Design a Safety Control System for the Instrument Air Supply in a Qatar Plant

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Abstract: **The report will compare and discuss the existing control system implemented by a plant in Qatar and the newly designed control system for the plant based on reliability and probability of failure on demand (PFD) calculations. This report also describes the new control system in terms of designing, building and testing phases of the control system. This plant uses the blowback system to filter out product dust from the waste gas using a filter. The filter is cleaned using the air flow that comes from the air header which is controlled by a poppet valve (solenoid valve). The poppet valve purges air for fixed intervals of time. The failure of the poppet valve (stuck open) led to a continuous flow of air and the pressure in the air header was decreased from 7 bar to 3.5 bar. This triggered the emergency shutdown alarm and the plant was shut down. Due to the shutdown, the company loses time and money. The company fixed the problem by implementing one transmitter and one on/off valve. The purpose of this project is to design (based on reliability), build and test a control system which will monitor and control the pressure in the instrument air supply line and takes the process to a safe state by closing the valve in case the pressure decreases below the setpoint. The instrument drawings for the new control system were created. The reliability calculations were done for both the control systems (company's solution and student's solution). The new control system was more reliable and the probability of failure on demand rate was lower than the company's solution. The control system was developed using programming languages (function block diagram and ladder logic diagram) with the help of RSLogix 5000 software and a HMI interface for the control system was created using Factory Talk View software. The developed program was capable of taking the process to a safe state (in case the pressure decreases below the setpoint) and the HMI interface displayed the pressure measurements and alarms triggered by the process. The recommendation with this report is to use a different type of voting system for the controller (2oo2 with diagnostics) which involves selecting the transmitters with Advanced HART diagnostics suite. The 2oo2 Diagnostics voting logic provides high safety and low false trips. The diagnostics feature continuously checks the health of transmitters and takes preventive measures by notifying the operator before abnormal process conditions can occur.**

Keywords**: Pressure, Safe, Process, Control System, Design, Air, PLC, HMI.**

1. INTRODUCTION

This section discusses the project's problem statement, gives a brief summary of the project's background, and the project's objectives and criteria. In order for an oil and gas company to be successful, its operation must be interrupted as little as possible. A shutdown of a plant will cost the company. The purpose of this project is to design, build and test a safety control system for the plant in Qatar which will monitor and control the pressure in the air header line to prevent the plant from shutting down upon decrease of pressure in the air header when a on-off valve fails.

1.1 BACKGROUND

The plant produces about 44 ton/hour of low density product. Figure 1 shows the the plant operation.

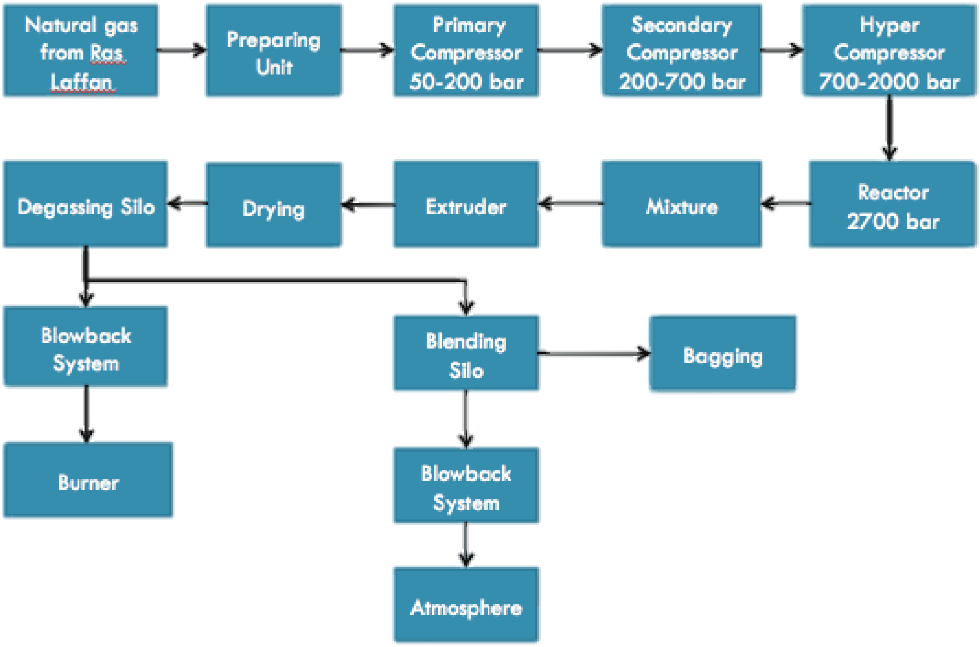

Fig 1: Plant operation.

The problem found is that the plant will shut down when the pressure decreases in the air header due to a failure of the blowback system. Figure 2 shows the operation of the blowback system. The blowback system is used to separate the waste gas from the product dust using a filter and then releasing the waste gas into the atmosphere. The waste gas is filtered to reduce the harmful emissions when released to the atmosphere. The filter gets contaminated over time and requires frequent cleaning using an air flow that comes directly from the air header. The air flow is purged to the filter for fixed intervals of time using an on-off valve (i.e., poppet valve / solenoid valve) during the operation of the plant. The dust from the filter is collected at the bottom of the filter in the dust collector bag. The air flow from the header to the filter is controlled using an on-off valve and a manual valve. The failure of the on-off valve (stuck open) leads to the continuous flow of air from the header and causes the pressure inside the header to decrease. The pressure in the air header decreases from 7.0 bar to 3.5 bar. When the pressure in the header is decreased to 3.5 bar in the main air header, the plant shuts down due to emergency shutdown alarm. This problem occurred at February 28, 2014. When the plant is shut down for maintenance, all the plant operations are stopped. Due to the shutdown, the company loses time and money. When the pressure decreases in the air header, the manual valve is closed manually by the operator to stop further pressure decrease in the air header. The problem with this system is that the operator must always be present near the air flow line from the header.

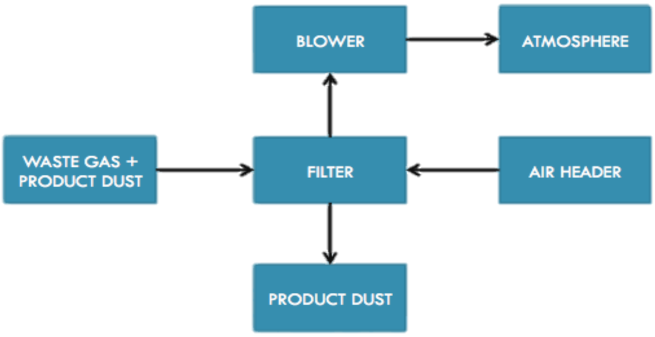

Fig 2: Operation of the blowback system.

Our proposed solution will be designing a control system which will prevent the plant from shutting down whenever the pressure in the air header decreases. The process control is applied to a plant for two reasons, to improve the management of the process and to improve plant efficiency by reducing the number of workers [10]. The basic instruments for a control loop are a sensor, a controller and a final control element (valve). The solution involves installing two pressure transmitters, a controller and a valve in the air supply line from the header. The transmitters are measuring the pressure in the air supply line and sending the signal to the controller (2oo2 voting logic - the controller needs two output signal from transmitters to activate the valve). The controller's set point is 5.5 bar and closes the valve when an input signal of 5.5 bar is received from both the transmitters. By implementing our solution, the plant will not shut down upon pressure decrease in the air header and there is no need for an operator to be near the airflow line to close the manual valve when the on-off valve fails. The company fixed this problem by replacing the old on/off valve (used for purging purposes) with the new on/off valve and also installing a safety control loop consisting of a and an automated ball valve which is powered by a solenoid. This solution works on the 1oo1 voting system. The 1oo1 voting system has no redundant transmitter and if the existing transmitter in 1oo1 voting system gives a false trip to the controller, it could lead to a false corrective action of the valve and this could create problems in the process. The voting logic systems are discussed in the 'Theoretical Concepts' section of this report.

1.3 OBJECTIVES AND CRITERIA

In general, the designed solution must be reliable and compatible with the existing plant operation and design. The planned design must be capable of taking necessary safe actions by closing the air flow line from the header to the filter in case the pressure in the air header line decreases below the set point (5.5 bar). Table 1 shows the objectives with specific criteria.

TABLE 1: PROJECT OBJECTIVES AND CRITERIA

Objectives	Criteria
Selecting an appropriate pressure transmitter	• Response time: 100 ms • Pressure Range: 0 – 10 bar • HART Communication protocol: 4-20mA
Selecting an appropriate on-off valve (solenoid, actuator, ball valve)	• Solenoid valve (24VDC) • Size of valve – 1" • Opening/closing time for valve <5 sec • Single acting actuator (Fail Closed)
New system must be highly reliable	• System cannot fail every once in 2 years of continuous operation • Probability of failure on demand value should be low
Creating the design	• The drawings will provide detailed information about the control loop and the arrangement of the equipment.
Building the design	• The design will be programmed using RSLogix 5000 and the program must be capable to control and respond to the changes in process. • Program must be able to send and receive data from the HMI (Factory Talk View SE)
Testing the design	• Ensure that the program and HMI works with actual physical connection of transmitters and valves.

The first objective is to select a pressure transmitter whose pressure range must be between 0 to 10 bar since the maximum pressure in the header line is 10 bar and it provides good accuracy for the measurement. The transmitter must also be HART communicable (4-20 mA output) so that the operator can access the transmitter directly in the field using a HART communicator device. The response time for the transmitter should be within 100 milliseconds. Pressure transmitters are small in size, but they are important for process optimization [9]. Selecting a pressure transmitter depends on the normal operating pressure of the process, high and low pressure ranges of the process under normal operation, and the maximum pressure the transmitter will experience under abnormal conditions [1].

The second objective is to select an on-off valve with solenoid, actuator (single acting) and a ball valve (size of 1 inch). The response time (opening and closing) for the ball valve should be within 5 seconds. The single acting actuator must be set to fail closed position upon loss of power supply or loss of air supply. The third objective is to make sure that the new control system is highly reliable. This system should not fail once in every two years. The probability of failure on demand value should be lower than the plant's existing system.

The fourth objective is to create the drawings for the new system which will provide detailed information about the control loop and the arrangement of the equipment in the air supply line. The fifth objective is to build the design using programming software (RSLogix 5000) and create a Human Machine Interface (HMI) display using Factory Talk View software. The developed program will ensure that it monitors and responds to the user's need accordingly. The HMI display must be capable of communicating and displaying data from the program and the field devices. The sixth objective is to test the programmed design by actual wiring of the transmitters and valve to the controller and then monitor the control loop using a HMI display.

2. THEORETICAL CONCEPTS

This section of the report discusses the theoretical concepts used in the completion of this project.

2.1 PROGRAMMABLE LOGIC CONTROLLER (PLC)

Most of the conventional relay controlled systems (hard wired systems involving usage of relay coils and normally open/closed contacts) are now being replaced with PLC controllers due to increased number of advantages. A PLC is a microprocessor controller which makes use of stored programming instructions (logic control, sequencing, timing, etc.) in its memory to control (mostly) or to monitor the processes (example - machine control, automated assembly and package). The PLC controller continuously monitors the state of input devices (example - transmitter, pushbutton, etc.) connected to the input card, executes the program and then changes the state of output devices (example - solenoid valve, control valves, pumps, etc.) through the output card according to the program [2]. Some of the advantages why PLC controllers are more used are:

- It requires less maintenance than the relay systems due to less field wiring connections.
- They are much faster than the relay control system.
- They are more reliable than the relay control system.

A general purpose PLC controller consists of power supply module, processor module, communication module, discrete input/output modules and analog input/output modules. This project involves using the ABB 1769-L30ER controller (see Figure 3) to execute the design for the new system. The program for this project is written and stored in this controller.

Fig 3: ABB-1769 Controller. Shows the PLC controller used for this project.

2.2 PROGRAMMING THE PLC CONTROLLER

There are many types of programming codes available to program the PLC controller. Some of the most used programming codes are ladder diagrams and function block diagrams. The programming of the controller can be done by a hand held device or personal computers [2].

A ladder diagram is a programming language used to execute the program based on the logic created. The ladder diagram consists of vertical ladder rails (power source) and the current flow to the input and output devices are through horizontal rungs of the ladder. Figure 4 shows the ladder diagram used in this project. The input field devices are powered, and the controller executes the program based on inputs. The controller scans the program from top to bottom and in a left to right sequence. The controller then changes the state of output field devices based on the programming logic and the state of input field devices. The ladder diagram works on 0 (off state) and 1 (on state) binary bits and true/false conditions of input/output field devices [7].

Fig 4: Ladder diagram. Shows the ladder logic programming code.

The Function Block Diagram (FBD) is a graphical programming language (see Figure 5). It is programmed by using function blocks such as AND, NOT, OR, ADD, MUL, SUB, etc. A FBD describes a relationship or function between input and output variables based on the theory of logical gate functions. The input field device is connected to the input port of the function block through the connection lines, the appropriate function block performs the logic and gives an output to the output field device (connected to the output port of the function block) [7]. The input to the function block and output from the function block can be in a boolean form (digital value) or in an integer form (analog value). All the function blocks are readily available in the software application (RSLogix 5000) from simple AND function block to complex PID function block.

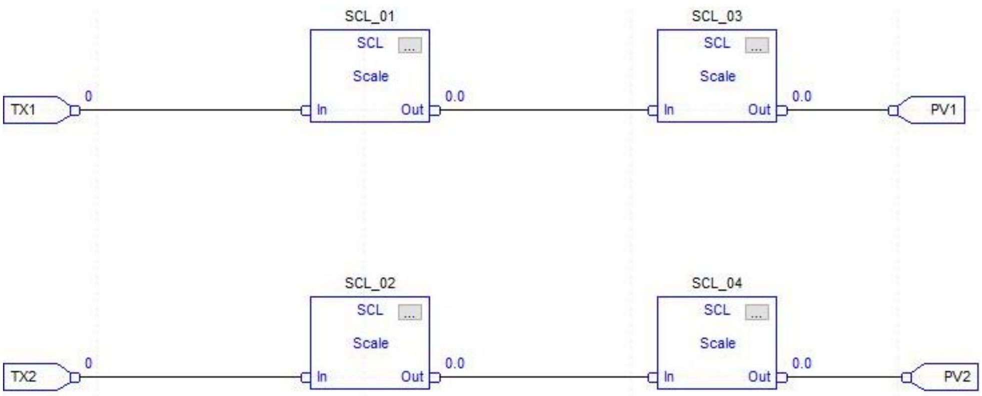

Figure 5: Function block diagram. Shows the function block programming used in this project.

2.3 HUMAN MACHINE INTERFACE (HMI)

The HMI is programmed and configured to generate a visual representation of the process of a plant on a display screen (personal computers). It provides the user with complete details such as instrument drawings of the process, animated graphics of a changing processes, control options, alarms and trends display. With the help of a HMI, the user can easily monitor and control the process of the plant and acknowledge the alarms triggered by the process instruments. The HMI constantly communicates with the program created for the process control and immediately displays any changes happening in the process [7]. The graphic design created in the HMI is linked with the PLC controller with the help of RSLogix 5000 application. This project involves creating a HMI display (see Figure 6) with the Factory Talk View software.

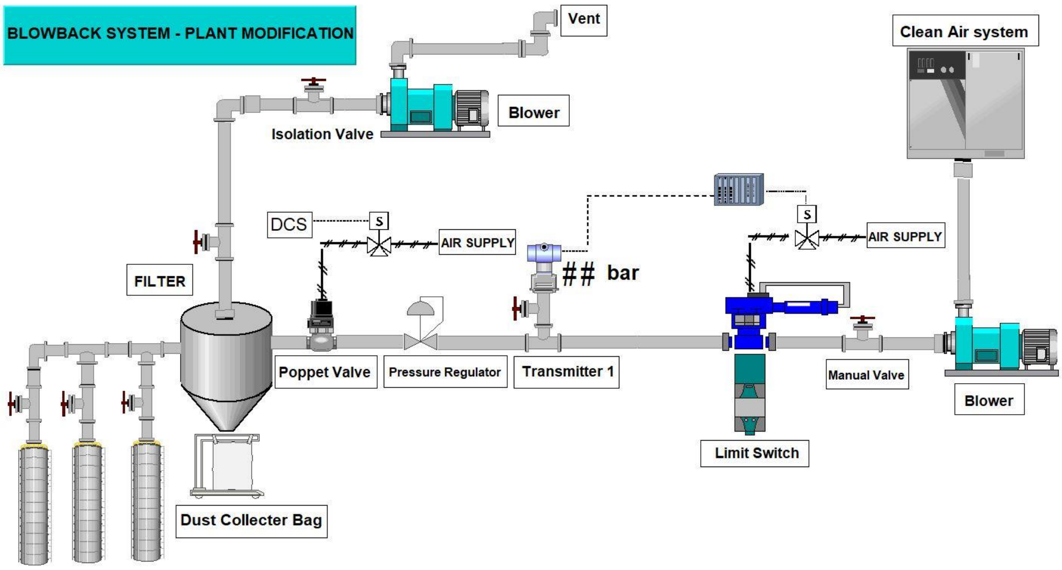

Fig 6: HMI display. Shows the graphical representation of the process.

2.4 REDUNDANCY

Redundancy of sensors in a system means that there are two or more redundant sensors in a system. If one of the sensors fails, the redundant sensor can tolerate the failure and work in place of the failed sensor. With redundant sensors, the reliability of a control system increases. "If multiple sensors are used, they should be connected to the process using different taps (where possible) as well as have separate power supplies so as to avoid common cause plugging and power failures" [6]. Redundancy system can be achieved with the help of voting systems.

The 1oo1 voting (1 out of 1). This type of voting logic for the controller needs only one signal coming from the sensor so that the controller can take action on the final control element (control valve). The 2oo2 voting (2 out of 2). This type of voting logic for the controller needs two signals coming from the two sensors so that the controller can take action on the final control element (control valve). The controller does not work when only one signal is received.

3. PROCEDURES AND FINDINGS

This section of the report discusses the tasks carried out to complete the project. The tasks include objective, analysis, method and result.

3.1 FINDING THE OPERATING PARAMETERS

The operating parameters are the parameters such as pressure, temperature and ambient conditions of a process.

The aim of this task was to collect the P&ID drawings of the blowback system in plant and find the operating parameters from the company. This task was important because the P&ID drawings of the plant were the foundation for this project (in terms of selecting the equipment and design). The P&ID drawings were collected from the company and the operating pressure of the pipeline was determined. A total of 3 P&ID drawings of the blowback system (before and after modification) were collected. The operating pressure in the air pipeline of the blowback system was obtained.

3.2 ANALYZING THE PROCESS

A process involves many variables and control loops which are needed to understand the operation of a process. The aim of this task was to study and understand the process operation using the P&ID drawings of the blowback system and the information provided by the company. Understanding the process operation of the blowback system was an important part for the completion of other tasks (selection of equipment and design) in the project. The P&ID drawings of the blowback system were studied and useful information about the process were obtained. A meeting was set up with engineers of the plant to gather detailed information about process (specifically about the reliability). The P&ID drawings provided information such as size of the pipeline (1 inch), environmental conditions (ambient temperature), type of process fluid (air) and information on the reliability of the system were obtained.

3.3 CREATING THE INITIAL DESIGN

An initial design of any system is always necessary before the actual fabrication of the system begins. The aim of this task was to create an initial design of the new system based on reliability and later modify the design accordingly. The initial design task was an important part in the designing phase of the project. The initial design of the new system was necessary to complete before moving on to the 'final design' and 'building the design' tasks of this project. The initial design was created using Microsoft Visio software application. The initial design (see Figure 7) consisting of two pressure transmitters, one logic controller and two on/off valve was completed. With the completion of the initial design, the final design task was clearly determined.

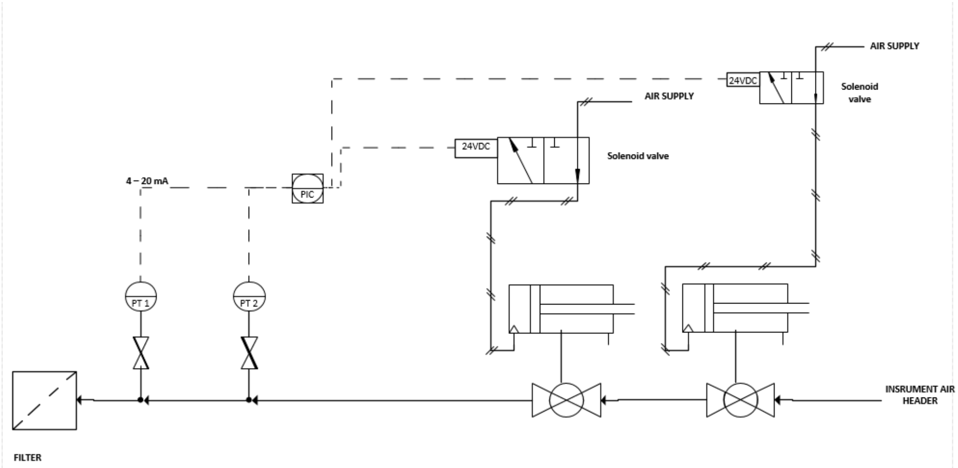

Fig 7: Initial design. Shows the initial design of the new control system.

3.4 CREATING THE FINAL DESIGN

Usually, the fabrication of a control system begins only after the final design of the system is completed. The aim of this task was to create the final design of the new system by improving the initial design. The final design of the new system is important because the programming code will be built based on the final design with the help of programming software. The final design will ensure that the reliability of the new system will improve. The final design was started by modifying the initial design of the new system. The final design was created using Microsoft Visio software application.

The final design is very much similar to the initial design. The final design was completed and it included two transmitters, one controller (2oo2 voting) and one on/off valve. Figure 8 shows the final design of the new system. This design was then used to build the programming code and create a HMI interface for the system. This design was chosen over the initial design because implementing two valves would increase the cost and the process fluid is air and not a liquid. The two valves are mostly used in controlling liquid flow in a process.

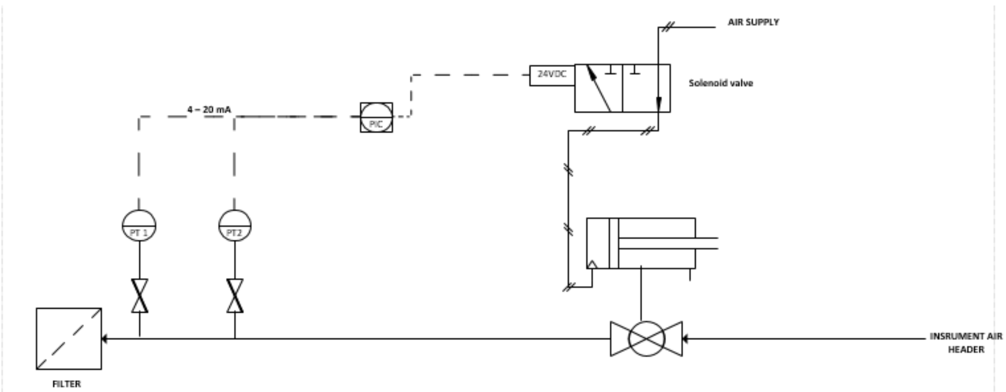

Fig 8: Final design. Shows the final design of the new control system.

3.5 SELECTING THE EQUIPMENT (TRANSMITTER, CONTROLLER AND VALVE)

Selecting the right type of equipment will ensure proper monitoring and controlling of a process system. The aim of this task was to select the equipment for the new system based on reliability, maintenance requirements and company's recommendation. This task has important information on the reliability calculations for the transmitter and was necessary to be completed. The reliability calculations for the company's solution and project's solution will prove which solution has higher reliability. The equipment selected must be highly reliable and the probability of failure on demand must be low.

The following steps were in order to complete this task:

- **Determining plant requirements and compatibility:** The type of transmitters and valves used in the plant were determined by visiting the plant and also asking the company's recommendation on transmitters and valves.

- **Determining the maintenance requirements:** The maintenance requirement for the transmitter was obtained from the manufacturer's datasheet of the transmitter.

- **Determining the reliability:** The reliability for the project The reliability for the company's solution and the project's solution were calculated as follows:

  - To calculate the reliability of a transmitter the Equation 1 was used**:**

$$R(t) = e^{-\lambda t} \qquad (1)$$

Where R is the reliability, t is the time (operation hours) and λ is the failure rate [5].

  - The reliability calculations for company's control system (1oo1 voting, 1 transmitter) are done as follows for 1 year of operation:

$$R_1(t) = e^{-\lambda t}$$

$$R_1(8760) = e^{-(101*10^{\wedge}-9)(8760)} = 0.999115 = 99.9115\ \%$$

Here time (t) = 365 days * 24 hours = 8760 hours, λ (Failure rate of dangerous undetected failures) = $101 * 10^{-9}$ failures per hour .

  - The probability of failure on demand (PFD) for 1 transmitter is calculated using the below formula [5]:

$$PFD_1 = 1- R(t) \qquad (2)$$

$$PFD_1 = 1\text{-}0.999115 = 0.00085 = 8.85 * 10^{-4} = 0.0885\%$$

  - The reliability and PFD calculations for the new control system (2oo2 voting, 2 transmitters) are:

$$PFD_2 = PFD_1 * PFD_1 = (8.85*10^{-4})^2 = 7.83 * 10^{-7}$$

$$R_2(8760) = 1\text{-}PFD_2 = 1\text{-}7.83*10^{-7} = 0.99992 = 99.992\%$$

The reliability calculations were done for both the systems. The company's system was 99.9115% reliable and had a PFD value of 0.0885%. The new system was 99.992% reliable and had a PFD value of $7.83*10^{-5}$ %. With these calculations completed, the reliability of the new system was increased by 0.08% and the PFD was decreased by 0.088% when using the new system.

3.6 CALCULATING MASS FLOW RATE AT CHOKED FLOW CONDITIONS

Choked flow is the maximum flow rate that can occur when the fluid pressure drops from upstream (before nozzle) to downstream pressure (atmosphere) [7]. The aim of this task is to prove that the pressure in the line was actually decreased from 7 bar to 3.5 bar which caused the plant to shut down. The flow rate at choked flow conditions is compared with appropriate pressure simultaneously. This task will ensure that at certain flow rate the pressure can be decreased from 7 bar to 3.5 bar. The following steps were done in order to calculate the mass flow rate at choked conditions of a nozzle.

- The equation used to calculate mass flow rate is given below [4]:

$$\dot{m} = C_d A \sqrt{\gamma \rho_0 P_0 \left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{\gamma-1}}} \qquad (3)$$

Where, m is the mass flow rate (kg/s), A (opening area of the nozzle) = 0.002026 m^2 (A = 3.14 * 0.0254 * 0.0254), γ (gamma)(Ratio of specific heats of dry air, dimensionless) =1.4 (Specific Heat Ratio of Air, 2003), P_0 (upstream total pressure of the gas) = 500,000 Pascals, P_0 (density) = 5.562 kg/m^3 and Cd (Discharge coefficient) = 0.9975 [9].

$$m = (0.9975)\,(0.002026)\sqrt{(1.4)(5.562)(500000Pa)\left(\frac{2}{1.4+1}\right)^{\frac{1.4+1}{1.4-1}}}$$

m = 2.308 kg/s

The mass flow rate obtained at choked conditions when the upstream pressure was 2.308 kg/s. From this mass flow rate, we could verify that the drop in pressure was from 7 bar to 3.5 bar using the compressor characteristic curve. This task was not fully completed due to lack of information on the compressor curve and only a sample calculation was done.

3.7 BUILDING THE DESIGN

The structure involved in building the design was based on the final design. The aim of this task is to develop a program and create a HMI interface for the new design of the system. The programming part of the design and creating a HMI interface for the new design are very important parts of this project. This task will ensure that the control system could be physically built and put in practical use. The programming codes used in this project are FBD and LD instructions. The HMI interface of the control system will provide the user with real time information of the process such as pressure readings and triggered alarms.

The programming code was developed using the RSLogix 5000 software and the HMI interface for the new system was developed using the FactoryTalk View software.

- For developing the programming code, the following steps were done:
  - The PLC controller was connected to the computer using USB cable. Using the RSLinx software, the PLC controller was able to communicate with the RSLogix 5000 software. The analog input and discrete output modules of the PLC controller were configured and added to the RSLogix 5000 software in order to communicate with the field devices.
  - After the input and output modules were added to the controller, the input and output tags for the transmitter and valves were created. The tags are the names given to the devices which includes assigning the addresses so that the controller can communicate (with the help of the program) to the connected devices. The transmitters were connected as the analog input devices to the analog input module of the controller (by fixing the wires in proper slot and channel of the controller). The solenoid valve and the reset pushbutton were connected as the discrete input device to the discrete input module of the controller. The indication lights (software based) and proximity switch are connected as discrete outputs in the discrete output module of the controller.
  - The next step was to create the programming using ladder logic and function block diagram programming languages. The values from the transmitters were scaled from 6272 and 31104 to indicate 4 milliamps (mA) and 20 milliamps (mA) using the scaling (SCL) function block. Then, the 4mA was scaled to represent 0 bar pressure and 20mA was scaled to represent 10 bar pressure. These scaling functions of the transmitters were programmed in FBD routine.
  - The actual program of the design was created in the main routine using the LD programming language. The LD program included Jump-to-Subroutine (JBR) command in the first rung so that the controller can take the transmitter values from the FBD routine. The LD program included all the logical commands necessary for the operation of the new control system. The setpoint (desired value of the process variable - pressure) was set to 5.5 bar. The program was based on 2oo2 voting logic for the controller. The controller needs 2 transmitters sending signal to the controller simultaneously.
- The HMI interface for the new control system was created using FactoryTalk View SE software and the following steps were done:
  - The communication between the RSLogix 5000, FactoryTalk View and the controller was created by creating an OPC link (communication protocol for the field devices and application software) by using RSLinx software.
  - After successful communication, the tags already created in RSLogix 5000 program were added to the FactoryTalk View software. The tags added were used to assign to the objects created in the graphical display of the interfaces.
  - The next step was to create interfaces which includes graphical representation of the process with the pressure and alarm indications.

- The final step was to test the program and the interface using RSLogix 5000 and Factory Talk View softwares and ensure both are working as expected.

There were 2 routines created in the programming part of the new control system. There were a total of 3 HMI interfaces created to display the blowback system process (without modification), blowback system with company's modification and blowback system with new modification. The program and the HMI interfaces were successfully created and tested. The program and HMI interfaces responded to any change occurring in the process.

3.8 TESTING THE DESIGN

The testing of the design was started when the design was completely built with all the required instruments. The aim of this task is to test the designed system using a PLC controller, transmitters (FLUKE loop calibrators), solenoid valve and a control valve. This task was the final task and the most important part of the project. The task will ensure that the program and the HMI interface can be put in practical use to achieve a safe control of the process. With the help of this task, any issues with the designed control system can be easily detected and can be modified to increase the capability. A control valve in an unused trainer located in our research institute. A metal extension plate was obtained from the facilities department which was placed on the stem of the valve so that the proximity switch can sense whether the valve is in open or closed position. The positioner was removed from the control and a solenoid valve (obtained from the plant) was fixed with the control valve. The solenoid valve was connected to the controller which will allow the valve to open or close fully.

The air supply was connected to the solenoid and the solenoid supplied air to the valve according to the program. A proximity switch was connected and placed below the metal extension plate. The loop calibrators, which resembled the transmitters were connected to the controller. The air supply was then opened for supplying the air to the solenoid valve only after all the instruments were fixed properly (see Figure 9).

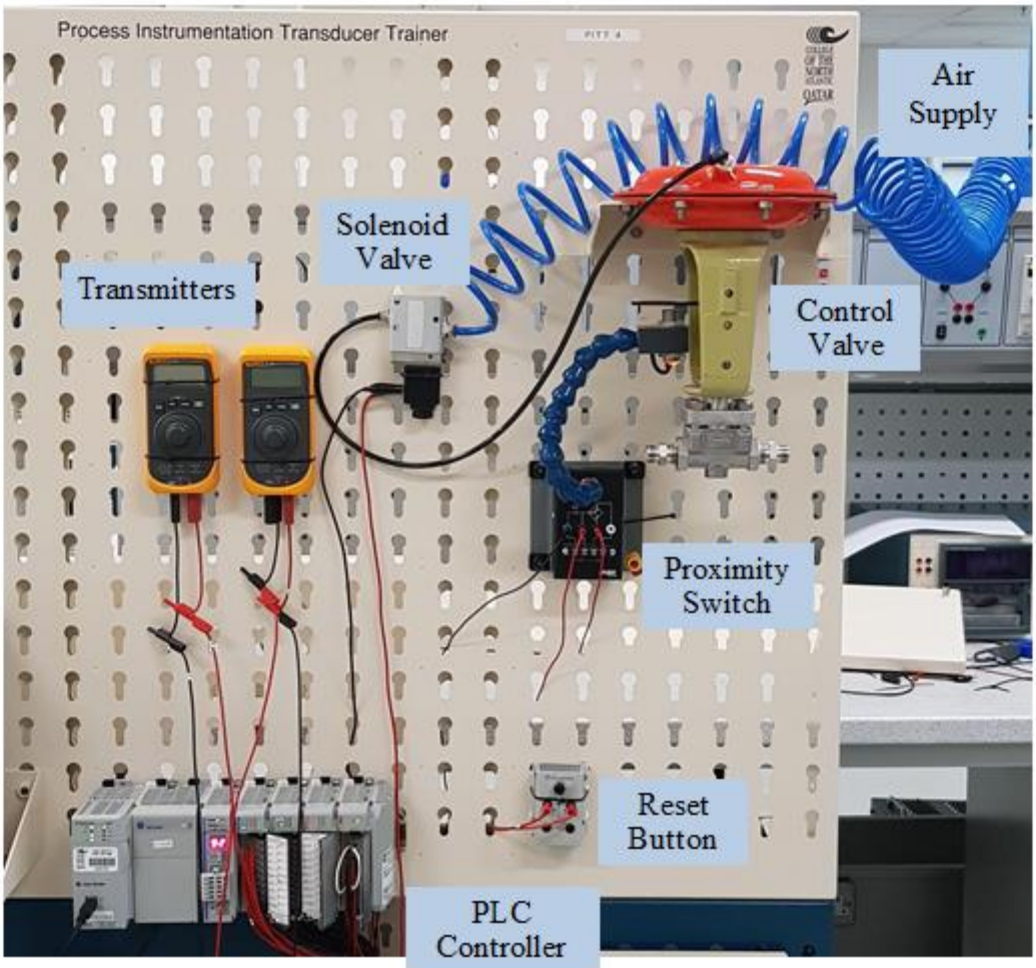

Fig 9: Process control system. Shows the transmitters, controller, control valve, solenoid valve, reset switch and proximity switch fixed on the trainer.

The following are the steps done in order to test the control system after connection to air supply:

- The program was downloaded using RSLogix 5000 software and was set to run mode.
- The HMI interface was opened using Factory Talk View software.
- At first, the pressure in the loop calibrators were set to 7 bar (normal operating pressure). The valve is in open position and the proximity switch is off. The HMI interface indicated the pressure values transmitting

from the transmitter 1 and transmitter 2 and also indicated green light for the normal operating pressure indication lights. The transmitter 1 and 2 low pressure indicating lights were red (indicating that the pressure was not low) on the HMI.

- The pressure was decreased to 5.4 bar by decreasing the current values going to the controller from both the transmitters. This low pressure activated the solenoid valve (by the controller) and the solenoid valve actuated the control valve to close 100% from the open position immediately. This closing action of the valve activated the proximity switch (due to the magnetic effect of the metal plate) which was to confirm that the valve was closed.
- As the pressure was decreased to 5.4 bar, the transmitter 1 and 2 low pressure alarms turned green, the normal operating pressure indication lights for transmitter 1 and 2 turned red (indicating that the pressure was not normal), the proximity switch and the control valve object indication light turned red (indicting the valve is closed) on the HMI interface.
- The pressure was increased to 7 bar (above SP = 5.5 bar) in both the transmitters. The HMI interface indicated the pressure readings and the normal operating pressure indication lights for transmitter 1 and 2 turned green (indicating that the pressure was normal), the transmitter 1 and 2 low pressure alarms turned red (indicating that the pressure was not low). Even when the pressure in both the transmitters were reading 7 bar, the valve was not opened. The valve was opened only after pressing the physical reset push button. The reset push button works only when the pressure in both the transmitters were above setpoint.
- After pressing the rest push button, the valve was opened by the solenoid valve. The proximity switch and the control valve indication light turned green (indicating the valve was opened) on the HMI interface.

The designed control system was working according to the user's need. The valve was closed when the pressure in the line was decreased below setpoint and both the transmitters detected this decrease in pressure.

4. CONCLUSIONS

The designing, building and testing phases of this project were successfully completed on time. The development of the program and creating a HMI interface will ensure that this control system can be put in practical use for the operation of a process.

All the objectives of this project were successfully completed. One of the objectives was to check the reliability of the new control system and the control system implemented by the company. This objective was completed and proved that the reliability of the new control system is more with less probability to fail on demand than the company's control system. The second main objective was to develop instrumentation drawings for the new control system, which was completed, and the drawings provided easier understanding of the control operation. The third main objective was to build the design of the control system, which included developing programming code and creating a HMI interface for the new control system. This objective was completed with the help of RSLogix 5000 and Factory Talk View software applications. The development of the program and HMI interface ensured that the control system could be used to monitor and control the process. The HMI interface was able to communicate with the process by displaying all the necessary information required in a process control. The fourth main objective of this project was to test the designed control system, which was successfully completed by connecting the transmitters (loop calibrators), solenoid valve, control valve, controller and testing them with the developed program and a HMI interface.

The testing phase of the project proved that the program developed for the new control system is capable of taking the process to a safe state whenever the pressure of the process is decreased below the setpoint. All the objectives of this project were met and successfully completed within the deadline.

5. RECOMMENDATIONS

The designed control system is not the only control system available today that can be incorporated into process operations that require the process to go to a safe state in case of a hazardous situation. One of the other types of designing a control system based on voting logic system for the controller can be 2oo2D (two out of two voting with Diagnostics). The 2oo2D voting system is the system which incorporates high safety and low false trips with the help of diagnostics features which comes built in mostly in transmitters and sometimes in safety controllers. The diagnostics feature continuously checks the health of the transmitters and takes preventive measures by notifying the operator (gives detailed alert and recommended actions) before abnormal process conditions can occur. Some of the diagnostics features include power advisory (checks for problems in electrical loop), provides maintenance alerts and diagnostic log [3].

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