University of Stavanger

Faculty of Science and Technology

MASTER'S THESIS

Study program/ Specialization: Offshore Technology - Marine and Subsea Technology	Spring semester, 2015 Open
Writer: Jan Fredrik Stangeland	.... (Writer's signature)
Faculty supervisor: Prof. Arnfinn Nergaard	
Thesis title: Subsea Standalone Vehicle System for Snorre B	
Credits (ECTS): 30	
Key words: -Standalone System -ROV -Snorre B	Pages: ……88…………… + enclosure: ……0…… Stavanger, 15.june.2015 Date/year

Preface

I would like to thank Prof. Arnfinn Nergaard for his help and guidance during this last semester.

In addition, I would like to thank Olav Bruset for his involvement, help and guidance with in this thesis and allowing me to visit Snorre B on a field trip.

Stavanger June 2015

………………………………………………

Jan Fredrik Stangeland

Abstract

The rig manager on Snorre B, a semisubmersible production and drilling rig for Statoil, has expressed the need for a subsea standalone vehicle that can perform specific tasks when the conventional remote operated vehicles (ROV) is not capable of diving due to rough weather. This is seen especially during the winter season. Having a vehicle in standby at the subsea location, during all-weather situations, will enable critical work to be performed on the subsea structures and increases safety, such as operating valves during emergencies.

By analyzing the ROV operation that have been affected by bad the weather, the main restrictions was fond in the launch and recovery of the ROV system, due to the large wave forces acting on the system during this operation.

If the standard launch and recovery system for the ROV could be removed or altered, a new system could be designed. It was found that if the hangar and vehicle where to be placed on the seabed during calm weather conditions and they could remain there for longer periods during rough weather, this would decrease down time during a possible malfunction.

The standalone system would need to remove the weather depended components in order to work during rough periods. This was achieved by changing out the way the ROV communicates and receives electrical power. By receiving power from subsea structures, and signals from a high weather tolerant piggyback solution, the standalone system can be operated during any storm the rig`s umbilical and risers can take.

The standalone components, which consist of a hangar and the vehicle, is connected through different types of tethers; power and signal tether, optical fiber tether, and wireless connection. These connection types give the vehicle the means for reaching and completing the required types of operations.

Table of contents

Preface i

Abstract ii

Abbreviations v

Symbols vi

1 Thesis background 1

2 Objective 2

3 State of the art, Current technology 3

3.1 ROV 3

3.1.1 Work class - WROV 4

3.1.2 Observation class - OROV 5

3.1.3 Tether Management System - TMS 6

3.1.4 Launch and Recovery System 10

3.2 AUV 12

3.3 Existing and vehicles in development 13

3.4 Manipulators 16

3.5 Sensors and equipment 21

3.6 Tooling & Skid 22

3.7 Power connections 28

3.8 Subsea Communication 30

4 Snorre B today 32

4.1 Possible position for equipment 33

4.2 ROV System 34

4.3 Riser systems 35

4.4 Subsea structures 36

5 Feasibility study of a retrofit standalone system 37
5.1 Functional requirements 37
5.1.1 Work tasks 37
5.1.2 Operational requirements 37
5.2 Base Case System Components 38
5.2.1 Vehicle 39
5.2.2 Hangar 48
5.2.3 Launch and Recovery systems 50
5.2.4 Power and control supply to the submerged system 54
5.2.5 Electrical Power layout 69
5.2.6 Communication Layout 70
5.3 Limitations 71
6 Evaluation and Selection of System 72
6.1 Steps 72
6.2 Hangar 72
6.3 Vehicle 73
6.4 Launch and recovery system 74
6.5 Connection cables 74
6.6 Final System selection 75
7 Conclusion and Recommendation for further work 77
8 References 78

Abbreviations

ROV – Remote Operated vehicle

OROV – Observation-class Remote Operated vehicle

WROV – Work-class Remote Operated vehicle

AUV – Autonomous underwater vehicle

AIV – Autonomous inspection vehicle

XMT – Christmas tree

CP – Cathodic protection

TMS – Tether Management System

LARS – Launch and Recovery System

BOP – Blow out Preventer

LMRP –Lower Marine Riser Package

MSW – Meter of Salt Water

SCM –Subsea Control Module

Symbols

u – The particle velocity

ξ – Wave profile

k – Wave number ($\frac{2\pi}{L}$)

g – The constant for gravity

x – Horizontal position of the wave

z – The depth for the velocity

L – Wave length

T – Wave period

d – Depth

1 Thesis background

ROV operations are restricted by weather conditions due to the forces induced in the splash zone during launch and recovery. These forces can damage to the ROV and its equipment. Bad weather launches may also cause the ROV to malfunction.

ROVs stationed on production rigs may provide the rig control-room view of the subsea situation and provide the possibility to operate during worse weather conditions. Example: operating subsea valves if the remote valves on the XMT fail. If the weather is above the ROV`s limits it cannot perform these operations, and the rig loses an emergency contingency.

The rig manager on the semisubmersible production and drilling rig Snorre B, have shown interest in weather independent ROV systems that can be submerged for long periods of time. To reassure that actions can be taken if valve operation would be required during bad weather. The purpose of this thesis is to perform a feasibility study on this concept, which can reduce the weather down time and have a vehicle in operation during all-weather situations.

2 Objective

Primary objective: To establish the feasibility of standalone remote controlled vehicle and hangar to operate without weather limits for inspection and light tooling for Snorre B

Secondary objective:

- Outline design of hangar to vehicle interface system
- Outline design of vehicle with necessary tools and accessories
- Propose deployment and recovery system (to be able to retrieve the system for maintenance and repair)
- Establish a feasible solution for supplying signal and power for ROV/AUV system to seabed.
- Define interface with existing subsea control system
- Present an overall system configuration

3 State of the art, Current technology

3.1 ROV

ROV is a remotely operated robot that can function in harsh environments where humans are restricted, it extends the divers depth and duration for subsea work. The operator of the unmanned submarine is normally sitting on a rig or ship while controlling the ROV, using joysticks to move it and different sensors and cameras to navigate. Under good operating conditions, the ROV can work 24 hours a day, as long as there are enough personnel to operate it.

The reason for using ROVs can be to reduce the risk of losing human life with dangerous diving operations, stream life video feed to operation rooms, handle heavy equipment for subsea use. The ROV can reach depths that would be impossible for human divers, as far as several thousand meters.

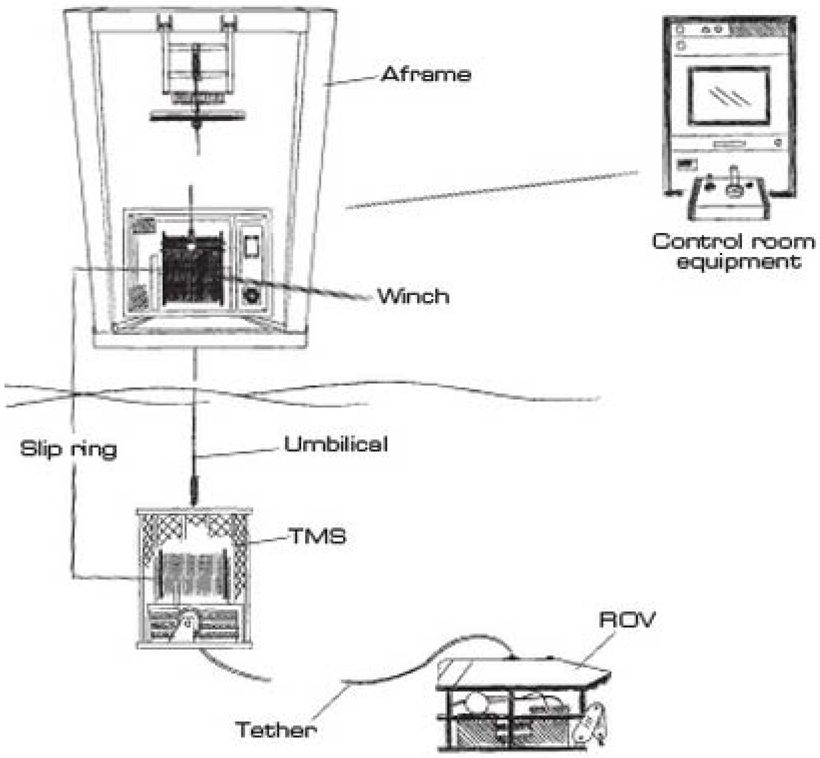

Figure 1 Illustration of a ROV system, taken from MacArtney.no

Figure 1 illustrates the normal main component setup for a ROV system. It includes the control room from where the pilot/operator is operating the ROV. The A-frame and winch launches and recovers the submerged units that are connected to the lifting umbilical and the submerged TMS and ROV.

The entire ROV system can be divided in two categories, Top side and Subsea units.

The Topside units consists of control room and LARS. The control room is where the crew operates the ROV. All video signals and communications to and from the ROV goes through the control room. The LARS, Launch and Recovery System are the components for deploying and retrieving the ROV and TMS in to the sea. Components involved in this can be an A-frame or crane, and a winch.

The Subsea units are connected with the lifting umbilical on the winch. The subsea parts are the TMS and ROV. The ROVs comes in many variations, but there are two main types “work vehicle” and “observation vehicle.”

3.1.1 Work class - WROV

Figure 2 Subsea 7 WROV (Subsea 7, 2015)

The work class ROV carries out the heavy-duty work, where typical tasks may be: moving objects, using tools, assisting in subsea lifting/crane operation and operating valves. For completing these tasks, the ROV uses manipulator to maneuver and operate the tools. These manipulators are powered by hydraulics.

The work class ROV is easily recognized by its size that varies around 2500mm in length and 1500mm width. The effect of the work vehicle increase in size is due to the thrusters, manipulators, tools and payload size.

3.1.2 Observation class - OROV

Figure 3 Observation ROV (moraymarine, 2015)

This observation class ROV is designed for capturing pictures, video and use of sensors, typical tasks for the OROV are visual inspection, survey, sonar scanning and all other sensor work. The observation class ROV is small by design in order to maneuver through more restricted areas than the work class ROV. The size of the OROV is relative to the amount of equipment it carries. The OROV may carry everything from only one camera to a fully equipped OROV with small manipulators. The standard size of an OROV is about 1000mm length and 700mm width.

3.1.3 Tether Management System - TMS

Figure 4 Tether Management System (Subsea 7, 2015)

The task for TMS is to control the tether, and to supply the ROV with electrical power and signals. The TMS can be regarded as a remote operated cable winch. The tether drum is connected to the main lifting umbilical trough a slip ring. The slip ring allows electrical and optical contact while the drum is rotating, and is located inside of the drum.

The winch is lowered into the sea to the required depth for the subsea operation, from this depth the ROV will detach from the TMS where it is latched on during the launch or recovery. When the ROV "swims," the TMS is operated by the ROV pilot and will pay out or spool in the required amount of cable. Some of the TMS units can also house the ROV, in that case the TMS is referred to as a garage or hangar.

Figure 5 ROV attached to TMS during recovery (CQI, 2008)

Tether The tether is the lifeline between the TMS (hangar) and the ROV (vehicle). The TMS supplies the ROV with power and signals using copper conductors and fiber optic cables in the tether. A cross section of a tether can be seen on Figure 6:

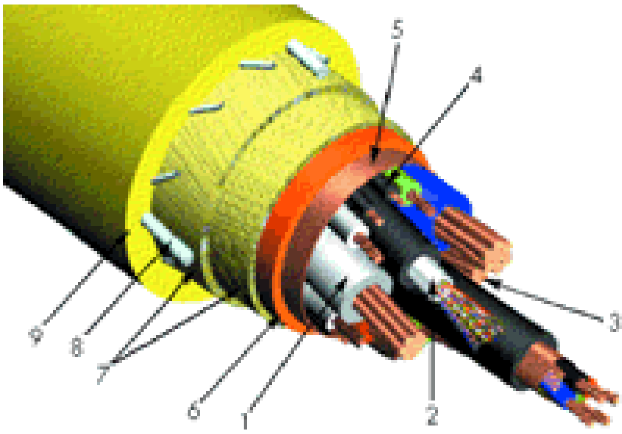

Figure 6 Nexans tether (Nexans, 2015)

1. The conductors going to the electric motor are usually the largest and supply the highest ampere.
2. Optical fibers protected by a steel tube
3. Instrumental power supply, these are the same as the ones to the electric motor only with a smaller cross section.
4. Earth conductors, discharges any fault in the electric system and any power build up in the cable
5. Copper laminate shield, increases the effect of the earth conductors.
6. The orange Inner shield is the inner protection from seawater.
7. Soft armor yarn provides tensile strength and torque balance.
8. Plastic fillers increase the attachment between the armor yarn and the outer sheath.
9. Outer sheath, a thick layer of thermoplastic elastomer, works as a mechanical protection, it also creates uplift for the tether and preserve the soft armor.

The tether is the link between the TMS and ROV, and will lay out in a horizontal direction. Tether is designed to be relative neutral in water, the more neutral the tether is the less it affects the vehicle during operations. The length of the tether provides the ROV a larger radius from the TMS from where it can work. The length of the tether also affects the power of the vehicles propulsion, as the ROV must be able to withstand drag on the tether when it is fully extended. This lets the larger work class ROV go much further than the observation class. Examples here can be taken from some of the standard OROV`s and WROV`s

Table 1 Step out - cable length compared to vehicle propulsion (Subsea 7, 2015) (Oceaneering, 2015) (IKM Subsea, 2015)

Vehicle Type	Forward trust	Lateral trust	Tether length	Tether diameter
Observation class	145 N	45 N	120 m	12,7 mm
Medium class	500 N	500 N	250 m	14,6 mm
Work class	4-8 kN	4-8 kN	400-1200m	Ca. 40mm

The tether lengths on the WROV are mainly restricted by the size of the TMS.

3.1.4 Launch and Recovery System

Winch: The ROV winch is either electric or hydraulic driven, and used for lowering and hoisting the entire subsea system while ROV is attached to the TMS. The winch uses steel armored dynamic umbilical for lifting. Figure 7 is a full electrical winch from MacArtney, designed for lifting WROV system. Typical size for a work class system is 5000x3000x3000mm

Figure 7 ROV winch from MacArtney

A-frame: The A-frame lifts and deploys the submersible system in positon outboard of the vessel. A-frames are not commonly used on rigs, when moon-pools are more available for launch and recovery.

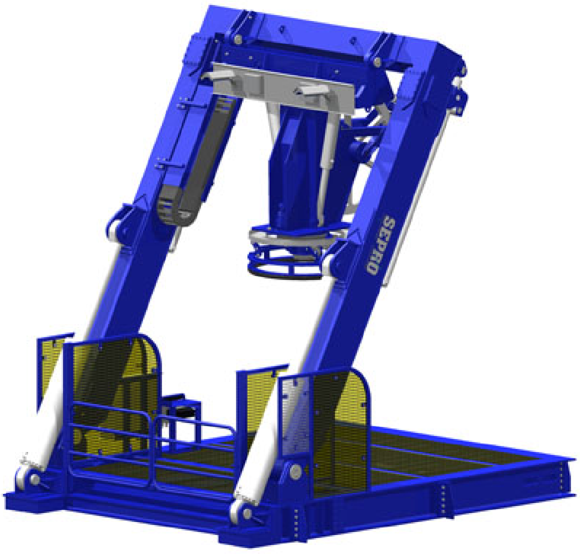

Figure 8A-frame for launch and recovery of the ROV (SEPRO, 2014)

Steel armored dynamic cable (Umbilical): Much like the tether, it contains copper conductors and optic fiber for both the TMS and the ROV. Because it also supplies the TMS, it must include a larger amount of power conductor and optical fibers than the tether.

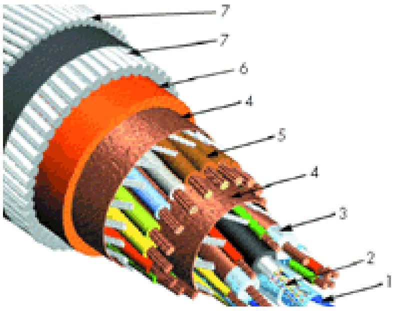

Figure 9 Steel armored dynamic cable (Nexans, 2015)

Inside the orange inner shield has the same content as the tether in section 3.1.3 , plus the extra conductors to the TMS. Outside the inner shield there are two layers of steel armor. The two layers of steel are twisted around in opposite directions as this removes most of the torsional movement. The main task for the steel armor is to take up all the tensile forces, this makes it suited for lifting the whole equipment.

3.2 AUV

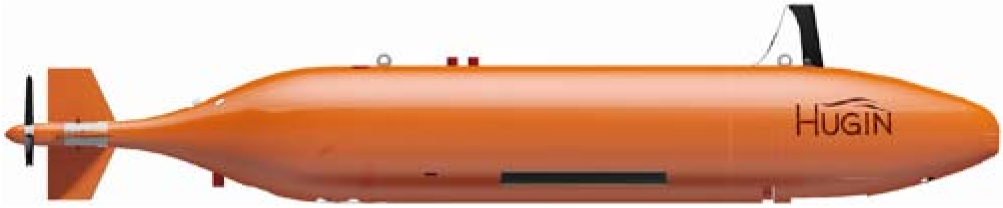

Figure 10Kongsberg AUV Hugin (Kongsberg , 2015)

Autonomous underwater vehicle (AUV)

One of the leading developer of AUV is Kongsberg maritime. Hugin, Munin and Remus are some of the AUV built by them. The Kongsberg AUV`s are designed for both civilian and military use. The common work tasks for a civilian AUV is mostly seabed-survey and –mapping.

The propulsion is normally one thruster and uses a rudder to navigate, combine this with the low hydrodynamic drag and it becomes very high efficient compared the traditional ROV with six thrusters and cubic shaped body.

The AUV can be pre-programmed and be independent from the main vessel or control station, the operator always has the possibility of monitoring the data recorded, as it is being sent through acoustics.
The AUV can also be used in a supervised mode where it gets position updated from the operator, and being reprogramed during its mission to ensure the best possible data recording.

Two types of batteries power Hugin: Aluminum oxygen semi fuel cell, these cells carry great amount of energy by creating electrical power from aluminum and oxygen. This type of battery cannot be recharged and will have to be replaced with a new battery. It can however be recycled and reused.

The other type of battery used is, a more common commercial battery called Lithium ion polymer. These are normally used in cars and mobile phones because of its good energy density and recharging capabilities.

3.3 Existing and vehicles in development

Some types of vehicles are relatively new to the industry. Some examples and the most relevant for this thesis are included here. Many of the other companies have the same type or similar vehicle to the once mentioned in this chapter.

Sabretooth

Figure 11 Saab Seaeye Sabretooth (Saab Seaeye Ltd, 2014)

Saab has developed and manufactured the sabretooth, this vehicle has the capability of an AUV and can be controlled as an ROV.

The large amount of thrusters compared to an AUV allows the Sabretooth to move like an ROV. This vehicle can operate in all 6 degrees of freedom, this means that it have the possibility to maneuver its body like a diver, giving it the advantage of being more flexible for different work tasks. It is achieved by using advanced maneuver programming and constructing the sabretooth with a center of buoyancy in the middle of the vehicle. Because of the less stream like construction compared to the conventional AUV, the sabretooth is not as efficient for long lasting surveys as the AUVs, because of the higher power consumption.

The sabretooth have the battery capacity of 20kWh, resulting in an operation time of 10-20 hours. For tooling operations this time will be depending on power consumption of the tool.

The Sabretooth have the option of using fiber optic tether, giving it a greater working distance than normal tether while being controlled by an operator.

Autonomous Inspection Vehicle

Figure 12 Subsea7 Autonomous inspection vehicle AIV (Subsea 7, 2015)

AIV is a technology developed by Subsea7 it is a full inspection/survey vehicle. Subsea7`s project with the AIV (autonomous inspection vehicle) is one of the leading technologies with image recognition, automatically locating and docking to garage.

This vehicle is a full AIV and is designed for inspection only.

Omni Maxx:

Figure 13 Omni Maxx Oceaneering, medium class vehicle (Oceaneering, 2015)

The Omni Maxx is a large observation class ROV, the increase in size and power lets it reach further than the smaller ROVs. It can also carry more payload and it has built in compartment for batteries in case of upgrades. These larger observation class ROVs have the possibilities of carrying tooling skids.

Merlin: IKM was early to use exploit advantage of electrical ROVs. The advantages of electrical ROV are more than just environmental friendly. When not relaying on one system as most of the hydraulic vehicles the ROV becomes more redundant, meaning if there is a leak in the hydraulic system the ROV can be in danger of not being able to return to the TMS.

Figure 14Merlin work class vehicle (IKM Subsea, 2015)

For a work class vehicle as the merlin it needs to have strong enough manipulators to be able to lift equipment, handle crane hooks and use tools. Not all tools have electrical versions, most of them are still hydraulic, the electric manipulators are still too weak. Therefore, the system is still in need of hydraulics in order to provide enough force to the manipulators and tools. This is some of the reasons why the Merlin is not a fully electrical ROV.

3.4 Manipulators

The manipulators are what allows the ROV preform different work tasks. They can be used for simple tasks as picking up and placing different objects, operating valves and holding and operating different tools are some of the things they are being used for.

Hydraulic Manipulators: The marked dominated manipulators normally uses hydraulically driven actuators, which requires a full hydraulic system on a ROV or separate system for the manipulators and tooling, this gives the manipulator system great power.

Electric Manipulators: Electric manipulators only rely on electrical power and signal, making the manipulator system lightweight compared to hydraulic system.

The 7 Function: The precision mechanic 7 function arms are designed for good reach and maneuverability, making it less robust than the heavy duty arm that are designed for rough work and heavy lifting with less functions, often not more than 5.

Figure 15 to the left Titan 4 from (Shilling Robotics, 2014), to the right ARM 7E, (ECAgroup, 2015)

Table 2 Comparison between hydraulic and electric manipulators

Functions	**7Functions (Shilling Robotics, 2014)**	**7 Functions (ECAgroup, 2015)**
Powered	Hydraulic	Electric
Lift capacity	122 kg Fully extended	40kg Fully extended
Reach	1920 mm Fully extended	1790 mm Fully extended
Wrist Torque	170 Nm	25 Nm
Weight in water	78 kg	49 kg
Depth rated	7000 msw	6000 msw

5 Function or work arm: The heavy duty arm`s work tasks are to grab on to equipment often to carry the load while the other arm (fine mechanic) does work like connecting, hot stabbing or disconnecting.

Figure 16to the left Rigmaster (Shilling Robotics, 2014), to the right ARM 5E, (ECAgroup, 2015)

Table 3Comparison between hydraulic and electric manipulators

Functions	**5 Functions (Shilling Robotics, 2014)**	**5 Functions (ECAgroup, 2015)**
Powered	Hydraulic	Electric
Lift capacity	181 kg Fully extended	25 kg Fully extended
Lift capacity	270 kg Retraced	N/A
Reach	1372 mm Fully extended	1000 mm Fully extended
Wrist Torque	101 Nm	25 Nm
Grip force	4448 Nm	600 N
Weight in water	64 kg	27 kg
Depth rated	6500 msw	6000 msw

Mini Manipulators: There are also smaller manipulators made for use on smaller vehicles like the large observation ROVs.

Figure 17Mini five function (ECAgroup, 2015)

| *Table 4Five-function electrical manipulator specifications*

Functions	5 Functions (ECAgroup, 2015)
Powered	Electric
Lift capacity	25 kg Fully extended
Lift capacity	N/A
Reach	850 mm Fully extended
Wrist Torque	25 Nm
Grip force	500 N
Weight in water	15 kg
Depth rated	3000 msw

3.5 Sensors and equipment

Pan and tilt unit – The cameras are mounted on the pan and tilt unit, which is operated by use of hydraulic or electric, allowing the cameras to move left, right, up and down.

Sonar – The sonar is a device that sends out acoustic signal at specific frequency. When the signal hits an object, it will be reflected back to the sonar. The sonar can then calculate the distance to the object according to the time it took the signal to return. Some material properties can also be recognized from the strength of the returning signal. The Sonar works in line of sight and by rotating it can have up to a view field of 360 degrees

Compensators: The compensators are oil storages that keeps a higher pressure that the surrounding pressure, this can be done by adding force from mechanical spring load. These oil reservoirs are used for two things: providing a stable over pressure and as a reservoir for excess oil. For the hydraulic system, a small leak in the system will be measured in loss of fluid in the compensator. The system will work as long as the leak does not empty the compensator. The compensators also provide pressure to units that are filled with oil to keep the seawater out. If there is a leak in these units, oil will leak out instead of water getting in, which will result in an electrical short circuit.

Compass Mechanical gyro. FOG (Fiber Optical Gyro) is not affected by magnetism and is therefore, used due to the amount of metal in surrounding rigs and subsea structure.

CP Cathodic Protection is measured with a CP-probe. The CP prove stabs through the coating of the structure to measure the electrical conductivity, it measure the voltage Potential between the structure and surrounding seawater.

Figure 18 Cp probe, the metal stab in the front pierces through coating to get electric connection

3.6 Tooling & Skid

Torque tool: Torque tools are used to torque nuts and valves. This is to pre tension, tighten or loosen the bolts, for construction purposes or opening and closing of valves. For the valves, the torque is set as not to damage the valve.

The ROV torque tool is fitted on to the ROV in such way that it can be operated with the ROV manipulators. The torque tool is powered through the ROV`s hydraulic system with the use of hydraulic hoses from the ROVs manifold outtake to the torque tool.

The tool is placed in the torque bucket where the tools anti-rotational lips on the tool fit with

Figure 19 ROV panel on Snorre B, picture taken by Snorre B ROV

the buckets socket; this prevents the tool for rotating during the torqueing operation.

On Figure 19 ROV panel on Snorre B the torque-operated valves are shown, if it is not possible to operate the valve remotely, the ROV can operate these subsea valves with a torque tool. This can be done as a safety function or a production function.

The torque tools are divided into different classes, the most common classes operated by ROVs are class 1-4:

- Class 1; Normally between 0 and 68Nm
- Class 2; Between 0 and 270 Nm
- Class 3; 0 and 1360 Nm
- Class 4; 0 and 2700Nm
- Class 5; up to 6780Nm

The classes are defined in lbs which is the reason for non-symmetrical numbering when using Nm.

A test jig is used for calibrating the torque tools. A sensor in the jig converts the input pressure (from the ROV it is calibrated against) into the corresponding torque. As the input pressure varies, the corresponding torque is plotted in a pressure/ torque graph. The ROV operator uses the table to adjust the pressure that is converted to torque by the tool, to achieve the required torque.

Figure 20Left: Hydraulic torque tool up to class 4 (Subsea 7, I-tech 7, 2015). To the right: Electric torque tool up to class 4 (BlueLogic, 2015)

Figure 20 shows two different types of torque tools, one is hydraulicla driven and one is elecrical. The different specifications for the tools are shown in Table 5 Specifications for electric and hydraulic torque tool.

Table 5 Specifications for electric and hydraulic torque tool

Specifications	Hydraulic torque tool	Electric torque tool
Weight	52kg	Total 48kg
Torque	Up to 2710kN 85 bar	Up to 2700kN
Rounds per minute	8rpm	4,5-5,0 rpm
Maximum consumption	85 bar 24 l/min,	1,54 kW

High-pressure washer: The high-pressure washer is a pump driven by a hydraulic motor which pumps salt water through a nozzle, and this creates a high pressure and speed of the fluid that can be used for washing subsea structure and equipment.

Dredger: Dredger is used for removing or adding sediment and smaller rocks from seabed one point to another. A water flow is pumped in to the dredger creating a one-direction flow, which creates a suction in the front of the dredger pushing it out the back.

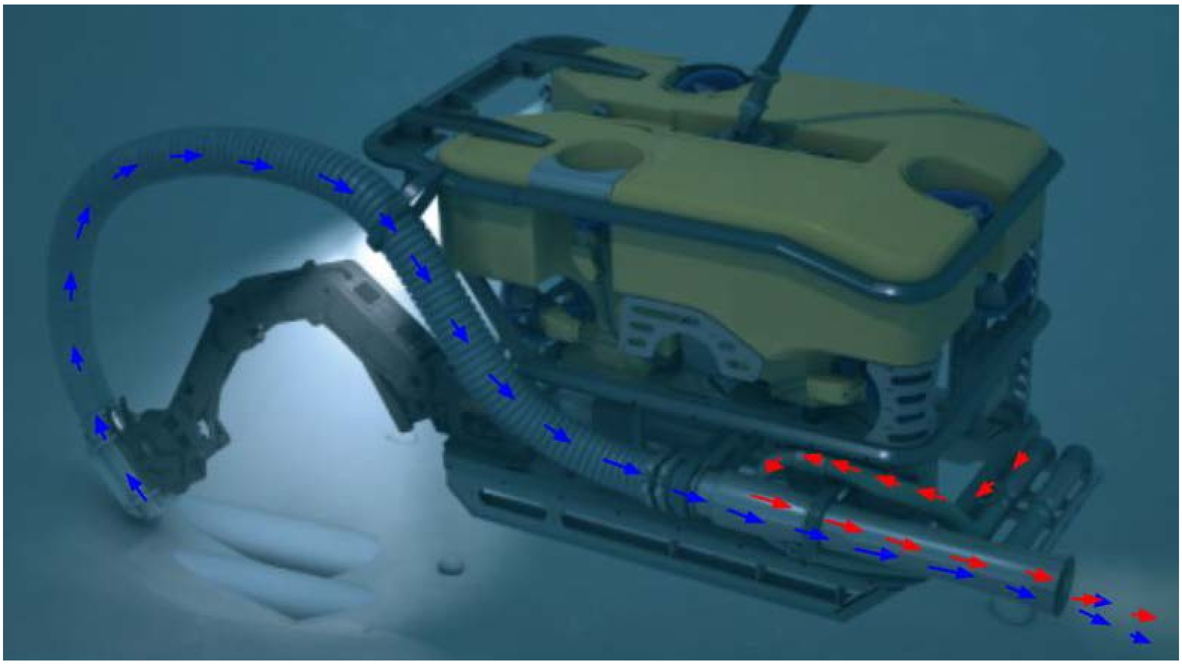

Figure 21ROV dredging, blue flow are created by the red flow of the pumped water

Skids are extra frames that the vehicle can mount or dock on to, providing the vehicle with larger space for more tools. The skids can be fitted with most of the tools and equipment, but the submerged weight should be buoyantly neutral for the ROV to be able to move with it when docked.

Examples of skids can be:

- Dirty oil pack: This is for supplying hydraulic pressure from the ROV to an external unit. The dirty oil pack on the skid is separated from the ROV`s hydraulics, leaving the ROVs hydraulic clean and uncontaminated.
- For smaller ROV`s there are skids that can be docked onto, giving the ROV small manipulator, the electric manipulators will not need an hydraulic pack on the skid. The manipulator from Figure 17
- Torque tool skid: For an ROV white out hydraulics a skid with an small hydraulic pack, only intended for the torque tool and the equipment on the skid

Figure 22 Torque tool and manipulator skid (Saab seaeye, 2015)

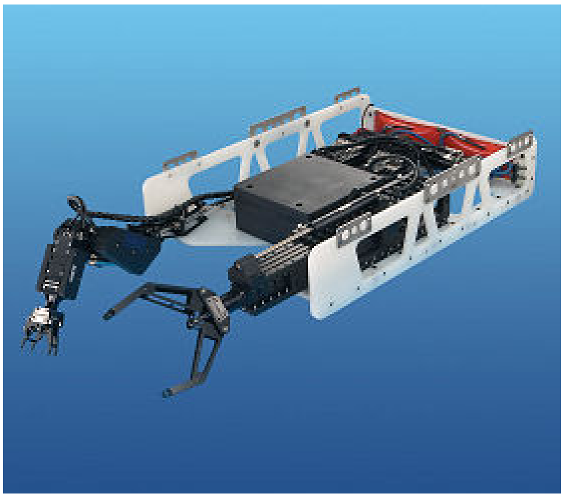

Figure 235 Function manipulator and 3 function grabber skid (Saab seaeye, 2015)

Battery is mostly used by autonomous vehicles when the tether is not wanted. Without the tether, the only limit for operation distance is the effect of the battery.

The most commonly used battery due to the weight, size, power density and the recharge capabilities is the Li-Ion battery. Tesla (car), laptops and mobile phones all uses this type of batteries.

Electrical thrusters made by IKM where tested at University of Stavanger, the battery packs for them where standard LI-Ion batteries capable of delivering 1900Wh

One third of the battery packs volume is the battery control unit the rest is Li-Ion cells that are the actual batteries.

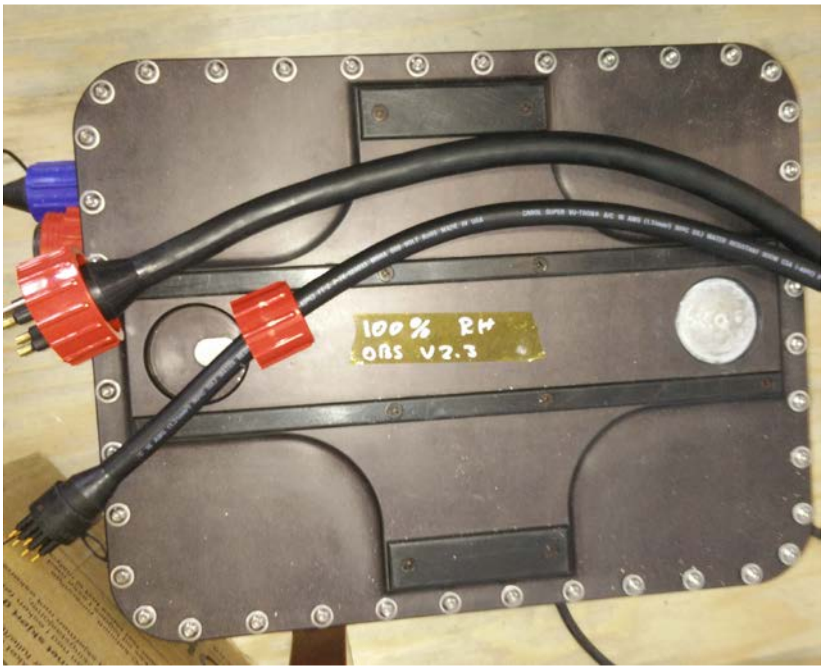

Figure 24Reap Li-Ion Battery pack for subsea use

Figure 25 Reap Li-Ion 1900Wh, size 500x400x150mm

3.7 Power connections

Inductive charging:

By manipulating electromagnetic fields, it is possible to change electrical currents, this is done by using copper wires spooled in coils, when electrifying these coils a magnetic field will be induced around the coil. By placing a secondary coil in this magnetic field, an electric current will be created in this coil, this can be explained with Faraday`s law that says: If there is a change in the magnetic field of an coil; voltage will be induced.

Since the magnetic fields are wireless; they can be used for sending wireless electricity from the garage to the vehicle to recharge the batteries.

Figure 26 Blue Logic induction plug, up to 2kW (BlueLogic, 2015)

Wet mate connector: Electrical connection can also be done subsea using a wet mate connecter. These connectors are normally connected with the use of an ROV. The wet mate connectors are normally used for supplying electrical units with power by connecting them with a wet mate cable to an SDU -Subsea Distribution Unit. Typical units that use these connectors are SCM (subsea control module) on the XMT.

The wet mate connector 1000 total cycles after factory testing. It consists corrosion resistant stainless steel and titanium, this gives it designed life expectancy of 25 years.

Figure 27Wet mate connector for subsea use (Teledyne oil and gas, 2015)

Microwave connector (no penetration): Microwave connectors can deliver power, but very limited, they are intended for signal transferee. See section 3.8

3.8 Subsea Communication

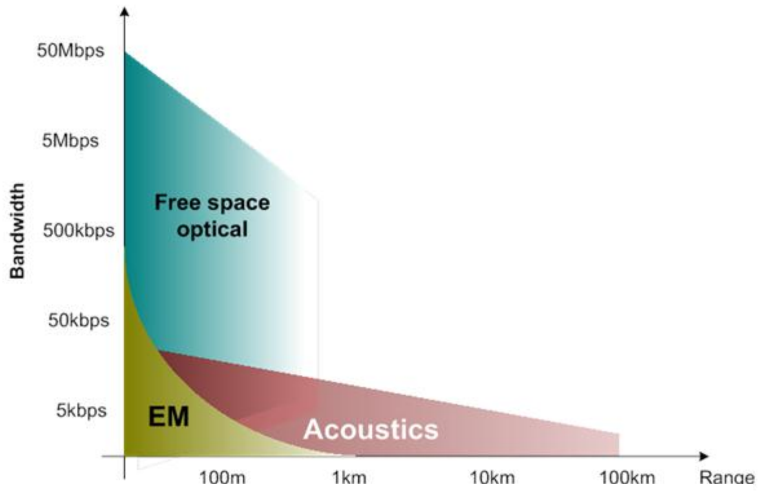

Figure 28 Bandwidth/Range for wireless communication subsea, " (ENI, 2015)

Figure 28 shows the limitations for the potential for the wireless data transferee at different distances for subsea use.

Optical Fiber: Optical fiber can achive great length without losing signal. By sending laser signals through fiber cables, high amount of data can be transmitted and received at both ends.

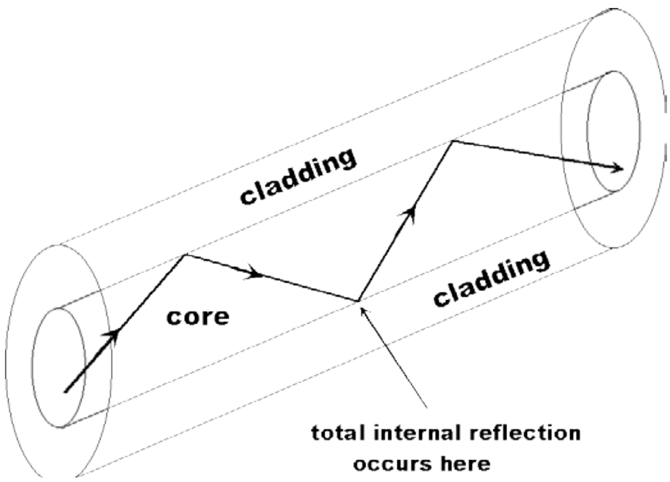

Figure 29 A single optical fiber. Built up by the core and cladding. (Davis, 2015)

Each optical fiber consists of a core that the light moves through and cladding witch sorrounds the core. The angle of the light in the core and the cladding keeps the light in the core by bounceing it all the way until the end where the angel are too obtuse to bounce and will break through. This is where the signal is received. (Davis, 2015). Wet mate connector allows for establishing of optical connection subsea (SEACON, 2015) (Teledyne Oil and Gas, 2014)

Optical signal/light: A light diode sends out signals in form of light (on/off) these signals are received by a photocell that converts the light in to signals. The light transmitter and receiver must be in line of sight to be able to transferee signals, particles in the water can reduce the light and therefore reduced the length of the transmission. Using diodes the bitrate can be as high as 20Mbps. (BlueComm Underwater Optical Modem, 2015)

Figure 30 Bluecomm, wireless optical communication trough seawater

Microwave: Microwaves do not travel far in water, but the high frequency gives possibility of very high data transfer up to 100Mbps. It can therefore be used over short distances instead of a hot stab connector. It also has the possibility of transferring power using microwaves, but it is very limited to around 150W (wisub, 2015)

Acoustic: Acoustic signals are today widely used for subsea wireless communication. The acoustic signal reaches great distances, up to approximate 100km. The bitrate can vary from 100-6000 bits/s. (Håvard, 2014)

4 Snorre B today

Snorre B is a semisubmersible drilling/production platform, located north in the North Sea. It produces oil, gas and water. The gas is re-injected to keep the pressure up in the reservoir. Snorre B uses three templates two for production and one for re injection of gas and water.

The Snorre B uses flexible risers to the subsea templates and XMT. This allows the rig to move to the position it wants to conduct drilling operations. The rig is moved by the anchor lines, there are four suction anchor in each corner, with 16 lines

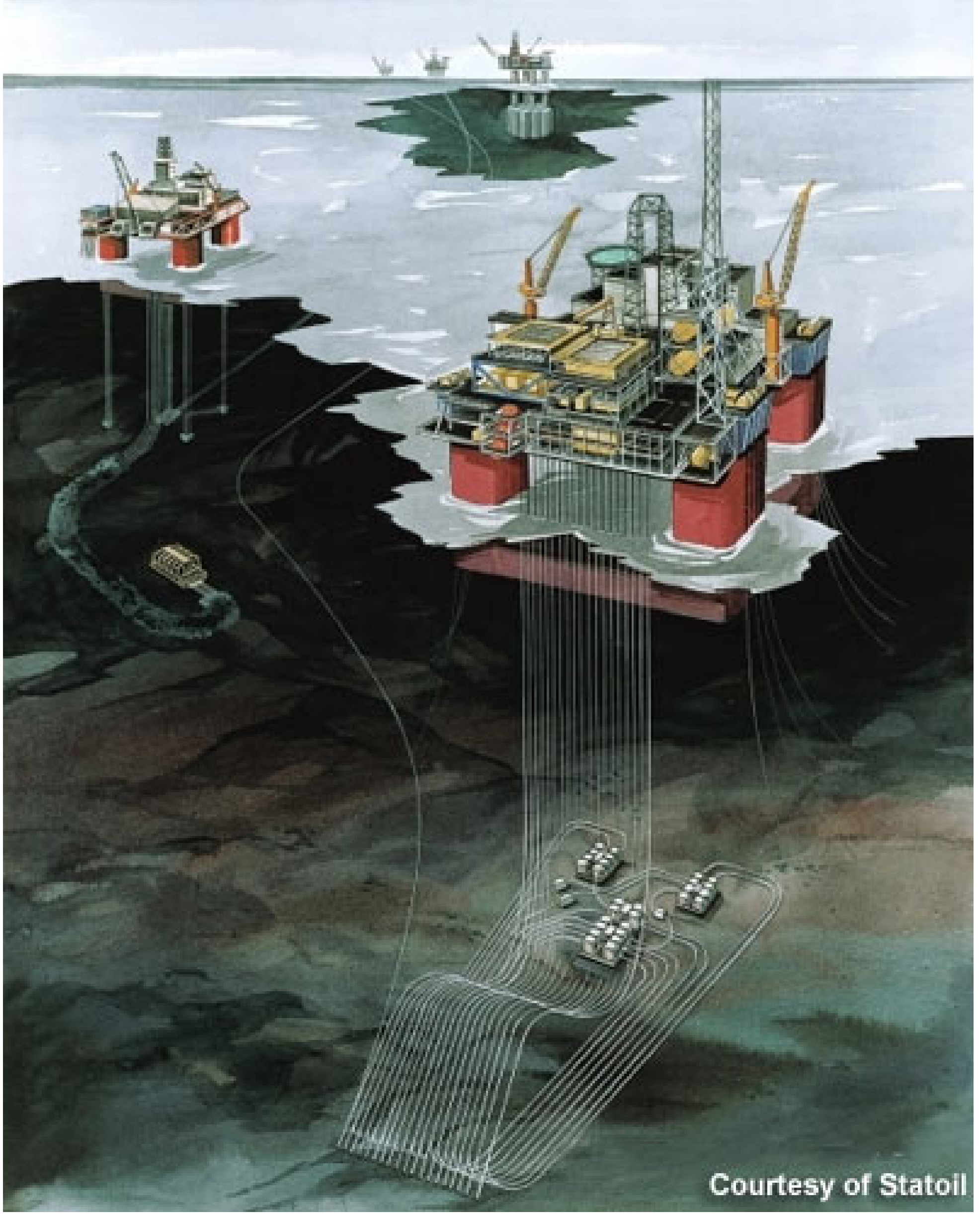

Figure 31 Snorre B semi-submersible production and drilling rig, with an overview of the subsea structures

4.1 Possible position for equipment

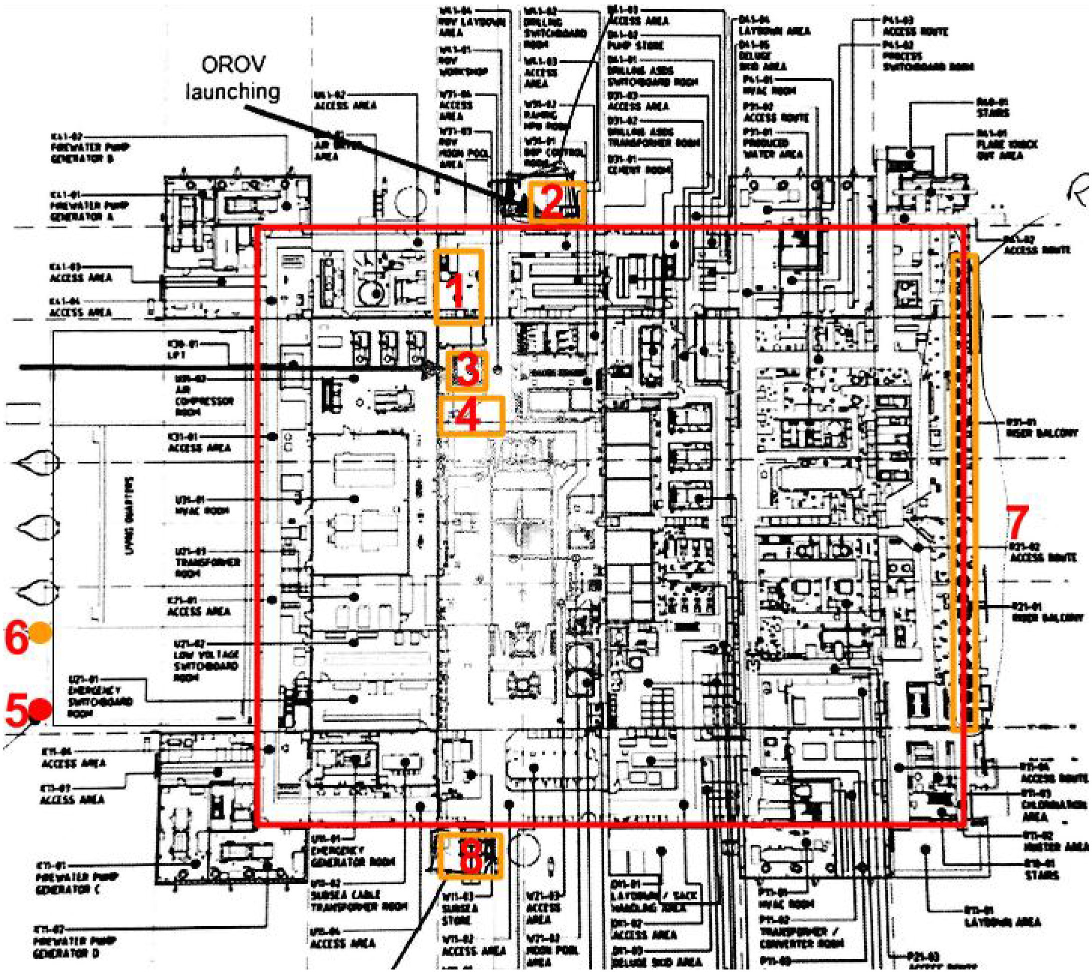

Figure 32 Deck layout Snorre B form bird view perspective

Figure 32 shows the main construction of Snorre B, the positions of interest are described:

1. ROV control room and work shop.
2. Observation ROV with launch system
3. WROV and moon pool
4. Winch
5. Location of power cable to Snorre A
6. Possible location for new cable
7. Pipelines and risers
8. Location of planned new A-frame and winch system for launch and recovery of subsea equipment

4.2 ROV System

Snorre B has two operational ROV systems, one work class for tooling, intervention, valve operation and maintenance work, and one observation class to assist the WROV, used for survey and inspection. Both the ROVs are operated from same control room (location 1).

The WROV is launched from moon pool at location 3 with a hydraulically powered winch. The OROV is launched on the outside of the rig from location 2 on Figure 32

Inspection frequency:

- Weekly visual inspection are done on the subsea structure,
- Pipeline and anchor chain are inspected every 12 months
- Every fourth year the pontoons are inspected

Tools currently used by WROV are; Torque tool, High-pressure washer, Dredger, CP probe and Hydrocarbon measurement equipment.

Weather downtime: When the weather is too bad to launch the ROV because the possibility of damaging the equipment, it will be recorded as waiting on weather. Recorded for 2014 the downtime caused by bad weather was between 500-600 hours for the WROV, and 600-700 hours for the OROV

4.3 Riser systems

Snorre B is currently using flexible risers hanging in a lazy loop before touch down to the seabed. As it can be seen on Figure 31, these risers are used for producing oil, gas and water and reinjection of water and gas. The risers systems consist of production lines, multipurpose line, umbilical, injection lines and export line.

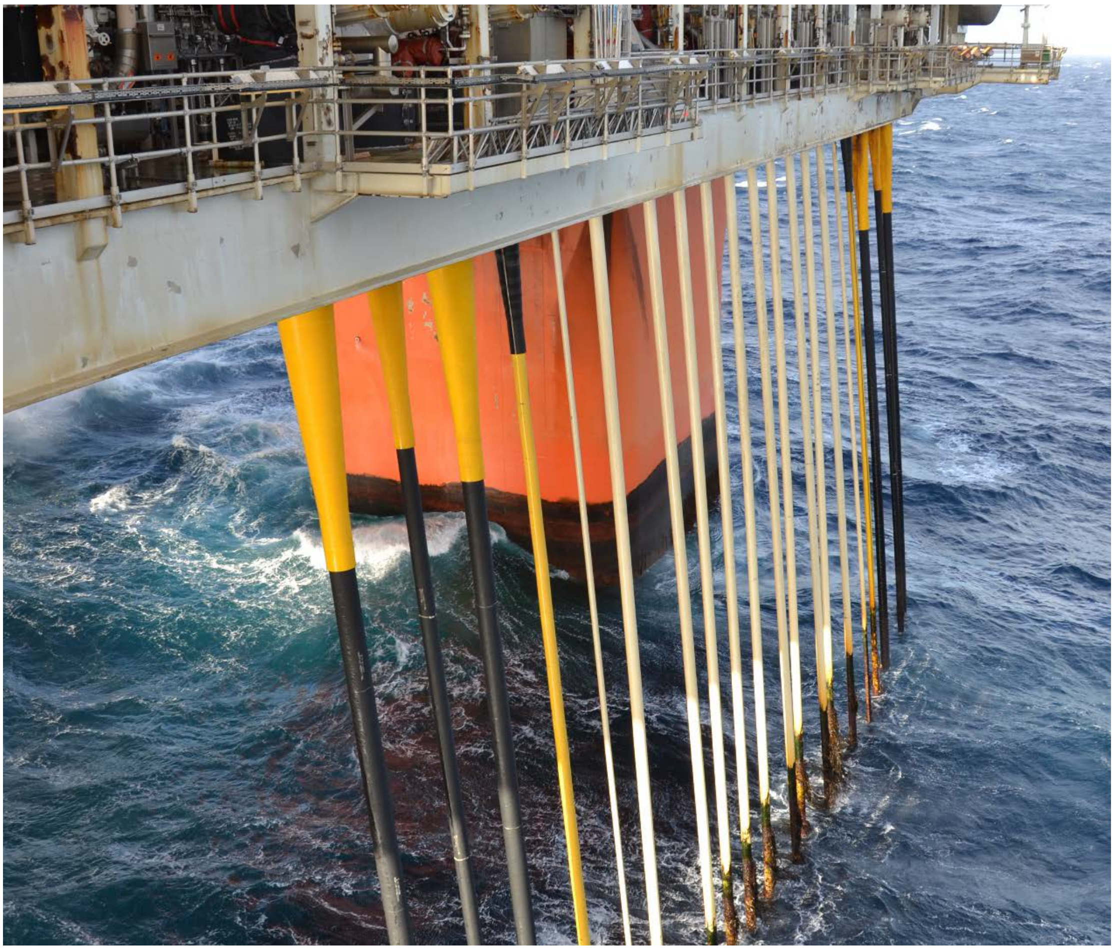

Figure 33 Riser balcony on Snorre b. The black production risers, White injection risers, Yellow umbilicals. Picture taken on student field trip at Snorre B

Umbilical runs from Snorre B to the subsea distribution unit (SDU). The umbilical contains lines for electrical power, hydraulics, and signal. From the SDU the power is where it is distributed to all the XMT and manifolds in the templates, the umbilical contains lines for electrical power, hydraulic, and signal.

Production risers are on the far side of the risers (the black risers on Figure 33), they run all the way down to the production template. In the template, there is a loop for allowing the pigs to run down and up the two risers.

Electrical supply cable: In the Southwest corner on Snorre B, where the power cable that goes between Snorre A and B hangs, this cable supplies and distributes power between the rigs. If Snorre A needs power then Snorre B can supply it through this cable or the other way around. This cable is assumed to have the same weather limitations as the rig umbilical.

4.4 Subsea structures

The subsea field on Snorre B consists of several subsea structures within a radius of approximate 150 meter (Woster & Amdal, 2015)

Templates are frame constructions for protection and they can contain several XMT in a subsea field. The produced hydrocarbons are gathered in the template manifold before it is transported through a pipeline. The templates can be viewed on Figure 31.

There are four templates on Snorre B:

The production templates are two identical templates that contains manifold and production trees. The templates can contain up to eight XMT and one manifold. The manifold and the XMT are all protected by covers and hatches. There are two production risers for each production template that are connected to the manifold, this creates a pigging loop for the risers. The templates are approximate 14 meter wide, 18 meter long and 9 meters high

There are two injection templates, one small with four slots for injections wells and one that is the same size as the production template with room for eight injections wells. For each well slot in the injection template there is a riser connected, the largest quantities of risers are used for the injection system.

EDU & SDU Electric Distribution Unit & Subsea Distribution Unit are connected to the main umbilical. These units distribute power, signal and hydraulic to the components at subsea. This can be done by cables or hoses and connectors. These can be seen as smaller structure between the two templates in Figure 31

The umbilical for SDU 2 have a pair of 4mm^2 conductors that are used for a Seahawk camera. The cable can deliver 25Amp with 500VAC, which results in 12,5kVA

The signals to the subsea structures are based on frequency modulation, which have a relative low bandwidth, due to the low precision and noise in the cable wiring (Mæhre, 2015)

Extra: An abandoned cuttings injection well is also located northwest from center of the structures. This was used for injecting cuttings in to the well, but the cuttings reappeared at another location on the seabed.

5 Feasibility study of a retrofit standalone system

5.1 Functional requirements

5.1.1 Work tasks

- Valve operation
- Small tooling
- Manipulator work
- Observation of ongoing operation
- GVI (general visual inspection)
- Use of inspection instruments,

5.1.2 Operational requirements

- Continues submerged for long periods of time min 3 months:
- Operation time minimum 6 hour of operation
- Tooling abilities, skid possibilities
- Wireless transferee of signals
- Fiber cable
- Maintenance free/reduced during deployed time
- Fully electric
- Autonomic function
- Work range: out to suction anchors

5.2 Base Case System Components

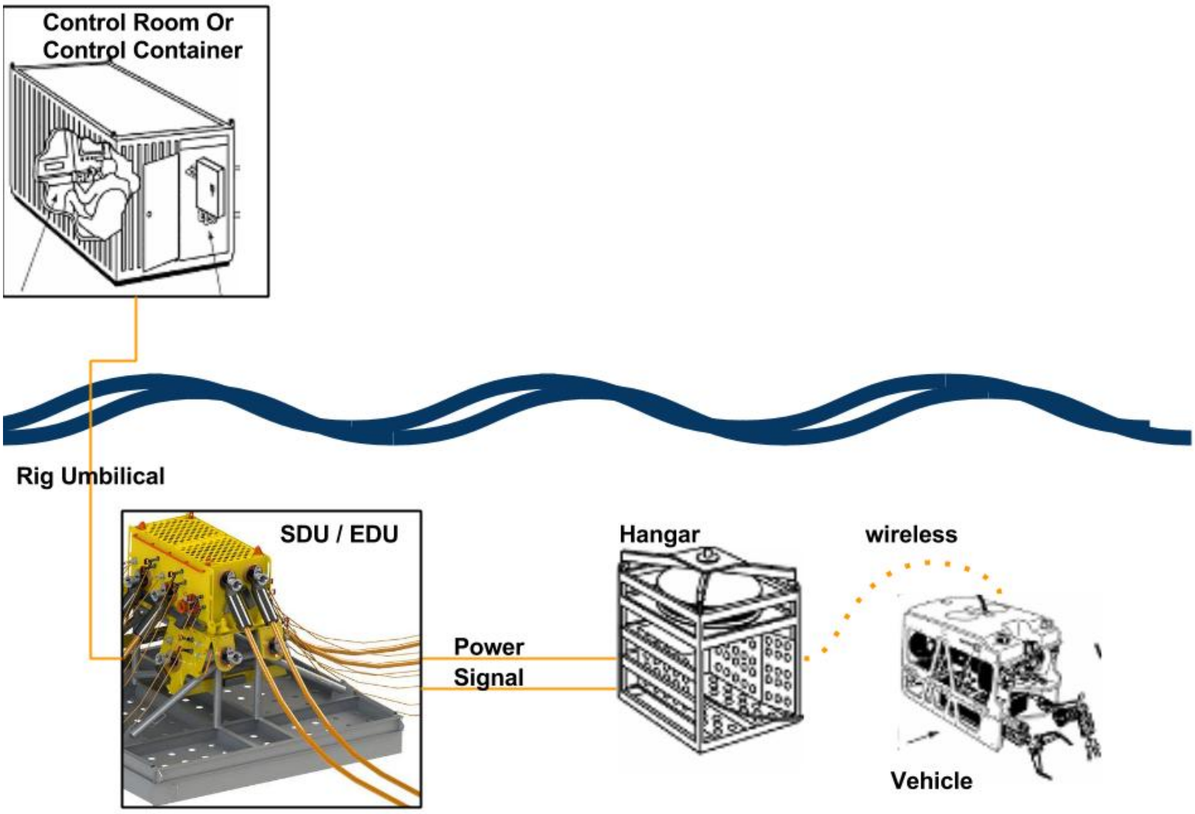

Figure 34 Base case components for the system, based on existing subsea infrastructure

The base case system in Figure 34 is based on using the existing subsea infrastructure as much as possible, and it is the preferred way of designing the system. It is the optimal design when wanting a system that will not be affected by the weather and being easy to recover.

The different ways of evaluating the components for this concept will be discussed in this chapter.

5.2.1 Vehicle

Vehicle size: Available power supply of 12,5kVAat Snorre B subsea limits the possible sizes of the vehicle a full WROV would draw a lot more power. The electrical WROV system Merlin from IKM is said to draw 250kVA (IKM Subsea, 2015). Use of WROV size cannot be done without using high voltage trough the available conductor in the rig umbilical.

Using the size of an OROV will be too small for use of tooling and manipulators. With a medium class vehicle, it will be large enough to carry manipulators and skids. The available power from subsea supply allows the standalone vehicle to have additional thruster force, power for tooling and longer step out for the tether.

Table 6 Step out for medium class – continuation from Table 1,

Vehicle Type	Forward trust	Lateral trust	Tether length	Tether diameter
Observation class	145 N	45 N	120 m	12,7 mm
Medium class	500 N	500 N	250 m	14,6 mm
Medium plus class	700 N	700 N	300 m	16 mm
Sabretooth	1000 N	900 N	-	-

The vehicle will have three main operation modes. The different modes will allow the vehicle to preform optimally for the specific work task it is given.

Tooling mode will be as an ROV with normal attached tether cable, this will allow the vehicle to operate within a step out radius of approximate 300 meter. Having continues power supply in this mode makes it perfect for tooling operations.

Inspection mode will be with optical connection trough light emitting diodes and acoustics, this reduces the tether`s reach to less than 200 meters. Running on battery supply, maneuverability from not having tethers gives it an advantage for accessing tight spaces and restricted access inspections.

Free mode will be connection trough a fiber optic tether cable. The thin cable allows great reach, much further than the required length of approximately 800s meters from the center of the subsea installations, while running on battery supply.

Table 7 Specifications for the different operation modes

Operation modes	Power transferee	Type transferee	Distance	Power depletion
Tooling mode	Through tether	optical fiber	250 meter	Unlimited
Inspection mode	Battery	optical fiber	>1000 meter	Limited
Free mode	Battery	Wireless	<200 meter	Limited

5.2.1.1 Hardware

To increase the reliability on the vehicle hardware modifications must be performed, by reducing or replacing the parts on a vehicle that have the highest frequent failure rate.

Reduction of hydraulic system: A big part of the scheduled maintenance is maintenance on the hydraulic system, filling oil, bleeding of water from the system, replacing several filters, tightening fittings, repairing flexible hoses and calibrating thruster valves. Some on these tasks are preformed on a daily basis. Hydraulic system failure is the main time consumer, this can be errors in either the electrical motor or the hydraulic pump.

By removing the hydraulic power system the traditional way of converting electrical energy to hydraulic energy is removed. Instead the electrical powered thrusters will be used for maneuvering the vehicle

Hydraulic manipulators are often the main cause of leaks due to wear and tear, the movement of the joints and hoses pulling on the fittings. Experience shows that vehicles submerged for a longer period have an increased leak and failure rate on the manipulators, this mainly due to the marine growth increasing the friction in the joints and actuators causing leak.

Pan and Tilt unit: the pan and tilt unit is normally operated through hydraulic or electric system, It is a unit that moves the cameras to be able to get different angles of view. By moving the cameras, the possibility of damaging the camera cables increases. By removing the pan and tilt unit this chance of damaging the cables is removed, and the maintenance interval reduced. This change will also narrow the field of view for the vehicle, which is a disadvantage for a submerged vehicle.

Increase of cameras: By increasing the number of cameras compared to a traditional ROV the loss of field of view from removing the pan and tilt unit can be compensated for. This also increases the redundancy for the video system by reducing the impact on the system of losing one camera. Wide view lenses may also compensate for the removal of the pan and tilt unit without increasing the amount of cameras.

Miscellaneous:

> **Flasher:** For ROVs without a tether, there is always the risk of loosing the ROV subsea. A blinking light, known as a flasher is installed on the ROV to increase recoverability. The flasher needs a continuous signal to prevent it from blinking. Disruption of this signal will initiate the flasher

5.2.1.1.1 Vehicle power supply

The vehicle must be able to complete the work tasks without running out of power, this can be during valve operation or an inspection.

High power consumption: Tooling and manipulators increases the amount of energy used. To keep the units running during the entire operation a steady and large amount of energy is required. By using batteries for tooling operations the amount or size of the batteries must be very large. The energy consumption problem can be solved by using a detachable tether. The tether will be used where it is need for high power consumption, this will normally be within the 150-meter radius of origin on seabed. By doing so the vehicle can perform the work without having to return for charging batteries. The vehicle mode used for high power consumption will be the tooling mode

Low power consumption: The battery pack is needed for the inspection or surveys that are done further than the 150-meter radius or as far as the tether allows. Disconnecting or disabling unnecessary tools and devises will conserve the batteries for the mission. Battery packs can be added on to skids and docked on to the vehicle for longer endurance so the vehicle can complete operations further away if needed. Vehicle mode used during low power consumption will be inspection or free mode.

The Sabretooth made by Saab have a battery pack of $20kWh$ it is said that the pack lasts more than 14 hours (Saab Seaeye Ltd, 2014). A medium size class vehicle is smaller and less powerful thrusters than the Sabretooth resulting in less power used. By assuming the medium class vehicle uses the same during low power consumption:

$$\frac{20kWh}{14\ h} = 1.42\ kW$$

Using similar to Reap battery pack each pack can deliver:

$$\frac{1{,}9\ kWh}{1{,}42\ kW} = 80min$$

From the wanted size of the vehicle more than three battery packs could be fitted inside it giving operation time during low power consumption of $80 \min \cdot 3\ packs = 4\ houers$

5.2.1.1.2 Skids, tooling and equipment

For each work task the vehicle needs to preform there is a set of tools and equipment needed, some of these tools cannot be fixed on the vehicle due to size, weight or high frequency of maintenance and calibration. Skids can be designed to include these tools batteries and sensors. The required tool can be fitted to the skid on the rig before it is lowered subsea where the vehicle can dock on to it.

Mini docking system: Tools will be connecting with a type of USB slot, supplying them with power and signal to operate. The tools will be held and operated by the vehicles manipulator. This can be a small enough torque tool to be ready for closing or opening a valve.

Using the wireless induction USB from (BlueLogic, 2015) shown in Figure 26 the tools can connect wirelessly, receiving both power and signals. The highest output for the wireless transferee of power is $2\ kW$, from “Table 5 Specifications for electric and hydraulic torque tool” the electric torque tool requires $1{,}54\ kW$ at full torque.

There is also an option for using the same wireless connector for charging of vehicle batteries, this will not be a time efficient charge when highest output is $2\ kW$. This connector can be used for the skids, establishing communication and power between the skid and the vehicle. An example can be a battery skid, trough this connection the vehicle can receive power from the batteries and endure longer operations.

Skid docking system: Tools may be fitted to skids that can be lowered to seabed or fixed in the garage for storage until needed. These tools are the larger or/and heavier tools that needs extra buoyancy fitted in the skid reduce their weight in water.

- Special sensor skid can be made for precise mapping, inspection of seabed, measurements of chemicals, hydrocarbons and so on
- Skid with electrical grinder
- Skid with torque tool, torque tool needs gears to increase the torque. If a high torque is required, the tool may need to be on a skid due to the weight of the gears.
- Expedition battery pack, skid with extra batteries allow the vehicle to operate further away for a longer period of time
- Manipulators can be mounted on skids, if a manipulator is normally not wanted to have on the vehicle one can be fitted when needed by docking on to the skid
- Skid for a dredger that can be operated by the vehicles manipulator

5.2.1.1.3 Buoyancy

The Buoyancy creates the uplifting force for the vehicle, it is designed by using the weight of the vehicle in water and adding the amount of buoyancy until it is neutral in the sea. The buoyancy placement is the factor when designing ROVs. Different center of buoyancy (B) have a large impact on the maneuverability of the vehicle and the possible work tasks.

Active Stability: By having a neutral center of buoyancy it will be possible of maneuver in

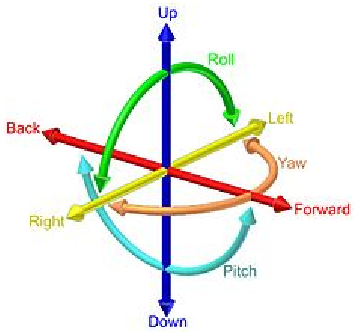

Figure 36 All 6 degrees of freedom

all 6 degrees of freedom, this lets the vehicle move in any degree and in what position it wants. For this to be as efficient as possible, the thrusters must not struggle to hold the position, this can be done by having low or none up-righting moment for the system. It is done by designing center of gravity (G) and center of buoyancy (B) to be at the same location at the ROV. This gives the vehicle the possibility of being stationary in any position it wants in all 6 degrees. Due to external forces / currents continuously acting on the ROV, the vehicle must actively compensate for these forces, which will increase the power usage..

Figure 35 Center of mass and buoyancy are in the same position the center for an active stabilized vehicle

Passive Stability: If a stable vehicle is wanted the distance between center of buoyancy and center of mass is increased, large $\overline{GB}$, this allows the vehicle to only move in 4 degrees of freedom, removing the option for controlling the pitch and roll movement. This is a necessity for vehicles that operate tooling, from the law of newton "for every action there is an equal and opposite reaction", the larger the $\overline{GB}$ the larger the up-righting moment will be, and it will be possible to lift equipment using the manipulator without the vehicle to pitch all the

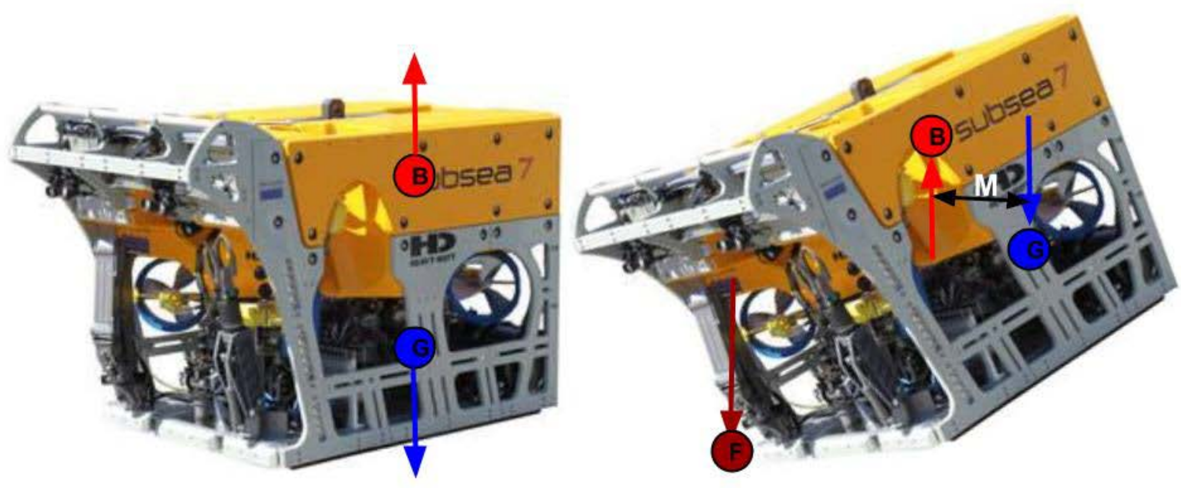

Figure 37 Work ROV`s change in stability

way down.

Figure 37 are showing that use of manipulator or adding load to the manipulator will change the position of the center of gravity and buoyancy hence creating a up-righting moment to countre the added force to the manipulator. The high stability vehicle is efficent and requierd when it comes to working with tools and manipulator. This is because if $\overline{GB} = small$ and a force or moment is added to the vehicle, it will have no up-righting moment and the vehicle will change position until the new center of mass are in a vertical line with the center of buoyancy. Unless another force, for example active thruster counters this momentum.

5.2.1.2 Communication

The three different operation modes require different ways of communicating: Both the two tether options; normal and fiber optic will have the possibility of a stable high speed and large amount of data transferee. The wireless option with optical light emitting diode and acoustics lets the vehicle be free of any tether.

Acoustics signals: Transferee communication over greater distance, this is included in the wireless option, the acoustic signals gives the vehicle commands from the operator. It is necessary to use the acoustic for this purpose since the optical light diodes will lose the communication when not in line of sight from the receiver

Optical Light Emitting Diodes: have a high bandwidth but limited distance, up to 200 meter. This allows the operator to get a video feedback even if the vehicle is wireless, this is necessary when changing between the two tether options. It also gives the option of operating vehicle wirelessly within the limited distance, giving it great advantage for inspection on restricted areas and tight spaces.

Optical communication subsea is a relative new technology; it is the preferred solution for this concept for further use and development, but needs to be proven before it can be trusted. Optical link have the highest of the wireless bandwidth.

Extra relay diode receiver and transmitters can be installed throughout the field increasing the wireless range of the vehicle. Installing relay on the BOP it can then receive video from the vehicle when it gets close. The vehicle can then follow the BOP at shallower depth down to seabed without any complications from tether.

Fiber optic tether: Tether that contains only optical fiber, no power cords. Have the highest bandwidth and the distance of the cable length. With the use of fiber cable the vehicle can be remote controlled as the operator wishes. The cable must be wheeled on a drum in the hangar; a small fiber cable can be long enough to reach the whole subsea field including the anchor while giving stable live video feedback to operator.

The drag in tethers are normally the limitation for the length, with a fiber optic cable it is approximately only 3mm in diameter, compared to the traditional tether which are normally 14,6 millimeter for the same size vehicle. (Saab Seaeye Ltd, 2014)

The optical fiber are required as a safety measure for stable communication, the operating companies will not accept the risk of new technology like the light emotion diode communication in a high-risk environment without a proper backup solution.

5.2.1.3 Vehicle software

Having an autonomous function to complete easy low risk and time demanding tasks increases the efficiency in both energy and time, this is important when if the vehicle are using batteries for power.

The high-risk operation must be done by done and supervised by humans, due to the amount of factors that needs to be taken in consideration when doing this type of operation. These tasks can be valve operation, tooling, stabbing and so on, where wrong decision can have a major effect.

Mode 1 Remote controlled: Will be manual mode where the vehicle can be operated as a normal ROV. This mode will be where there is complicated work done by the vehicle; valve operations, hot stab, and work done by manipulators. This mode requires high bandwidth and needs tether attached to the vehicle, which gives live video feedback to the operator.

Another factor for using manual mode is the trust level between operator and computer, before the system are fully tested and proven stable, there must be a possibility for fulfilling these work tasks a normal ROV.

Mode 2: Live feed position input: Hybrid mode are when the vehicle are in an auto pilot, the operator are giving inputs on where he wants the vehicle and where to look, the vehicle are using its sensors actively to verifying its position and to avoid obstacles when navigating to new positions.

This can be done by using 3D models of the subsea field, by selecting an area of interest the

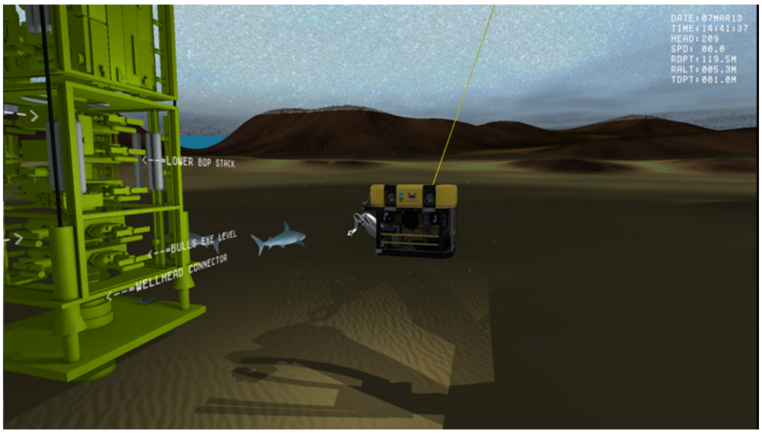

Figure 38 ROV simulator

vehicle will move there, give a view and take pictures of the specific part/item/area.

Figure 38 shows a picture from simulator training, a semi-autonomous vehicle can be operated this way by using a combination of different sensors and acoustic position feedback, an accurate position can be plotted in the 3D program which will give an overview of the ROV`s position.

As the trust, level that for the vehicle grows the operator can use this mode for Inspection and surveys to simple valve operations and stabbing jobs while being monitored by the operator, this will be a transition to the full autonomous mode

Mode 3: The Autonomic mode; The vehicle are given a work task; chosen from a set preprogrammed options of work. The vehicle the finds the location and completes the task, when returned and docked in the garage the data recorded from the task are downloaded from the vehicle to the control room where it can be analyzed.

The vehicle uses its sensors to find position, by comparing its input from the sensors with a pre-installed 3D map of the operating area and acoustic reference signals.

Low quality video feedback and acoustic position can be sent to control room, this lets the operator monitor the operation, and allowing the operator to take control of the vehicle if needed.

Programing: Using a digital existing or created 3D model of the field the preprogrammed surveillance can be seen and tested before it is implemented to the vehicle, by doing so it can be easy to choose witch parts to have a thorough inspection. Adding real time position feedback from the vehicle it can be controlled with a low bandwidth

The importance is to not delay the use and process of these type of ROV, by being able to use the vehicle in a ROV mode, the AUV and Hybrid mode can be implemented later and learn

5.2.2 Hangar

Hangar criteria's

- Housing of ROV
- Power distribution to ROV
- Launch and recovery system
- Communication with operator
- Power connection from topside
- Continues submerged for long periods
- Signal transference with ROV close, long and wireless distance communication,

5.2.2.1 Hardware

Power: The hangar must include a power distribution unit, this is where the incoming power are distributed to the different system. The two main branches are the garage power system and the vehicles power system. The different transformer located in the hangar steps up or down the current to the required voltage output. It is then distributed to the vehicle and the components in the hangar.

A socket for induction connection can be installed on the hangar; this allows the vehicle to charge the batteries without having any tether connected, or recharging of battery skid.

5.2.2.2 TMS and Communication

The vehicle rely on tether for communication and power (during high energy consumption). The TMS in the hangar are responsible for managing the tether, and must consist of two drum systems. One for the conventional tether with power and optical fiber, and one for the long and thin optical fiber tether.

With use of slip-ring free TMS the drum becomes stationary and will not rotate when paying out tether. The two stationary and rotary junction boxes and the slip-ring will be removed. This reduces the components are less faults that can happen. The slip-ring free TMS have a bit more complicated system for spooling out and in the tether, since the drum are stationary the spooling mechanism must rotate around the drum.

Continues communication with the vehicle is a necessary. An optical receiver can detect and receive the signal broadcasted from the vehicle, this way the vehicle have an established communication even when changing tether type.

5.2.2.3 Position

The garage must be positioned in a way that it will not be an obstacle for or if there will be any further subsea development at Snorre B.

Giving the garage a designated area on the seabed where it can safely be placed for the required duration. This area can include a permanent installation where the garage can land on to, to be secured against sinking inti the seabed/mud.

5.2.3 Launch and Recovery systems

Different ways to launch and recover the standalone system will we evaluated in this chapter. The different launch and recovery systems will be designed according to the hangars connection options:

- Launch and recovery of rig supplied hangar
- Launce and recovery of subsea supplied hangar

Figure 39 Location of the Rigs A-frame and winch system, Picture taken on student field trip for Statoil

5.2.3.1 Positioning of the recovery systems

Rigs outboard LARS: Recovery and launch of the standalone system can be done with use of the rigs A-frame and winch. Which will be installed on the rig for launch and recovery of subsea components. On Figure 39 the location for the recovery system can be seen, it is to be installed, the frame from old system can be seen (rusty blue frame).

Moon-pool: The rig`s moon-pool is often used for deploying subsea equipment, this is placed in the middle of the rig underneath the drilling tower.

5.2.3.2 Launch and recovery of rig supplied hangar

If using a free hanging cable connected to rig and hangar, precautions against entanglement must be taken. Moving the rig will change the distance between the rig and hangar`s subsea position, and will change the cables form and direction, increases its chances of interference with rig or subsea structures.

Free hanging cable requires a winch during launch and recovery for recovering of the free hanging cable. The cable-winch carries no load except of the cable weight and drag. This lets the cable to hang in a loop. The winch (2) for the cable (4) can then be placed in a different location from where the LARS (1) are, illustrated on Figure 40.

Figure 40 Launch of garage with use of soft cable

Figure 40 illustrates the positioning of the different launch and recovery components:

1. Rigs A-frame and winch system
2. Soft cable winch
3. Garage and vehicle system
4. Soft cable

The challenge with this type of recovering system is that it is lifted by a single wire, not having any way of withstanding the natural twists and turns in it. This can cause the power cable to entangle around the hangar and lifting wire.

Steel Armored Dynamic cable (Figure 9**)** the lifting umbilical removes the entanglement situation for the soft cable during the launch and recovery

The dynamic cable requires a larger winch (Figure 7) for lifting the standalone system. For the winch's spooling to work, the dynamic cable cannot change the angel of the force direction. To have a straight line for the winch, it needs to be placed behind the A-frame, this will restrict or tighten the access to the rigs subsea winch.

After deployment standalone system on seabed, the dynamic cable end above the hangar can experience compression forces due to the loss of hangar`s weight. The dynamic cable is designed for tensile dynamic forces, when experiencing compression the steel cords can untwist reducing the properties of the Steel dynamic cable.

Using the dynamic cable the LARS will be the same as free hanging cable Figure 40, without components 2 and 4.

With use of the rig-supplied cable the standalone system is powered and are therefore in no need support from another ROV to assist with the installation.

5.2.3.3 Launce and recovery of subsea supplied hangar

Using rigs moon pool: If launched and recovered from the rigs moon pool the launch will be the most stable and controlled, due to the use of guide wires. The guide wires are launched through tunnels on the sides of the garage, they are then lowered to the required depth where the guideposts are on the landing frame (5.2.3.4) they are then locked in the guideposts and tensioned. The wires are now acting like guides for the equipment lowered to seabed, keeping the equipment from turning or twisting during the ride down.

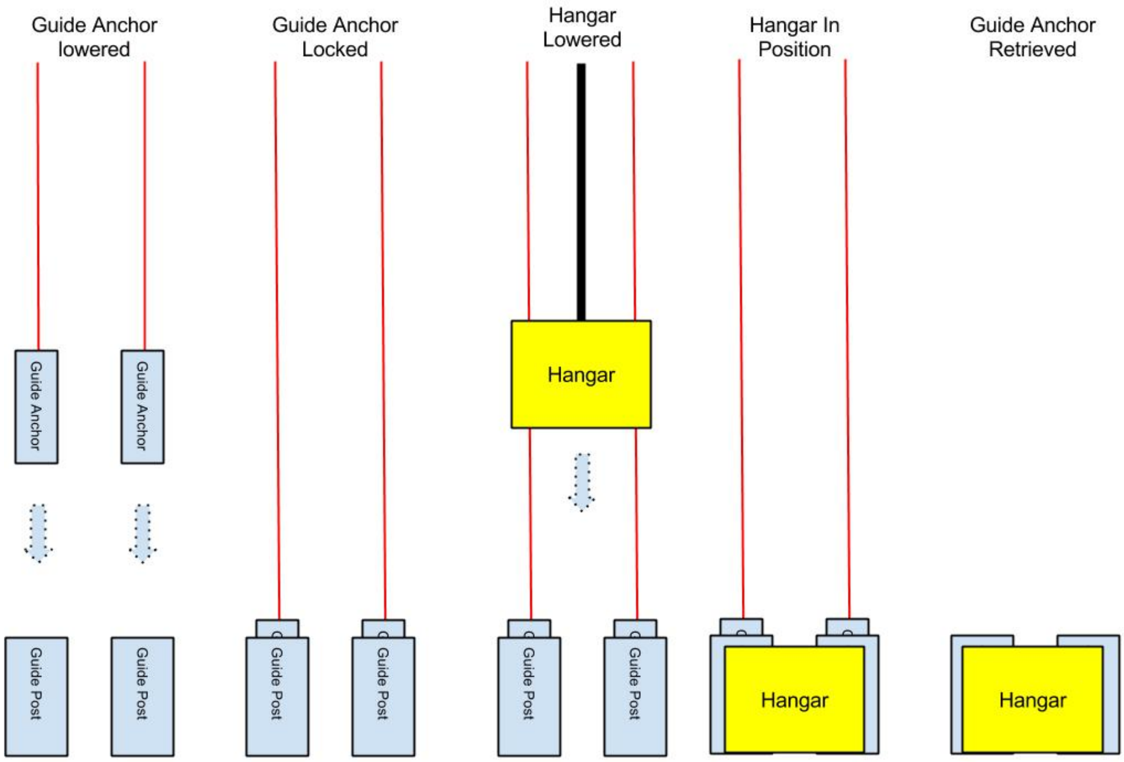

Figure 41 Five steps of launching hangar with use of guide wires (Made by Student)

Due to the high activity in the moon-pool on the rig, any permanent solutions with cables to hangar are not possible. This is because of the chance of snagging on other equipment or interfering with the work that is done there.

For a subsea hangar that uses signal/power supplied from the existing subsea infrastructure and are not connected to an cable from the rig a launch from the moon-pool will be a usable option. The guide wires will ensure that the hangar is placed in the right direction, and guaranty that it land directly inside of the guide posts.

The maneuverability of a detached hangar on the rig gives the option of launching it from many different locations, the parts required are a winch with subsea capabilities.

Table 8 LARS options summary

Cable connection	Constant signal/Power during launch	Weather independent	Mobility on rig	installation support ROV
Rig connected	Yes	No	Low	Not required
Subsea connected	No	Yes	High	Required

5.2.3.4 Landing frame

A landing frame with guideposts will secure the position of the garage. The guideposts there is a possibility of using guide wires when launching the garage through the moon pool on the rig to ensure a safe deployment and the right position.

The landing frame can hold the end of the subsea pre-installed cables in a dummy slot, ready to be connected to the hangar when it is landed on to the frame.

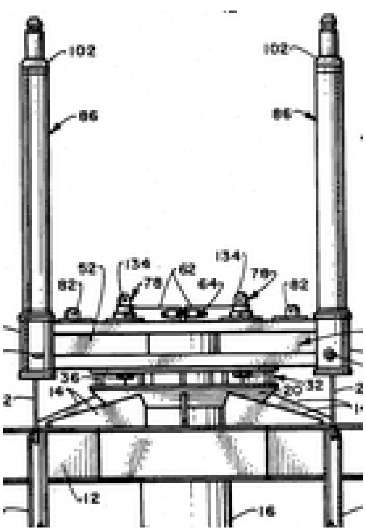

Figure 42Illustration of a well frame with guide poles. Guide anchors are locked inside the top the poles (Vetco Offshore Industries, Inc, 1986)

The landing frame is preferred to be an existing structure at seabed. If there is an abandoned well the well frame could easily be used for this purpose. Landing the hangar on the frame and stabilized by the guide poles.

A new frame can also be installed, this frame must be properly secured to seabed and prevent from sinking in, this can be done by whit the use of a small suction anchor the underneath the frame.

The landing frame includes:

- Frame
- Guide posts
- Open dummy slot for the power cable
- Open dummy slot for the fiber cable

5.2.4 Power and control supply to the submerged system

There are different ways of providing power and signal to hangar and vehicle, different concepts will be looked in to for supplying the subsea hangar with both power and data transferee. The supply to the system must have ha high bandwidth for transferring high amount of data, and large enough source for powering the vehicle and charging batteries

5.2.4.1 Supply options

There are different ways of supplying the hangar with power and signal in this chapter the different possibilities will be evaluated.

To be able to design the cable, umbilical or know if available supply at subsea can be used the power consumption of the system must be accounted for. Assuming that the vehicle will draw one third more than the medium class Omni Maxx $\frac{4}{3} \cdot 8\ kW = 10{,}67\ kW$

Assuming the standalone system then uses $11kVA$

New subsea rig umbilical: A new umbilical can provide the system with power and signal, a hub will be there to distribute the signal and power trough universal connection points.

For installing a new rig umbilical the decision must be made to expand the field, only then there will be need for more power and communication in a large enough scale for it to justify the cost of installing a new umbilical. If the expansion of the field is decided, there should be planned for connection point for the garage and vehicle in this planning face.

This type of solution are the preferred, it will remove the chance of damage cables and possibility of cable snagging on other equipment during harsh weather when the hive and current are high, and during retrieving and deploying of subsea equipment. It will also give a more stable and permanent solution for the submerged vehicle system.

This option is not be used due to the extreme cost.

Installing a free hanging cable: Using a free hanging cable from the rig to the seabed will give the possibility of retrieving the cable using a winch. This option increases the maintainability for the system by making it easier to retrieve the garage and vehicle. A winch will have to be added for this to be an option.

By using a new cable from the rig to seabed, it must be properly fastened in a way that it does not intervene with other equipment. If the cable are not secured it can be caught on other equipment and experience forces that it is not designed for, this can for instance be; lowering or hoisting equipment like BOP or other equipment moving to or from subsea. If there is a large current or the rig are moving in to a drilling position there is scenario`s where the cable can hook on to parts on the BOP.

> **Simple cable:** If there were an option of receiving power or signal from a subsea cable, it would be enough with installing a cable for supplying the rest of what the hangar and vehicle needs with a cable from the rig. This will reduce the cost when a simpler cable can be used instead of a complex; containing both power and signal.
>
> This option require a ROV to install the system every time it is recovered or deployed since the vehicle lacks either power or signal
>
> **Retrievable power and signal cable:** Using a cable that includes both power and signal simplifies the installation and removes the necessity of having an ROV during the launch and recovery of the garage. The winch and the same system for launch and recovery are there, the cost will not be a lot more than for a single fiber or single power cable, most or the only difference in cost will be the cable. This can for example be a tether cable from Figure 6 Nexans tether
>
> **Steel armored Retrievable power and signal cable for lifting:** Same as the relivable power and signal cable, but on this option there will be no need for lifting equipment. The weight of the garage and vehicle will be carried by the armored cable and the winch. This increases the size and power needed for the winch, and will be more expensive than the other options for free hanging cables. This can for example be a Figure 9 Steel armored dynamic cable

Using existing subsea supply: Spare power outlet at an EDU is available for use, extension cable from the SDU can be connected to the garage and supplying it with power. This existing infrastructure is limited to 25 ampere due to overheating in cable. The supplying voltage is 500 volt, which will give an total power of $12{,}5\ kVA$

Since the vehicle are assumed to use up to 11 kVA the existing power available are believed to be enough for supplying the vehicle and hangar.

If more than 12,5 kVA are needed the power can be increased trough the cable by Increasing the voltage supplied in cable the power also increases, while still using 25 amp limitation

Since the ampere (I) are the limitation and are not changeable, the power (P) will change according to the voltage (U)

By definition from IEC, (International Electronica Commission , 1983) voltage above 1000V is high voltage, and therefore must follow rules and regulations for high voltage. When increasing voltage for the supplying system it should not be larger than 1000Voltage. By choosing 900volt for the supply, the laws and regulations for low voltage can still be used and the power supplied can then be:

$$990volt \cdot 25amp$$

$$24{,}75\ kVA$$

By only increasing the voltage there is a possible of supplying ha much higher electrical power to subsea, almost 20kW can be supplied without using high voltage.

Piggyback: Using the stability of existing cable or structure a new cable can be piggy backed to the existing one. This means that the new cable are stropped or clamped on to an existing cable or structure, this reduces the chance of entanglement for the new cable. It is a permanent solution, by using piggyback the cable cannot be retrieved when recovering the garage and vehicle. This gives that the cable must be reconnected to the garage every time it is deployed at subsea.

5.2.4.2 Simulation of cable options

From DNV recommended practice (DNV, 2014) it is recommended to use Figure 43

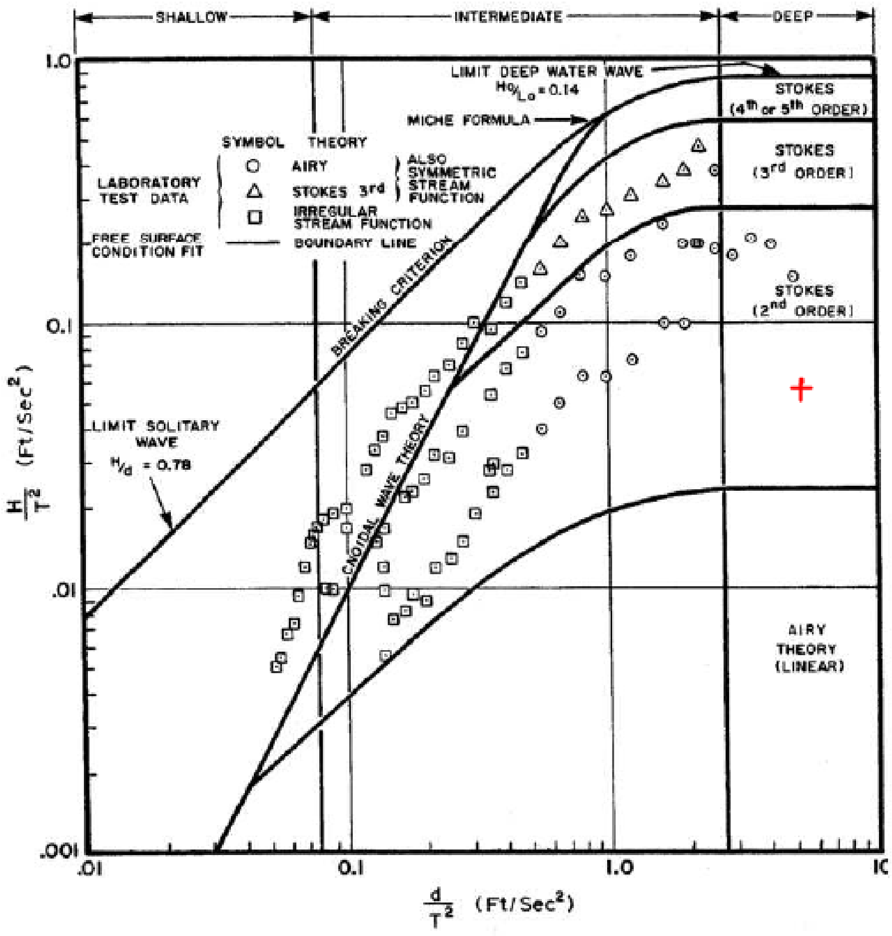

Figure 43 Ranges of validity for various wave theories (DNV, 2014)

establishing the fitting theory for the specific type of waves.

H = wave height

T = wave period

d = water depth

The recommended of wave theory from Figure 43 DNV to use for calculations is to use Stokes 2enorder for the for the 10 year situation. Using Orcaflex as the simulation program it does not support Stokes 2en or 3en order, the closest to DNV`s recommendation on Orcaflex are Airy`s linear theory

5.2.4.2.1 Environmental

The environmental loads used for calculations will be taken from the extreme state for significant wave height Hs 1, 10 and 100 year. Environmental factors will be checked by manual calculations the results for combined current and wave velocity witch have a large influence on the cable loading and subsea motion.

Choosing the environmental design constants

Table 9 Extreme sea state from (Mathiesen Martin, Eik, & Nygaard , 2007)

Direction (°)	Sector Probability (%)	Return period (year)					
		1		10		100	
		Hs	T_p	Hs	T_p	Hs	T_p
345-15	14.1	8.2	12.8	10.7	14.0	13.1	15.2
15-45	8.3	6.9	12.1	8.9	13.1	10.7	14.0
45-75	0.9	3.2	10.0	4.2	10.6	5.0	11.0
75-105	0.5	2.9	9.8	3.9	10.4	4.6	10.8
105-135	0.7	3.7	10.3	4.9	11.0	5.8	11.5
135-165	8	10.0	13.7	12.4	14.8	14.5	15.8
165-195	15.5	11.0	14.2	13.0	15.1	14.9	16.0
195-225	9.4	8.8	13.1	10.8	14.1	12.6	14.9
225-255	10	8.8	13.1	10.8	14.1	12.6	14.9
255-285	11.6	8.2	12.8	10.7	14.0	13.2	15.2
285-315	9.3	8.1	12.7	10.4	13.9	12.6	14.9
315-345	11.6	8.0	12.7	10.2	13.8	12.3	14.8

From Table 10 the wanted situation can be gathered for input in simulation of behavior for the cable. Where the Hs = Using the Omni directional for every situation the highest significant wave height are found disregarding the different directions. In this case, the highest values are the same direction 165-195 degrees.

1 year return period													
Depth (m)	**0°**	**30°**	**60°**	**90°**	**120°**	**150°**	**180°**	**210°**	**240°**	**270°**	**300°**	**330°**	**Omni**
Surface	98	98	89	85	80	83	83	75	86	120	120	120	120
50	105	105	79	85	91	96	87	91	74	74	86	84	105
100	85	61	52	65	74	77	85	72	53	53	45	61	85
200	56	58	43	54	71	80	68	61	48	40	51	47	80
3 m above seabed	35	35	30	36	48	48	48	35	30	25	29	31	48
10 years return period													
Depth (m)	**0°**	**30°**	**60°**	**90°**	**120°**	**150°**	**180°**	**210°**	**240°**	**270°**	**300°**	**330°**	**Omni**
Surface	117	115	105	98	89	94	97	89	103	130	130	130	130
50	115	115	93	98	101	107	99	109	90	92	104	101	115
100	100	74	60	76	82	85	100	87	68	66	53	73	100
200	66	70	50	61	79	85	77	72	58	47	60	54	85
3 m above seabed	41	40	33	39	53	53	53	40	36	29	33	36	53
100 years return period													
Depth (m)	**0°**	**30°**	**60°**	**90°**	**120°**	**150°**	**180°**	**210°**	**240°**	**270°**	**300°**	**330°**	**Omni**
Surface	134	131	119	109	98	104	109	103	119	140	140	140	140
50	125	125	105	110	111	117	110	126	106	109	120	116	125
100	110	87	68	85	89	93	110	101	81	78	59	85	110
200	75	82	55	68	87	90	86	82	68	54	68	60	90
3 m above seabed	45	45	36	42	58	58	58	45	40	32	36	41	58
Directional distribution of current speed (%)													
Percentage in sector at surface	6.9	9.6	11.3	16.1	15.8	10.4	6.8	3.4	3.5	5.5	5.4	5.2	100
Percentage in sector at 50 m	3.9	3.5	5.6	10.5	22	25.2	11.9	5.1	2.8	2.2	3.2	3.9	100
Percentage in sector at 100 m	4.1	3.5	5.2	9.4	22.3	27.4	11.6	4.7	2.5	2.1	3.3	3.9	100
Percentage in sector at 200 m	4.0	3.9	5.6	8.6	22.1	27.3	13.0	4.7	2.2	2.1	2.7	3.7	100
Percentage in sector 3 m above seabed	4.5	5.6	8.0	15.4	28.0	17.4	7.8	3.5	2.2	1.6	2.7	3.2	100

Comparing environmental factors: The data from the environmental design basis (Mathiesen Martin, Eik, & Nygaard , 2007) are implemented in to Orcaflex. In the environmental menu, the input for wave and current can be done according to the environmental data.

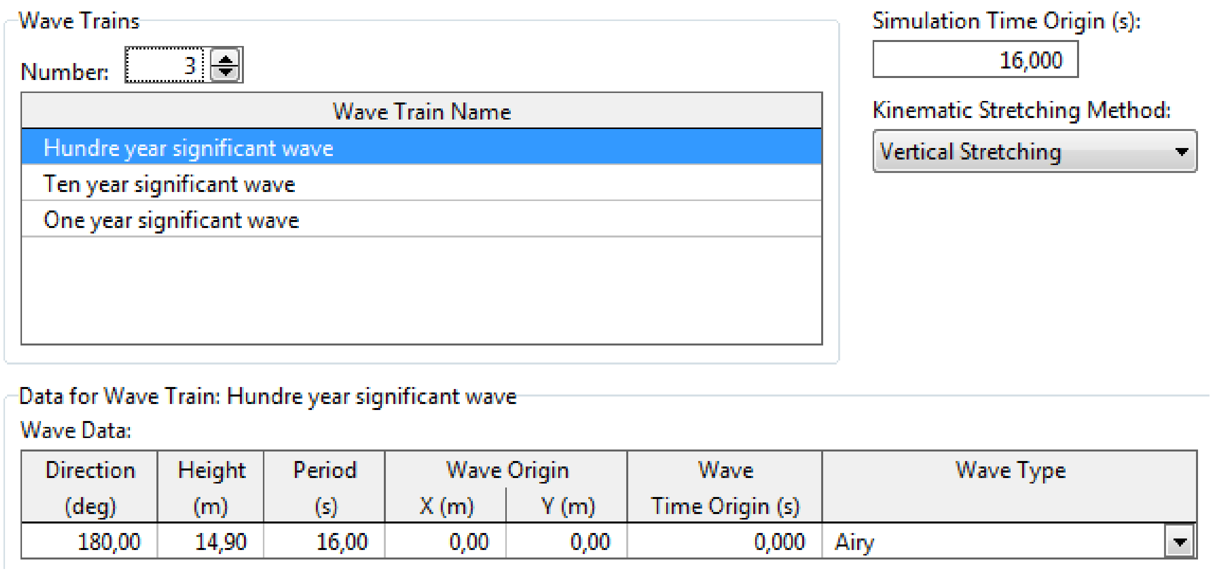

Figure 44 Wave data Used for simulating the 100-year significant situation

The different waves are set up in the wave options, direction height and wave period are the essential data. The wave type describes the shape of the wave, Airy`s linear theory describes the wave shapes as sinusoidal shaped waves.

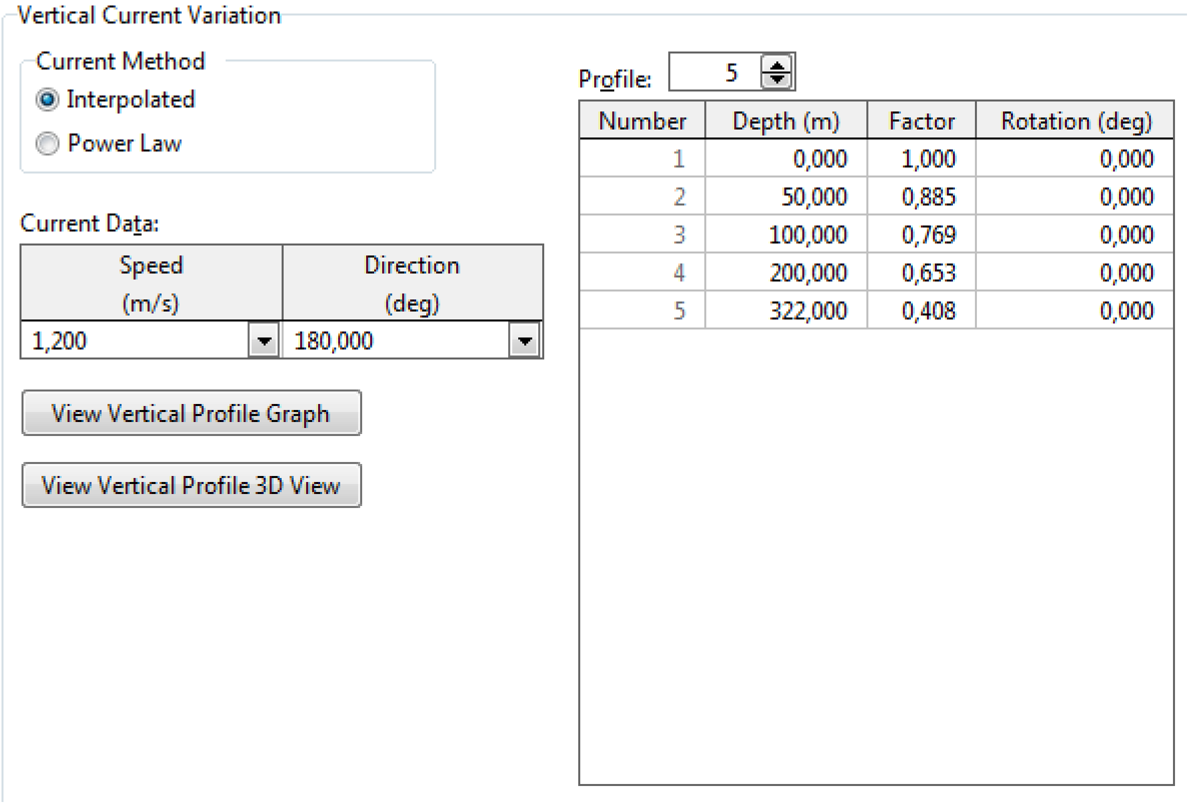

Figure 45 Current data used for simulating 100-year significant situation.

For the current inputs in Figure 45 the program allows you to define a current profile, by adding different sections with a reduction factor for each section the desired profile are created. To create the current profile from the design premises (Mathiesen Martin, Eik, &

Nygaard , 2007) 5 steps was needed with different reduction factors. The current profile can be viewed in Figure 47 Velocity for the current profile for water depth.

Particle velocity: The current will have a large effect, when the wave particle velocity decreases rapidly with the water depth, the reduction of the current have more linear decrees. From (Gudmestad, 2014) the particle velocity of a wave can be described by:

Airy linear theory:

$$u = \frac{\xi_0 k g}{\omega} \cdot \frac{\cosh\big(k(z+d)\big)}{\cosh(kd)} \cdot \sin(\omega t - kx)$$

For the deep-water $\frac{\cosh\big(k(z+d)\big)}{\cosh(kd)} = e^{kz}$

Airy linear theory for deep-water wave:

$$u = \frac{(\xi_0 \cdot k \cdot g)}{\omega} e^{kz} \cdot \sin(\omega t \cdot kx)$$

To use this formula it must fulfill the requirement of a deep-water wave which mean that the wavelength can maximum be double the depth of the sea before the formula for deep-water cannot be used. The different sea states are classified:

$$Shallow < Intermediate < Deepwater$$

$$\frac{1}{20} < \frac{d}{L} < \frac{1}{2}$$

From the linear theory the wave must follow a sinus curve, this means that the wavelength only depends on the wave period.

$$L = g \cdot \frac{T^2}{2\pi}$$

The depth on Snorre B is approximate 325 meter, since the wavelength cannot be larger than two times the depth $L < 2 \cdot D$

$$L < 670 meter$$

The maximum period can be found by arraigning the formula for wavelength:

$$T = \sqrt{\frac{L \cdot 2\pi}{g}}$$

$$T = 20{,}7sec$$

This means that the deep-water approximation cannot be used of the wave period exceeds 20,7 seconds at this depth.

From Table 10 Extreme sea state from the wave period can be found. Highest period is the 100-year situation with period of $P = 16{,}0$ seconds. For all the situations, the wave period can be classified as deep-water waves.

When using Airy`s formula for deep-water the wave particle velocity can be plotted, in excel a graph with respect to Velocity/depth. Given that the position of the wave are at the start $x = 0$, and the time of the wave are at the start $t = 1$, which will give the highest horizontal velocity at the crest of the wave.

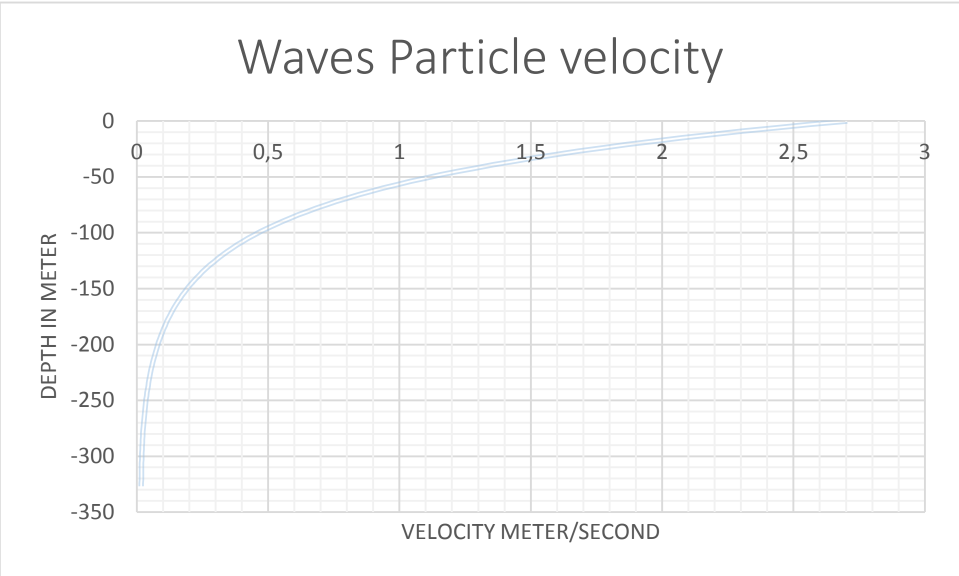

Figure 46 Velocity profile from 0 meter to -325 meters, for an significant 10 year situation wave with wave period of 15,1 second

From Figure 46 Velocity profile the particle velocity contribution from the waves is plotted, it is clear that the contribution from waves after half the depth 150 meter can be neglected compared to the current velocity. This gives that most of the force from the waves are created at the top.

Current: Plotting the current profile from the given data in Table 11 the design premises for Snorre B

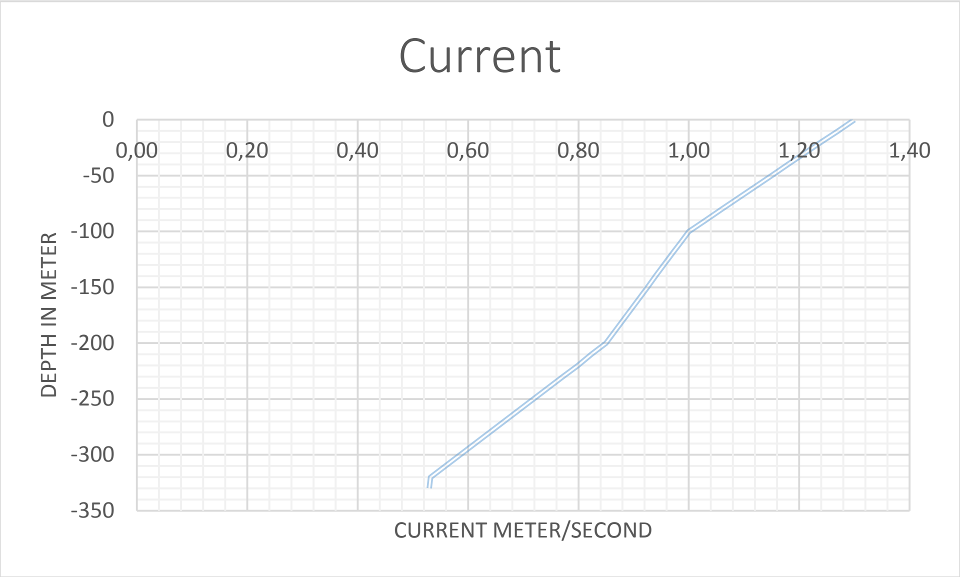

Figure 47 Velocity for the current profile for water depth, using ten year situation

It can be seen that the velocity for the current a linear function depth change, compared to the higher order function of the particle velocity of the wave

Total Velocity:

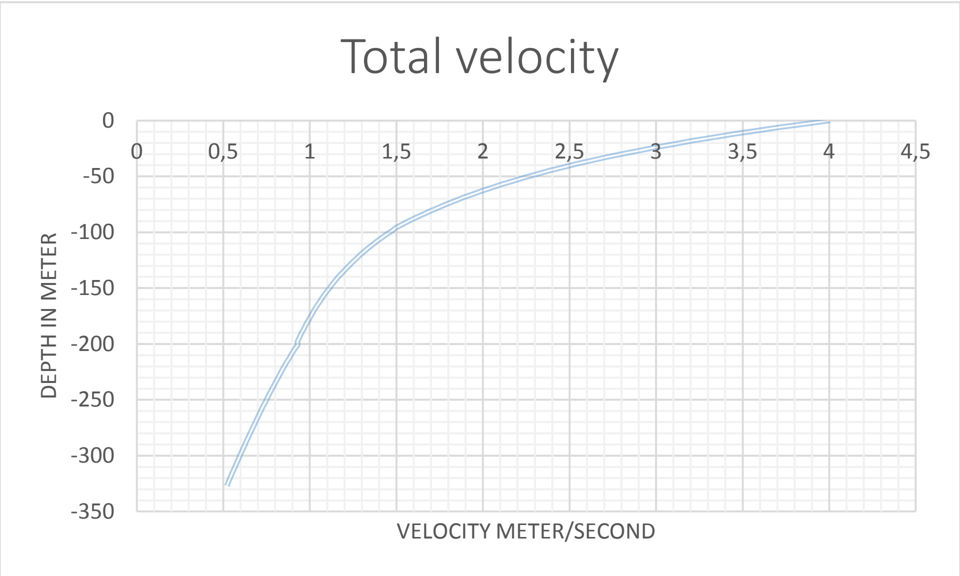

Figure 48 Total velocity from wave particle and current together

Environmental comparison for Orcaflex and Excel calculations: The difference between the velocity results will show if Orcaflex is using the theory the program was set to use. If the result from Orcaflex has a large deviation from the excel results further investigations must be done to approve the Orcaflex method.

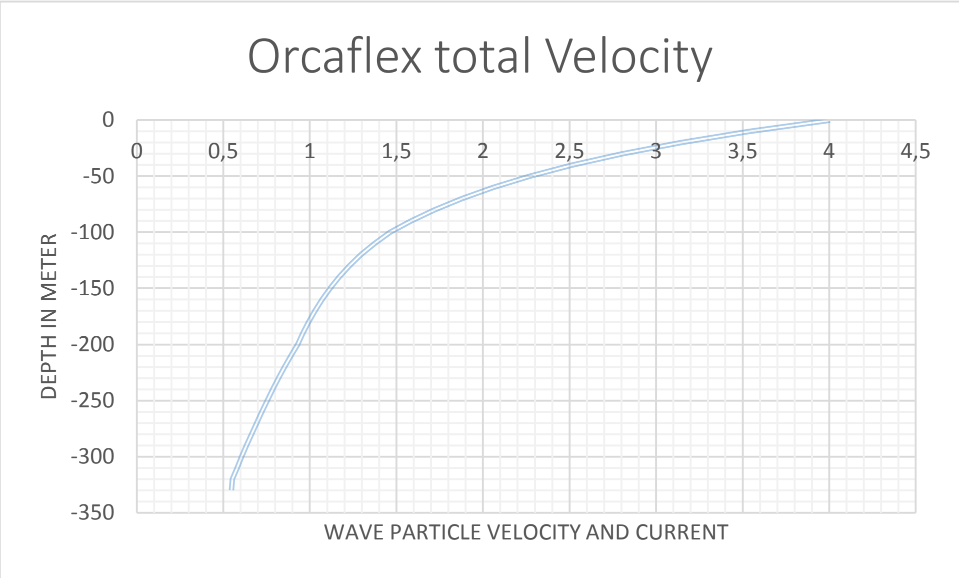

Figure 49 Velocity profile taken from Orcaflex simulations

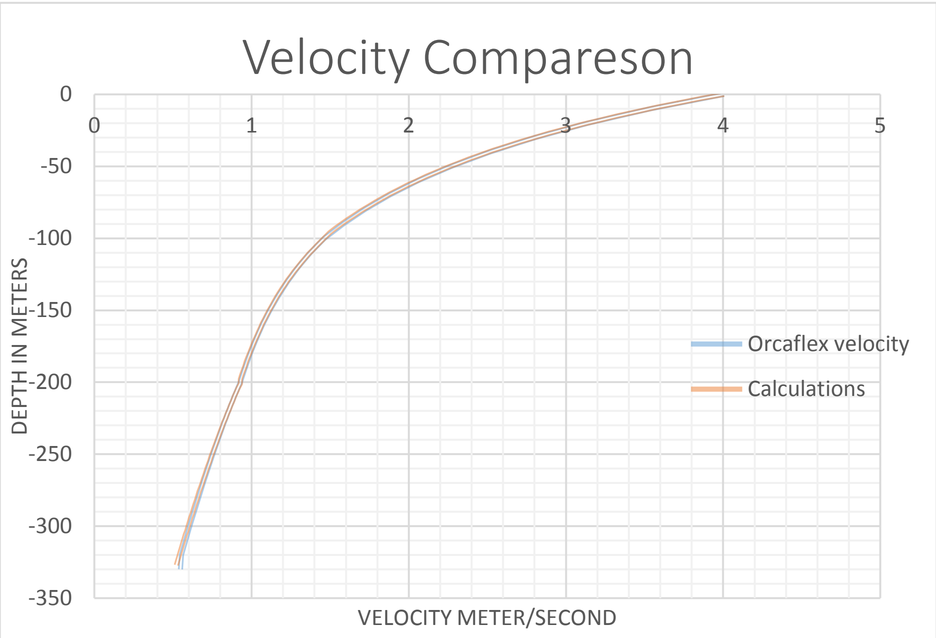

Figure 50 Comparison of Orcaflex velocity profile and profile calculated in Excel

When combining Figure 48 and Figure 49 it shows that there are no deviation between the manual calculated profile and the profile from Orcaflex. This is only done to check with the

10 yeas situation, the good result gives no reason to test with the other situations. This gives good reason for trusting the program.

Table 11 Environmental data to be put in to the simulation program Orcaflex

Situation	**Significant wave**	**Wave period**	**Current 0 meter**	**Current - 322meter**
1 year	11 m	14,2s	1,20 m/s	0,48 m/s
10 year	13m	15,1s	1,30 m/s	0,53 m/s
100 year	14,9m	16s	1,40 m/s	0,58 m/s

5.2.4.2.2 Design and calculation for free hanging cable

Nexans tether for an ROV will be used for this free hanging simulation (Nexans, 2015), this for the flexibility to have on a winch, the cable strength fiber, high voltage and fiber optics

From own calculations, finding the total force acting on to the cable: the cable has a weight of 40 gram/meter when submerged, by removing the uplift from seawater the weight in air is calculated to be$1{,}3315\ kg/m$.

The maximum workload in tensile force is$18\ kN$, which means that during work this is the tensile load should be lower than this. The ultimate strength is$130\ kN$.

Static calculation of cable

The total length 0f the cable will be 400 meter

Weight above sea level:

$$F_{suface} = 14m \cdot 1{,}3315\ kg/m \cdot 9{,}81 m/s^2$$

$$F_{surface} = 182{,}9\ N$$

Subsea weight: From Nexans the submerged weight for the tether cable is 50 gram/meter, this makes the tether slightly heavier than seawater and the combined force from total submerged cable length will then be.

$$F_{subsea} = 386m \cdot 0{,}04 \frac{kg}{m} \cdot 9{,}81 \frac{m}{s^2}$$

$$F_{subsea} = 151{,}50\ N$$

Total Static force for weight from umbilical:

$$F_{total} = 334{,}4\ N$$

Comparing the static calculation with Orcaflex static result:

Static calculation	334,4 N
Orcaflex static result	301,6 N

Simulation and analysis

Table 12 Result from the simulation in maximum tension for free hanging cable

Description	One year	Ten years	Hundred years
Current	1,20	1,30	1,40
Wave height	11,00	13,00	14,90
wave period	14,20	15,10	16,00
Static Load	0,30	0,30	0,30
Dynamic load	0,36	6,35	13,21

The result from the simulations for the one, ten and hundred year situation can be viewed in Table 12. The static loads are the same for all situation due to the waves and current have no effect during static analysis in Orcaflex. The forces acting on the cable are within the workload for the cable, thus the cable are strong enough.

Next step will be the check the positioning of cable.

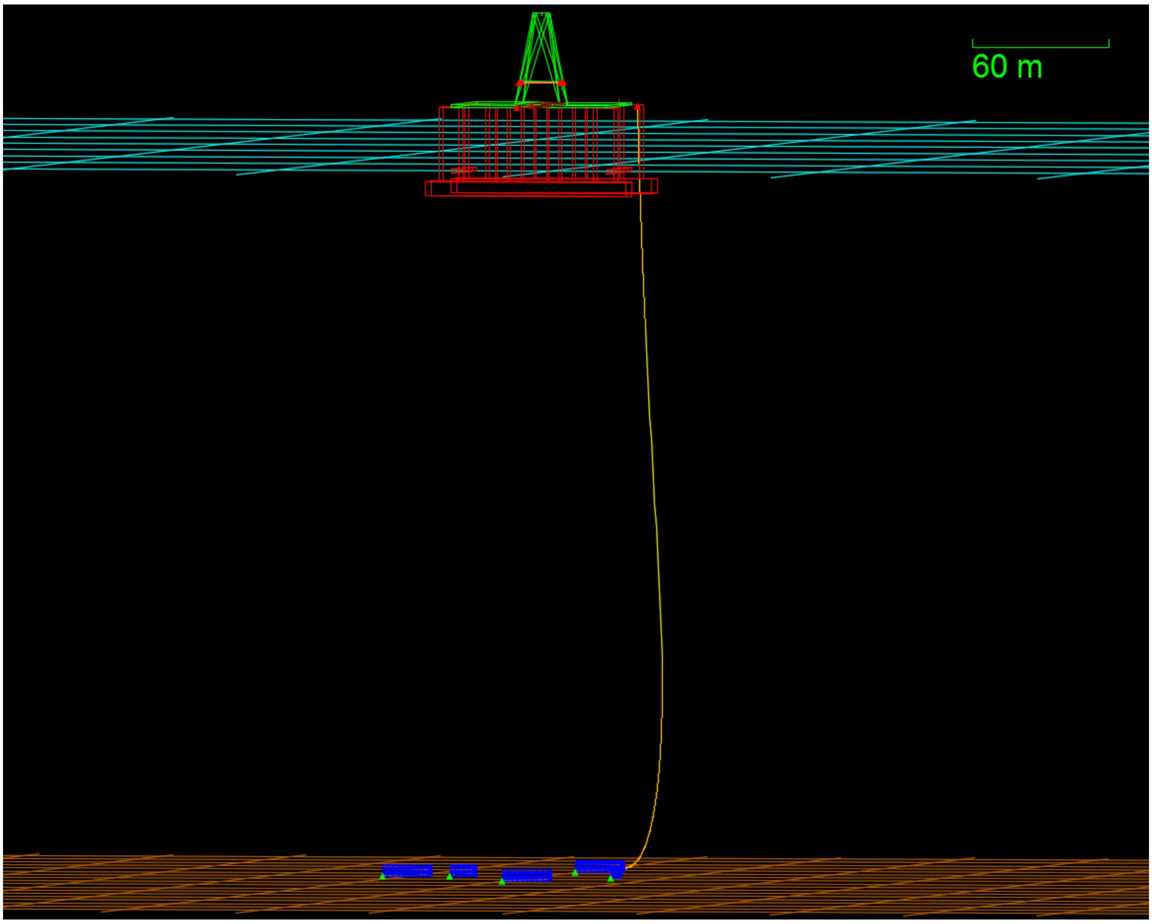

Figure 51 Static analysis of the cable, showing the yellow cable`s position. Blue boxes placed on seabed to simulate the templates and hangar.

The static position of the cable can be viewed in Figure 51, by adding the wave and current the position for the cable will change its position.

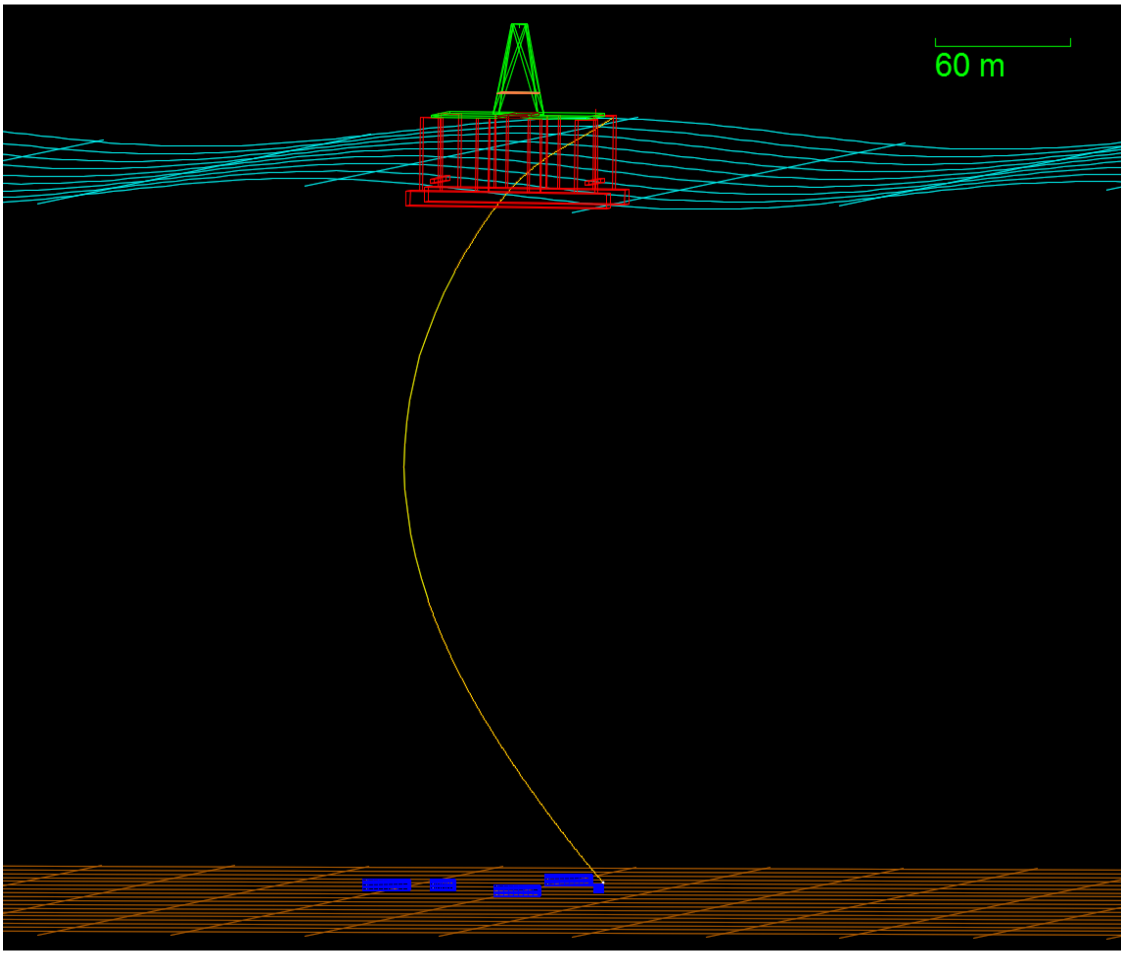

Figure 52 Dynamic simulation of free hanging cable showing the position of the cable in a ten yeas situation.

With current and wave force the profile of the free hanging cable will change, for a blow on situation the drag force will pull it under the rig creating complications if subsea equipment are lowered or hoisted.

5.2.5 Electrical Power layout

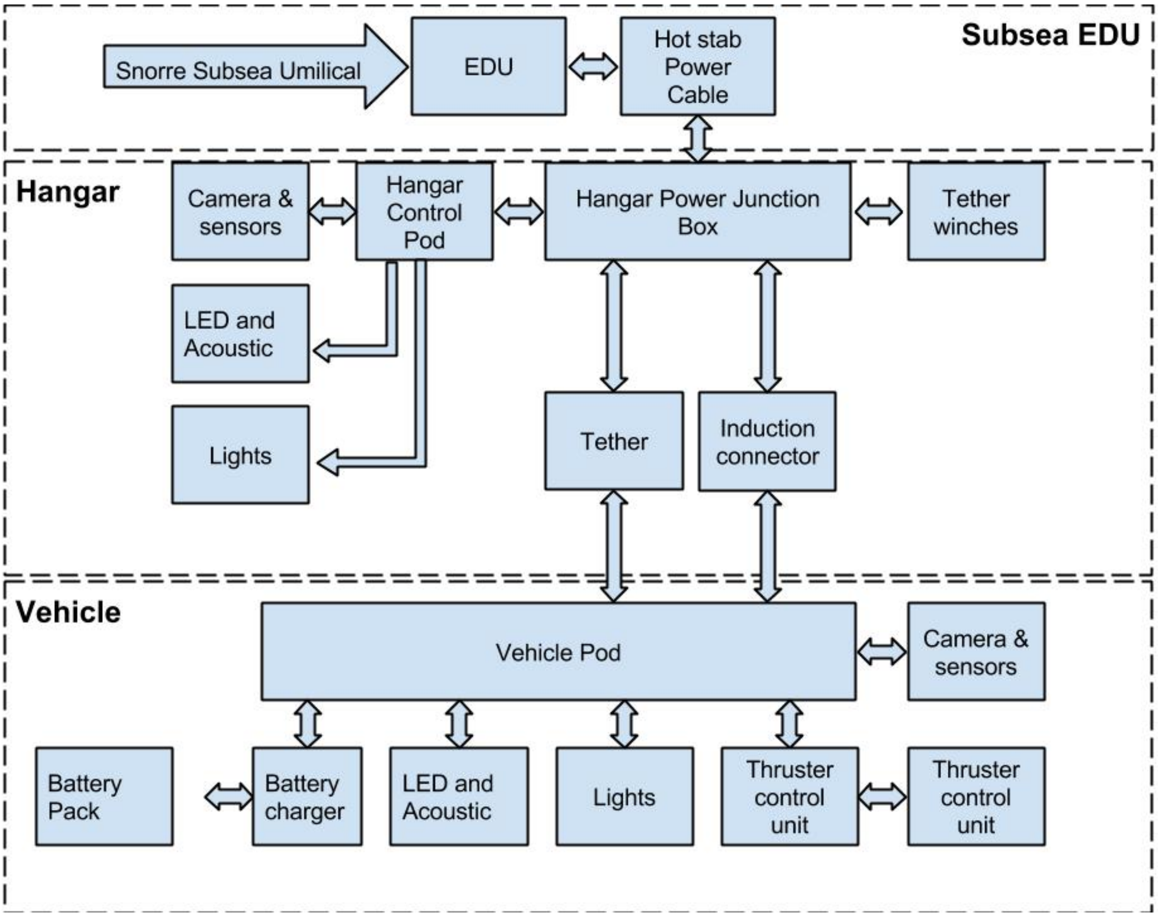

Figure 53 Electrical power block diagram(Made by Student)

Figure 53 Electrical power block diagram shows how the power is distributed throughout the main systems.

The Subsea EDU: The EDU is the Electric Distribution Unit; its task is to distribute electrical power supplied from the rig through the subsea umbilical. From the EDU a subsea cable will connect the EDU to the Hangar this will supply the system with electrical power

The hangar`s power junction box unit (HJB) is powered by EDU through an subsea cable with hot stab connector. The HJB then distributes power to all the components in the hangar supplying them with the correct type of voltage that are alternated with a transformer located inside the HJB.

The power for the vehicle is stepped up to the required voltage in the HJB with the use of transformer before it is sent through the tether and arrives to the vehicle PDU

The Vehicle: the power is again transformed to different size of voltage for the different requirements of power. The PDU also powers the battery charger for recharging the batteries. When vehicle are running on batteries the power changes direction Then the batteries powers the PDU

5.2.6 Communication Layout

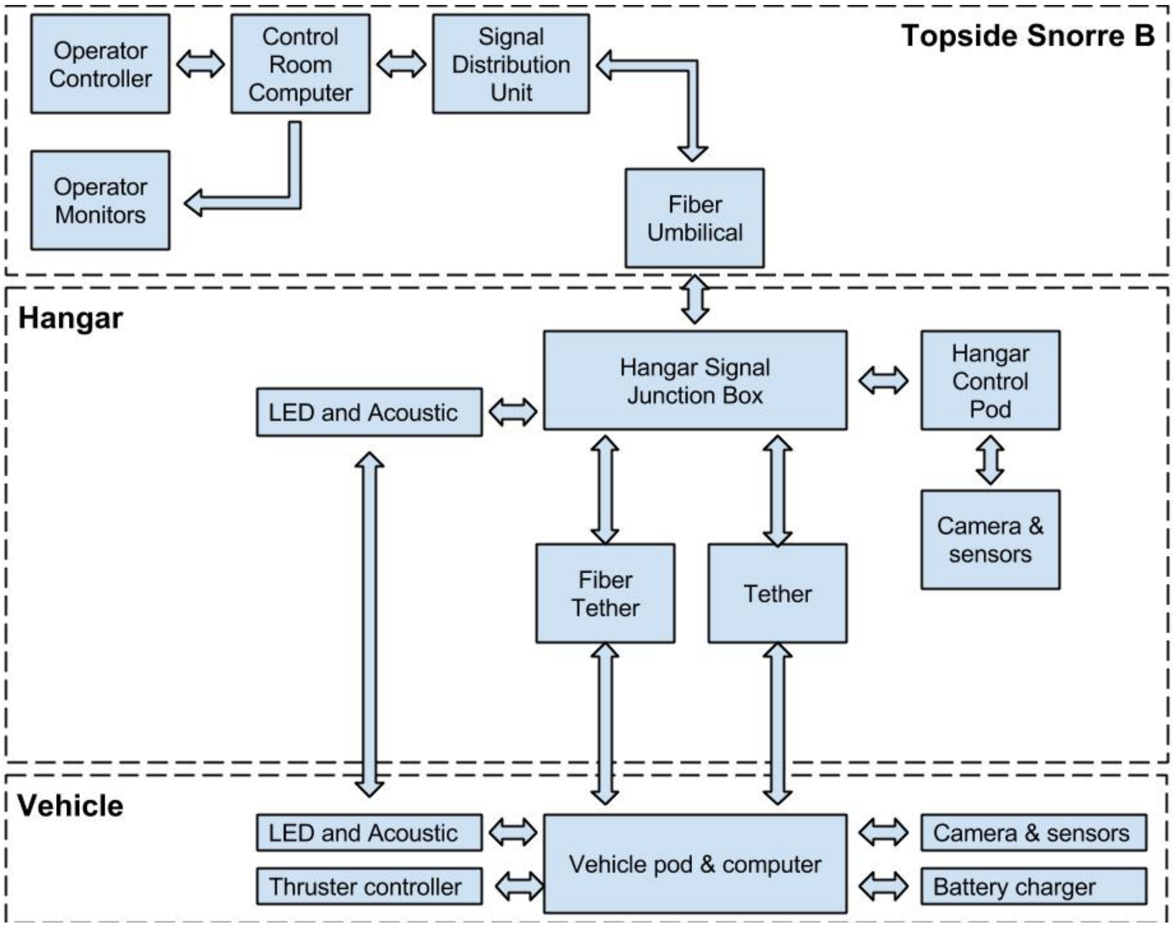

Figure 54 Systems signal block diagram, for the standalone system(Made by Student)

Topside Snorre B Control room: The signals to vehicle and hangar starts at the control room computer. In the signal distribution unit it is converted for optical fiber which allows it to travel great distance with low loss, it is then sent down the fiber umbilical traveling from the rig to the seabed where it ends up going to a subsea connector in the Hangar Signal Junction Box (HSJB)

Hangar: Signals traveling to the hangar is in the HSJB converted from fiber optic signals to electrical signals before continuing to the control pod, this pod receives the signal and transmits back from the sensors.

Signals to the vehicle remains as signals for optical fiber and passes through the HSJB continuing through both of the tethers. Commands to the vehicle is also going in to the acoustic unit allowing it to send wireless commands over a great distance and without line of sight. The LED unit also the vehicle to work wireless, this is over a shorter distance, and are only used for receiving video and larger amount of data from the vehicle.

Vehicle: Fiber optic signals received from tether or from fiber tether is the same signal, the signal in the fiber tether is a duplicated signal of the tether signal sent on a separate fiber cords, and this is so that only one of them is needs to establish connection between the control room and vehicle. Signals from thruster controller, Cameras, sensors and battery info are processed in the vehicle computer before the information are sent back through the established communication route witch can be either Fiber Tether, Tether or Wireless LED and acoustic.

5.3 Limitations

Battery technology for charging at subsea is a new concept not much developed a not in use yet. Batteries used for vehicles with tooling are relative new to the marked and need to be tested to see how fast tooling drains the batteries. Weight size and duration of the batteries will have a large impact on the vehicles operational specifications. Autonomous or planned rout can make the battery last longer, Human operator will thrust and over compensate, which will drain the batteries much quicker.

Manipulator The strength of the electrical manipulator are low compared to the hydraulic once, this can be a problem when trying to lift heavier equipment.

Detachable tether is a new concept and needs to be developed and tested before it can be used. Doing so will have great potential for the remote vehicle industry.

Keeping connector clean when the hangar is not connected can be problematic.

Lack of information: Due to the strict rules in Statoil for sharing information and drawing, the amount of assumptions where greatly increased. This can have a negative effect on the results.

6 Evaluation and Selection of System

To meet the objectives for this continues submerged system, we must be willing to change or remove the parts that work for a conventional ROV system.

This concept will be able to perform some of the work tasks done by WROV on Snorre B. This does not mean that it will replace the large work ROV. There will always be need for the WROV to do the heavy operations, but standalone system must have some of the capabilities the WROV. During periods when the weather limits are too high for launching an ROV the standalone system is already in position, this gives a low reaction time and increased safety if anything should happen.

6.1 Steps

There should not be any large quantum leaps during the design of the system. All the new technology must be tested and proven stable before use in the field. This is the reason why tethers are still being used and we do not rely on battery technology. Previous experience has shown that natural steps are still needed to get the experience of what will work and what will not work, too a large step and this experience will be lost.

The field operators are not ready for full autonomous work vehicle; it needs to be a gradual transference from a traditional system implementing new technology bit by bit from a ROV to an AUV.

The correct step would not to remove the operator but to relocate him, by using standalone system the need for maintenance done on vehicle offshore will reduce. This reduces the need for having an operator on the rig. With the expansion and development and increase of the optical fiber network and in the mobile network (4G) can give the option for the operator be on shore while controlling the standalone system

6.2 Hangar

The system is designed to be as flexible as possible, using the same wet mate connector as the subsea structures allows the standalone system to be disconnected from any cable during launch and recovery. Without the cable boundary's, the hangar can be launched and recovered by any LARS system using crane hook. Hangar to LARS connection will be a master link.

The wet mate connection to power supply and signal for hangar allows this flexibility. It gives the option of changing to alternative power sources from existing subsea structures. It also makes it easy to test the hangar and vehicle when the system is located on the rig deck, by connecting a power and an optical fiber wet mate from control room.

The flexibility of the standalone system allows it to be swapped easily with another identical system. This reduces the maintenance onboard the rig by sending the standalone system back to shore for maintenance and repair.

The hangar`s main task is to be a link between the operation room and the vehicle, this is done with two different technologies, one wireless and tethered:

> **Wireless** uses optical light for large data transfer and acoustics for position input received by the vehicle.
>
> **Tether and TMS**: The other technology used is tethers. Hangar must have two TMS (3.1.3) for spooling in and out the tether, one small optical fiber tether and one larger standard tether. Using TMS without slip ring reduces maintenance and cost. The powered tether will have a shorter range but include power and optical fiber. The optical fiber tether will be a much thinner cable containing only optical fibers, reducing the drag and increases the length of the cable.

6.3 Vehicle

For the standalone system to be as versatile as possible, it will be a medium plus sized vehicle. Its size is limited by the available power at subsea. A medium sized system increases the movability, makes it easy to transport the system on the rig, to ships and on shore

Main operation mode of control will be manual, using a pilot to operate the vehicle in the same way as a conventional ROV. The uncertainties of using fully autonomous vehicles inside the critical zone where the subsea structures are located are the main reason for having a human operator.

The vehicle is controlled in three different modes, one mode for every different tether and wireless option:

> **Tooling mode**: require continues power supply, this is done by using a conventional tether with conductors. Extra power can also be drawn from the batteries when needed.
>
> **Inspection mode**: Optical fiber tether gives the vehicle large step out length, necessary for inspecting suction anchors, mooring and risers.
>
> **Free mode**: Wireless connection allows for inspection where there is restricted or limited access, also necessary for having continuous communication with the vehicle during tether changing.

If maintenance on the vehicle is needed, the vehicle can be switched to free mode disconnecting from the hangar, it can then move in to a basket or crib lowered by the rigs LARS. In this way, the vehicle can be serviced and maintained without retrieving the hangar.

The fully electric vehicle will be equipped with two electrical five-function mini manipulators Figure 17Mini five function (Figure 17), for valve operations, handling tooling and so on. Standard sensors for navigation and operation will be equipped (3.5) the specific types are not relevant when they are all interchanging. Passive stability of the vehicle gives the manipulator the required stability when lifting objects. Section (5.2.1.1.3)

Thruster size will be a step larger than medium class vehicle; this gives the vehicle enough force for withstanding the drag in tether, and power to be able to lift equipment. In Table 6 the thrust for medium plus class vehicle is shown.

The vehicle`s docking system for skids can carry extra vital tools, equipment or sensors for the work tasks. This can be heavy slow rotation torque tool. With the use of wireless induction connector, the skid connections can be standardized.

Through the induction coupling, the batteries can be recharged; this will be a slow charge due to the highest power transferee of 2 kW.

6.4 Connection cables

Piggybacking the optical fiber will be a permanent solution; the installation cost can be higher than other solutions, due to the measures taken ensuring the safety and stability of the new system. These measures are the piggy backed supply cable and the landing frame with guideposts.

The different options have been evaluated in section 5.2.4. One of the system criteria is to operate in harsh weather and seas, an attached rig attached free hanging cable options will be a limitation during strong current, high waves and rig moves.

Using the advantage of existing power infrastructure at subsea, a piggyback cable from the rig to the hangar can then be used for signals purpose only, this reduces the diameter of the cable by using optical fiber. By choosing the piggyback option on the Snorre A power cable, the optical fiber to the hangar will be in a safe position all the way down to the seabed and to the landing frame.

The power supply cable will be connected to the electric distribution unit EDU at subsea, the other end laid to landing frame, placed in the dummy slot. This keeps the remote operated vehicle system powered as long as the cable is connected. The weather will not affect the power supply to the standalone system.

6.5 Launch and recovery system

When not using any form of attached cables on hangar it will be more mobile, this makes it able to be launched in different ways from different positions on the rig. It also gives the possibility of moving the hangar and vehicle inside during repairs, ensuring a better repair and maintenance isolated from harsh weather, which is necessary when opening the watertight pods.

During launch and recovery there will be need for a separate ROV to assist during this operation, it will need to connect the guide wire. If guide wire is not in use, it will help guide the hangar in right place during landing. After landing, the ROV must connect the wet mate connectors to hangar. This is an acceptable option since Snorre B must have a work class system stationed for the heavy-duty operations, which cannot be replaced by this standalone vehicle

Recovery requires less effort when it is only to disconnect the wet mate connectors and place them in the dummy slot. Then connect the crane hook, guide wires are not required.

Using the abandon well frame, there would not be any need for a new frame, the hangar fits inside the well frame on special guide tunnels placed on the outside of the hangar. This can be done at Snorre B where there is abandon cuttings injection well. Landing frame with guidepost should be installed if the abandoned cutting well cannot be used. Including dummy slots for the wet mate connector, will ensure they stay in positon and protect them from dust and debris.

6.6 Final System selection

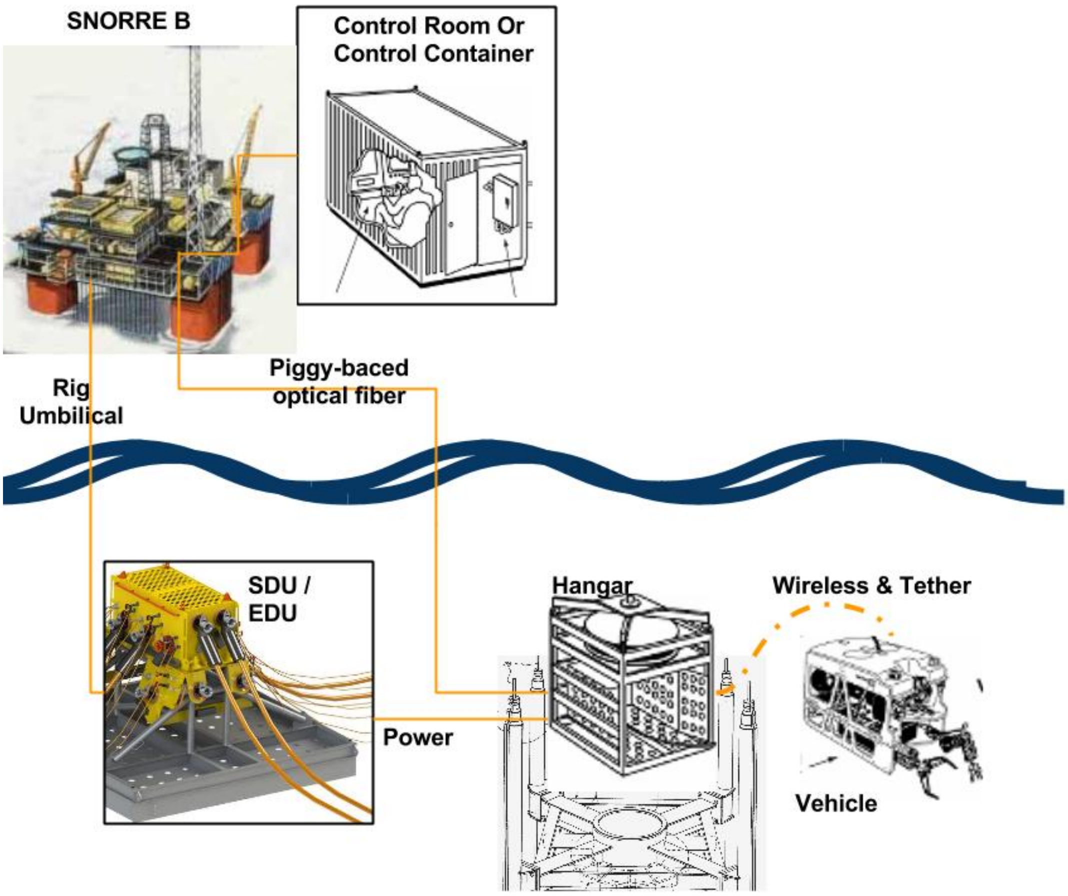

Figure 55 Final System Components for Standalone system. With control room on Snorre B, the subsea module SDU/EDU, Hangar with landing frame and Vehicle

The final overall system configuration for the standalone system is illustrated in Figure 55. Mainly the system includes Vehicle, hangar, Optical fiber cable and the control room. Other components are existing components used to improve the system and reduce amount and size of new installed compotes.

The medium class vehicle that is chosen will have the ability to operate tooling and manipulators. It can perform continues work with tooling and manipulators powered by the conventional tether, or long distance inspection with use of an optical fiber tether.

The versatile hangar can connect to different subsea systems using wet mate penetrator, the penetrator needs to follow the subsea field standard to fit, for power and optical fiber. It is supported by the guidewire system, meaning that the landing frames guideposts are able to fit the hangars guide tunnels. This gives the hangar secured positon in the landing frame, which restricts it from any movement during its time at subsea.

Using the cutting injection well will be used as a landing frame, with its stationary frame and guideposts the installation of new frame is not required.

The EDU is used for supplying different components on the seabed with power, it can also be used for supplying the hangar and the vehicle. The rig`s umbilical is connected to the EDU, it the distributes that power to the hangar with use of a subsea power cable.

The optical fiber is clamped on to the existing power cable; this piggyback option lets the optical fiber “ride” on the power cable, giving them the same route and stability. The forces induced by the waves and current will be taken by the power cable which are designed for extreme weather situations. This leaves the end of the optical fiber cable unaffected by weather.

7 Conclusion and Recommendation for further work

Conclusion

The standalone system can be powered at subsea by using wet mate connector to connect to the existing electrical infrastructure at subsea. The infrastructure is supplied from the rigs main umbilical and distributed by EDU at subsea where the standalone system will connect. This is a feasible solution for supplying electrical power to the standalone system.

When piggybacking on existing power cable that is designed for all weather situations on Snorre B, the piggybacked cable gains the same characteristics as the supporting main cable, achieving the same weather limits. It is concluded that piggybacking the optical fiber signal cable is a feasible solution for delivering high-speed communication to the standalone system.

The deployment and recovery system is kept to a simple and all-round design. It is concluded that the standalone system is versatile, making it easy to launched and recovered from many different systems. With use of ROV during the deployment and recovery of the standalone system it feasible.

The hangar is concluded to be a feasible solution if the detachable tether is developed and tested. The hangar completes the needed tasks for supporting the vehicle for its operations.

Having a vehicle with its power, tool and skid operating capabilities, and universal connection point for the detachable tether allows it to complete the operations from the work descriptions. It is concluded that the vehicle is be a feasible solution for the standalone system at Snorre B

IT is concluded that the standalone system is a feasible solution for use on Snorre B.

Recommendation

It is recommended that the detachable tether solution be further developed, to be able to have a versatile standalone system.

Battery endurance during tooling operation and inspection must be tested to know if it tooling can be done without continues power supply.

Many new technologies are included in this system; Optical wireless signal, Induction connector and should be tested before rely on them.

8 References

BlueComm Underwater Optical Modem. (2015, 05 19). Retrieved from http://www.sonardyne.com/: http://www.sonardyne.com/products/all-products/instruments/1148-bluecomm-underwater-optical-modem.html

BlueLogic. (2015, 1 1). *Electric torque tool.* Retrieved from http://www.bluelogic.no: http://www.bluelogic.no/bilder/produkter/02%20mechanical/type%2008%20actuation/00%20doc/600144-td-0001_product_technical%20description%20class%201%20-%204%20electcrical%20actuation%20system_rev-01.pdf

BlueLogic. (2015, 1 1). *Wireless Subsea Connection.* Retrieved from www.bluelogic.no: http://www.bluelogic.no/bilder/produkter/03%20electrical/00%20ppt/subsea%20usb%20ppt.pdf

CQI. (2008, 1 1). *Aberdeen ROV facility.* Retrieved from http://www.thecqi.org: http://www.thecqi.org/Community/Branches/CQI-Scotland/CQI-North-of-Scotland/Past-events/March-2008-Visit-to-Technips-Westhill-Aberdeen-ROV-facility/

Davis, C. C. (2015, 04 12). *FIBER OPTIC TECHNOLOGY AND ITS ROLE IN THE INFORMATION REVOLUTION.* Retrieved from http://www.ece.umd.edu/~davis/optfib.html: http://www.ece.umd.edu/~davis/Image2.gif

DNV. (2014). *DNV-RP-C205 Environmental Conditions and Environmental Loads.* DNV: DNV.

ECAgroup. (2015, 01 01). *ROV manipulator arm ARM 7E.* Hentet fra http://www.ecagroup.com: http://eca-media.ecagroup.com/player/pdf?key=c9faef88b70ef5dade8ffa5249ae5584

ENI. (2015). *AUV Future Development.* Stavanger: ENI.

Gudmestad, O. T. (2014). *Marine Technology and Operations.* Stavanger: University of Stavanger.

Håvard, A. (2014). *Simulation of subsea communication network.* OSLO: UNIVERSITY OF OSLO.

IKM Subsea. (2015, 1 1). *Merlin WR 200.* Retrieved from www.ikm.no: http://www.ikm.no/ShowFile.ashx?FileInstanceId=193dc306-8669-4bc7-a276-274d7eee4401

IKM Subsea. (2015, 1 1). *Rov Operasjoner*. Retrieved from http://www.ikm.no/: http://www.ikm.no/rov_operasjoner

International Electronica Commission . (1983). *IEC 60038:1983.* Unknown: International Electronica Commission .

maritimejournal. (2012, 10 26). *'Superskid' gives Cougar a torque tool.* Hentet fra www.maritimejournal.com: http://www.maritimejournal.com/news101/marine-civils/diving-and-underwater-services/superskid-gives-cougar-a-torque-tool

Mathiesen Martin, M., Eik, K. J., & Nygaard , E. (2007). *Snorre Metocean Design Basis.* Stavanger: Corporate Statoil.

Mæhre, Ø. (2015, 05 11). Electrical engineer. (J. F. Stangeland, Intervjuer)

Nexans. (2013, juni 13). *Nexans Norway* . Retrieved from Submarine Medium Voltage cables: http://www.nexans.no/Germany/2013/SubmPowCables_FINAL_10jun13_engl.pdf

Nexans. (2015, 05 04). *Multipurpose Fiber Cable.* Retrieved from www.nexans.no: http://www.nexans.no/eservice/Norway-en/pdf-family_10581/Multipurpose_Cable.pdf

Nexans. (2015, 05 04). *ROV Tether cables.* Retrieved from www.nexans.no: http://www.nexans.no/eservice/Norway-en/pdf-family_-67276/Tether_cables.pdf

Nexans. (2015, 01 01). *Steel armoured dynamic cables.* Retrieved from www.nexans.no: http://www.nexans.no/eservice/Norway-no_NO/pdf-family_-67413/Steel_armoured_dynamic_cables.pdf

Oceaneering. (2015, 1 1). *ROV Systems*. Retrieved from http://www.oceaneering.com: http://www.oceaneering.com/rovs/rov-systems/

Rosnes, R. (2015, 5 13). Subsea Technology Oceaneering. (J. F. Stangeland, Interviewer)

Saab seaeye. (2015, 1 1). *cougar*. Retrieved from http://www.seaeye.com: http://www.seaeye.com/cougar.html

Saab Seaeye Ltd. (2014). *Technical background Sabertooth.* Sweeden: Saab Seaeye Ltd.

SEACON. (2015, 1 1). *WET-MATE, OPTICAL CONNECTOR.* Hentet fra http://seaconworldwide.com/: http://seaconworldwide.com/wp-content/uploads/HYDRALIGHT.pdf

SEPRO. (2014, 3 27). *DPL™ 3-25 (dipping).* Retrieved from http://www.seprotechnology.com/: http://www.seprotechnology.com/?p=282

Shilling Robotics. (2014, 01 01). *Schilling Robotics TITAN 4 Manipulator.* Hentet fra http://www.fmctechnologies.com/: http://www.fmctechnologies.com/en/SchillingRobotics/Technologies.aspx

Subsea 7. (2015, 1 1). *Subsea 7 ROVs.* Retrieved from http://www.subsea7.com: http://www.subsea7.com/en/what-we-do/fleet---facilities/rovs.html

Subsea 7, I-tech 7. (2015). *Rotary Docking Class 1-4 Torque Tool.* Aberdeen: Subsea 7.

Teledyne Oil and Gas. (2014, 1 1). *Rolling-Seal-Hybrid.* Retrieved from http://www.teledyneoilandgas.com/: http://www.teledyneoilandgas.com/product/rolling-seal-hybrid.htm#tab5

Teledyne oil and gas. (2015, 1 1). *Nautilus 1.75-60 connector.* Retrieved from http://www.teledyneoilandgas.com: http://www.teledyneoilandgas.com/product/nautilus-1.75-60.htm

Toolpusher. (2015, 1 1). *ROV Dredger.* Retrieved from http://toolpusher.com: http://toolpusher.com/?ad_listing=rov-dredge

Vetco Offshore Industries, Inc. (1986, 9 16). *Retrievable exploration guide base/completion guide base system.* Retrieved from http://www.google.com/patents/: http://www.google.com/patents/US4611661

wisub. (2015, 04 29). *High Performance.* Hentet fra http://www.wisub.com: http://www.wisub.com/techspec/maelstrom_tech_spec_print_.pdf

Woster, R. B., & Amdal, R. (2015, Mars 11). Meeting about Snorre B subsea layout. (J. F. Stangeland, Intervjuer)