Dynamic Modelling and simulation of High Integrity Pressure Protection System (HIPPS)

By

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CERTIFICATION OF APPROVAL

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Approved:

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TRONOH, PERAK

December 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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Basel Ibrahim Hashish

Abstract

High Integrity pressure protection system is a very essential component in the plants-related industries. The dynamic modeling and simulation of this system has proved to be extremely important in the process of designing and controlling. This report presents the steps followed to realize an integrated simulation of this system and the findings that were discovered after using this simulation to explore real life situations, problems and natural phenomena.

The software used to realize this simulation is SIMULINK which is a subsidiary of the program MATLAB, and it is a quite simple program to use and it usually deals with the dynamic and mathematical equations which makes the system easier to be accurately represented and simulated.

The HIPPS was integrated in a 3-phase separator system and was tested under different situations to observe the reaction of the system.

The simulation was used to encounter one of the most prominent problems in the industry which is the slug flow phenomenon, this phenomenon was tested and the simulation showed the kind of damage it has on the equipment and the normal flow of the process.

The simulation was also used to test the proposed solutions by the industry for this phenomenon and it showed that they actually greatly decrease the harmful impact of this phenomenon and increase the stability and the regularity of the process flow in the system.

The simulation was used in a different aspect which is the designing of the HIPPS safety control valve, as the system was tested under different failure situations and the HIPPS valve was observed in order to reach the best and most suitable parameters that makes it very effective in protecting the system from any danger resulting from over pressure.

The simulation has shown that it has a great potential to be extended and to be used in many different application that will make the process of designing and controlling parts of the plant a lot easier on the engineers in the industry.

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Chapter 1

Introduction

1.1 Background of study:

1.1.1 High Integrity Pressure Protection System:

HIPPS is a safety instrumented system that separate the downstream part of the plant from the upstream part in case of over pressurization which protect the system from explosion and spillage of hazardous and toxic material, HIPPS can be used in both topside and subsea operations, it is thought to be one of the best choices to protect the plants and increase the safety in the places where ordinary pressure relief systems are not enough to guarantee the safety. The most important aspects of HIPPS are safety, economic and environmental considerations. [1]

HIPPS is a complete functional loop consisting of:

- Detectors / Initiator which detect the increase of pressure and send a signal to the next part of the loop , initiator can be either electronic or mechanical
- Logic solver which take the signal from the initiator and process it to find the most proper signal to send to the third part of HIPPS
- Final element which is the last part of HIPPS , it receives the signal from the logic solver and then undertake the corrective measurement , the final element is a control valve that for example shut down in case of over pressurization. [2]

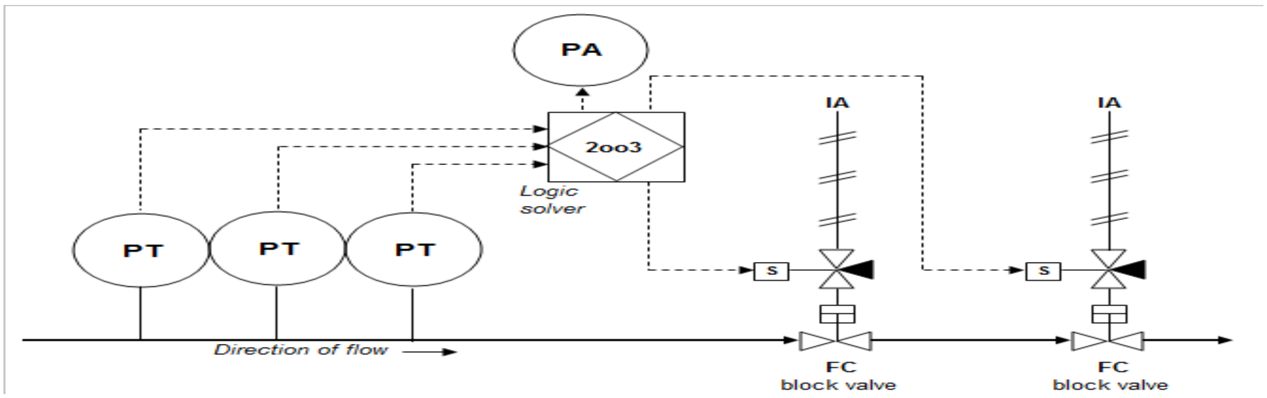


Figure 1: Illustrative picture of HIPPS components

The designed HIPPS is in a “3-phase separator” system that includes the following equipment:

1. Control Valves

2. 3-phase separator

3. Valves controllers

4. Pipes

5. HIPPS Valves

6. Pressure Relief Valves

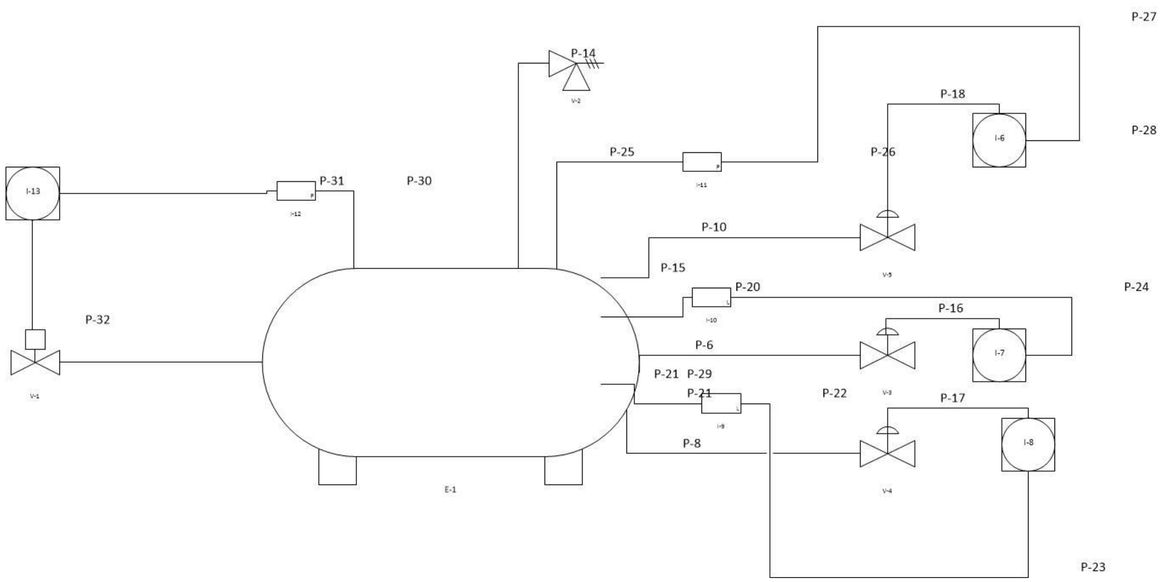


Figure 2: Rough diagram of the simulated system

<u>1.1.2 MATLAB Simulink:</u>

“Simulink is a block diagram environment for multi-domain simulation and Model-Based Design. It supports system-level design, simulation, automatic code generation, and continuous test and verification of embedded systems. Simulink provides a graphical editor, customizable block libraries, and solvers for modelling and simulating dynamic systems. It is integrated with MATLAB®, enabling you to incorporate MATLAB algorithms into models and export simulation results to MATLAB for further analysis.” Simulink can be used in modelling and designing dynamic systems including nonlinear dynamics and control systems including nonlinear controllers and plants and also in signal processing design and simulation. [3]

1.1.3 Slug flow phenomenon:

In this project a very important problem is being addressed which is the slugging behavior in some plants. The slug flow has a quite negative effect on some parts and equipment's of the plant and it's a problem that needs to be addressed properly to prevent its downfalls. In the case of this project the slugging happen in the riser that comes from the well which is considered a vertical pipe.

"Slug flow is a multiphase-fluid flow regime characterized by a series of liquid plugs (slugs) separated by a relatively large gas pockets. In vertical flow, the bubble is an axially symmetrical bullet shape that occupies almost the entire cross-sectional area of the tubing. The resulting flow alternates between high-liquid and high-gas composition."[4]

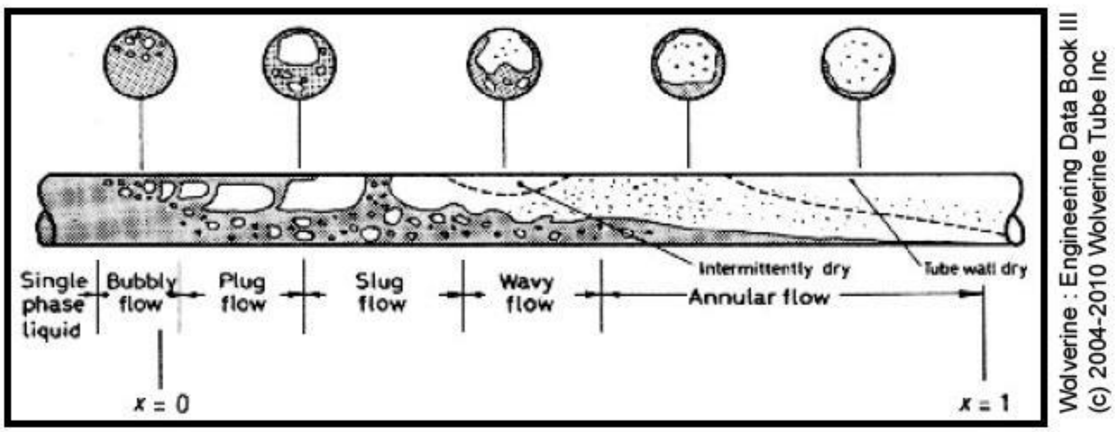


Figure 1.2. Illustration of two-phase flow patterns occurring in horizontal evaporator tube.

Figure 3: Illustration of two-phase flow patterns in horizontal pipe

1.2 Problem statement:

1.2.1 HIPPS Simulation design:

This project was initiated to realize a simulation of a system that incorporate the HIPPS in its pressure safety protocol.

The design process of any plant is a very tricky task as there is many things to take in consideration, the designer engineer has to account for many factors that can affect his design including physical, chemical and even environmental factors. This makes the designing project much harder on the engineer and even after finishing up the design, there is very limited ways to make sure of the safety and efficiency of the design and sometimes even after the design in implemented and made, a previously un-seen problem emerge and it becomes extremely difficult to fix it which sometimes render the design useless.

This project aim to provide a way to the designer engineer to have a “preview” look to his design and test it in many ways via digital simulation. Having this type of tool can be very helpful and useful and it’ll prevent some prominent problems that emerge from blind-Designing like Over-designing which means that the designer design a part of the plant to sustain a certain factor like pressure for example in a much higher amount than needed which of course will cost higher, another problem is Under-Designing which is exactly the opposite to the previous problem and it leads to system failure and sometimes explosion.

Safety being a major point in the oil & gas industry, this project was started with safety in mind and the part that was chosen for the simulation is a main safety system in different plants in the Industry to furthermore understand this system and –if the simulation is successful- test it under different circumstances and failures.

1.2.2 Slug flow phenomenon:

This phenomenon happen in the vertical riser that transport the crude oil from the well to the Test separator system, the slugging behavior results in a very inconsistent outflow of both oil and gas which have drastic consequences on some parts in beyond the 3-phase separator system which are:

- The Gas-compressor: which is a mechanical device that undertake the compression of outflow gas by increasing its pressure and reducing its volume, it is a very important part of the plant and it's beyond the 3-phase separator simulated system yet the effect of an inconsistent Gas outflow is very harmful to the compressor and could cause it to get stuck as the input gas oscillate between no flow, medium flow and high flow.

- The fluid control valves: in the 3-phase separator system, there are control valves that monitor and adjust the outflow of water, oil and gas after getting separated in the 3-phase separator; those control valves are automatically controlled. They are adjusted to keep the water and oil at a specific height and the gas at a specific pressure, the oscillating inflow of water, oil and gas will cause their respective control valves to try and adjust to their inflow in order to keep their level and/or pressure at the point previously set. The continuous opening and closing of the control valves is very harmful and reducing to the life span of each control valve.

- The economic implications that involves the maintenance and/or the replacement of control valves and gas compressors are very sever and will certainly harm the budget of the project. This made addressing this problem a very high priority.

1.2.3 Design and parameters of HIPPS safety valve:

HIPPS safety valves are the third component of the HIPPS safety system which receives the appropriate command from the logic solver according to what the initiators are sensing with respect to pressure.

The design and modification of the HIPPS safety valves is a very tough task that involve various calculations with taking in consideration many factors that could affect the outcome, it's all very important to put in consideration the possibility of failures in parts of the plants like control valves.

There are three important aspects that need to be calculated which are:

- Pressure-Set-Point: it's the value of pressure detected by the initiator of HIPPS that should be an indicator that HIPPS must start closing.

- Time of closing: The time that the HIPPS valve will take to fully close and separate the upstream (high pressure) part of the system from the downstream (Low pressure) part of the system.

- Number of HIPPS safety valves: which is the appropriate number of adjacent HIPPS safety valves to insure the complete and utter safety of the system and in the same time the best economically feasible arrangement.

The problem here is reaching the previously mentioned points; the conventional way through hand calculations is a very hectic process that could be made a lot easier through the use of computer software.

1.3 Objectives:

- To Simulate the 3-phase separator system with HIPPS
- To encounter the Slug flow
- To Specify the most suitable parameters for HIPPS safety valve
- Study and understand the response of different systems

1.4 Project scope and expected outcome:

I. The expected outcome of this project is an accurate simulation design for the HIPPS in a 3-phase separator system; this design is to be used for many research and testing purposes like:

- Simulate the situation of the inflow doubling or cutting of inflow
- Simulate failure in control valves
- Research and determine the best pressure characteristics for equipment's
- Research and determine the best way to control slugging behavior
- Research and determine the best characteristics for control valves and HIPPS safety valves.

II. The outcome simulation should be simple to use and easy to modify according to the project that is being studied.

III. The simulation design will need to take in consideration the unique factors that each plant is subject to.

1.5 Relevancy of project:

In this technological era, nearly everything in all fields operate on a quick base. The need for new technologies that can reduce the time and effort of doing something has been in the greatest demand. Oil & Gas industry leverage on those technologies to increase the efficiency and effectiveness of their operations and products is the. This project will help save a lot of time and effort and will open a new way and a new perspective of how to design and control a plant or a part of a plant; it will also contribute in the field of using simulations to come up with answers and solutions to physical obstacles and phenomenon like Slugging flow. This project is also supervised by SBM offshore company which operates in the same field that the project is focusing on.

Chapter 2

Literature review

2.1 High Integrity Pressure Protection System:

HIPPS has a lot of advantages that spans over three different fields:

- Economic: The usage of HIPPS protects a lot of assets like valves and pipelines and it also contribute a lot in the design of those equipment, as with the existence of HIPPS the design of pipelines would not need to sustain huge levels of pressure which will greatly decrease the cost, HIPPS will lead to a lighter and cheaper pipes and vessels with a higher capacity which will also lead to reduction in the cost for transportation and storage.
- Environmental: The usage of HIPPS will make other pressure relieving systems quite obsolete, the conventional pressure reliefs systems used to release flames in the air and HIPPS will prevent this operation.
- Safety: HIPPS is a very reliable system that will prevent over pressurization which will lead to a well-protected set of equipment including pipes, valves and controllers. [5]

HIPPS was used in Subsea application in Gulf of Mexico, it had many different set of advantages like:

- Reduced topside pressures
- Reduced flow line and riser wall thickness
- Reduced offshore welding time
- Reduced temperature induced axial force due to reduced wall thickness, leading to less onerous buckling behavior.
- Improved riser design
- Potential to use existing, lower pressure flow lines and risers [6]

HIPPS is preferably used in the following situations:

- Limitations on the pressure relief systems (Environmental cause)
- Need to reduce the over pressurization risk

- Extremely high pressure and/or flow rate
- Difficulty in designing the pressure relief device[5]

2.2 Dynamic Modelling and simulation:

The previously cited information had been featured in many articles, reports, conference proceedings and technical papers, that shows how HIPPS is a very well-known and thought after system that is being greatly leveraged upon in the industry. The information that will be featured furthermore will be about the articles intake on dynamic modelling and simulation of a particular physical process and/or operations.

"Process modeling is the single technology that has had the biggest impact on our business in the last decade" Frank Popoff, Former CEO, Dow Chemical, April 1996

Dynamic Simulation is a very important tool in most industries as the ability to have a physical system simulated in a digital form that can be altered, tested, observed, challenged and even pushed to the limits is a revolutionary thought that did indeed revolutionized a lot of industries including the Oil & Gas industry.

The dynamic simulation is essential is the designing process of a plant, it has a prominent rule from conception to decommissioning in the following ways:

- It provides a way to assess the ability to operate and control the plant
- It provides a way to efficiently design and test different control systems which leads to being able to choose the best control structure, algorithm and tuning.
- It provides a way to test the operating process including the running and shutting down process
- It provides a way to assess the Health, Safety and Environment issues and identify the possible hazards
- It provides a way to choose the most proper protective and relief devices
- It provides a way to predict the emission of different hazardous materials and their effect on the environment
- It provides a way to observe the interior dynamic process [7]

2.3 Slug flow phenomenon:

Steady state operation of two-phase flow (Liquid + Gas) usually entails that there is a constant flow rate of liquid and gas. This results in constant conditions at any point in the pipe like:

- The flow pattern
- Average void fraction
- Average pressure drop
- Average local flow rates

And those conditions do not vary with time.

In the case of constant flow rate of liquid and gas in a pipe, a steady state nature is expected, but in the case of the pipeline-riser system in an offshore platform, realizing the steady state operation is nearly impossible as conditions of severe and/or terrain slugging appear. This phenomenon push the system into reacting in an undesirable way by producing high gas flow rate following long liquid plugs (Slugs). [8]

So starting with defining what slugs are and what are their types:

Hydrodynamic slugs are formed due to the instability of waves on the gas-liquid interface in stratified flow under certain conditions. When a large number of hydrodynamic slugs are present, the pipeline is considered to be operating in the "slug flow regime". In this condition the flow characteristics of the liquid and the gas are quite complex and it operates randomly.

Multi-phase flow lines are widely used in oil and gas plants, the multiphase surges are a big problem as the constant large changes in oil and gas flow rates greatly harm the processing facilities.

Those multiphase surges / slugs are one of those three types:

1. "Hydrodynamic slugs: A property of the stratified flow regime where slugs are formed due to instability of waves at certain flow rates."
2. "Terrain Induced Slugs: Caused by accumulation and periodic purging of liquid in dips along the flow line, particularly at low flow rates."

3. “Operationally Induced Surges: Created by forcing the system from one steady state to another.”

The hydrodynamic slug’s formation goes through three different stages:

1. Firstly the two-phase flow is stratified which means that the gas is at the top of the pipe while the liquid is at the bottom, the passing of gas over the gas creates a pressure drop and then a pressure recovery which create a small force upward within the wave, assuming the existence of correct conditions, the force could be enough to lift the liquid wave to the top of the pipe.

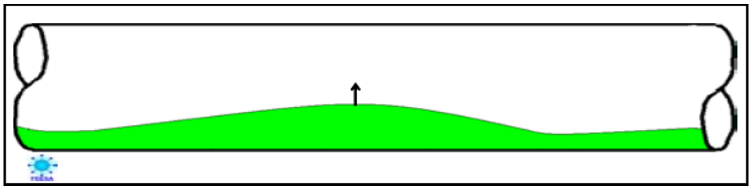


Figure 4: First stage of slugging flow

2. Secondly when the wave reaches the top of the pipe, a familiar slug shape is formed with a nose (on the right side) and a tail (Left hand side). The formed slug is then pushed by the gas which results in its traveling with a higher velocity than the liquid film. This results in ingress of liquid into the slug nose.

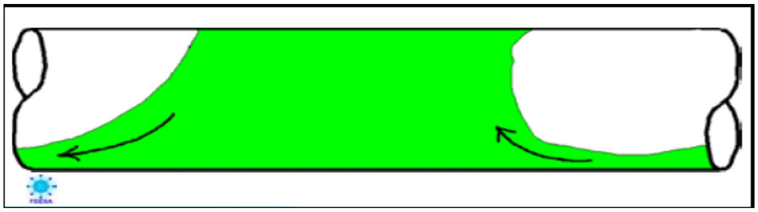


Figure 5: Second stage of slugging flow

3. Lastly the access of liquid into the front of the slug creates a jet which contains gas bubbles, the formation of those gas bubbles interfere with the mechanism of liquid access and increase the turbulence within the slug. [9]

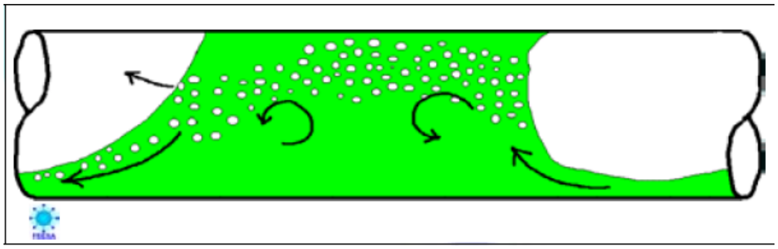


Figure 6: Third stage of slugging flow

- **Why is slug flow problematic?**

Typically the arrival of a hydrodynamic slug at a production or processing equipment is very problematic, even sometimes at severe cases it would cause the whole platform to shut down. The slug flow starts with an accumulation of water and oil in low-lying parts of the pipelines, the gas keep collecting downstream of the slug which keeps on increasing in pressure till it reaches a certain level where it push the slug to move towards the pipeline outlet and so on. Resulting in bulks of oil and water followed by surges of gas. That has a very devastating effect on production and processing equipment's.

- **What is the progress in the study of slug flow and slugging behavior?**

Extensive researches have been done on the slug flow and slugging behavior and it has been going on for many years. A lot of different approximate ways to calculate slug hydrodynamics have been developed, in the past those studies mainly relied on the experimental data and their relations to other factors, but in recent years dynamic modeling has been used to simulate the slug flow behavior in a more of an accurate manner to calculate pressure drops and other flow parameters and it increased the confidence the results obtained. [10]

2.3.1 The proposed solutions from the industry:

a) The conventional method used to control the level of liquid inside the 3-phase separator is a controller PI actuating in the liquid output valve, in the case of the controllers programed to maintain a constant level, this will lead the variation and oscillation of the inflow of the liquid to propagate and show up in the outflow of the liquid which will lead to instability in the downstream equipment.

   The proposed ideal PI controller is a liquid-level control that will allow the level of the liquid to vary within a certain permissible range, which will lead the outflow to be smoother than the severely oscillating inflow. This can't be achieved using the conventional PI controller, a denominated level control methodology by bands was defined which allow level oscillations within certain limits (minimum and maximum of a band); this method results in an outflow rate that equals the average of the inflow rate.

In this “band” control when the level of the liquid is within the band, the action of the PI controller is quite slow as the reduction in the capacity of the performance of the controller gives a greater fluctuation in the liquid level inside the separator, on the other hand when the level of the liquid exceed the band, the PI controller switch to the fast response mode with the objective of getting the liquid level to within the band. [11]

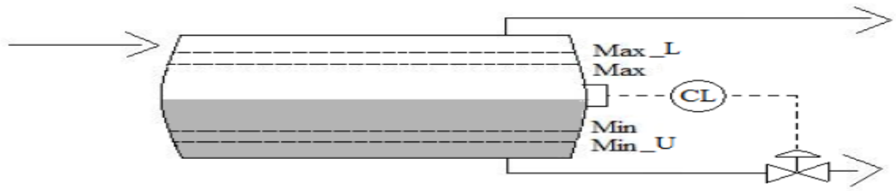


Figure 7: Illustrative diagram of Gap controller

b) Another proposed solution in the industry for the slug flow is the active use of the topside choke, this method is considered to be the easiest and most applied solution and it is implemented by reducing the topside choke opening until slugging is reduced to an acceptable level and produce with this static choke opening.

The topside choking helps eliminate riser slugging by increasing the pressure drop across slugs, the pressure drop is given by the pressure difference between the foot of the riser and the downstream of the choke, an increased pressure drop over the choke will counter the slug acceleration and will keep the slug in the riser until a more stable gas and liquid flow is established, with dynamic choking the production rate will not be reduced which makes it a better solution than static choking.

A successful slug control system will not only control riser slugging but also operate a stable production with a minimum flow line pressure. In slug control the production choke will be used to control the flow and stabilize the flow line pressure.

The slug control has two main modes:

- Volumetric Flow PI control:

  This aims to stabilizing the volumetric flow through the choke.

- Flow line pressure PI control:

  This aims to keeping a stable pressure in the flow line at the seabed. [12]

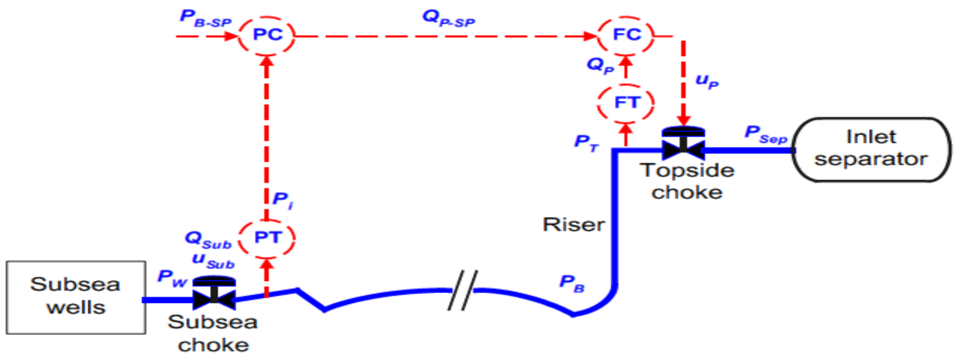


Figure 8: Illustrative diagram of Top side choke Modes

The controller modes:

	Set Point (SP)	Controlled Variable	Manipulated Variable
Flow Control	Operator	Volumetric Flow	Choke position SP
Pressure control	Operator	Flow Line Pressure	Choke position SP

2.4 Design and specifications of HIPPS valves:

When setting the process performance of HIPPS, evaluation of the process dynamics is a must in order to make sure that the response time of HIPPS is fast enough so the vessel will not be subjected to overpressure.

The response time of HIPPS should take into consideration that HIPPS is a fully integrated fail-safe system that has its own sensors/initiators and its own logic solvers and its own final elements (Valves) so the time that the initiators will take to detect an increase in pressure and the time it will take to send this info to the logic solver and the time it'll take for the logic solver to process the information and send the appropriate command to the HIPPS valves and the time that the HIPPS valves will take for a complete closure should all be counted to reach a precise closure time.

The required closure must be determined for each installation based on many factors like acceptable leakage rate as it has a direct effect to the downstream pressures and relief loading. An additional aspect will be making sure that the valve's actuator is strong enough to close the valve under the highest and worst possible pressure case.

The HIPPS system needs to be put into test under all possible situations and operations, and the whole system needs to be observed under pressure, whenever an overpressure happen, it will indicate that changes needs to be done in the HIPPS system, if the tested system faced overpressure in one of the tests where there was a failure in control valves, the design engineer should strongly suggest using TWO HIPPS valves in order to fully control the system.

The HIPPS system should be an independent system and should be able to fully function under any circumstances and under the possibility of failure in any part of the system.

The HIPPS needs to be tested also to make sure that it covers up all the expected safety aspects on behalf of the conventional pressure relief system (flare) as it will be replacing it.

Once the independence of HIPPS is ensured, common cause failures related to the design must be examined. [13]

Chapter 3

Methodology

3.1 Research methodology:

According to the objectives of the project there are three main aspects that are being worked on, those three different aspects address three different problems and issues that are faced by the design and faced by most of the oil & Gas plants in real life.

Those three main aspects are:

1. System design and simulation
2. Slug flow and Slugging behavior
3. Design and characteristics of HIPPS valves

Each one of those aspects will be worked on individually then they will be brought together at the end model to test and record their effect.

3.1.1System design and simulation:

The concept adopted in this project is to study all the components involved in the system very carefully and fully understand their purpose and their effect in the process, after identifying the use for each component, we proceed with choosing the suitable mathematical equation to describe it, and then using blocks in SIMULINK to represent every operation in those equations. For each component there has to be a representative mathematical equation in order for the Simulink to be able to accurately estimate the effect of this component in the whole process, following the order of the components mentioned in the previous section of the paper, the next part describes the theoretical and practical representation of each component.

I. 3-Phase separator:

The function of an oil production facility is to separate the oil well stream into three components or “phases” (oil, gas, and water), and process these phases into some marketable products or dispose of them in an environmentally acceptable manner. For the purpose of the simulation the separator was initially treated as a cylinder tank where there is 3 separated fluids (water, oil and gas) where all types of interactions between them is merely volumetric-related. To get the volume of the separator as a cylinder is fairly easy but on the other hand to get the volume of the liquid inside a partially filled separator was quite tricky.

The volume of cylinder:

$$\boldsymbol{V = \pi . R^2 . L} \tag{1}$$

The volume of liquid in partially filled cylinder (horizontal):

$$\boldsymbol{V = A_l . L} \tag{2}$$

$$\boldsymbol{A_l = \pi . R^2 - R^2 \cos^{-1}\frac{R-h}{R} + (R-h)\sqrt{2Rh-h^2}} \tag{3}$$

The required value to be calculated is H which is the height of the liquid in the separator and this value can be obtained by

$$\boldsymbol{H = L - h} \tag{4}$$

The tricky and challenging part in this equation is that it's implicit equation and in order to extract from it an equation that can calculate ***h***, a way to solve including differentiation should be used as follows:

$$\boldsymbol{\mu\frac{dh}{dt} = \left[\pi R^2 - R^2 \cos^{-1}\frac{R-h}{R} + (R-h)\sqrt{2Rh-h^2}\right].[L] - V} \tag{5}$$

The Equation used to get Height using the value of volume:

$$\boldsymbol{\frac{dh}{dt} = \frac{\left[\pi R^2 - R^2 \cos^{-1}\frac{R-h}{R} + (R-h)\sqrt{2Rh-h^2}\right].[L]}{\mu} - \frac{V}{\mu}}$$

**While μ is a very small value = 0.0000001 (Nearly Zero)*

Having Equation 6, it can be easily translated into Simulink blocks using the differentiation block. The volumetric aspect of the separator is regarded to be the most important as from it we can get to know the height of water and oil and also the volume of gas hence its density and pressure will be calculated. While running the simulation the separator will be getting inflow of Water , oil and gas and in the same time giving outflow of the 3 fluids , that difference in the inflow and outflow will result to variations in volume , hence a variation in the height of fluids and the pressure of gas inside separator. The following equations represent how the rate of change is calculated for both types of fluids in the separator.

a. Liquid (water / mix of water and oil)

For the water:

$$\frac{dm_w}{dt} = F_{inw} - F_{outw} \tag{7}$$

$$m_w = \rho_w . V_w \tag{8}$$

$$V_w = \frac{m_w}{\rho_w} \tag{9}$$

For the Mix:

$$\frac{dm_m}{dt} = (F_{inw} + F_{ino}) - (F_{outw} + F_{outo}) \tag{10}$$

$$m_w = \rho_m . V_m \tag{11}$$

$$\rho_m = \frac{V_w}{V_w + V_o} . \rho_w + \frac{V_o}{V_w + V_o} . \rho_o \tag{12}$$

$$V_m = \frac{m_m}{\rho_m} \tag{13}$$

And once the volume of either water or the mix is calculated, the height of the respective liquid can be calculated by the previously mentioned equation. On the other hand in the situation of gas.

b. Gas

The equations for the gas is used to find the density and the pressure of the gas while the volume of the gas is basically = Volume of the separator – Volume of the liquid mix

$$\frac{dm_g}{dt} = F_{ing} - F_{outg} \tag{14}$$

$$m_g = \rho_g . V_g \tag{15}$$

$$\rho_g = \frac{P . M_w}{Z . R_a . T_{[k]}} \tag{16}$$

And from that equation, it's possible to measure the pressure in the separator (which is the condition of interest that is being controlled by HIPPS valve).

After specifying the equations that will be used to represent the 3-phase separator, the second part of the project comes which is using those equations in Simulink to create the simulation required. The 3-phase separator will need to be represented by 3 sub-systems:

i. Sub-system that calculate the volume of water and mix
ii. Sub-system that calculate the height of water and mix

iii. Sub-system that calculate the volume of gas and its pressure.

1. Pipes

The effect of pipes needs to be studied thoroughly, pipes have 2 different effects on the flow of the fluids:

The pressure drop across the pipe, and the time the flow takes to move from one end of the pipe to the other end.

First step when dealing with pipes is calculating the pipe constant (C_d):

$$\Delta p = C_d . \rho_m . {V_{sl}}^2 . \left(\frac{L}{D}\right) \quad (17)$$

$$C_d = \frac{\Delta p}{\rho_m . {V_{sl}}^2 . (\frac{L}{D})} \quad (18)$$

And after solving for the C_d the pipe is simulated as a pressure drop in the system and a transit delay for the flow.

2. PI controllers

The PI algorithm is used in this simulation by the control valves and the representative equations is as follows:

$$CO = CO_{bias} + K_c . e(t) + \frac{K_c}{T_i} \int e(t)dt \quad (19)$$

While e (t) = Set value (SP) – Actual value (PV)

A set point for the height of liquids and pressure of gas is set and the PI controllers make sure that the actual value is equal to the set point, or else it will instruct the control valves to either open/close accordingly to fix the difference.

3. Control Valves

Control valves are used to regulate the outflow of fluids from the 3-phase separator, they are a very important component in the simulation as they will be responsible for keeping the system safe and operating in the steady state. The types of control valves use are liquid and gas control valves, the equations that describe the operations of those valves are taken from **Masoneilan** valve handbook which was based on the use of nomenclature and sizing equations from ANSI/ISA Standard S75.01.01 and IEC Standard 60534-2-1.

i. Water Valve (Normal Condition)

$$C_V = \frac{w}{N_6 . F_P . \sqrt{(P_1 - P_2) . \gamma_1}} \quad (20)$$

ii. **Oil Valve (Choked condition)**

$$C_V = \frac{w}{N_6.F_{LP}.\sqrt{(P_1 - F_F P_v).\gamma_1}} \tag{21}$$

iii. **Gas valve (Normal Condition)**

$$C_v = \frac{w}{N_6.F_P.Y.\sqrt{x.P_1.\gamma_1}} \tag{22}$$

$$Y = 1 - \frac{x}{3.F_k.X_T} \tag{23}$$

$$X = \frac{\Delta P}{P_1} \tag{24}$$

$$F_k = \frac{k}{1.4} \tag{25}$$

Those equations are used first to solve for the valve's specific flow coefficient C_v and then the equations are modified to solve for the flow (w) and put into the simulation.

4. HIPPS Valve

HIPPS valve is an ON/OFF valve which means that it doesn't have "in-between" state, it monitors the pressure in the whole system (Separator Pressure + Pressure drop in the pipes), if this pressure reach a certain point the valve will close shut protecting the system from being overwhelmed by excess pressure. The way this valve operates is that it has the ability to completely cut the inflow to the system, before any damages happen, there is no specific equation that governs the attitude of this valve, and on the other hand there is a specific characteristic to the flow out from this valve depending on its openness, the characteristic graphs is as follows:

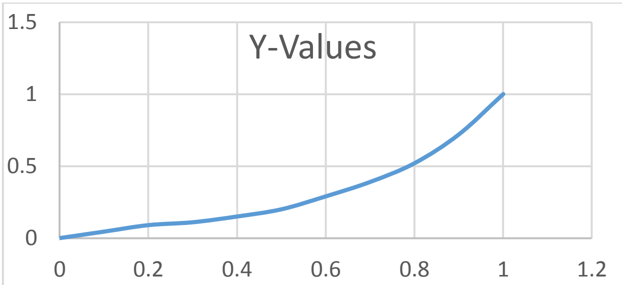


Figure 9: Characteristics graph of HIPPS valve

Moreover the HIPPS valve is designed so it will close shut permanently and it'll remain closed even until the stabilization is achieved.

5. Pressure relief valve

This is a quite simple valve as it doesn't use any of the equations for the control valve, it merely help release some of the outflow for gas in case the pressure reached a certain point (this valve is dedicated to the flare). The flow characteristics of the pressure relief valve is as follows:

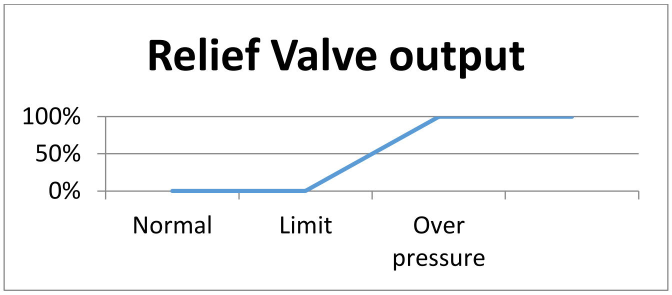


Figure 10: Characteristics graph of PRV

By using this following formula, it was fairly easy to deduce an equation that can express the operations of the relief valve.

$$\frac{y - y_1}{y_2 - y_1} = \frac{x - x_1}{x_2 - x_1} \tag{26}$$

6. Gap Controller

In slugging conditions, the need for a Gap controller arises, the purpose of gap controller is to simply change the way a PI controller operate in a way that instead of focusing on a single set point and comparing the value of interest to this set point, it will have a range of set points and in case the value of interest is within that range, the system will be fine and will not need further controlling. The gap controller operate in three different cases:

Case1: If Observed value (H) < Least point in range

The result will be making the Set point of controlled value = to the least point in range.

Case2: If (H) > Highest point in range

The result will be making the set point of controlled value = to the highest point in range

Case3: If (H) is within the range

The result will be making the set point = H, hence no change in the control valves.

7. Choke Valve

The choke valve is another component that is used in the case of slugging to counter the sluggish inflow of fluids, it is actually a water control valve, oil control valve and a gas control valve integrated all together in one valve.

Same as the normal control valve, the first step here is to calculate the flow coefficient for the 3 valves but this case they will all be considered to be in (choked) conditions so the equations for choked flow will be the ones to use.

The three valves will share the same X (openness of the valve) and the inlet and outlet pressure as well (they are treated as 1 valve).

3.1.2 Slug flow and slugging behavior:

According to the literature review, the proposed solution for this issue according to the industry is:

- Gap Controller
- Topside choke operation

In the original simulation, the slug flow was not taken into consideration which means that there are few new parts that needs to be added to the original design which is:

- Water control valve gap controller
- Oil control valve gap controller
- Riser
- Topside Choke Valve

A. Gap controller:

The gap controller is an addition device to the original PI controller, it's added to ONLY the water and the oil control valves as it'll contribute in making the control of the level of those two liquids depending on a band of values instead of one constant value.

The gap controller's job is to choose and send the desired level "set-point" to the PI controller which in turn compares the current level of the respective liquid in the 3-phase separator with the incoming set-point and depending on the outcome; the PI controller will send the appropriate command to the control valve of that liquid.

The theory of the gap controller:

The inputs of the gap controller are 3 variables:

1. Height (Level) of the liquid (oil / water) in the 3-phase separator
2. Lowest set point (Minimum band limit)
3. Highest set point (Maximum band limit)

The gap controller operates in 3 different ways:

1. If the level of the liquid is lower than the lower set point (H<LSP):

The resulting Liquid Set point will be equal to the lower set point (LSP) which means that the goal here is to get the height of the liquid back to within the band of values that the gap controller operates on.

2. If the level of the liquid is higher than the Upper set point (H>USP):

   The resulting liquid set point will be equal to the upper set point (USP) which means that the goal here is to get the height of the liquid back to within the band of values that the gap controller operates on.

3. If the level of the liquid is LOWER than the upper set point and HIGHER than the lower set point (within the band) (LSP<H<USP):

   The resulting liquid set point will be equal to the current liquid level (H) which means that as long as the liquid level is within band, the liquid set point will always be compatible with it which means that the control valves will not act on any changes as long as they are within the band.

B. The riser:

The riser is a vertical pipe that transports the crude oil coming from the well into the separation facility, most of the slug flow form in the riser due to its vertical shape and turns at its beginning and ending. The riser will be simulated in the same way as a normal pipe in the system.

C. The choke valve:

One of the most used ways to overcome slugging problem was topside choke, and to implement this solution, a choke valve needs to be inputted upstream of the system right after the riser.

The choke valve will include the following equipment:

1. Water Control Valve (Operating in Choke condition)
2. Oil Control Valve (Operating in Choke condition)
3. Gas Control Valve (Operating in Choke Condition)
4. There will be a common inlet pressure (P_{in}) and a common outlet pressure (P_{out})

The choke valve will hold the slugged inflow till it reaches a certain level of smooth flow then it'll let it pass to the separator system.

3.1.3 Design and characteristics of HIPPS valve:

It is quite clear that the design and characteristics of HIPPS safety valves are of very high priority as the HIPPS control and protect the system and ensure the safety of the equipment and personnel working in the plant.

The characteristics that are being studied and tested in this stage of the project are:

i. The appropriate number of HIPPS valves
ii. The best closure time of HIPPS valves
iii. The most appropriate set point for pressure where the HIPPS must close

A. the number of HIPPS valves:

The industry has indicated that the best case possible is having two HIPPS valves to ensure complete and utter protection of the system, as relying on one HIPPS valve and the fluid control valves might not be as efficient because sometimes a failure might happen to the fluid control valves leaving the system vulnerable to overpressure and maybe destruction.

B. The best closure time of HIPPS valves:

In this aspect, some simulations will be undertaken to observe the difference effect of various closure times on the response of the system in case of an overpressure situation. Closure time tested will be within a band of (5 – 15 Seconds)

C. The most appropriate set pressure:

Set pressure is the point of pressure that if the system reaches, is an indication of an overpressure case that needs the HIPPS to kick in and shut down its valves, the pressure set point choice should take in consideration many things like:

a. The design pressure for the 3-phase separator and the equipment in the system
b. The pressure drop in the pipes between the 3-phase separator and the HIPPS initiators (Sensors)
c. The closure time of the HIPPS safety valves
d. Other pressure relief devices (If used)

3.2 Project Activities:

In this part of the report, the practical representation of the theoretical view is featured; the practical representation was in the form of simulation block diagrams in Simulink

3.2.1 Design and simulation of the system:

Each component of the 3-phase separator system was simulated in SIMULINK by placing blocks that coincide the respective representing equation of each component.

Some of the simulated components are shown below:

1) 3-phase separator:

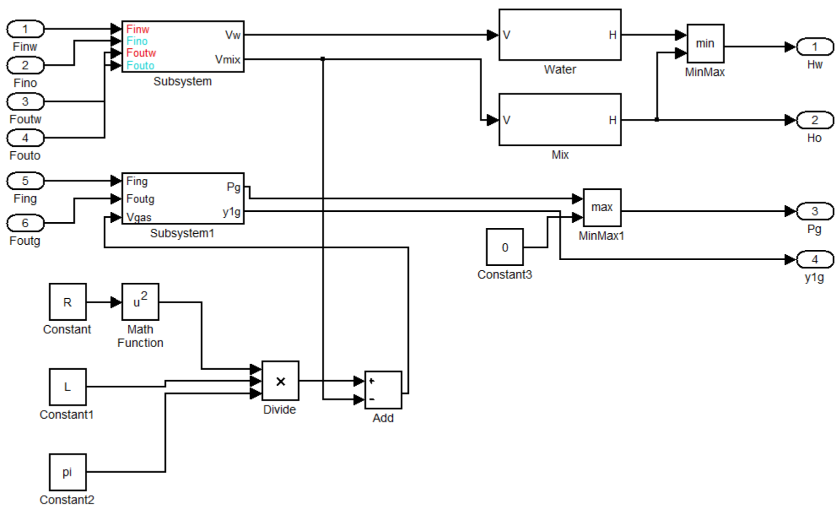


Figure 11: simulation blocks of 3-phase separator (Full)

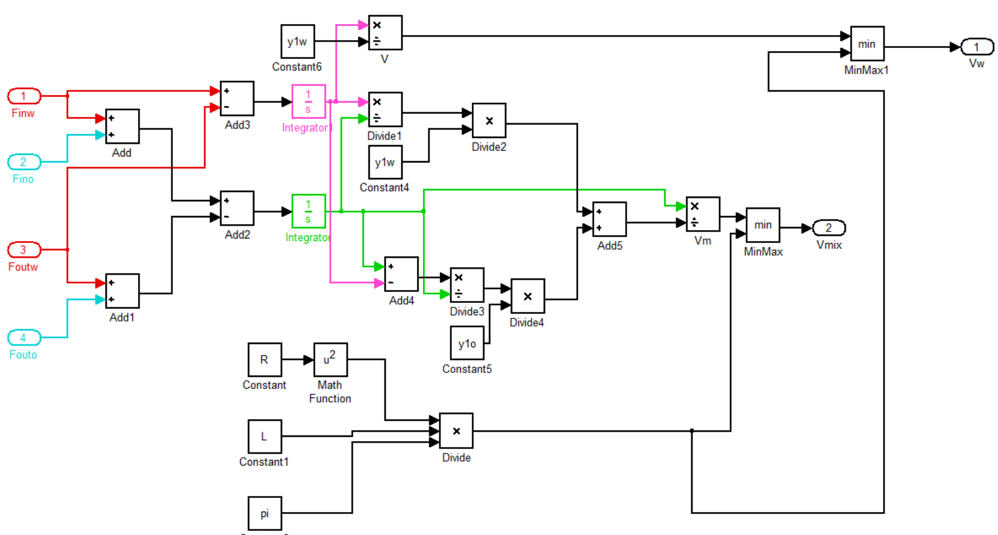


Figure 12: Simulation blocks of 3-phase separator (Partial)

2) Control Valves:

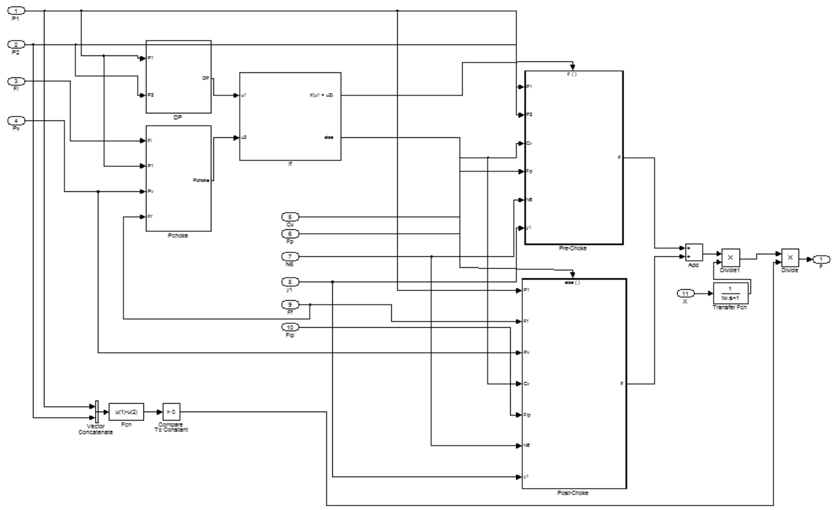


Figure 13: Simulation blocks of Control valve (full)

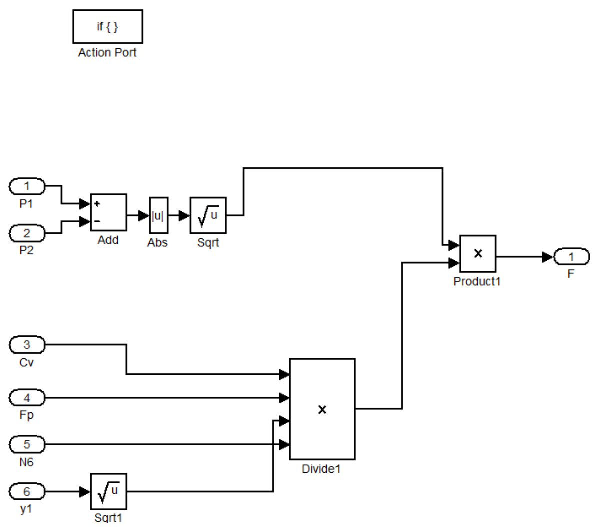


Figure 14: Simulation blocks of control valves (partial)

3) HIPPS safety valve:

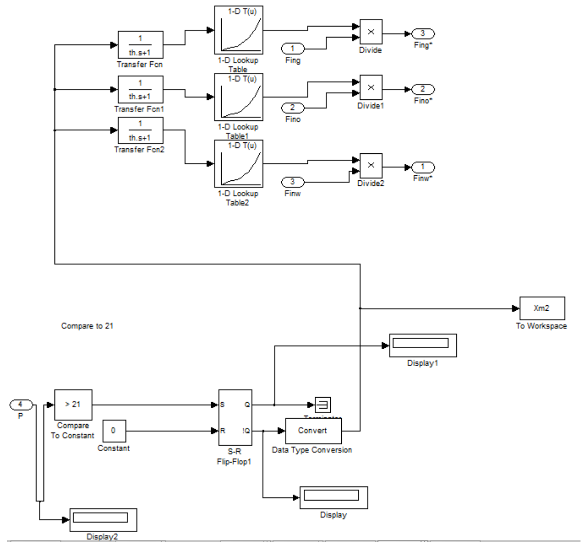


Figure 15: Simulation blocks of HIPPS valve

4) Pipes:

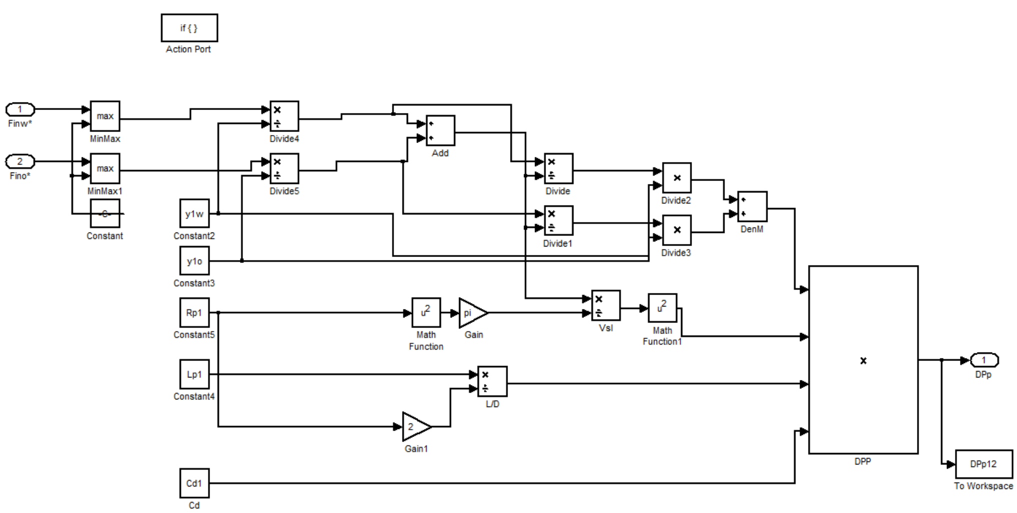
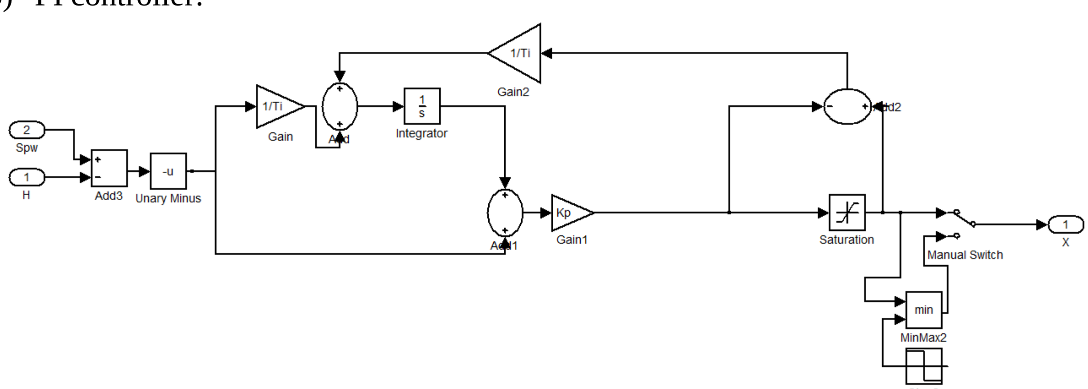


Figure 16: Simulation blocks of Pipes

5) PI controller:



Full system:

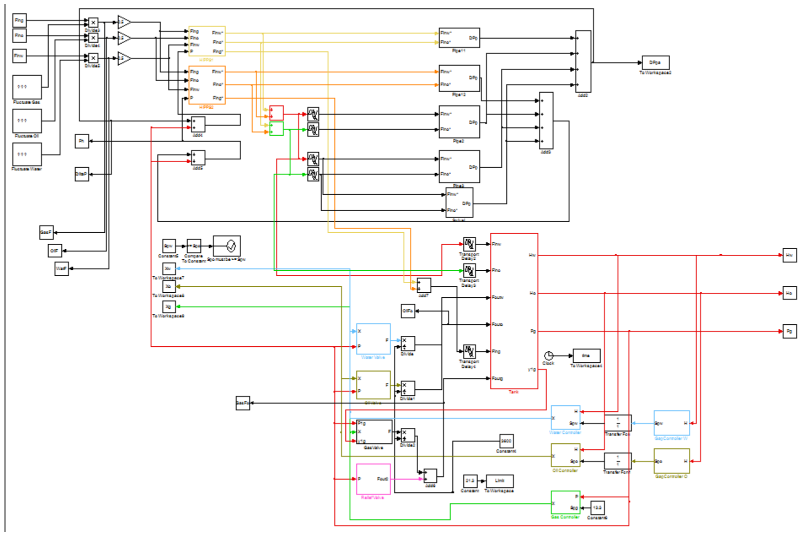


Figure 17: Simulation blocks for the whole system

3.2.2 Encounter the slug flow

1. Gap controllers for water and oil has been designed and added to the PI controller for those two fluids.

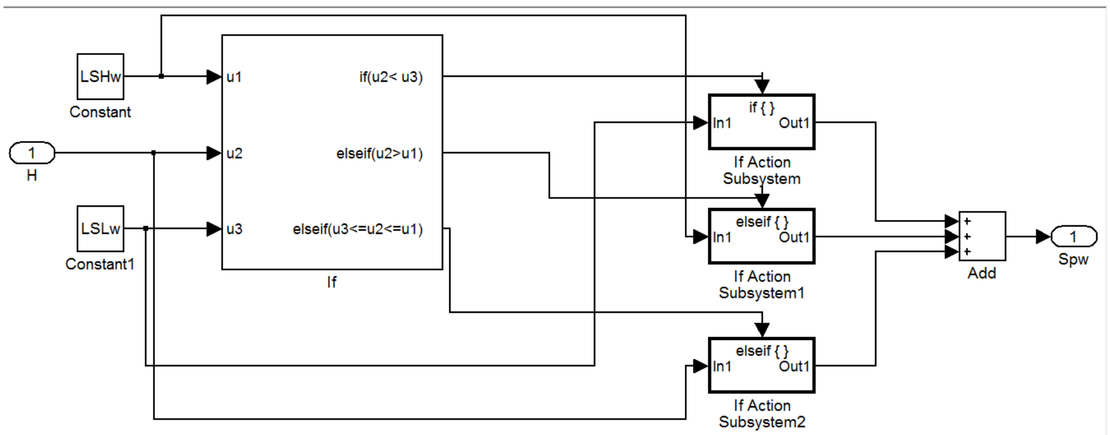


Figure 18: Block Diagram simulation of Gap Controller

Where the gap is 10% of the original set point, if the original set point = X, then Lower set point = X (1-0.1) and Upper set point = X (1+0.1).

2. Topside Choke (Choke Valve): which consists of 3 control valves operated in chocked conditions:
    a. Water and oil control valves (Choked), the chocking conditions is monitored based on the following rule $\Delta p \geq F_L^2 (P_1 - F_F P_v)$

       The choked liquid control valve equation is:

$$C_v = \frac{w}{N_6 F_{LP} \sqrt{(P_1 - F_F P_v) \gamma_1}}$$

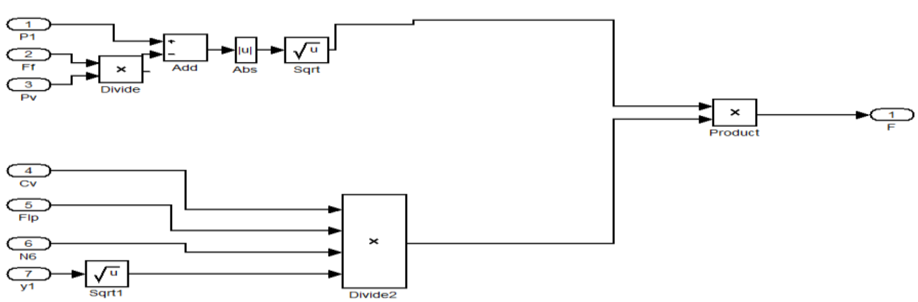


Figure 19: Block diagram simulation of liquid control valves in choked condition

b. Gas control valve (Choked),The chocking condition is monitored based on the following rule $x > F_k X_T$

The chocked gas control valve equation is:

$$C_v = \frac{w}{N_6.F_P.Y.\sqrt{x.P_1.\gamma_1}}$$

$$Y = 1 - \frac{x}{3.F_k.X_T}$$

$$X = F_K X_T$$

$$F_k = \frac{k}{1.4}$$

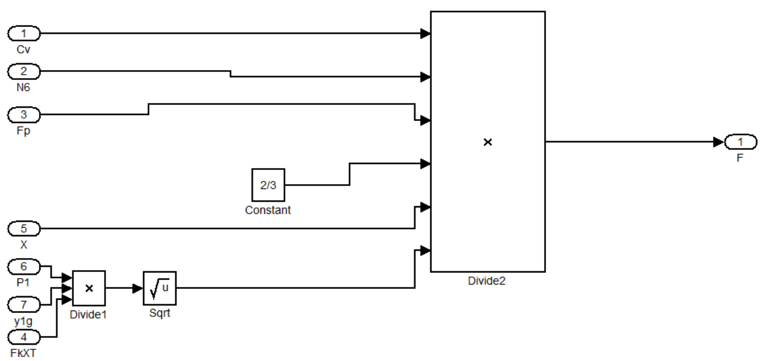


Figure 20: Block diagram simulation of gas control valve in choked condition

c. Grouping the 3 control valves together in one valve with a common inlet pressure, outlet pressure and openness of valve.

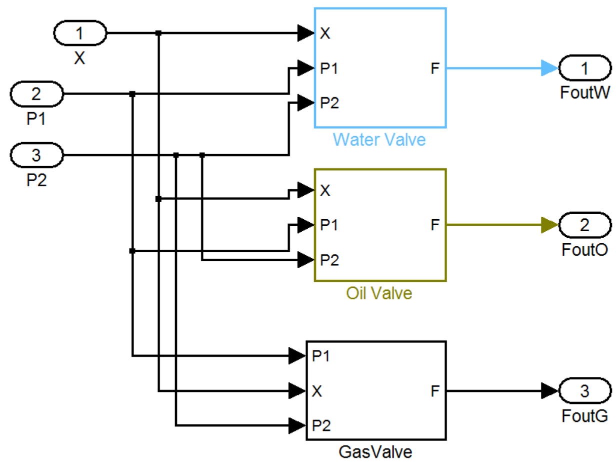


Figure 21: Block diagram simulation of the combination of the three control valves to create the choke valve

3. Modification of Inflow to show the fluctuations resulted from the severe slugging behavior in the system, the assumed fluctuations will range from (full on flow ➔ Medium capacity flow ➔ no flow), this adjusted change is realized by coupling an oscillating signal in the same required manner and the normal inflow.

   The oscillating Signal:

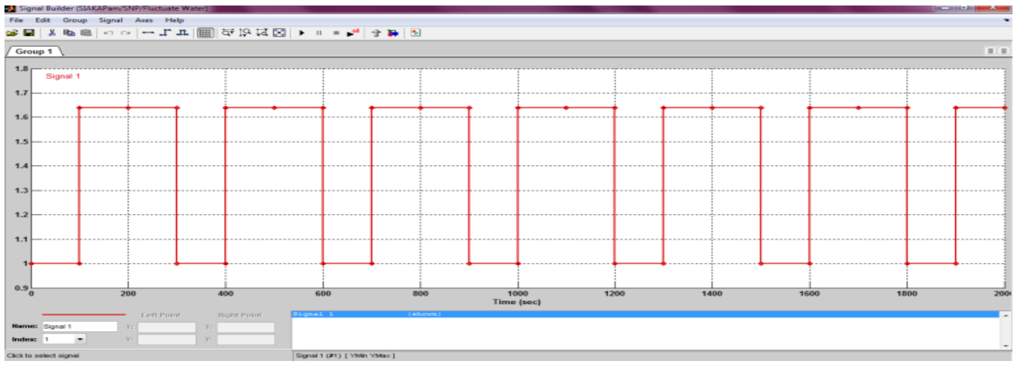


Figure 22: Oscillating signal that is used in the input to stimulate slugging

The multiplication of normal input X oscillation signal:

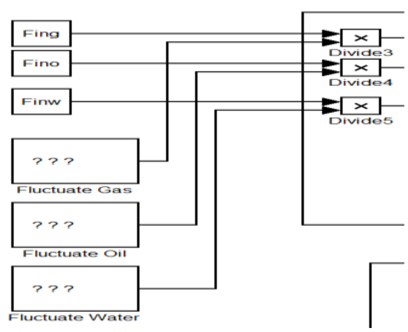


Figure 23: The multiplication of the original input and oscillating signal to stimulate slugging flow

3.2.3 HIPPS Design and characteristics.

This objective entailed few changes and additions that need to be implemented in the design.

Firstly, the addition of another HIPPS safety valve to the system:

HIPPS valve is an ON/OFF valve which means that it doesn't have "in-between" state where the valve is partially open / partially closed; it will be easier full opened or fully closed. There is no specific equation that governs the attitude of this valve; on the other hand there is a specific characteristic to the flow out from this valve depending on its openness, The HIPPS valve is quite different in its simulation as it needs to use a block that isn't used in the whole project which is the S-R flip flop , the function of this block is to trigger the closing of HIPPS with no coming back , which means that the controller in the HIPPS is different from the control valves , it closes when pressure exceed certain point but it SHOULD NOT open when the pressure go down to normal level , for HIPPS once close it should remain closed and this is where the flip flop came in use. The simulation of HIPPS valve include a pressure tester to check the pressure and compare it to the set – point and it also has a characteristics graphs that show how the flow will react in certain points when the HIPPS valve is closing. This characteristic was based on scientific papers that tested and monitored the effect of closing the HIPPS valve on the flow.

The characteristics graph is represented by the values in this following table:

	Data
Table	[0,0.045,0.09,0.11,0.15,0.2,0.29,0.39,0.52,0.72,1]
BP 1	[0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1]

Figure 24: Table of HIPPS valve characteristics

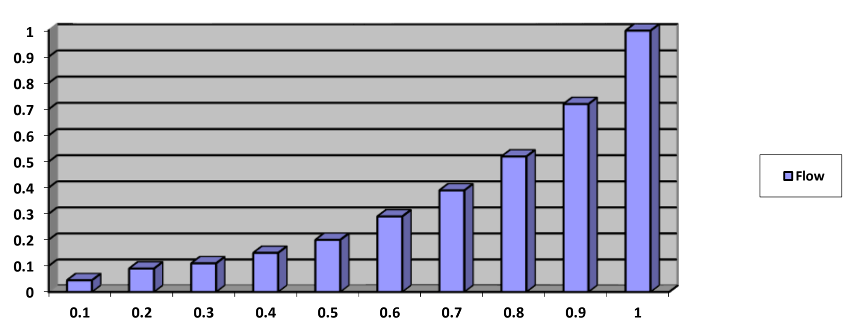


Figure 25: Graph that represents the flow characteristics of HIPPS safety valves

In addition to the instalment of the second HIPPS valve, Tests and simulations has been made to reach the perfect value for HIPPS safety valve closure time and set pressure. The tests will involve the following situations:

1) (+) Disturbance in the Inflow of Fluids (Water, Oil, Gas) (Increased to Double)
2) (-) Disturbance in flow of Fluids (Water, Oil, Gas) (Decreased to Zero)
3) (+) Disturbance in Controlled Set point (increase)
4) (-) Disturbance in Controlled Set point (Decrease)
5) Failure in Control valve (Open)
6) Failure in Control Valve(Closed)

Each one of those situations will be simulated and the response of the system will be observed. Those situations will be tried with different values of “closure time” of HIPPS safety valve to reach the most appropriate value; they will also be tried with different values of set pressure to reach the most appropriate value.

3.2.4 Additional project activities: Designing the calculative blocks for two of the most important variables in the system:

The two variables that are to be simulated in term of calculative blocks:

1. Control Valve Flow Coefficient:

    a. For Liquid control valve operating in normal condition

$$C_V = \frac{w}{N_6 . F_P . \sqrt{(P_1 - P_2) . \gamma_1}}$$

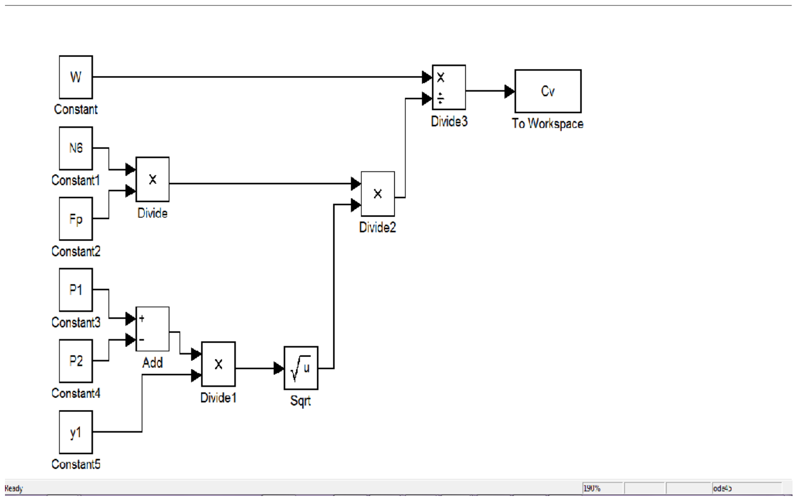


Figure 26: Block diagram simulation of Liquid control valve calculation of flow coefficient in normal conditions

    b. For Liquid control Valve in Choked Condition

$$C_V = \frac{w}{N_6 . F_{LP} . \sqrt{(P_1 - F_F P_v) . \gamma_1}}$$

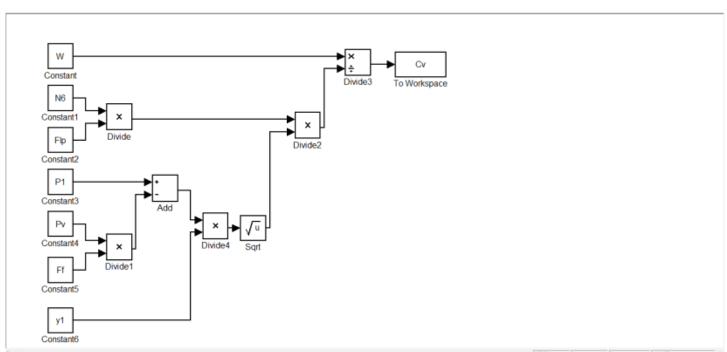


Figure 27: Block diagram simulation of Liquid control valve calculation of flow coefficient in choked conditions

c. For Gas Control Valve in normal condition:

$$C_v = \frac{w}{N_6 . F_P . Y . \sqrt{x . P_1 . \gamma_1}}$$

$$Y = 1 - \frac{x}{3 . F_k . X_T}$$

$$X = \frac{\Delta P}{P_1}$$

$$F_k = \frac{k}{1.4}$$

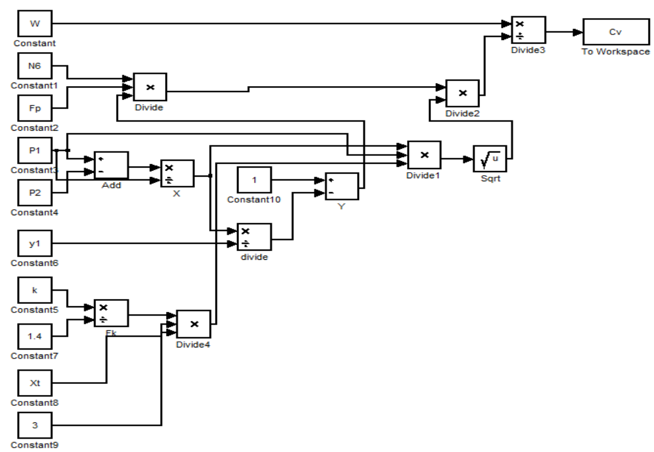


Figure 28: Block diagram simulation of gas control valve calculation of flow coefficient in normal conditions

2. The pipe constant:

$$C_d = \frac{\Delta p}{\rho_m . {V_{sl}}^2 . (\frac{L}{D})}$$

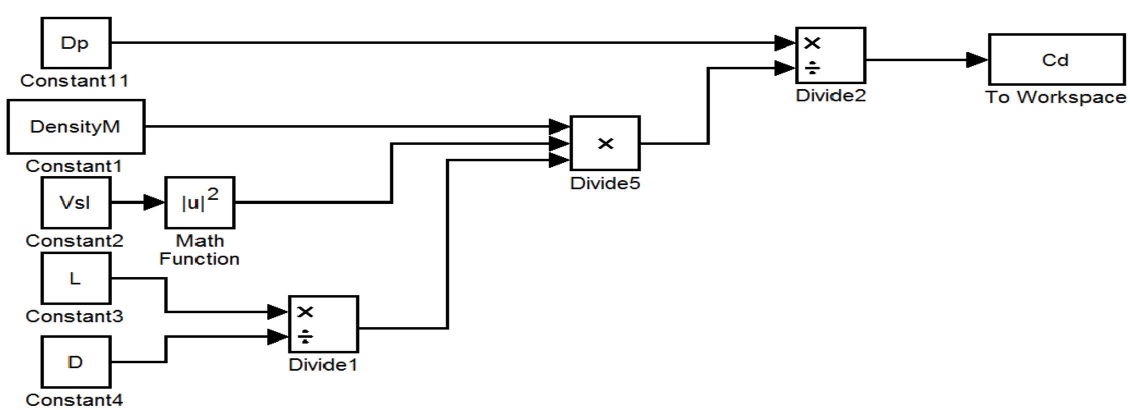
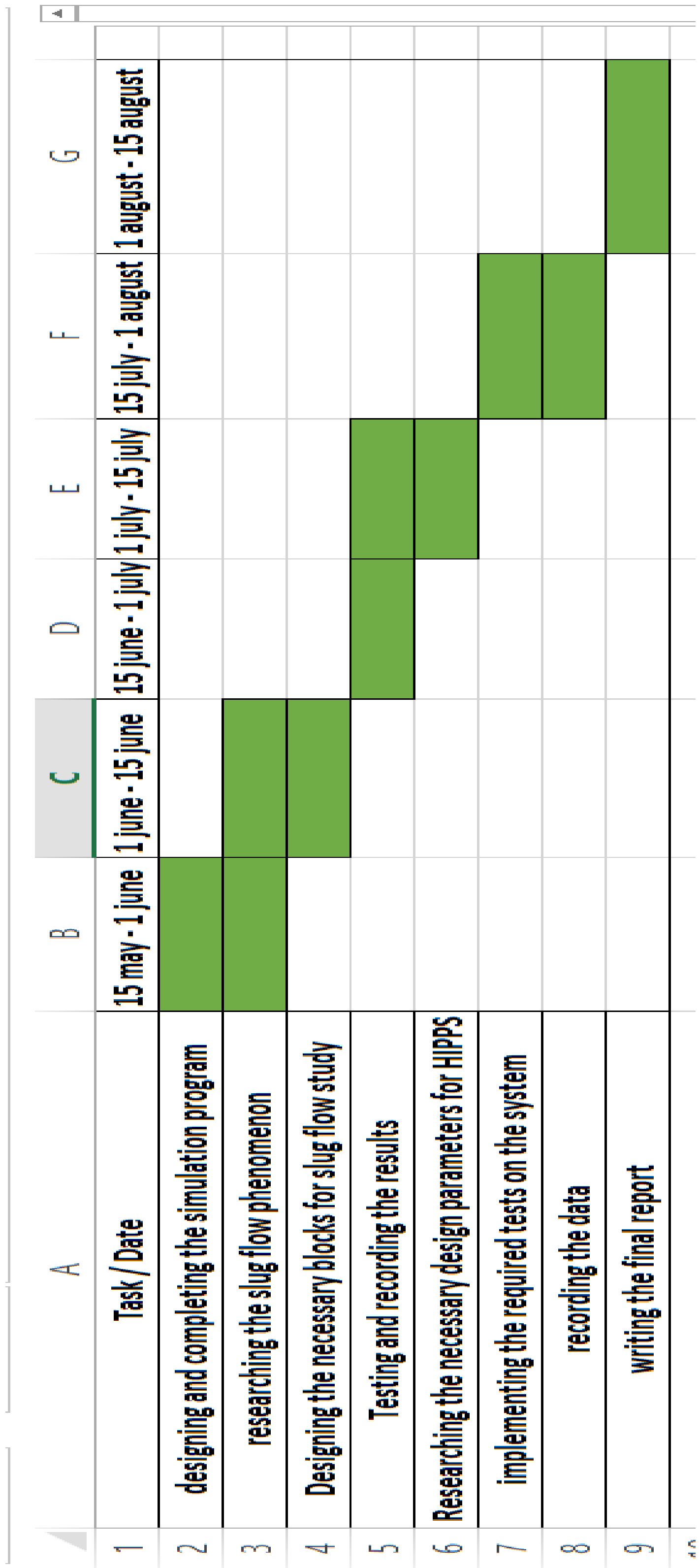


Figure 29: The block diagram simulation of the calculation of pipe constan

3.3 Gantt chart:



Chapter 4

Results and discussion

4.1 Design and simulation of system:

The simulation program was designed based on SIAKAP North project that is being implemented by SBM Offshore N.V office in Kuala Lumpur, in the number of pipes, valves and their design specifications, the values for the parameters and variables were inputted in the M-File and the system was simulated.

The stability of the system and effectiveness of the HIPPS valve were tested under various circumstances which were:

1) (+) Disturbance in the Inflow of Fluids (Water, Oil, Gas) (Increased to Double)
    - The increased fluid keep rising up until it fill the tank except if the fully open control valve for this respective valve can take the extra inflow and dispose of it efficiently.
2) (-) Disturbance in flow of Fluids (Water, Oil, Gas) (Decreased to Zero)
    - Due to the immediate cut of the inflow of the fluid , the respective control valve for this fluid shut down immediately to maintain the set point of this fluid (Height / Pressure) Stable at the desired point.
3) (+) Disturbance in Controlled Set point (increase)
    - The control valve for the fluid with increased set point will shut down until the height/pressure of this respective fluid increase to match the new set point then it will open again to keep the fluid stable at this point.
4) (-) Disturbance in Controlled Set point (Decrease)
    - The control valve of the fluid with decreased set point will open until the height/pressure of the respective fluid decreased to match the new set point then it will close again to keep the fluid stable at this point.

5) Failure in Control valve (Open)

- In this case a failure condition is induced to one of the three control valves controlling the three fluids, the failure condition is that the valve is stuck in fully OPEN position, the result is that the respective fluid with the faulty valve will deplete and be gone from the tank in a short while.

6) Failure in Control Valve(Closed) (Gas valve failure featured in figure below)

- In this case a failure condition is induced to one of the three control valves controlling the three fluids, the failure condition is that the valve is stuck in a fully CLOSED position, the result is that the respective fluid will keep increasing which will result in drastically increasing the pressure in the tank which will trigger the HIPPS valve to close in order to protect the system (in earlier trials without the HIPPS valve , the pressure kept increasing and it actually "mathematically" reached Infinity which in "real life" is disastrous).

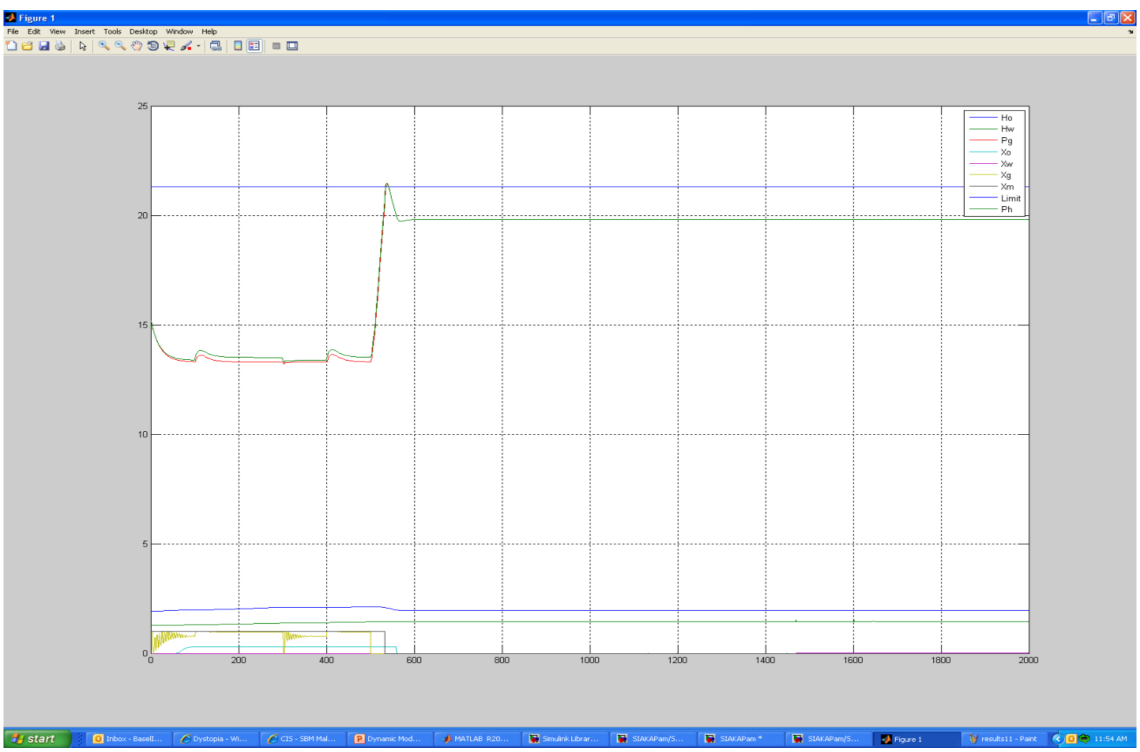


Figure 30: Graphic representation of the system response in situation 6

4.2 Slug flow phenomenon encounter:

The original Inflow of fluids is represented by this graph:

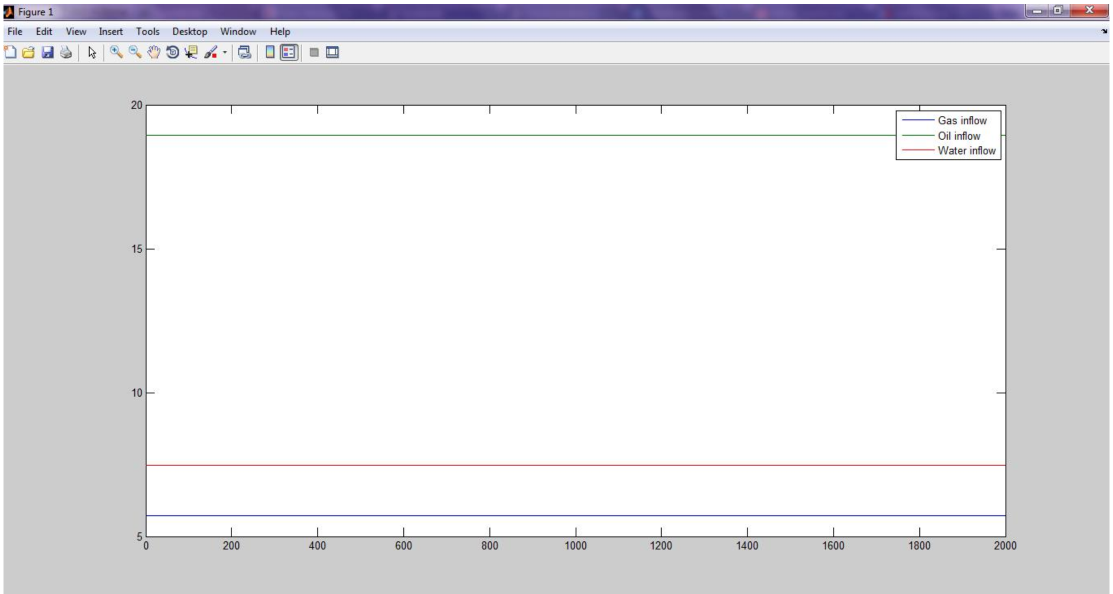


Figure 31: illustrative plot of the original inflow of fluids

In order to simulate the slugging flow, the inflow needed to exhibit fluctuations that are in a way vary through time, to get the resulted inflow that will represent the inflow in the case of slugging, the following signal was used to be multiplied by the original inflow values.

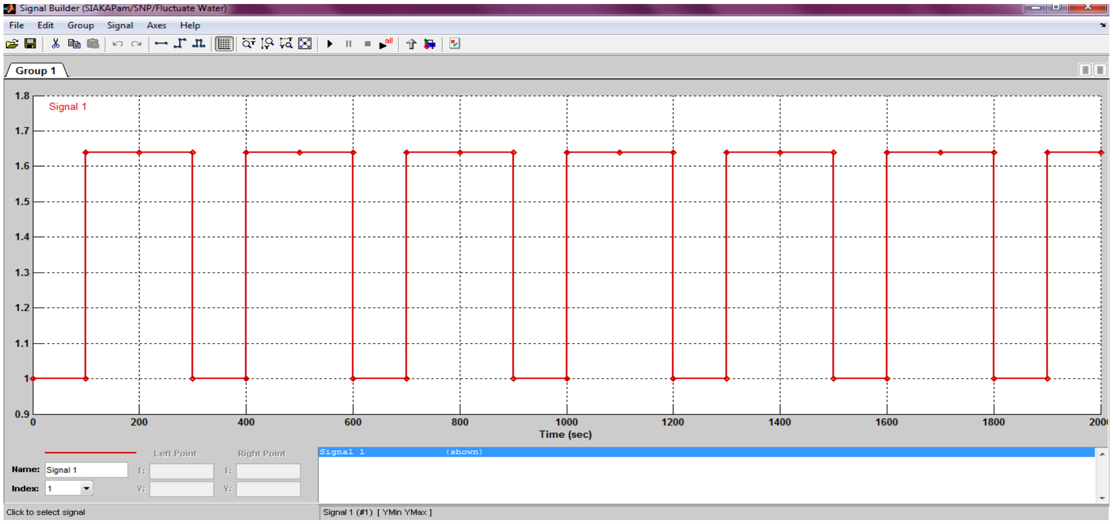


Figure 32: Oscillating signal that is used in the input to stimulate slugging

The resulted inflow that is a multiplication of this oscillating signal and the original inflow is the data that proceed to the system, and based on this data, the system was observed and tested to see the effect of a slugged inflow to the current system being simulated.

The following figure is the modified inflow signal (Slugged):

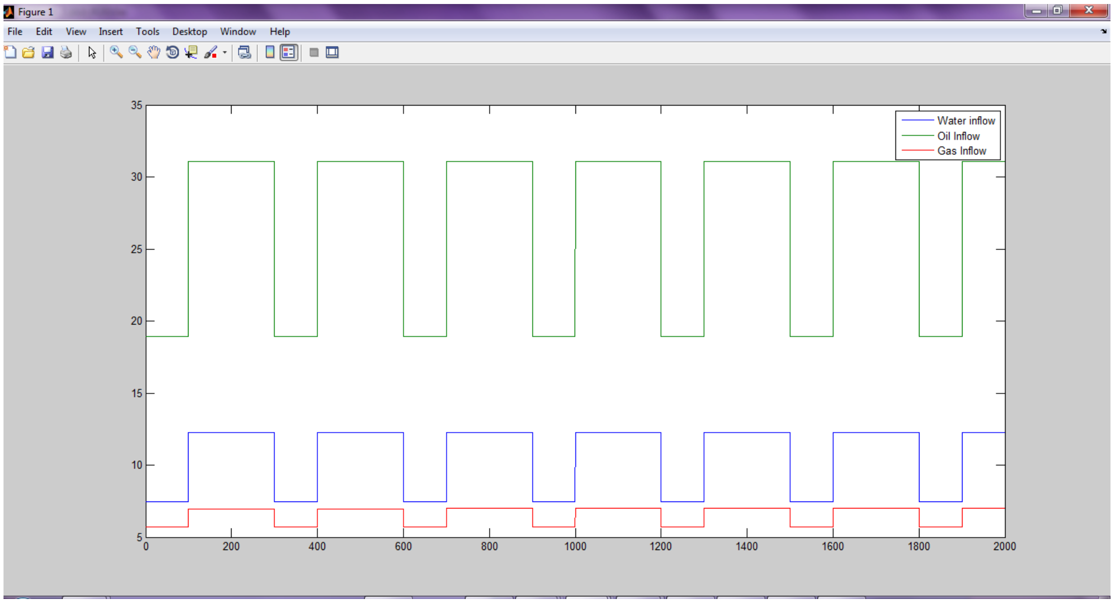


Figure 33: The fluids' inflow after stimulating slugging flow

The system was simulated using that input, and few aspects were observed.

Firstly the outflow of fluids (Water, Oil and gas) as viewed in the next figure:

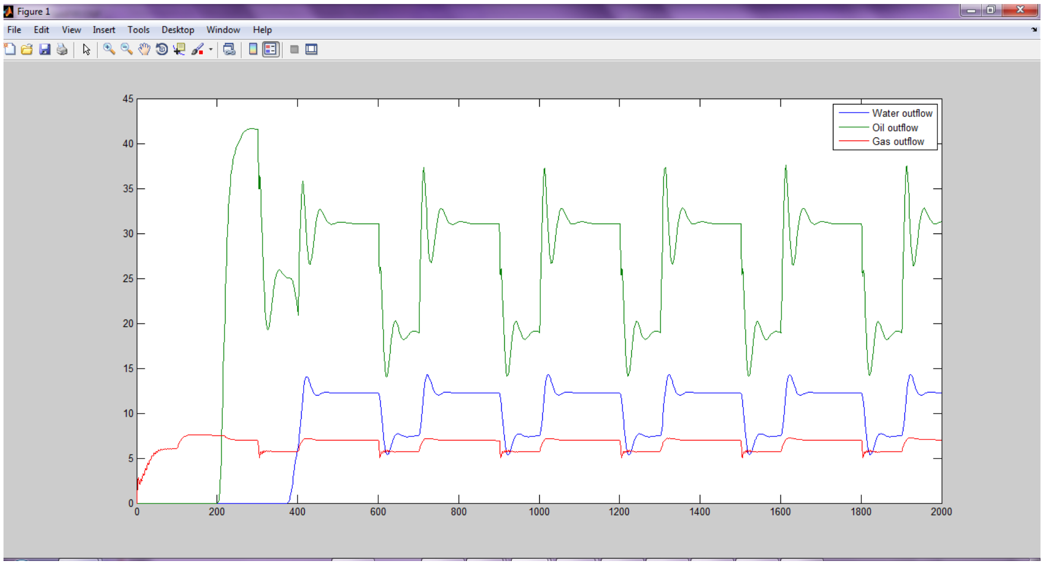


Figure 34: Outflow of fluids due to slugged inflow

By observing the outflow of water, oil and gas we can clearly see that the instability is too great to be handled by the processing and separation process, the difference in the output graph and the input graph (the few spikes) show the response of the system to this respective input, the inflow go through many process till the point of separation, the difference in the response times between different equipment results in the formation of spikes in the outflow.

The effect of this outflow falls upon the many processing equipment that are beyond the scope of the simulated project, like the compressor that will be facing a great difficulty processing the outflow gas, this may lead into the compressor getting stuck and for the compressor life to be shortened.

The effect of the slug inflow INSIDE the scope of the simulation can be observed in the effect it has on control valves, the next figure show the response of the control valves to the slugged inflow.

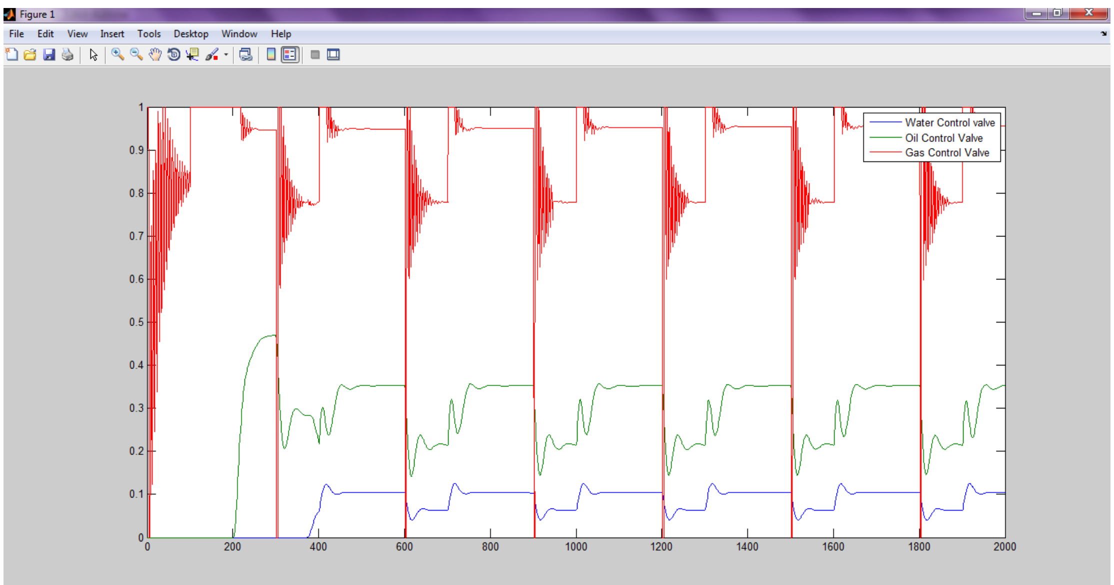


Figure 35: Automatic response of control valves due to slugged flow

As it can be seen in this graph, the response of the control valves is very aggressive and full of fluctuations; this is a factor that if left untreated will severely damage the control valves and accelerate the need to change them.

All those response graph show some of the effects that the slug flow has on the system, it is quite clear that slug behavior is a very serious problem that has implications on many equipment and facilities both inside and outside the 3-phase separator system.

Solutions for the slug flow needed to be chosen and implemented, the proposed solutions will aim to reduce the effect of slug flow and slugging behavior, having few factors in mind which are the outflow of the fluids and the response of the control valves, The implemented solutions will be tested to see how useful they are to those two factors and whether they are sufficient to solve the problem.

Solution 1:

The first proposed solution was to use gap controllers and integrate them into the original PI controllers.

What this solution entails is basically changing the concept of controlling a single set point of level and/or pressure into a group of points in a band with minimum and maximum value.

As long as the controlled aspect (Level) is within this group of points, it should be okay for the control valves to stay at their current state.

This is a PI controller that compares the current controllable aspect (Level) with the set point.

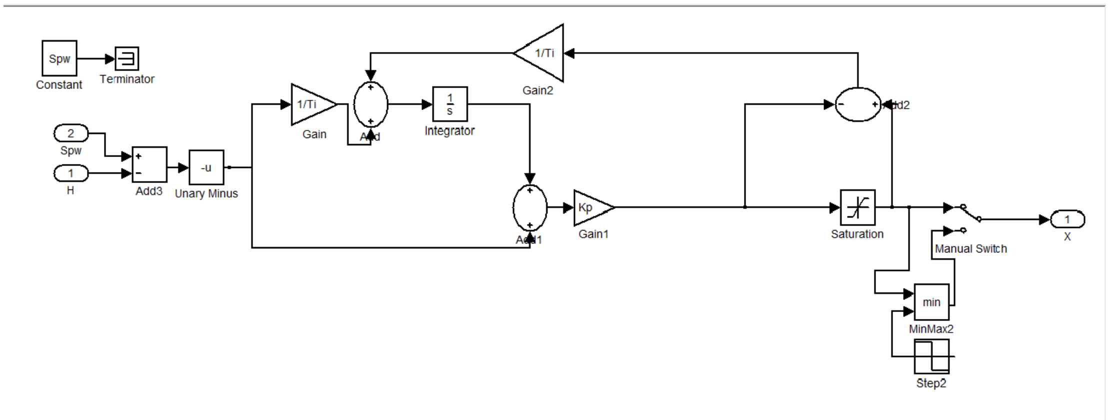


Figure 36: Block diagram simulation of PI controller

The “Set point” input to this controller is NOT a constant in the file, however in this case the input “set point” is taken from the Gap controller.

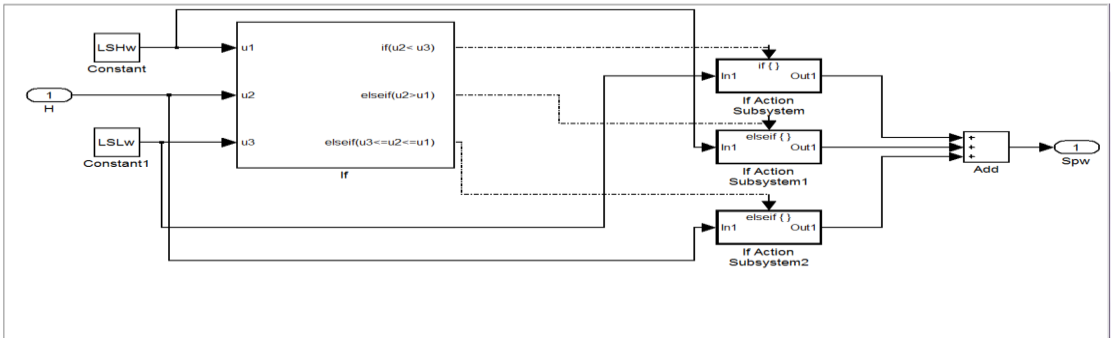


Figure 37: Block Diagram simulation of Gap Controller

After placing the gap controllers in addition to the original PI controllers, the simulation was run and the results were recorded to see if there are any changed in the outflow of the fluids and/or the response of the control valves.

Firstly regarding the fluids outflow, this graph was recorded:

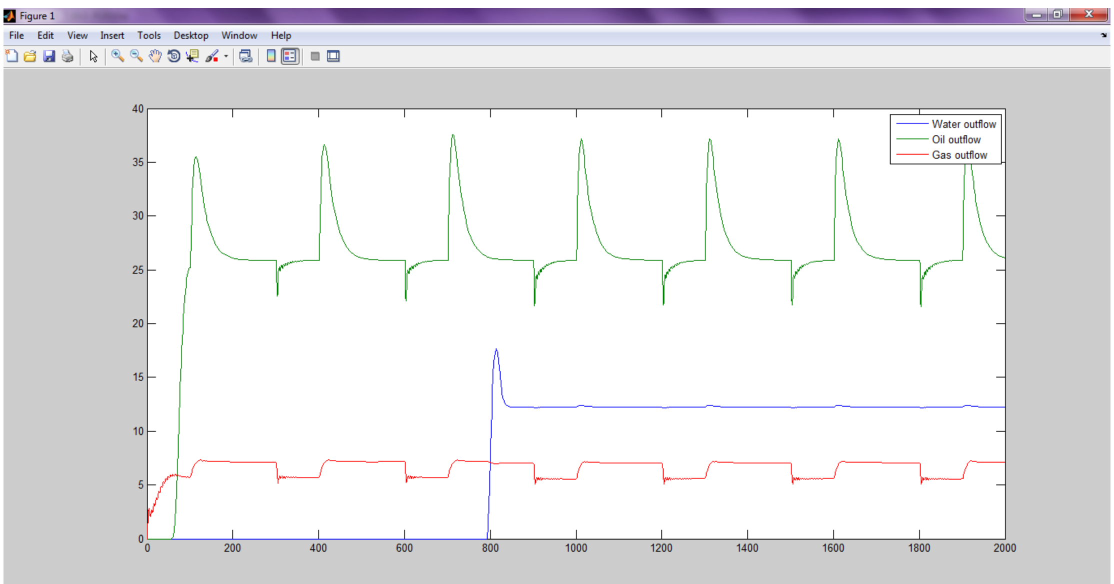


Figure 38: the outflow of fluids in slugged condition AFTER the implementation of gap controller

It's quite obvious here that by adding the gap controllers that set a gap of

[Set point*(1-0.1), Set Point*(1+0.1)] had a drastic improvement in the outflow of the three fluids, another observation that the gas outflow is still suffering from minor spikes due to the difference in response time across the different equipment in the simulation.

In order to fix the spikes that are showing in the gas outflow, the gap controller's band can be widen to account for more changes, this could help eliminate or reduce the severity of some of the spikes that might appear in the fluid outflow.

The gap controllers were used on the PI controllers of both water and oil , as it's much easier to control the level of both those fluids, on the other hand the PI controller of the gas valve depends on pressure which is quite hard to control via the gap controller as the gas is compressible and if the gas control valve is not letting out the appropriate amount of gas every now and then, the gas accumulate inside the 3-phase separator and with each huge intake of gas due to slugging, the outflow of gas has a major spike which will be very harmful to the compressor and any other facilities or equipment outside the 3-phase separator system.

The second aspect that the gap controllers contribute in helping with was the response of the control valves as show in this figure:

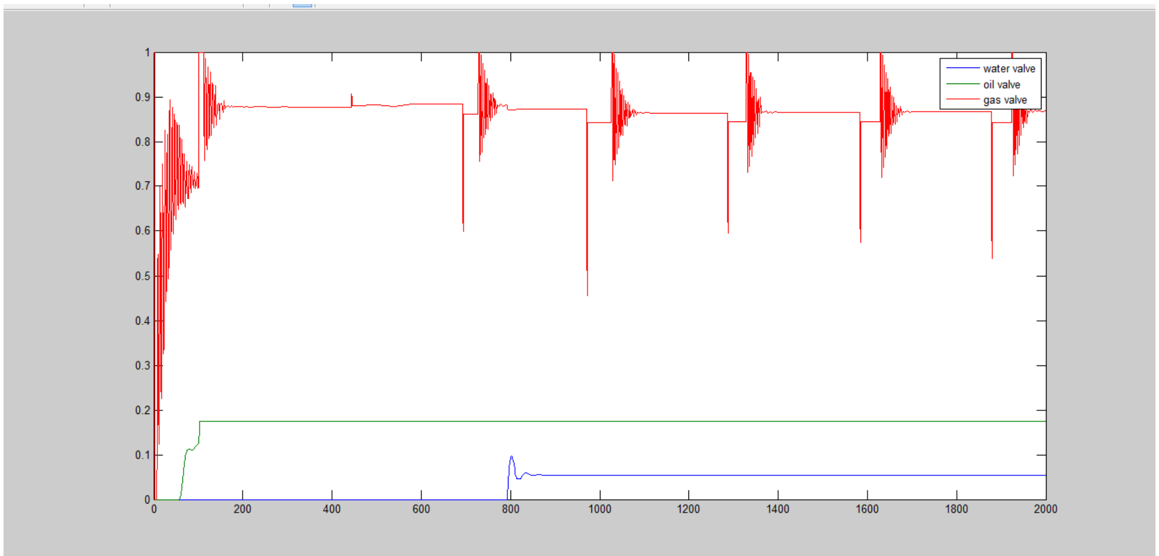


Figure 39: the automatic response of the control valves in slugging condition AFTER implementation of gap controller

Looking at the response of both the water and oil valve, it is obvious that the gap controller had a huge impact on the response which appears to be very stable and very healthy for the control valve.

On the other hand for the gas valve, there is still quite severe response to accumulate for the rapid change in the inflow of gas and hence the pressure of gas.

Solution 2:

The second solution for this problem is the use of a choke valve upstream from the riser, what it does is basically hold off the inflow till a certain point where it's smoothed out and then it let it in the system resulting to a stable and constant inflow that possess no danger to the equipment and facilities in the system.

The choke valve operates based on the inlet pressure (from the riser/well) and the outlet pressure (From the 3-phase separator system), based on the pressure drop across it, the outflow of the fluids that are going through it is determined.

In the figure below, it shows the Outflow from the choke valve which is the Inflow to the 3-phase separator system.

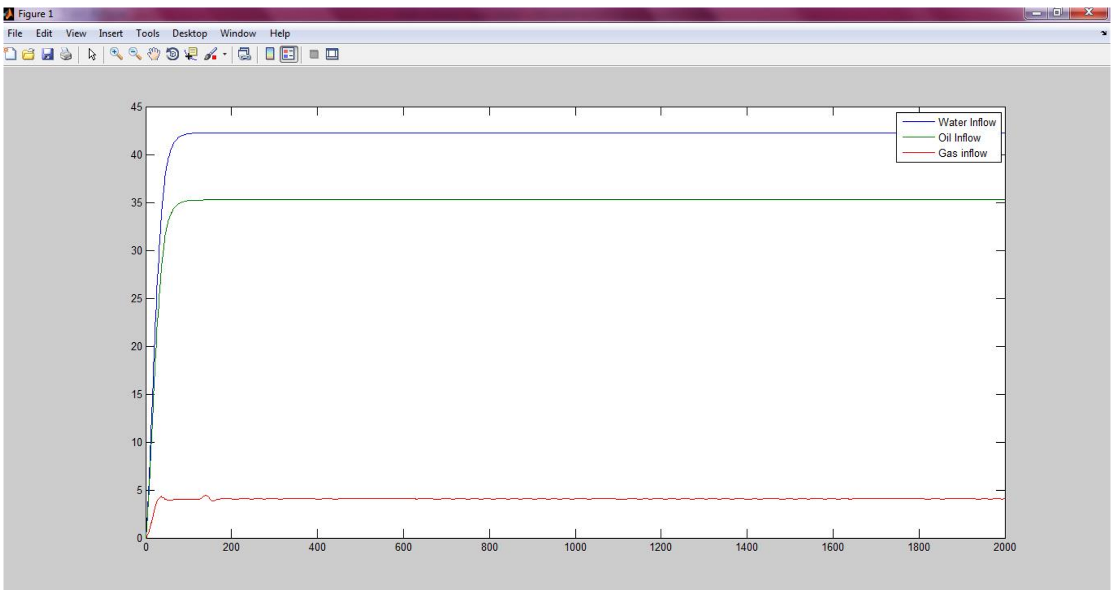


Figure 40: inflow of fluids to the system after passing by the top side choked valve

As it appears here, the input to the system is very smooth and stable which will result in a promising smooth outflow of fluids and healthy response from the control valves.

In the figure below is the graph for the outflow of the fluids:

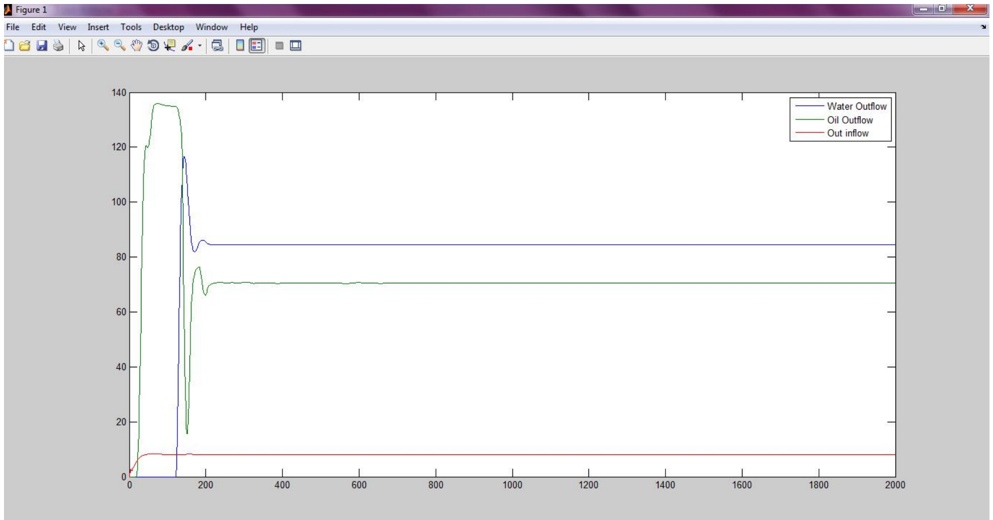


Figure 41: The outflow of fluids after separation

It can be seen that the outflow of the three fluids is very stable except for the few spikes at the beginning which are "simulation-based" and they are usually an indication of the process that the simulated system takes to reach the "steady-state".

It also appears in the figure below that represent the response of control valves:

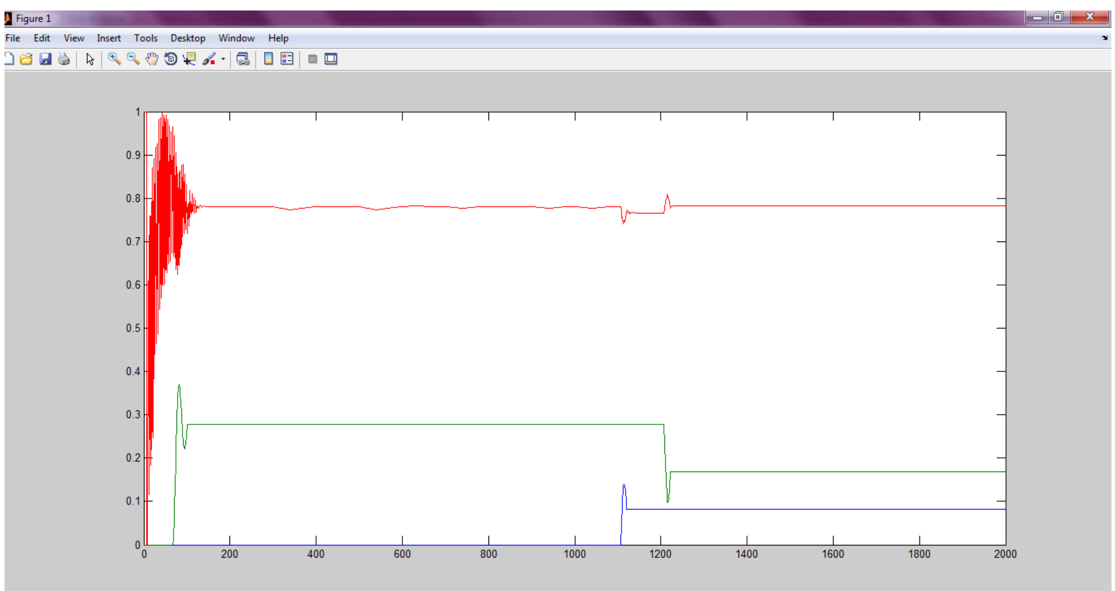


Figure 42: The automatic response of control valves AFTER implementing the top side choke valve.

It can also be seen that the choke valve had a great effect on stabilizing the control valve response except for the few spikes at the beginning that the system go through to stabilize.

Those graphs are a visual proof and representation to how the system reacted to the slugging problem on its own, and then how the solutions introduced affect the response of the system and whether they are viable and useful solutions.

It also shows the aspects that need to be further studied like the continuous fluctuations of the outflow of gas and the severe response of the gas control valve.

4.3 HIPPS valve design and characteristics:

In this part of the objective, a system is subjected to a failure in a control valve, this failure will result in an increase of the pressure in the separator, and the HIPPS valve should close and separate the high pressure point from the low pressure point quick enough before the system explode or rupture.

In this graph, they system is in steady state (No failure)

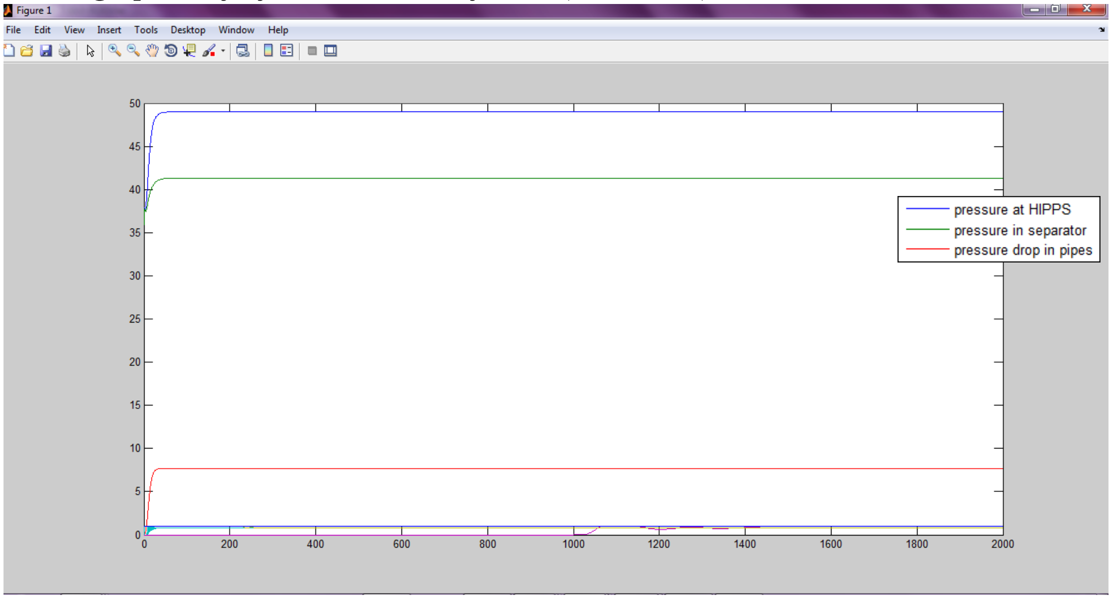


Figure 43: Pressure at HIPPS & Pressure in separator & pressure drop in pipes in steady state condition

After introducing a failure in the system's gas control valve, the valve is closed shut and the gas is all trapped inside the three phase separator.

As the inflow of gas is continuous, the volume of gas inside the separator will increase and since the volume of the separator is finite, the pressure of gas will keep on increasing, the goal of the HIPPS is to cut off the inflow of fluids before the pressure inside the separator gets higher than the designer pressure which will cause rupture and destruction of the 3-phase separator.

The first aspect that we will examine is the closure time of HIPPS safety time.

This is the response of the system at (HIPPS closure time = 50 Seconds):

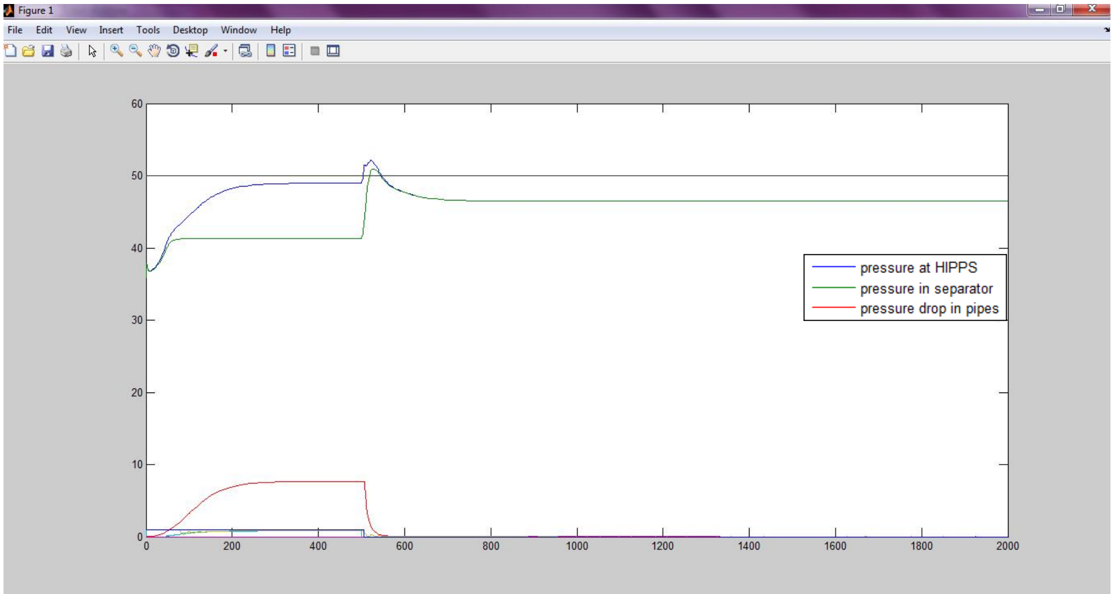


Figure 44: Pressure response to the failure with HIPPS closure time at 50 seconds

This is clearly not a suitable closure time as it took the valve a really long time to close, and by the time it closed the 3-phase separator pressure level has already reached > 50 which is the design pressure, this means that the system has already failed and got ruptured.

This is the response of the system at (HIPPS closure time = 25 seconds):

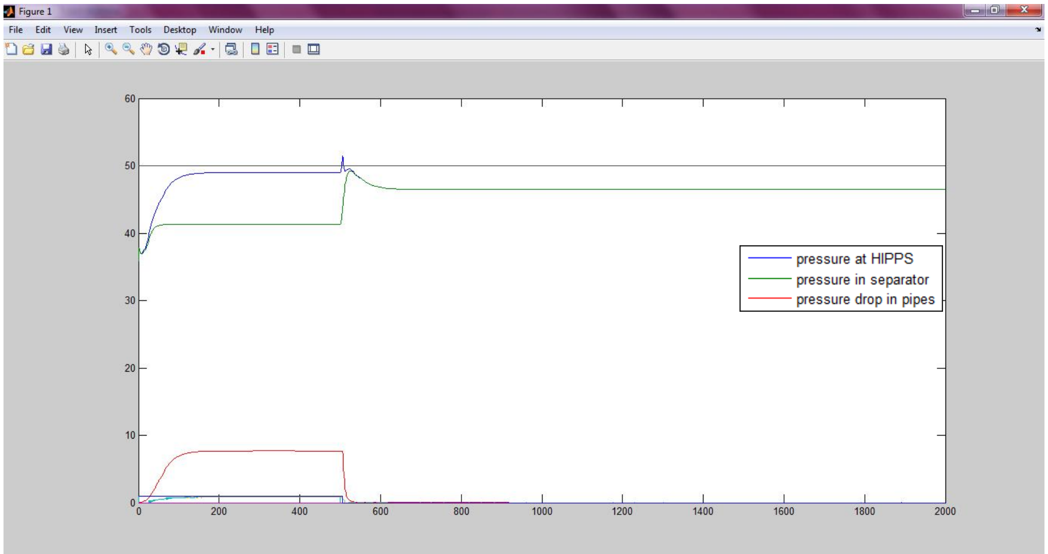


Figure 45: Pressure response to the failure with HIPPS closure time at 25 seconds

As shown here, this situation “might” work but it’s definitely not perfect, as the pressure detected by the HIPPS valve (Pressure in 3-phase separator + pressure drop in pipes) has bypassed the designer pressure, however the pressure in the 3-phase separator didn’t bypass this point which means that the separator was barely saved from rupture.

This is the response of the system at (HIPPS closure time = 15 seconds):

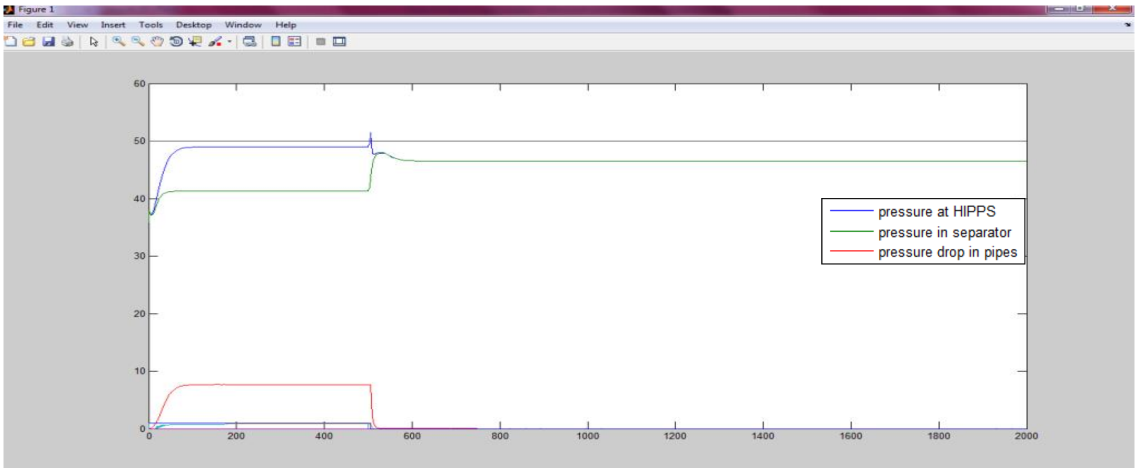


Figure 46: Pressure response to the failure with HIPPS closure time at 15 seconds

This closure time is a lot safer than the two before it, the 3-phase separator’s pressure is retained back to steady state with a good allowance for error, and the pressure that is detected by the HIPPS is also retained to steady state before the design pressure is hit.

This is the response of the system at (HIPPS closure time = 5 seconds):

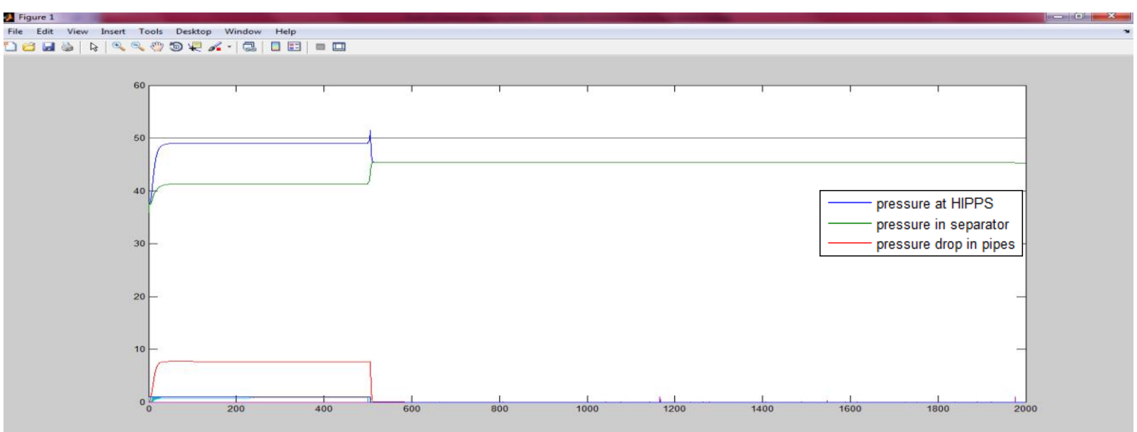


Figure 47: Pressure response to the failure with HIPPS closure time at 5 seconds

This closure time is by far the best out of all the previously tested, as it can be seen that the pressure in the 3-phase separator is only disturbed slightly due to the failure in the control valve, it quickly regain its steady state without getting close to the danger zone.

This shows that the most appropriate closure time for HIPPS system is 5 seconds, this closure time will depend on how big is the HIPPS valve, if the HIPPS valve needs to be bigger, then it can only be allowed up to 15 seconds of closure time, as if the closure time takes longer than 15 seconds, the system will be subjected to surpassing the design pressure and will be in danger of failure, explosion and rupture.

The second aspect that was examined is the pressure set point:

The design pressure of the system is set to be = 55 bar

The set pressure for the HIPPS is tested in a range of [50:54] bar, with having the closure time of HIPPS constant at 5 seconds and the failure is in the gas control valve.

This is the system response at (HIPPS pressure set point = 54 bar):

Figure 48: Pressure response to the failure with HIPPS set pressure at 54 bar

This set pressure is quite suitable to the system as the pressure in the separator is smoothly retained to its steady state, the pressure at the HIPPS got a little bit closer to the design pressure which in a way increase the risk of a system overpressure.

This is the system response at (HIPPS pressure set point = 52 bar):

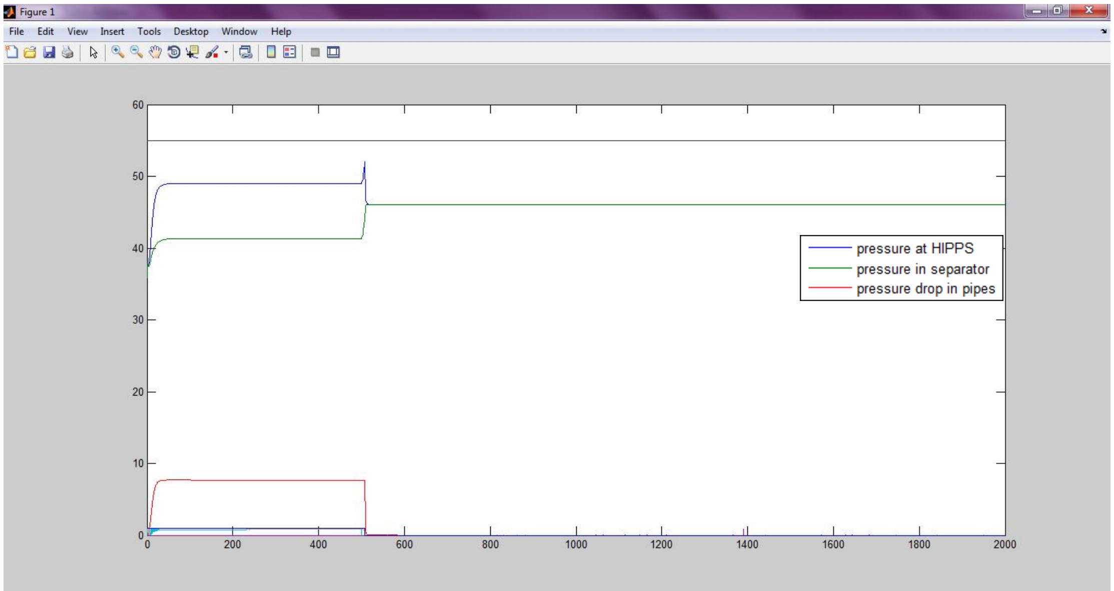


Figure 49: Pressure response to the failure with HIPPS set pressure at 52 bar

In this case, the pressure at HIPPS is receding from the design pressure which decreases the risk of a system failure.

This is the system response at (HIPPS pressure set point = 50 bar):

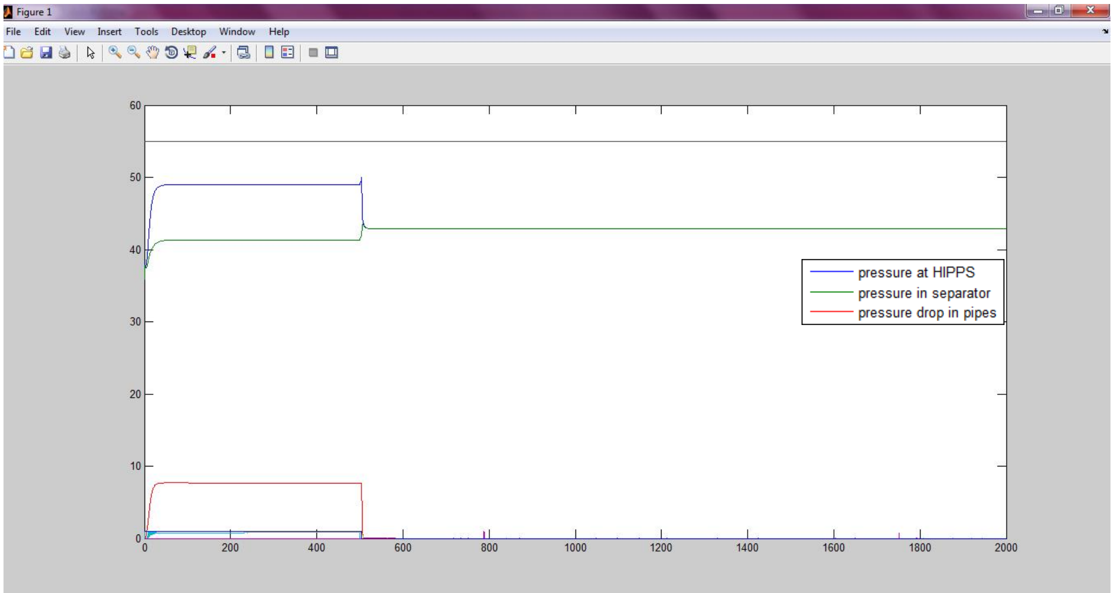


Figure 50: Pressure response to the failure with HIPPS set pressure at 50 bar

In this case, the spike in the HIPPS pressure is reduced greatly; both the pressure in separator and pressure at HIPPS are retained to their steady state without coming even close to the design pressure which makes the system in the utmost safety condition.

The concluded results concerning this part of the objective is that:

- HIPPS closure time of 5 seconds is the best and most appropriate closure time that can be used in the industry to insure a fast and safe system securing.
- The HIPPS pressure set point is best chosen at 90% of the design pressure to ensure that the HIPPS valves will close in time before the pressure reaches a danger stage.

4.4 Simulating a different project:

The simulated design was used to represent a different project entitled "**KAKAP**", this project has some differences from the original project that the simulation project was designed based on.

The differences were both in the design (number of pipes and their connections), and the data sheets which specified values like (inlet and outlet pressure on control valves, inflow and outflow of fluids, pressure drop across the system and the design pressure of the 3-phase separator).

The simulated design was modified according to the changes in the project, the values of constants and variables in M-file were also modified to suit the new project, with everything else intact (connections of different components / method of testing).

The system was tested under different circumstances like disturbances in inflows and failures in control valves, the response of the system was plausible and convenient, and they also coincided with the theoretical values.

This showed that the concept behind the realization of the simulated design and the theory followed in representing the components and connecting them is a valid theory and that this design can be used to represent multiple projects who share similar outline and schematics.

Simulating this project successfully was the assuring proof that the values that comes out of this simulation is valid, reliable and accurate.

Chapter 5

Conclusion and recommendations

5.1 Conclusion:

In this project a computer software (Simulink) was used to simulate the process in separator part of the plant, having this simulation it opened up many possibilities and ways for it to be used and for us to leverage on it.

This simulation was used to fulfill the following objectives:

A. **Study the system response in different situations: (change in flow/set point)**
   The system was put under different circumstances like increased and decreased fluids inflow and alternating set points, the reaction of the system was recorded and presented graphically and it led us to have a clear view and idea of how the system response in real life might be

B. **Review and solve the problem of slug flow phenomenon:**
   The system was used to study and understand one of the most important phenomenon in the offshore industry which is the slug flow phenomenon, using the simulation we managed to implement and test the solutions provided by the industry and to know the exact effect of each of those solutions on the system outflow and the control valves' operations, those solutions can later be implemented in real life to overcome this problem

C. **Specify the design parameters of HIPPS safety valve:**
   The simulation was used to test the system under different types of failure to observe the operations of the HIPPS valve, based on those tests, the HIPPS safety valve was viewed under different failure situations and it gave us a good and a specific idea of the most suitable parameters of design of that valve, parameters like the closure time and pressure limit are very crucial elements that are quite difficult to find without using the simulation.

D. **Simulate different projects and check the reliability of the simulated design:**
   The simulated design was used to represent a different project that has a different set of pipes connections and different values of system variables, the goal of this step was to test how reliable is the simulated design and whether it will be

compatible with other projects and the results was very helpful, the system yielded a very suitable outputs that coincide with the literature review and the theoretical study of the system which prove that the simulated design can indeed be used to represent different projects and that the equations used and the method implemented to come up with it is reliable and accurate.

5.2 Recommendations:

5.2.1 Concerning the design:

- Represent the equipment in the system more accurately (take in consideration the hydrodynamic relations between the moving fluids inside the system)
- Increase the fail-proof aspect of the system by covering up all the equations that might lead to a point of singularity result (infinity results cause the simulation to stop and issue an error message)
- Synchronize the response time of different equipment in the system in order to reduce the formation of spikes in output
- Represent the system from a modern control engineering point of view (ABC matrix that shows the stability, controllability , observability , detectability and stablizability of the system)
- The addition of new components to the system like (Riser, Compressor, etc.)
- Have a clearer representation of all the variables and constants in the system so it would be easier to view and observe them
- Develop a troubleshooting frame work to make identifying and fixing error an easier task

5.2.2 Concerning the usage:

- The simulation should be used to represent different projects (preferably an actual existing project so it'd be easy to compare the results from the simulation to real life results which show how reliable the simulation is)
- The concept of using computer software and simulation to help in the design and control process should be spread and taken care of as there is a huge potential in this field and it can save time, effort and money
- The simulation should be used to discover and address different phenomenon and problems that might face the system
- The simulation should be used to identify the best way to utilize the equipment in the system
- The simulation should ease up the process that usually take a lot of calculations by hand and may involve human error.
- The simulation should be used before the implementation of any new equipment or new system protocols to know first what is the response of the system to this newly installed equipment and/or newly implemented protocol

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