

Interim Report - Final

by James Davies

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PSDE 6019 – Major Project
Interim Report

Submission Date – 18/1/2018

Kiln Plant H2 Blower Pressure Switch Replacement and Functional Safety Assessment

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1. Introduction

The Vale Clydach refinery is a world-leading producer of nickel products for various industries. The carbonyl extraction process, discovered by Ludwig Mond and Carl Langer in 1899; is the main process used on site. This process involves extracting pure nickel from nickel oxide. This oxide is obtained from ore, and is concentrated by various processes in order to maximize yield.

Once the pure nickel has been obtained, it is fed into kilns and reacts with hydrogen gas in order to reduce the nickel oxides, leaving impure nickel. This can then react with CO (Carbon Monoxide) in order to form the volatile gas, nickel tetra-carbonyl, $\text{Ni}(\text{CO})_4$. Upon application of further heat, this molecule readily decomposes back into pure nickel and carbon monoxide gas. (Lancashire, 2000)

Hydrogen gas used in the nickel extraction process is highly flammable. Any amount leaking into the atmosphere can present a significant hazard to any persons in the vicinity. The H2 blowers on-site are a potential area for a major leak in the event of an overpressure scenario. There are currently high and high-high pressure switches on each blower as a safety instrumented system (SIS), but they are unreliable and provide spurious trips. In the event of pressure switch failure, there will be a potential for a H2 leak; and a spurious trip will lead to down time, which inhibits the capability of nickel production.

To resolve these issues, a decision has been made to replace the high-high pressure switch with a pressure transmitter. This transmitter will be connected to a logic solver, which will be programmed with the correct set point.

The aim of this project will be to design the new system following all relevant protocols stated in the IEC61508 functional safety standards. The following objectives will be met:

- Research the existing system in order to learn its operation so that an effective solution can be implemented.
- Calculate the Safety Integrity Level (SIL) rating for this system. Use this rating to determine the design of the circuit and the required components.
- Show three possible solutions that can solve this problem, and choose the most appropriate one. Full justification should be shown for choice.
- Develop a specification for solving the problem, and produce deliverables that can be reviewed to check if project was successful.
- Build and test the prototype. Review the data and determine whether the specification has been met.

Very clear introduction stating the problem and what needs to be done in rectifying it. Consider adding some sort of monitoring system for alarms or integrating into existing IAS system

2. Background Research and Literature Review

2.1 Research

The first stage of the carbonyl extraction process is to reduce the nickel oxide in the FMW in order to separate the nickel. This reaction involves H₂, and blowers are used to move the gas around the system. As stated, blower overpressure trips are necessary to control the circuit and avoid a catastrophic failure, which could cause a fatality.

The system currently has two pressure switches for each blower; these are arranged to provide a high and high-high level trip. Throughout their lifetime in the plant, their reliability has been questionable; therefore, the high-high switch will be replaced with the Foxboro IDG20B pressure transmitter that will feed an analogue signal into a logic solver. This logic solver will then provide the necessary trip signal.

The following formula is used to calculate the mA output for a given pressure (SensorONE Ltd, n.d.):

$$\text{Linear mA out} = 4 + (16 \times ((\text{Rdg} - \text{Low Rdg}) / (\text{High Rdg} - \text{Low Rdg})))$$

The lowest and highest reading for the IGP20B are 0.125 and 7.2 psi respectively. By using these values, along with the desired pressure of 5.5psi, the output current will be 16.155mA. This will be set in the STA as a percentage of the total span.

???

The

The transmitters will be in an explosive zone according to the ATEX (Explosive Atmospheres) section of the Dangerous Substances and Explosive Atmospheres Regulations (DSEAR). It is vital that they are rated for this area. Careful analysis of the datasheet confirms this with the following extract “The transmitters are designed to meet Agency flameproof and zone requirements.” (Foxboro Inc., 2013) *Excellent*

There are four H₂ blowers in the kiln plant, with two on each kiln line; one of these is shown in Figure 1. Photos can only be taken at a distance as only equipment rated for explosive zones can be used in close proximity.



Figure 1: H₂ Blower

Explain?

A diagram of the system would help at this point

The existing pressure switches are wired directly into safety relays located in a local wiring panel. The transmitter replacing these switches will output a 4-20mA signal that will be proportional to the pressure.

The current pressure switch used is the HNL series 700, as show in Figure 2. These provide a simple relay output which switches when the specified pressure is reached. They are EX rated, which means they are suitable for use in explosive atmospheres.



Figure 2: HNL Series700 pressure switch (MJ Wilson Group Ltd., n.d.)

2.1.2 SIL Rating Calculation

In order to find the SIL rating, a Layers of Protection Analysis (LOPA) will need to be conducted. LOPA is the newest tool for determining SIL. In terms of rigour and sophistication, it lies between the qualitative (Hazard operability, what if analysis etc.) and quantitative (fault trees and event trees) methodologies. It is mainly suited towards companies striving to meet specific risk targets (ABS Group, n.d.).

The process starts by first identifying the Safety Instrumented Function (SIF) and providing an identifying tag. The trip that will be looked at in this instance will be for Hydrogen Blower A/B outlet pressure (high).

The next task is to determine the hazard that is being protected against, as well as the consequences. In the case of blower overpressure, the likely outcome would be a release of H₂ and a subsequent explosion. The consequence of this would be severe injury or death to anyone occupying the area.

With this information in place, a tolerable risk (TR) factor can be stated; the standard figure for the Clydach refinery is $1e-5$ in the event of a fatality. The TR is the acceptable figure for this system and in this case represents one occurrence every 100,000 years. (Dearden, 2016) With that decided, the required Risk Reduction Factor (RRF) could be calculated. The next task will be to identify the initiating events in the system, as well as any inherent protection layers there may be.

Two initiating events could be identified for this scenario. The first would be a downstream valve closure as a result of basic process control system (BPCS) error, and the second would be operator error when switching blowers, resulting in the same scenario.

Conditional modifiers will also influence the outcome of an event. Whilst the modifiers are a layer of protection, they cannot be influenced in any way and act more like a last line of defence i.e. a failure has occurred, but no event has happened due to the conditional modifiers. The conditional modifiers in this system are ignition probability of the gas, the occupancy, and the individual profile time on site.

Typically, there will be independent protection layers (IPLs) for a given SIF. These are factors inherently built into the system, and will provide some degree of protection against risk. In this case, the BPCS is the only IPL, but no more than a factor of 0.1 can be claimed.

It is worth noting that even though certain defences may be present, they are illusory i.e. they occur too late to prevent a consequence. An example of an illusory defence in this scenario is the H₂ detection system, which sounds an alarm when a leak is detected. This would only take action if an overpressure event had already led to a burst, and does nothing to prevent the pressure build up.

*Very good detail
You may consider monitoring pressure rather than
just setting an alarm.*

The aforementioned factors can be put into Table 1 along with their values:

Initiating event:		Valve failure	Operator error
Independent Protection Layers	Frequency:	0.02	0.02
	BPCS	1	1
Conditional Modifiers	Ignition Probability	0.1	0.1
	Occupancy	1	1
	individual presence on site	0.2	0.2
Intermediate Event Frequency		0.0004	0.0004
Total Event Frequency (without SIF)		0.0008	
Tolerable Risk		1.00E-05	
Required Risk Reduction Factor		80	

Table 1: LOPA Summary

The explanation of these values is as follows. The frequency of each event is decided because the blowers are switched over every six months. The operator will likely leave the valve closed in error every one out of a hundred operations, which results in a frequency of 0.02 events per year, or one every 50 years. The same can be said of BPCS failure in the event of start-up, which could lead to upstream valves being kept closed.

The ignition probability was decided to have a value of 0.1, or one event every ten years based on it being a zone 2 area, whilst individual presence on site was 0.2 because an individual would be on site 1/5th of the time on average. No claim can be made against occupancy because the occupant carries out the action near the blowers, putting them at risk 100% of the time; therefore, it is left at one. A claim also cannot be made against the BPCS as it is already an initiating event, and claiming would be what is known as 'double-dipping' in this situation.

With all of these values, an intermediate event frequency is calculated by multiplying the figures in each column. The sum of these intermediate values is then found to give the total event frequency that will occur with no SIF in place. In order to find the RRF, the total event frequency is divided by the TR.

By referring to the table in Figure 3, it is possible to determine the SIL rating from the RRF. It shows the SIL ranges for Probability of Failure on Demand (PFD), which is simply the inverse of RRF. The PFD obtained is 1.25e-2, which will correspond to a SIL 1 rating.

PFD - Probability of Failure on Demand per year

Safety Integrity Level (SIL)	PFD (Low Demand Mode)	PFD (High Demand Mode)
1	$> 10^{-2}$ to $< 10^{-1}$	$> 10^{-6}$ to $< 10^{-5}$
2	$> 10^{-3}$ to $< 10^{-2}$	$> 10^{-7}$ to $< 10^{-6}$
3	$> 10^{-4}$ to $< 10^{-3}$	$> 10^{-8}$ to $< 10^{-7}$
4	$> 10^{-5}$ to $< 10^{-4}$	$> 10^{-9}$ to $< 10^{-8}$

- Low Demand Mode – intermittent operation (less than once a year)
- High Demand Mode – Continuous operation or systems that operates more than once a year

Figure 3: PFD Requirements

*Can't say I understand this completely!
Clarify please.*

2.2 Solutions

The following three design solutions have been considered to a trip signal when the pressure reaches a certain level:

2.2.1 Moore Industries Safety Trip Alarm (STA)

The STA is designed to perform as a logic solver, and will produce alarm outputs based on the how it is programmed; it is certified to SIL 2 and SIL 3. It is user programmable, and can be set using SIL certified software or via the front panel.

The STA will accept 4-20mA signals which are currently provided by Crowcon Xgard gas detectors. However, for the purposes of this prototype, a 4-20mA generator can be used in its place and the user can manually set the input. A 4-20mA output is also provided so that the input signal may be relayed to an IA system for trending and data logging. (Moore Industries Inc., 2017)

The cost of each unit is approximately £783 as of 2017, and four units will be required leading to an approximate cost of £3000. (Radwell International, n.d.)

The STA will be connected directly to a Pilz safety relay, which will remain closed when active. These relays are SIL certified, and are used to provide a trip for the system. Figure 4 demonstrates how these devices will interconnect:

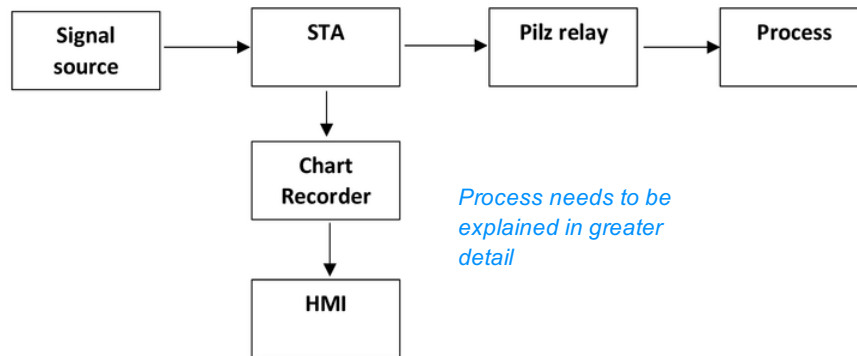


Figure 4: Moore Industries STA block diagram

One of these devices could send information to the plant monitoring system!

2.2.2 National Instruments cRIO

National Instruments are a company which develop a range of high quality instruments for data gathering and automation, including a range of embedded controllers such as the RIO, whose available processing targets include: a real time processor for communication and signal processing, or a user programmable FPGA for high speed applications. (National Instruments, n.d.). There are digital and analogue cards available for the cRIO platform which means it can accept a 4-20mA signal and provide the logic for the alarms.

The software used to control and provide a graphical interface for the user is LabView, meaning the current IA system would be redundant. This software is programmed by using functional blocks, and process variables can be displayed to the user. Figure 5 shows layout of this system:

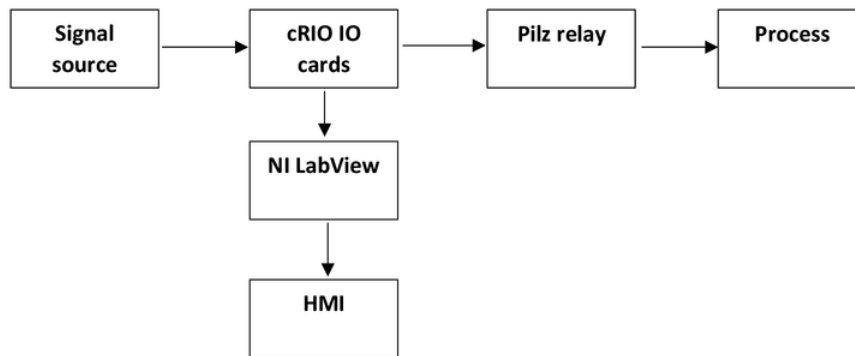


Figure 5: NI cRIO Block Diagram

Good explanation given although the cRIO would not be a good choice because of the low number of IO required

The following is a price breakdown for this solution:

- NI cRIO 9030 - £2,210
- NI 9375 - £485
- NI 9219 (x3) - £3,570
- Ni LabView software - £2,980
- Total - £9,245

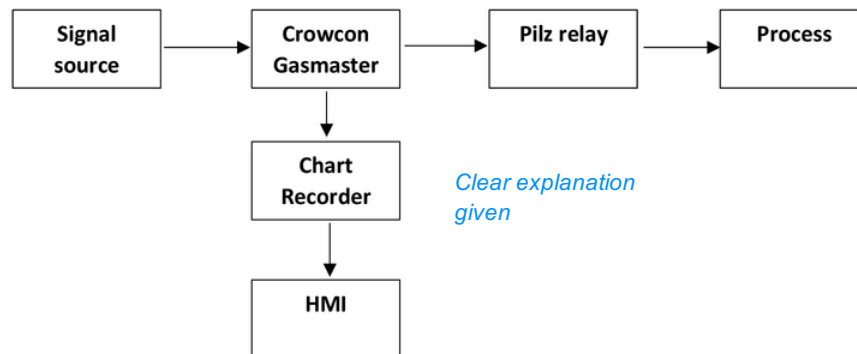
These prices were obtained from the National Instruments website (National Instruments, n.d.)

2.2.3 Crowcon Gasmaster

The Crowcon Gasmaster is a gas detector control panel designed to be used in conjunction with Crowcon gas detectors. The sensor will accept 4-20mA inputs and display these values on a built-in LCD. The unit has an RS485 Modbus module installed for communication purposes, and an optional port is available for PC communications.

There are two alarm outputs available on this device, a low alarm and a high alarm; which can be fed into another system. The device itself is rated to SIL 2, which means it will have a certain level of reliability. (Crowcon Inc., n.d.)

Figure 6 represents how the Gasmaster would fit into a system:



*Clear explanation
given*

Figure 6: Crowcon Gasmaster Block Diagram

The approximate cost of the Gasmaster is around £1742 (PSE Priggen, n.d.)

All solutions referenced correctly

2.2.4 Chosen solution

	Moore Industries STA	National Instruments cRIO	Crowcon Gasmaster
Operating Voltage	24V	24V	24V
Dimensions	102 x 56 x 142mm	219.5 x 88.1 x 109.2 mm	288 x 278 x 110mm
SIL capability	SIL 2	NA	SIL 2
IP rating	NA	NA	IP65
Function	General	General	Specific
Cost per Unit	£1000 approx	£10,000 approx	£2000 approx
Inputs	Analog	Analog/Digital	Analog
Outputs	Relay	Analog/Digital	Relay

Table 2: Summary of Solutions

The NI cRIO and Crowcon Gasmaster may be able to perform to the specification, but they have not been adopted on site. As a consequence, staff will need to be trained in the use of their systems, as well as any associated software. This could result in a large cost for the company. The STA is widely used on the refinery, is easily obtained, and is generally kept as a stock item. This results in shorter periods of downtime in the event of a breakdown.

It can be difficult to justify the purchase of new equipment, as it can pose a risk to the company if it does not perform as expected; therefore, it is sensible to incorporate currently stocked items. This will increase maintainability and take less time to install because engineers will already be familiar with the device.

The STA will be far easier to implement than the other system, as the amount of software configuration would be minimal. Creating effective LabView user interfaces can be cumbersome, and would be difficult for untrained personnel to maintain; with an existing IA system in place, it would be unnecessary to implement additional software.

The Gasmaster will not fit in the existing panels; therefore, it will need a new mounting point, which is an issue due to the risk of disturbing asbestos and using power tools in an explosive zone. It would require installation by trained personnel, which will increase cost.

The Gasmaster is aimed towards gas detection, and is not suited for general use. The STA has no specific function; it will work well with any equipment that produces a 4-20mA signal. The Gasmaster is also too large to fit inside the existing panel; therefore, it would have to be externally mounted. The STA on the other hand will fit directly into the panel.

The NI system is not SIL rated, neither is the LabView software. This means that they are entirely unsuitable based on the SIL rating calculated from the LOPA. In the event of demand on the cRIO, there is no way to guarantee that it will reliably perform its function.

Based on these arguments, the chosen solution will be the STA. it would be impossible to justify the use of the NI system due to the aforementioned points, and the Gasmaster is not appropriate for this type of system. The STA will provide the necessary functions, and has the appropriate SIL rating for this project.

The Foxboro pressure transmitters are approximately £1000 per unit, which means that the total cost of the project, including approximately £1000 installation cost, will be around £9000.

Good, clear and reasoned choice made!

3. Specification

3.1 Project Requirements

The scope of this project will be to investigate the functional safety requirements of this modification and manage the change of each valve, to include modifying the design and allocating resources. The following requirements are the project deliverables in a black box format:

1. Pressure to be continuously monitored
2. Trip to occur at 5.5 psi
3. Must conform to the following regulations:
 - a. DSEAR
 - b. IEC 61511 and 61508 functional safety regulations
 - c. Low voltage directive
4. Design must conform to SIL rating, to encompass the following:
 - a. Hardware Fault Tolerance
 - b. Systematic Capability
 - c. Process Safety Time
 - d. Safe Failure Fraction
5. Must not exceed budget of £15,000
6. Accuracy of 1% to be achieved across the full range
7. Trip signal supplied by volt-free contact at 24VDC

These have been provided by the kiln plant supervisor, and will be used to assess whether the project has been completed as intended.

Good detail but consider adding plant

3.2 Technical Specification

mentioning or remote alarms

The following technical specification will provide more in depth details about the project:

1. All equipment installed must work at 24VDC
2. Foxboro IGP20C pressure transmitter to be used
3. Pressure transmitter must be calibrated to provide 16.155mA output at 5.5psi
4. Pressure transmitter to provide analogue signal to the STA, which in turn will provide a trip signal to the existing Pilz relays
5. Correct wire colouring and numbering scheme to be followed
6. STA output relays to be configured as a redundant pair
7. All equipment used must have a CE rating to show conformity to European regulations

Good detail

3.3 Environmental Specification

The following will be a list of all environmental requirements for the project:

1. Ensure that all waste is properly recycled
2. Ensure that any effluent is directed to the proper processing facilities

3.4 Safety Specification

The following list details the safety requirements of the project:

1. Ensure that all work procedures conform to the Health and Safety at Work Act 1974
2. Ensure correct PPE is provided to the technicians installing the project
3. Ensure the correct isolation procedures are followed in order to prevent electrocution and gas leaks when implementing the new transmitters

What does PPE refer to?

All of the requirements will become part of the project testing once the chosen solution has been implemented. A testing table will be made in order to check against the test criteria, and to write any relevant comments.

Good detail on safety and environmental issues

4. Planning and Procedures

In order to carry out this project, there will many aspects to consider. A major consideration will be on health and safety. While undertaking the work to install the new equipment, the correct procedures and legislation will need to be followed, such as wearing the correct personal protective equipment (PPE), and ensuring all work equipment is safe to use.

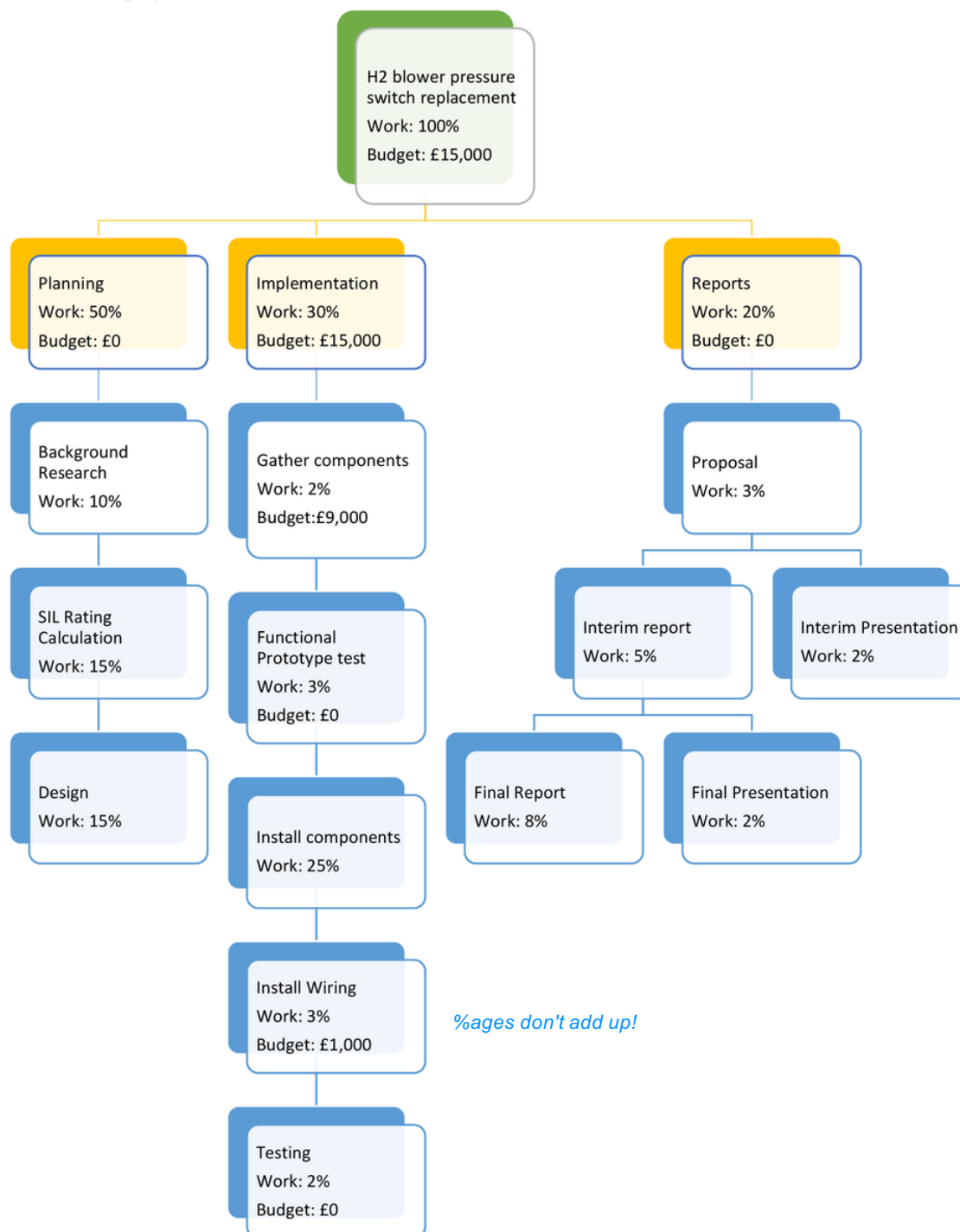
As mentioned previously, this is an explosive area under DSEAR regulations. As a result, care will need to be taken to avoid igniting any gas leaks. Any work or equipment that could produce an ignition source should be confined to the safe areas. This includes any sort of power tools, or any source of sparks.

A functional test will be performed to demonstrate the correct operation of the system, and then the project will be implemented on site. Due to limitations in terms of plant shut down times, these functional test results can be used as a contingency option if the main system cannot be installed in time.

As outlet pressure will now be measured, it may now possible to provide complex control of an existing pressure relief valve. This may aid in preventing the blower from overpressure; therefore, an investigation into a control scheme for his system could be carried out, with the Simulink software used to provide simulated results. It will be possible to experiment with PID control using this model in order to provide effective control of the process reaction curve, and the results of this investigation may lead to further improvements at a very low cost.

In order to maintain safety standards, a risk assessment will be carried out in order to show the hazards present, and the mitigations that are in place to reduce the risk. This will also provide evidence to the HSE that the project is safe.

The following work breakdown structure was created to represent the various stages involved in this project:



Good detail in WBS which has led to a good Gantt Chart covering all aspects of the work to be carried out.

With the work breakdown structure made, the following Gantt chart can be created:



Several tasks are shown to be on schedule thus far, with the dark section in the middle representing current progress. This is a good indication that the project is successfully underway and the tasks are being completed on time.

5. Project Progress and Testing

With the SIL rating calculated, and the appropriate solution chosen, it is now possible to continue with the design of the circuit. Many aspects to the IEC61508 and more specifically IEC61511 state how the circuit should be arranged in order to comply with the calculated SIL rating.

In order to meet the specification, evidence will need to be provided to show that the deliverables have been met. To show compliance with the regulations, the report will be assessed by an expert in the field.

As a small test of the system, a prototype setup was built in a workshop. A loop tester was connected to the STA in order to provide a 4-20mA signal, and the STA trip indicator lamps showed whether there had been a trip or a fault. The ranges programmed into the STA for this test were -12.5 at 0mA, and 62.6 at 24mA. The low alarm was designed to occur at a reading of 4.3 EGV (Engineering Value), and the high at a reading of 51.25 EGV. The scale was set to 0 at 4mA, and full at 20mA.

The following table demonstrates the tests carried out to prove the STA works correctly:

Test	Result
1. Supplied 0mA to the STA	Reading on device was -12.5 EGV, which was out of range. Trip 1 active as shown in Figure 7.
2. Supplied 4mA to the STA	Reading of 0EGV shown on device. Trip 1 remains active as shown in Figure 8.
3. Supplied 8mA to the STA	Reading of 12.5EGV on device. Trip 1 no longer active as shown in Figure 9.
4. Supplied 20mA to the STA	Reading of 50EGV on device as shown in Figure 10.
5. Supplied 24mA to the STA	Reading of 62.5EGV shown. Trip 2 now active as shown in Figure 11.



Figure 7: Test 1



Figure 8: Test 2



Figure 9: Test 3

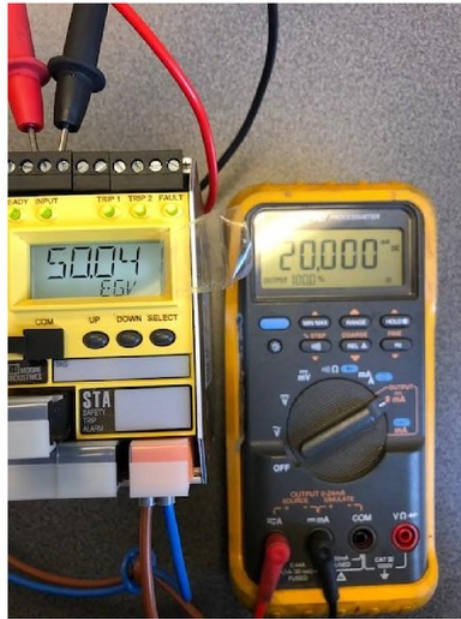


Figure 10: Test 4



Figure 11: Test 5

Good use made of pictorial evidence showing the Safety Trip Alarm works within the set limits

6. Conclusions and Recommendations

In conclusion, the project is successfully underway. With the SIL rating calculated and the solution chosen, the next step will be to continue with the circuit design. There are many considerations to be made under the functional safety standards, such as: Hardware Fault Tolerance, Safe Failure Fraction, Systematic Capability and Process Safety Time. These will all be required to conform to the SIL rating in order to be compliant.

The background research has provided all of the information required for the specification, and this is what will be used to determine whether the project is complete. The deliverables will be checked off at the end in order to show that the work has been finished, and the project was successful.

The judgements made in the design, as well as test results will be the evidence used during safety audits in order to prove that the system is tolerably safe. In the event that an incident was to happen, this evidence will also be upheld in a court of law as proof that considerations were made towards functional safety. The figures used for the LOPA analysis can be used as justification of the engineer's intent at the time, and proves that there was no ignorance of safety during the design process.

The prototype test demonstrates the correct operation of the equipment, as well as the type of procedure which will be used to calibrate the device. For the main installation, a pressure transmitter will be used. The chosen solution is clearly the most appropriate; it should result in a reliable safety system.

As for project timing, it is on schedule. According to the timing plan, by this point the research should have been complete, and the design and implementation ready to begin. As part of the planning, the SIL rating has also been calculated. It is clear from the report that those objectives have been met, and progress can be made towards the other goals. A detailed logbook has been kept in order to track progress throughout the project.

Good general conclusion given

Would have been nice to see some research as to the type of pressure transmitter that could have been chosen instead of stating that it would be the Foxboro IDG20B.

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*Good set of references noted which shows good
research carried out*

Interim Report - Final

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

67 / 100

PAGE 1

PAGE 2

PAGE 3

PAGE 4

Text Comment. Very clear introduction stating the problem and what needs to be done in rectifying it. Consider adding some sort of monitoring system for alarms or integrating into existing IAS system

PAGE 5

Text Comment. ???

Text Comment. Excellent

Text Comment. Explain?

Text Comment. A diagram of the system would help at this point

PAGE 6

PAGE 7

Text Comment. Very good detail

Text Comment. You may consider monitoring pressure rather than just setting an alarm.

PAGE 8

PAGE 9

Text Comment. Can't say I understand this completely! Clarify please.

PAGE 10

Text Comment. Process needs to be explained in greater detail

Text Comment. One of these devices could send information to the plant monitoring system!

PAGE 11

Text Comment. Good explanation given although the cRIO would not be a good choice because of the low number of I/O required

PAGE 12

Text Comment. Clear explanation given

Text Comment. All solutions referenced correctly

PAGE 13

Text Comment. Good, clear and reasoned choice made!

PAGE 14

Text Comment. Good detail but consider adding plant monitoring or remote alarms

Text Comment. Good detail

PAGE 15

Text Comment. What does PPE refer to?

Text Comment. Good detail on safety and environmental issues

PAGE 16

PAGE 17

Text Comment. %ages don't add up!

Text Comment. Good detail in WBS which has led to a good Gantt Chart covering all aspects of the work to be carried out.

PAGE 18

PAGE 19

PAGE 20

Text Comment. Good use made of pictorial evidence showing the Safety Trip Alarm works within the set limits

Text Comment. Good general conclusion given

Text Comment. Would have been nice to see some research as to the type of pressure transmitter that could have been chosen instead of stating that it would be the Foxboro IDG20B.

Text Comment. Good set of references noted which shows good research carried out

GRADING FORM: CSG-RUBIC

JAMES DAVIES

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RESEARCH-INFORMED LITERATURE



Introduction (4/5): Aims and objectives clearly set out. Consider adding a monitoring system to your objectives. Background Research (3/4): Good evidence of research, however, the addition of some diagrams would greatly help the reader. Harvard referencing (3/4): Very wide range of sources listed and cited correctly. Literature Review (4/7): Some evidence of research but choice of solution seems to write off the other two far too early. If plant monitoring is added, a different solution may have been chosen.

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KNOWLEDGE AND UNDERSTANDING

-  WBS (7/10): Good, consider adding remote monitoring features. Specification (7/10): Good, very detailed and professionally written. Considering increasing spec to include remote monitoring. Gantt Chart (6/10): Good level of detail but no contingencies

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ANALYSIS

-  Analysis of test results (6/10): Results show that the Safety Trip Alarm works within the set limits. Helpful comments made. Conclusions (7/10) Good conclusions drawn up which does include some reflection.

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PRACTICAL APPLICATION AND DEP.

-  Progress to date (4/5): Good evidence of testing. Action plan clearly shows the project is on schedule. Presentation of test results (3/5): Presented in table form with supporting evidence.

7

SKILLS FOR PROFESSIONAL PRAC.

-  Recommendations (6/10): Conclusion states clearly what is left to do to complete the project. This could expand to include the plant monitor system. Quality of report (7/10): Very good structure, well written and presented. A few more diagrams would help in the introduction.

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