

# **Subsea Production System (SPS) Control Modelling**

by

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# **CERTIFICATION OF APPROVAL**

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A project dissertation submitted to the  
Mechanical Engineering Programme  
Universiti Teknologi PETRONAS  
in partial fulfilment of the requirement for the  
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Approved by,

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TRONOH, PERAK

SEPTEMBER 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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MOHD MUSLIM B ABD KOHA

## ABSTRACT

The motivations of this project work are to develop a simulation model for a direct hydraulic control system, find the effect of changing key parameters to the system's response time, and also to demonstrate Emergency Shut Down (ESD) feature which is a requirement for the subsea production control systems (SPCS). The methodology of this project involves selecting a control system to be studied which is a direct hydraulic control system, gathering technical details and data regarding the control system and components that constitute the control system, and translating the technical details and concepts into acceptable simulation forms in the simulation's software. This project used SimulationX to simulate the developed model. The developed model consist of a hydraulic power unit, a topside control panel, hydraulic lines, a subsea control module and two actuator valves. The Cadlao oil field has been selected as the case study and simulation models were built according to the Cadlao field's SPCS. The simulated model is validated by comparing the Cadlao's performance curves and the acquired results. The simulation is done by varying 3 parameters which are umbilical length, umbilical diameter, and actuator size. Each parameter is tested to study its influences on the signal time and shift time. To find the effect of umbilical length on the signal time, umbilical lengths of 6000 ft, 12000 ft, and 18000 ft have been used. Time taken are 47 s, 110 s, and 195 s respectively. For the simulation using different umbilical diameters, 0.15 inch, 0.35 inch and 0.50 inch have been used. Time taken to fully pressurize the umbilical are 111 s, 39 s and 48 s respectively. For the second part, to find the effect of varying parameters on shift time, three parameters are changed (umbilical length, umbilical diameter and actuator diameter). 6000 ft, 12000 ft and 18000 ft umbilical lengths have been used and the recorded shift times are 13 s, 21 s and 31 s respectively. For the simulation using different umbilical diameters, 0.15 in, 0.35 in and 0.50 in have been used and the recorded shift times are 113 s, 19 s and 13 s respectively. Lastly, sensitivity analysis is done using three different piston diameters. Diameters of 6 in, 9 in and 12 in have been used and the recorded shift times are 28 s, 36 s and 56 s respectively. Lastly, emergency shut-down simulated showed that the actuator is able to return to fail safe condition in 33 s.

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## ABBREVIATIONS

CAPEX	Capital Expenditures
CIU	Chemical Injection Unit
DCV	Directional Control Valve
DHSV	Down Hole Safety Valve
HIPPS	High Integrity Pressure Protection System
HPU	Hydraulic Power Unit
OPEC	Organization of the Petroleum Exporting Countries
SCM	Subsea Control Module
SDU	Subsea Distribution Unit

SEM	Subsea Electronic Module
SPCS	Subsea Production Control System
SPCU	Subsea Power and Communication Unit
SPS	Subsea Production System
SRM	Subsea Router Module
UTA	Umbilical Termination Assembly
XT	X-mas Tree

# CHAPTER 1

## INTRODUCTION

### 1.1 BACKGROUND STUDY

Nowadays, oil and gas exploration have moved toward deeper water region due to increase in demand for more oil and gas energy. It also due to depletion in shallow water oil reserves. Figure 1 shows forecast global oil consumption from 1965 until 2035.

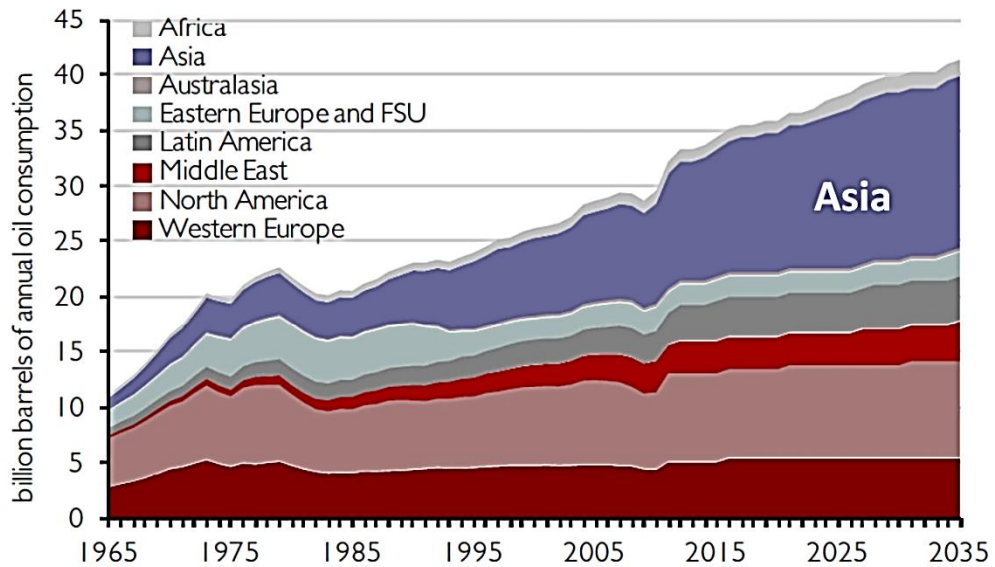


Figure 1: Global oil consumption [1]

With overall OPEC (Organization of the Petroleum Exporting Countries) oil production is declining, the key drivers of growth in oil production are the US and Canada. Exploration and production (E&P) expenditure growth is growing slowly but still healthy (Barcap report 8.8% in 2012 vs. 10% forecast. 7% forecast for 2013). Although E&P expenditure is not increasing as rapidly as expected, report on SUT by Liam Kelleher state

that current predictions that total E&P expenditure is expected to increase from US\$600 billion in 2012 to US\$644 billion in 2013. Along with increase in offshore spending, subsea hardware is predicted to have an overall CAPEX of US\$135 billion spread over the next five years (representing a 14% increase from previous five years) [2]. Figure 2 present the deep-water production statistic and Figure 3 present the world subsea hardware market.

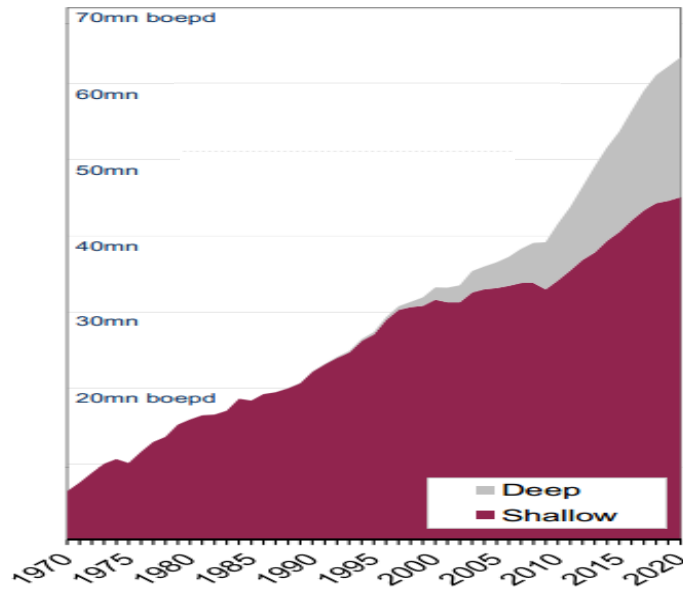


Figure 2: Offshore production from 1970 to 2020 [1]

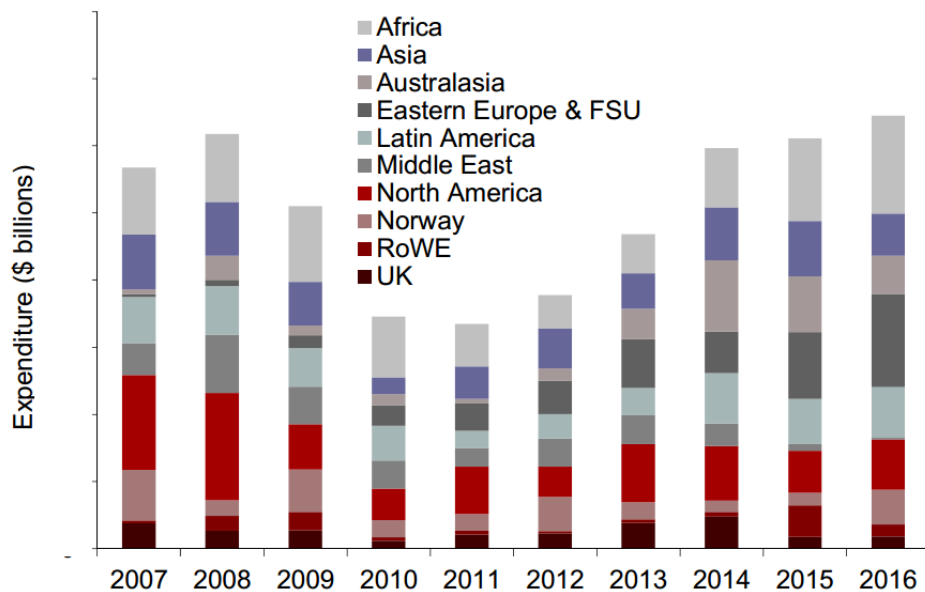


Figure 3: World subsea hardware market [1]

Subsea production system is a combination of subsystems that have their own roles aiming to assist in bring out hydrocarbon from reservoir to the surface and stores at a topside facility or at a distance facility. The main subsystem are [3]:

- Subsea well heads and x-mas tree equipments
- Production control system
- Umbilicals
- Intervention system
- Subsea structures and piping systems
- Subsea flow lines

Table 1: Advantages and disadvantages of subsea system

Advantages	Disadvantages
Eliminate or reduce CAPEX of the platform	Complex hardwares
Cost burden transferred from CAPEX to OPEX	Inaccessible for maintenance and repair
Construction cycle is conducive to fast-track projects	Intervention is expensive and complex
Suitable to phased projects	

The brain of the subsea production system is the production control system which control all the subsystems that comprise the SPS for the aim of producing hydrocarbon. Subsea production control system (SPCS) is used to control subsea control valves installed on subsea equipments located on seabed. SPCS is also used to provide information of the subsea equipment's status. In term of safety, SPCS is required to detect adverse conditions and effect its own automatic shut-down to prevent accident or broken equipment [4].

SPCS is designed according to standards regulated by industry, national and international agencies including the operation, design and testing of the system. System is subjected to strict quality reviews such as failure modes, effects and critical analysis.

## **1.2 PROBLEM STATEMENT**

As oil field moving toward deeper region, as shallow water reserves have mostly depleted, operator requires new technologies to be implemented to cope with new challenges faced in this region. To understand new technology capabilities, beside physical experiment on model, which will consume a lot of time and very costly, developer nowadays are using simulation software to virtually test their proposed solution. By simulation, system can be virtually tested in various operation conditions and verified the system capability to run in the field. This will increase the confidence in the system. Despite that, many other alternative solutions also can be tested and each solution can be compared to find the most dependable one. For example, the effect of varying dimension of umbilical or different actuator size can be analysed and their impact to system performance can be acquired quickly. The need for simulation is heightened as umbilical is the most expensive component in subsea system, and if wrongly dimensioned, it can result in major time and cost overruns. Therefore, various alternative solutions of umbilical can be tested through simulation in order to select the best solution.

## **1.3 OBJECTIVES**

The objectives of this project are:

1. To develop simulation model for a direct hydraulic control system.
2. Investigate model's signal time and shift time under varying parameters.
3. Investigate model behaviour under emergency situation.

## **1.4 SCOPE OF PROJECT**

The scope of the study covers the following:

1. Study on a various subsea control system and select a system for modelling and simulation.
2. Develop a simulation model focusing on the critical components in subsea production control system (hydraulic power unit, umbilical, subsea control

module, and actuator) that operates the subsea gate valves and effectively illustrates the gate valves operations on controlling an oil or gas flow.

3. SPCS model is simulated using real operating field data acquired from patents.
4. Behaviours of the developed umbilical and gate valves are studied and their effects on the system's response time are shown through performance curves.
5. Emergency shut-down feature included in model is simulated to show system behaviour under emergency situation.
6. Cadlao oil field is selected as the case study for this project and the developed simulation model is validated by comparing the performance curves of the Cadlao field and the acquired results.



## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1 SUBSEA PRODUCTION CONTROL SYSTEM**

With reference to API 17F, subsea production control system is defined as a control system operating a subsea production system during operations [5]. Subsea Production Control System (SPCS) manages the operation of subsea equipment located on the seabed during various subsea functions execution. The control functions include:

1. Operates valves and chokes on subsea trees, manifold/templates, and pipelines remotely from topside.
2. Receives and transmits the data between the topside and subsea equipment, which helps engineers monitor the status of production.
3. Enable safe operation of subsea wells by enabling the operator to control the opening and closing of valves and perform shut down operation during emergency.

Appendix I illustrates an overview of a subsea production control system. The control of SPCS is done at the topside facility and transferred to seabed where the control function is executed. It typically consists of three sections [6]:

1. Topside (surface control unit)  
Comprises of a hydraulic power unit (HPU), electric power unit (EPU) and well panel. The HPU can be on surface station on land or a work over rig platform.
2. Umbilical (control line)  
Combination of electric cables, hoses or steel tubes, either on their own or in combination (or with fibre optic cables), cabled together to increase flexibility and mechanical strength. It is used to transfer electrical power and signals, hydraulic

power, and/or chemicals to the subsea components on the subsea production system.

### 3. Subsea installations

Subsea installations include subsea control module (SCM), subsea distribution systems (distribute chemical, electrical, and hydraulic from umbilical termination), and subsea located sensors.

Satisfactory response time is an important factor that may affect system's reliability and safe of operation. As communication distance between topside production facilities and subsea installations increases, total well that have to be controlled increases and water depth become deeper, earlier control method using direct hydraulic control become less feasible. As a result, more advanced and complex control method being developed. There are several type of control system:

1. Direct Hydraulic Control System
2. Piloted Hydraulic Control System
3. Sequential Piloted Hydraulic Control System
4. Hard-wired Electrohydraulic Control System
5. Multiplexed Electrohydraulic Control System

Selection of fluids to be used should consider maximum operation temperature and pressure that the fluid will be exposed to. Besides, compatibility of the fluid with system components also have to be considered [5]. Two commonly used fluid for subsea production system are high water content-based or synthetic hydrocarbon control fluids. Mostly used fluid is high water content-based.

The characteristics of high water content-based fluid depend on the ethylene glycol content (typically 10% to 40%), viscosity varies with temperature (normally 2-10°C). Due to government regulations does not allow venting mineral-based oil into the sea, the system that uses this type of fluid must be closed-loop system, which requires extra conduit in the umbilical, thus making it more complex [6].

## 2.2 DIRECT HYDRAULIC CONTROL SYSTEM

Direct hydraulic control system operation is the relatively simple and straight forward system in which HPU and control panel for each well to be controlled located on the topside facility. The control panel consist of solenoid-operated control valve which control the flow of the hydraulic fluid. When operator set the control valve on control panel to open position, allowing pressurized fluid to pass through and transported to actuator located on the X-mas tree via umbilical hose.

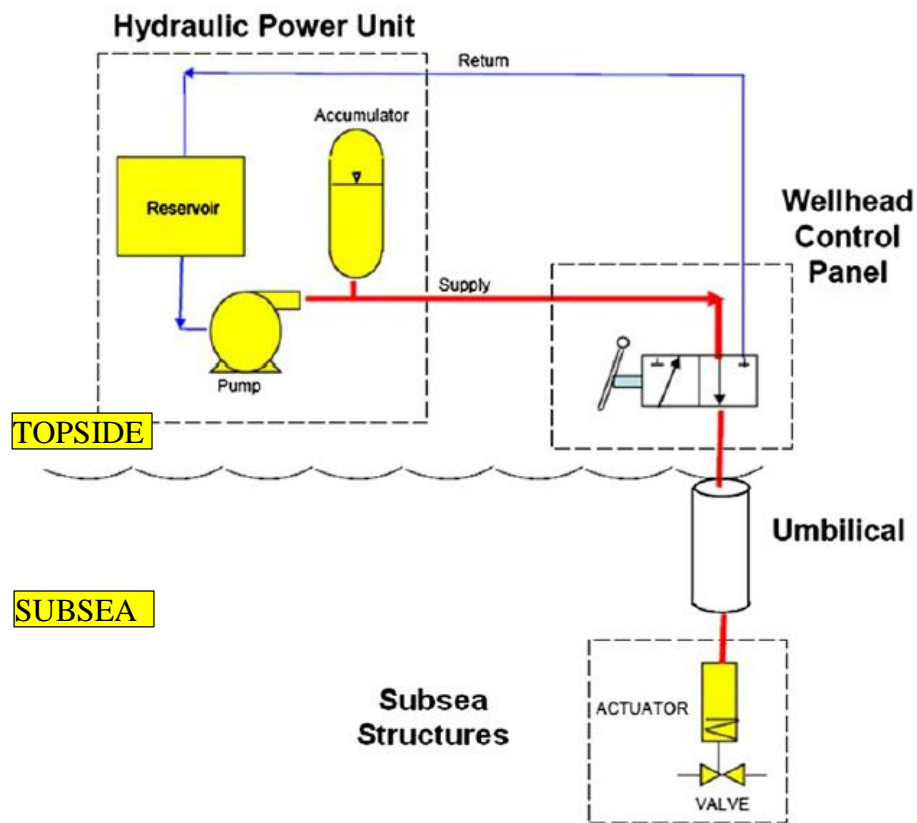


Figure 4: Direct hydraulic control system [7]

The system advantages are relatively simple control system, high reliability, ease of service, and minimization of subsea components [6]. Regardless of the strengths of the control system, it also has downsides such as complex hydraulic line as it has to contain all the individual line for each subsea function. The size of the umbilical also increased. Hence, cost also increased. Besides that, it has slow response time caused by the need to

pressurize the fluid until it reached the pressure that enough to operate subsea actuator or to perform other task. Slow response of the hydraulic fluid is influenced by the fluid's properties (e.g. bulk modulus, viscosity), characteristics of the umbilical (e.g. wall roughness, elasticity) and compliance and volume of actuators. Due to slow response time, this type of control system is limited to applications where the distance between the topside facility and the operated subsea equipment is less than 3-4 km [6].

### **2.2.1 Hydraulic Power Unit (HPU)**

By Norsok Standard's requirement, HPU shall supply regulated hydraulic fluid to the subsea installation. Output fluid from the HPU shall as a minimum satisfy cleanliness requirement of NAS 1638 class 6. Hydraulic system shall be designed 10% above the maximum operating pressure. Maximum operating pressure should be 5% above normal operating pressure. Typical operation pressures for Christmas tree and manifold functions are 3000 psi and 9000 psi for down hole safety valves (DHSV) functions. The pressure difference is dictated by the function of water depth and process pressures [6].

HPU functioned to supply fluid at correct pressure, flow rate and acceptable cleanliness to remotely operated subsea valves through the umbilical. The reason for cleanliness is to maintain the reliability of the system. Besides that, HPU also regulates supply pressure to avoid overpressure or during insufficient hydraulic pressure. HPU normally installed on the FPSO or platform or may be located onshore for subsea-to-beach tiebacks. Fluid is supplied via the controls umbilical, the subsea hydraulic distribution system, and the SCM's to operate subsea valve actuators. The pressurized fluid provided by pump is driven by an electric motor. There are many types of pump, but the most common type uses accumulators that are charged by fix pumps. Redundancy for the motor pump sets act as backups in case of pump failures or maintenance.



Figure 5: Hydraulic power unit [7]

### 2.2.2 Topside Umbilical Termination Unit (TUTU)

TUTU is the interface between the surface and subsea equipment. The function of TUTU is to route hydraulic fluid from the HPU to the subsea umbilical. It provides hose coupling points and an electrical junction box. Additionally, it houses block and bleed valves for each hydraulic function.



Figure 6: TUTU [8]

### **2.2.3 Subsea Control Module (SCM)**

SCM is the interface between the control lines and various end users such as actuators located on trees and manifolds. SCM can be installed on a subsea tree, manifold template and other components and it is packaged in a retrievable housings. SCM consists of many components such as:

1. Electrohydraulic or hydraulic piloted DCV and other valves (check valves and shuttle valves)
2. Sensors and transmitters
3. Filters
4. Accumulators
5. SEMs

Typical well control functions provided by SCM are [9]:

1. Actuation of fail-safe return production tree actuators and down hole safety valves and other valves (e.g. shut-off valves, choke valves)
2. Provides data (e.g. pressure, temperature and flow rates) of subsea systems.
3. Monitoring position of chokes
4. Filters hydraulic fluid
5. Direct hydraulic fluid supply to respective lines to actuate valves

Directional control valves located on the SCM will directs fluid to or from actuators during operation by controlling the spool position or orifice area.

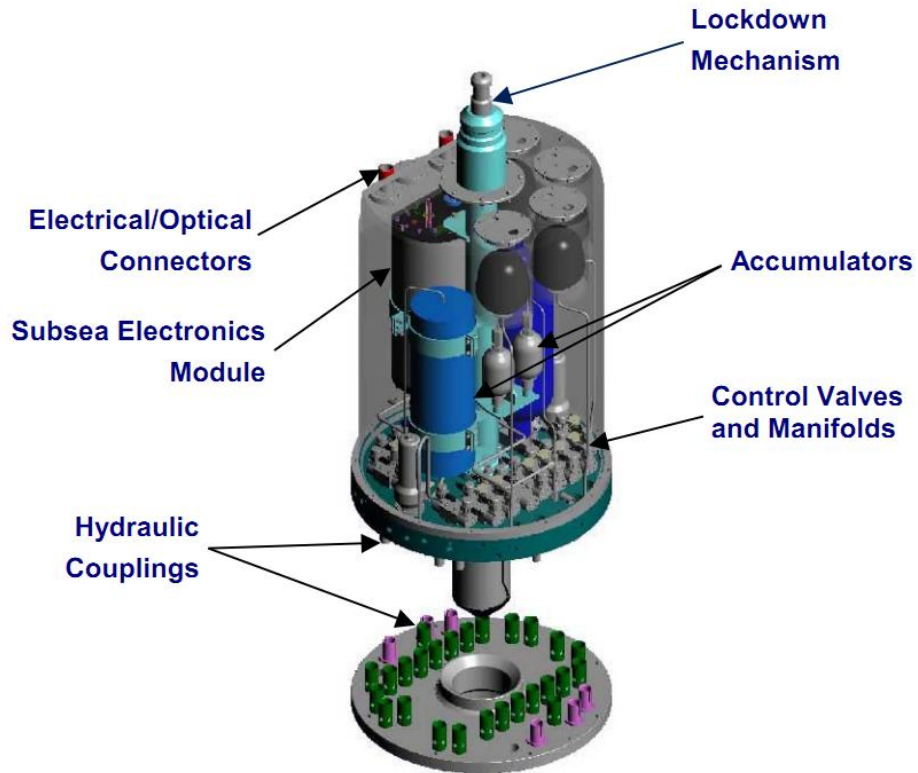


Figure 7: Typical subsea control module [10]

#### 2.2.4 Umbilical

Umbilical is a composite cable containing tension wires, hydraulic pipes, electrical power, control and communication signals which is installed from host facility to subsea installations [11]. The main functions of the umbilical are:

1. To deliver control fluids or electric control signals to control the functions of subsea equipment (e.g. tree, valves, manifold)
2. To convey chemical during chemical injection to subsea trees or manifolds
3. To monitor pressures in well annulus

There are many types of umbilical and the choice of umbilicals can depend on the application and type of system deployed. Figure 8 shows the umbilical used for direct hydraulic control system.

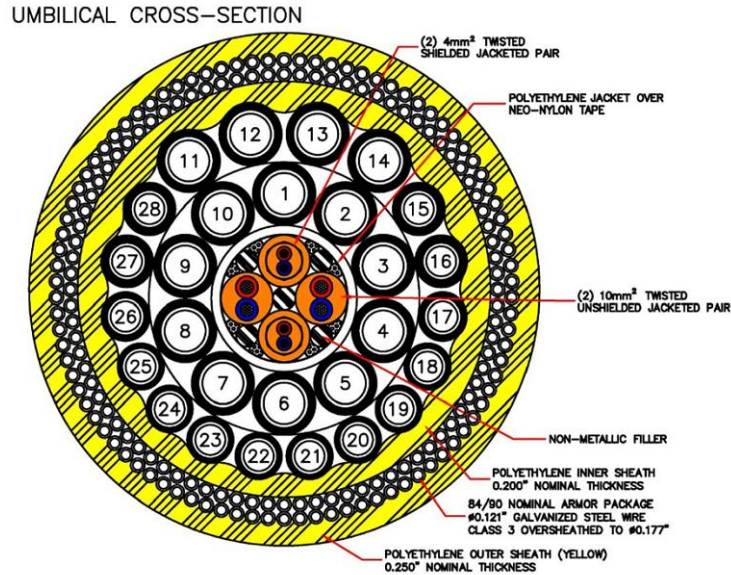


Figure 8: Direct hydraulic umbilical [12]

Umbilical dimensions typically range up to 25.5 cm in diameter. The umbilical may be very long, in some cases up to 20 km or more depending on the offset between the host facility and the subsea equipment that it connecting to. To avoid any potential faults, the umbilicals are fabricated in continuous length [6].

Due to long umbilical's length, the flow resistance in the hydraulic line becomes substantial and can affect the response time of the valve actuators in the system. The ability of hoses to accumulate liquid can be a disadvantage in a system that requires rapid bleeding of lines. However, this property can also turned into an advantage in systems where large actuators are to be operated. Using hoses with high volumetric expansion can be in some cases replace accumulators on the seabed.

The design of the hydraulic lines are important to the performance and operation of the whole system. It is therefore important that model of the hose is accurate, and that it includes the delays that are experienced in real operations [13]. There are many types of umbilical available such as hybrid umbilical, thermoplastic, steel tube, optical fibre and electrical power components. Figure 9 shows the criteria in selecting hydraulic lines. For



this report, 2 criteria of hydraulic line will be simulated to investigate the impact on the system response time which are the length of control line and size of hose bore.

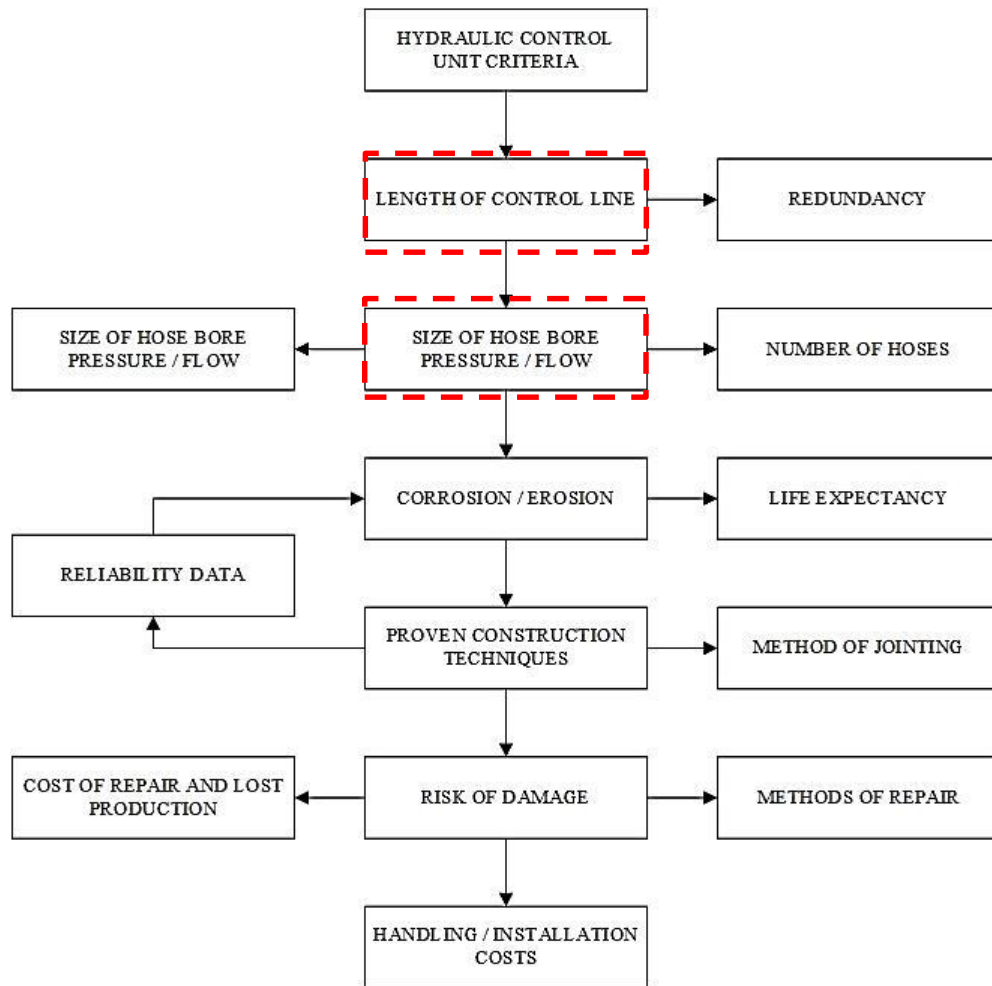


Figure 9: Hydraulic control line criteria [4]

### 2.2.5 Valve Actuator

Typically, linear actuators are used in the SPCS [13]. In subsea production system, production valve is used to control oil and gas flow from wells. Wellhead Xmas tree is installed on top of the wells comprises process control valves, where each process control valve is provided with an actuator for the operation of the valves. Actuators can be operated electrically or hydraulically but mostly for wellhead Xmas tree, hydraulic actuator is used.

The switching of the actuator valves is by means of hydraulic which uses spring-return actuators. The maximum actuation pressures that occur during opening of valves that are in closed, pressurised position, typically as follows [6]:

1. Tree valve open: 750-2200psig (50-140bar)
2. Tree valve closed: 600-1000psig (20-65bar)
3. Down hole safety valve open : 2500-9200psig (160-600bar)
4. Down hole safety valve closed: 500-4500psig (32-290bar)

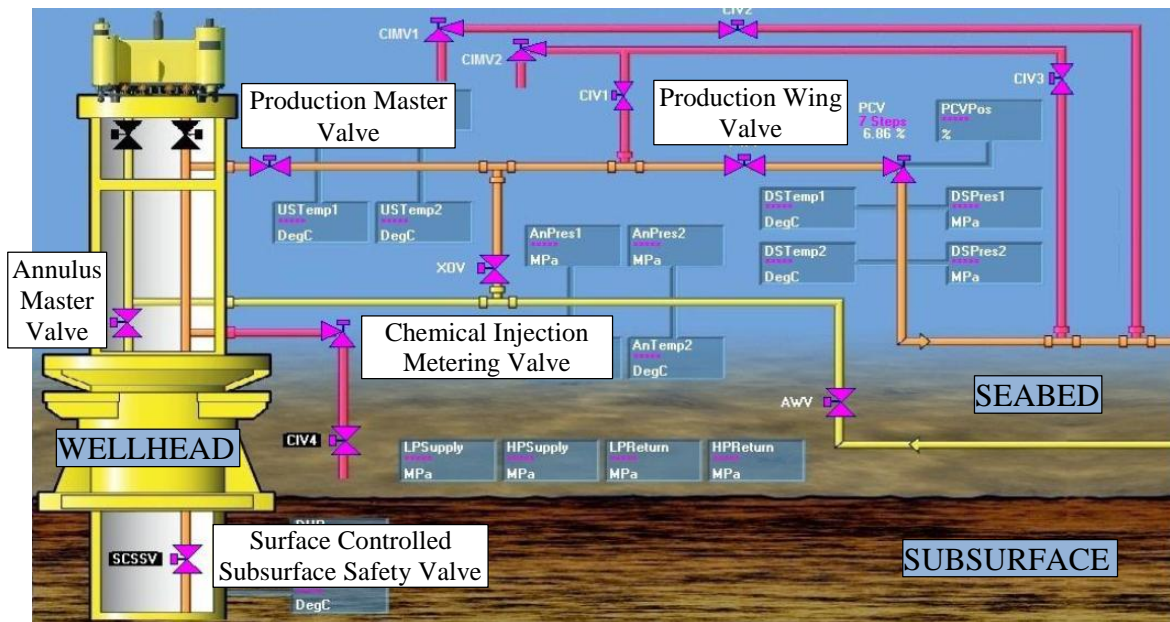


Figure 10: Subsea production valves on X-mas tree [14]

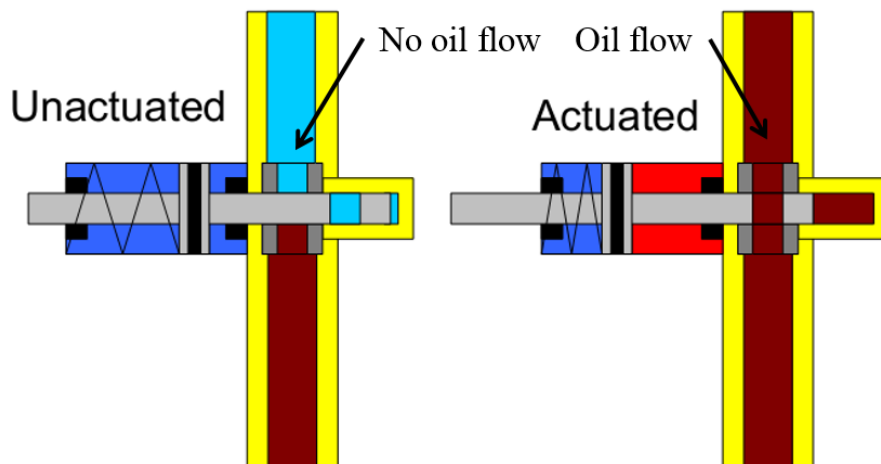


Figure 11: Illustrations of a typical gate valve in closed and open position [13]

### 2.3 ARTICLES REVIEWED

Subsea production control system has been crucial and the most interesting topic for researchers. The need for new technology to be applied in the field drives researchers to continually investigate potential technology that can be introduced to overcome challenges found in the field.

Tony Pipe through his work, SPE 13399, has extensively outlined the hydraulic aspects of subsea control system. Various system configurations and particular applications are discussed. He did discuss about other type of control systems such as pilot hydraulic, sequence hydraulic, electro hydraulic and multiplexed control system which are designed as a solution to the problems faced in the oil field industry as shown in Table 2. He also present the scenarios that lead to the solutions and considerations for the subsea system. Factors to consider for fluid selection are included in the paper and he also mentioned about the criteria that people in the industry normally try to maintain through the operation (e.g. bacterial growth). For control lines, he is comparing between flexible hose and rigid line. He states that majority of expansion experienced in the flexible hose happened during low pressure range which can be eliminate by incorporating a pre-charge pressure of 500 – 1000 psi, which will greatly reduce the response time [4].

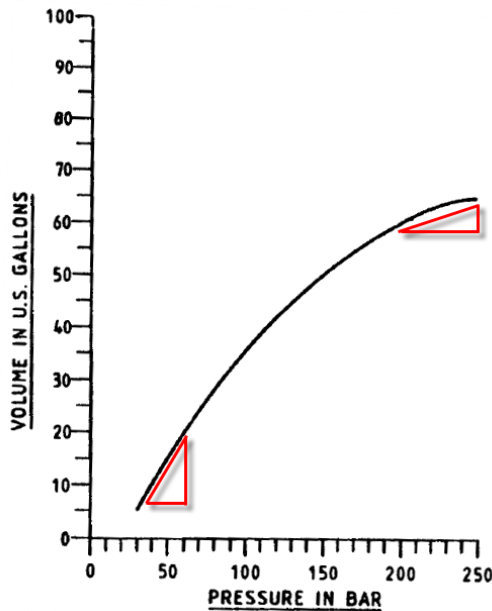


Figure 12: Typical volumetric curve for 1" line (2000 ft. length) [4]

In the end, he highlighted that the most important system characteristics that should be considered. The characteristics are as the following [4]:

1. How quickly can a system be charged and ready for operation?
2. The time required to open or close valve actuators under normal condition.
3. How many valves can be operated before hydraulic pressure need to be re-charge?
4. What is the system leak rate likely to be?
5. What is the maximum leak rate that may be tolerated and still permit valve operations?

All systems are likely to have leakage. In system that operates multiple valves, the leak rate for each valve maybe small but as combined with all the leakage for all the valves, total leakage will be multiplied. This is very important when sizing control lines and accumulators [4].

Table 2: Control system selection criteria

System	Distance (km)	Response time	Subsea line	Function supply
Direct hydraulic	5	Very slow	Very large hose bundle	Control
Piloted hydraulic	5	Slow	Very large hose bundle	Control
Sequential hydraulic	8	Slow	Large hose bundle	Control
Electro hydraulic	10	Fast	Large electro-hydraulic cables	Control, data limited analogue inputs
Multiplexed electro hydraulic	15	Fast	Small electro-hydraulic cables	Control, data analogue inputs, pulse counts
Subsea hydraulic power generation	30	fast	Small electric cable	Control, data analogue inputs, pulse counts

Other researcher, Thomas Stavenes, in his Master thesis titled “Subsea Hydraulic Leakage Detection and Diagnosis” discussed about numerous ways on detecting leakage. In the thesis, he states that 98% leakage in hydraulic system were caused by directional control valve (DCV) problems. The problems were caused by the long term seawater presence

due to the seawater ingress during installation. Besides that, hydraulic fluid caused biodegradation that led to the DCV leakage. In other statement, he states that close circuit system is more reliable than open circuit system due to seawater ingress and type of fluid used (water based or mineral based) [15].

The following state-of-the-art leakage detection and diagnosis methods that can be used for pipeline [15].

1. Line balance calculation (conservative of mass)
2. Real time transient model (simulation model)
3. Statistical analysis (by comparing historical data)
4. Pressure/flow monitoring

The author also mentioned about the current leakage detection and diagnosis efforts that are used such GE Smart Centre which responsible to monitor and gather data from subsea from around the world, and then interpret the data to gain knowledge for decision purposes. Another technology used by FMC is Condition and Performance Maintenance (CPM) which functioned to monitor systems including subsea control system. Data collected from SCM and sensors are then processed for decision purposes [15].

Another work done a group of three inventors to detect leakage in subsea production control system. In the patent, leakage detection is done by monitoring the valves signatures during accumulator recharging. The pressure differential between two points adjacent to subsea equipment (before and after component) should be zero for non-leaking system. Figure 13 shows leaking hydraulic control system of an approximately 5 gpm [16].

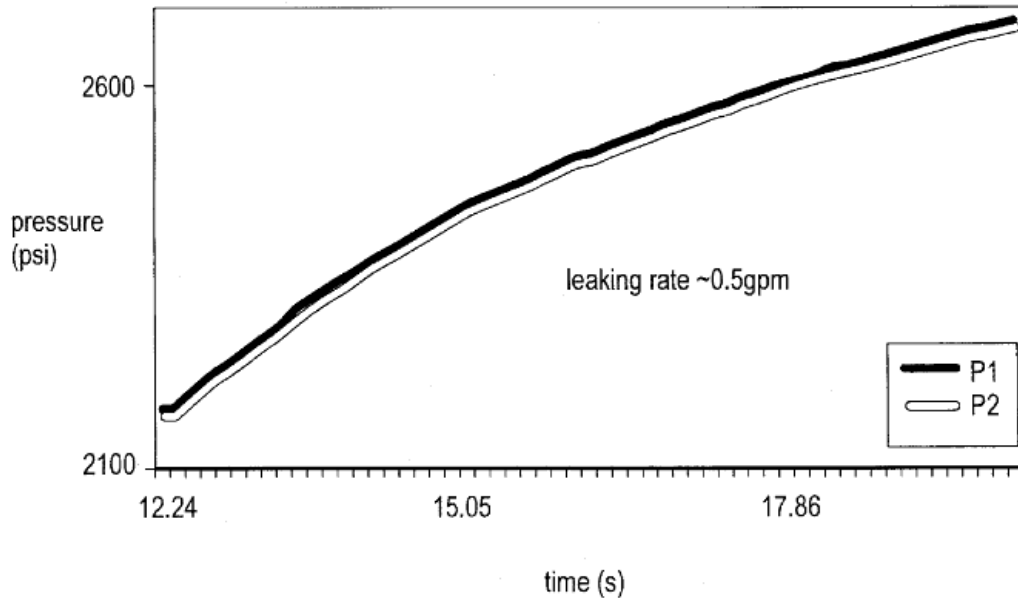


Figure 13: Leakage hydraulic control system [16]

Today, exploration and production are moving toward deeper regions, and there are many efforts in tackling new challenges that arise. Developers are suggesting solutions to cope with the new obstacles. One of the solutions proposed is by using an all electric subsea system. There are many articles and patents discussing this technology. M. Theobald in his research paper titled “Autonomous Control System (SPARCS) For Low Cost Subsea Production Systems” describes a Subsea Powered Autonomous Remote Control System (SPARCS) which is invented for controlling subsea infrastructures without the use of electro-hydraulic control umbilicals. One of the benefits of using SPARCS is low cost subsea developments. By using acoustic telemetry for communication between surface facility and subsea infrastructures, this innovation is estimated to reduce overall costs by £72.5 million over a period of 10 years. Currently, the break-even on capital outlay compared with existing technology is when the total length of umbilical is approximately 2.3 km [17].

In another paper, M. Theobald addressed the benefits of using all electric subsea production control systems [18]. The benefits include cost saving in the capital expenditures and the operational expenditures due to an increase in system reliability, availability, and maintainability.

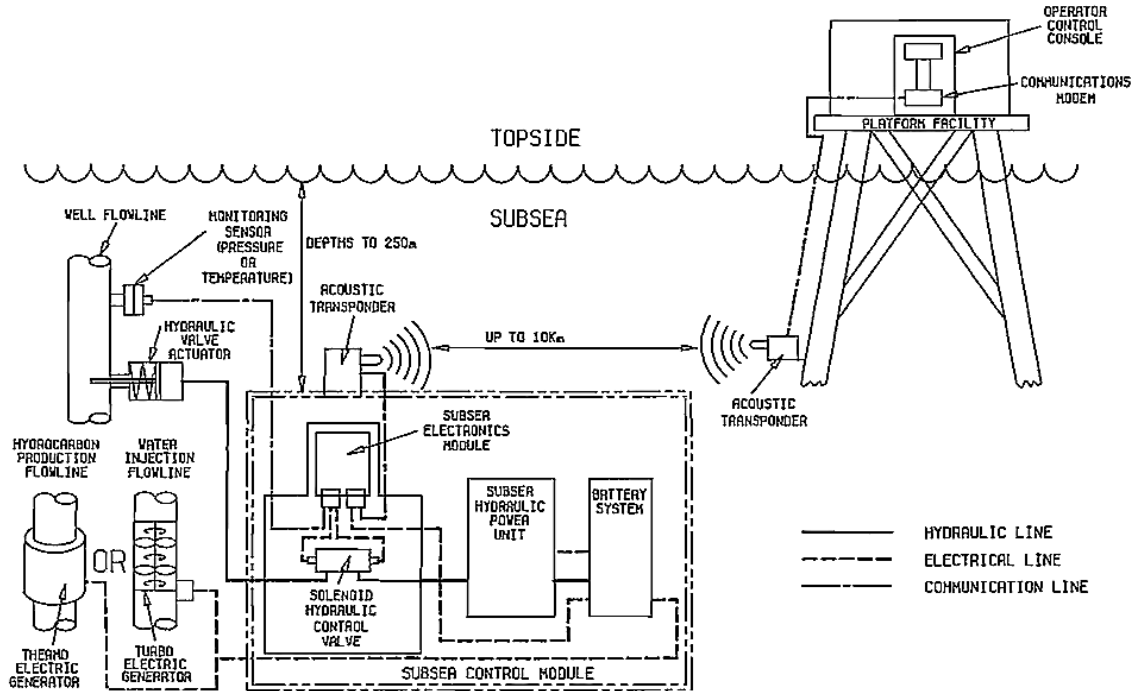


Figure 14: Simplified SPARSC design [17]

This technology has already been successfully implemented in K5F in the North Sea operated by Total E&P Netherland BV, hence, becomes the world first field uses all-electrical x-mas tree. The supply of the all-electric subsea production system was awarded to Cameron. The field began production in September 2008 at initial rate of 45Mmscf/day and increased up to 90Mmscf/day in few months later. With the advancement of the technology, the exploration towards harsher and isolated region which impossible to develop before this, will be feasible [19].

## 2.4 LITERATURE SUMMARY

Through literature review, few bench markings or key references have been taken as the basis for developing simulation models for this project. The main points or bench markings extracted from literature review are illustrated in Table 3.

Table 3: Summary of literature review

Author/s	Year	Title	Finding
NORSOK Standard	1995	Design Requirements: Subsea Production Systems	<ol style="list-style-type: none"> <li>1. Control system main components and functions</li> <li>2. Emergency shut-down &lt; 60s (Work over control system)</li> <li>3. Main components encompass a SPCS</li> </ol>
Technical Committee ISO/TC 67	2003	API Specification 17F	<ol style="list-style-type: none"> <li>1. Rated working pressure for hydraulic control components (exclude SCSSV) = (10.3 MPa, 20.7 MPa, 34.5 MPa)</li> <li>2. Subsea pipe, tubing and hoses &lt; 6 mm nominal outside diameter</li> </ol>
Baha Tulu Tanju, Hailing An, Karamchandani	2008	Subsea Control System Diagnosis	Method used to detect leakage in system.
Thomas Stavenes	2010	Subsea Hydraulic Leakage Detection and Diagnosis	Methods for leakage detection in subsea system.
Jacek S Stecki	2003	Production Control Systems – An Introduction	<ol style="list-style-type: none"> <li>1. Various type of control systems is extensively discussed including the main components (HPU, umbilical, gate valve).</li> <li>2. Advantages and disadvantages of each system.</li> </ol>
Tony Pipe	1982	Subsea Hydraulic Power Generation and Distribution for Subsea Control Systems	<ol style="list-style-type: none"> <li>1. Criteria for selecting control system components.</li> <li>2. Concerns when operating multiple valves.</li> <li>3. Basic components in subsea production control system.</li> </ol>
M Theobald	2005	Benefits of All-Electric Subsea Production Control Systems	<ol style="list-style-type: none"> <li>1. Issues in existing subsea developments.</li> <li>2. Concerns when developing new system.</li> <li>3. Future technology to be applied.</li> </ol>
	1993	Autonomous Control System (SPARCS) for Low Cost Subsea Production Systems	



## 2.5 AGITO SIMULATIONX

SimulationX is a program for modelling, computation, simulation, and reliability analysis of components and systems in many areas of technological development. The computational includes mechanics, fluid, control, electrical technology and magnetics are represented by models which are found in the libraries. With the integrated models found in SimulationX's library, systems or models can be designed fast and efficiently with validated standard elements. This include subsea hydraulic library which contain commonly used elements.

Users also can create their own models without the need for setting up differential equations, signal flow diagrams or transfer functions. Elements can be arranged and connected graphically in order to resemble the physical structures of needed systems or components. The variables such as the pressure, temperature, density are kept as simple as possible and close to the technical device. Furthermore, it also can be manipulated to comply with the experimental system's parameters. An extensive fluid library offers a great variety of predefined hydraulic fluids. However, users can easily modify the predefine fluid as needed [20]. The working area of ITI SimulationX can be subdivided into different windows and areas as illustrated in Figure 15.

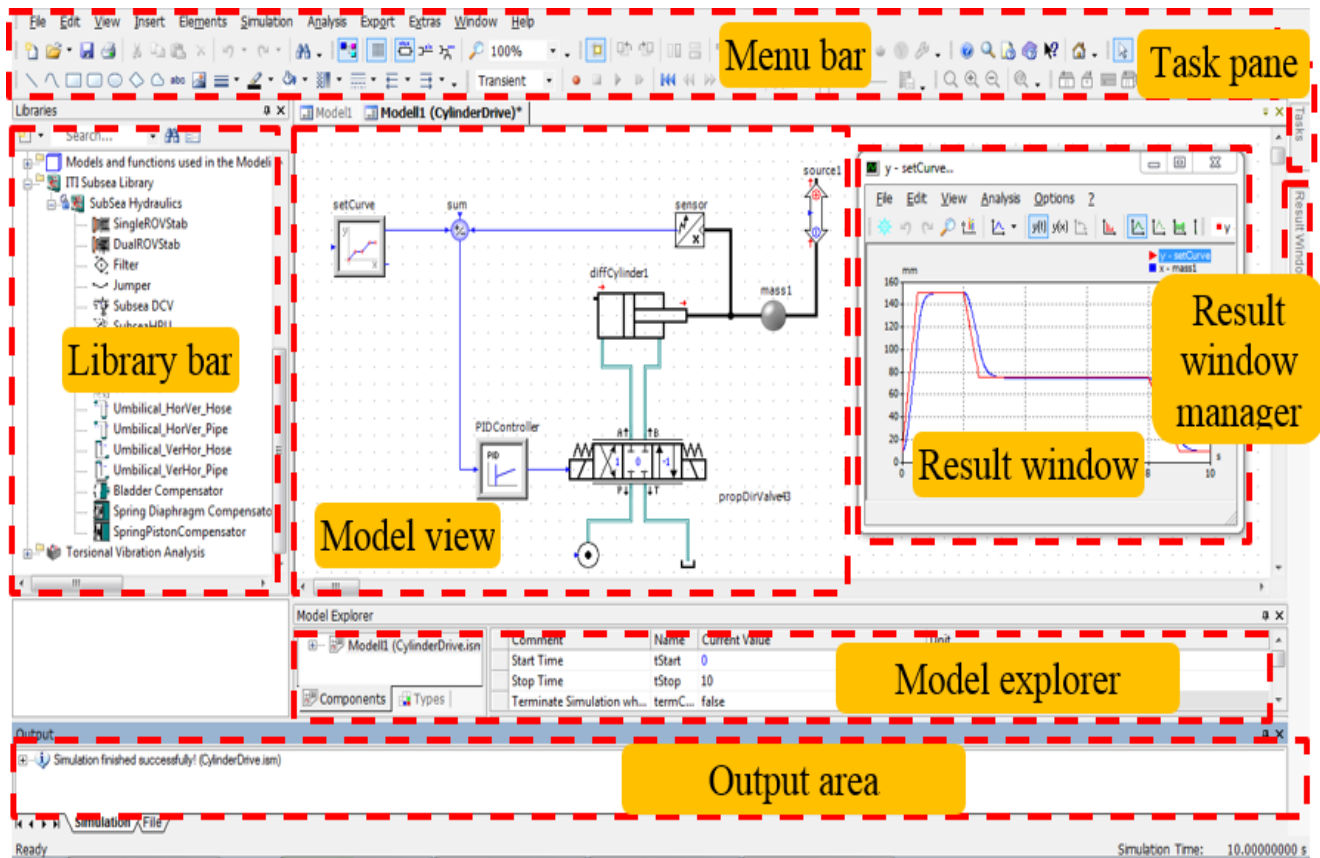


Figure 15: SimulationX GUI Overview [20]

Table 4: Function of areas in SimulationX GUI

Menu bar	Allow access to all tools and commands of SimulationX
Task pane	List frequently used command and can be called directly from here
Library bar	Serves for selection, management and editing of elements types
Model view	SimulationX support 4 types of views (diagram view, 3D view, text view and documentation view)
Result window	To display result curves
Result window manager	Facilitates the central management of the result windows of all opened models
Model explorer	Offers access to properties of the components of a simulation model
Output area	Output area messages, tracing outputs, warnings and error messages are logged

Subsea library included in this software help in modelling the SPCS for this project. The subsea library consist of several elements as can be seen in Figure 16 below.

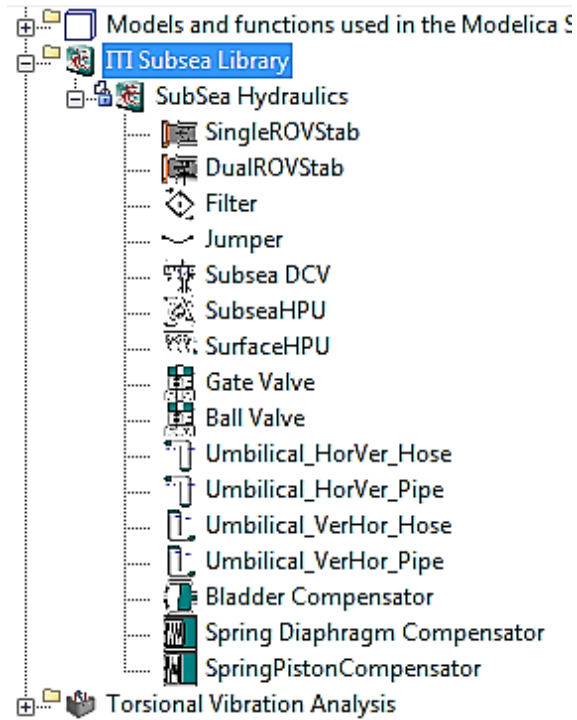


Figure 16: Elements in subsea library [20]

## **CHAPTER 3**

### **METHODOLOGY**

#### **3.1 WORKFLOW**

This project work aims to investigate the effect of varying length and diameter of umbilical, and size of actuator to the model's signal time and shift time. Firstly, simulation model have to be developed. In this chapter, work flow of this project is elaborated. For this project, direct hydraulic control system have been chosen to be modelled. The reasons for choosing direct hydraulic control system are:

1. Direct hydraulic control system is the simplest control system. Therefore it will not generate complex simulation model as the components included are hydraulic power unit, control panel, umbilical, subsea control module, and actuator.
2. Direct hydraulic control system is the most common control system. For this reason, huge range of aids can be found to assist model development.
3. Can be a stepping stone in understanding newer and complicated control system such as electro-hydraulic control system.
4. As the case study selected for this project used a direct hydraulic control system, therefore, simulation model is developed based on the real system for the validation purposes.

Modelling and simulation of SPCS involves observing the system, noting various components that building it, developing an acceptable representation of the system for further study and experimentation virtually to understand its behaviours, interaction between components and evaluate the operations of the system. With proper analysis, suggestions can be made for further improvement of the system.

In order to make sure project's plans executed properly, process flow is created and followed. This also helped in identifying the main concerns and aims for this project and determine the steps to be taken if problems occur. Figure 17 illustrates the project flow chart.

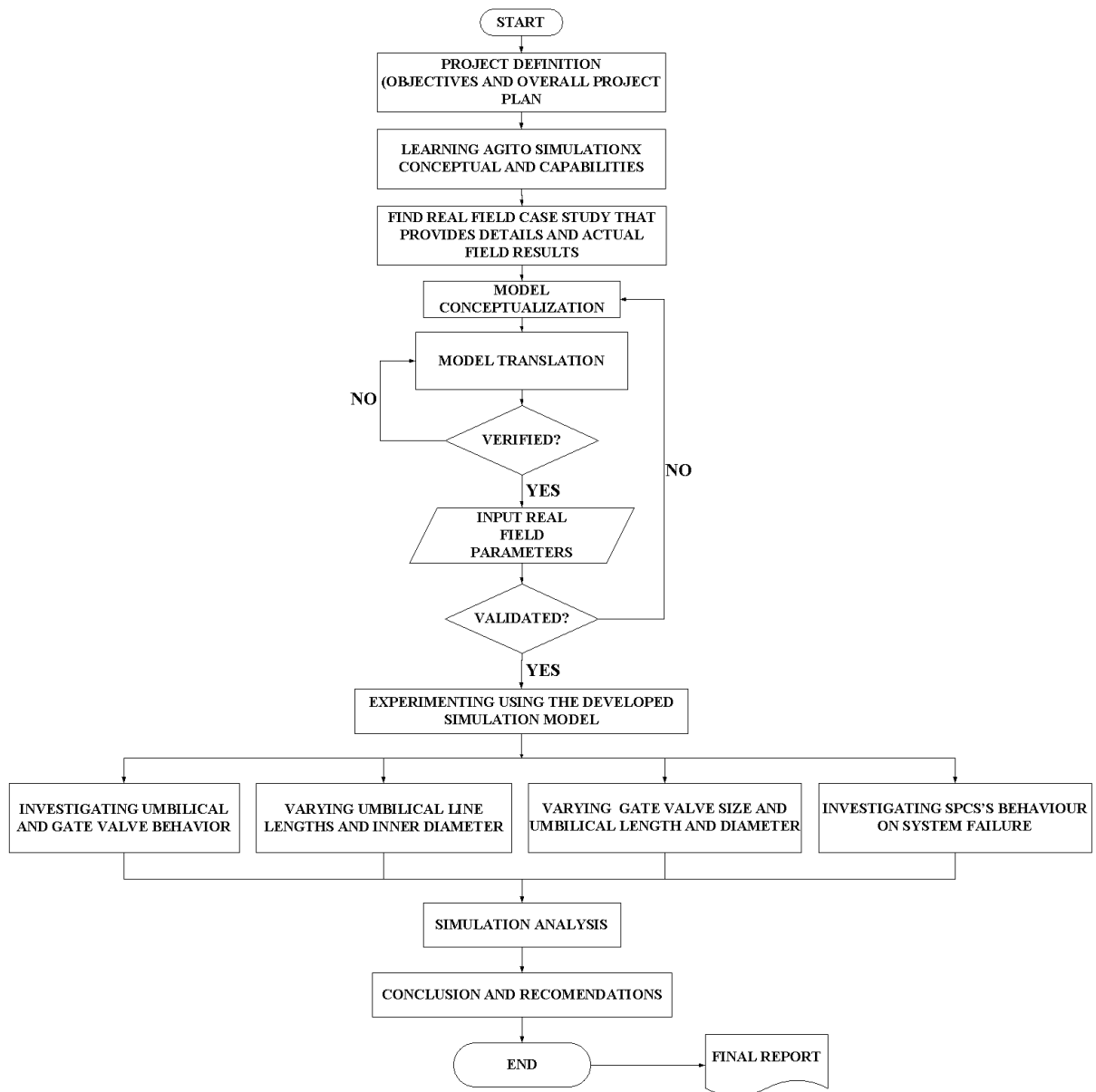


Figure 17: Flow Chart of the Project

### **3.2 PROJECT ACTIVITIES**

Project Gantt chart can be seen in appendices section. It is the list of all the activities done throughout this project.

### **3.3 CASE STUDY**

SPE 12001 by W.S. Manuel and J.E. Hall has been acquired and selected for further study [21]. The report on Cadlao oil field located in Philippines shows the performances of the field using a direct hydraulic control system. The experimental testing in the SPE 12001 report was simulated in 29 different operating conditions and data and results from this report is crucial for this project especially in validating the developed simulation model. Due to time constrain only a few of the tests will be used to validate simulation model.

The offshore 20 m depth Cadlao oil field located 400km southwest of Manila in the offshore North West Palawan, Philippines was discovered in 1977 by Amoco. The field is then developed in 1981 and produced about 11.235 mmbbls of light oil (47° API) from two wells by natural flow. Its production stopped in 1991 due to high operating costs and low oil prices. Two reports showed that the remaining oil reserves is around 6 mmbbls (most likely) and 4 mmbbls (proven) [22]. Redevelopment of the field by Blade Petroleum Limited that act as the operator with share of 80% of equity interest in the field and VenturOil Philippines Inc. has the 20% of the equity interest.

The reasons why Cadlao oil field has been chosen as case study are:

- All the required parameters for this project is well presented in the report by W.S. Manuel and J.E. Hall and therefore making the simulation possible.
- The testing results conducted at Cameron Iron Works plant in Berwick, Louisiana are also included in the report. Hence, validation of developed control system is possible by comparing the performance curves of the field and the acquired results from model.

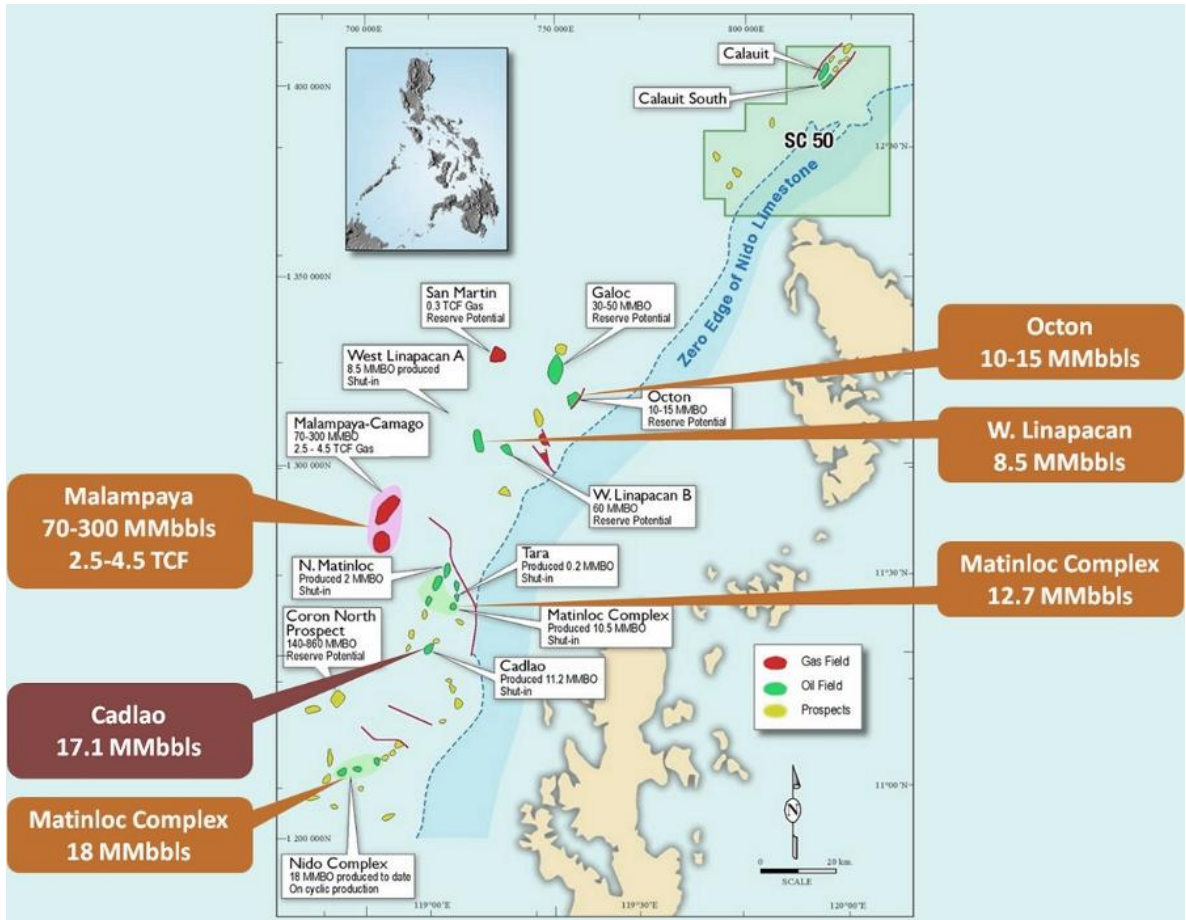


Figure 18: Cadlao Oil Field [23]

The schematic of test arrangement that Cameron Iron Works used is shown in Figure 19 and data used are shown in Table 5.

Table 5: Data used in Cadlao field [21]

Umbilical Length	6000 ft (1830 m)
4 hoses	½ inch inner diameter @ 3500 psig
3 hoses	¼ inch inner diameter @ 5000 psig
valve	4 inch piston diameter
Estimated operating time for ½ inch hose	60 – 90 seconds
Fluid	10% Cameron 590 in water at 45 – 55 °F (SG=1.072, viscosity@100°F=3.78 cSt)

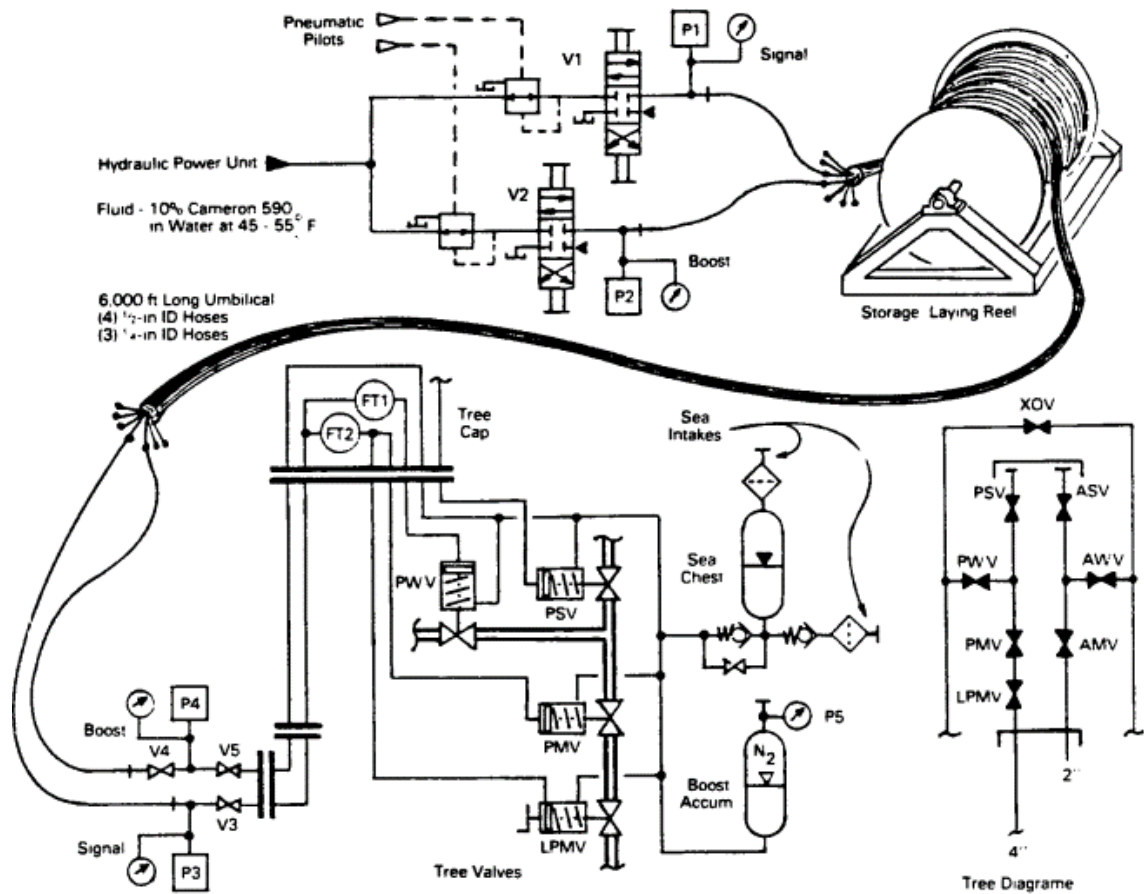


Figure 19: Schematic of test arrangement [21]

The reason for presenting the schematic diagram and the data is to show that the simulation model developed is based on the system's configuration used by the Cameron Iron Works. The real data are used in simulating the developed model and validation done by comparing results acquired with the actual results.

Figure 20 shows the effect of varying hose size (diameter) and valve volume (diameter) to the shift time and Figure 21 illustrates the effect hose length and hose diameter to the signal response time for Cadlao field's control system.



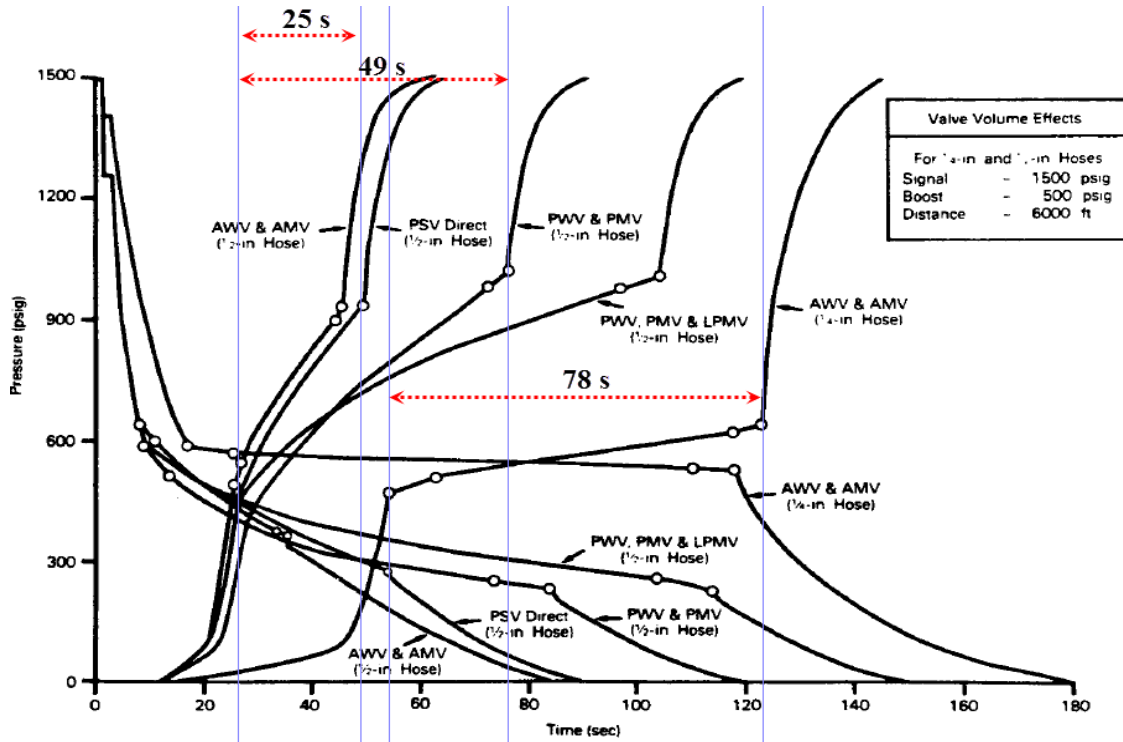


Figure 20: Effect of valve volume and hose size to shift time [21]

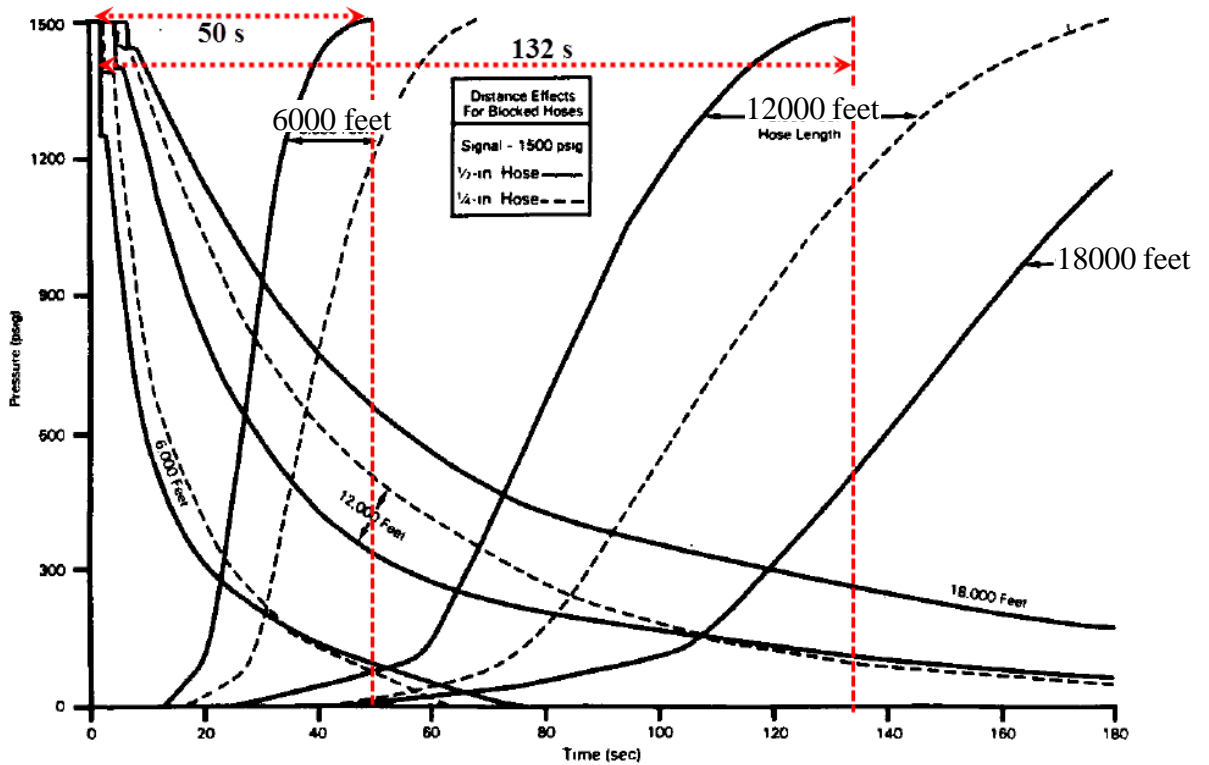


Figure 21: Effect of hose length and hose diameter to the signal response time [21]

### 3.4 MODEL CONCEPTUALIZATION

Before simulation models are constructed in simulation software, it is important to understand the system first and construct a conceptual framework that describes the system in order to give a better insight on critical components in the system. By understanding the concept of the system and components inside it, this will help to avoid miss-place or missing in critical components in simulation model afterward. Figure 22 below illustrates the components that have been selected for modelling.

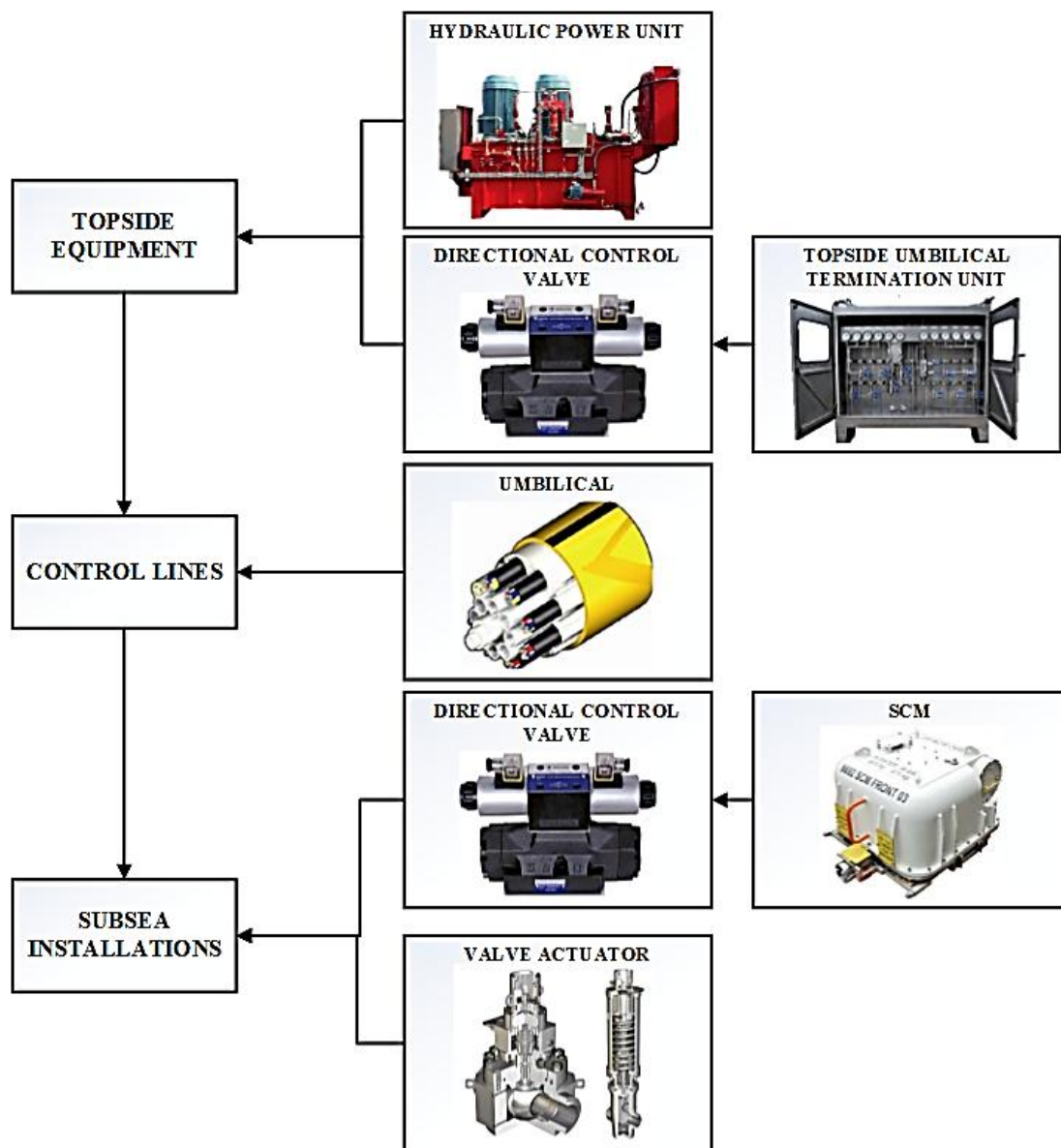


Figure 22: Model conceptualization

Despite satisfactory operational characteristics, control system also need to have acceptable response time in order to ensure its reliability and safe operational. Response time is the combination of signal time and shift time.

Signal time is the time required for the pressure wave to travel down the control line connecting topside facilities and subsea equipment and for the pressure to build up (or decay) to the level necessary for the valve actuator to start to shift. Figure 23 below shows the signal behaviour if the line was blocked at the gate valve actuator.

Shift time is the time required for the valve gate to travel from one end to the other [21].

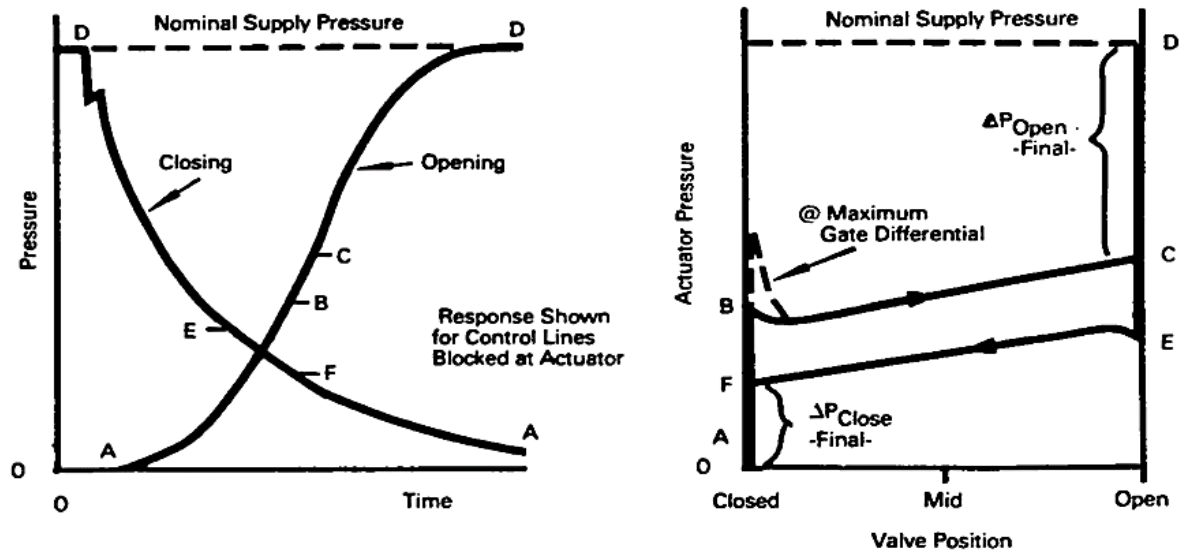


Figure 23: Signal time and shift time [21]

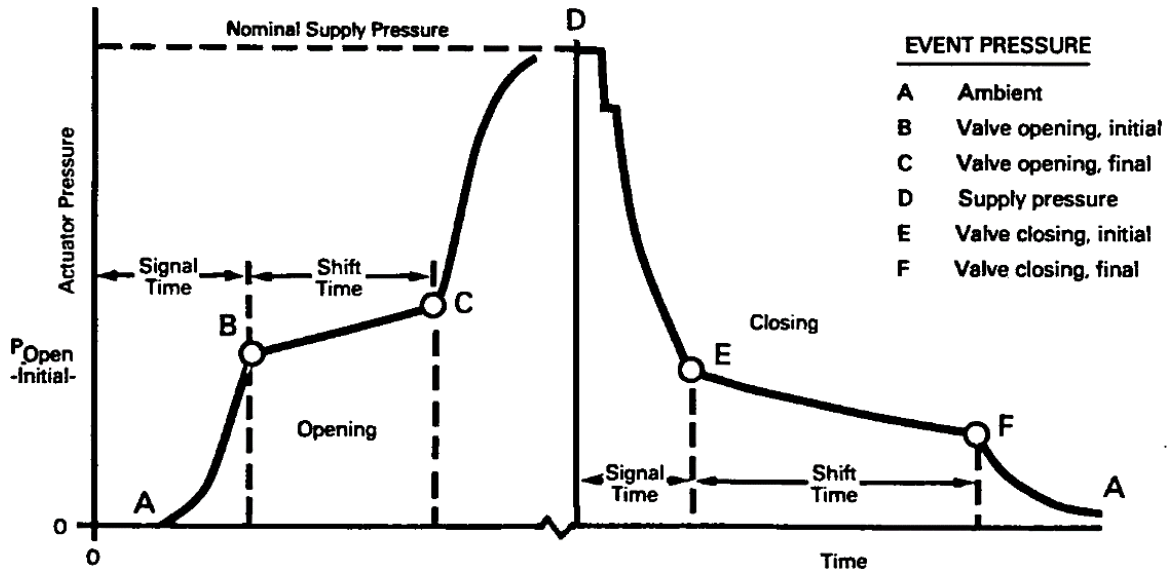


Figure 24: Overall response time expected behaviour [21]

### 3.5 MODEL TRANSLATION

After the conceptual framework that describes the system is identified, next stage is to translate the concept into acceptable simulation forms in simulation software which is SimulationX. Elements to be modelled are HPU, TUTU (DCV), Umbilical, SCM (DCV) and gate valve actuators. Several other elements such as piping and local resistances also included to account for losses that are experienced in real practices.

#### 3.5.1 Hydraulic Power Unit Model

During modelling stage, HPU is modelled as shown in Figure 25. Based on literature review, HPU is required to provide a clean and pressurized hydraulic fluid for actuation of the actuators. For modelling, HPU model includes two pumps, a tank, an accumulator, a pressure regulator, and two check valves. The two pumps included are duty pump and standby pump. Standby pump only starts when the pressure of the system drop below the pre-set pressure which is 310 bar, and both pump stop when fluid supplied have reached the pre-set pressure which 510 bar. To simplify the model, only major components with minimal redundancy included in the model. The limitations also applied based on the SimulationX capabilities. The developed model is based on the following assumption:

1. The model does not take contaminations in the fluid into account and therefore dividing filter between reservoirs shall not be used.

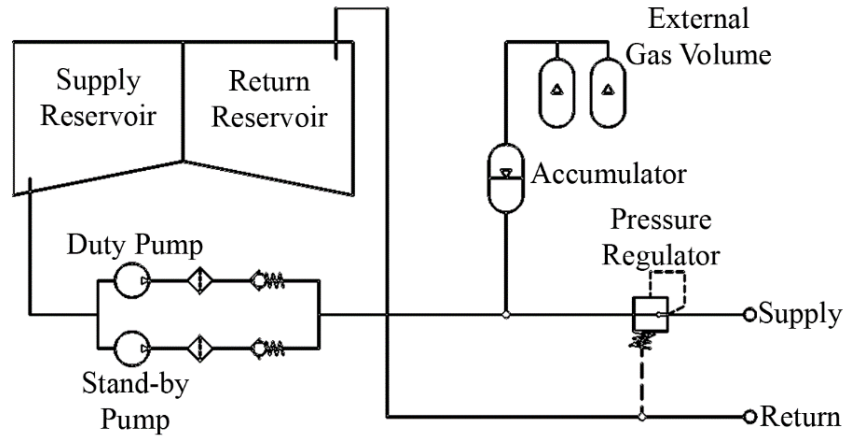


Figure 25: HPU Model [20]

For this simulation, the HPU is already defined in the SimulationX's library. The HPU model and parameters needed are as in Figure 26.

Reservoirs/Ports	Pumps	Accumulator	Pressure Regulator	Return Line Check Valve	I
Supply Reservoir Volume	Vsupply:	2000			
Return Reservoir Volume	Vreturn:	2000			
Supply Reservoir Startvolume	Vsupply0:	Vsupply			m <sup>3</sup>
Return Reservoir Startvolume	Vreturn0:	0			
Dead Volume Port S	V0S:	1			
Dead Volume Port R	V0R:	1			

Figure 26: HPU model and parameters

### 3.5.2 Topside Umbilical Termination Unit (TUTU) Model

As describe in Chapter 2, TUTU is used to route hydraulic fluid from HPU to the subsea umbilical. In SimulationX, TUTU is represented as 2 ways, 3 ports directional control valve (DCV) which allows or terminates hydraulic fluid flow.

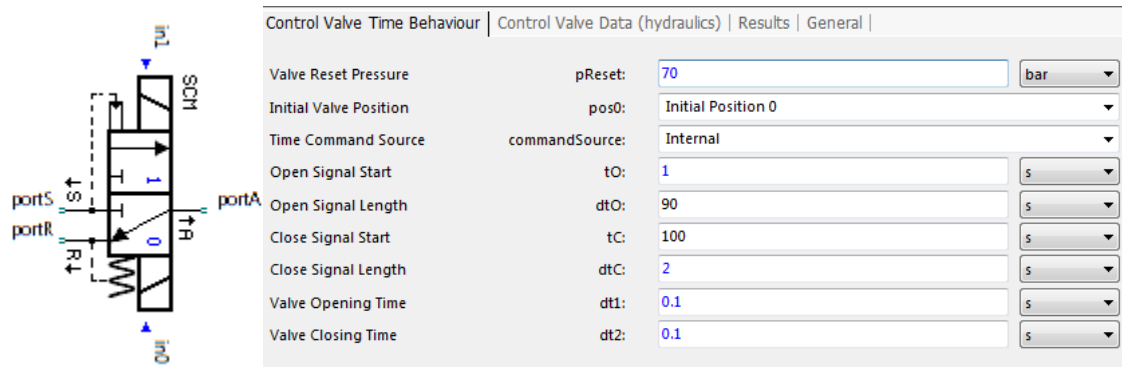


Figure 27: TUTU model and parameters

### 3.5.3 Hydraulic Lines Model

Hydraulic line or umbilical is one of the most important components in hydraulic control system. It is used to transport pressurized fluid from topside to subsea equipment and vice versa. The umbilical properties such as elasticity and flow resistance of the umbilical will affect the system response time. For system that requires fast bleeding time, this could be a great disadvantage but as for operating big actuators, high expansion hoses will be an advantage. Therefore, it is important to model the umbilicals accurately.

Umbilicals have been modelled using distributed line model. For this method, the spatial distribution of the fluid flow along the length of the umbilical is considered. Therefore, all flow and fluid variables (e.g. pressure, flow, density, compressibility) are not only a function of time, but also a function of space. With the modelling of fluid behaviours in hydraulic lines, we can include the time delays during operation accurately, which are experienced in real practice.

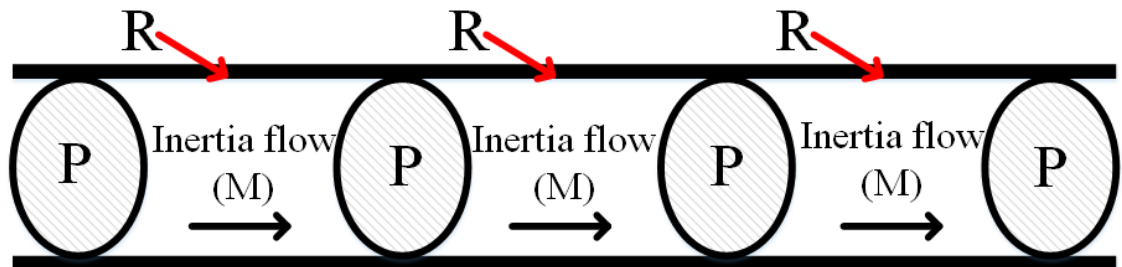


Figure 28: Distributed Line Model [13]

Figure 29 shows the definition of each parameter for umbilical and Figure 30 shows the properties box where parameters can be set. Figure 31 is the graphical model of umbilical.

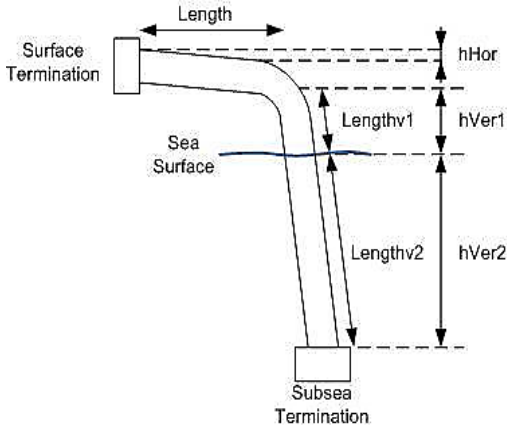


Figure 29: Umbilical's parameter definition [20]

Geometry   Wall Elasticity   Initial Conditions   Results   General	
Inner Diameter	di: 0.5 in
Average Wall Roughness	k: 10 μm
Vertical Part above Surface	
Total Length Vertical Part Above Surface	Lengthv1: 25 m
Height Vertical Part Above Surface	hVer1: Lengthv1 m
Vertical Part below Surface	
Total Length Vertical Part Below Surface	Lengthv2: 6000 ft
Height Vertical Part Below Surface	hVer2: Lengthv2 m
Number of Finite Volumes Vertical Part	nvert: 10 -
Horizontal Part	
Length of Horizontal Part	Length: 20 m
Height Difference on Horizontal Part	hHor: 0 m
Number of Finite Volumes Horizontal Part	nhor: nvert -

Figure 30: Umbilical's parameters [20]

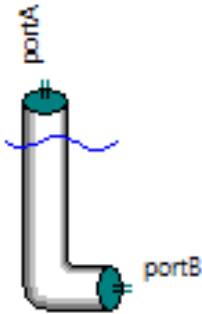


Figure 31: Umbilical model [20]

### 3.5.4 Subsea Control Module Model

SCM is modelled with one 2 positions, 3 ways directional control valve. The opening and closing of the DCV is controlled by signal that have been set. During open position, the pressure from the HPU is supplied to actuator through the DCV. In close position, the pressure supply port is closed and fluid is vented to the sea through an exhaust port. A check valve has been included to make sure one way flow from the actuators to the sea.

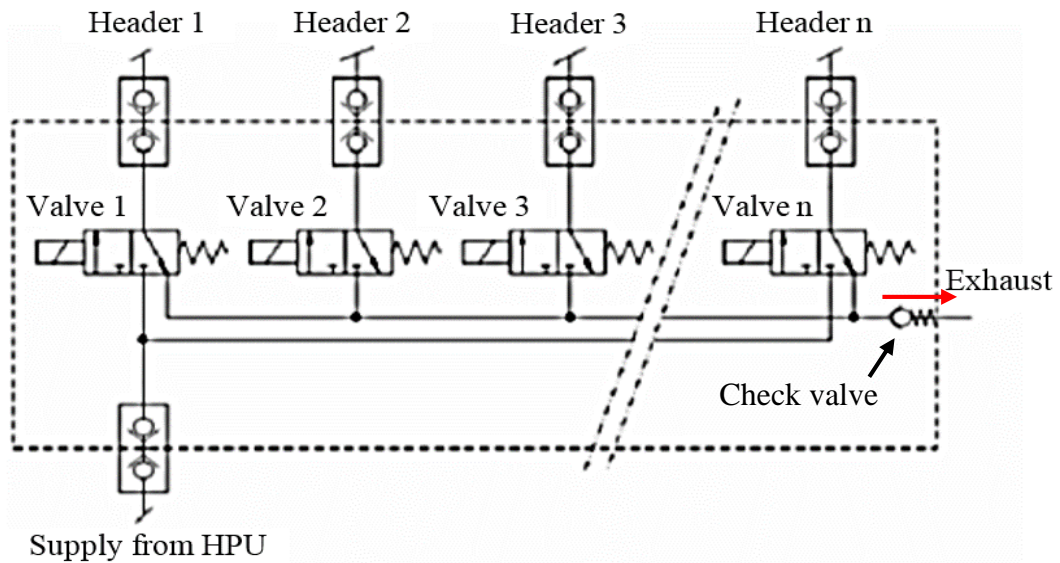


Figure 32: SCM schematic diagram

The SCM modelled includes a check valve, vent to sea, two DCVs and a bladder compensator as illustrated in Figure 33.

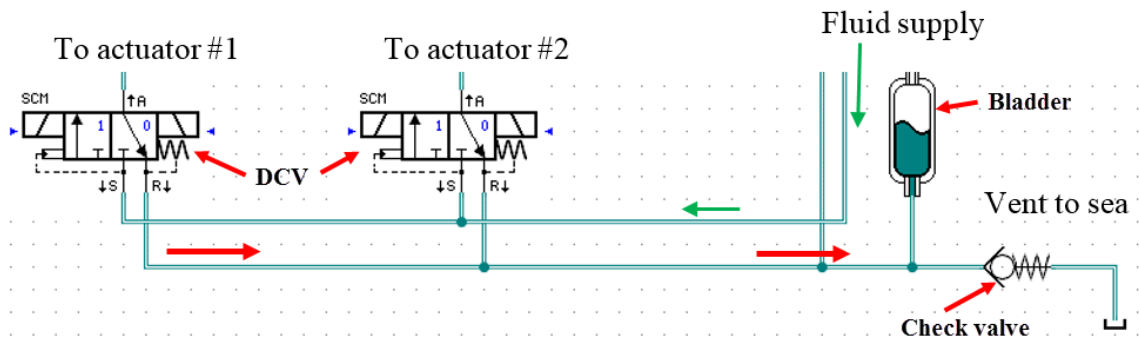


Figure 33: SCM modelled in SimulationX



The parameters of each element that builds the SCM also need to be defined similarly with previous elements. Figure 34 shows the main specifications needed for the check valve.

Parameter		Results	Advanced	General
<b>Opening Behavior</b>				
Cracking Pressure	pOpen:	1		bar
Full Opening A -> B	pMaxOpen:	2		bar
<b>Throttle Range</b>				
Pressure Drop (Throttle Range)	dpThr:	10		bar
Flow (Throttle Range)	QThr:	60		l/min
Reference Density	rhoRef:	0.89		g/cm <sup>3</sup>
<b>Laminar Range</b>				
Critical Reynolds Number	ReK:	200		-
Turb. Flow Coefficient	alphaT:	0.7		-

Figure 34: Main parameters for the check valve

### 3.5.5 Subsea Actuator Valve Model

Subsea actuator modelled in SimulationX is based on spring-return. In case of loss of hydraulic pressures or equipment failures, the gate valve will return to initial state which is closed position (normally closed actuator) to prevent situations become worse. The pressure inside the open chamber must overcome the forces exerted by the spring and pre-loaded force in order to move the piston.

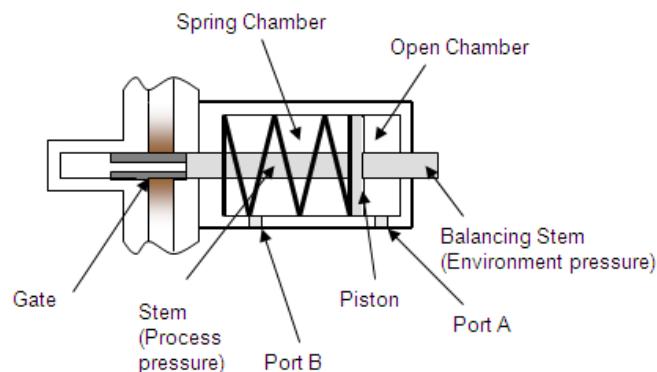


Figure 35: Actuator definition and parts [20]

Each element that building the actuator (e.g. piston, spring, friction) can be modelled separately but for this report, model which available in the SimulationX's library has been used. Figure 36 shows the model and parameters needed for actuator in SimulationX.

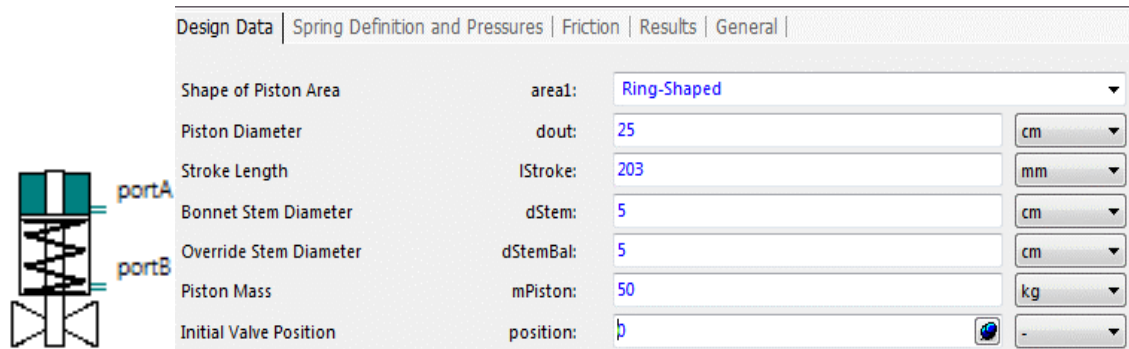


Figure 36: Actuator model and parameters

### 3.6 OVERALL MODEL

By combining all the elements included in model conceptualization, the overall simulation configuration is shown in Figure 37. The model is developed based on the system used for the Cadlao field. Additional components included in the simulation model are representing the connections between each component.

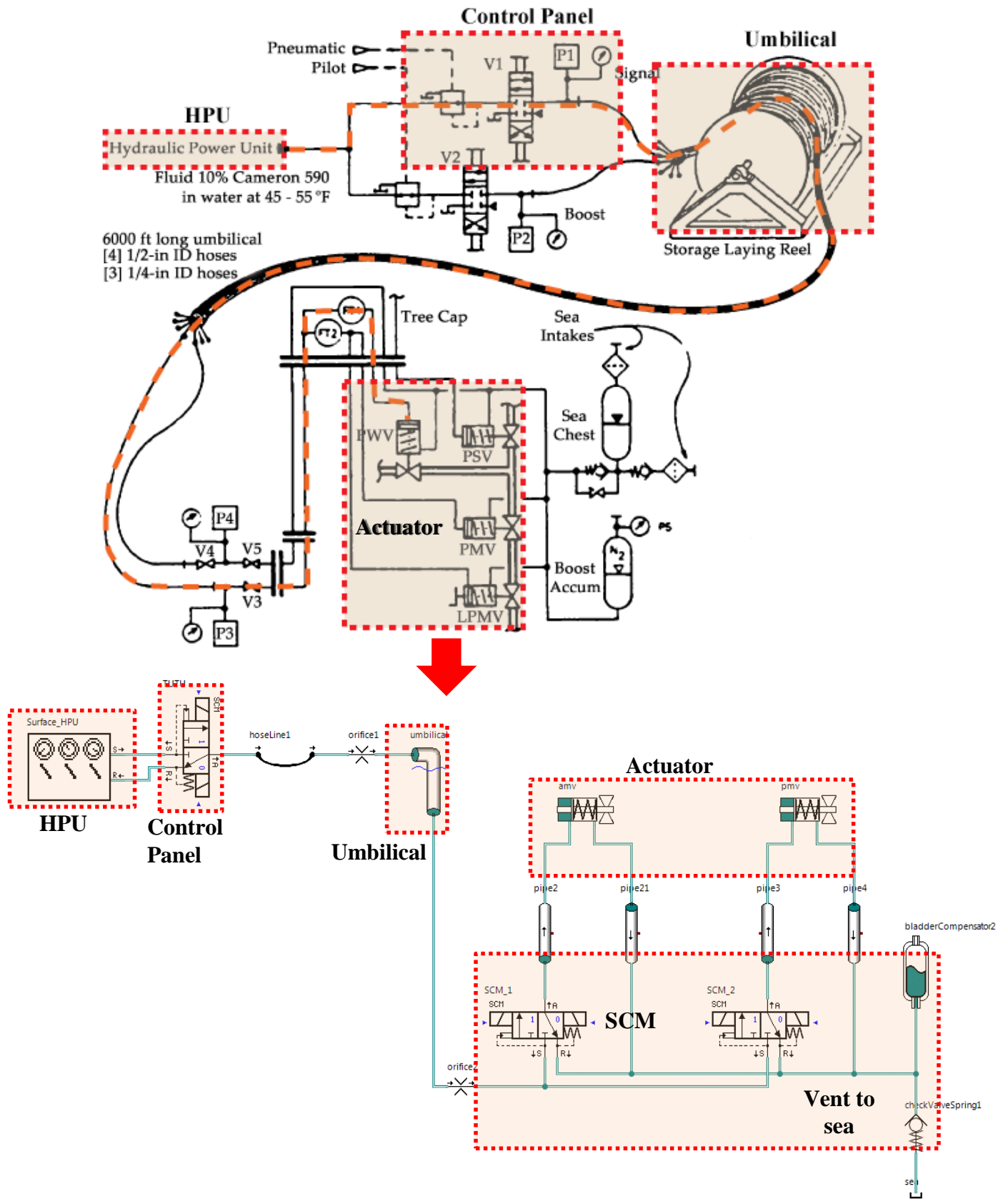


Figure 37: Overall simulation model

### 3.7 MODEL VALIDATION

Validation of the simulation model build is important to ensure the model assumptions are correct, complete and consistent. Additionally, validation is also done to prove that the simulation model developed is acceptable and can be used to represent the actual system, and will be able to behave similarly to the real system. To validate the model, the simulation model used variables from Cadlao field as recorded in Table 6, 7, and 8. Additional variables are taken from the default values available in the SimulationX. The reason why default values are used because SimulationX's specialization is in subsea modelling. Therefore all the default values in the SimulationX are the typical dimensions for subsea applications. Another reason is, due to time constraint. Specification sheets from online source does not provide enough parameters and mostly only provide the working pressures and maximum working pressures. To get full specifications, request have to be made to the manufacturers which will need more time. The parameters used are as in the following tables:

Table 6: HPU configurations

<b>Pumps</b>	
Duty pump flow-rate	10 litres/min
Standby pump flow-rate	10 litres/min
<b>Accumulator</b>	
Volume	250 litres
External gas volume	250 litres
<b>Pressure regulator</b>	
Set pressure	3500 psi
<b>Return line check valve</b>	
Cracking pressure	2 bar
Full opening pressure	3 bar

Table 7: Umbilical configurations

<b>Geometry</b>			
Inner diameter	0.15 in	0.35 in	0.50 in
Length from sea surface to sea bed	6000 ft	12000 ft	18000 ft
Bulk modulus	700 Mpa		

Table 8: Actuator configurations

<b>Design data</b>	
Shape of piston area	Ring shaped
Piston diameter	4 inch
Stroke length	203 mm
Piston mass	50 kg
<b>Spring definition and pressures</b>	
Spring force preload	30 kN
Spring force compressed	45 kN

As the hydraulic fluid used in the Cadlao field’s system, Cameron 590, is not available in SimulationX, Castrol Transaqua HT has been selected as hydraulic fluid the simulation model as the properties of Castrol Transaqua HT are similar to the Cameron 590 which is used in the Cadlao field. The properties of the fluid are shown in Figure 38.

Property	Units @	-25°C (-13°F)	0°C (32°F)	20°C (68°F)	40°C (104°F)	100°C (212°F)	175°C (347°F)
<i>Density</i>	<i>g/ml</i>	1.0880	1.0741	1.0630	1.0519	1.0186	0.9770
	<i>lb/ft³</i>	67.92	67.05	66.36	65.67	63.59	60.99
<i>Viscosity</i>	<i>cSt</i>	29.1	8.2	4.4	2.4	0.8	0.3
<i>Bulk Modulus</i>	<i>N/m² (x 10⁹)</i>	2.75	2.74	2.7	2.64	2.29	1.52
	<i>Psi (x 10⁶)</i>	3.99	3.98	3.92	3.83	3.33	2.20

Figure 38: Fluid properties [24]

Additional data for umbilical are needed as the data presented in the SPE 12001 are insufficient for simulation. Specification sheets from manufacturer’s sites are acquired to find an umbilical with the same or similar properties to the umbilical used in Cadlao field. When selecting the most suitable umbilical, several factors have been put into consideration such as fluid compatibility, temperature rating, and pressure rating. In the end, umbilical type 2040H has been selected as it poses similar properties to the umbilical used in Cadlao field.







# Part No	 inner diameter			 out di.	 working pressure		 burst pressure		 R	 kg/m	Fitting Series
	mm	inch	dash	mm	bar	psi	bar	psi	mm		
2040H-03V10	4.8	3/16	-03	9.8	340	4930	1360	19720	30	0.12	56/PX
2040H-04V10	6.3	1/4	-04	11.9	310	4495	1240	17980	40	0.17	56/PX
2040H-05V10	7.9	5/16	-05	14.0	250	3625	1000	14500	50	0.21	56/PX
2040H-06V10	9.5	3/8	-06	15.9	240	3480	960	13920	60	0.26	56/PX
2040H-08V10	12.7	1/2	-08	19.3	185	2680	740	10730	75	0.31	56/PX
2040H-10V10	16.0	5/8	-10	23.5	140	2030	560	8120	110	0.43	PX
2040H-12V10	19.1	3/4	-12	26.7	125	1810	500	7250	170	0.53	PX
2040H-16V10	25.0	1	-16	33.5	100	1450	400	5800	230	0.72	PX

Figure 39: Umbilical parameters [25]

## **CHAPTER 4**

### **RESULT AND DISCUSSION**

This chapter presents the simulation results obtained. Firstly, the system is verified by simulating the simulation model using parameters from the Cadlao oil field to show whether the model behave accordingly or not. Performance curves of Cadlao field are then compared to the acquired curves from simulation.

After the model have been validated, simulation model is simulated using different operating conditions. Due to time constrain in developing simulation model, only parameters of the umbilical and actuator are changed for this project simulation. Additional simulation test on the effect of umbilical's bulk modulus also included. The aims for simulation testing are to study the effect of changing these parameters on the system performance. The simulation system is simulated using three conditions as the following:

1. Varying umbilical length
2. Varying umbilical inner diameter
3. Varying valve piston actuator size

An Emergency Shut Down (ESD) simulation done to show how quick the system can recover to its initial safe position after the hydraulic supply from the topside is terminated. This feature is included in control system because it is considered critical in determining the reliability and boost confidence in the control system. ESD also a requirement for SPCS.

The results obtained are compared to case study's results showed similar behaviours and getting an exact results are not possible mainly due to lack of data. Only critical data such as working pressures and hose lengths are presented in the reference paper. At the same time, when developing simulation model, many other parameters are still need to be set. Therefore, assumptions made by author influence the acquired results.

## 4.1 SYSTEM BEHAVIOUR

### 4.1.1 Gate Valve

Before proceed to the simulation testing using different parameters, validation has to be done first. For the validation purpose, developed simulation model is simulated using default values which are used in Cadlao field. The results acquired from simulation are then compared to the results of Cadlao field. Figure 40 below are simulated using 3500 psi (241.3 bar) regulated pressure, 6000 ft. long hose, ½ inch diameter hose and 4 inches actuator's piston diameter.

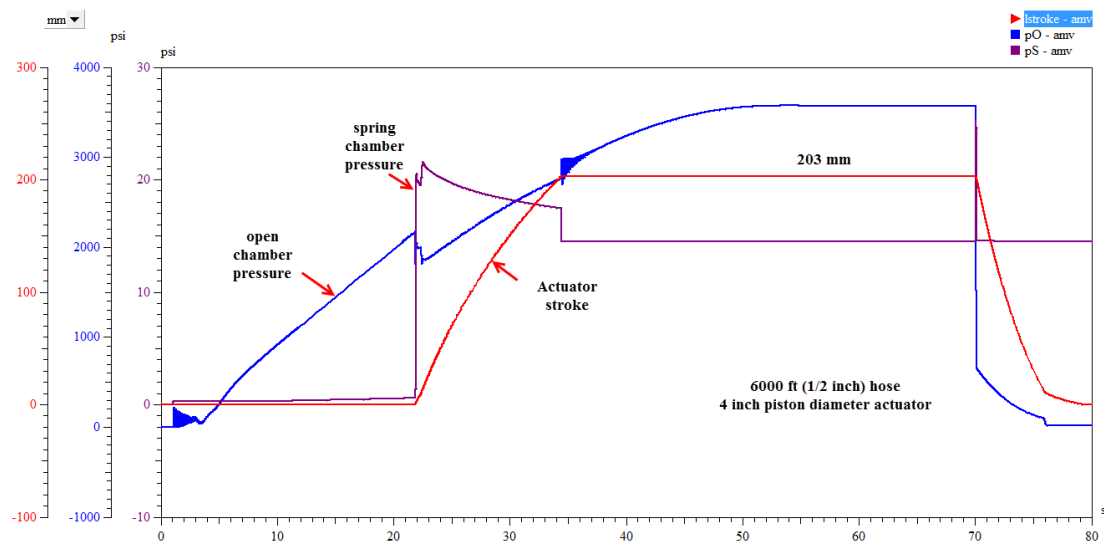


Figure 40: Gate valve behaviour during opening and closing

From the graph, we can see that the actuator start to shift at  $t = 22$  s at a minimum differential pressures of approximately 130 bar, and fully extended at  $t = 35$  s. Therefore,



shift time is 13 s. The Cadlao field’s shift time recorded was 25 s, a disparity of 12 s are observed. The difference is due to the insufficient data provided for the case study especially for actuator. Assumptions and calculations have been made to predict the appropriate values for the missing dimensions. The system seem to experience disturbances during pressure build up but the system has completely actuating the gate valve.

Pressure variation will be experienced during operation and if the variation is too high, opened valves might start to close and consequently, unwanted shut down might happen. To study the pressure drop in the system, the SCMs in the developed simulation model is set to move to open position at different time. First, gate valve #1 is actuated and at  $t = 50$  s, the SCM #2 moved to open position allowing hydraulic fluid pass through and actuates the actuator #2. Observation on the pressure variation experienced in the system during actuation of actuator #2 is made and analysed to study the pressure drop during actuation of actuator #2.

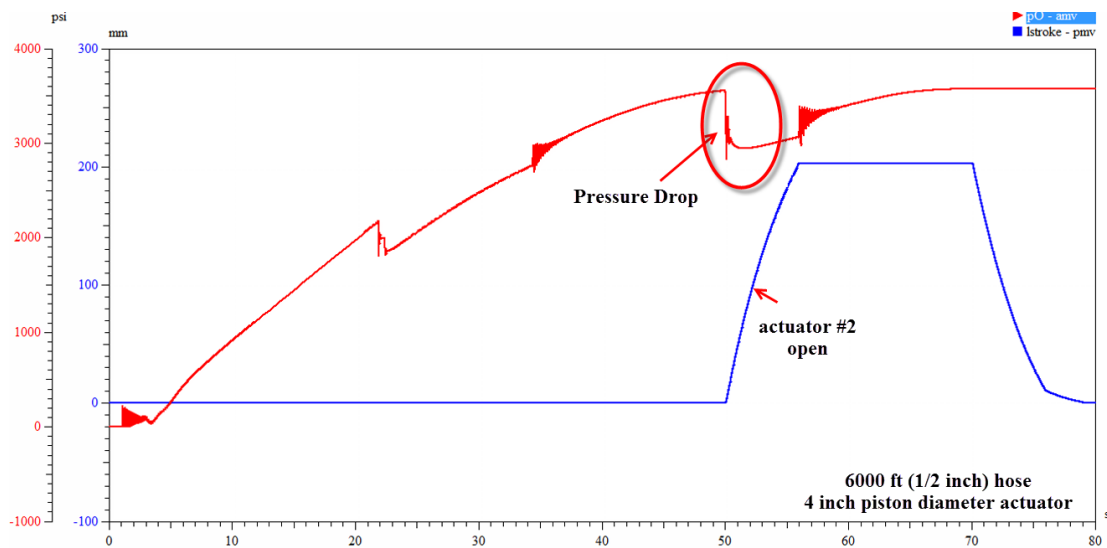


Figure 41: Pressure drop when operating second actuator

From Figure 41, we can notice that gate valve #2 operation at  $t = 50$  s caused a pressure drop of approximately 610 psi (42 bar). As DCV #2 opened, fluid that was compressed in actuator #1 moved to fill up empty space in actuator #2. As a result, pressure drop is

experienced in the system. If the pressure drop is too great, the opened actuator #1 might start to close, but for this system, pressure did not fall below the reset pressure of DCV #1. In real practices, operator usually used subsea accumulator or increase the hose size to reduce the effect of pressure drop but consequently, the time needed for umbilical pressurization and bleed it when shutting down will be affected.

### 4.1.2 Umbilical

This test is conducted to assess the time needed for the umbilical to stabilize after the surface HPU energized and supplies the fluid power to the subsea umbilical. The graph acquired by closing the two DCVs located at the end of the umbilical on the sea bed. Figure 42 illustrates the performance of a 6000 foot long and ½ inch diameter umbilical with a regulated pressure at 3500 psi (241.3 bar).

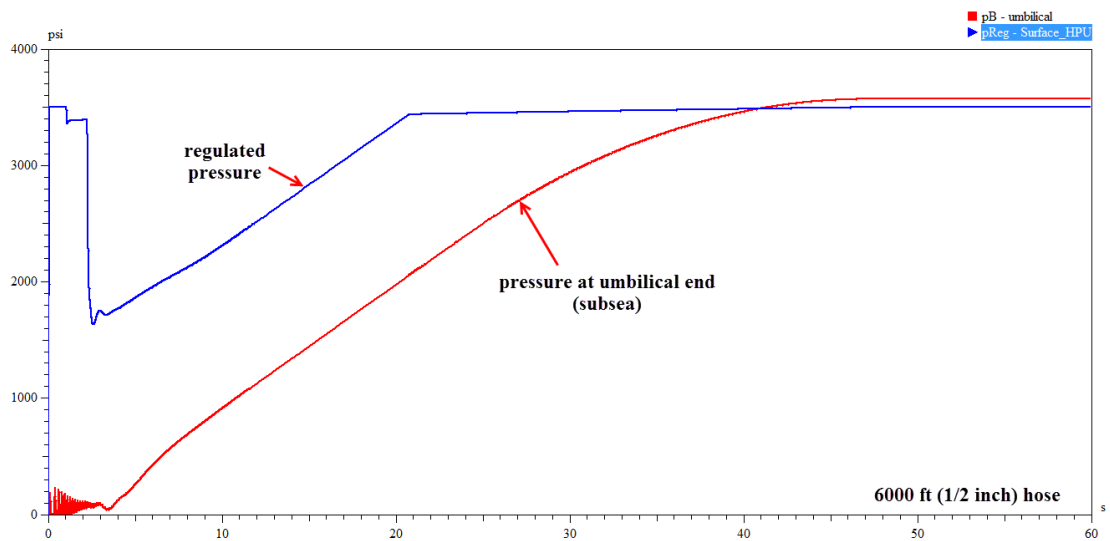


Figure 42: Umbilical hose pressurization

From the graph (Figure 42), we can observe that the umbilical requires approximately 47 seconds to reach steady state at 3571 psi (246.2 bar), which is slightly higher than the regulated pressure due to water depth of Cadlao field (20 m). The value is important especially when there are plans to expand the system afterward.

## 4.2 SIGNAL TIME

### 4.2.1 Umbilical's Bulk Modulus Effect

Bulk modulus of the umbilical also play an important role in the umbilical pressurization because it is a measure of the umbilical's resistance to the uniform compression. It affects the umbilical pressurization and bleed time. Most importantly, response time of gate valves will varies depending on the bulk modulus. Figure 43 shows the time needed for the pressurization of an umbilical at different values of bulk modulus.

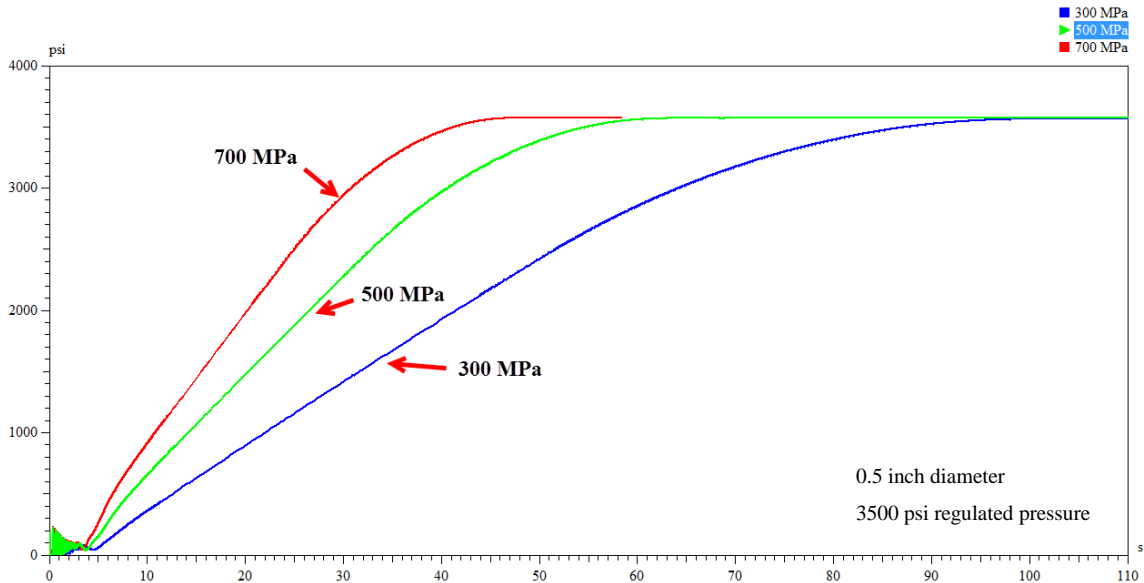


Figure 43: Umbilical pressurization time for different bulk modulus

From the graph, we can observed that 700 MPa bulk modulus yield the quickest pressurization which is approximately 47 seconds, followed by 500 MPa and the longest pressurization experienced by hose line with 300 MPa of bulk modulus. Hence, the lower the modulus, the more volume the umbilical can occupy, and longer time needed for pressurization. In some cases, high expansion hydraulic hoses can act as accumulators to reduce fluctuation in line and also used for actuating large actuator valve. The time taken for each bulk modulus is recorded in Table 9.

Table 9: Effect of varying bulk modulus of hose pressurization

Bulk Modulus (MPa)	Time (seconds)
700	47
500	63
300	100

#### 4.2.2 Umbilical's Length Effect

Simulation done on umbilical at different lengths to study the effect of varying the lengths of an umbilical line to the pressurization time. The results are shown in Figure 44. As the fluid compressed in the umbilical hose, longer hose needs more fluid to fill up the spaces in the umbilical line. As a result, time needed for fluid to travel to the end of the umbilical increased as the length increased. Therefore, longer pressurization period is experienced.

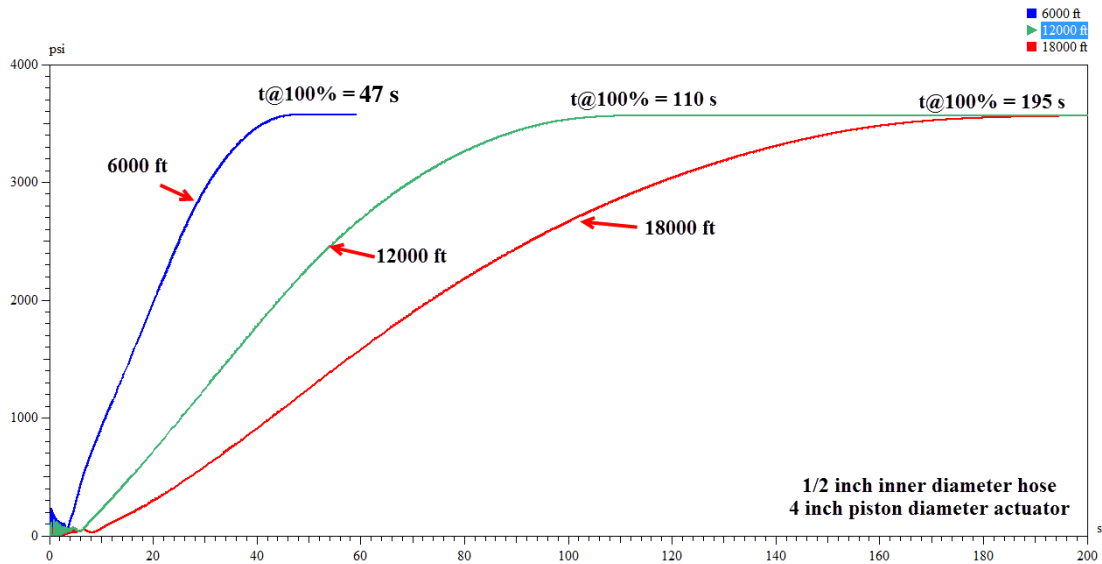


Figure 44: umbilical pressurization at different length

Time taken for each length is recorded in Table 10 below.

Table 10 : Effect of varying umbilical length to pressurization time

Length (foot)	Time (seconds)
6000	47
12000	110
18000	195

### 4.2.3 Umbilical's Inner Diameter Effect

For this simulation, the effect of an umbilical's inner diameter is studied. As the inner diameter of an umbilical increased, more fluid is needed to fill up the umbilical before the pressurization can start. As a result, longer time is required to pressurize larger umbilical. In other word, the time for the pressure to build up to the level necessary for actuator to start to shift will also increase. The effect of umbilical's inner diameter to the signal time can be seen through Figure 45.

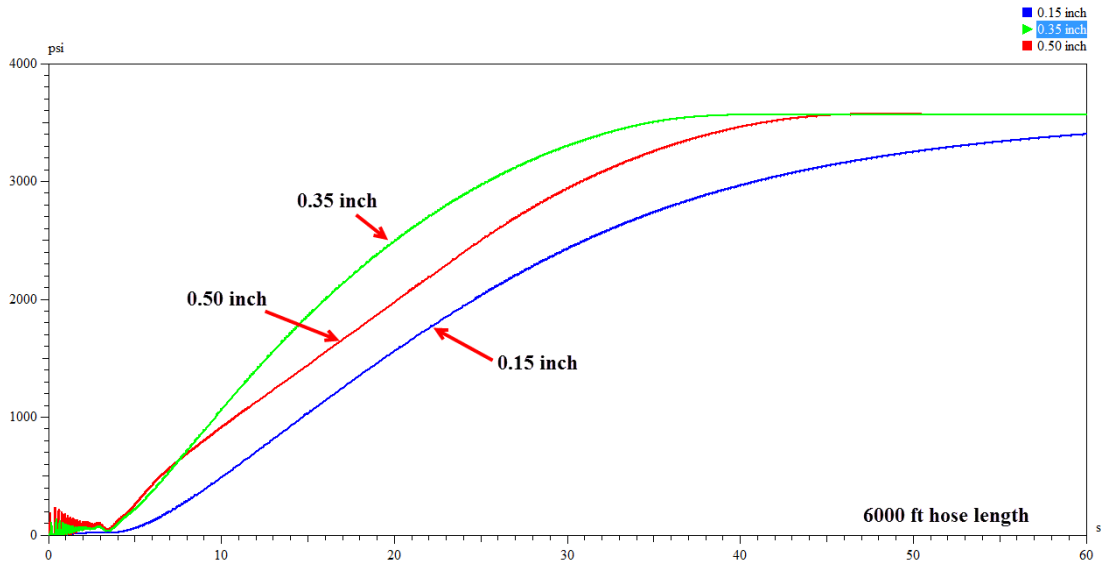


Figure 45: Umbilical pressurization at different diameter

From the graphs, 0.35 inch hose diameter yield the quickest signal time followed by 0.5 inch hose diameter, then 0.15 inch hose diameter, and lastly umbilical hose with 0.10 inch of diameter as can be seen in the Table 11.

Table 11: Effect of varying umbilical diameter on pressurization

Diameter (inch)	Time (seconds)
0.15	111
0.35	39
0.50	47

Smaller size (0.15 in) will experience high pressure loss. By Darcy-Weisbach equation, the umbilical diameter is inversely proportional to the friction loss [26]. The velocity also

higher in 0.15 inch compared to 0.35 inch and 0.50 inch umbilical. Higher velocity will caused higher friction as stated by the Darcy-Weisbach equation. Therefore, the 0.15 inch internal diameter umbilical requires the longest time to be fully pressurized. Comparing 0.35 inch with the 0.50 inch hose, as both simulation used the same flow rate, the time taken to fill up larger hose will increase. Therefore, the time required to fully pressurize the umbilical for 0.35 inch hose is shorter.

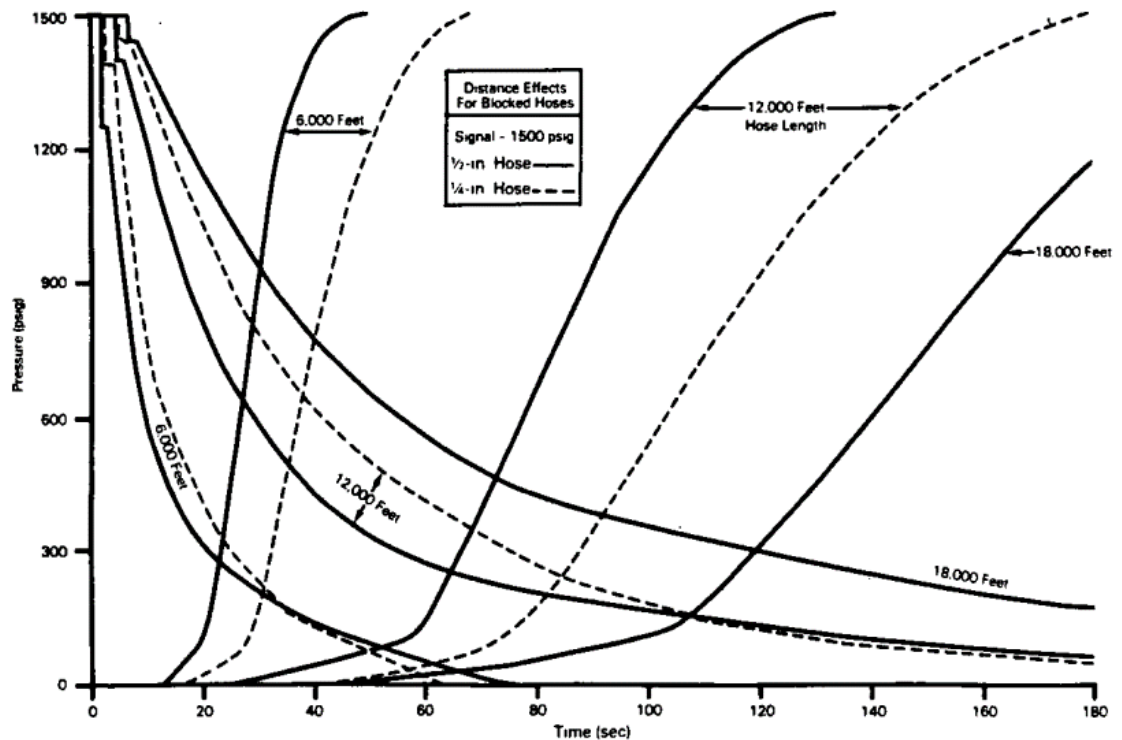


Figure 46: Cadlao response time for umbilical at different length and diameter [21]

For validation, the performance curves of the Cadlao field are compared with the acquired results obtained through simulations. The developed model yields similar response time curves as the Cadlao field. For the hose length of 6000 ft 1/2 inch, the response time for Cadlao field is approximately 50 seconds, while the response time from the simulation is 47 seconds, a disparity of 3 seconds. For 12000 ft length and 1/2 inch hose, the response time for Cadlao is roughly around 132 seconds, while response time acquired through simulation yielded 110 seconds, a disparity of 22 seconds. Lastly, response time for 18000 ft length and 1/2 inch diameter hose for Cadlao is greater than 180 seconds, while the

simulation yield more or less 195 seconds. From all the simulations done, a disparity of less than 30% between the acquired results and Cadlao field's response time. Therefore, the simulation model is valid to represent the system used in Cadlao field.

The simulation is not exactly yield an exact result as from the Cadlao field, but the system behave as predicted and similar to the actual system. The main reason for this is due to the incomplete data. Therefore, assumptions are made to predict the values for the missing variables based on calculations and from the specification sheets found online.

### **4.3 SHIFT TIME**

Second objective for this project is to find the effect of varying parameters to the system's signal time and shift time. The simulations to study the effect of varying parameters to the signal time are done in the previous section (Section 4.2). For this section, the effect of varying the parameters to the system's shift time is studied. The simulations are done by using different values for these properties:

1. Umbilical length
2. Umbilical size
3. Actuator size

#### **4.3.1 Umbilical's Length Effect**

The simulation are done using three lengths, which are 6000 ft, 12000 ft, and 18000 ft. The results obtained are shown in Figure 48. From the results, it is observed that as the length increased, the shift time also increased. Analytically, the reason for the pattern is due to the fact that longer time is needed for the fluid to travel in longer umbilical. As the velocity of fluid stays the same, hydraulic fluid will need more time to reach the end of the umbilical located on sea bed. Pressure builds up slowly in longer length umbilical. Therefore, time taken to build up the pressure to a level sufficient to overcome the forces acting the stem area is increased.

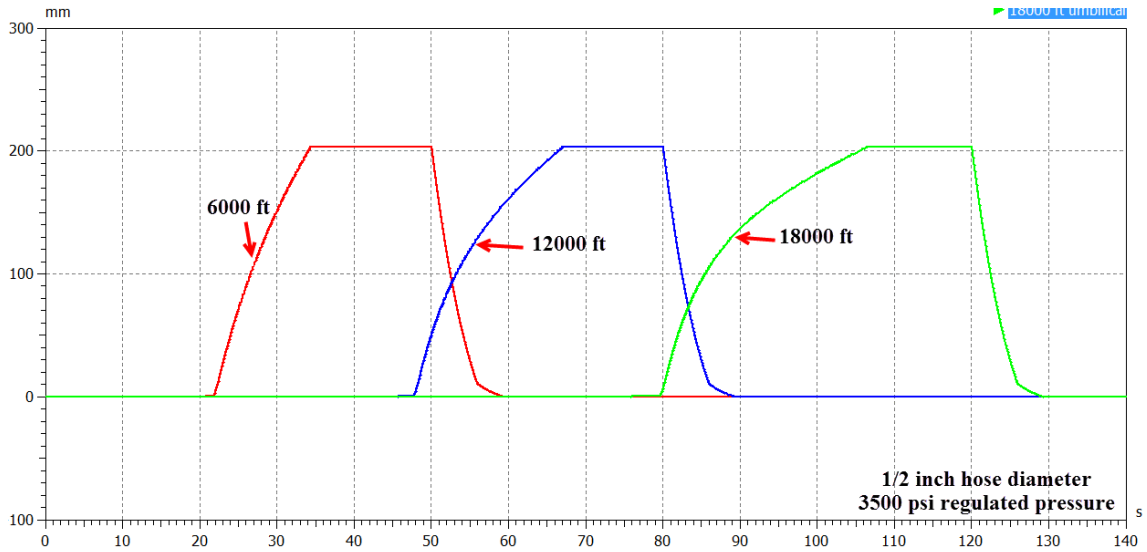


Figure 47: Shift time for different umbilical length

Table 12: Time taken to fully open actuator valve using different hose length

Length (ft.)	Time to fully open (s)
6000	13
12000	21
18000	31

### 4.3.2 Umbilical's Inner Diameter Effect

This simulation done to study the effect of varying umbilical's inner diameter to the system's shift time. Diameters used are 0.15 inch, 0.35 inch, and 0.50 inch. The time taken for the piston to travel to open position is illustrated in Figure 48.



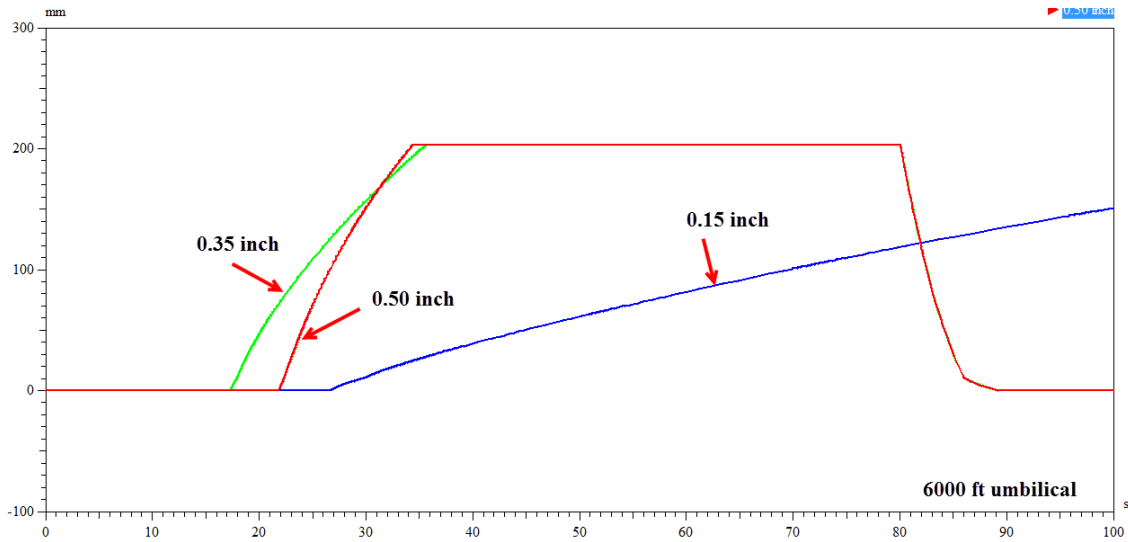


Figure 48: Effect of varying hose diameter

Table 13: Recorded time for piston to fully shift to the other end

Diameter (inch)	Time to fully shift (s)
0.15	113
0.35	19
0.50	13

From the results, we can observed that 0.15 inch inner diameter umbilical yields the longest time for the actuator to be fully opened. The reason for this behaviour is, only small amount of hydraulic fluid can be transferred at a time and huge pressure losses are experienced in a smaller umbilical's diameter. As a conclusion, The bigger the diameter, the shorter the shift time experienced.

### 4.3.3 Actuator's Size Effect

To show the effect of varying actuator' piston diameter on the shift time, different sizes have been used which are 6 inches, 9 inches and 12 inches. The results are shown in Figure 49.

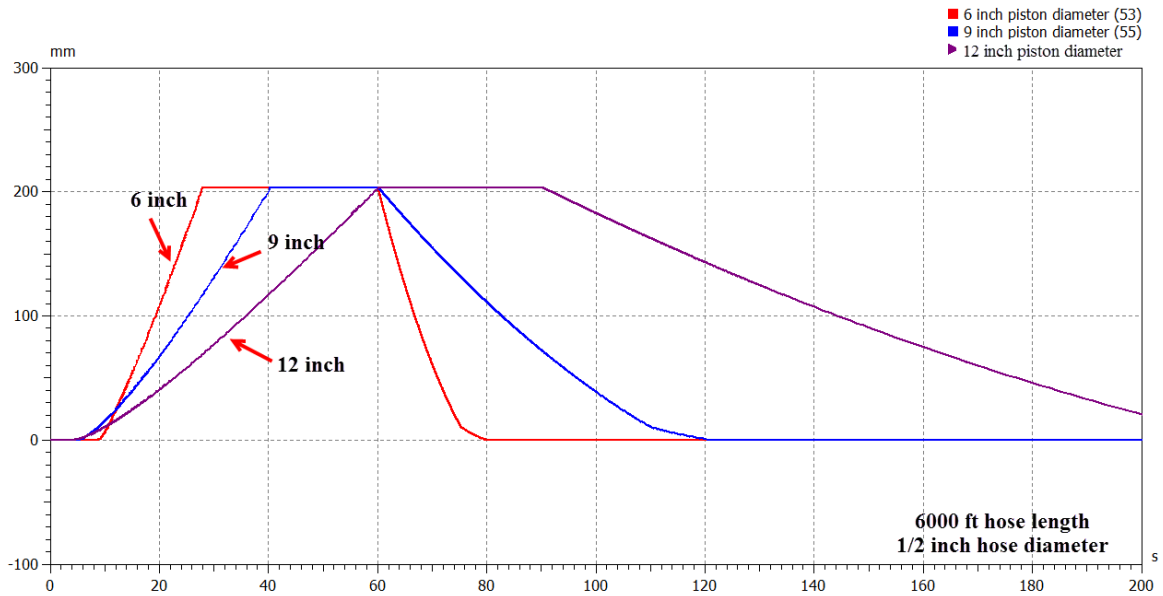


Figure 49: Effect of actuator size on shift time

Table 14: Recorded shift time for different piston diameter

Valve piston diameter (in)	Time taken to fully open (s)
6	28
9	36
12	56

From the results (Table 14), the shortest time recorded is 28 seconds, simulated using 6 inches actuator’s diameter, followed by 9 inches actuator (36 seconds) and the longest time recorded is 56 seconds when using 12 inches piston diameter. A smaller piston will results in a smaller volume of the actuator. Therefore, the time needed to fill up the actuator’s cylinder is shorter as compared to the bigger size actuator. Thus, we can conclude that the bigger the size of the cylinder, the longer time required for hydraulic fluid to fill up the actuator’s cylinder.

#### 4.4 EMERGENCY SHUT DOWN (ESD)

Lastly, simulation on emergency shut-down is done to demonstrate how the system behaves during accidents or hardware failures. For this simulation, the header valve located on the surface facility is closed during operation resulting in termination of the

hydraulic supply. During the simulation of the emergency shut-down, hydraulic fluid supplied by the HPU is vented back to the tank. This simulation done to predict the time needed for the actuator valve to return to its fail safe position, and block the flow of hydrocarbon in the wellhead, in order to prevent any further dangerous occurrences or further lost. The graph below (Figure 50) shows the actuator's behaviours during emergency situation.

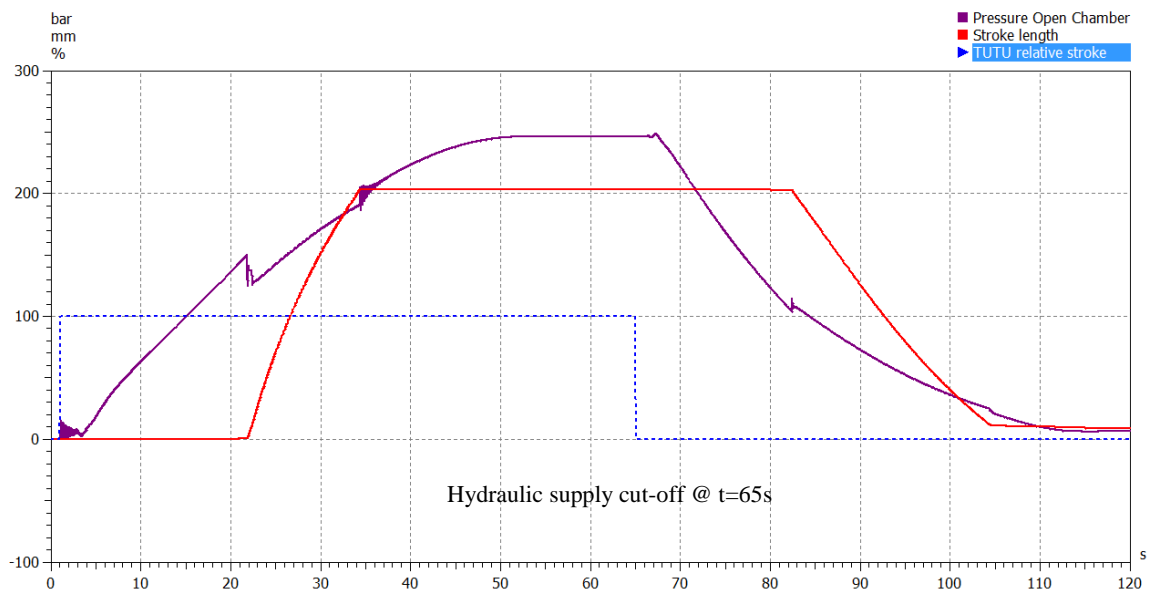


Figure 50: Gate valve time to return to safe state

For this system, gate valve take too long to return to its initial state. This is due to the insufficient spring force on the actuator which cannot overcome forces exerted by the hydraulic fluid in the umbilical hose. This unforeseen event could have led to disaster if the system were to put into operation before simulation is thoroughly done.

To solve the problem, spring force and preload force are altered. The new values was then simulated to confirm the gate valve position. After few trial and errors, the graphs plotted shows that the valve fully returned to its safe position in 37 seconds. This value can still be reduced by increasing the spring force and preload force, but higher spring force means that higher force is required to open the actuator valve during production. Hence,

increased in the opening time of gate valve will be experienced. Regardless of that, the ESD was successfully simulated and gate valve was fully closed in 33 seconds.

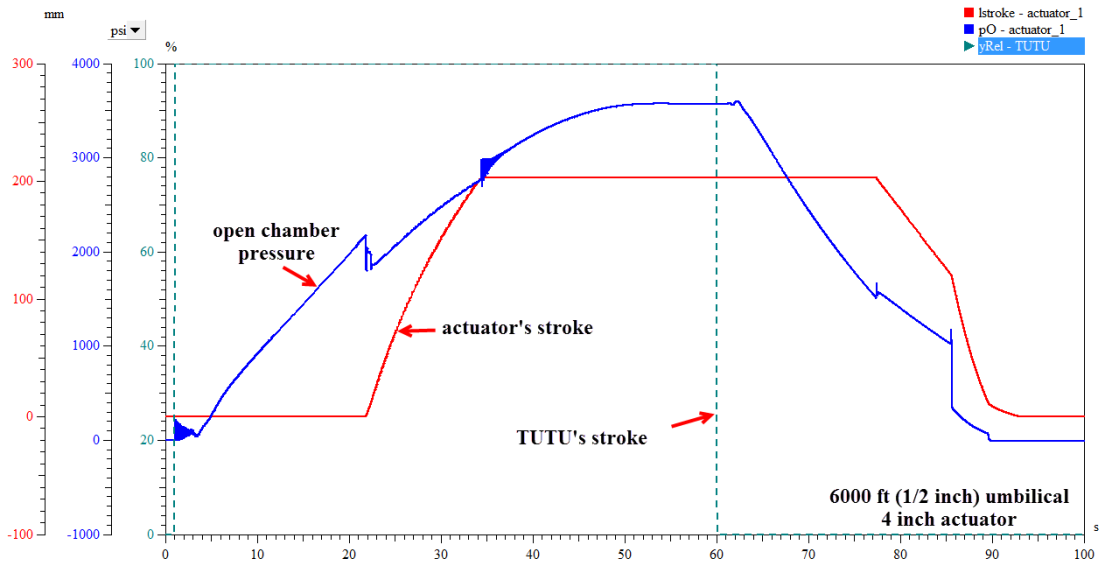


Figure 51: correction on spring force and preload force on spring

## **CHAPTER 5**

### **CONCLUSION AND RECOMENDATION**

#### **5.1 CONCLUSION**

As the conclusion, simulation offers great help in analysing the subsea production control system. All the components in a system can be tested in various ways to analyse their integrities and behaviours. The influence of a component to the overall system's performance can be studied and appropriate actions can be taken to improve the system. This is important for newly designed system. Before putting the system into operation, the system can be virtually tested first to increase confidence or to understand the operation of the system.

For this project, the first objective is successfully achieved as illustrated in Figure 37 which is to develop a simulation model for a direct hydraulic control system. Several guidelines and steps have been strictly followed in order to design a model for the direct hydraulic control system. Simulation model is build based on the model used in the case study for this project, which is Cadlao field. While studying the case study, literature review is done on the direct control system and various components in the system are identified. After the critical components are recognized, further study done to understand the concepts and functions of each component. At the same time, the conceptualized components are translated to acceptable form in the simulation software. During this stage, simulation model developed are constantly tested and simulated to verify whether the developed model can be simulated properly or not. During this stage, the configurations of the system are frequently changed. After the developed model is verified and all main components that build a direct hydraulic control system are included, real field data are

used to simulate the developed system and validation is done during this stage. After validation is completed and the developed model is proved to behave similar to the real system in Cadlao field, simulations are continued to study the effect of varying parameters to the shift time and signal time, which is the second objective for this project work.

To achieve second objective for this project work, the developed model is simulated using different values for three main parameters in the system, which are the umbilical length, umbilical inner diameter, and actuator size. The simulation are successfully done and the effect of varying the parameters are analysed and discussed in the previous chapter, which is Chapter 4. The conclusions made about the effect of the varying parameters to the system's signal time and shift time are as the following:

1. Pressure drop is experienced when operating neighbouring actuators. Therefore, a thorough consideration is needed when designing the operation of the system.
2. Delay is experienced when a function is initiated at the topside and executed at the seabed. Careful contemplations for the system's design will help in reducing the effect of the delay.
3. Subsea production control system's signal time is directly proportional to the umbilical length, and is inversely proportional to umbilical inner diameter.
4. Subsea production control system's shift time is directly proportional to umbilical length and inner diameter, but inversely proportional to the actuator size (diameter).

Lastly, the third objective is also successfully accomplished which is to demonstrate the emergency shut down (ESD) feature which is a requirement for subsea control system. The ESD simulation showed that the personnel on the topside facility are exposed to risk within the 33 seconds recorded in Figure 51. Quicker fail safe time is preferred for the subsea system in order to reduce or eliminate the risk but the period is still acceptable as the requirement for ESD for work over control system is less than 60s [27]. If this developed model is used in real field, there should be a plan and set of actions to be done during the emergency shut down. The time for the actuator to return to its fail safe position should be used to plan appropriate actions that can be done during emergency. The steps

or actions taken will decide the life of the personnel on the surface platform. Hopefully, the tragedy of Piper Alpha which caused 167 personnel died will not happened again as proper actions planned to make sure everything is in control during the 33 s.

## **5.2 RECOMMENDATION**

Simulation model developed showed similar behaviour to system in Cadlao field. Regardless of that, there are few things that, in my opinion, can be done to improve the outcomes of this project. My recommendations are as follows:

1. SimulationX should include recommendation on how to solve an error during simulation. This will help beginners such as myself to troubleshoot error quicker. As for now, only the cause of error is shown, and length calculation or consideration have to be made to find the problematic parameter or component.
2. Other factors should be investigated rather than umbilical size and length, and actuator size as it is already done in this project. Other parameters can be used for future works such as bulk modulus and water depth.
3. Future works should model and simulate newer control system such as multiplexed control system so that alternative solution can be suggested to improvise current limitations in the system.
4. As all the operators are aiming for low cost and reliable system, all-electric subsea systems are introduced. Future works may include studying the all-electric subsea control system which seem to have huge potentials and can be further improved.

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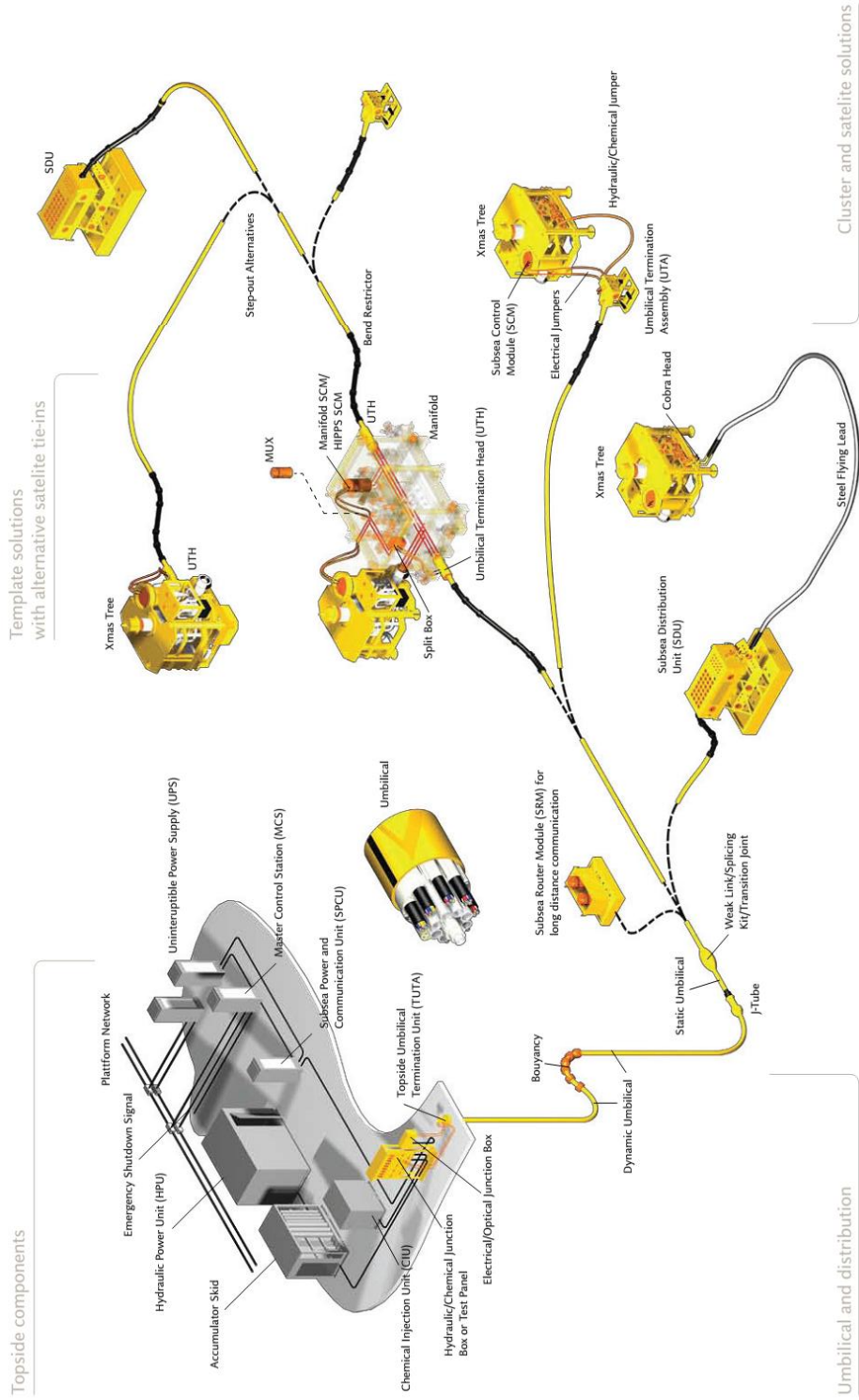


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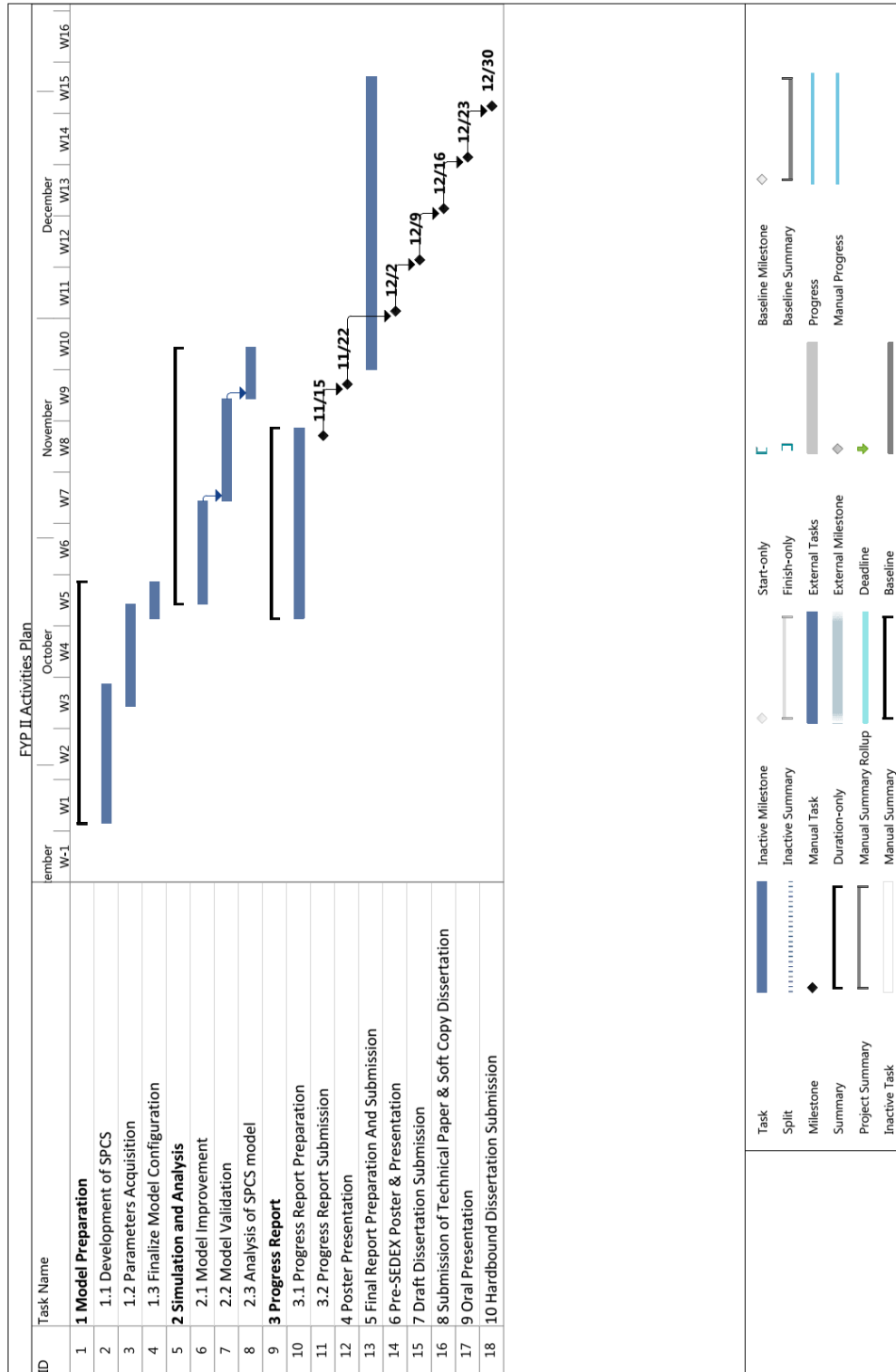
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# APPENDICES

Appendix I: Typical subsea production system (Courtesy of FMC)



# Appendix II: FYP I Gantt Chart



# Appendix III: FYP II Gantt Chart

