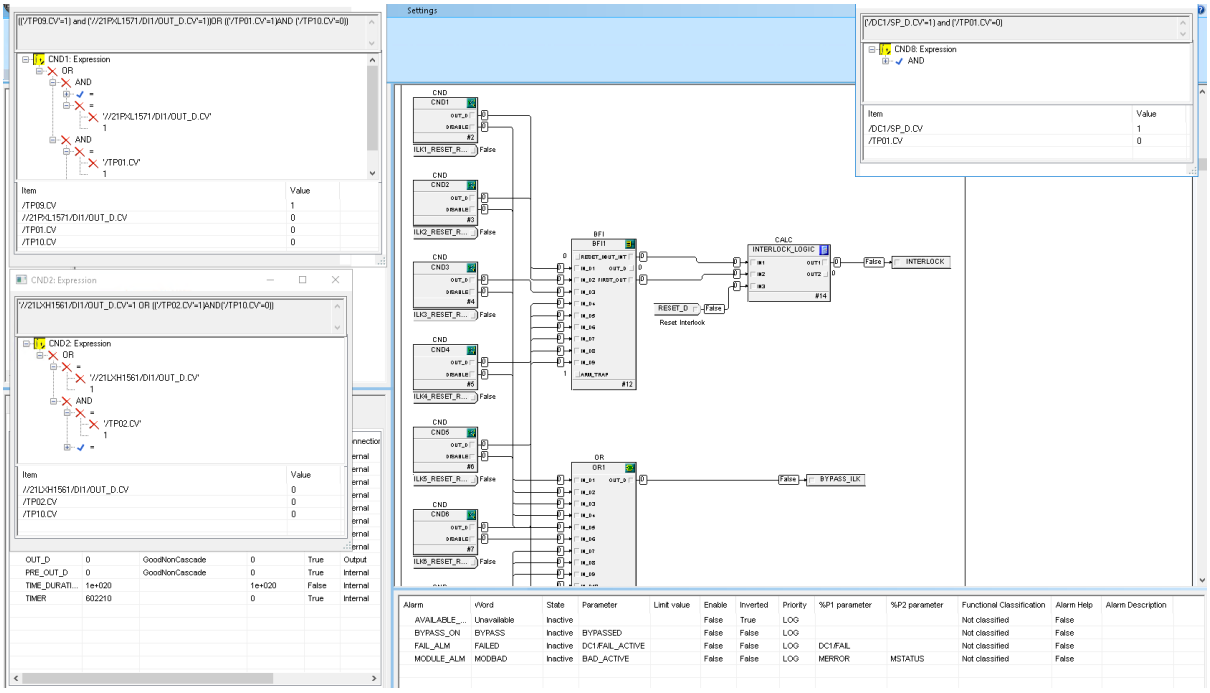


Appendix 58: Pressure transmitter set up.

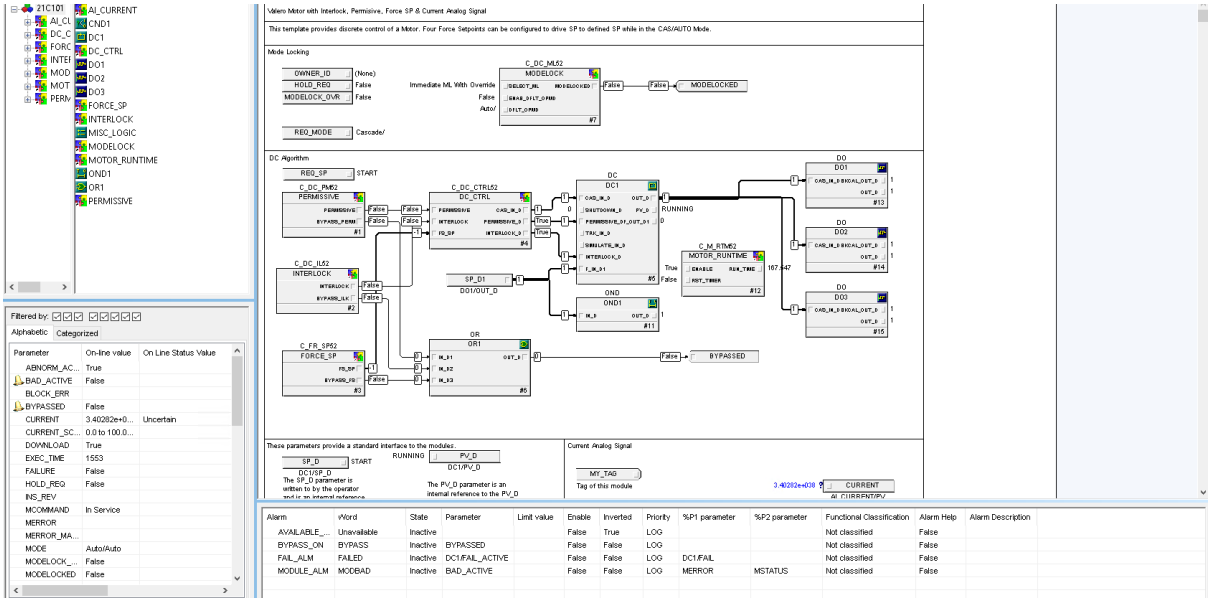


Appendix 57: Operator interface console.

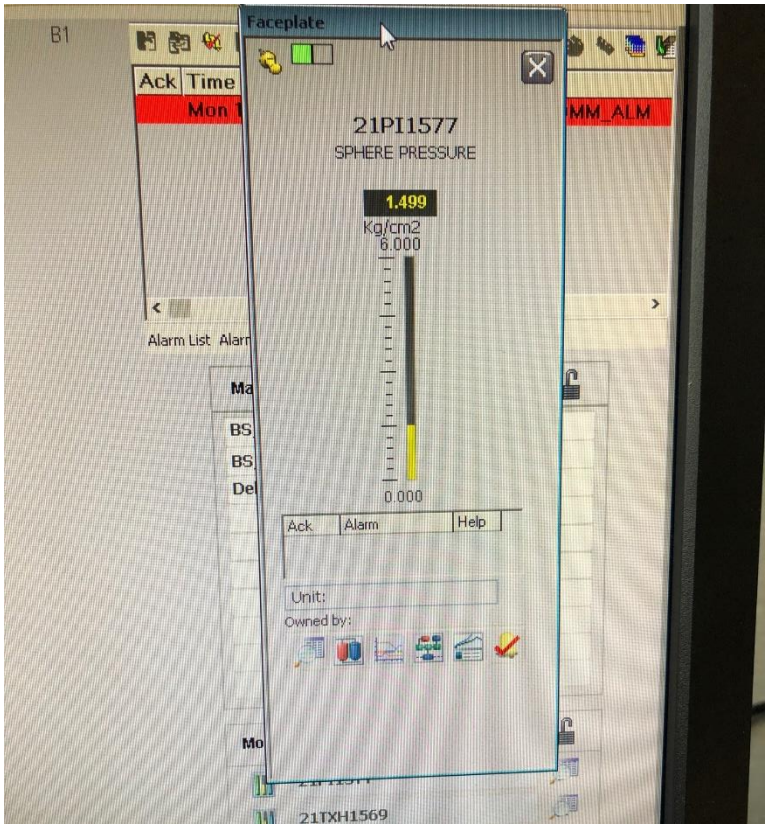
8.2 Testing Evidence



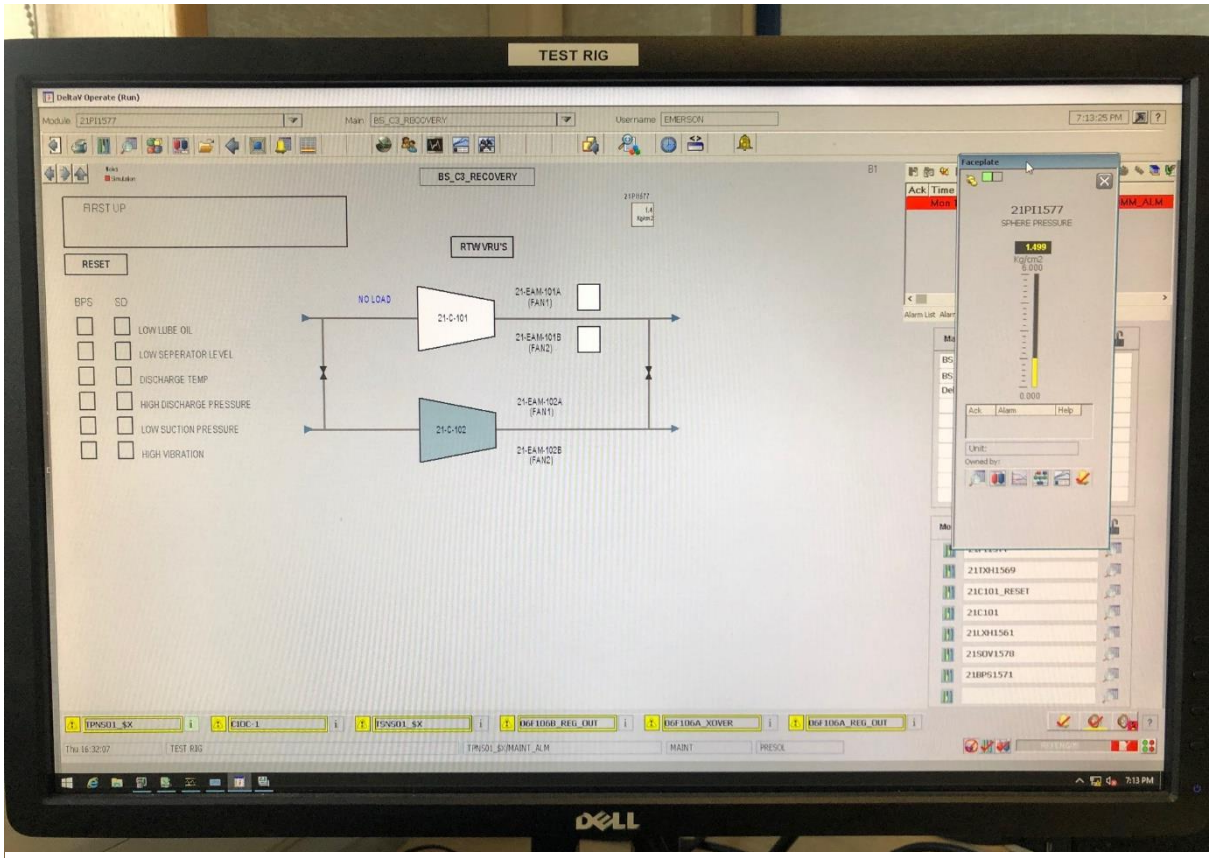
Appendix 59: Final interlock logic.



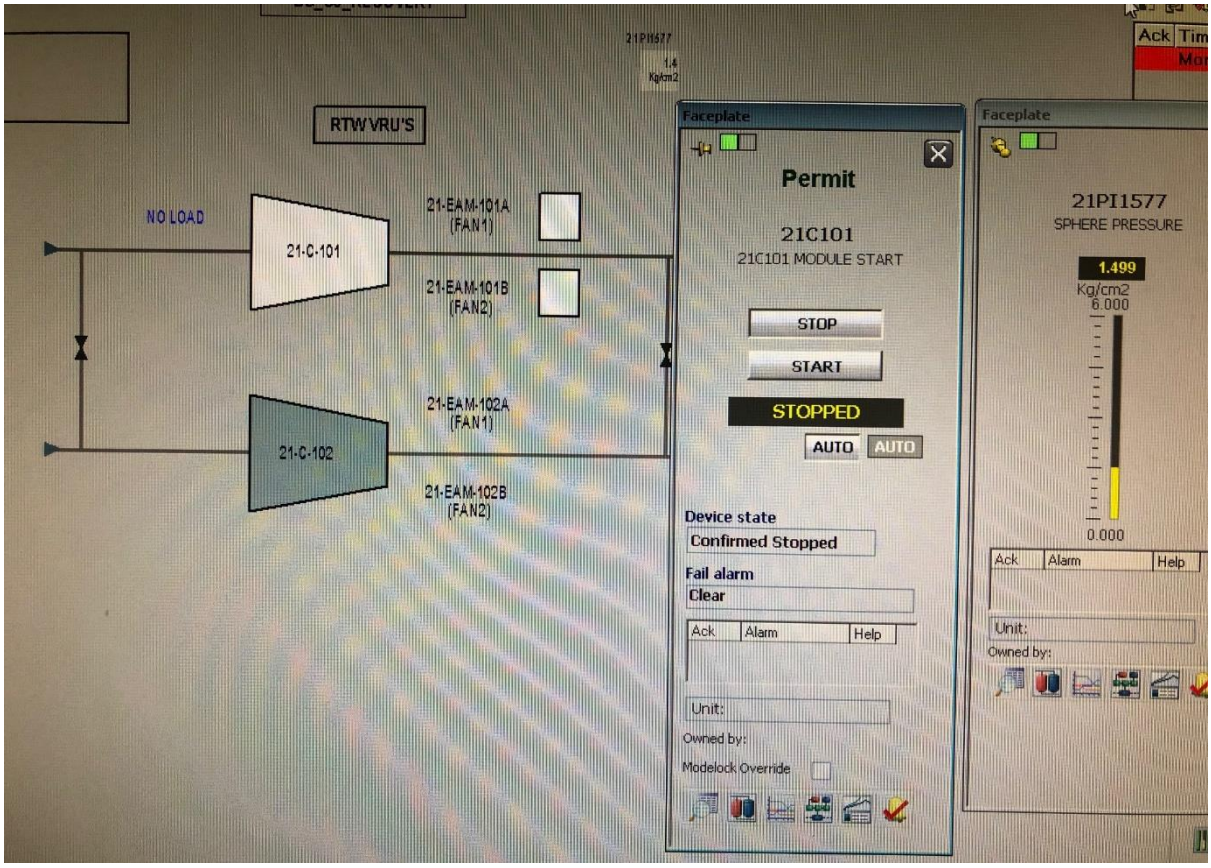
Appendix 60: Final compressor module logic.



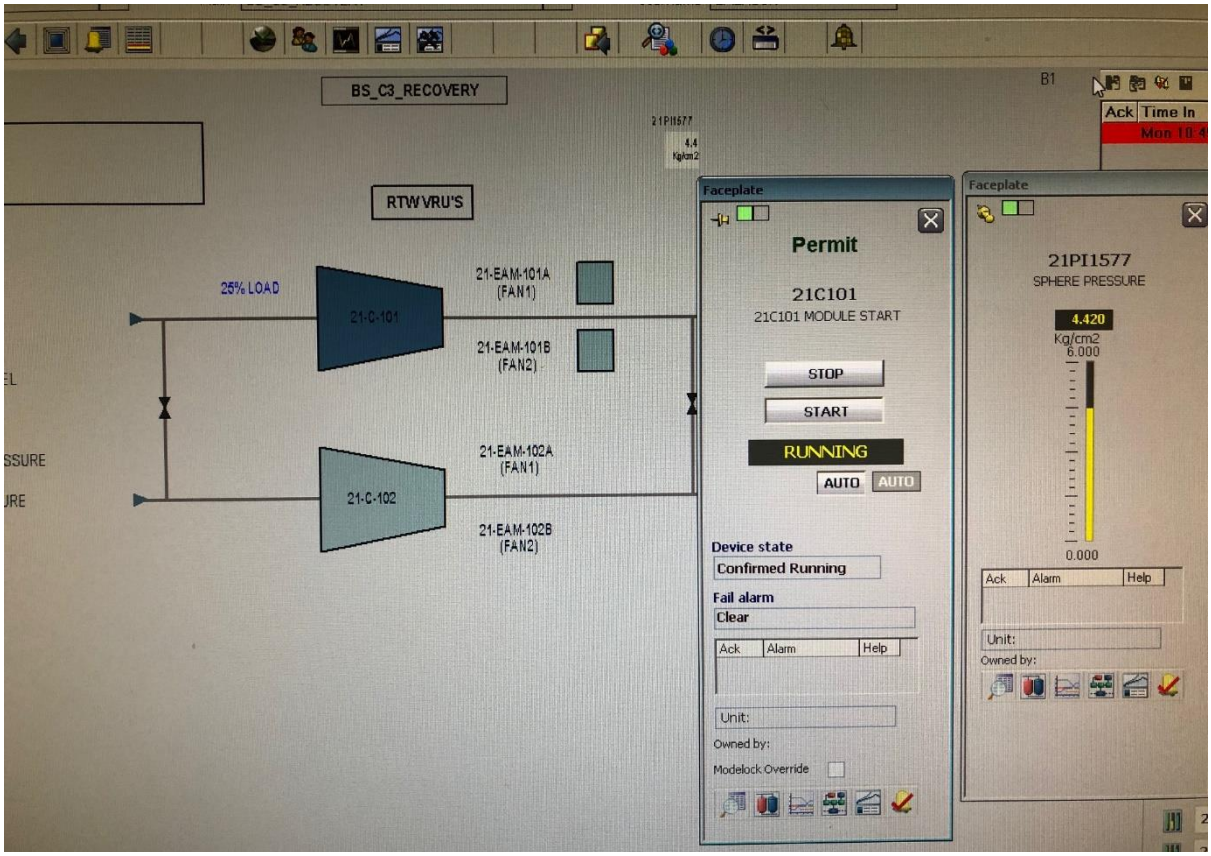
Appendix 61: 25% pressure.



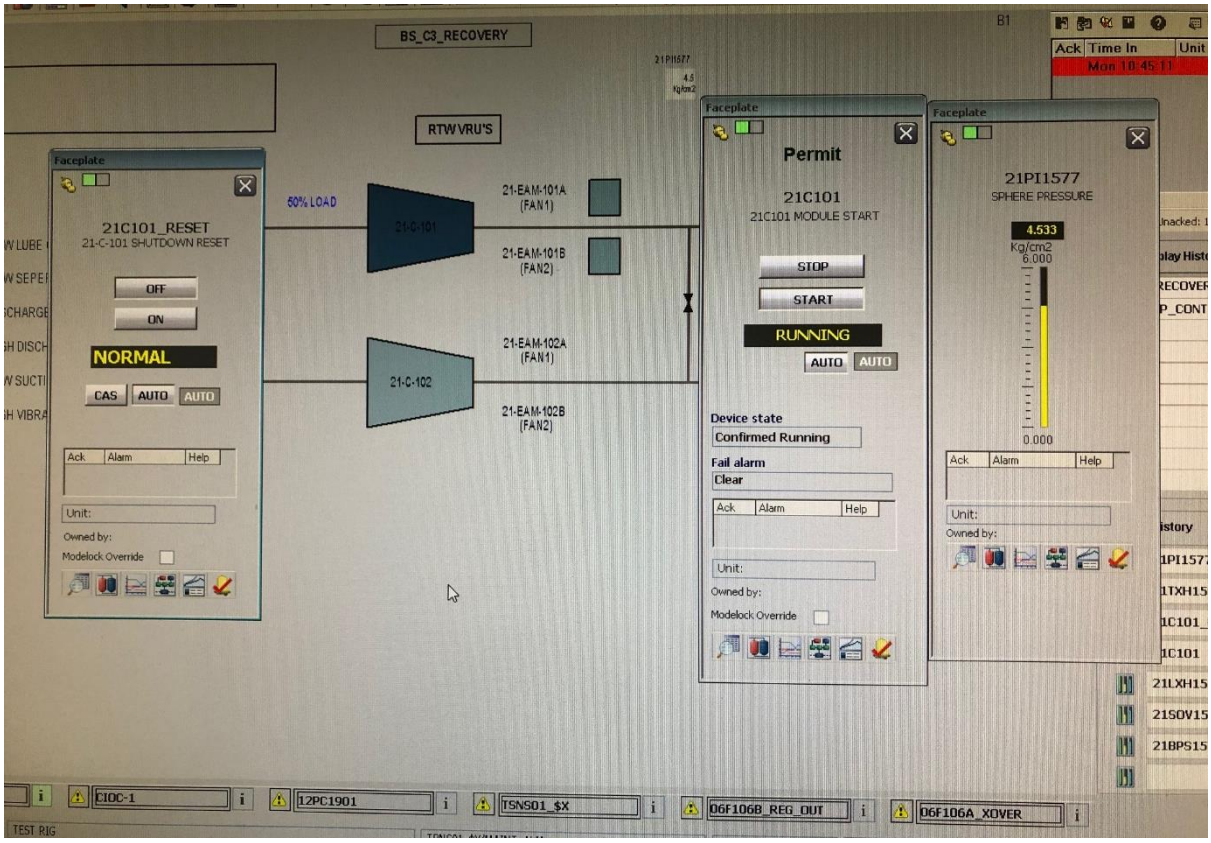
Appendix 62: Operator interface console.



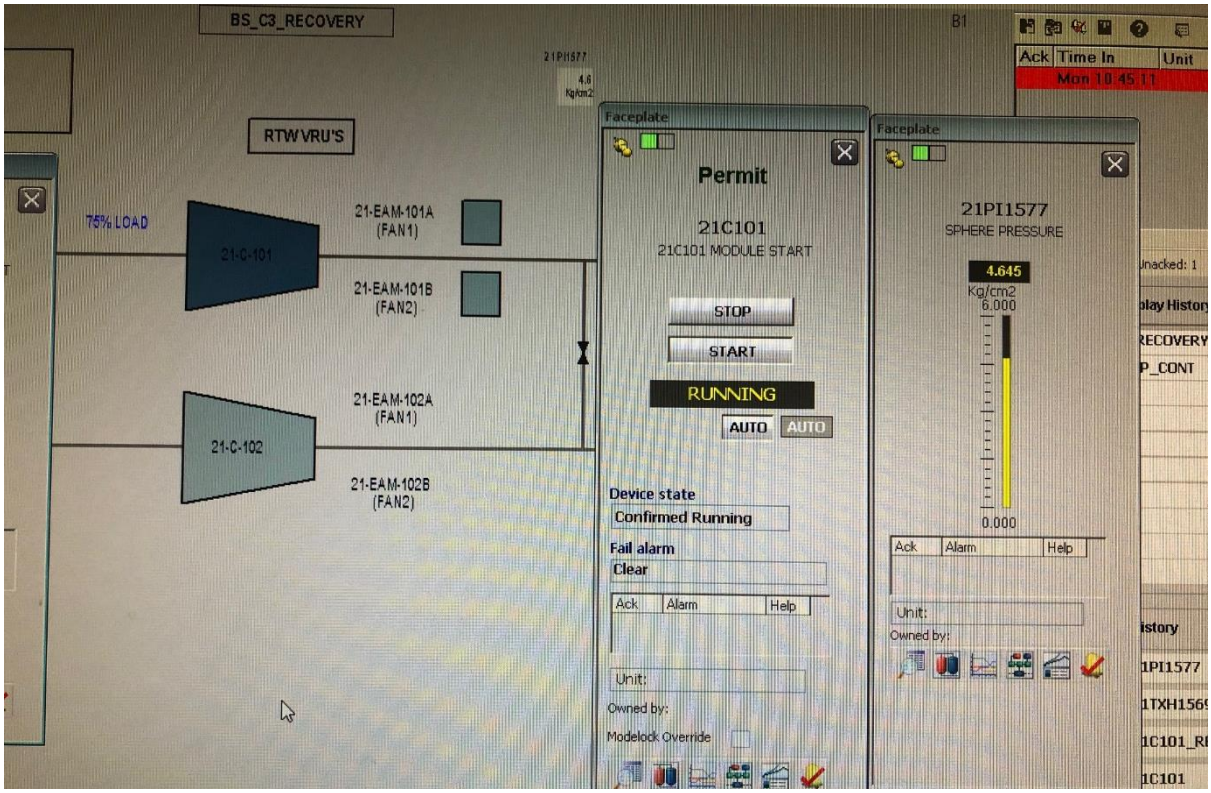
Appendix 63: Auto below set point.



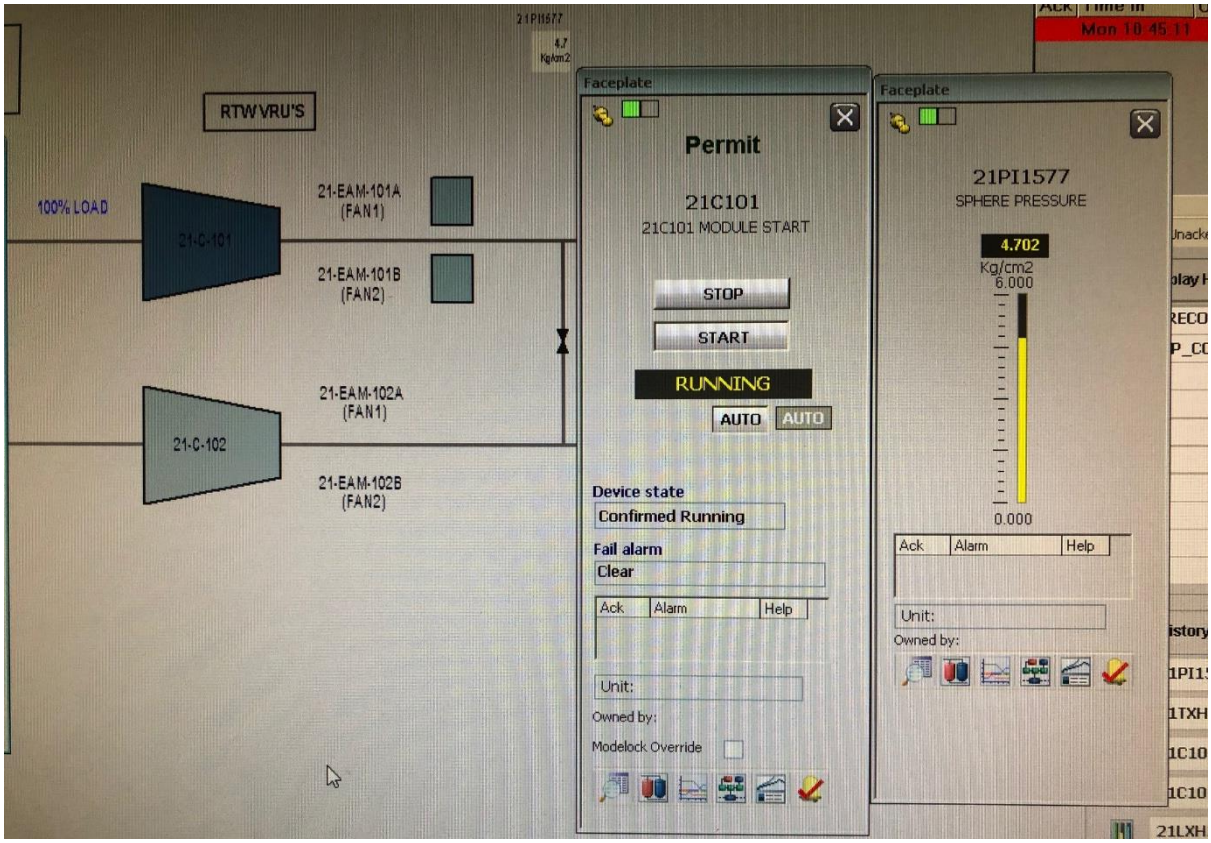
Appendix 64: Compressor cut in 4.42kg/sqcm.



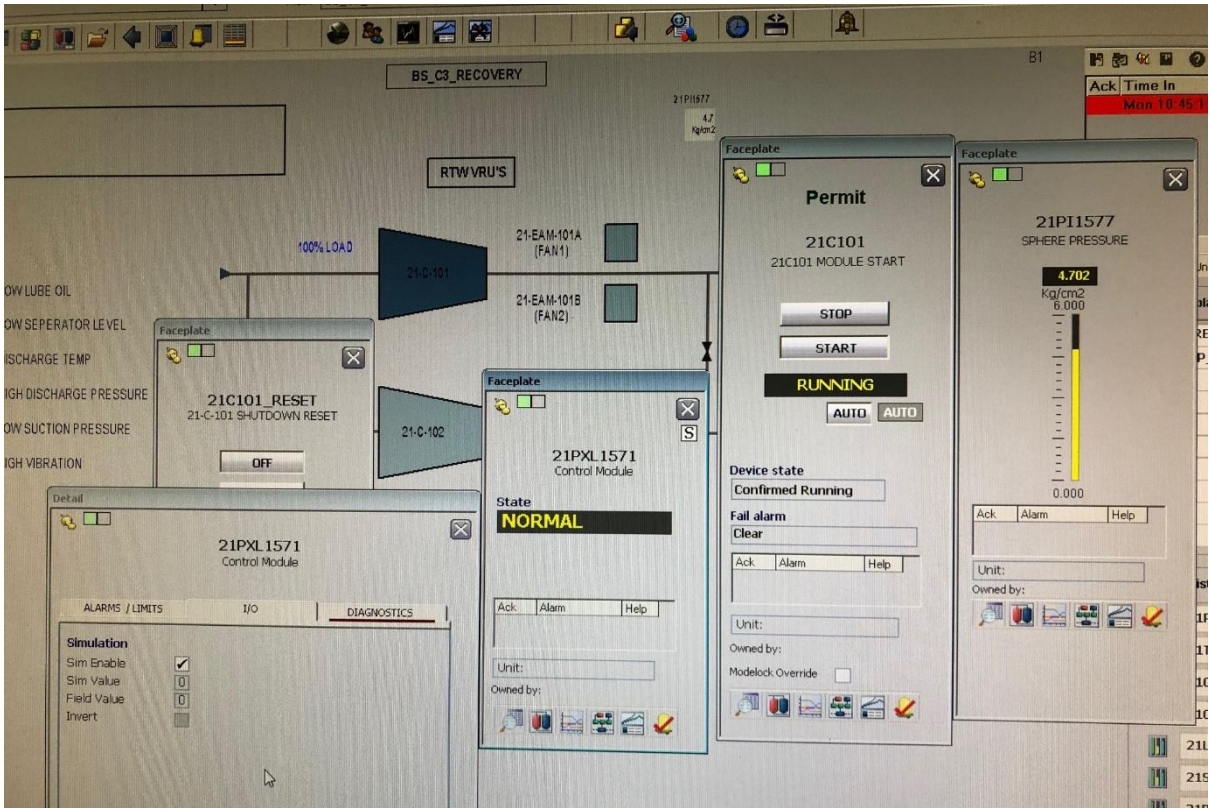
Appendix 65: Compressor 50% loading at 4.533kg/sqcm.



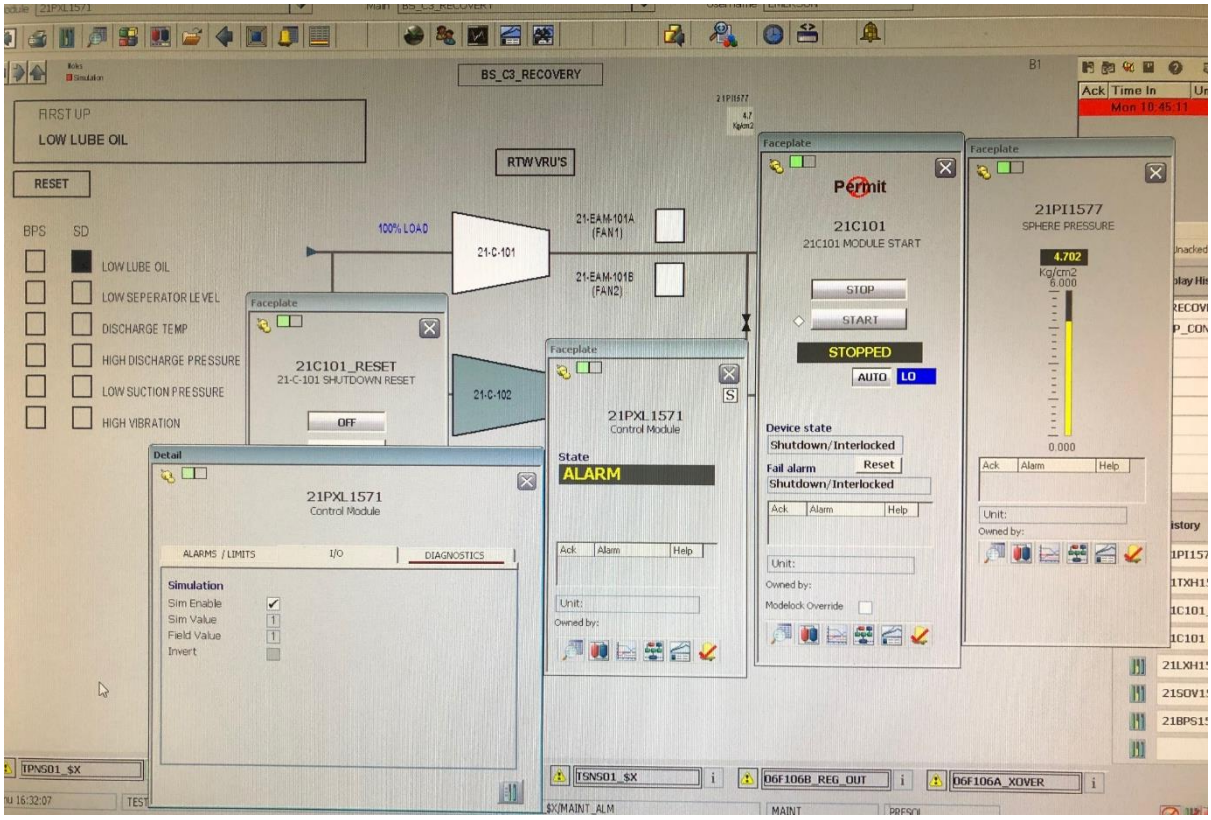
Appendix 66: Compressor 75% loading at 4.645kg/sqcm.



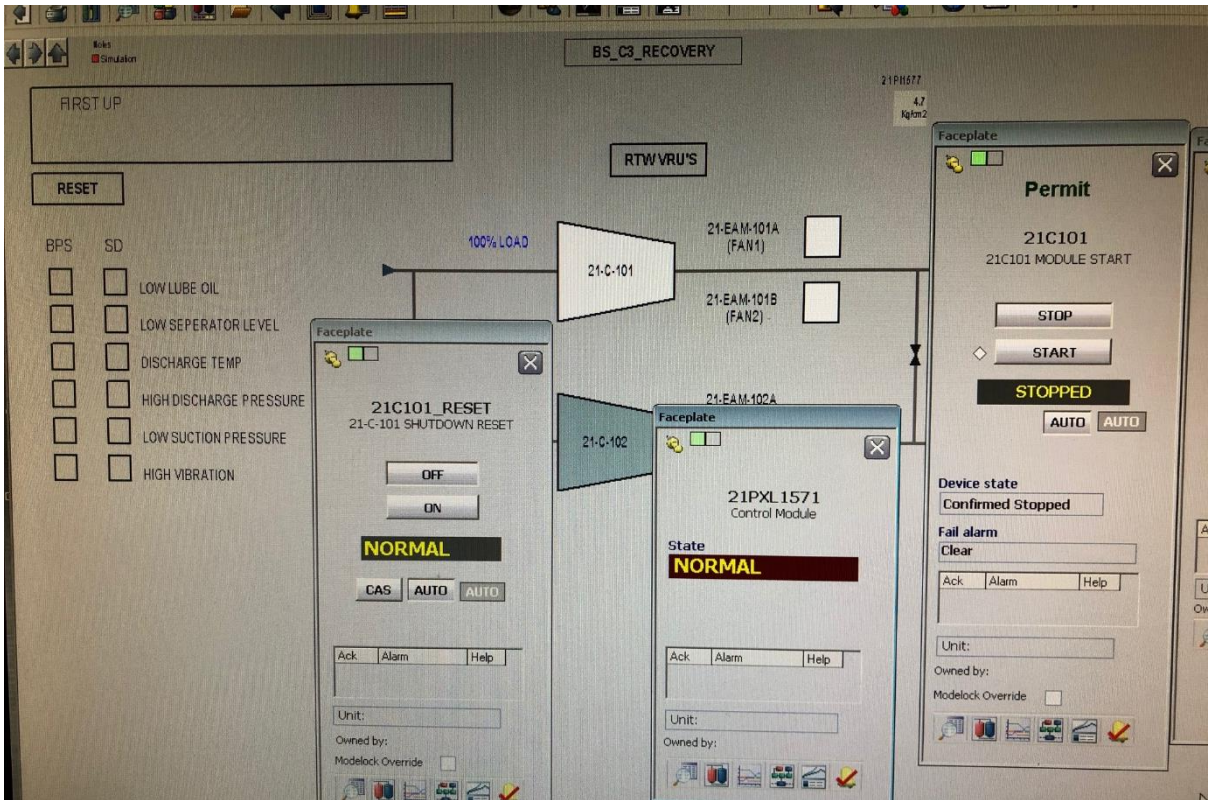
Appendix 67: Compressor 100% loading at 4.702kg/sqcm.



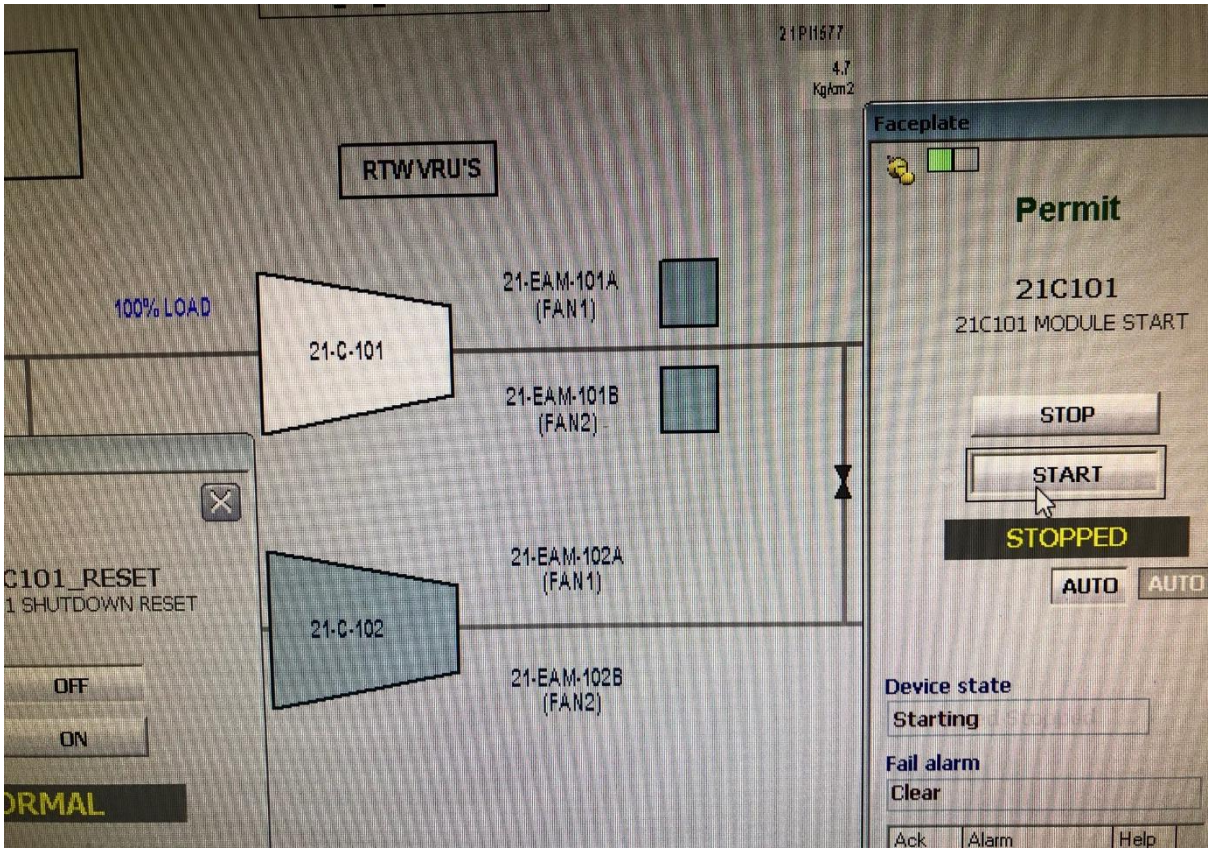
Appendix 68: Compressor running with healthy lube oil pressure.



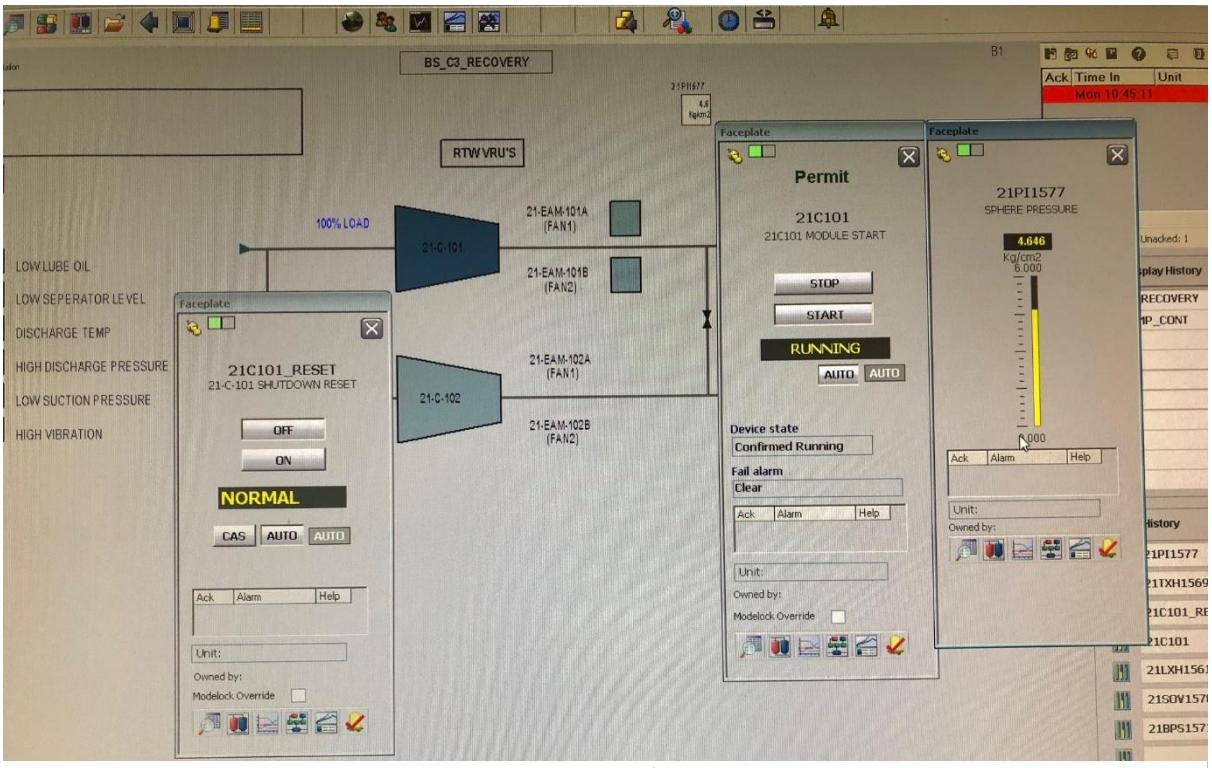
Appendix 69: Low lube oil tripped compressor and interlock active preventing restart. First up alarm active.



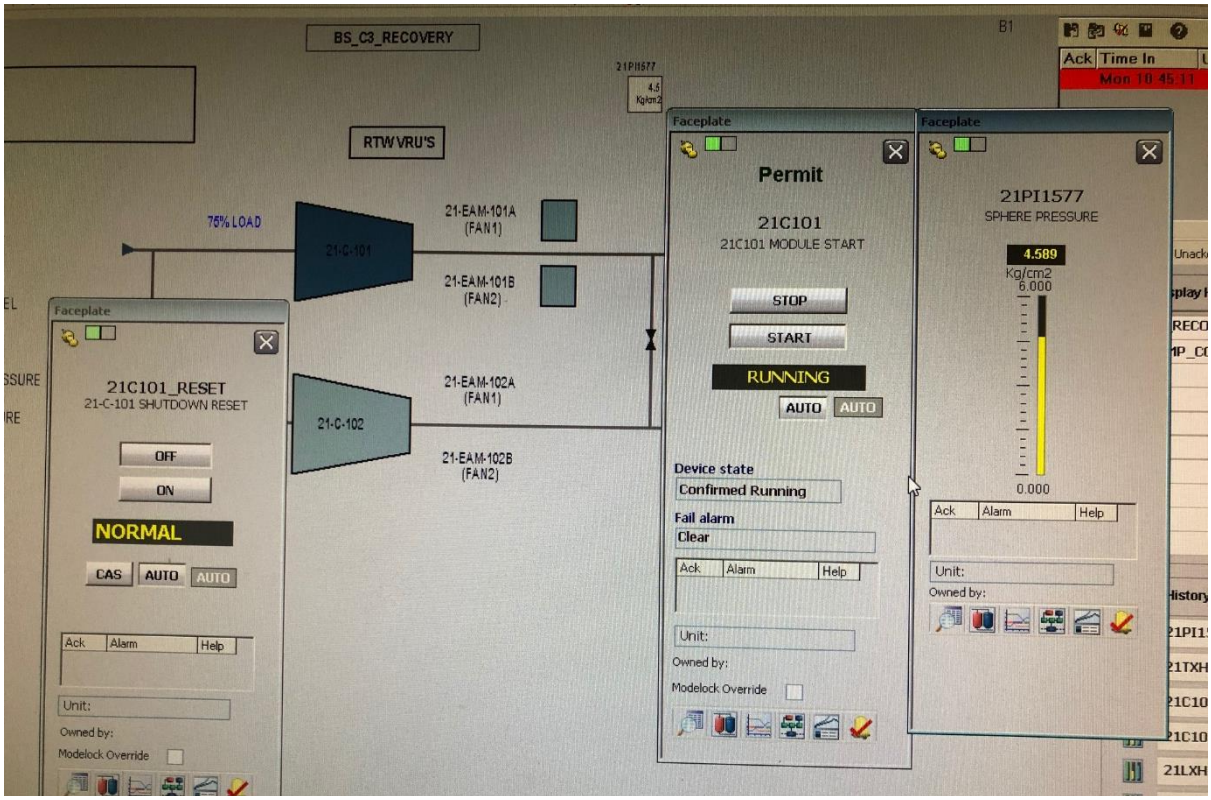
Appendix 70: Healthy lube oil pressure and reset pressed. First up and interlock has cleared.



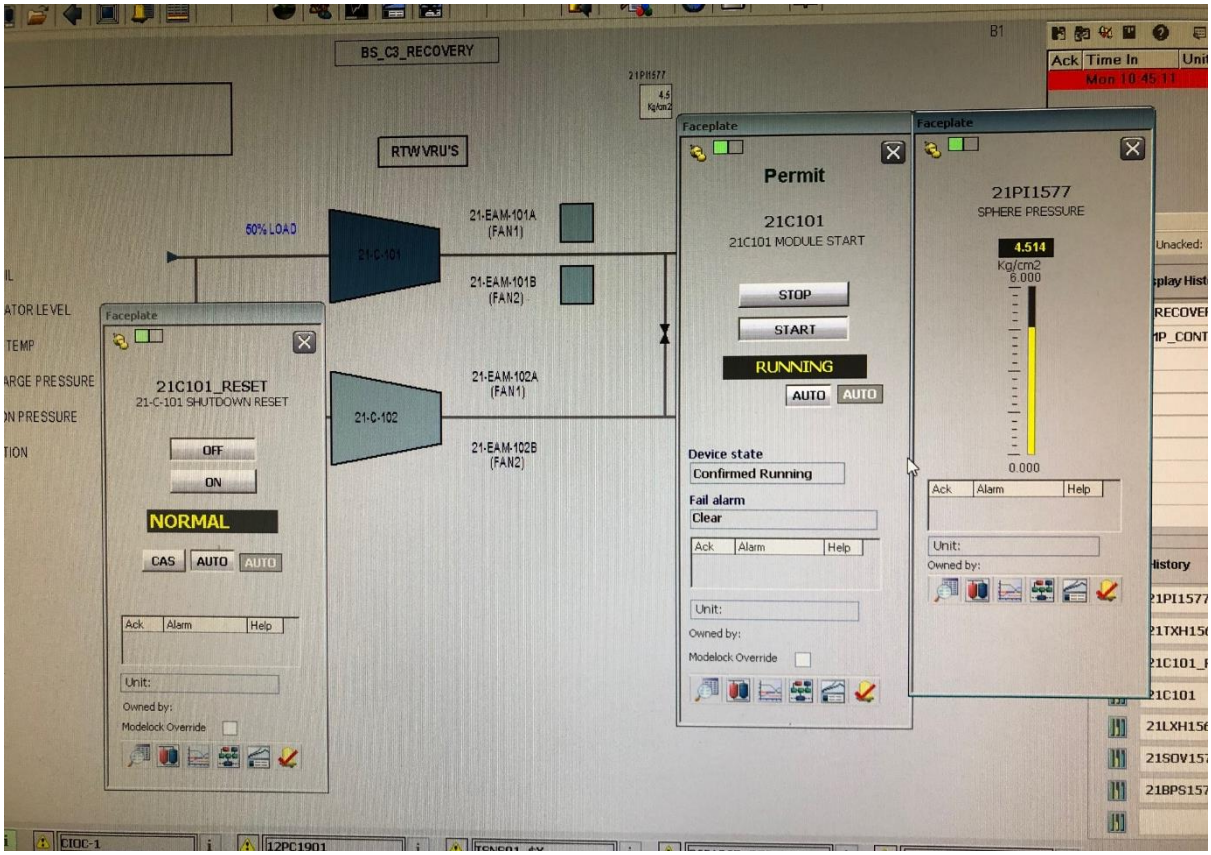
Appendix 71: Start initiated, fin fans have started before compressor. Set point means compressor will attempt to load to 100% once running.



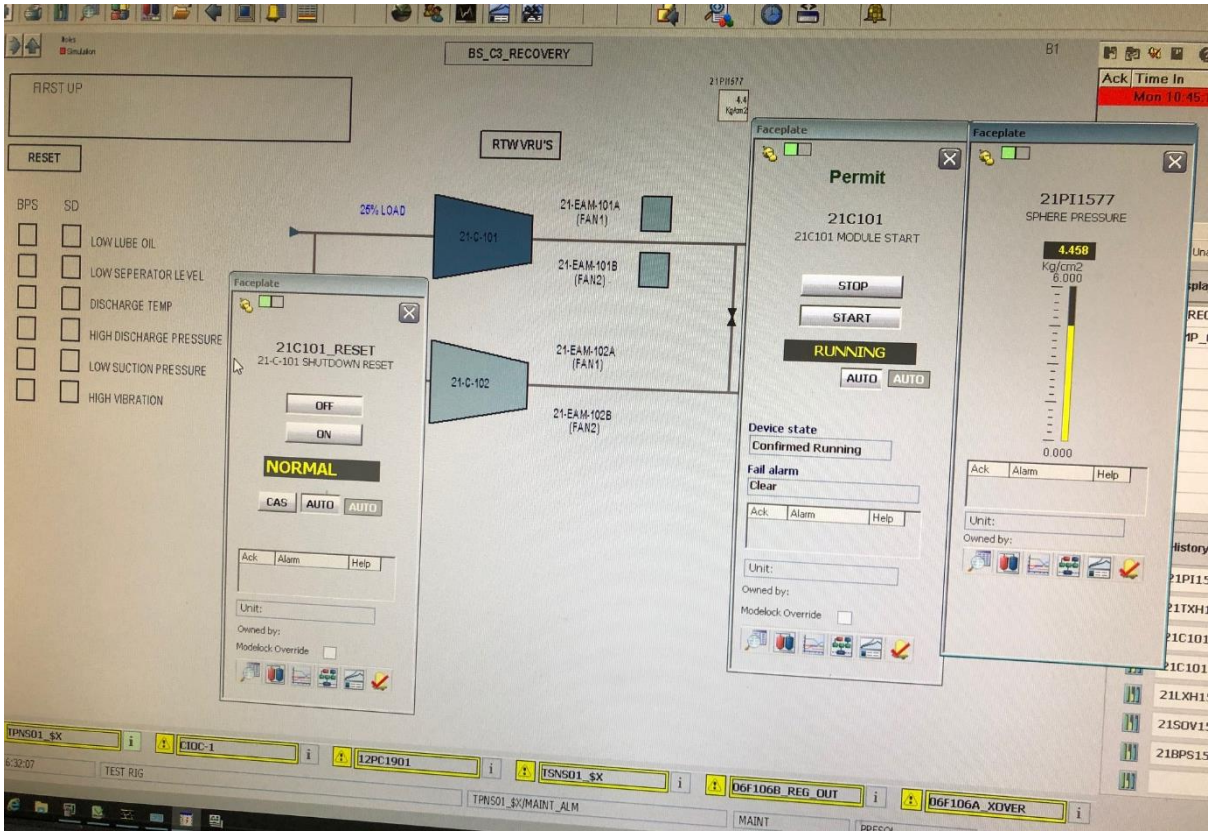
Appendix 72: Unload sequence at 100% loading, pressure 4.646kg/sqcm.



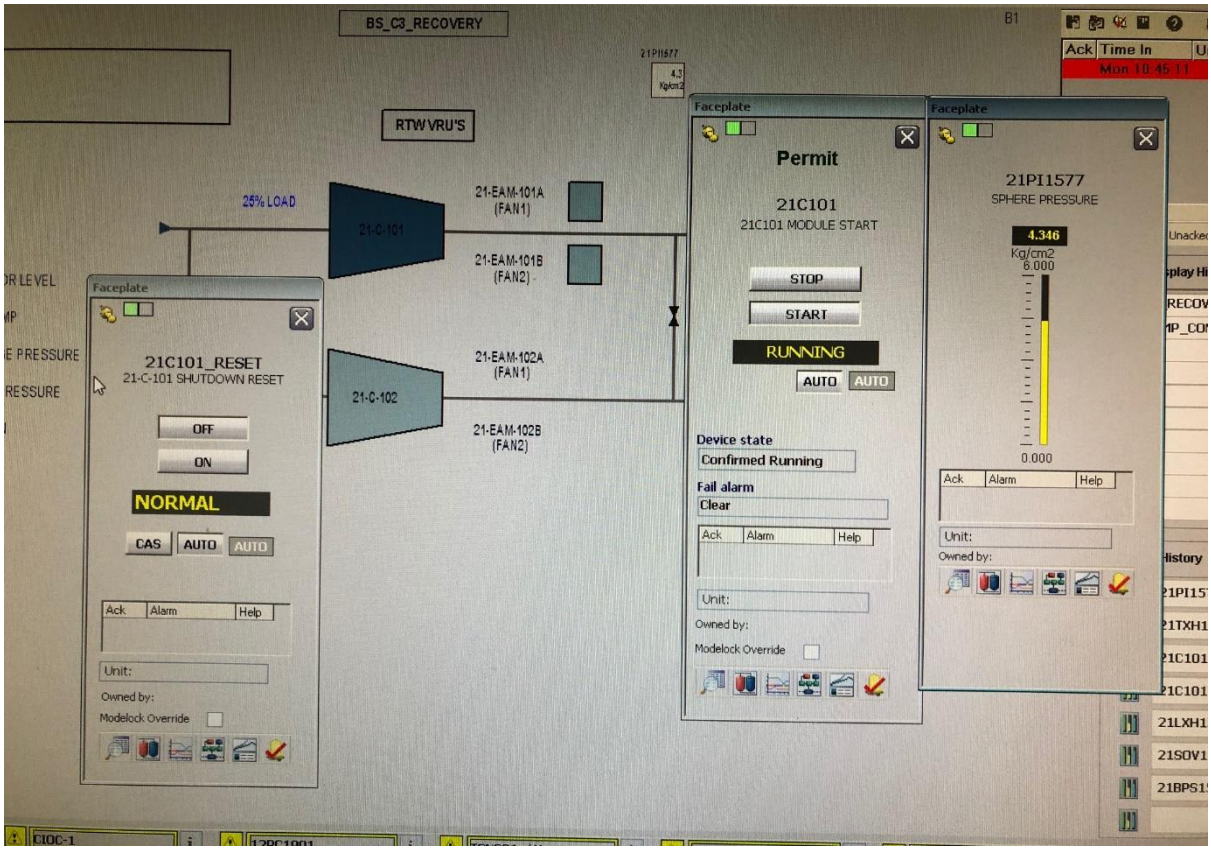
Appendix 73: Unload sequence at 75%, pressure 4.589kg/sqcm.



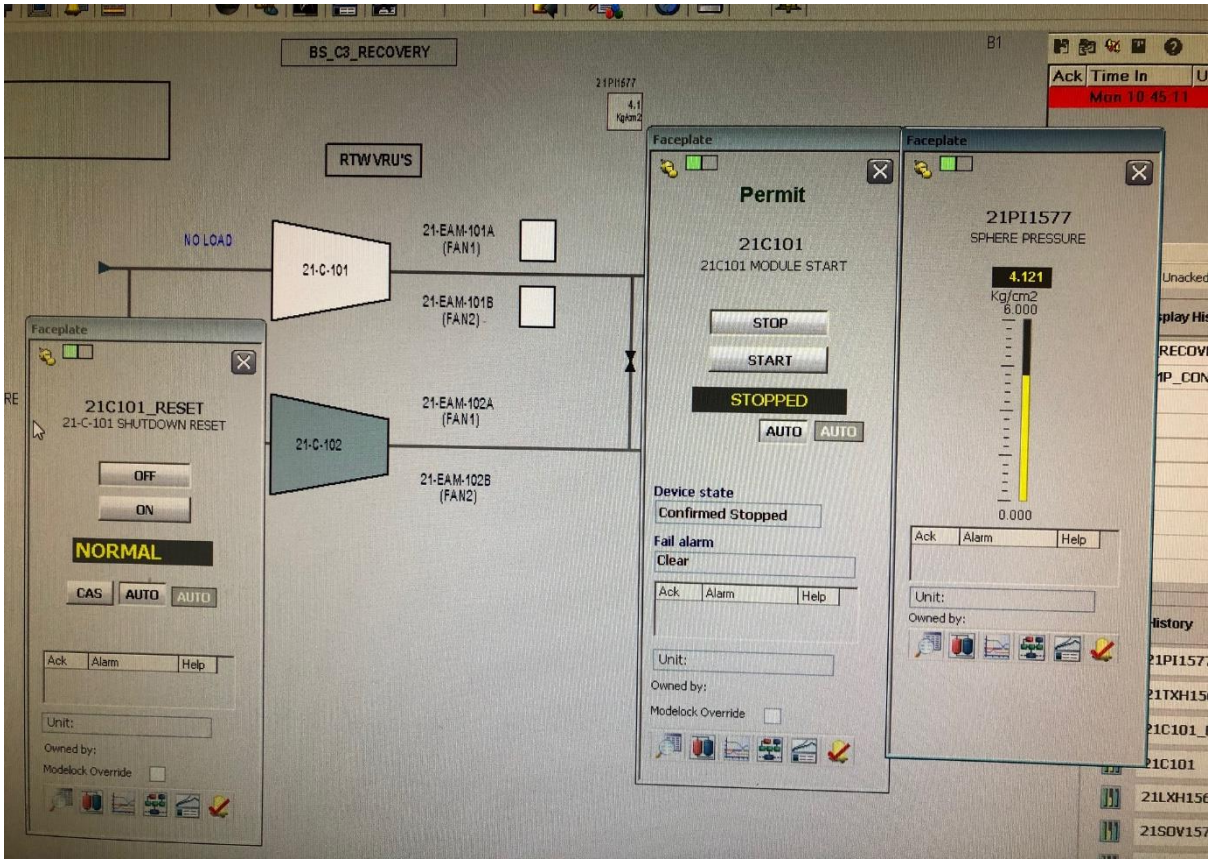
Appendix 74: Unload sequence at 50%, pressure 4.514kg/sqcm.



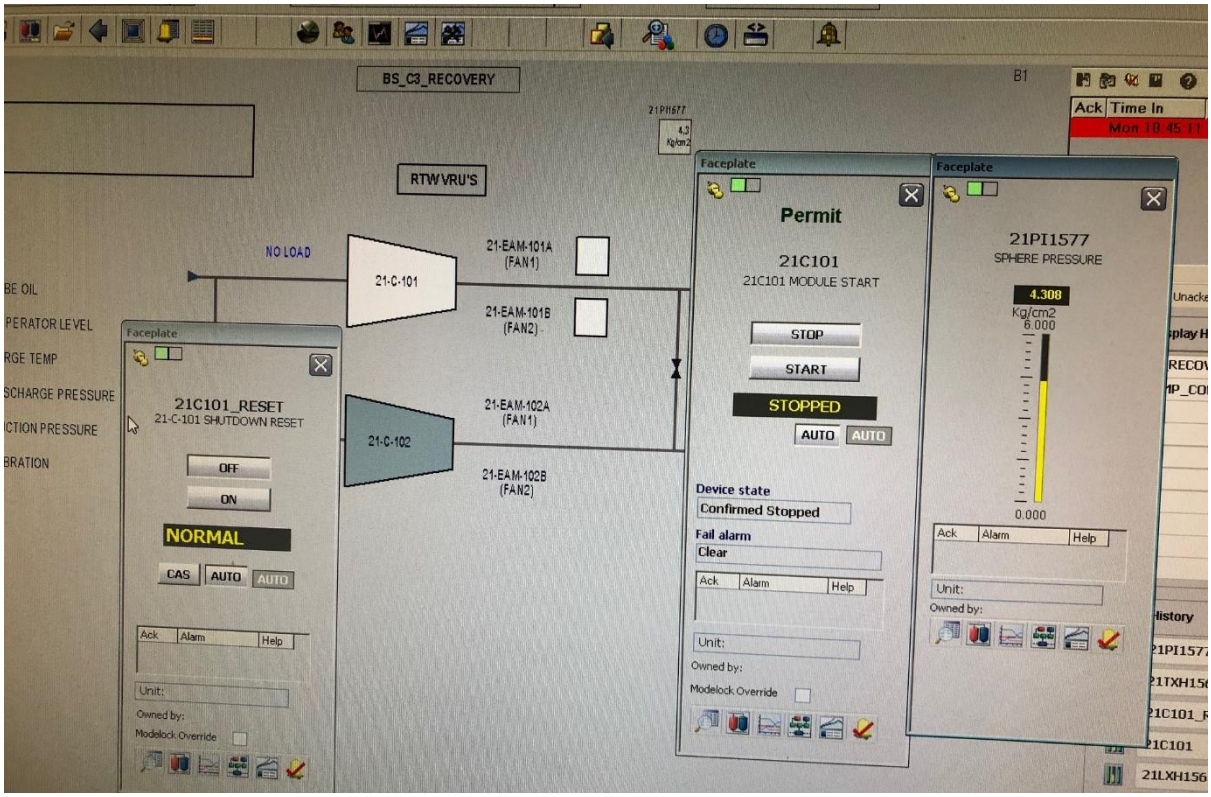
Appendix 75: Unload sequence at 25%, pressure 4.458kg/sqcm.



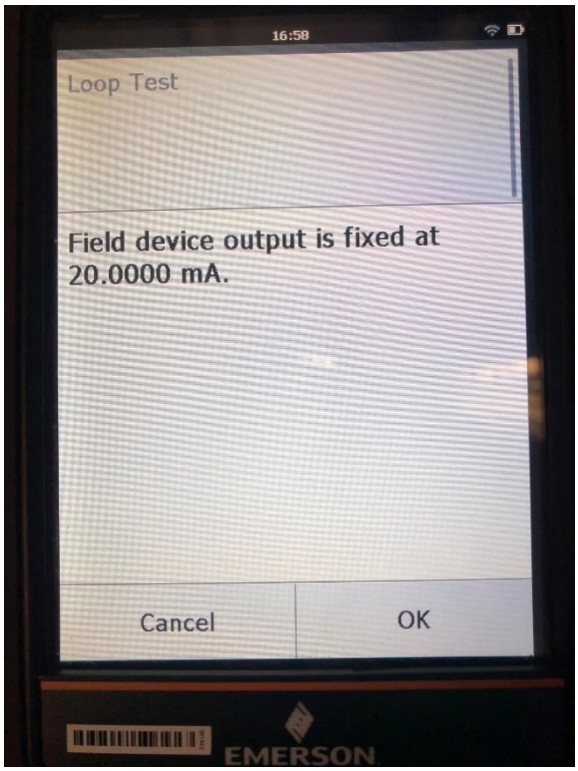
Appendix 76: Unload sequence still at 25%, pressure 4.346kg/sqcm.



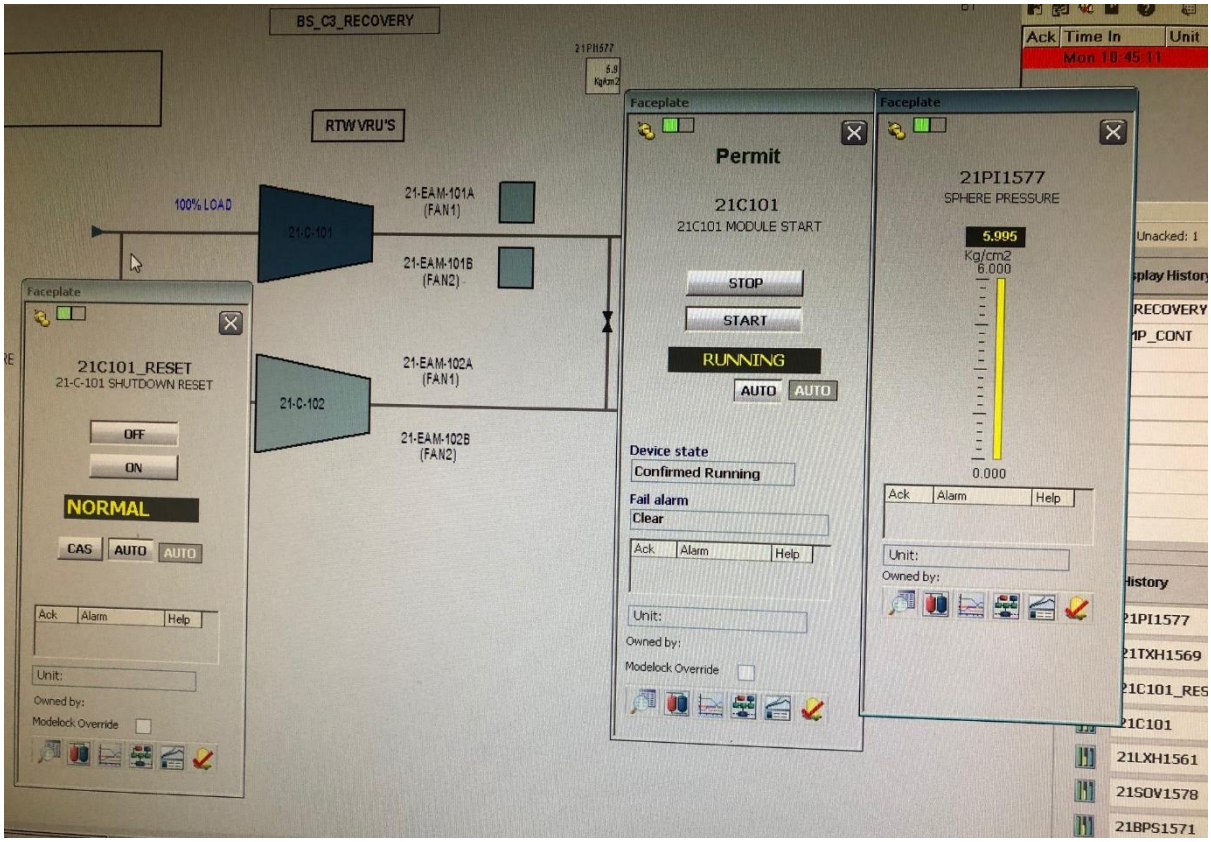
Appendix 77: Compressor offline and unloaded automatically as pressure below set point.



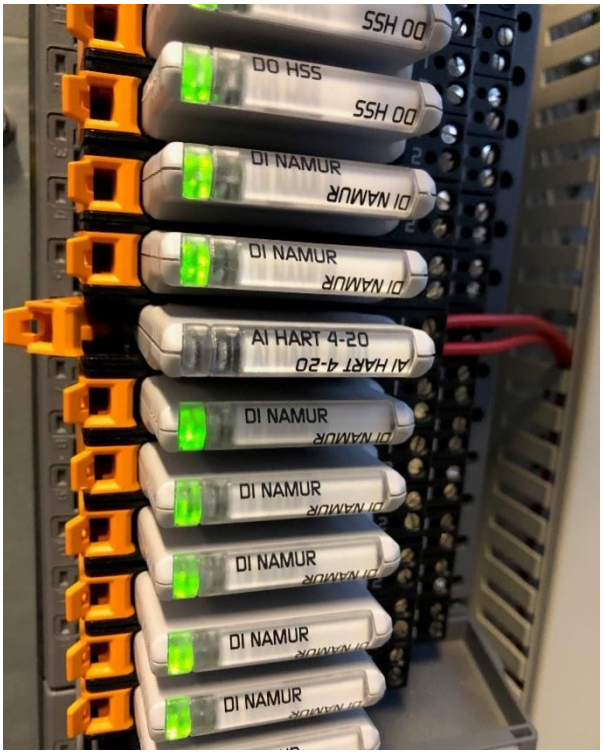
Appendix 78: Pressure increased back up below auto cut in, compressor not started.



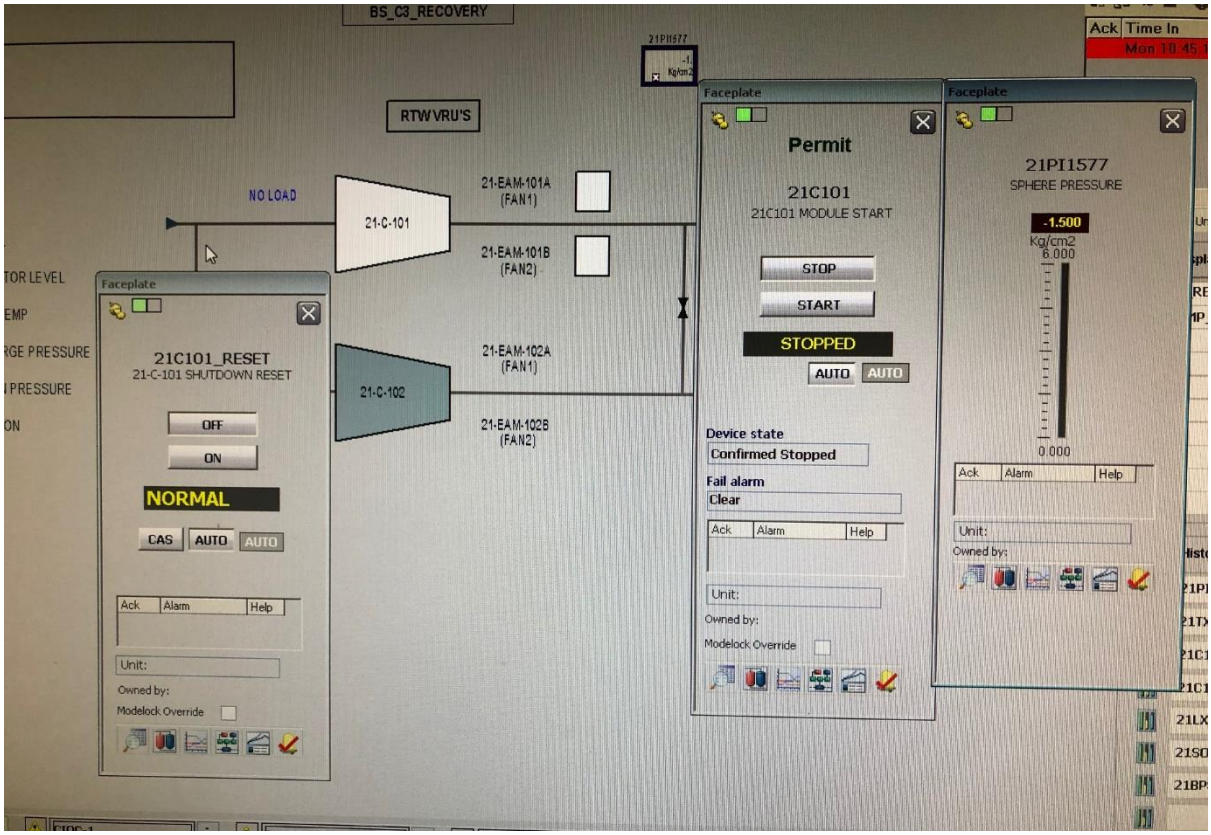
Appendix 79: Pressure full range loop check.



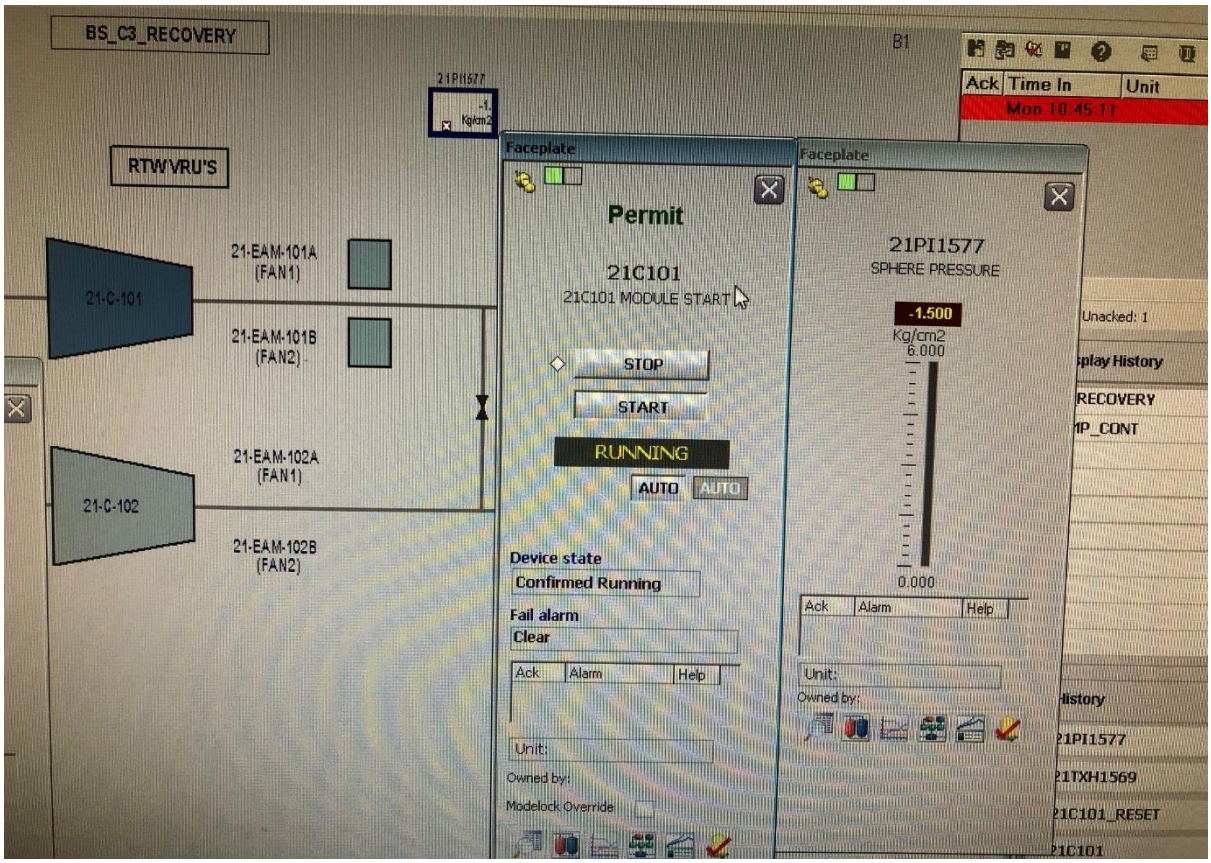
Appendix 80: Full pressure range.



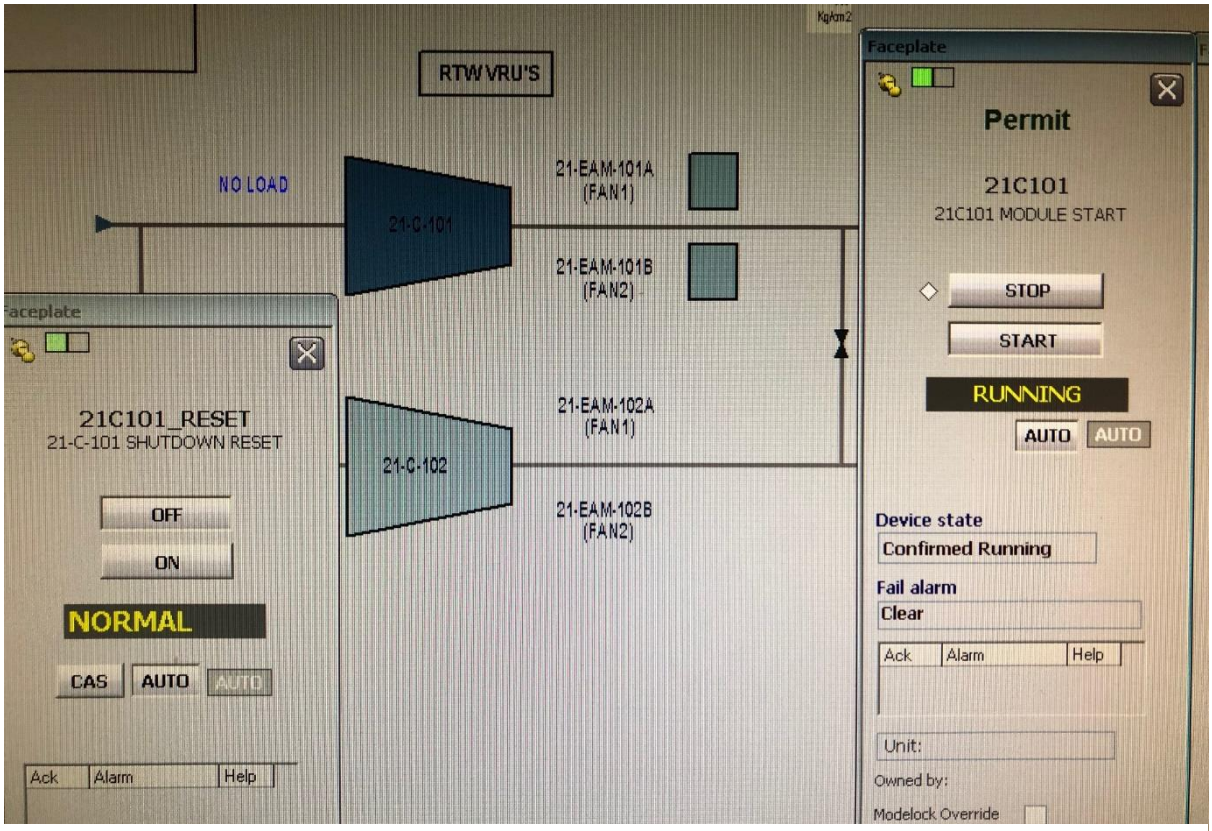
Appendix 81: Charm disconnection/Isolation test.



Appendix 82: Pressure AI failed to -1.5kg/sqcm. This prevents compressor auto cut in if transmitter fails. MODBAD highlight box/alarm present on top graphic indication. BAD PV indicator also active.



Appendix 83: Manual starting of compressor still functional when indication failed.



Appendix 84: Compressor unloaded for first 10 seconds as per start procedure.



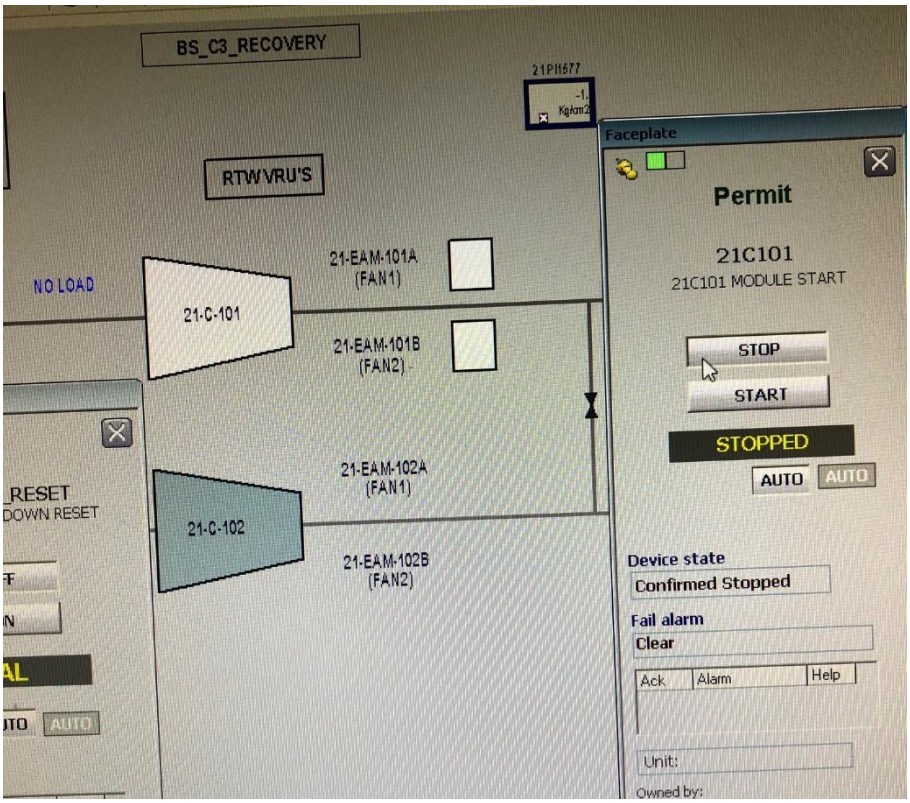
Appendix 85: Line fault highlights Charm analogue input alarm.



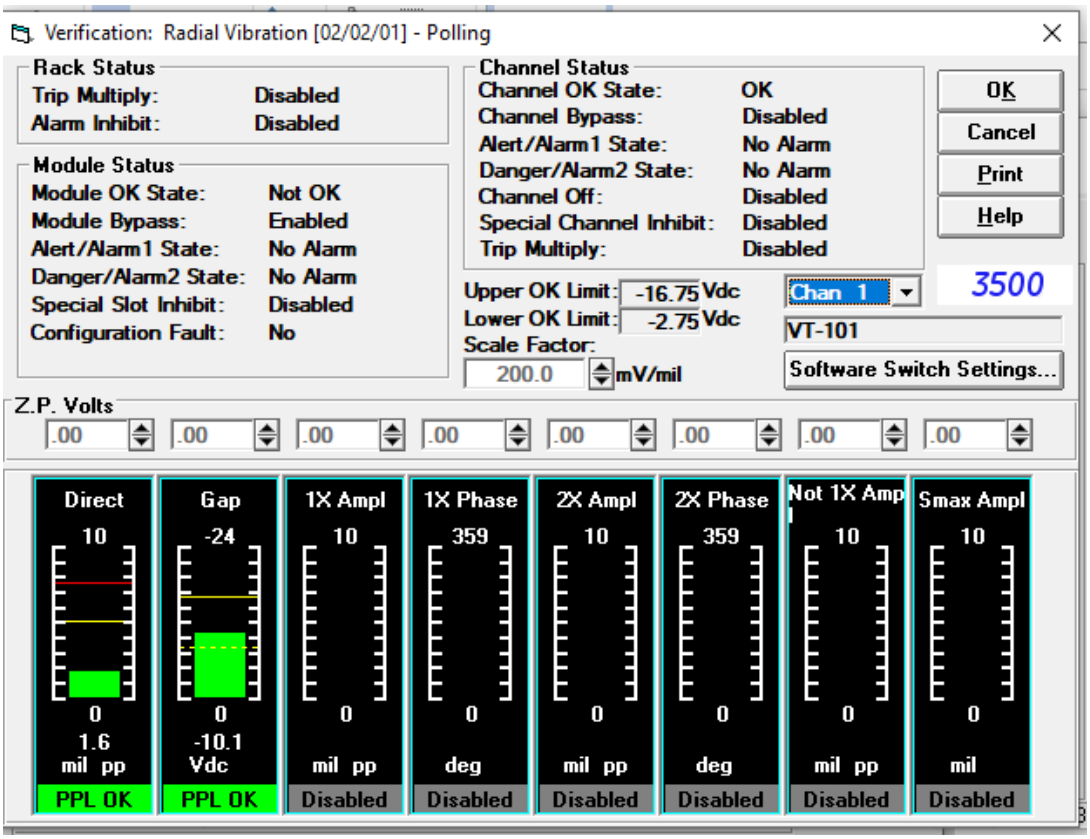
Appendix 86: Dual redundancy controllers and power supplies. Currently left hand in service.



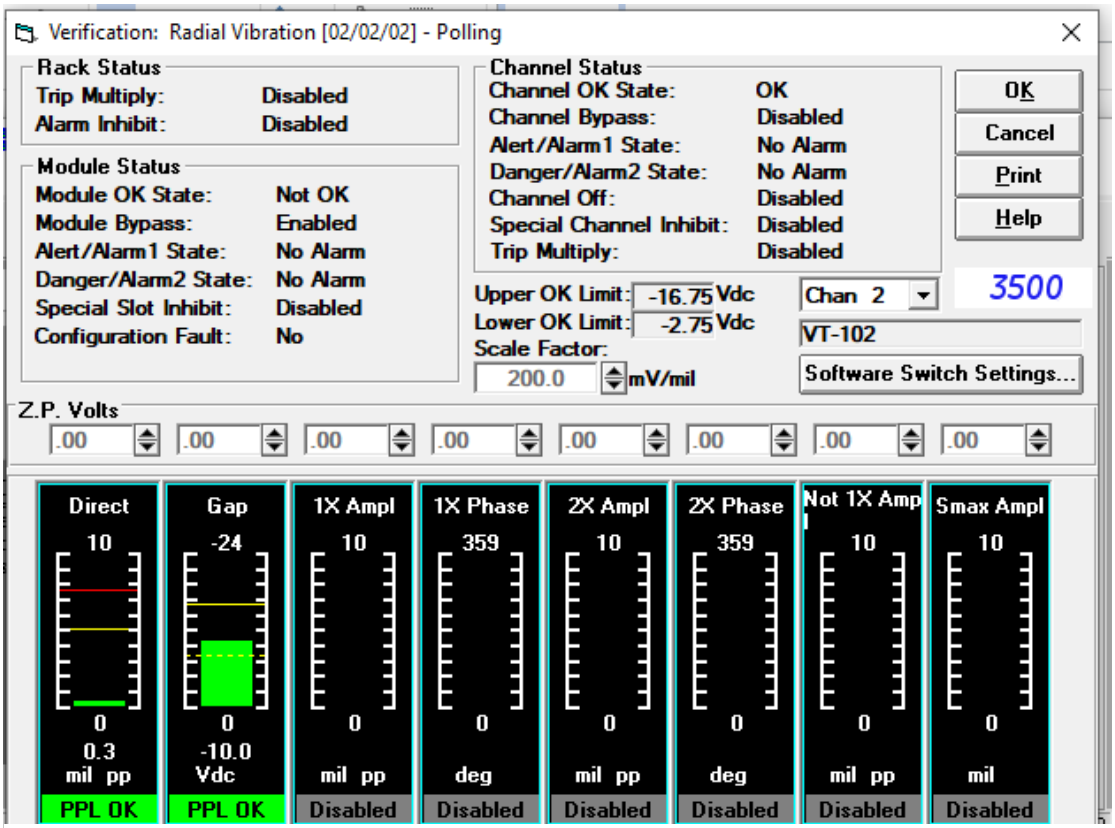
Appendix 87: DeltaV test rig.



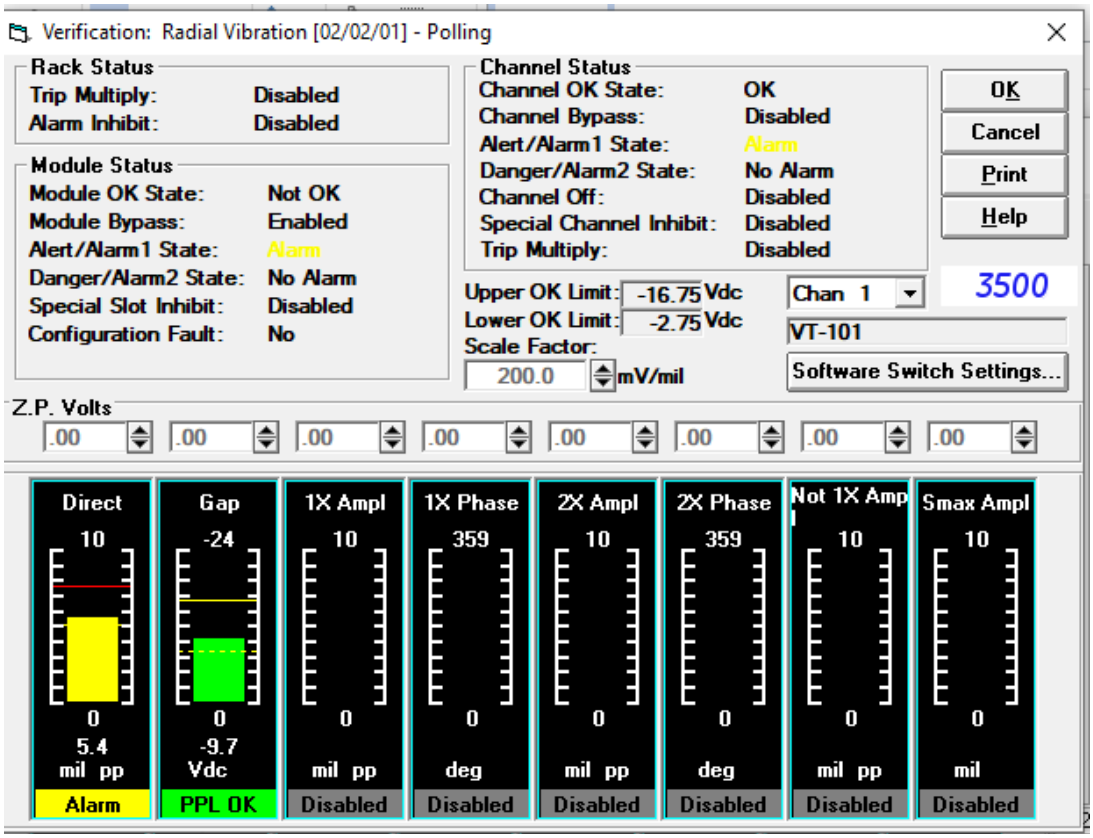
Appendix 88: Compressor manual stop test.



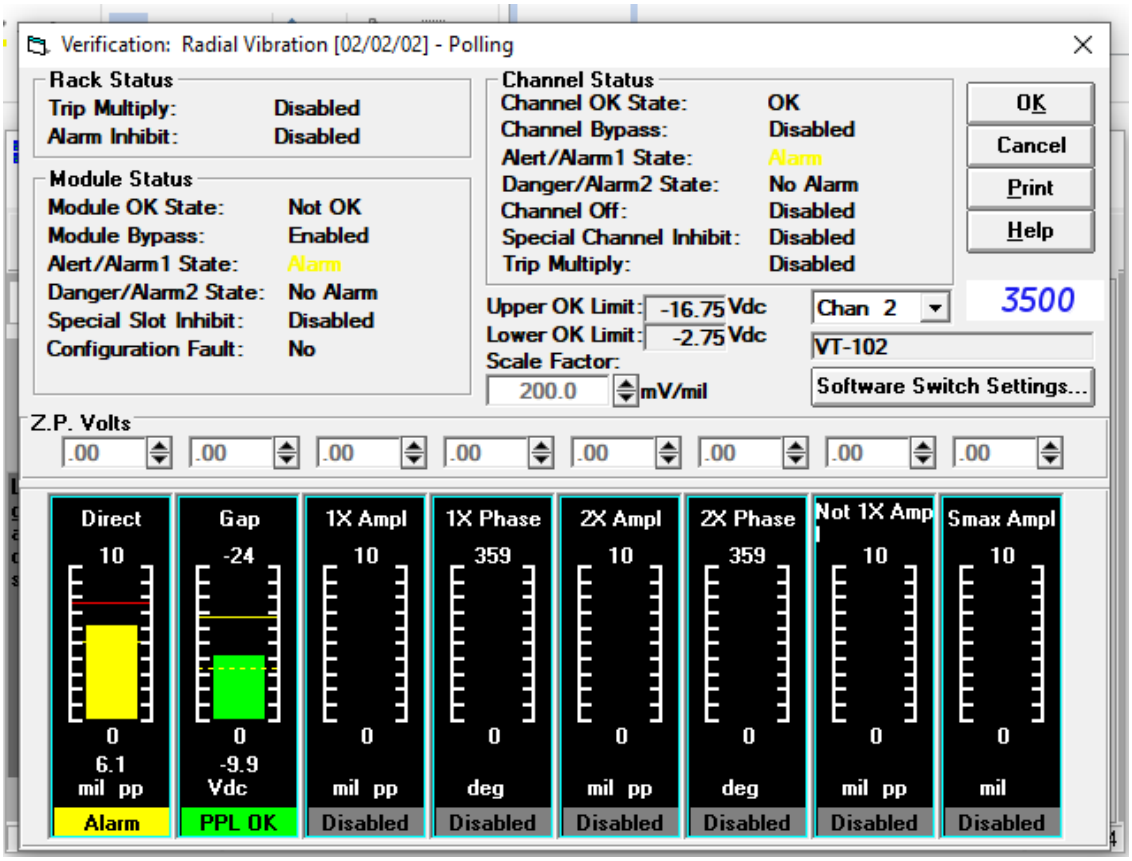
Appendix 89: VT101 probe on wobulator. gap voltage of 10V.



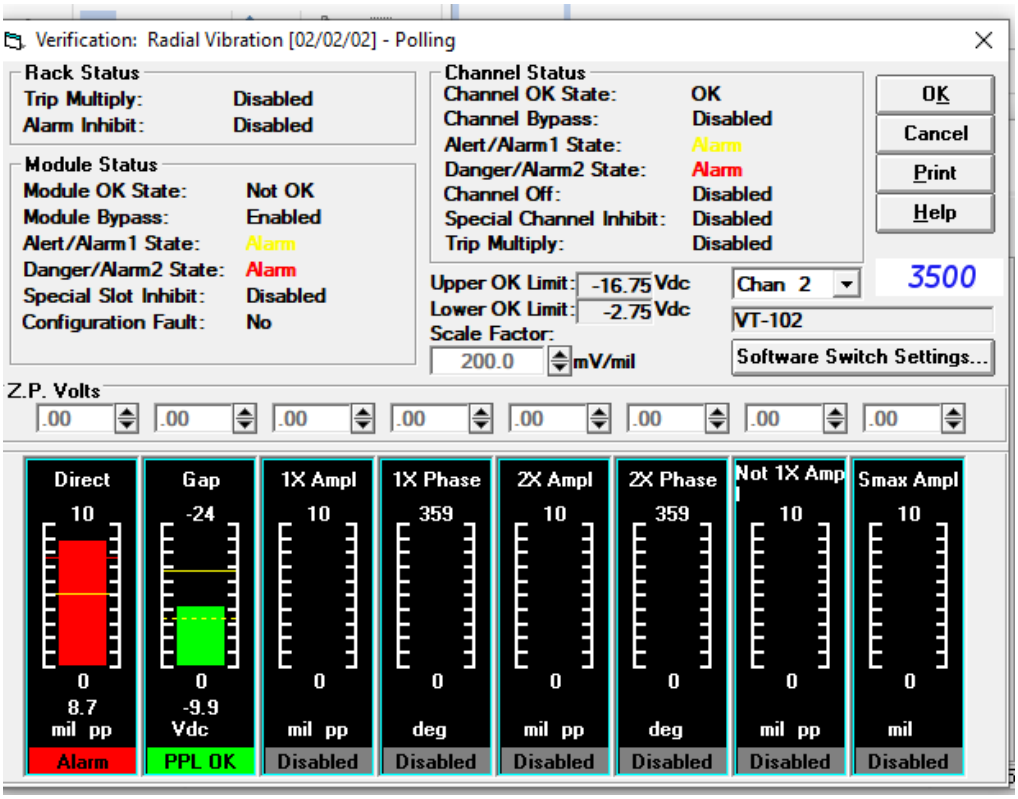
Appendix 90: VT102 on wobulator. Gap voltage of 10V.



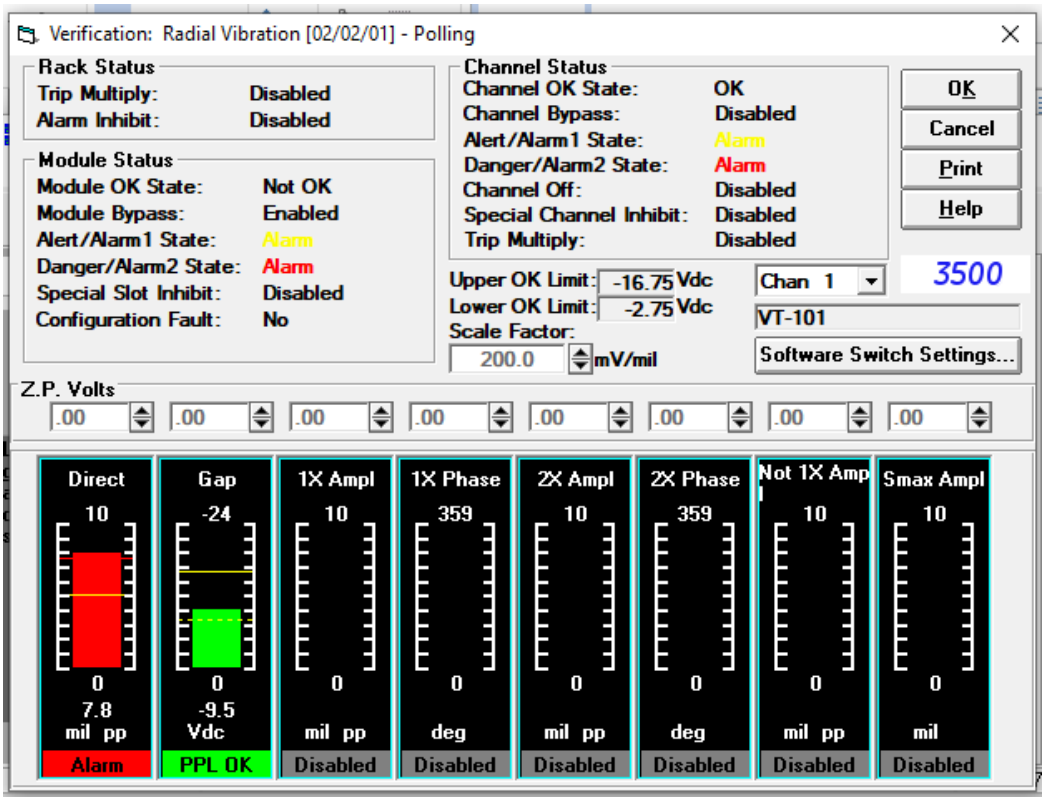
Appendix 91: VT101 in Alert.



Appendix 92: VT102 in Alert.



Appendix 93: VT102 in Danger.



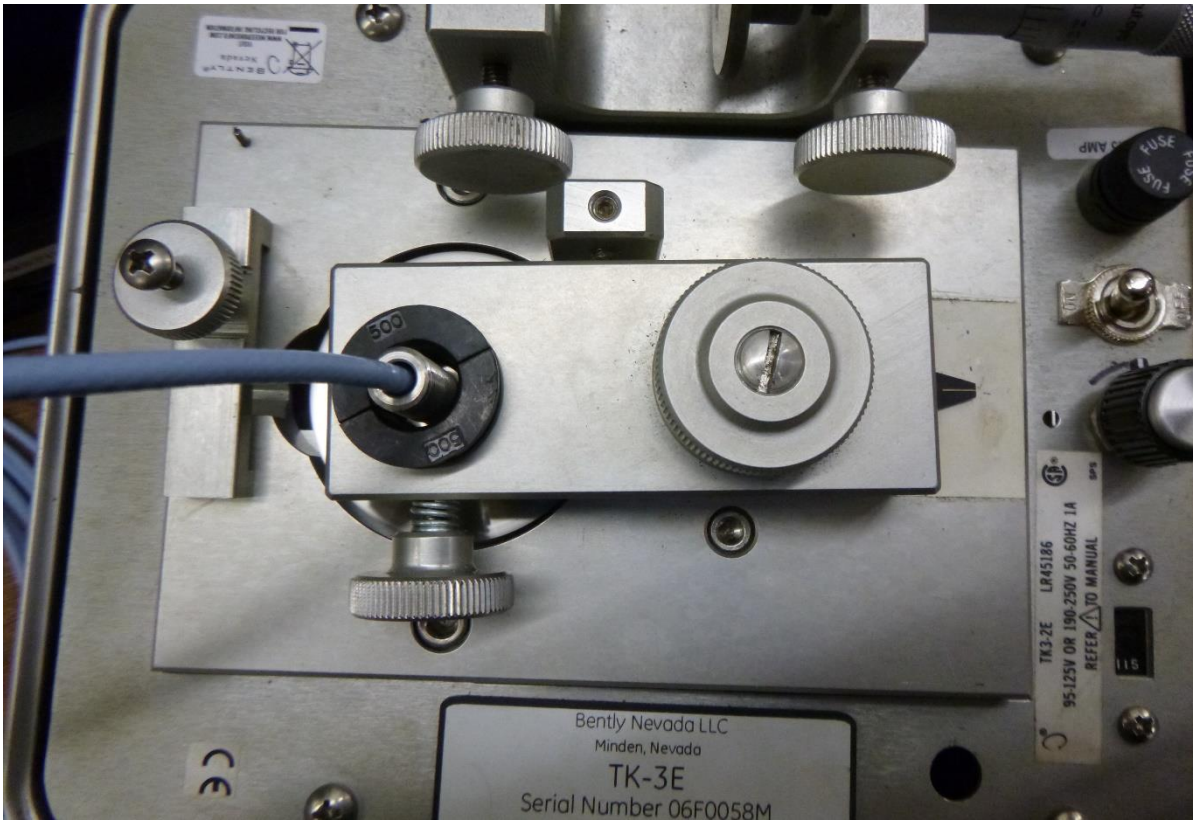
Appendix 94: VT101 in Danger.



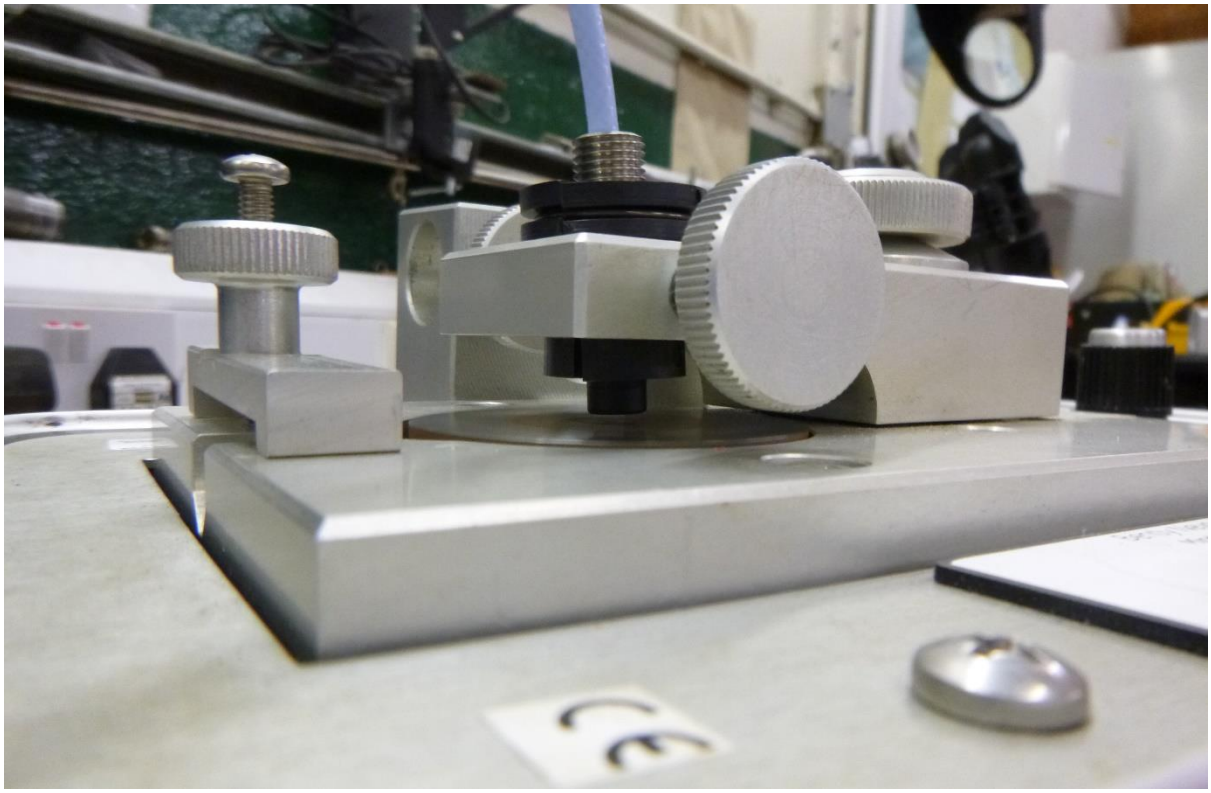
Appendix 95: 3500 rack.



Appendix 96: 3500 proximitor and extension for probes.



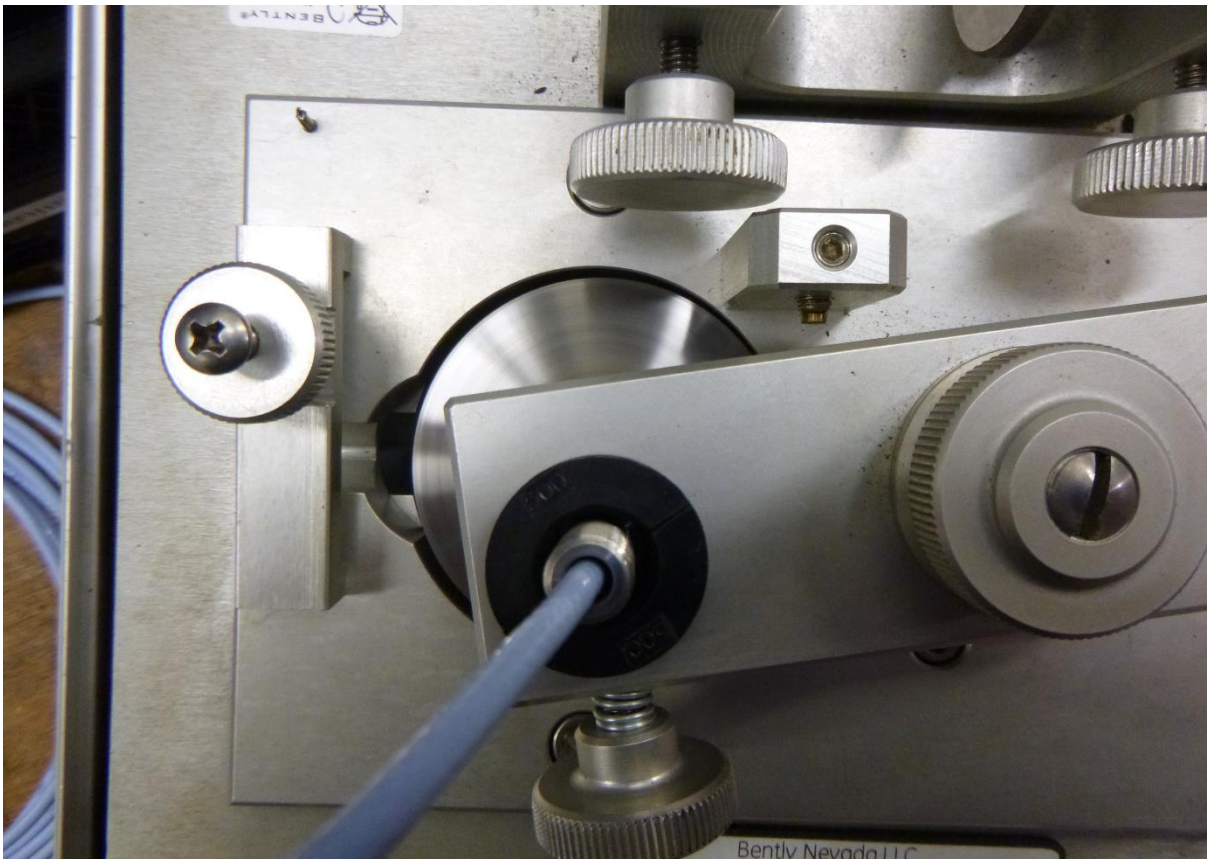
Appendix 97: Wobulator set up with probe positioned central.



Appendix 98: Gap voltage set to 10V.



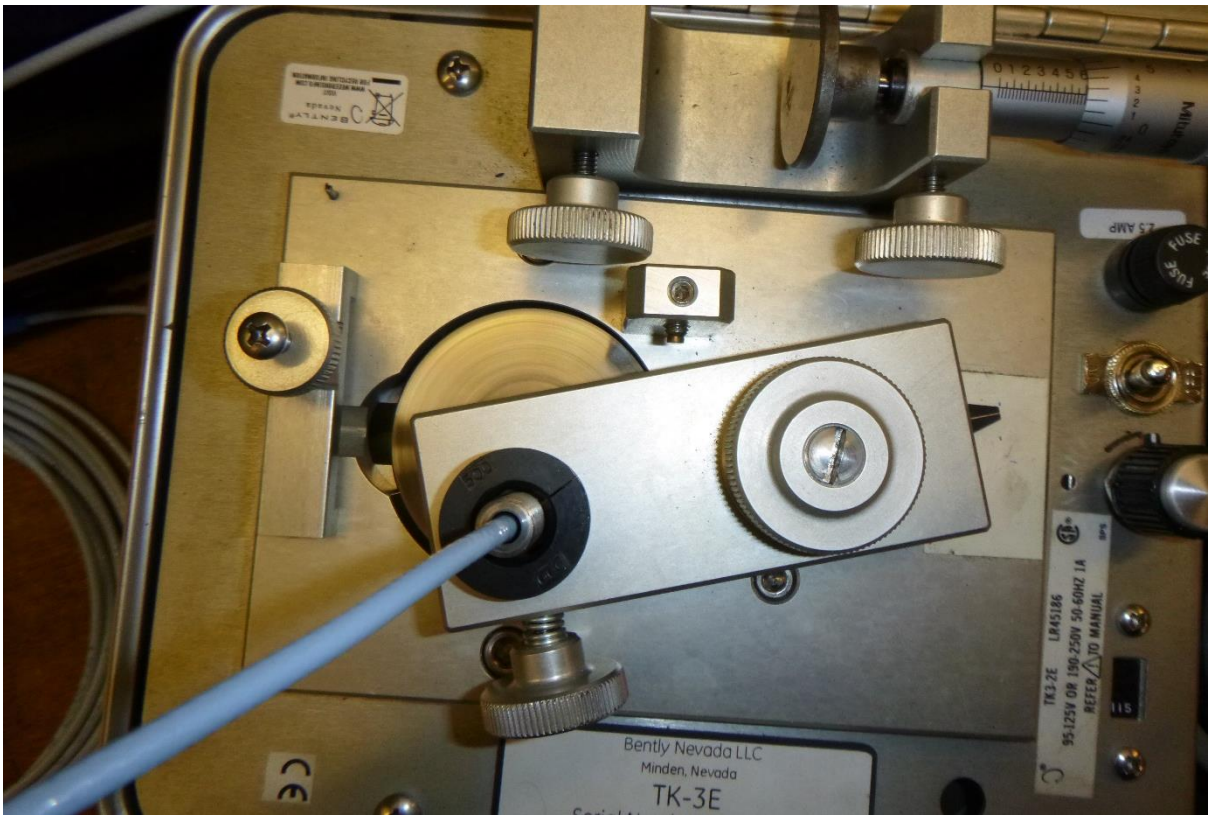
Appendix 99: With both probes below alarm limits, no alarms present on rack.



Appendix 100: Shift in vibration levels to Alert.



Appendix 101: Relay card output active, Alert OR logic condition has been met.

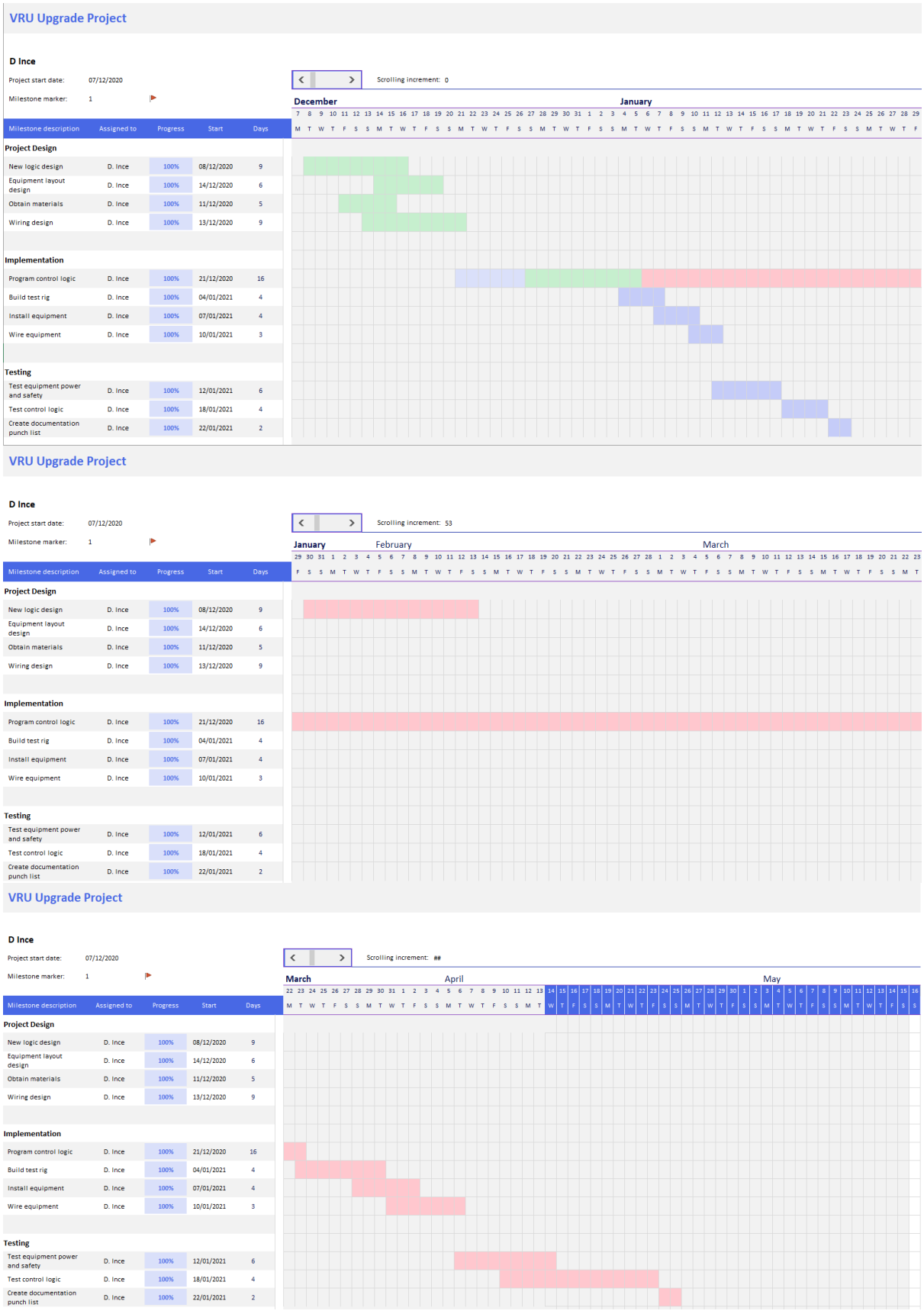


Appendix 102: Vibration levels increased to Danger for both VT101 and VT102.



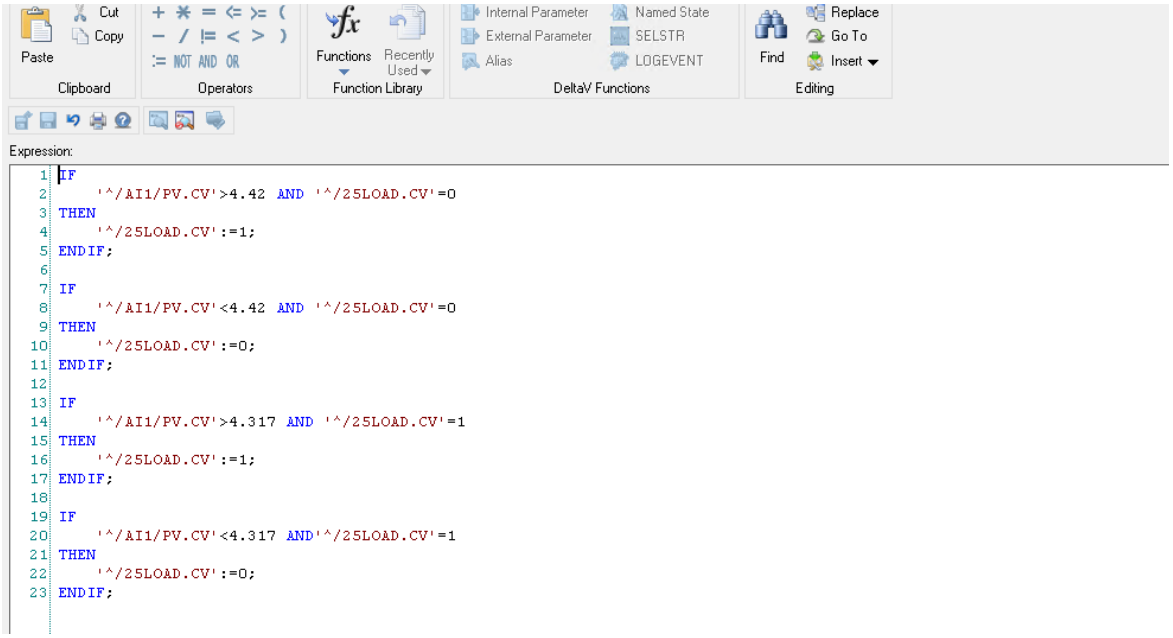
Appendix 103: Voting AND criteria met for Danger trip condition. Relay card shutdown output active.

8.3 Plan and Evaluation



Appendix 104: Project Gantt chart.

8.4 Miscellaneous



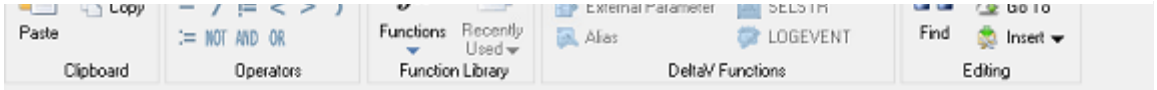

```
IF
    '^/AI1/PV.CV'>4.42 AND '^/25LOAD.CV'=0
THEN
    '^/25LOAD.CV':=1;
ENDIF;

IF
    '^/AI1/PV.CV'<4.42 AND '^/25LOAD.CV'=0
THEN
    '^/25LOAD.CV':=0;
ENDIF;

IF
    '^/AI1/PV.CV'>4.317 AND '^/25LOAD.CV'=1
THEN
    '^/25LOAD.CV':=1;
ENDIF;

IF
    '^/AI1/PV.CV'<4.317 AND'^/25LOAD.CV'=1
THEN
    '^/25LOAD.CV':=0;
ENDIF;
```

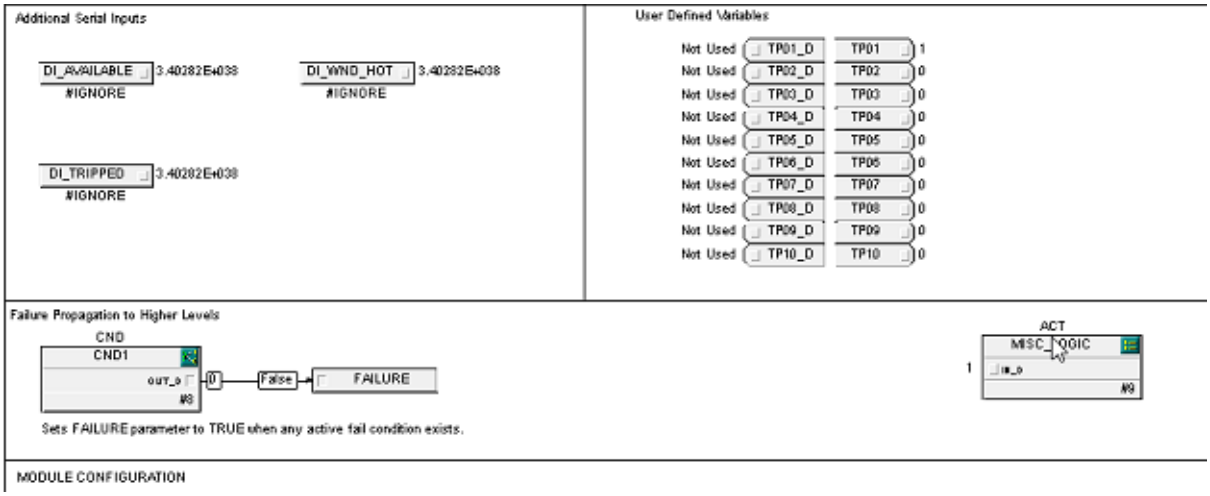
Appendix 105: Initial 25% loading logic.



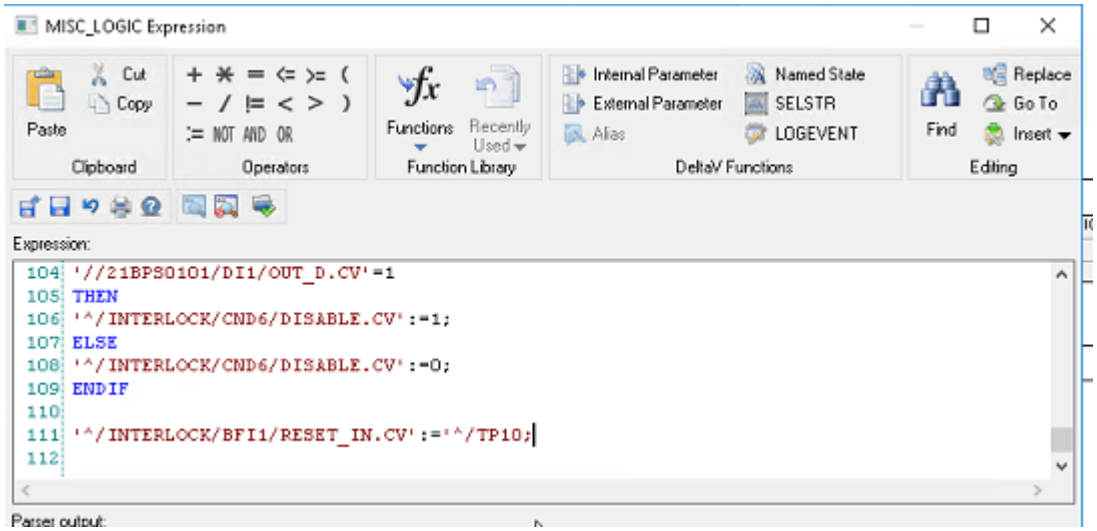

```
(*
=============================================================================
Set CAS_IN_D and SP_D of the DO1 block to REQ_SP and SP_D respectively if the values
are changed.
=============================================================================
*)
SP_D := '^/SP_D.CV';
REQ_SP := '^/REQ_SP.CV';
DO_MODE := '^/DO1/MODE.TARGET';
IF
    ((('^/DO1/CAS_IN_D.CV' != REQ_SP) OR (SP_D != REQ_SP))
    AND (DO_MODE = CAS))
THEN
    '^/DO1/CAS_IN_D.CV' := REQ_SP;
    '^/SP_D.CV' := REQ_SP;
ENDIF;
IF
    (('^/DO1/SP_D.CV' != SP_D) AND (DO_MODE = AUTO))
THEN
    '^/DO1/SP_D.CV' := SP_D;
ENDIF;

IF
'/DO1/OUT_D.CV'=1
THEN
'^/SP_D.CV' := 0
ENDIF;
(*
-----------------------------------------------------------------------------
Set the PV_D Named set parameter to ON and OFF depending upon the values of
DO1/PV_D parameter
-----------------------------------------------------------------------------
*)
'^/PV_D.CV' := '^/DO1/PV_D.CV';
(*
=============================================================================
End of Code
```

Appendix 106: ACT1 logic expression.



Appendix 107: Failure and Misc logic location.



Appendix 108: TP10 expression.