Master Thesis 2013

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Title: Integrated Operation - Define and Present Data for Analyzing and Optimization

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Lower Degree Programmes – M.Sc. Programmes – Ph.D. Programmes TFver. 0.9

Telemark University College
Faculty of Technology
M.Sc. Programme

MASTER'S THESIS, COURSE CODE FMH606

Student:	**Christian Francis Aanning**
Thesis title:	**Integrated Operation – Define and Present Data for Analyzing and Optimization**
Signature:	. . . .
Number of pages:	92
Keywords:	**Control system, ICT, safety, risk assessments**. . . . .
	. . . .
	. . . .
Supervisor:	David Di Ruscio sign.: . . . .
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Censor:	sign.: . . . .
External partner:	sign.: . . . .
Availability:	Open

Archive approval (supervisor signature)**:** sign.: . . . . **Date :** . . . .

Abstract:

This master thesis was carried out in consultation with Aker Solutions subsidiary company Aker Engineering & Technology AS (AET) at Fornebu in Oslo. The student who is accomplishing this thesis is an employed at AET, currently working on one of AET's projects. The purpose of this thesis is to study Integrated Operations in the oil & gas industry. The topic of this thesis is Integrated Operations with the subtitle "Define and present data for analyzing and optimization. In 2004 the Norwegian Parliament published an announcement (St.meld.nr 38, 2003-2004) on petroleum activity on the Norwegian Continental Shelf. The government objective was to deliver a message to the Norwegian Petroleum Directory to initiate and evolve all parts to improve and encourage the use of Integrated Operations (St.meld.nr 38, 2003-2004). This message evolves innovation and creativity that can increase the productivity and to clarify technical, organizational and safety issues that are related to transferring of data offshore (St.meld.nr 38, 2003-2004). An initiator and a driving force for further development for a competitive oil and gas industry has been the Oil Industry National Association (OLF). The OLF has reported that since 2004 it has been seen a positive trend in productivity and cost reduction as a result of Integrated Operations. The OLF has divided the implementation of Integrated Operations in two stages, the first by Generation 1 (G1) and the second by Generation 2 (G2) (OLF, 2005). The G1 addresses integrated onshore and offshore processes and centers with continuous support (OLF, 2005). The G1 is already implemented and tested out. The G2 includes operator and vendor centers support, automated processes and 24/7 operations (OLF, 2005). It has been prepared a deadline to reach the target within 2015 (OLF, 2005). This thesis touches the area specification of G2. The content in this thesis is based on a litterateur study where relevant approaches and methods are discussed.

Table of contents

Preface

This Master thesis marks the end of the study within Master of Science at the faculty for Technology at Telemark University College, Porsgrunn. I have a background as a certified electrician and have completed a Bacholer of Science 2011 within Electric Power Engineering.

It has been carried out since spring 2013 a Master thesis with the purpose of studying approaches and methods related to responsibility task towards Integrated Operations for the petroleum industry.

The topic of this thesis was formulated with demands from the oil and gas industry and was written in cooperation with Aker Solutions and Telemark University College. During my thesis I have received guidance and support from contact persons within Aker Solutions.

My internal supervisor from Telemark University College has been David Di Ruscio. My external supervisor at Aker Solutions has been Rolv Werner Erichsen. Tom Kristen Bergum Røed and Hristian Mitrevski have also assisted during the work.

I want to use this opportunity to thank my supervisors David Di Ruscio, Rolv Werner Erichsen, Bergum Røed and Hristian Mitrevski for all support and guidance during my work with this Master thesis. I want to thank Aker Solutions that has given me permission to write this thesis.

This Master thesis also marks the end of six years of study. Therefore I want to give a heartily thank to my family, wife and kids for all support during these years. Their support has given me courage and enthusiasm to keep on working.

Porsgrunn, 03.06.2013

Christian Francis Aanning

Nomenclature

DCS – Distributed Computer System

DFT - Discrete Fourier Transform

ERP – Enterprise Resource Planning

FFT - Fast Fourier Transform

G1 – Generation 1

G2 – Generation 2

HSE - Health Security Environment

IMS – Information Management System

IO – Integrated Operations

IT – Information Technology

LDS - Light Diode Signal

MES – Manufacture Execution Systems

NORSOK - Norsk Sokkels Konkurranseposisjon

ODBC - Open Database Connectivity Tool

OLF – Oljeindustriens Landsforening

OPC - Open Process Control

PAC – Programmable Automation Controller

PLC – Programmable Logic Controller

PTIL - Petroleum tilsynet

RTU - Remote Terminal Unit

SCADA – Supervisory Control and Data Acquisition

SQL - Structured Query Language

SSB - Statistisk Sentralbyrå

Definition

NORSOK - "Norsk Sokkels Konkurranseposisjon" is a norm that has the purpose of reducing costs for maintains and completion, modification, building and operation of offshore installations. NORSOK has made it possible to produce installations to smaller field that earlier where shown not profitable. Finn Kristensen was the initiator of the standard and he was in the period 1990-1993 council for the Olje- og Energidepartementet.

Overview of tables and figures

1 Introduction

1.1 Background

In an announcement from the Norwegian Parliament (St.meld.nr. 38, 2001-2002) the government goal was to find a solution and facilitate for having a profitable production of oil and gas in a long term perspective.

Integrated Operations are results of new-innovation where value creation on Norwegian Continental Shelf is in constantly development. The oil & gas industry is continuously looking for improving the efficiency, operative solution for management of resources, reduce cost, optimal operating solutions and improve safety and reduce risk.

In the Norwegian Parliament it has been published an announcement for the definition of "Integrated Operations". Referring to the announcement (St.meld.nr 38, 2003-2004) it has been described as following:

Norwegian Parliament announcement nr.38 (2003 – 2004) – about the petroleum activity – Challenges and strategies for realizing a long-term scenario – E-operations/Integrated operations:

"Integrated Operations involve the use of information technology to alter organizational and work processes functionalities for achieving better decisions, to remote processes and equipment and move functionalities and personal onshore"

The Norwegian oil- and gas industry has experienced a rapidly increase in activity on Norwegian Continental Shelf since 1971where the first well was drilled. From the start-up period in 1975, when the first produced Norwegian crude oil was sent to the refinery, the income of the petroleum activity has played an important role in Norwegian economy (Wikipedia, 2013). Many new production fields have been explored, developed and the economy has been characterized by growth and increasing production. The petroleum activities have now continued for over thirty years and the situation of oil production has been declining year by year. This is a result of a reduction in resource quantities in the existing reservoirs (St.meld.nr 38, 2003-2004). A reduction of oil quantities also means a decline in Norwegian economy, challenges the government to aim for new operational solutions and optimize profitable extraction of the present oil fields (St.meld.nr 38, 2003-2004). New proven reservoirs have been discovered but are anticipating inter alia environmental impact assessments and consequence analysis. In the meantime, and also for future petroleum activity, the government needs to act for maintaining a competitive exploitation of the resources on the Norwegian Continental Shelf (St.meld.nr 38, 2003-2004).

1.2 Problem Description

The topic of this thesis is “Define and Present Data for Analyzing and Optimization”.

The problem description was formulated considering the status of IO today. The aim of this thesis is to study G2 of IO which touches the area specifications onshore centers and vendor support. The focus in this thesis will be to look into approaches that can be used and what to consider when it is desired to perform analysis and optimization. To do analysis, data needs to be defined and it needs to be presented to reach a solution where decisions can be made. This leads to the following question to be answered:

- How can data be accessed between on-offshore centers?

Because, if analyzing and optimization should be carried out there needs to exist a solution for access and extracting data. Transferring and access to data are vital, touching the subject ICT. Communication between offshore and onshore centres involves establishing communication entry paths that leads to a certain risk assessment concerning network security. It is important that IO does not contribute to degradation of the existing security level.

With implementation of IO, G2 leads to a variety of challenges concerning technical challenges, work processes and organizational factors. In this thesis there are highlighted important elements concerning human and organizational factors, which will have a great significance of a successful implementation of IO. Organizational structures, work procedures and collaboration will be examined to reveal the importance of sharing knowledge and experience to meet competence requirements.

The approach of the problem description will be done with the following steps:

1. First there will be a system description explaining the building blocks of a general SCADA system. A SCADA system is vital for IO since without a SCADA system it will not exist IO.
2. A literature study on IO is carried out on issues and challenges related to technical, organizational and human factors. It will be discussed approaches that can be used to find a solution to the challenges IO face.
3. Procedure for prepare defining and present data issues is presented. It is emphasized on data consideration and processing.
4. A practical case is used to illustrate and capture the importance of doing proper preparations ahead of implementation concerning diagnostic and condition monitoring.
5. At de end it is presented and discussed methods that can be used for performing analysis and optimization.

1.3 Purpose

The thesis is related to study IO G2 in the petroleum industry. The background for the thesis is the government's desire to improve the productivity on the Norwegian continental shelf and better exploitation of resources in the present reservoirs (St.meld.nr 38, 2003-2004). It is expected that IO will become more and more used in the future. Therefore it is important to consider different methods to be used.

The purpose of this thesis is to study onshore centers and vendor support. The contents in the thesis can be seen as a contribution to better understand the different challenges that IO face. Connecting people, better interaction across different disciplines, exchanging of knowledge and experience, are among others issues that are discussed in this thesis. Task responsibilities between on-offshore are looked into. Related to access of information between onshore and offshore brings issues to be discussed about ICT and IT security.

The thesis is accomplished to get a better overall picture and understanding of IO.

1.4 Delimitations

For this thesis it has been done the following delimitations:

- The thesis only refers to IO related to the Norwegian petroleum industry
- The methodology of IO will be introduced
- The material in this report is delimited to the literature used. Different literature is discussed along to reach an approach that can be used.
- This thesis is delimitated to remote processes of IO that handle analysis and optimization tasks.
- The basis for define and present data for analysis and optimization towards IO.
- It will be highlighted what kind of responsibility that lies in organization and work processes in IO since it will be an important factor of improvement.
- The thesis is delimited to find a methodical approach towards defining data and presentation for processes to be analyzed and optimized.
- The thesis is delimited to process engineering and optimization and not reservoir and well execution.
- The thesis is delimited to risk assessments related to work procedure and ICT.

1.5 Method

To perform this task it has been accomplished a literature study. Different approaches and methods have been discussed along in this thesis seeking answers that can be used to get a better understanding of the challenges that IO faces. The thesis is divided into two parts; Part 1 Theory; Part 2 Methods.

1.6 Outline of the thesis

The thesis is divided into two parts. Part 1 is theory and part 2 contains the methodical approach.

Chapter 1. Introduction: Presenting the problem description of this thesis and its background. It is also stated important delimitations according to the topic.

Chapter 2. System description: It gives an overview of different building blocks involved in a Superior & Control and Data acquisition system (SCADA) and their functionalities.
Chapter 3. Integrated Operations: This chapter is based on a literature study. There are discussed important elements that include IO. It is presented methodical approaches to solve the problem description. Organizational, work processes, human factor and technical challenges are what considered.

Chapter 4. Define and Present Data: It is represented a method for how one can prepare issues related to analyzing and optimization. Preparation and data handling is the topic that is being discussed.

Chapter 5. Performance monitoring and diagnostic: This chapter concerns work tasks related to IO. Performance monitoring and diagnostic is part of the work responsibility, analysing and optimization towards IO. It is in this chapter concentrated on to look into opportunities for performance monitoring and diagnostic of an electrical machine.

Still the main purpose is to highlight that there can be many areas to consider when looking for solutions to perform analysis and optimization.

Chapter 6: Methods for condition monitoring of asynchronous motor: Method for condition monitoring of an electrical asynchronous motor is presented. This chapter includes the approach of carrying out such an experiment. The focus is on detecting rotor faults and explains a proper problem description, definition of data and theory that can support the suggested solution.

Chapter 7: Analyzing and Optimization: This chapter handles the important functionality of IO concerning the opportunities to improve today's traditional operation. It is referred to different methods to recognize and identify systems. Approach for analyzing, validating and optimization of models are presented based on literature study. Discussions of methods have been made along.

Chapter 8: Results: Result from the study made about Integrated Operation Generation 2. The challenge that Integrated Operation face, and involvement of external parts. Result from practical example and method for doing analysis and optimization.

Chapter 9: Discussion: Opinion and understanding of the result.

Chapter 10: Conclusion and Suggestion to further work: A conclusion of the problem description is derived. Answering questions related to the problem description. A suggestion to further work is presented.

Chapter 11: Appendix: Task Description.

Part 1: Theory

2 System Description

A system description is presented to get an overall view of the important elements that include the ontology of IO in the oil and gas industry. The technical part of IO is mainly involving transferring of data, meaning that data integrity is critical since data on a process level needs to be available on a management level. According to OLF (2007, pp.1) the term “Integrated Operations” has been defined as “real time data onshore from offshore fields and new integrated processes”. IO will be explained and derived more in further chapters but the philosophy of the term is to make low level information in a system available also on a high level, so that information can be exchanged for researching and decision making (OLF, 2005). Data also needs to be made available for onshore centers so personnel can use these data for improving the operational solution. Collaboration on high level in real-time is an important factor with onshore support, resulting in high expectation to ICT (OLF, 2005). ICT is an important factor for the technical part of the process securing data from the technical level that includes data from valves, actuators and instruments from hundreds to several thousands of tags being available at all levels (OLF, 2005). Data need to be handled to achieve data integrity on a management level where decisions are taken to improve operational solution. Beside the technical part there are also many challenges related to new integrated work processes and organizational factors with IO. The functionality and work responsibilities of IO are shown in Figure 1.

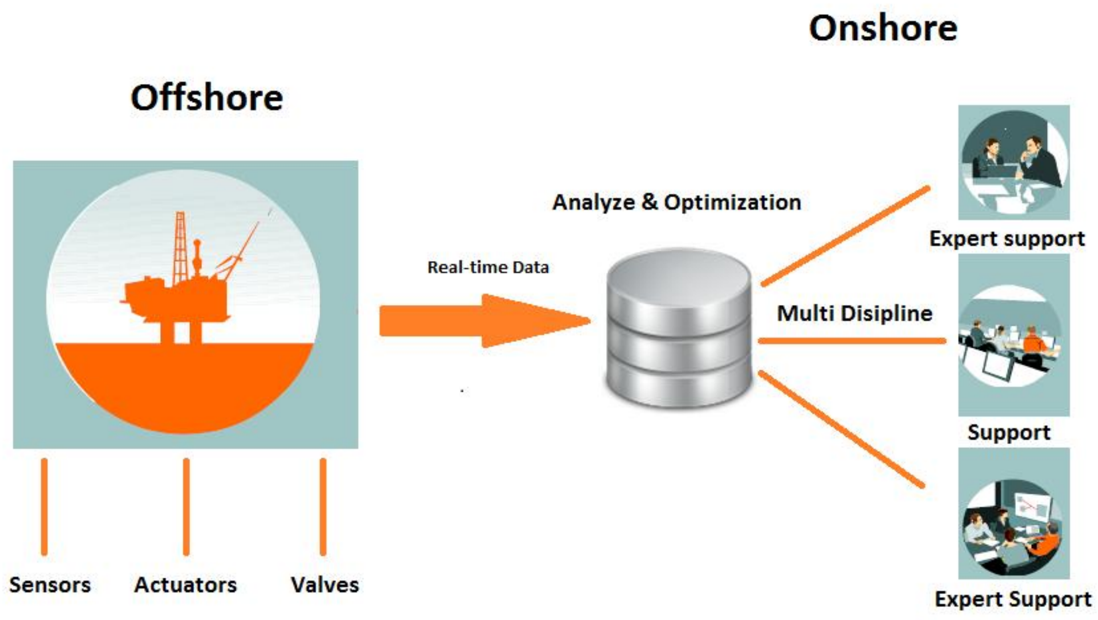

Figure 1: Communication between offshore and onshore centers (OLF, 2007 pp.5).

2.1 System overview

In the process industry there are many modules involved that need to interact to fulfill a complete industrial system where data flows constantly between levels in a system. For monitoring and controlling a process, a SCADA system needs to be established. The oil and gas industry offshore installations are often divided into different systems. Each system performs separated tasks that are important e.g. either for the oil and gas export or supplying portable water to the facility. These tasks need to be monitored and controlled not only to achieve a high quality product but also to have an operational solution that fulfills the requirements for a secure and reasonable operation. There are many different components and entities that evolve a complete SCADA system. Such as input/output signals from sensors and hardware, process controllers, HMI, communication medium, servers and databases.

For Process Control Systems (PCS) a SCADA system can involve computer systems like Distributed Control Systems (DCS), Programmable logic Controllers (PLC) and Programmable Automation Controllers (PAC) that are located in different area locations in the plant (Knapp, 2011). The SCADA system will get information from these modules for monitoring and control. It is important that every part and module in the system is able to interact with each other to get reliable information from different parts of the system. Data exchange and storage is vital for communication to be established between all levels.

A PLC is a programmable controller used to automated parts of a process. It can be used both in a PAC and DCS (Knapp, 2011). A DCS can be assembled with controlling and monitoring one part of a system. A PAC is used for analog and digital inputs and is used in combination with a PLC (Skeie, 2012). PAC and PLC relatively hold the same functions and the major difference between PAC and PLC is the programmable interface. The SCADA for control and monitoring part of the system also known as the Industrial Control System (ICS) can be recognized as the industrial IT system that handles process I/O (Knapp, 2011). Above the industrial IT system in a layered presentation is a management system. A management system called the Superior SCADA consists of among others ERP, MES and IMS systems each having separated tasks and functionalities (Skeie, 2012). The ERP has a business role in a Superior SCADA system handling business functions, manufacturing and financial issues (Skeie, 2012). The MES is a material production system where all fabrication and products can be scheduled and hold tracked on (Skeie, 2012). The IMS system has the responsibility for handling information on all levels. The IMS will manage data flowing in the industrial system. Data from devices on a technical level is used for monitoring and control on a process level and also for business purposes on an administration level. A layered presentation of an industrial system is presented in Figure 2.

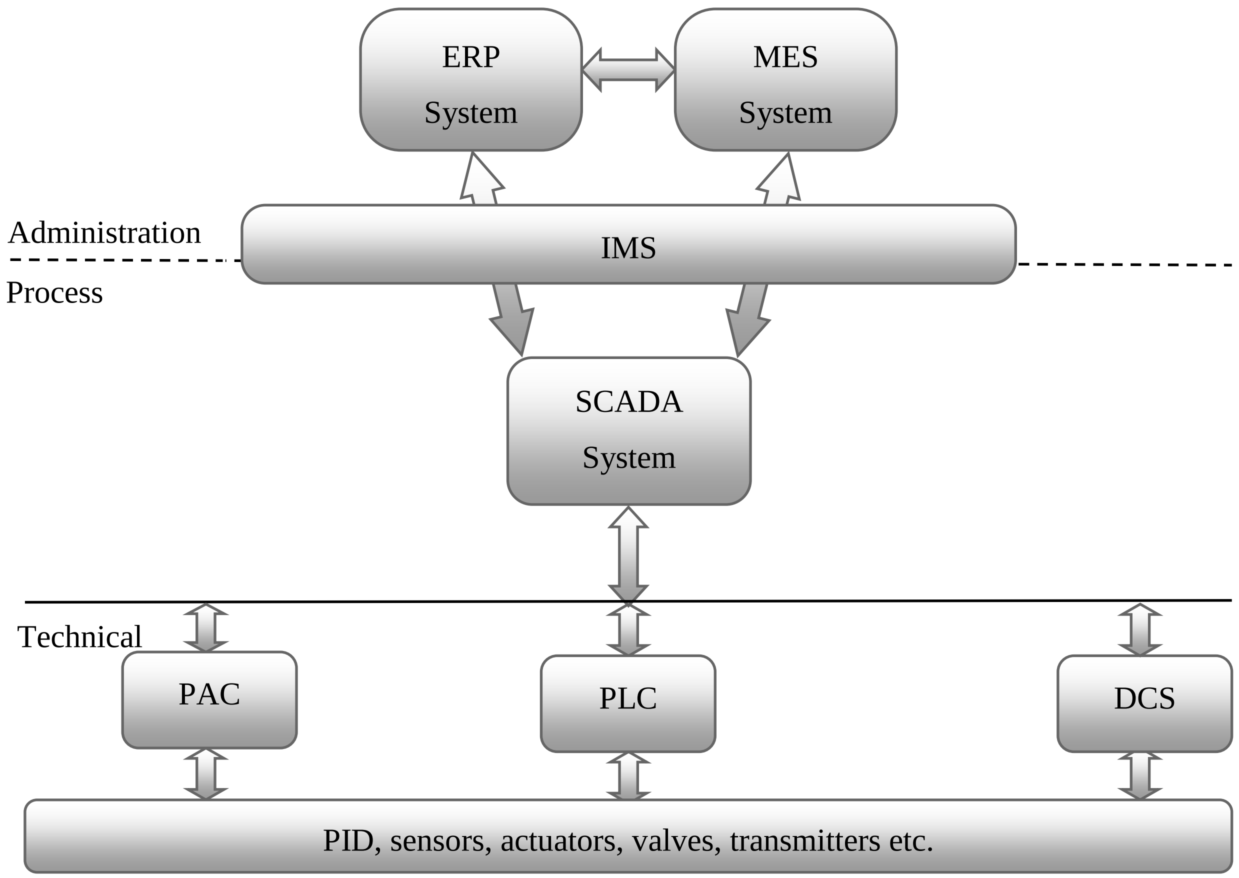

Figure 2: Layered presentation of a general industrial system.

2.2 SCADA Monitoring and Control

The SCADA for control and monitoring part of the system can be recognized as the industrial IT system that handles process I/O for control and monitoring.

In a SCADA system the control and monitoring is one part of the whole SCADA system.

In offshore installations different devices are used for monitoring and control of a process. RTU, DCS, PAC and PLC can be one of these devices. These devices are often used to automate parts or a whole process in combination with a monitoring system. This is what mainly involves in SCADA systems on production and process level. In different literature authors use different concepts and names for talking about the same thing. Some authors mean that RTU, DCS, PLC and PAC are separated from the SCADA monitoring and control system. This is because there are components that are part of the technical level in SCADA systems. Knapp (2011 pp.7) mentions that "Supervisory Control and Data Acquisition, is just one specific piece of an industrial network, separate from the control system themselves, which should be referred to as Industrial Control System (ICS)". When he mentions "Supervisory Control and Data Acquisition" he means the monitoring and Control part of a SCADA. Knapp (2011) is more satisfied with separating these terms. Regardless of terms a monitoring and control part of SCADA is getting information from RTU, DCS, PAC, PLC etc.

Operators located offshore are sitting behind monitoring systems observing the performance and evolution in the plant. When irregular incidences occur in a process the operators will handle, trying to adjust, change parameters and initiative action from the control panel or going out in the plant for inspections.

2.2.1 RTU

Remote Terminal Units (RTU) is used a lot in the industry located in different sub-stations or other remote areas. They are used to handle parameters coming from the field (Knapp, 2011). It mainly consists of inputs/outputs and can handle both analog and digital signals. The RTU is a distributed computer that is dedicated to a specific job. This job can be part of a strategy or it can be a control task that obtains certain process values in a plant. A RTU is operating in real-time and is a physical unit that can be monitored and controlled like a PLC. RTUs can transmit parameters to monitoring stations often using standard industrial protocols (see Figure 3). Summarized the RTU will be an industrial computer system consisting of (Skeie, 2012 pp.24):

- Inputs; analog/digital inputs
- Outputs; analog/digital outputs
- Communication; communication with a SCADA system
- Process and memory
- Software dedicated to the functions of the RTU

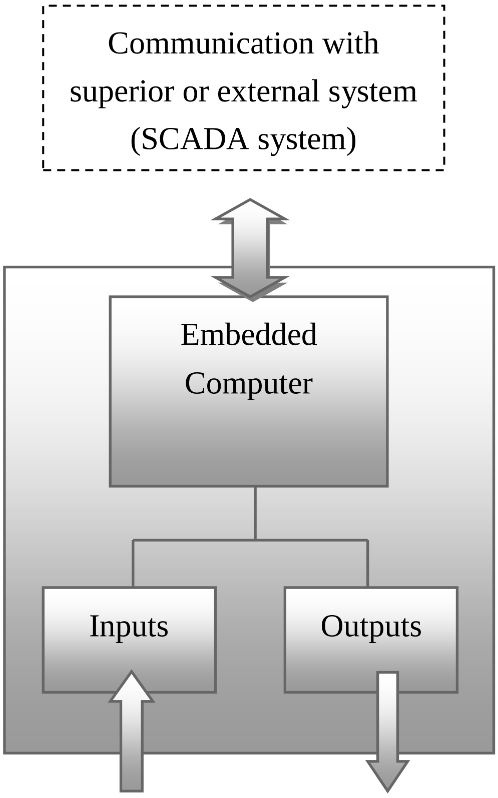

Figure 3: Remote Terminal Unit dedicated to a specific task (Skeie, 2012 pp.24).

2.2.2 PLC

A programmable logic controller (PLC) is widely used in the industry. It is often used as a brick in a bigger system and operates as a standalone unit. It is often used as part of a strategy handling on and off signals. It is a RTU that can be monitored and controlled using software that supports the specific component. The component has inputs and outputs that can both handle analog and digital signals (Mackay, Wright, Park & Reynders, 2004). There are often Light Diodes Sensor (LDS) located on top of the PLC indicating ones and zeros that are fed into the memory of the PLC. PLCs have mostly replaced traditional relays and are simple and effective (Knapp, 2011).

2.2.3 DCS

In oil plants, systems are divided into different parts, for instance the well and oil production can be a separate system on a platform. A Distributed Control System (DSC) can be used for controlling that part of the system containing many computers that are collecting I/O to a control system (Mackay, Wright, Park & Reynders, 2004). These devices are dedicated to a specific task in the control system, often for monitoring and handling signals (Skeie, 2012). Devices performing different tasks in a process may have small displays for local UI (Mackay, Wright, Park & Reynders, 2004). Often on a platform DCSs from different vendors are involved in the process. One company can e.g. be delivering the DCS for the production wells and another company the DCS for monitoring and control of oil export. From this it can be concluded that a DCS can consist of one single control loop to a complete SCADA system (Skeie, 2012)

2.2.4 PAC

A Programmable Automation Controller (PAC) is used for analog and digital inputs and is used in combination with a PLC featuring all the capabilities that a PC-control system would have used (Skeie, 2012). It can be said that a PAC contains the program logic for a PLC to handle and will be providing the reliability for the task. PAC and PLC are mostly performing the same functions. The main difference is the programming interface where PLC often uses logic ladder diagrams while PAC uses typical programming languages as Visual C#, C++ or others.

2.2.5 HMI

Human Machine Interface (HMI) can be seen as a control panel that is used to control some kind of electronic component. A HMI allows an operator to control and do configuration to different entities located in an industrial system. Devices that can be operated through an HMI are among others entities such as PLCs and RTUs. A typical HMI can consist of a graphical representation of a process showing process outputs, or it can be digital displays showing input and output data. Configuration that can be done is for example changing parameters, adjust set points or start and stop cycles.

HMIs can have restrictions for usage such as log in requirements as password or some kind of legitimating to prevent unauthorized personnel access.

2.2.6 Protocols

For a SCADA to work it is vital to have protocols that can establish communication between all components and electric entities. Protocols are vital so devices in an electrical system can communicate. To have devices that communicates means sharing a common communication protocol. It can be familiarized with two people talking, if they do not share a common language it is not possible to understand each other. There are many different protocols available in industrial contexts. Vendors of different equipments use their own protocol. There are standard communication protocols that are made in modern time to ensure common communication between system and devices. This has revolutionized the industry making it much easier to establish communication instead of adjusting each and every protocol.

2.3 Superior SCADA systems

A management system is reliable of valid information from the SCADA monitoring and control that involves all information from an offshore plant. This information is used for planning and decision making. The management system can consist of ERP, MES and IMS each having separate tasks and functionalities. A Superior SCADA system can be named as the Business system where financial management, production management decisions are taken. Analysis of production, economical questions dependent of report and information from the SCADA monitoring and control system are typical handled in a Business system.

2.3.1 ERP

ERP can be described as a system that handles internal and external management information across an entire organization in a company (Wikipedia, 2013). It can be said that ERP has the business role in the superior SCADA system because it maintains business functions such as Manufacturing, Supply Chain Management, Financial, Projects, Human Resources and Customer Relationship Management (Wikipedia, 2013).

2.3.2 MES

The MES is a material production system where orders and vendor equipment can be kept in track and trace. In MES, follow-up of products ordered from vendors can be scheduled indicating when and where products are manufactured and its status and state. Industry companies can have their own chosen MES systems programming tools which they can use for initiate jobs, follow up vendors, installers, time account and checklists.

2.3.3 IMS

Information Management System (IMS) is an information system that makes low level information available on all levels in the organization (Skeie, 2012). The objective of the IMS is to collect and store plant time stamped values, alarm/event/system data for historic storage and distribution of these data for internal use or external systems (Sadagopna, 1998) When mentioning low level information it means collecting data from instrumented systems and shall be the common data repository for the facility (Sadagopan, 1998). In this matter the IMS plays an important role on a management level since the IMS responsibility is data flow in the enterprises. It is critical in an IMS system that the data are stored in a structured way related to some philosophy (Sadagopan, 1998). A challenge with an IMS system is access to data. Who shall have access to data and does it affect the network security? The data shall often flow between different infrastructures like between offshore plants, on-offshore centers and also vender control and monitoring centers. Data exchange and access to data shall be considered carefully in thoughts of networks security. It should not lower the security level but still there are often functional requirements like support of standard protocols for an IMS coming from operator companies that need to be obtained without affecting or degradation of the security level.

2.4 Safety

A SCADA system is required to follow technical and functional requirements for safety provided by the Norwegian petroleum industry. These requirements are well known as the NORSOK standards. The NORSOK standards where developed by the Norwegian petroleum industry as a result of the NORSOK initiative, agreed in 1993. The purpose was to establish standards that ensure adequate safety, value adding and cost effectiveness for all parts involved and thus are used in existing and future petroleum industry (Standard, 2001). In the offshore industry such a system that handles safety related to control logic and different functionalities is called a Safety and Automation System (SAS). A SAS system performs safeguarding of a system and monitors every aspect in the installation (Standard, 2001). It generates and handles alarms, to perform actions like tripping signals when abnormal events in the process occur or process exceed normal operation values.

2.4.1 SAS - Safety and Automation System

Safety and Automation System (SAS) is a system that sees signals from the process and secure and electro reaches the right nodes at the same time as they get the right logic. SAS engineers often have programs that can be used to show an overview of where nodes and signal cables are terminated.

A node can for example be a PLC. If temperature is measured and the temperature exceeds a defined limit then the node will adjust according to a logic diagram. The node can be connected ether with hardware input/output, analog or digital input and output. Usually the vendor of different nodes handles all the programming. A SAS task is to describe with text or logic diagrams how nodes shall be programmed.

Nodes often read alarm signals that come from installed equipment. Alarms will be indicated in the monitoring rooms for the operators and give information if an unwanted instance occurs. When an alarm occurs the logic will make sure that the right procedures are performed.

2.4.2 Safety system

Safety Integrity Level (SIL) is requirements for the processing chain, reading, evaluating and responding (61508, 2013). Regarding a SCADA SIL will provide an integrity and risk picture of the system asset every component from sensors, RTUs and actuators.

The SIL gives information about the safety risk of a process where the measure of a risk is defined on different levels. The SIL consists of four different levels for integrity. Each level represents an order of magnitude of risk reduction. The higher the SIL level the greater the impact of a failure. The lower the failure rate is, it tends to acceptable. When an instrument, software/hardware device is rated, the entire control loop needs to be taken into considerations. When a device is rated, it can be specified that the device is suitable for operating in a specific SIL level.

IEC 61508 Functional Safety of Electrical/Programmable Electronic Safety-related Systems

IEC 61508 is an international standard that applies to all types of industry. It is defined as safety relating to equipment under control .The standard consists of eight parts that are divided into the different topics (Skeie, 2012):

- Functional safety and IEC 61508
- General requirements
- Requirements for E/E/PE safety-related systems
- Software requirements
- Definitions and abbreviations
- Examples and methods for determination of safety integrity levels
- Guidelines on the application of IEC 61508-2 and IEC 61508-7
- Overview of techniques and measures

2.4.3 Shutdown system

An offshore installation is divided into different systems to obtain platform safety. This gives the SAS system different functionalities and requirements. The different systems are mainly for HSE reasons to protect the environment, plant and humans. The systems can be described as which state the process is in, as following according to NORSOK I-002 (Standard Norge, 2001 pp.5):

- PCS – A Process Control System is used to control equipment and monitor data from the plant. It controls the process system when it is operating within normal constraints.
- PCD – Process Shutdown System is for a controlled shutdown if a malfunction or dangerous rates occur.
- ESD – An Emergency Shutdown System is used to take action when the process goes into a malfunction or dangerous rate. For maintaining these rates, limits for process values are set, LowLow (LL), HighHigh (HH), Low (L) and High (H). These limits allow precautions before serious incidents occur.

- F&G – Fire and Gas system protects against fire and constitute firefighting controlling fire devices.
- PDCS – Power Distribution and Control System. Purpose is to control and monitor electric power generation and distribution network.
- Mechanical package control involves mechanical devices that are used in final safety solution.

2.5 Database

A Database is a tool for storage. Databases are important parts of a computer system and are vital elements in industrial computer systems. Database systems are used in all kinds of industrial organizations and are used to gather huge amounts of data coming from a process. A database is according to Kristoffersen (2009 pp.4) "a collection of logic related data used for certain purposes". When collecting measurements from one coherent process through different sensors located in the plant, these measurements are more or less related to each other creating a total picture of the process. An important task for a computer system can be storing large amount of data over a longer period of time (Kristoffersen, 2009). These data need to be stored in a secure way and they need to be organized orderly so that data can effectively be found if users rely on these data to perform their jobs.

A database system can be very complex and often it needs to communicate with many different programming systems at the same time. A benefit is that it has been developed standard connectivity tools that can communicate with a database (Kristoffersen, 2009). This means that ether if it is a Microsoft program or a program from National Instruments both can communicate directly with the database. This means that they must use the same protocol. Tools used to provide these are Open Process Control (OPC) and Open Database Connectivity (ODBC). ODBC has become a standardized interface, in other words a standard application interface (API) for the connections to be established and also between databases from different vendors. OPC is today, probably the most common tool in the industry. OPC has had a large impact in the industry solving the big challenge with different equipments, control systems and other applications that have used different protocols to communicate. A common challenge has been that different vendor equipments have shared their own proprietary protocol causing conflict between different systems that may be dependent on each other's information. Before OPC came on the pitch, these challenges caused huge frustrations in the industry. By having an API to solve these things there is no need for developing custom drivers between all new applications and data sources (Kristoffersen, 2009).

What has been mentioned earlier is that organizing of data in a database is an important factor for getting data out efficiently. A database system needs to provide these services where different query techniques can be used to extract data.

First there are different ways of storing data. The way of organizing data in a database goes under different strategies and names. Kristoffersen (2009 pp.8) mentions some different methods of structuring data:

- Hierarchy databases
  - In hierarchy databases data are stored in a three structured where a mother-node has connections to its children nodes. Further on the children nodes can have more branches and children nodes.
- Network databases
  - Network database is more and less the same concept as hierarchy database but the branches are more random.
- Relational databases
  - In relational databases data are stored in tables where these tables are related to other tables in form of keys that link the relations. The data is handled and manipulated using SQL[1] query language. In modern time these type of model is the dominate type of database system.
- Object Oriented databases
  - With object oriented databases there are possibilities to create own ways of structuring data. This kind of method is a more advanced method and was developed in the early 90's where there was a need for a more advanced method for structuring data, especially in thought of creating maps, pictures, sound etc.
- Logic databases
  - Logic databases stores data based on logic statements where one true statement can resolve in another true statement and further on.
- NoSQL databases
  - NoSQL database is an alternative to relational databases that are based on storing data in tables. With NoSQL it is easier to store larger amount of data that is not made for storage in tables like document collections. In e.g. social media there is more a collection of articles, documents and different networks. NoSQL gives more possibilities.

[1] SQL - Structured Query Language, used for extracting data out of a database

Part 2: Methods

3 Integrated Operations

Integrated Operations are depending on high level interaction between different building blocks in an overall system. A system design needs to be established to achieve important fundamental requirements that are set for the specific system. There are several aspects and areas that involve system engineering, that system designers and engineers need take into consideration in the planning phase of a project.

A system is a collection of different elements that produce a result or results that are not possible by any of the elements alone (Kossiakoff & Sweet 2003). Interaction between different parts and levels in a system should have the functionality and view acting as one complete system. A success factor for Integrated Operations is that teams use ICT solutions in facilities that enable real-time collaboration (OLF, 2005). What this says is that IO is not only depending on optimal communication of real-time data on a process control level but on a production and management level as well. Information from the production level will be important for vendors but also communication on a management level where decisions are made. Work processes need to be well organized and decisions that are taken should be done by people with high expertise and long experience consulted with the operators that are located offshore. For onshore support management and teams will be located onshore making it critical to respond to real-time data to achieve the benefit of on-offshore communication.

3.1 Why Implement IO?

The concept of introducing IO in the oil and gas industry is based on the belief of improving the value creation on the Norwegian Continental Shelf at the same time as maintaining the standard of today's operational solution (OLF, 2005). The idea is to increase the effectiveness related to new methods of leadership that will give the industry more benefits (OLF, 2005). Reducing cost and improving Health, Safety and Environment (HSE) involve assembling more work and decisions transferred to onshore centers. According to a study made by OLF (2003 pp.7) reducing personnel has not affected the safety and operation on the platform in a negative direction. It has rather increased profits (OLF, 2003). OLF (2007 pp.3) is mentioning in a report on IO and HSE that HSE should be a driving force for inducing IO. By shifting work and administrative tasks that burden the offshore personnel to people organized in onshore centers, will reduce risks related to the operation. This will give the operators offshore to better focusing on the tasks related to the operation on the platform, resulting in better efficient management of resources. Reducing personnel on the offshore plants will also reduce the risk of exposing personnel for work in hazard areas and rather take planning, discussion for solving problems and seeking better operational solutions to onshore centers (OLF, 2007).

A concrete example of improved efficiency and value creation as a result from IO can be found from the Olje-og Energidepartementet (St.meld.nr 38, 2003-2004) where ConocoPhilips[2] has established an onshore center in Tananger. This onshore center is used for gathering people with expertise, knowledge and long experience in the oil industry to discuss and solve problems. A part of the personnel that earlier has worked offshore are now working in this onshore center getting the same information as the personnel offshore at the same time. Conocophilips claims that by using this onshore center where more people can be involved in decisions and where experience across different subjects groups can be exchanged, has resulted in a cost reduction of 60mill.NOK[3] in less than a year. Another example from the Olje- og Energidepartementet is Bragefeltet[4] where ABB the producer of valves related to the wells are controlling these valves in such a way that the wells are being optimized. According to Hydro[5], this has resolved in an increase of 600-1100 oil fat [6]per day. A table has been used to make an overall impression about the meaning of this case according to key numbers from 2012 shown below (see Table 1).

Table 1: The calculations are based on the average price of crude oil 2012 (offshore, 2013) and pay statistics from the "Statistisks sentralbyrå" per 1 October 2012(ssb, 2013).

	Worst Case (600 fat)	Best Case (1100 fat)
Increase of income per day	67’800 US dollar	124’300 US dollar
Increase of income per month	2’067’900 US dollar	3’791’150 US dollar
Increase of income per year	24’814’800 US dollar	45’493’800 US dollar
Income per year corresponds to number of North sea workers salary	190	350

Implementing IO requires new forms of work processes and collaboration between people within different work disciplines. The OLF has seen implementing IO as a long term goal (OLF, 2003). The implementation of IO has been divided by two generations (see Figure 4). The first stage G1 involves establishing onshore centers that will integrate processes and people onshore (OLF, 2005). Stage one (G1) has been implemented by operator companies

[2] ConocoPhilips - American oil and gas company

[3] NOK - Norwegian krone

[4] Bragefeltet - Oil field on the Norwegian Continental Shelf

[5] Hydro - Norwegian oil and gas company

[6] oil fat - 1 oil fat corresponds to200 liter oil

today where examples are described by the Olje- og Energidepartementet (St.meld.nr 38, 2003-2004). Stage second (G2) involves more direct contact with operators utilizing vendor competencies for improving the operation (OLF, 2005). The G2 is demanding bigger challenge in that way, where vendors are more closely in touch with the process. This requires that the role and responsibly of the vendors need to be defined.

If successfully implementation of these stages is done reservoir optimization, process optimization, updating of drilling targets and more remote control can be done (OLF, 2005). There is a huge potential in IO that can be achieved if the human factors and technical challenges can be solved.

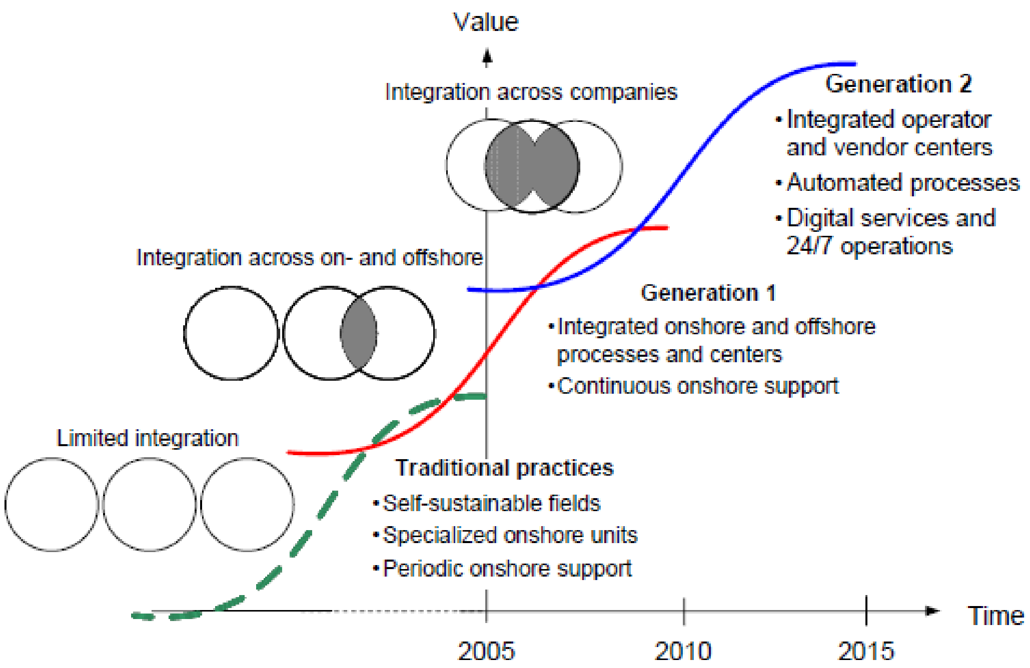

Figure 4: Foreseen implementation of IO where existing and future practices are shown (OLF, 2005 pp.9).

3.2 Issues with IO

For successfully implementing IO in the oil & gas industry some barriers need to be broken. There are examples from the industry today where existing implementation of IO has resolved in positive responds. Still with referencing to documentation and presentation and various conferences that indicate benefits with the concept of IO, the approach towards implementation of IO is limited. Development of IO is going slow having in mind that IO was introduced for the oil & gas industry more than ten years ago (OLF, 2008). The OLF can refer to factors like (OLF, 2008 pp.4):

- Lack of understanding of commercial benefits of IO
- Perceived technology risk impacting operability

- Perceived risk to project cost and schedule
- Insufficient front-end loading from Operators and key vendors

The cases of existing implementation of IO today has appeared to be positive but the "Petroleum Tilsynet (PTIL)" still has improvement potential for the oil companies (PTIL, 2013):

- Responsibility and management related to ICT-safety
- Update of technical operational documents
- Frameworks for work process descriptions

When studying the issues concerning IO it often relates to challenges with user and roles. The experience and the expert knowledge seem to be in place but the challenge lies in who is given the responsibilities and which role each part should have. Economic and financial relations need to be studied related to responsibility tasks and knowledge. Which personnel have the best knowledge about the task that needs to be performed? Should the vendors be given the optimization task in the part of a process where they are the producers of the equipment or should the oil companies own operators perform this task? This question can only be answered by collaboration between the oil companies and a third part. How much enlightenment in the technical part of the equipment the operators are allowed by the producers is one issue, and can be vital for who is given the responsibility. An agreement between the oil company and the vendors about a maintain agreement can be a solution where the vendors can do a service once a week. Having people observing one type of equipment seven days a week may not be beneficial, opening for a financial question and only illustrates that there are many assessments to be taken before a final decision. Say if the vendors are given the responsibility where should they be located? To build and obtain support centres for the vendors will give expenditures and ICT issues that need to be discussed. If the vendors are given the task, they may need 24/7 communication and access to data coming from the facility. This can be summed up by:

- Decisions must be made
- Decisions are dependent on information. What kind of information needs to be organized to enable to take those decisions?
- To enable make the right decisions it is needed to be a composition of the right qualified personnel
- Do the right qualified people need to be located at the same place or can modern technology be invoked so that collaboration and decisions can be made across geographical locations?

- Do the right qualified people need to follow some kind of work procedure to perform the job? What kind of technology must be available for those who take the decisions? Is different technology dependent on who that is involved in the process of taking decisions?

Based on the bullets derived above it must be questioned: What if many vendors are involved in optimization tasks related to the process? Say if five different vendors are involved in such job, which are going to take the responsibility for defining and manage these data that the vendor requires? An answer to this may be that an information management strategy needs to be obtained to support, share and handle all this information. Often different facilities have their own operational philosophy deciding what kind of information is going into an IMS. Support of access to data mentioned above is giving some elements on a system level that need to be taken into consideration and can be important for a project where decisions are made in an early stage in a project:

- Automation of functions and traditional operations
- Network and ICT infrastructure
- Information management concerning access and data flow
- Collaboration and communication between work centres.

The technology selection that corresponds to an operational philosophy during a project development phase will have impact on successful implementation of IO (OLF, 2008).

3.3 Organization and Work processes

A success factor for IO is organizing of team and work processes. To have a successful implementation of IO there is a need to have an understanding of how people work and to have the right mix of people. An organizational structure of people that fulfill the competence and experience that are required to fulfill the job is absolute vital. To meet this requirement collaboration between disciplines both onshore and offshore, across operators, vendors and disciplines need to be achieved (OLF, 2008).

In an organizational structure it is important to understand the roles within an organization. According to Westhagen (2009, pp.35) the general characteristic of an organizational structure can be divided into 4 parts:

- **Structured Principle**
  - Functionality
  - Product
  - Category etc.
- **Hierarchy**
  - Levels

- Span of control
- **Responsibility and authority**
    - Responsibility area
    - Authority and decision, who can formally decide what
- **Work Processes and routines**
    - Strategies, who does what and how

If knowledge and experience shared through multi-disciplinary teams is supposed to be an advantage for the operational solution of a plant, the roles of each part should be clear for everyone. To have an effective multi-discipline team there is need for self-awareness of fulfilling that part of a role. A common understanding of the situation is needed to act effectively. It is of course crucial to have the technical skills that are required for solving a task but also to have synergy and harmony in a team (Westhagen, 2009). The social element is important for collaboration and to discuss and share different thoughts achieving synergy in team. Taylor (2013, p. 93) mentions to realize the benefits brought about by availability of real-time data and the ability to share data when parts of a team are located in different locations. Each part needs to work productively together towards a common understanding of the operating environment (Taylor, 2013). Generally speaking most decisions related to the daily operation of an offshore plant today belongs to operators located offshore (OLF, 2005). In the future it will still be need for attendance of personnel offshore, but more tasks will be transferred to onshore personnel and automated. The organization of these onshore centers and what kind of attendance of personnel needed may depend on the oil field and what challenges to be found. Is it Greenfield [7] or is it Brownfield[8]? For Greenfield the main focus would be planning and developing a viable oil field. For Brownfield it is more focus on optimizing today's operational solution caused by reservoir reduction. It should be considered by the operator companies to rotate onshore and offshore personnel to ensure experience and knowledge within the company.

Improving the extraction of oil and gas related to Brownfield can be described in three categories (OLF, 2005 pp. 13-14):

- Well planning, execution and completion
- Production optimization
- Maintains planning

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[7] Greenfield - New oil field

[8] Brownfield - Operational oil field.

In these three points it is obvious that vendors and producers have a key role in collaboration with the operator company's personnel. Contractors and drilling service providers, producers and vendors of equipment should be highly involved. These parts will sit on crucial information and experience related to their equipment. A suggestion to handle these different work areas could be to divide them into business units where it should be organized separated groups with the best knowledge and expertise focusing each part. For each work area either if its product optimization or well planning, separated groups with the best knowledge and expertise should be gathered in teams. The essential with an acting team is according to Westhagen (2009, pp.121) that the participators in a team is committed to the specified tasks. The participators must have a common goal, purpose and a common mindset of following the same rules for how to work together (Westhagen, 2009). The best teams put a lot of effort into their work and invest much time defining their goal. Having something to reach for will bring enthusiasm into a team. A suggestion to a work environment is shown in Figure 5 inspired by (Henderson, Hepsø, & Mydland, 2013). Such a work environment must also be capable to communicate with similar teams and discipline at other locations onshore like vendor locations and different company locations.

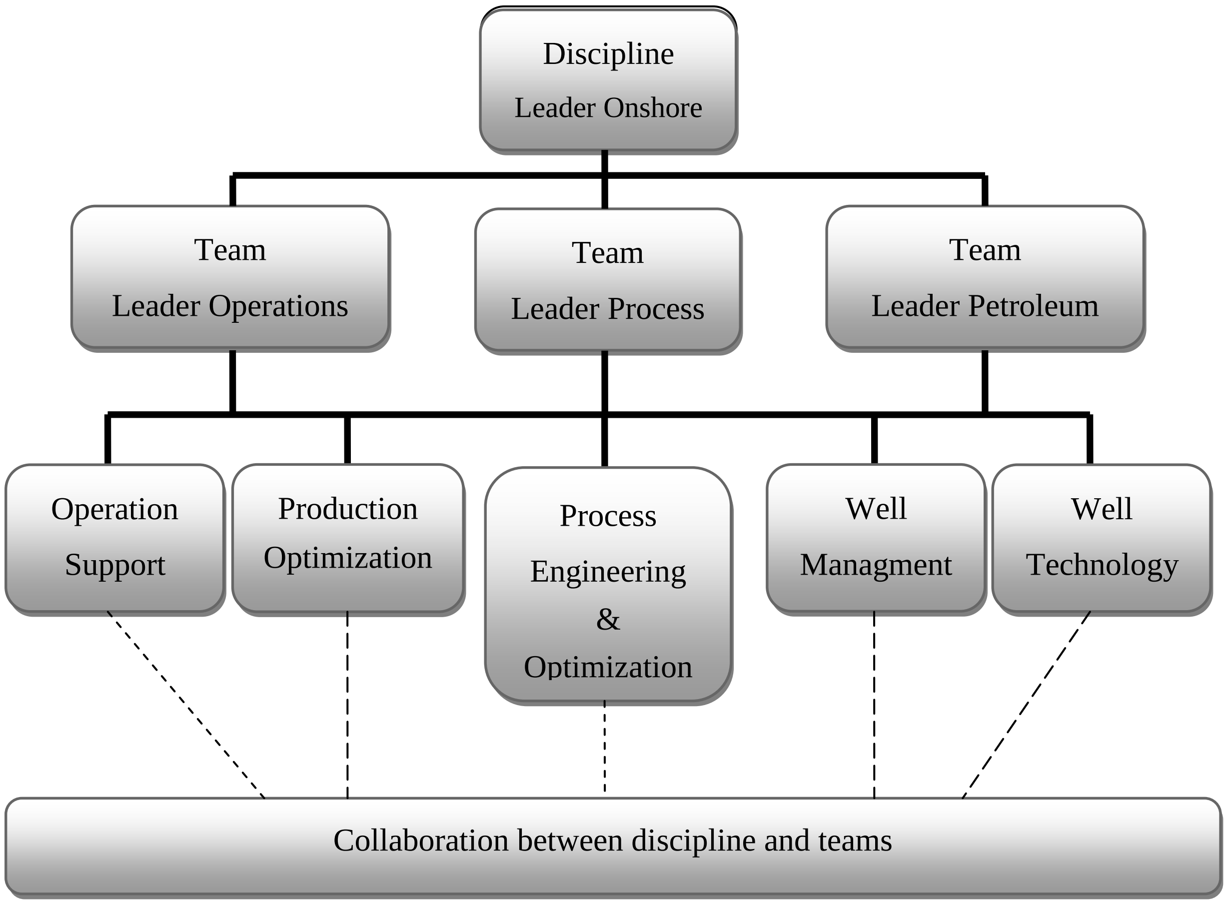

Figure 5: Collaboration based work environment design with thoughts of clarified task and responsibilities (Madsen, Hansson & Danielsen, 2013).

The important factors for organizing and work processes for such implementation can be summarized by (OLF, 2008 pp.9):

Organizational factors

- Organizational structure; defining different work disciplines and obtain a hierarchy composition of people to clarify leadership and tasks in a group.
- Business Models/Contract strategies; Achievements and goals for the execution and contract strategies for all involved parts.
- Work force; Presence of people and strategy for execution

Work Process

- Multidiscipline; Experience and knowledge will be streamlined between different location requiring common understanding and collaboration of the tasks. It is crucial that the personnel onshore also have experience with work processes towards offshore if maintains or other jobs are remote handled.
- Decision; Many decisions needs to be taken requiring skills, experience and clarified roles for each parts involved.
- External and vendor expertise; Evaluate which part have the best prerequisite for handling different circumstances.
- Remote decisions; Highlight responsibilities and involvement a remote part should have.

3.4 Onshore Centre

Centres for IO in the Petroleum industry has the purpose of integrate people. The centres functionality shall act as one knowledge arena where people with different knowledge and experience can collaborate with each other. Collecting different knowledge and experience will lead to better and faster decisions since people, systems and information are enhanced. The goal for onshore centres is also to have an increase in remote actions to land. More of the functionalities in the petroleum activity are desired to move to land so remote action can be performed. Optimizing and atomizing tasks will be emphasized to contribute to increase the value creation on the Norwegian Continental Shelf. Moving tasks and responsibilities to land will improve the safety for people, environment and asset value since exposing people for work in harsh environments poses oil and gas companies for a major risk (OLF, 2005).

The centres, actors and participants can be described in a “Triangle” (IO Center, 2011 pp.7):

- Research institutions
- Suppliers
- Operators

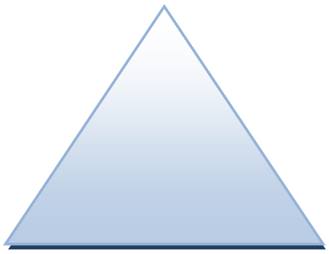

Figure 6: The "Triangle" of participants for centers for Integrated Operations (IO Center, 2011 pp.7).

Research institutions - will involve work tasks that are related to analysis and optimization. It will be deled with everything that has with improving the operation offshore and seeking newer and better operational methods, from improving reservoir management, well planning and process optimization.

Operators - involve 24/7 support onshore. This will be operators in control room onshore that has the same UI as the offshore operators. They will also have the possibilities to configure and control the process.

Suppliers - will be the third part that can support offshore operators. The supplier's involvement will be sat by the oil company's staff. The oil company staff will be the once that define the work tasks that the suppliers shall have.

Visualisation and collaboration through onshore centres will open many new doors for reaching people. Video conferences and live communication will contribute to improve better understanding and exchange of information, not only between people in Norway but also through international partners (Moltu, 2013). Geographically, it will play an important role where language, working procedures and culture can be a challenge (Moltu, 2013).

In the previous part chapter it was mentioned content in organization and work processes for IO. These elements will be important from the very first step in following up-tasks either it is within reservoir management, well or process system. Whatever category in question, data needs to be exchange between acquisition systems. Configuration data like (Olsson & Piani, 1998):

1. Parameters for all sensors and actuators (all Input/Output),
2. Parameters for the computation of derived variables,
3. Event definition and connection with control actions (if required),
4. Parameters for the digital controllers.

These may be important to exchange because all categories are at the end one complex system. Reservoir management for example will include its own physical processes and measurement systems. Therefore collection of data should be stored according to category. Data related to separate systems should be orderly organized in a database. Data coming from different systems may not necessarily be independent but also dependent on each other's information. Dynamic-data exchange should be considered since data coming from reservoir can effect applications in the well or process system (Wikipedia, 2013). For real-time data it is important that the data is trustworthy. When real-time data is received for analysis and optimization, it needs to be valid. That is important for researchers if data is going to be compared with a model of a process.

A model of the physical system will be an important tool for simulation, performance and condition monitoring in IO centres. With a mathematical model based on the physical parameters coming from the process, real-time data can be can be observed so that regulation to the real system can be done. Simulators of real plants are important so every complexity in the system can be tested out before implementation in real life. With experience and knowledge about the behaviour of the physical system a mathematical model can be recognized, state estimation and prediction methods can be used to atomize regulation of abnormal behaviour of the system (Ruscio, 2011). Transfer functionalities and finding methods for atomize the physical process is where the big money can be earned.

At the end visualizing and presenting the data and models are important so that every involved part can participate when taking the final decision.

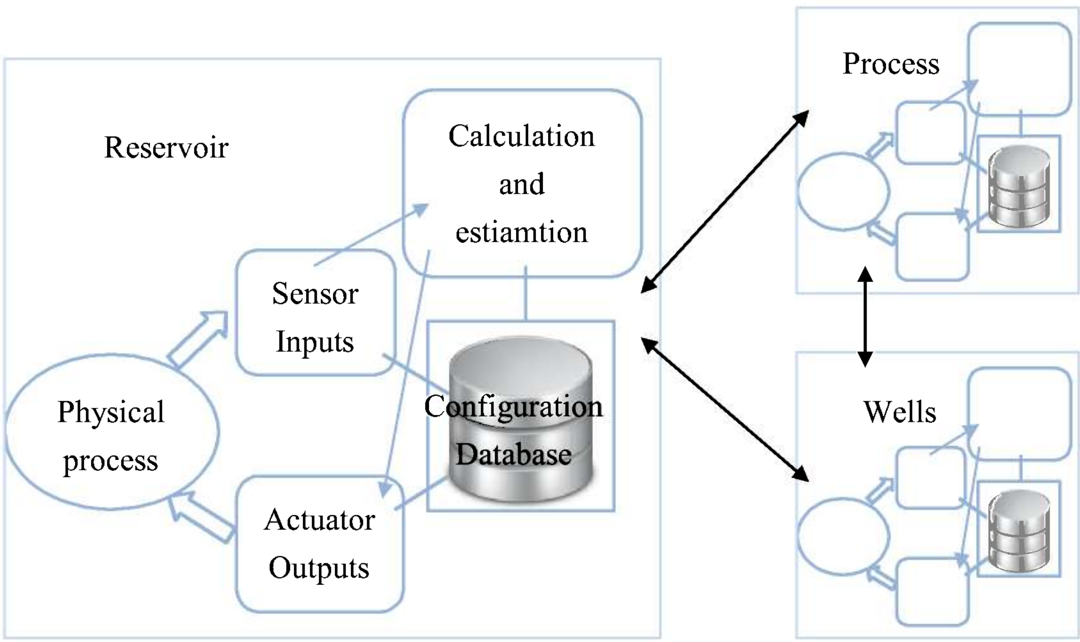

Figure 7: Data exchange between work areas.

With successful integration of knowledge, integrated planning and execution between people, the four important business objectives of IO can be achieved:

- Increased production
- Improved oil and gas recovery
- Reduced costs as a result of improving today's traditional operation
- Improved HSE

By collecting both the organizational responsibilities and the technical aspect of IO, it can be shown as illustrated in Figure 8 from a process control level (data from sensors, actuator) to a management level related to onshore centre where decisions are made.

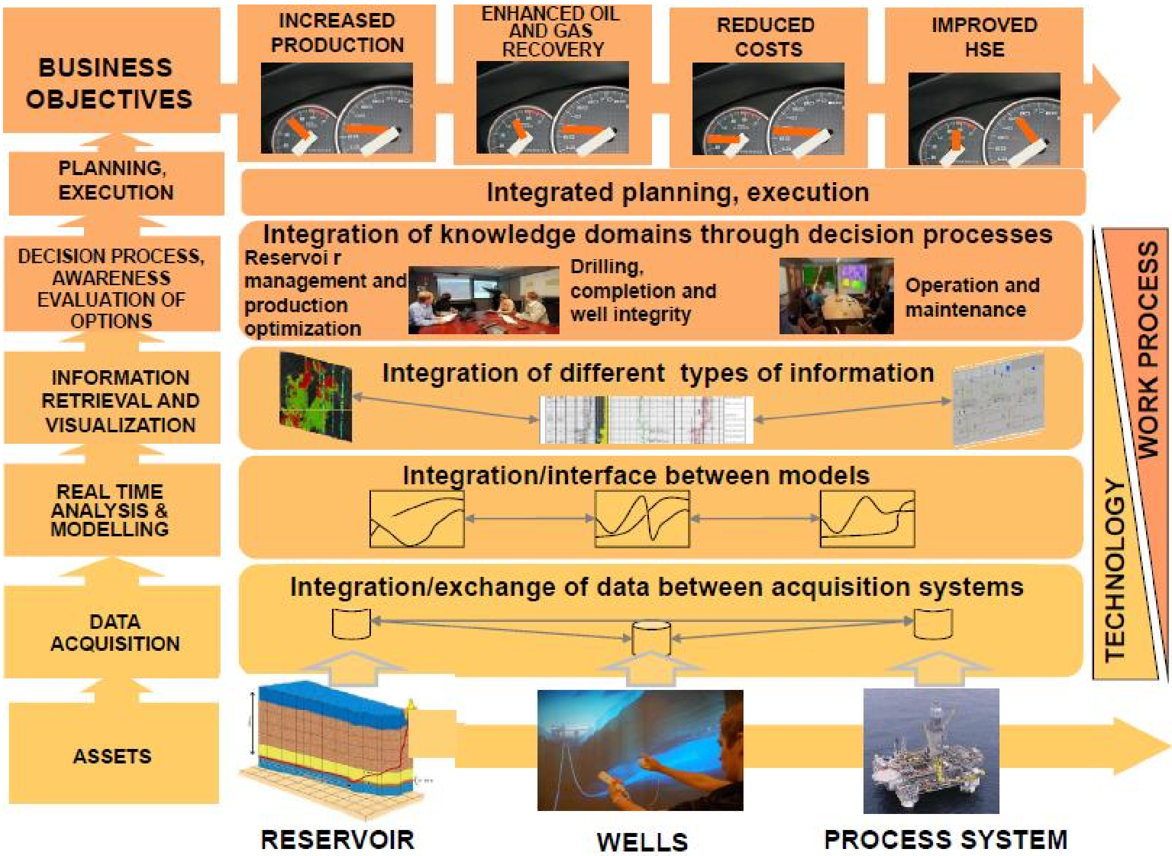

Figure 8: A layered presentation showing the organizational and technical aspects for centre of Integrated Operations. The clue is to show the approach from sensors to decision (IO Center, 2011 pp13.).

3.5 User Interface and access between offshore and onshore

The vital part of IO is the UI and access between an offshore plant and onshore remote processes. With IO there is a question about having an information system that can play a role that allows flexible and speedy access to accurate data. Onshore 24/7 support for operating companies need to have the exact same data that are monitored offshore. This means that the UI needs to be the same between both onshore and offshore, especially having in mind 24/7 support. When it comes to vendor support there is a challenge about security and controlled access. Giving uncontrolled access to external partners, can lead to fatal consequences if access to the plant is abused or if external personnel do not have good enough knowledge and experience about the plant. There is a certain risk assessment following with giving access to the plant. One thing is unskilled personnel and another thing are hackers. Giving access must not sacrifice the security level and should be done through secure mechanisms (Knapp, 2011).

In industrial computer systems offshore there exist IMS that has the functionality to handle data flow through different levels in the overall system. The IMS is not a standard entity. The IMS is adjusted to a specific project and its operating philosophy deciding what is going in and out. This statement can be supported by Sadagopan (2004 pp.2) which mentions that an IMS is a philosophy since much of management involves decision-making and decisions have to be supported by accurate data. Information systems shall help the management in decision making. When it comes to a general SCADA system on a platform all the electronic components involved constitute one big complex system. The IMS needs to understand the complexity of the system, the organizational dynamics, processes and control system (Sadagopan, 1998). For the operators located on the platform the important thing is data, coming from SAS/IMS. All data from the production plant need to go through a SAS system and the IMS will handle all data for monitoring and storage. Data that needs to be managed by SAS /IMS is production real-time data, historical data, alarm and event data. The UI of SAS shall be identical between on-offshore. The opportunity to do configuration and control of the process control system must be available.

For onshore 24/7 supports centres, the vision must be that on a process level the onshore personnel must have the same UI.

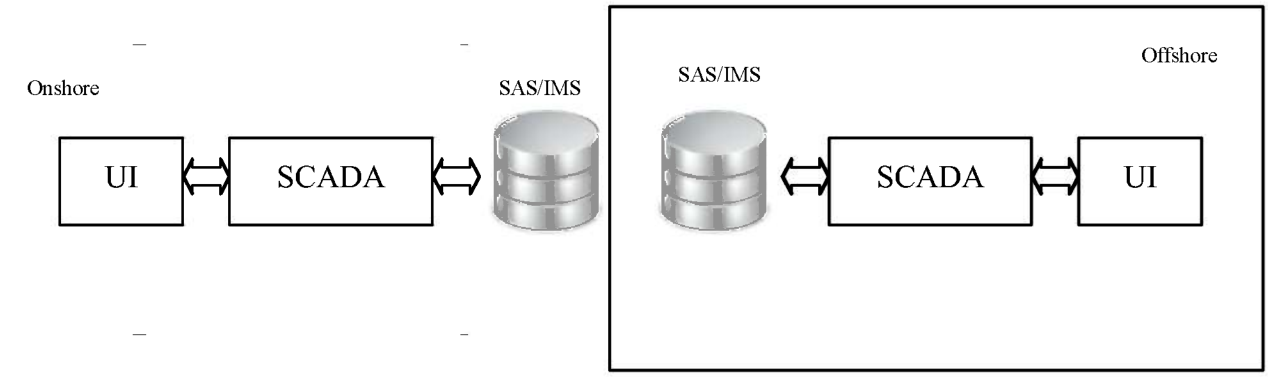

Figure 9: UI between on-offshore.

For vendor support it is necessary also to have the same access to process data but also to have access on a technical level. Let say a vendor is getting the information needed from the SAS/IMS. Then vendors can extract this data from the database to do analysis. What if a vendor sees optimization advantages that require entering the system on a technical level and adjust parameters for that exact controller, valve etc.? Then the vendor needs access to the technical level for reaching out to their equipment where the vendor can carry out a "Drill-

Down" operation. A "Drill-Down" operation can be described as going from a secure zone into a critical zone in an industrial network.

When such a mission shall be performed it needs to be expert personnel involved, specialist engineers. In modern time there has become a certain risk involved in IT operations. There will always be uncertainty involved in giving a third party full access to an industrial system. Keeping that in mind there should be questioned if there are outsiders or insiders that are brought into the plant system? It is important to consider if there are trustworthy people that will access the plant. According to Knapp (2011 pp.24) access control is one of the most difficult yet important aspects of cyber security. Would the security level decrease and become more vulnerable to cyber-attacks? Is it critical if outsiders are getting control of different control units in the plant or stealing secret information and accesses databases? These actions can be done by outsiders hacking into the industrial network by passing through firewalls.

There are methods that can prevent abuse and attacks from hackers, but one can never be too safe. Most commonly there are firewalls that are used for preventing attacks.

Giving vendors access that is limited to certain IP addresses and MAC addresses can be one solution. One must make sure that the once that get access needs to fill in employee numbers, password and following some kind of log inn procedure/authentication to get access. It is important to remember that there can be many different vendors that are involved. A role based application could be a good solution and may be absolute necessary. What kind of access to claim may be different between vendors and would most probably require different HMI. Having a fool proof HMI that prevents users to type in wrong parameters can be vital since there can be done comprehensive damages if a user has no restrictions.

Having the communication line open at all time may be something to consider as a possible IT risk. To reduce the risk of intruders from the outside world there can be discussed to only having the communication lines open at certain time during a day. This can be a very good solution if the operating companies have signed a service agreement with a vendor company. This can be solved by controlling the TCP[9] or UDP[10]network ports.

For the operating companies to achieve full control of who is having access at all time it can be included as a standard in work procedures that it is issued a work permission to those who want access to the system. The work permission could include company name, employee number and personal information that identify the person who is going to perform the job. Details about the work to be done, location and work area, describe risks, what it affects and the reason for performing the job. After the work permission has been filled in, the document

[9] TCP - Transmission Control Protocol is network protocol used for transferring information

[10] UDP - User Diagram Protocol is a network protocol used for transferring information

must be approved by a responsible person. After a job is done the work permission could have been submitted to know that the vendor personnel are checked out of the system. Work permissions could also be time limited. If the vendor personnel did not manage to finish the job within the time limit, they had to apply for new extended work permission. This is a question about frequent remote access. Authentication will be an important factor strengthening access control. Knapp (2011 pp.24) illustrates in Table 2 what can strengthen access control mostly presenting more and less the same that has been discussed earlier.

Table 2: Strengthening of access control (Knapp, 2011 pp.24).

Good	Better	Best
User accounts are classified by authority level	User accounts is classified by functional role	User accounts is classified by functional role and authority
Assets are classified in conjunction with user authority level	Assets are classified in conjunction with function or operational role	Assets are classified in conjunction with function and user authority
Operational controls can be accessed by any device based on user authority	Operational controls can be accessed by only those devices that are within a functional group	Operational controls can only be accessed by devices within a functional group by user with appropriate authority

The procedure and access permission for vendor involvement can be presented in a flow chart as below Figure 10.

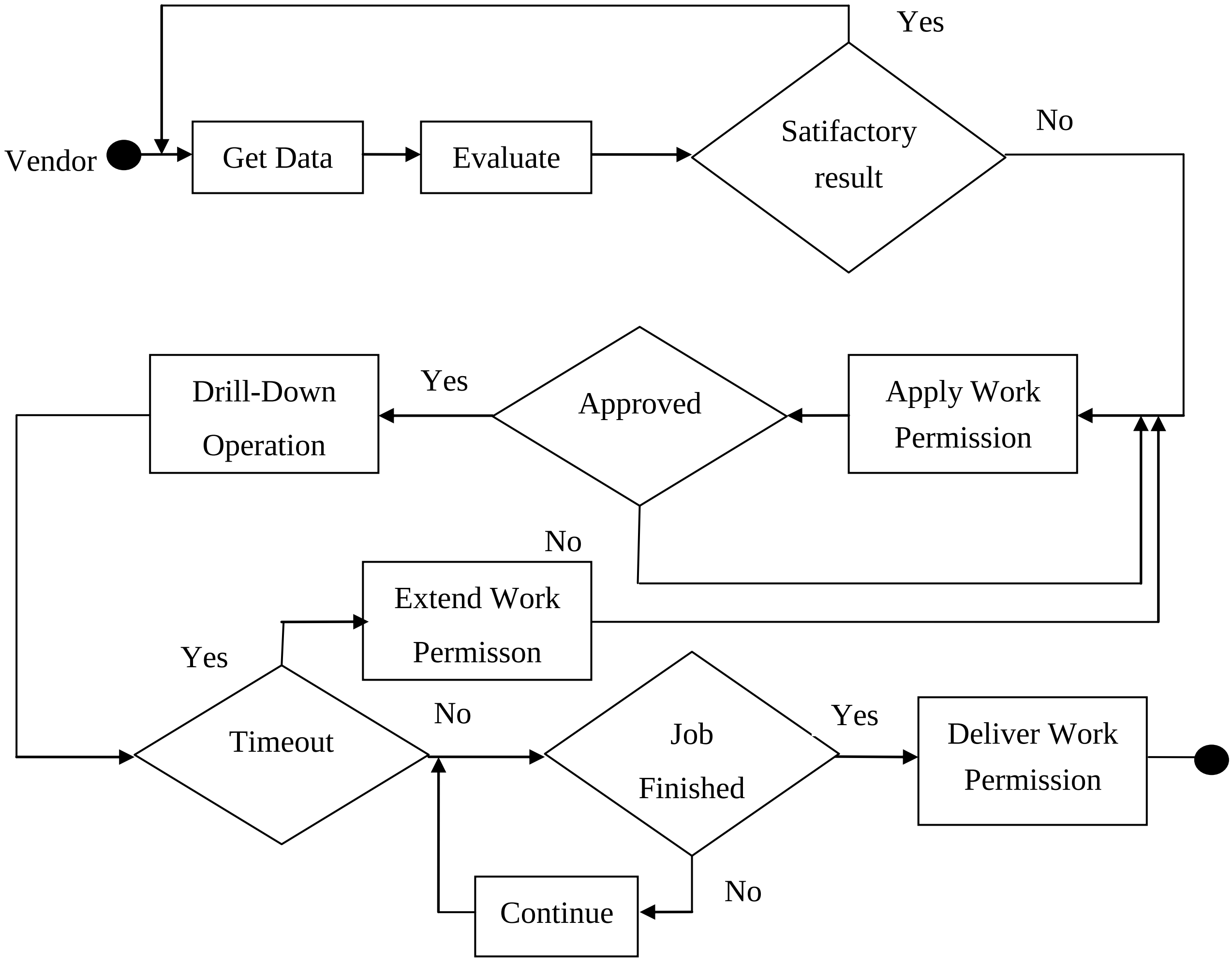

Figure 10: Flow chart for permission of a "Drill-Down" operation.

To illustrate a “Drill-Down" operation it can be considered a set of DCSs in Figure 11 where it is illustrated that a vendor's entry path is going through each level. This is just an example and the entry path for the vendor could be going into other levels in the industrial system. This DCS can for example perform collection of sensor data. The DCS may operate under one private network or more that include firewall settings that need to be passed to be able to get into the technical level. Let say a vendor is getting access to data from the database located on a process level. After some kind of trending has been performed, the vendor sees that a further "Drill-Down" is necessary to solve a situation. Then the vendor may pass through new firewalls to establish a connection to the specific equipment because a firewall needs to be present to obtain a certain security level that can prevent cyber attacks.

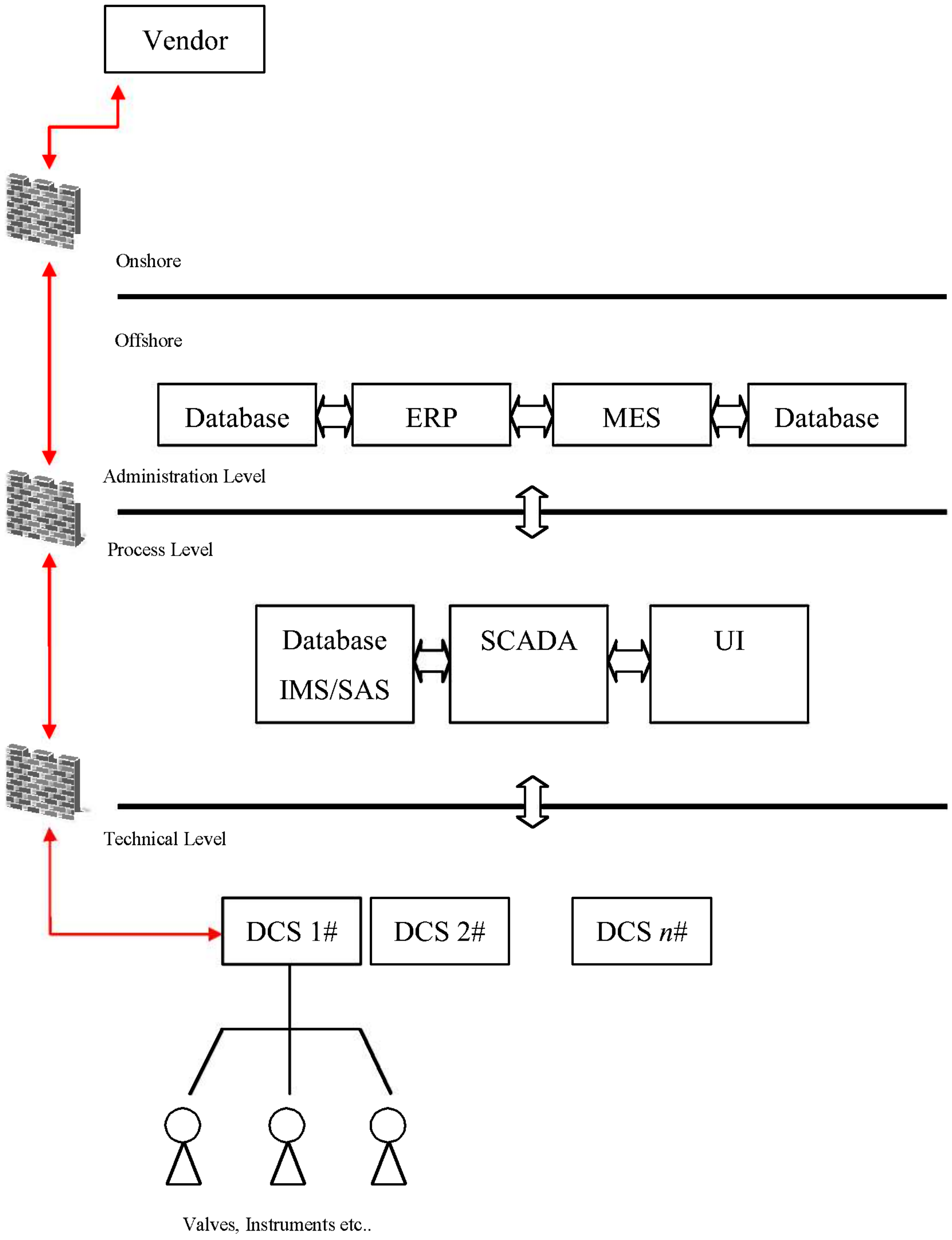

Figure 11: A "Drill-Down" operation may involve passing through many security barriers in an industrial network.

The vendor network can be seen as a Business network since a Business network will rely on information from SCADA and DCS systems (Knapp, 2011). A Business network will rely on operational data coming from the process system meaning that the Business network will need to be a replicate of the process system. The vendors are absolutely fully relied on having this information so an overall evaluation can be done. It is not so that the vendors are doing the business information management for the plant. This is the operating companies of the plants that do this analysis and sees the opportunities to fine-tune operations, improve efficiencies, minimize costs and maximize profits. Therefore they are the once that involve the vendors because the vendors may be those that are most qualified to do that certain job. When a vendor needs access to a plant it is a question about remote access. The vendor needs historian data and access to industrial devices.

The different levels in a SCADA system can be explained by different networks that a vendor probably must enter to connect the different devices. There have been mentioned three levels, administration, process and technical. These levels in a general industrial network can be familiarized with the business, supervisory, technical network or Business and information system, SCADA Supervisory system and industrial automation and control system. See Figure 12 (Knapp, 2011).

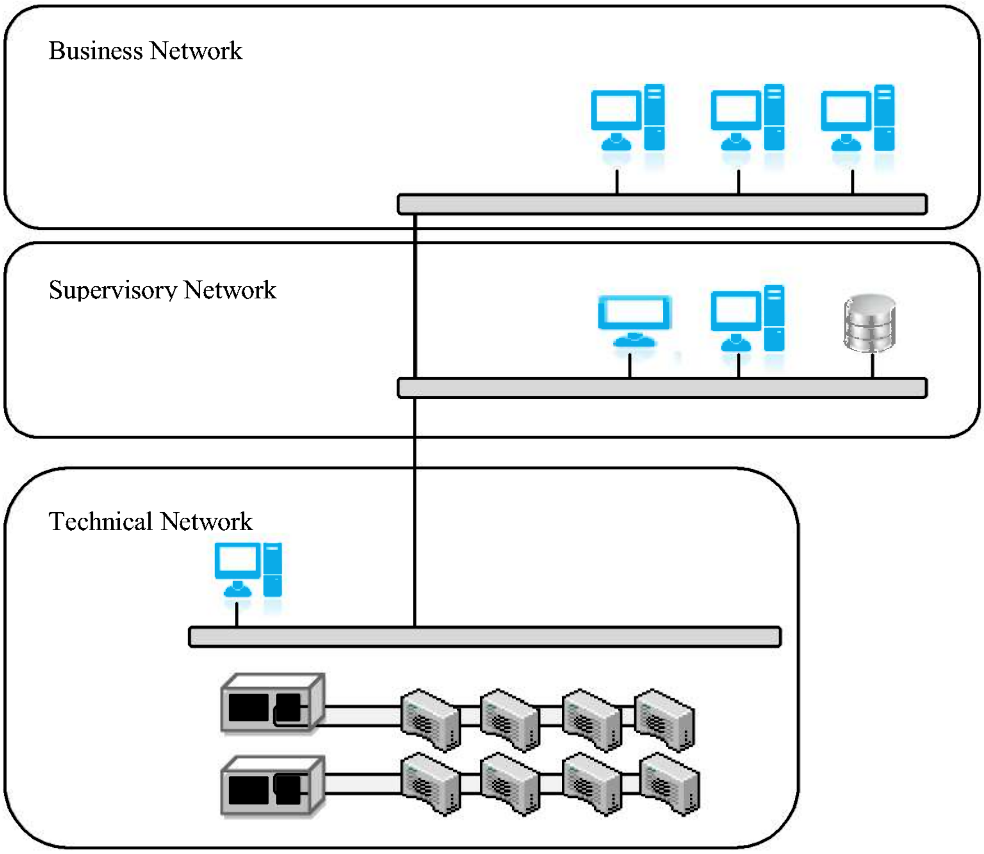

Figure 12: General industrial network distinct between area and functionalities (Knapp, 2011 pp.124).

What will be important for the vendor is information from the supervisory and technical network. In many industrial systems, industrial devices allow remote access for technical support and diagnostics. Knapp (2011 pp.154) recommends that remote access should be done via specialized virtual network or remote access servers (RAS). Access to RAS can be done via routable network connection and further with point-to point connections from known entities over secure and encrypted channels (Knapp, 2011). With different vendors come equipment that needs different HMI requiring their own applications and communication lines that constitutes different functional groups. Therefore it can be useful to divide functional groups into different networks. When a third part needs access they can be given access only to the specific network. Each network can then contain a terminal that contains a HMI application that allows a vendor to control and do configuration. That terminal will be responsible for one part of a process or certain vendor equipment. The terminal must also have remote capabilities so the vendors outside the network have the possibility to communicate with the terminal.

Accessing a terminal means there is a need for maintains or configuration. If a vendor needs access to historical data, how are this data accessed? If a vendor needs to see trends over a period of time historical data is needed. In a SCADA system there is a SAS/IMS database that stores process data. This database is often located in the Supervisory network. The Supervisory network where the control and monitoring part of SCADA is located goes under something called a Demilitarized zone (DMZ). The DMZ is something known as a secure/unsecure zone. What the DMZ does is isolating services and controlling traffic between zones and network in an IT system. If possible there is always an advantage to isolate services. Having a third part working in the DMZ is something that must be avoided and should be separated from vendor involvement because it only adds more IT security issues to handle. A solution to this can be to have a replicate of the IMS/SAS database onshore. In that respect all third part personnel onshore do not need to apply for a work permission to get access to historical data. A terminal onshore could have been used containing e.g. SQL application where SQL could have been used to execute queries against the historian server.

Summarizing, what has been mention above is if a vendor needs access to historian data or configuring and controlling equipments. The vendor can then be located any place in Norway communicating through the Internet. First a vendor must enter the operating company network. In relation to the company network there must be a terminal that can be connected with an IP address that allows the vendors to remote access. The terminal located at the operating company has the functionality as a Remote Terminal Unit or as previously mentioned, RAS. When work permission is issued and approved, then IT staff will configure firewalls so the vendors can get access to the technical/critical network offshore. Access will then only be given to a specific terminal like giving DMZ limitations. The vendor and terminal can be marked as permanent functional groups. A third part terminal and its devices can be seen as a functional group because within the group every entity can communicate with each other. Devices that can communicate with each other are talking the same language. It can be said that the devices are sharing a common protocol and thereby constitute one functional group. If there is a question about historical data then the vendor only has to connect to the terminal server located in the onshore enterprise and from there access the historical database (see Figure 13).

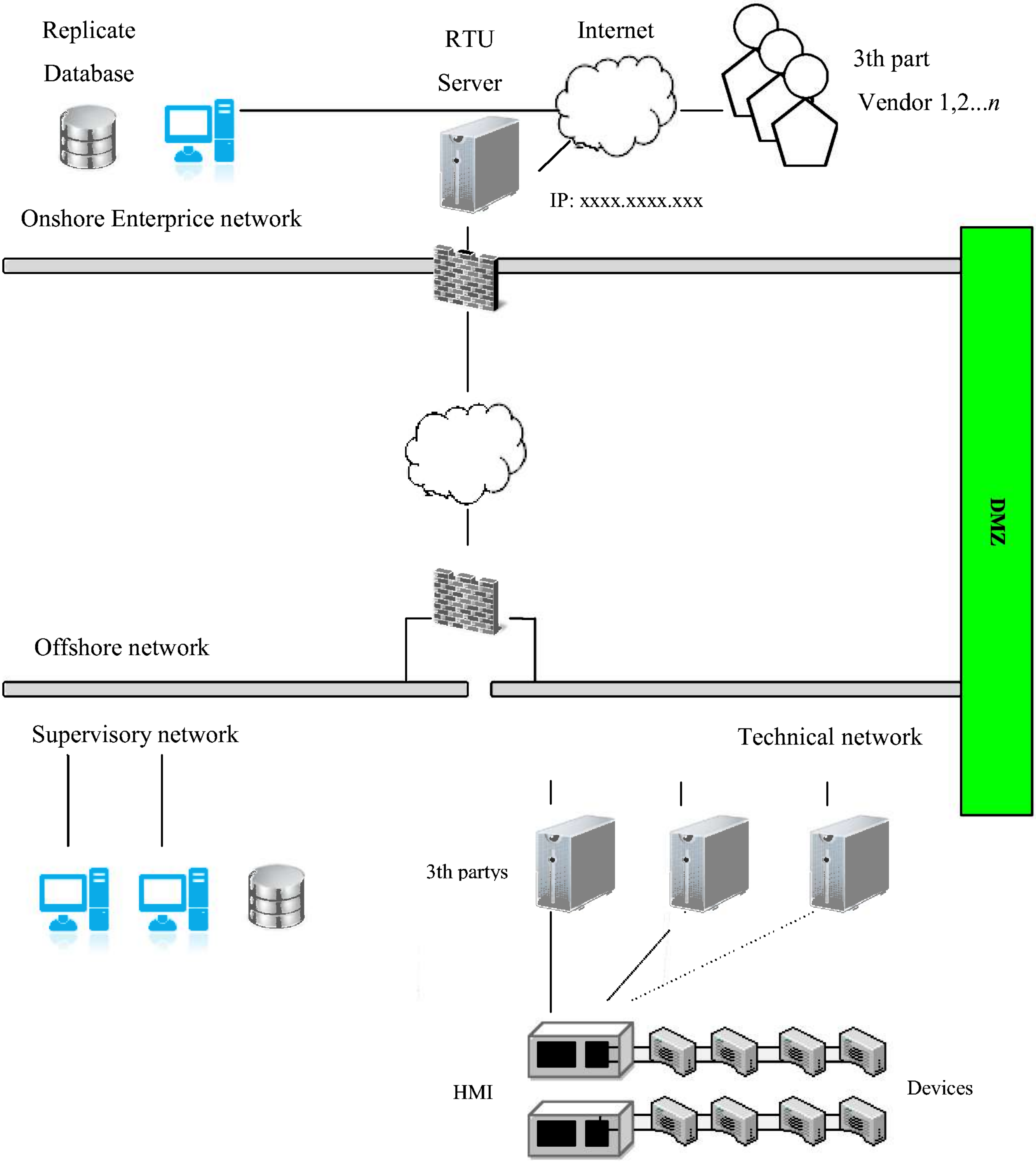

Figure 13: Suggestion to vendor remote access.

For human inter action Knapp (2011 pp.155) also mentions some important elements with user and roles when it comes to accessing an HMI. This supports what is being said previously that with accessing HMI to adjust a process it is just as important to define which users should legitimately communicate with devices and to require a degree of Identity and Authentication Management (IAM) which defines user and roles.

This is a huge advantage of vendor support for the oil companies. When it occur failures on equipments the operating companies' personnel can choose if they want to involve the vendor or not. When the operators offshore get error indications from the SAS system involving some equipment they can ether fix it themselves or they can also request the vendors how to fix the equipment. If the equipment must be fixed by the vendor, the vendor can get remote access to the equipment, preparing and get an overall picture of the situation so the vendor only brings the necessary tools to the platform. If there is just a small adjustment or maintains that must be done to fix the equipment then maybe the vendor can guide the operators through the process by visual communication.

3.6 Risk Assessment

Risk concerning remote access is important to screen. When opening entry path for vendors it means opening a path where the vendors get access to the most critical network in the entire industrial system (Knapp, 2011). The technical network is often divided into something called the critical network. The critical network represents all devices that actually control the industrial process which are extremely important to secure (Knapp, 2011). The technical network resolves in the most ultimate target to attack since it involves devices that can make huge damage to the process if accessed by outsiders that have no clue about the functionality and consistency of the system. Because of remote access it is possible for attackers to get access to the critical entities. Having located a replicate database in the onshore enterprise it can be looked upon as one minor risk factor since a third part is held out of the offshore SCADA system. To prevent attackers to get full access into a critical network it is important to have DMZ zones that can limit the access of a third part. By having DMZ zones it can be prevented that larger parts are getting overruled by outsiders. With DMZ zones groups can be isolated in the way that one vendor only gets access to their equipment. Limited access allows creating isolated functional groups that belongs to each vendor.

Diagnostic access that the vendors need opens for direct entry path to the control system and the 3th part terminal. That terminal will handle all the insecure protocols that come with different vendor equipment and devices. Possible entry point path for vendor access is shown in the following Figure 14.

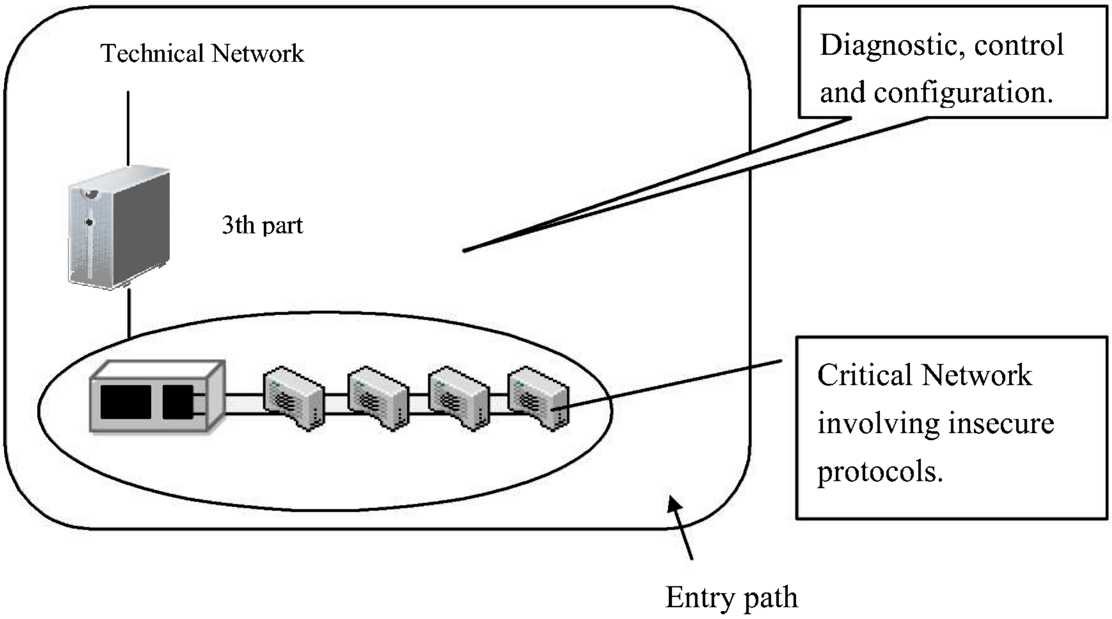

Figure 14: Access entry path for diagnostic control and configuration.

Regarding remote access it is important to separate and isolate vital functions in a system. Creating functional groups that only are dedicated to specific tasks can contribute to minimize the risk for attacks and also minimize the damage of what an attacker is capable to do.

There is much vulnerability assembled to a technical network or any industrial network. The path into industrial network can be poor configured firewalls, in general poor network security policies and structure or through software bugs and all kinds of entities that can be accessed directly (Knapp, 2011).

There are regulations and standards to be followed concerning industrial network security like ISA-99 standard that are dedicated to industrial control security and offers many security recommendations (Knapp, 2011 pp.17):

- FR1-Access control (AC)
- FR2-Use Control (UC)
- FR3-Data Integrity (DI)
- FR4-Data Confidentiality (DC)
- FR5-Restrict Data Flow (RDF)
- FR6-Timely Response to an Event (TRE)
- FR7-Resource Availability (RA)

These functional requirements do also consist of multiple system requirements (SRs).

ISO 27002 is another standard for security recommendation but is more a general standard compared with ISA-99 that directly defines security recommendation towards industrial systems. ISO 27002 handles in general information technology, security techniques and code of practice for information security management (Knapp, 2011).

When a remote access is created through RAS it is always important that the connection is not done directly into the critical network, but rather pass some kind of cyber defense as firewalls that can ensure secure enclaves. Allowing communication, allows network communication where open ports service the entry path where proper configuration of firewall are very important.

Configuration of firewall should be done in a manner as if there is a risk picture of (Knapp, 2011):

- Traffic in both direction through communication lines
- IP address information and source addresses (define nodes and links)
- restrictions for protocols that can access through firewalls
- awareness of the services that are performed is inbound to the functional groups

Especially for remote access Knapp (2011 pp.132) mentions that all field access communication should be done via private lines, a controlled environment and limited access to devices and functional groups.

With remote access comes responsibility. There will be a risk letting people with lack of knowledge and experience into a system concerning the operator company and vendor personnel. Giving unskilled personnel access can lead to misunderstanding and instability. Personnel that have access or get access needs to be familiarized with work procedures, ICT tools and know the complexity of the physical system.

Another aspect with risk related to remote access, is if vendors are getting access without any kind of work permission or without anyone checking that it is safe to work in that area. Take a situation where a vendor has the opportunity to turn on the electricity for some kind of rotating equipment but it is actually turned off because it is carried out a service on that equipment. That can lead to a serious situation if an installer is working on that equipment. It is therefore very important to follow some kind of work procedure where risks are being asset about the current situation and work area. Work permission should be provided to have an overview of the current situation

4 Define and Present Data

For a monitoring environment related to onshore centers, were focus is on receiving data for analyzing and optimization, it is described some general elements that are important to considerate when defining and presenting data.

It may be a matter of improve and optimize the process or a desire for observing and extending the lifetime of certain equipments. The common thing for this is that people who decide what procedure to do need to understand what kind of data are needed and specify which attributes that should be collected for the job to be done. Gathering data is very important to make it possible to get acquainted with the process and equipment. Before starting an experiment or an experimental program, it should be provided that observations and solutions can be documented (Wheeler & Ganji, 2010). In this chapter it will be provided a systematic approach and guideline for designing, planning and implementation of experiments.

4.1 Carrying out an experimental program

There is a verity of experiments that can be carried out, but a common thing for achieving good experimental programs is to have systematic order and a strategic approach. An experimental program should be a study of a certain activity and documented extensively (Wheeler & Ganji, 2010). Although different studies have different names of the various activities, the steps or experimental program has a general approach (Wheeler & Ganji, 2010). There can be many reasons for carrying out experimental programs but for IO there is special interest in investigating certain activities in the oil & gas industry that lies in the term "optimization". For example there can be many different investigations such as maximizing a chemical process output; minimizing amount of contents used to produce some kind of material; or reduce the time for receiving data for a computer system. If a response surface has been discovered and identified it can be used for optimization (Wiley & Sons, 2010). The general steps of an experimental program can be as the following approach (Wheeler & Ganji, 2010 pp.432):

1. Problem definition
2. Experiment design
3. Experiments construction and development
4. Data gathering
5. Analysis of data
6. Interpreting results and reporting

4.2 Problem definition

When an experimental program is initiated the objective of the experiments need to be clearly stated. For example in the oil & gas industry there is one main goal: to deliver oil and gas. For this procedure there are stages that involve different people and stakeholders. For presenting a product it may involve design engineers, for fabricating the product it may involve process engineers and other types of engineers that complement the type of knowledge and experience that are needed. All parts and elements involved in an experiment should provide input (Wiley & Sons, 2010). The response that is expected from an experiment is the outcome from observations. However it could be that the response or required output is poorly defined. Included in performance monitoring there can be many instruments and sensors that can participate finding the required output, it all depends on the cost and success. Performance monitoring can include a low-cost oriented testing program for presenting and demonstrating the performance, but if low performance is discovered it then may include much more comprehensive testing and instrumentation (Wheeler & Ganji, 2010). The option of low-cost or high cost testing can also be a trade between a safe or high risk experiments. Decisions for such approach should be taken with seriously concern and great care in consultation with the different parts involved. According to Wheeler & Ganji (2010, p.433) engineers frequently spend insufficient time defining the problem, and they initiate the design process without even being aware that they have eliminated many better options. The awareness of this is that the process of a problem definition is undoubtedly very important and should be taken with concern from the start. It has been said by Locander & Cocanougher (2011 pp.1): "without a well-defined problem statement, time, energy, and money may be wasted no matter how well the remainder of the project is conducted". Below there are illustrated important elements in the process of providing a problem definition Figure 15.

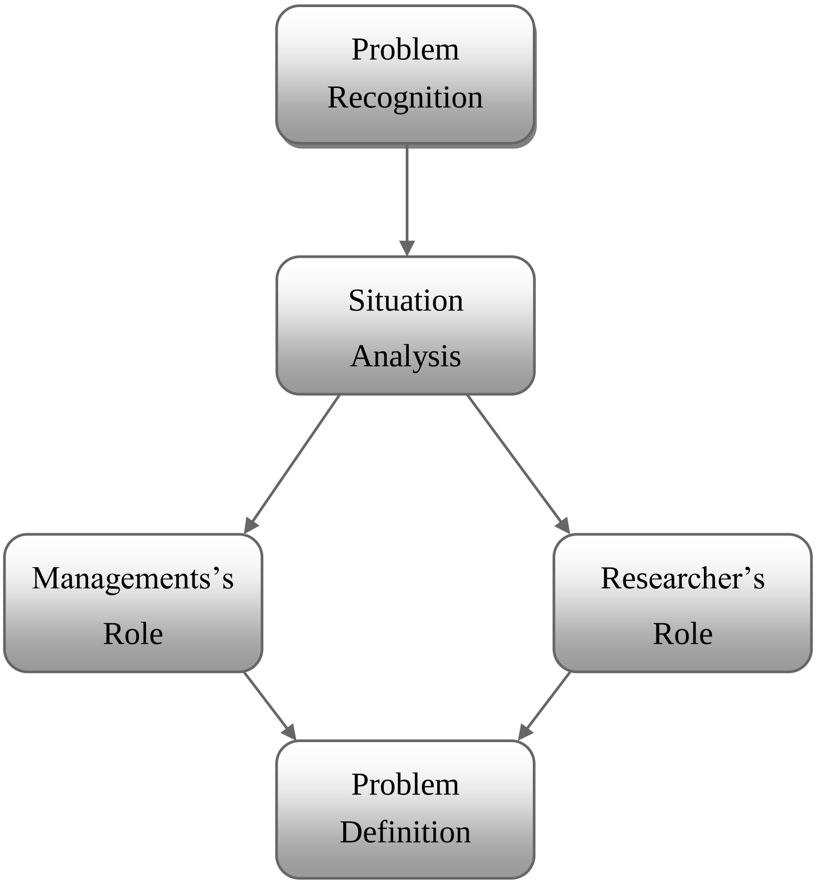

Figure 15: Elements in a problem definition process (Locander & Cocanougher, 2011 pp.2).

4.3 Design of Experiments

In the planning phase of experimental design it can be included the following components that can be used to make proper preparations for a analyzing and optimization program (Wheeler & Ganji, 2010 pp.433):

1. Searching for information (usually a literature survey)
2. Determining the experimental approach
3. Determining time schedule and costs
4. Determining the analytical model(s) used to analyze the data
5. Specifying the measured variables
6. Selecting instruments
7. Estimating experimental uncertainties
8. Determining the test matrix (values of the independent variables to be tested)
9. Performing a mechanical design of the test rig
10. Specifying the test purposes

Components involved in the process of planning experiments involve also people that are not directly involved with the technical part of the experimental program. Cost and scheduling plays an important role for carrying out experiments and contributes discovering unexpected events. The planning phase is an important opportunity to investigate the comprehension of the experiment, to exclude unexpected failures and foresee failures that may occur. Such a brainstorming can be an important factor of a successful experimental program.

According to Wheeler & Ganji (2010, p.433) most test programs are carried out in two parts: a preliminary design and a final design. The scope of a preliminary part will mainly be a study including cost estimates and results. As a program is provided it will be reviewed and studied by a higher hold in an organization. Then a group will be chosen to follow up and complete the experiment.

4.4 Constructing Experiments

In this phase there are carried out acceptances testes of instruments and sensing elements that are included in the package of the experiment. When data are defined and all the components involved in an experiment chosen, they need to be tested and validated to see if they pass the requirements that are sat for the operation. These testes are often done in workshops with the vendors and engineers. There is the consulting engineer that decides if the components involved pass an acceptances test. If the validity of the tests is not accepted the vendor needs to adjust and improve their components if they want their equipments installed in a rig.

This phase is probably the most expensive part of the program since all the equipments need to be procured and installed. It is very important for further investment that the first experiment is carried out successfully after it is installed in the plant. Often companies are very skeptical to new methods, especially if there is no documentation from earlier projects showing the new solutions have given satisfactory results.

There have been examples from the industry were new solutions for diagnostic monitoring has been used without giving positive results. It was a situation where a failure on a motor was found by diagnostic monitoring. The operators stopped the process for carrying out a service on the motor. Stopping the process means losing money and that is what the companies want to avoid, since down-time means loss of income. While doing service on the motor it was found that it was nothing wrong with the motor. The failure was to be found in sensors. That resulted in the diagnostic monitoring was unplugged and disconnected from the system. The solution was to do it the traditional way with service inspections.

4.5 Data requirements

If components involved in an experiment pass the acceptance test data can be gathered for trending and analyses. When doing performance observations or diagnostic checks as part of an experiment it is need for defining the requirements for data. Besides knowing the exact process data it is also a need for specifying which attributes should be collected for each task. When data is gathered it needs to be presented and by only having raw process data it will be difficult to analyze and find the cause of irregular behaviors that may occur. Attributes to include can be (Omerovic, 2004 pp.115):

- Timing: When did it occur?
- Symptom: What was observed?
- Mechanism: how did it occur?
- Cause: why did it occur?
- Locality: Where did it occur?
- Consequences: Impact of alarm and warnings?

- Repeatability: Is the error a one-time occurrence or does it happens regularly
- Severity: ripple-effects
- Phase: Life cycle phase of errors and irregular behaviors
- Activities: the activity taken place when errors occurs

4.6 Data analysis

When data is gathered it needs to be analyzed. There are many methods for analyzing and validate data. Checking data is important to make a statement about the validity of the data (Wheeler & Ganji, 2010).The first thing to do when analyzing data is to process the data and get it visualized. The data need to be studied and observed by plotting it in different ways. By looking at data and comparing the data with similar data sets or valid data sets, there will be noticed things that can indicate failure or errors (Janert, 2010). Questions can be answered by looking at the data and observations can lead to unexpected incidents that may occur in an experiment. It is very important to know that the data used for analyzing is valid. Validation of data is important to know if the data are trustworthy or not.

Analyzing tools are most often decided by what program software that a company licenses or what the engineer are familiar with. It is also a question of what the experiment and data set require, to make it lead to some reflection.

4.7 Interpreting Data and Reporting

Results shall be presented and documented in a report when experiments have been carried out. The reasons for anomalous behaviors and trends in data should be explained along the observation of the experiment. The trustworthiness of the data should also be derived using methods for validating and checking the data. The interpretation of the data should be used to respond to all the project objectives that has been decided (Wheeler & Ganji, 2010). Writing a report representing and explaining the result will be very important for further commitment. If the experiment is primarily meant for making good money by selling the package solution to the industry, documentation will be crucial.

5 Performance monitoring and diagnostic

This chapter concern work tasks related to IO. Performance monitoring and diagnostic is part of the work responsibility analysing and optimization towards IO. It is in this chapter concentrated on to look into opportunities for performance monitoring and diagnostic of an electrical machine. It is in such type of example where fault detection can be used to extend the lifetime of equipment and also to detect already faults in time before even larger damages are done. Such example touches the area "Field Engineering" on a platform. Field Engineering involves among other equipment installed on a platform. Performance monitoring of an electrical machine is a relevant example for analysis and optimization on a platform. Still the main purpose is to highlight that it can be many areas to consider when looking for solutions to perform analysis and optimization.

5.1 Performance monitoring and diagnostic of electrical machine

In all industrial activities both land based or offshore operations it is important to reduce the number of failures in a process to a minimum. This can bring a need for maintenance routines that must be incorporated in an operation enterprise. For onshore centres such maintenance plans need to include methods for error detections for electrical machines so personnel has a clear strategy if there are situations that need serious attention. In this performance and diagnostic experiment there is used an asynchronous-motor[11]. An asynchronous motor construction its operation and behaviour is based on the induction principle meaning that it can only be used for alternating current. The reason why it is called an asynchronous motor is that with a given load, the rotor rotates with an asynchronous rotational speed with respect to stator rotational-field. The construction of an asynchronous motor consists of two main parts, an outer stationary part, the stator, and an inner rotating part, the rotor. In both stator and rotor there are electric conductors that will constitute the electro-dynamic force effect (making the rotor rotate). The stator contains of electric windings, the rotor can be constructed with ether electric winding or something called a short circuit rotor. To understand the practical terms mentioned, the construction of such a motor is shown in Figure 16.

An asynchronous motor presents in an industrial context, complex electromagnetic systems and with this in mind there should be performance monitoring that is based on numerous methods.

[11] Asynchronous Motor - A rotating electromagnetic machine which works after the induction principle

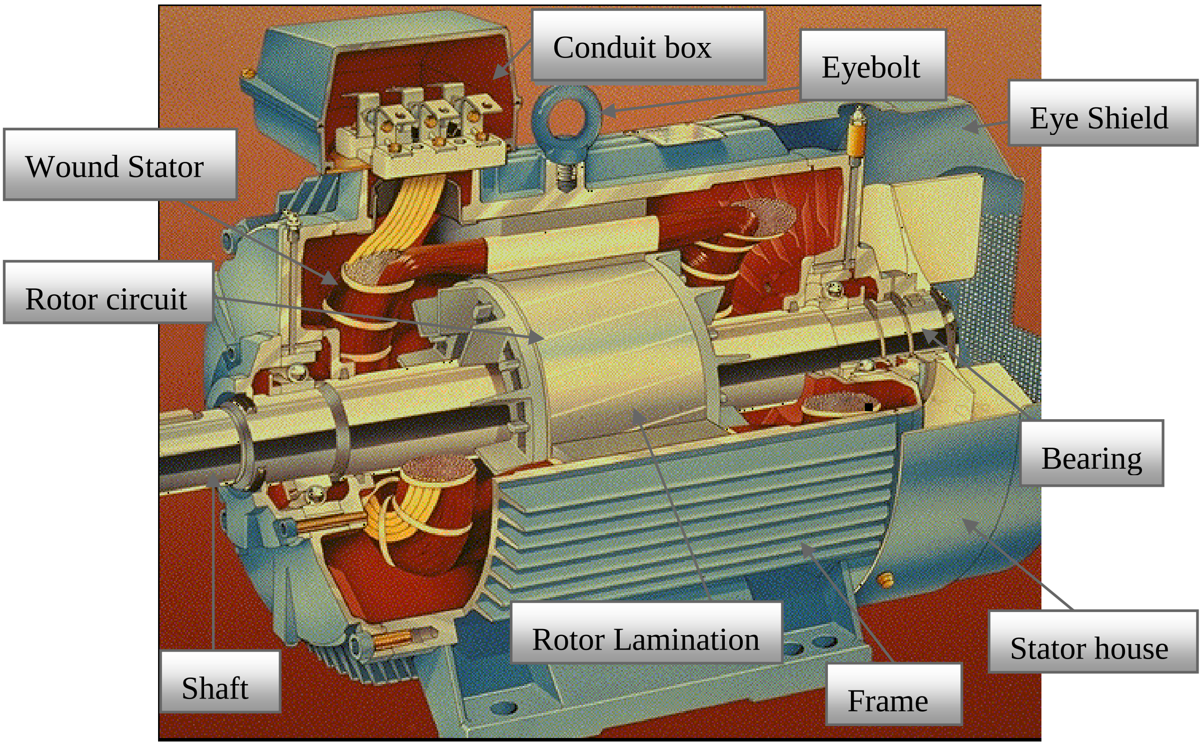

Figure 16: The construction of an asynchronous motor with a short-circuit rotor (Strømme, 2002 pp.16).

5.2 Regular failures and error causes in asynchronous motor

It is decided to be done an experiment that includes performance monitoring and diagnostic of an asynchronous electrical machine. For that experiment there is a need to be derived a proper problem description by the engineers that will perform this job. This should involve everybody that are included in the experiment such as, engineers with electrical, instrumentation and system and control monitoring background.

For electrical machines there can be mentioned some of the most typical failures that can occur (Throsen & Dalva, 1998):

- Bearing
- Stator Windings
- Rotor staves
- Shaft & Mechanic coupling
- External equipment

Each of these bullets mentioned above are important factors in the behaviour of electrical machines. The bearings for a rotating machine play an important role and accounts for more than 40% of all electrical failures (Hamid, Subhasis, Seungdeog & Choi, pp.9). Many machines in the industry are running under non-ideal conditions. Often instruments that are used to measure and control motor systems are dependent on the dynamic properties of the motors bearings (Hamid, Subhasis, Seungdeog & Choi). Bearing failures can be caused by attrition over time as a result of poor maintenance, shaft deviations or radial tensions. These failures can cause vibrations and larger attrition.

To monitor and solve this problem there are instruments that can be used for detecting such a failure. Bearings failures can be detected by vibration-measurements, puff pulse-measurements using piezoelectric[1] transducers or acoustic measurements (Hamid, Subhasis, Seungdeog & Choi). To find the optimal solution for this it will be important with collaboration between the different engineers and also to interrogate with the vendors of such equipment.

Stator failures – stator failures are usually related to windings and isolation failures. It can be demonstrated that in such cases there can be a little increase in frequency components in respect to a completely healthy machine (Joksimovic & Penman, 2000). It is shown that a reliable method for detecting failures in stator is to analyse and detect the axial leakage of flux (Thorsen & Dalva, 1998).

Rotor failures – for a short circuit rotor the most common problem is related to fraction in rotor staves. This can be caused by overcharge if overloading the axel. When rotor failures occur it causes velocity variations, moment charge and variations in the frequency components of the stator current and axial flux (Thorsen & Dalva, 1998). As a result of fraction in the rotor staves there will be registered overheating in the other conductors and flame arc can occur since it becomes an unsymmetrical electric current flow.

Mechanical failures – may occur if the rotor is out of its axial position. This is a very common problem that causes vibrations that will result in bearing problems. When the rotor is out of its axial position it will be extra loaded on the bearings. This is a problem that is taken very seriously in the industry as it can cause consequences for the entire operation. Vibrations are very important to detect. When a rotor is out of its axial position rotating harmonic frequencies in the motor inductance will occur (Gritte, Habetler & Obaid, 2000).

6 Methods for condition monitoring of asynchronous motor

This chapter shows the importance of doing proper preparations and to consider different areas and methods to perform analysis and optimization on an electrical machine.

An experiment will not be performed in practice but theory and illustration will be emphasized to support a practical implementation of a failure detection method on an electrical asynchronous machine. The scope of the experiment is to observe and detect failures so that actions can be taken before equipments go into a critical condition that can harm its performance. By performing such an experiment there can be detected anomalies behaviours and contribute to extend the life-time of equipments.

The goal is not to seek a new revolution of fault detection but to understand the methodical approach and what benefit it can have for IO. The theoretic example will reflect much of what that has been said in chapter 4 about how to perform an experimental program.

When a proper problem description is derived there is a need to determine a strategy for solving the problem. The experimental approach for cost estimation, uncertainty analyses and scheduling are important parts in an experiment but it is more a management issue than a technical issue. That part needs to be handled on a management level in collaboration with the engineers that are responsible for the specific experiment.

For the technical part of the experiment the sensing elements that can sense the wanted data need to be defined so orders can be made for constructing and developing the performance monitoring and diagnostic analysing environment. It is important to examine if wanted measurements are measurable or not. Which methods can be used for solving the problem?

There are many techniques that can be used. A literature survey can be useful. For fault diagnostic of electrical machines several methods have been performed and carried out in the industry. Some of these strategies are (Toliyat. Nandi & Choi, 2013 pp.4):

- Signal-based fault diagnosis
  a) Mechanical vibration analysis
  b) Shock pulse monitoring
  c) Temperature measurement
  d) Acoustic noise analysis
  e) Electromagnetic field monitoring through inserted coil
  f) Instantaneous output power variation analysis
  g) Infrared analysis
  h) Gas analysis

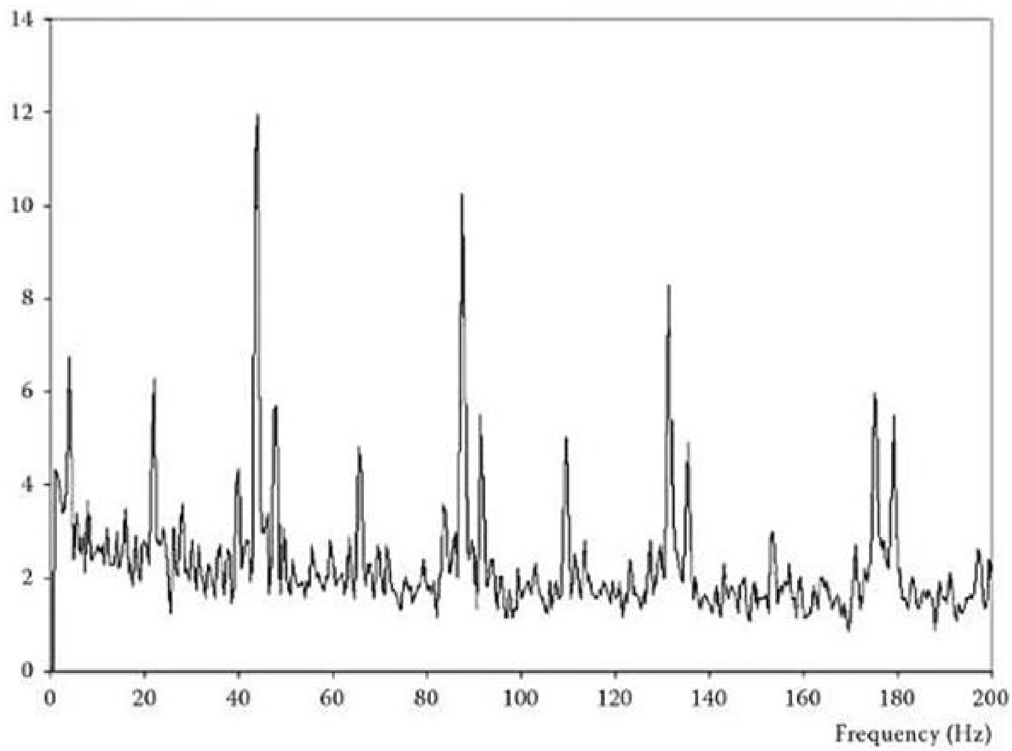

Figure 17: Monitoring of vibration spectrum for an electrical machine used for detecting bearing faults (Toliyat. Nandi & Choi, (2013 pp.5).

i) Oil analysis
j) Radio-frequency (RF) emission monitoring
k) Partial discharge measurement
l) Motor current signature analysis (MCSA)
m) Statistical analysis of relevant signals

Further on it will be focused on rotor fault detection in an electric asynchronous motor using the method "Motor current signature analysis (MCSA)".

6.1 Analysis of the Induction motor current supply

Analysing the current supply frequency spectrum for an induction motor can give many answers to the condition of a motor. Analysing the current supply frequency spectrum can be done by using a Spectrum-Analyser that is an electronic measurement device that can measure frequency and signal level (SNL, 2013). With such device the electrical signal can be monitored.

Another method, is importing the electrical signal to a computer after doing measurements. Then Fast Fourier transform (FFT) can be performed on the signal so the frequency spectrum can be analysed. FFT is a mathematical algorithm that is used widely in applications and in this case can be used to decomposing a sequence of values into different frequencies (Wikipedia, 2013). By performing FFT a signal can be converted into the frequency domain to analyze the frequency spectrum.

6.1.1 Rotor failure

In the start sequence of an induction motor it can occur currents that are 5- 8 times the nominal current of the motor (Toliyat. Nandi & Choi, 2013). This is a large stress factor for the machine especially the conductors where the current flows. How large this load affects a machine depends on how long a motor takes to obtain normal running operation. A consequence of these high currents that may occur is the heat exchange inside the stator house that can damage the performance of a motor. Motors have usually a fan connected on the rotor axle that constitutes the cooling performance of the motor. This fan has its minimum performance in the start sequence for the motor since the rotor is running slowly. Therefore the fan will not contribute reducing the heat exchange inside the motor when it is in its critical period.

The consequence of breach in one of the conductors in a short-circuit rotor will most probably result in (Thomson & Rankin, 1995):

- Overheat can occur in a short circuit rotor stave.
- As a result of broken rotor, flame arc can occur.
- Because of a broken rotor stave, higher current will flow in the rotor circuit.
- Larger mechanical and thermal stresses especially in the start sequence can occur.
- Laminating of the rotor can be damaged because of the high thermal stress.

For analysing the current supply frequency spectrum for an induction motor, its urgent to be said something about the frequency of a healthy motor to be able to decide whether a motor contains rotor failures or not. What can be expected in an asynchronous motor is that the stator and rotor are operating with different frequencies under nominal operations (Thomson & Rankin, 1995). This is a result of deceleration that occurs because of friction and iron losses inside the motor. The rotor frequency will then decrease and stator and rotor will get different frequencies. This can be expressed by:

$$f_2 = S_N * f_1 \qquad (1.0)$$

where

f_1 = stator frequency

f_2 = rotor frequency

S_N = deceleration

When analysing a stator current frequency spectrum it can be found multiple of the deceleration frequency as sideband of the stator current fundamental harmonic component (Throsen & Dalva, 1998). Because of breach in the rotor circuit there will be asymmetry that can be pointed out that will produce negative and positive sequences of rotor MMK[12]. These sequences will occur symmetric around the fundamental frequency with rotor frequency $s\omega_1$. The angular frequency for the stator current fundamental frequency component can be expressed as $\omega_{1.}$ As mention in the bullets above when there is a breach in one of the conductors, it occurs overheat and an amplitude increase in the frequency components. The sidebands will have the same location as a healthy machine (Vas, 1993). From this there can be distinguish between a healthy machine and a machine with error in the rotor circuit (Vas, 1993).

In the stator when it is a rotor fault it will occur MMK with positive and negative angular velocity created by asymmetry in the rotor, this can be expressed by (Starr & Rao, 2001)

$$\omega_r+s\omega_1 = \omega_1 \text{ and } \omega_r-s\omega_1=(1-2s)\omega_1 \tag{1.1}$$

where

ω_1 = Stator angular velocity

Therefore the stator frequency will now with a fault in rotor include both the fundamental frequency component ω_1 and the error frequency component expressed as $(1-2s)\omega_{1.}$ It is not unknown that an electrical machine with a rotor fault will produce a negative frequency that will induce a current. This is proven in many articles.

The frequency caused by the rotor fault is twice the deceleration frequency and will occur as sidebands in both the positive and negative sequence. In Figure 18 it is illustrated a situation where it is clearly shown sidebands that occur beside the fundamental frequency of the stator. This figure shows what can be expected by doing a FFT analysis. When performing FFT analysis the frequency components of a signal can be filtered out to give an overall impression of the signal. In this situation the anomalies behaviours can be detected.

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[12] MMK - Magnetic Motor Work

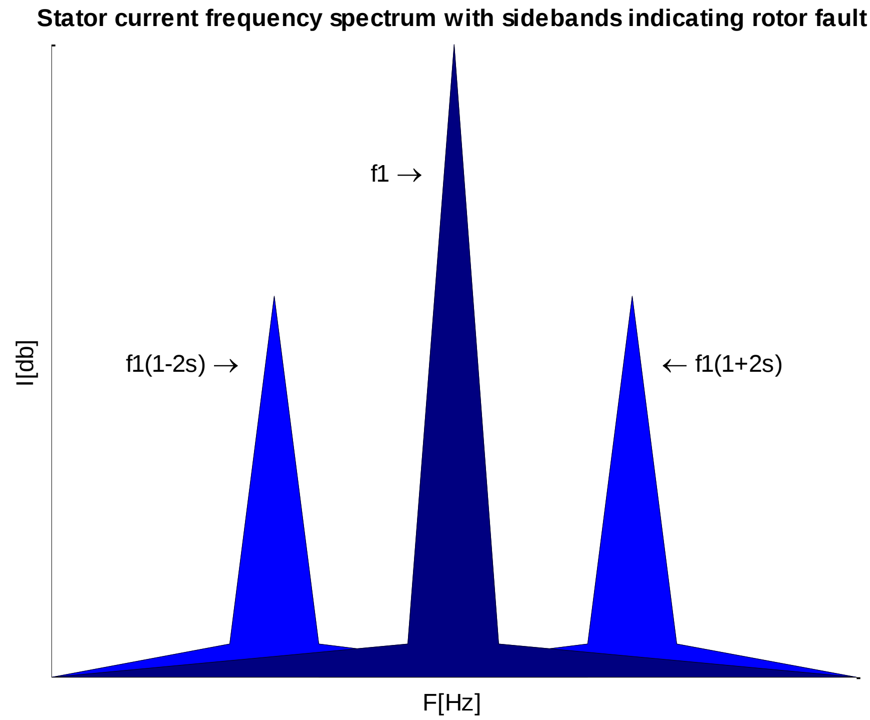

Figure 18: A typical current supply frequency spectrum with sidebands indicating rotor faults.

From the equation (1.2) there can be derived an expression for the *k-te* frequency components that occurs (Thorsen. & Dalva, 1998):

$$s\omega_1 \pm k\omega_1(1-s),\ k = 1,3,5,7\ldots \quad (1.3)$$

There is shown that a breach in a rotor stave will produce both a negative and positive stator flux with respect to the stator fundamental angular velocity ω_1 and the rotor rotation. The relationship between the negative and positive induced stator flux can be expressed:

k=1:

$$\omega_1 + (2s-1)\omega_1 = \omega_1-(1-2s)\omega_1 = 2s\omega_1 \quad (1.4)$$

6.1.2 Defining parameters and sensing devices

After a problem description has been derived and proper preparation and researches for an experiment has been done, it is now possible to define the right parameters that are needed for creating a performance and monitoring environment. Once the parameters are defined it can be installed sensing devices so data can be presented for a monitoring environment. In the case of detecting rotor faults that can harm the performance of an induction motor and its process relations, it was question about observing the current supply of an induction motor. Analysing the current supply is known as the concept of “Motor Current Signature Analysis (MCSA)” (Chang, 2003). MCSA is used to analyse trends and anomalous behaviours of electrical systems. A typical MCSA system used for performance monitoring of an induction motor includes different elements as:

- Sensing device
- Signal processing
- Monitoring ability

A sensing device is needed for detecting the parameters. This requires that the parameters are observable. If not, other methods need to be considered. Current supply observation was meant to examine the frequency spectrum of the electrical signal. To examine the frequency spectrum of an electrical signal, the electrical signal needs to be processed in some way. Components and software can be used to convert the signal. Monitoring ability is needed so the frequency spectrum can be analysed so decisions can be made.

The objective of this experiment was to analyse the current supply of an induction motor. The important parameters of this experiment are:

- Voltage signal [V]
- Current signal [A]

Motor current analysis is a procedure that can be done by measuring the voltage and current (Chang, 2003). When measuring voltage, the difference of electrical potential between two points is detected. For measuring voltage it is needed two phases of different potential, often referred to as a positive phase potential and a negative phase potential. Voltage is expressed in Volts. There are different techniques and sensing elements that can be used for measuring voltage. The most famous one is probably a voltage divider that is integrated in voltmeters[13] (see Figure 19).

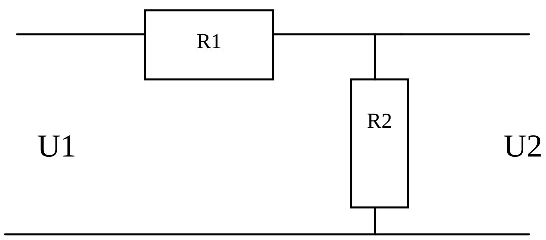

Figure 19: Voltage divider where the voltage can be measured before or after R1using a resistor R2.

When measuring the current a shunt sensor can be used. A voltage will always be the input signal as it do not exist current without a potential difference. The intention of a shunt resistor is converting the current to a voltage signal. In that way the magnitude of the current can be detected (see Figure 20).

[13] Voltmeter - A measurement instrument used to measure electrical voltage

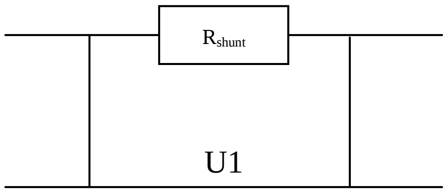

Figure 20: The current flows through the shunt resistor so the current can be measured.

In current meters a shunt resistor with a low value is used so that the current can flow through the shunt and be measured. Another method for finding the current is by taking advantage of the Hall-effect. The Hall-effect arises when electrical current flows through a conductor (see Figure 21). When current flows through an electrical conductor it arise a magnetic field that can be sensed using a hall sensor. The way the current is measured with a hall sensor, is by using a clamp-meter that enclose the conductor, and the magnetic field is measured.

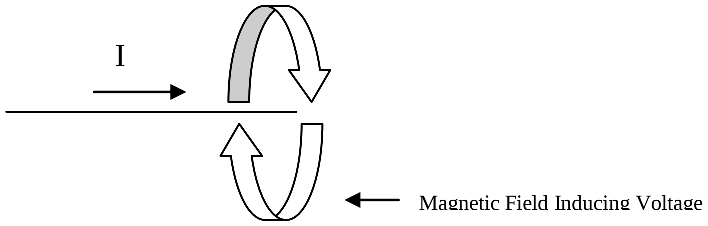

Figure 21: An electric conductor inducing an electric Voltage. This is the Hall-effect.

As the parameters are defined the physical components can be introduced. For sensing the current supply of a motor a clamp meter can be connected to one of the motors connection phases. This can be done in the cabinet or junction box that is associated to the specific motor. The measured current signal then needs to be transferred to a signal processor that can handle the raw data. For trendsetting and presentation of the frequency spectrum it can be used a spectrum analyser. The spectrum analysis will present the current signal in the frequency domain. With a spectrum analyser the frequency signal can be monitored.

From the signal processer, the signal also can be imported to a personal computer. Once the signal data is imported, it can be used software that can perform FFT. An FFT algorithm can be used to convert the current signal into the frequency domain so the frequency spectrum can be monitored. What that can be expected by performing FFT is the magnitude information about each frequency component in the current signal.

The MCSA system for this experiment can be illustrated with the physical components involved (see Figure 22).

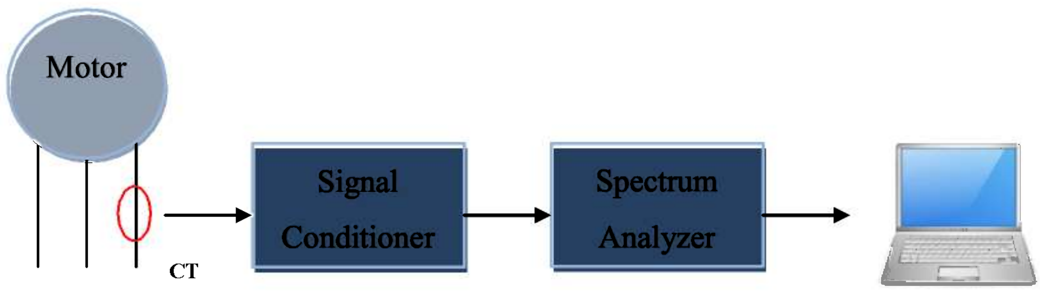

Figure 22: A general Motor Current Signature analysis system.

The current is measured with a current transducer from one of the phases for the electric motor and transmitted through cables. The current signal is then processed and transformed to observe the frequency spectrum. With a spectrum analyser the frequency spectrum of the current signal can be analysed and monitored.

The raw signal can also be imported into a computer system using some kind of data acquisition system. When the data is imported, programming tools can be used to perform FFT analysis and to plot the results for detecting sidebands from the frequency components.

7 Analysing and Optimization

The important functionality of IO is to seek opportunities to improve today's traditional operation. Analyse and optimization is in general a detail study of improving and understanding the behaviour of a process. It is a question of experience and knowledge about analysing trends and using methods that can improve a process output. Optimization can also mean improving part of a process like detecting anomalous behaviours that can extend the lifetime of equipment.

For doing analysis and optimization there must be used a kind of detection method that rely on experience and knowledge about a system. If there is a question about diagnostic and detecting failures, parameters that are representing a system need to be identified. To determine if there is a failure, it is natural that there exists knowledge about the system's normal behaviour and variances to distinguish between a healthy or broken system (Keesman, 2011). One method for identifying a system is by using "System Identification" where a model can be created based on observations. When a model is created, diagnoses between an analytical model and the real process can be determined by analysing the state of estimated parameters (see Figure 23).

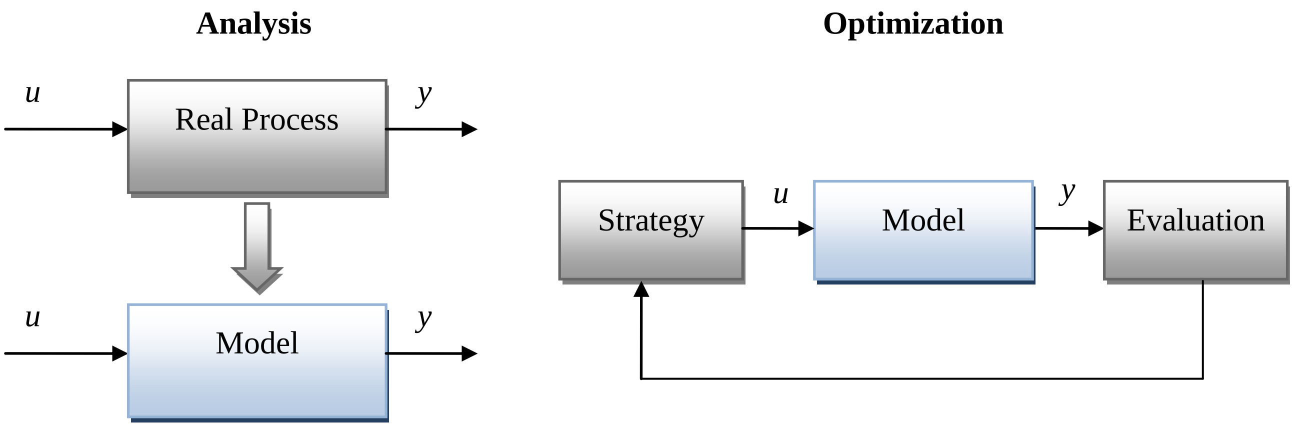

Figure 23: Analyzing and Optimization procedure (Nelles, 2001 pp.3).

7.1 System Identification

System Identification is a method used for identifying a real process. There are different methods for System Identification. Some approaches for identifying a system is based on having a mathematical model that describes a system or something called "black-box" methods that are based on not having any mathematical model of a system. There are many definitions of a system. What follows a system is in this case considered to be a process that contains different variables that interact with each other. There may be situations where the desired variables are unknown. Then the system needs to be treated as a black-box, identifying its inputs and outputs. If all desired variables are available there is a matter of identifying the process initial state to be able to control the process. Putting sensors into a plant indicate that there is a demand for monitoring and observing a system (Keesman, 2011). Sensors are part of an analysing and optimization problem, doing the job of gathering parameters that can be used for control theory.

System identification involves setting up experiments for parameters to be collected. Collecting input and output signals require logging of a real system so it can be identified (see Figure 24). Data can be imported into a computer system where it can further on be used to create a model (Keesman, 2011). It is important that the real system is adequately signed.

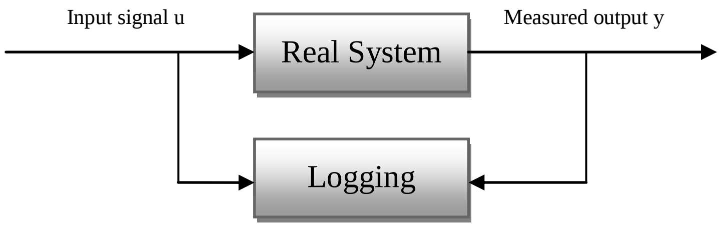

Figure 24: Identifying a real system by logging its input and output response.

For identification of a general dynamic system there can be defined some system variables.

Input u: An input sequence is most often recognized as the input *u*. The input *u* is meant as the signal input to the system that can be controlled and manipulated by the user.

Disturbance w: The disturbance *w* is a known phenomenon in sensor and instrumentation technique. Disturbance originates from the environment and directly affects signals. Sometimes it is necessary to remove these frequencies by filtering the signal.

Disturbance v: The disturbance *v* is the second phenomenon that occurs when measuring the signal. This is known as measurement noise. Measurement noise is not possible to manipulate (Keesman, 2011). It often occurs when a signal is measured discretely instead of continuously (Wheeler & Ganji, 2010).

State x: The state x is the result of the observations of the behaviors of the input *u* and the disturbance *w*. Therefore the state *x* is representing the dynamics of the system.

Output y: The output *y* is a result of the process output. It represents the effect of manipulating the input *u* and the disturbances that affect the final output. The output *y* is therefore the result of many observations that have been carried out through logging the outputs of a real system.

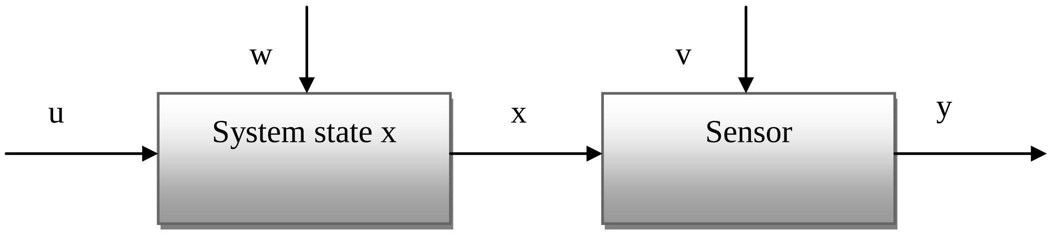

Figure 25: Illustration of a general system (Keesman, 2011 pp.2).

The variables that are mention in Figure 25 above can describe a process system. Identifying a system with the system variables can be done by using different techniques. With a mathematical model created for a specific system, an experiment can be set up and the inputs and outputs can be logged to identify the system. With an adequate data set available, techniques as "Trial and Error", "Least square" or "Step response" methods can be used. The "Trial and Error" method is based on logging the inputs and outputs of a process and compares it with a mathematical model. By analysing the two different plots the model parameters can be adjusted in respect to the real process for the model to be optimized fitting the real process better. Typical model parameters that usually need to be adjusted are time constants and gain. There is also often noise corrupting a signal and other anomalies behaviour as spikes and outliers that need to be removed. This is called signal processing. An easy technique that can be used for removing noise in a signal is by subtracting the mean value from a signal. Taking the mean value from just the first part of a data set may probably be enough to smoothing the signal.

A step response technique is a method where a step in the input signal is given to the system for an observation of the system can be done. Step response technique is an experiment done in the time-plane. The input voltage to a system is mostly used for testing the response of a model based on physical laws or a transfer function. Using a first order transfer function model for describing system, time delay, gain and time constant, can be calculated. Having a second order transfer function model may include more parameters to estimate as damping factor, natural frequency, gain, phase angel and wave frequency. Poles, zeros and the transient response are important for analysing and designing for regulating systems. For example if a process is important to control, a step response is a good technique to use for control engineers to be aware of the dynamic of a system. A process that needs to be controlled shall first be tested in an open loop to identify the system before adding feedback. When the system is identified, a closed loop can be added. The "Least Square Method" is based on a logged data set including inputs and outputs of a process. The Least Square is a mathematical approach that can be used for minimizing the error that describes a process (Tveito, Langtangen, Nielsen & Cai, 2010). An example can be a set of data that describes different locations in the time plane. How can these different locations be described with one straight line? The approach is to minimize the deviation between the line and the different locations and to find the optimal description of the different locations. What's being said is that a regression line is used to fit the observed data (Johansson, 1993).

The variables x and y can be presented in something called a "State Space Model" (SSM). A SSM is a linear model that can describe a system (Ruscio, 2010). A SSM can be described on the discrete form:

$$x_{k+1} = \mathrm{A}x_k + \mathrm{B}u_k \tag{1.5}$$

$$y_k = \mathrm{C}x_k \tag{1.6}$$

The integer k >_ 0 is the discrete time, x_k the state vector, u_k is the input vector. The constant matrices A, B and C in the SSM are of appropriate dimensions (Ruscio, 2010). The constant matrix A is the state matrix, B matrix is the input matrix containing the manipulated or measured inputs and C the output matrix. A discrete SSM model is based on using discrete data. Discrete data is variables only available at defined sampling frequencies. This means that the periodic observable parameter x(t) is sampled with a certain sampling interval. For a continuous variable x(t) it exists a discrete x(k). The x(t) variable is only measured for k = 0 ,1,2... etc. This gives that the discrete variable x(k) can be describe as follows (Johansson, 1993 pp.36):

$$x(k)_{-\infty}^{\infty}; x_k = x(kh)\ , \quad for\ k = \cdots, 0,1,2, \ldots \ldots$$

where the variable h is the sampling period.

When using a discrete sampling frequency the discrete variable x(k) will be discretized from x(t) as Δx. It can be seen as the continuous signal is switched on and off.

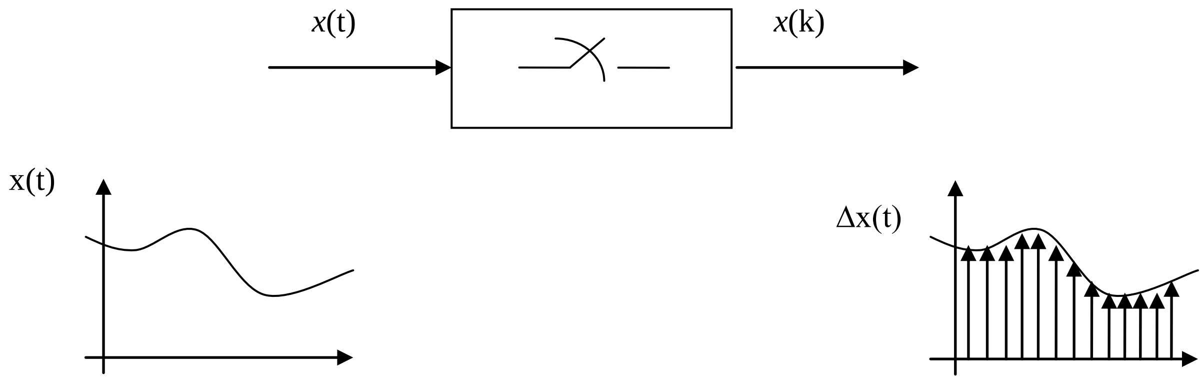

Figure 26: A discretizied signal can be compared to switched continuous signal (Johanssen, 1993 pp.36).

In a "Blackbox" method it is estimated an SMM model based on inputs and outputs. There are no mathematical models of the system. The method for identifying a system is by using advance algorithms that can recognize a system based on its inputs and outputs. This means that a model is not found by physical laws but on forcing and respond (Johanssen, 1993).

7.2 Observers

Basically for an observer is a mathematical model. To generate a model the input and output parameters need to be collected. When a model is created of a real system, the signals that generated a model can be used to enable detection of a healthy or a broken system. Distinguishing between a healthy and a broken system can be done by analysing estimated parameters. These are techniques that assume a prior knowledge of the variation that occurs in parameters and models with respect to a system's operating conditions (Trigeassou, 2011). Diagnostic methods using analytical models can be divided into three categories (Trigeassou, 2011 pp. 12-16):

- State estimation techniques
- Residual generation technique
- Identification techniques

State estimation technique is based on finding the right estimates according to the real system. Values of the estimates can be adjusted by finding the right eigenvalues[14] so the estimates can converge to the real values. An analytical model can consist of many state variables that can influence the model error in a linear way or with nonlinear parameters that influence the model in a nonlinear way. Using estimation techniques involve evaluating a model output based on its input, which further on requires using identification techniques. Using a finite

[14] Eigenvalue - Is a solution to a characteristic equation.

input and output data sets can be seen as the procedure of learning how the model acts and detecting the dynamic of a system. The more training sets that are used, the better conclusion can be taken to determine if the model is good or not. Optimizing a model structure or its parameters, in order to minimize the error that can cause a loss in describing the real model, is by training the model with new data. This technique has some similarities with artificial neural networks which are also based on training and validation data sets to confirm a status for a model (Nelles, 2001). There are many advantages by using a state estimator (Halvorsen, 2012 pp.2):

- Not physical measurable: A state estimator can calculate unknown parameter to a system that may not be physical measurable.
- Expensiveness measurement equipment: A state estimator can calculate state variables so money can be saved instead of making purchases of valuable measuring equipment.
- Measurement noise: A state estimator can give better estimates of measured states because often measured states contain noise that can disturb the signal.

A process system develops and changes over time. The evolution of a model might change because of changes in its environment or its local variables. When the process changes the estimated parameters will deviate from the real system. The principles of observing a real system collecting estimates that can describe the process, is shown in Figure 27.

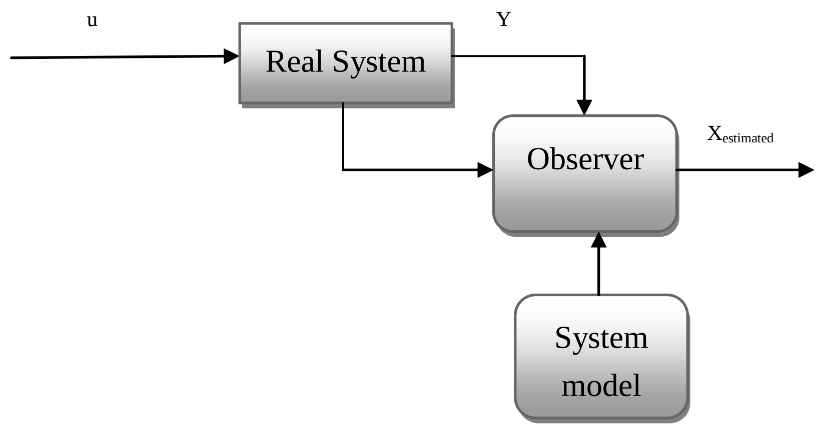

Figure 27: Principle of observing a real system collecting estimates that can describe the real system (Trigeassou, 2011 pp.12).

As described in the part chapter System Identification, inputs set to the system and the output responds can be described as a linear equation on discrete form.

x_{k+1}=Ax_k + Bu_k

y_k = Cx_k

Based on equation 1.5 and 1.6 an estimator can be described for the SMM model that is used to minimize the error between the real process and the estimated parameters.

$$x_{k+1} = Ax_k + Bu_k + K(y_k - y'_k) \qquad (1.7)$$

where K is the gain used to minimize the error between measured and estimated parameters.

The expression y_k - y'_k can be defined as the error:

error = $y_k - y'_k$ (1.8)

This equation is the deviation between the real and estimated parameters that can be familiarized with the term "Residuals". The Residuals are representing the deviation between a real system and a model. It can be distinguished that Residuals close to zero reflect a healthy system. According to Trigeassou (2011 pp.13) this is what can be called the Residual generation technique extracting residuals to indicate faults and provide important information that can give specific information about a failure.

From equation 1.6 and 1.7 and equation 1.8 the estimator can be derived as follows:

x'_{k+1}=Ax_k + Bu_k + K(y_k - Cx'_k) (1.9)

y_k' = Cx' (2.0)

By multiplying the parentheses:

x'_{k+1}=Ax_k + Bu_k + Ky_k (2.1)

y_k' = Cx' (2.2)

it gives the final equation:

x'_{k+1}= (A-KC)x'_k + Bu_k + Ky_k (2.3)

y_k'= Cx'_k (2.4)

The constant system matrix A becomes:

$A_{estimator}$ = A – KC (2.5)

Finding the observer gain for the final equation can be done by finding the eigenvalues of equation 2.5. By finding the eigenvalues it can be decided how fast the estimated values should converges the real values (Ruscio, 2010).

A block diagram of the Observer can be drawn showing the model updates by finding the deviation between the measured parameters and the estimated parameter (see Figure 28).

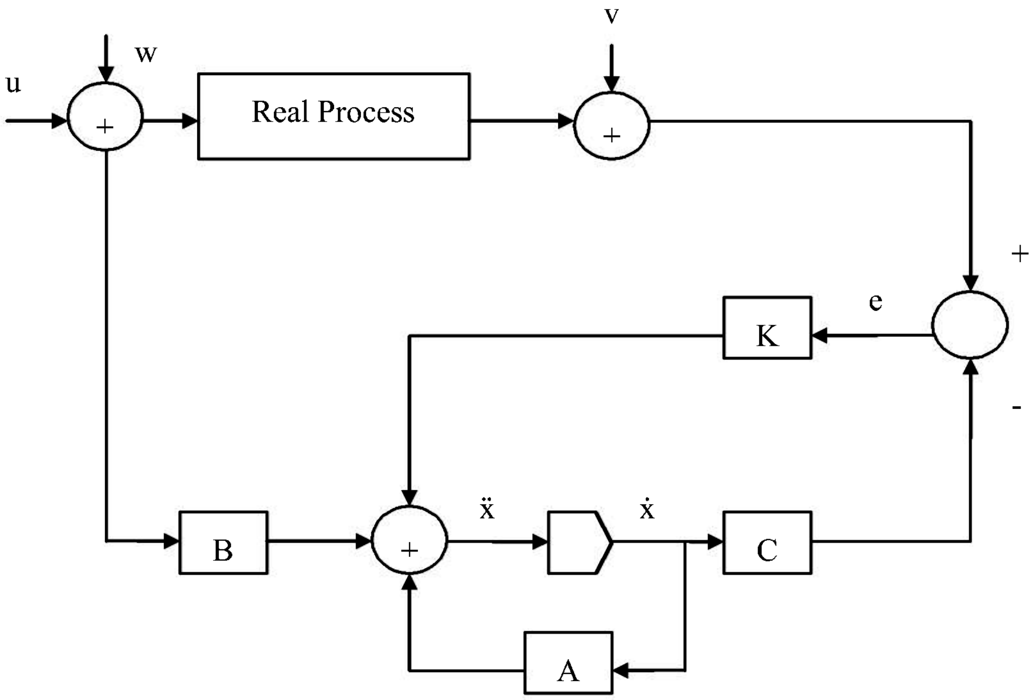

Figure 28: Block diagram of the Observer.

7.2.1 Observer gain K

The observer gain K is handling the deviation between the real and estimated parameters by multiplying with the error. As the estimated parameters are updated the Observer will continue comparing the real and estimated parameters. The eigenvalues of A-KC can be used to decide how fast the estimate will converge towards the real process values. The Observer gain K can be found by solving the following equation:

$$\det(sI-(A-KC))=|sI-(A-KC)| = 0 \qquad (2.6)$$

7.2.2 Observability

Observability of a system is a requirement for using Observers. If it is possible to determine the initial state of a system based on adequate information about its inputs and outputs there can be determined that the system is observable. This means that for a discrete SMM having past inputs and outputs $u(0)$, $u(k\text{-}1)\ldots.u(k\text{-}2)$ and $y(0)$, $y(k\text{-}1)\ldots.y(k\text{-}2)$ it should be able to determine the initial state $x(0)$.

An Observability matrix can be defined as:

$$O = \begin{bmatrix} C \\ CA \\ : \\ CA^{n-1} \end{bmatrix}$$

Where n is the number of states.

The following requirements can be set for the observability matrix to decide whether a system is observable or not (Ruscio, 1996 pp.22):

- A system is observable as long as the number of states n is equal to the observability matrix rank.

  rank(O) = → Observable

- Observability can be verified finding the determinant of O. If the determinant of O is unequal to 0, O is observable.

7.3 Model Predictive Control

Model predictive control (MPC) is based on having estimated a model. It is a model based control and has been used widely in the oil industry (Ruscio, 2006). MPC relies on having a model of a process and SMM models are often used to present the dynamics of a system. MPC involves predicting the future response of a process system or plant. To predict future response, a model in combination with a computer control algorithm is used. What happens in the control algorithm is that for each control interval fed into to a system the algorithm tries to optimize the future behavior. Consider having an SMM model for MPC. For the control input vector u_k that is fed into a process at a discrete time, step k is obtained by solving an optimization problem over a finite future horizon. The solution yields a sequence of input vectors but only the first vector in the sequence is fed to the plant, the rest is discarded. This is because the length of the prediction L is constant at each time step. The MPC algorithm involves the MPC components (Ruscio, 2006):

- Model of a process
- Constraints
- Cost function

7.3.1 Prediction model

The prediction model is generated from a SMM model of the process in a plant. The prediction model is a recursive equation meaning that the next output is related and a result of the present output. Considering having a SMM model of a process the prediction model is generated from this discrete SMM and relates future outputs over a prediction horizon L, $y_{k+1/L}$, as a function of future control inputs to be computed. The prediction model is vital because it is part of an optimization problem (Ruscio, 2006).

Based on a discrete model,

$x_{k+1} = ax_k + bu_k$

$y_k = cx_k + du_k$

in order to obtain "integral action" a prediction model can be expressed in terms of input change:

$$y_{k+1} = F_L^{\Delta} \Delta u_{(k|L)} + p_L^{\Delta} \tag{2.7}$$

where

$$F_L^{\Delta} = F_L S, \text{ and } p_L^{\Delta} = p_L + F_L c u_{k-1} \tag{2.8}$$

and

$$F_L = [O_L B \;\; H_L^d], p_L = O_L A x_k, O_L = [C \; CA \ldots CA^{L-1}]^T \tag{2.9}$$

$$H_L = \begin{bmatrix} 0 & 0 & ..0 \\ CB & 0 & ..0 \\ \vdots & \vdots & ..0 \\ CA^{L-2} & CA^{L-3}B & ..DB \end{bmatrix}, \quad c = \begin{bmatrix} I_r \\ I_r \\ \vdots \\ I_r \end{bmatrix}$$

$$S = \begin{bmatrix} I_r & 0_r & ..0_r \\ I_r & I_r & ..0_r \\ \vdots & \vdots & \vdots \\ I_r & I_r & \ldots I_r \end{bmatrix}$$

I_r is the identity matrices and, specifies the number of inputs.

7.3.2 Cost Function

The mindset of a MPC controller is to calculate a sequence of future control actions such that a cost function can be minimized. In the cost function weight matrices can be specified that are used for adjusting control action, rate of change in control action and the process output. The cost function is minimized for specified control and prediction horizon. The cost function, also known as the control objective J_k, is an equation that expresses the error between predicted outputs and the specified set-point with the change of control input in a sum of square with constant matrices Q and P that are known as the weight matrices. The weight matrices are adjustable and can be changed until the optimal response of the controller is obtained. The cost function *J(k)* is minimized for specified prediction and control horizon N_p and N_c. The cost function used by the MPC controller can be expressed as follows:

$$J(k) = \sum_{i=1}^{N_p} (\hat{y}_{k+1} - r_{k+1})^T Q_i (\hat{y}_{k+1} - r_{k+1}) + \sum_{i=0}^{N_c-1} \Delta u'_{k+1} P_i \Delta u_{k+1} \tag{3.0}$$

The formulation of J_k describes the error between the predicted output and the reference. It expresses the input rate of change rather than inputs because zero steady state or zero error between the output and reference are required by integral action.

To find the Optimal MPC control Min (J_k) the following equation needs to be solved:

$$\frac{dJ}{d\Delta u_{(k|L)}} = 0\ , for\ u_0 \tag{3.1}$$

7.3.3 Constraints

Constraint is an advantage with MPC. Think of an example with a heat exchanger. The heat exchanger may have constraints related to the voltage that are fed into a process. The voltage range can be between1-5 volt. It is important to take these limits into consideration when finding the optimal control for the heat exchanger. Constraints for the output may also be important if the heat exchanger should deliver an output temperature range between zero and 30 degrees. If constraint limits are known these limits can be specified as maximum and minimum for the process input and output. What happens when adding constraint to the MPC controller is that the algorithm adjusts the controller so the specified constraints never exceeds.

The inputs, outputs and the control input rate constraints can be expressed as follows:

$$u_{\min} \leq u_{(k|L)} \leq u_{max} \tag{3.2}$$

$$y_{(k+1|L)}^{\min} \leq y_{(k+1|L)} \leq y_{(k+1|L)}^{max} \tag{3.3}$$

$$\Delta u_{\min} \leq \Delta u_{(k|L)} \leq \Delta u_{max} \tag{3.4}$$

The following relation is used

$$u_{k|L} = \mathrm{S}\Delta\mathrm{x}_{(\mathrm{k}|\mathrm{L})} + cu_{(k|L)} \tag{3.5}$$

this relation is combined with the inequalities expressed in A and b matrices

$$A\Delta u_{(k|L)} \leq \boldsymbol{b} \tag{3.6}$$

The inequality is further used in the minimization approach.

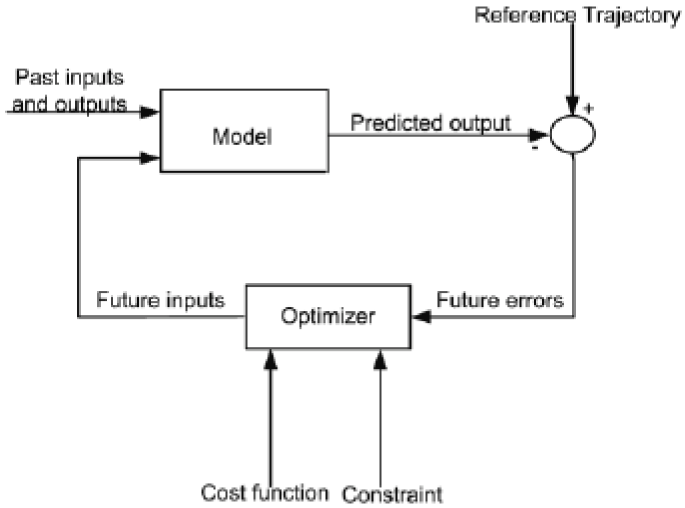

Figure 29: Algorithm off an MPC controller (Orupke, 2006).

7.4 Fault detection

Models for fault detection are widely used in the industry. Creating simulators that can reflect the behaviour of a real process is an advantage for monitoring and understanding the complexity in a system. According to Nelles (2001 pp.5) normally one model is built to describe a real process under normal conditions, and one model is built for each fault, describing the situation when a fault occurs in the system. This can be an advantage for identifying different faults that can occur and to recognize the state of the fault. Identifying faults include an identifying technique like comparing the process outputs of a nominal case with a fault model. For example if the nominal case output compared to the fault model output is *e*rror > 0, then this must be an indication that it occurs an error in the system since there is a deviation between those two outputs. The threshold for if it is an error or not must be determined with deeply consideration and knowledge about the system one face. By detecting faults systems come generations of alarms. Faults and alarms are coherent terms. Dealing with alarm systems the work with quality assurance is important. Having a too sensitive system that generates and tolerate frequent false alarms is not positive and will probably cause more frustration than having a positive effect. It may even cause that the alarm system will be turned off (Nelles, 2001). If alarms are missed and not detected it may rather have a too low sensitivity level. Detecting already faults are also important to be handled quickly before they expose the equipment for even larger damages. According to Nelles (2001 pp.6) adjusting a fault system sensitivity is the trickiest part in the development of a fault detection system. This is true because the severity of not detecting serious faults will cause high magnitude costs and causing that a part or a whole system to be shut down. The costs of such a case will therefore increase parallel with the downtime.

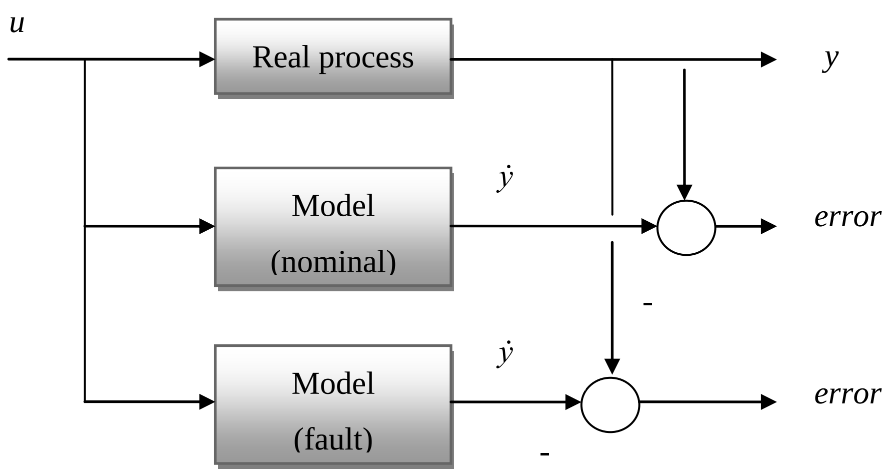

Figure 30: Fault detection (Nelles, 2001 pp.3).

7.4.1 Fault Detection of Rotor failure in an Asynchronous motor

In case of fault detection of an asynchronous motor, there is a question about distinguishing between a healthy and a broken motor. A model for a healthy motor can be used to compare with a motor that is currently running in a process. This contains estimating a model that is equal to a healthy motor. A method as system identification can be used to create a model that is based on input and output data. Usually identifying a model requires a set of data that can be imported into a computer system using programming tools that can treat the data. The method for detecting rotor faults in asynchronous motor mentioned earlier was by performing spectrum analysis. This was based on analysing the current supply signal of a motor. Measuring the current involves only one parameter. Using SSM models in this experiment would rather describe the dynamic of the motor if the voltage was used as an input and the current was observed. Then a SSM would be a good solution because it is based on discrete input u_k and state vector x_k (if using discrete data) to decide the dynamic of a system. In spectrum analysis it is a question about observing the frequency spectrum of a signal. This signal can be a continuous or a discrete signal. There are certain elements that need to be taken into consideration when doing such an experiment. Having sensors that are observing the current supply of a motor has a sampling frequency. When analysing a signal there is a need to be considered if the data is adequate enough to give reliable answers. Performing FFT or DFT on a signal involve transforming a continuous or discrete signal into the frequency domain. If frequency components can give answers if a motor is broken or not as it is proven to do earlier, it is important that the signal is adequate enough to represent the periods that can explain these frequencies. The sampling frequency is also very important to describe the real signal. According to Nyquist-theorem the sampling frequency shall be twice as large as the highest frequency that can be observed in a signal (Wheeler & Ganji, 2010). This is a requirement for reflecting the real signal. This gives that the signal spectrum shall be $\frac{f_s}{2}$ the Nyquist frequency.

If the negative sequence period for a signal also shall be presented it should be considered in the FFT analyses that frequency spectrum shows from $-\frac{f_s}{2}$ to $\frac{f_s}{2}$. Using mathematic programming tools as Matrix Laboratory developed by MathWorks® there can be used the built in function FFT for spectrum analysis. A current signal can be imported into the program and defined in the syntax FFT(x,N). The parameter x(n) will be the signal including a number of samples and N the sampling frequency (number of points in the FFT).

To automate detection of a rotor fault it can be tried to implement an algorithm that compares the theoretic values to the observed values. A real physical process compared to a model. It is theoretically proved that sidebands $(1-2s)f_s$ occurs with rotor faults and that these rotor faults occur within the frequency range 0-200Hz (Starr & Rao, 2001).

Imagine the case of fault detection of the asynchronous motor was decided to be implemented in an offshore installation. The experiment relays on historical data. Analysing frequency components could be done ether by the oil company's own staff or by the vendor of the equipment. If the fault detection was atomised and a failure occur the oil company staff could have decided ether to fix it themselves or contact the vendor. It is a question who has the knowledge and experience to do the job. How often it is necessary to do such analysing only the vendors will know. If decided that the oil company's staff can handle the job maybe the vendor can be contacted if a failure occurs. If a failure occurs the vendor can decide whether this problem can be handled by the operators themselves by guidance of the vendor or if the vendor has to handle itself. If the vendor decides to do the service itself it can prepare what to do and arrange all the necessary equipment and tools that are required ahead. The extent of the damage of the motor will decide if the rotor can be fixed or exchanged with a new motor. This can be seen from the frequency components. Having remote access has many advantages as if the vendors perform service on the equipment they can do proper preparations to avoid bringing unnecessary tools and equipment to the site.

A typical diagnostic experiment as the example mentioned above will concern one vendor. This experiment relies on logged data. The diagnostic experiment would belong to one functional group involving the third part and the operating company. If the vendor needed access to the industrial system then the vendor would only have access to that specific third part terminal that can communicate with the equipment.

8 Results

The thesis is academic with a technical appearance. It has been reached and concluded with the following solutions and methods. Implementation of IO in the oil and gas industry has been seen to give profitable advantages. The example used from Conocophillips onshore center in Tananger is a proof for further commitment. As well as technical challenges, IO face challenges regarding organization, work procedures and human factors. It shows that collaboration between people is a vital factor for successful implementation of IO. When studying the issues of IO it often relate to human factors. Clearly defined work task, composition of people with different knowledge and experience, location and information are vital. Ether if it is within well and reservoir planning, production optimization and maintains planning it is needed to be the right composition of people that are competent enough to take important decisions. The solution can be to split the different work areas into different categories.

It must be one group of people that handle operational 24/7 support. With implementation of IO it will be a reduction of offshore personnel. Operators that are not needed on the platform anymore can be transferred to onshore support centers. Utilizing those operators not needed on the platform will ensure that precious competence still stays within the company.

Operators that are dedicated to support the offshore operators need sit in front of a monitoring environment that has the same UI as the operators offshore. The UI onshore needs to be a replicate of the offshore UI. This is vital for collaboration and decision making.

Process optimization must be a group that only focuses on reaching the potential in the plant. There must be a group of people that have the knowledge and experience dedicated to this kind of jobs. People must have the opportunity to concentrate about specified tasks.

A clearly ICT infrastructure must be created. Parts involved in optimization issues can be external or vendor expertise. It is a question about remote process and remote access. Therefore a clear responsibility and a keen involvement must be highlighted. It has been created a flowchart that gives a suggestion for how access to an industrial network can be carried out. It appears in this thesis that access control is very important. It is recommended to require a degree of Identity and Authentication Management which define user and roles. It has been encouraged using work permission that can be issued by the oil company's staff.

An industrial system is a vulnerable area and an exposed target for hackers and unauthorized intruders. If outsiders are getting access to an industrial system it can result in huge damages. Risk assessments concerning remote processes and remote access show that proper securing of firewalls can prevent outsider's access to the plant. It is important to configure secure enclaves and entry paths.

For performing optimization issues it is important to do proper preparatory work, describe broadly the problem definition and consider every aspects of an experiment. The approach of an experiment is important and so are requirements for a monitoring environment. When deciding to perform analysis and optimization there must be specified what attributes to expect and what kind of information the experiment relies on. Concerning experimental design there will be a financial asset.

A theoretic example that concerns the work responsibility of IO was carried out. It was illustrated how one can do preparatory work for a diagnostic and performance monitoring environment. The purpose was to highlight that it can be many areas to consider when looking for solutions to perform analysis and optimization.

Assessment concerning different performance and diagnostic methods for analysis and optimization of an electrical machine was presented.

First there was given some basic theory about the experiment and then it was decided to perform rotor fault detection. It was shown by observing the current supply for the electrical motor rotor faults can be detected. Sidebands between the normal frequency components in the current supply signal can indicate rotor fault. It will occur a clearly amplitude increase in these sidebands. It was shown theoretically the consequence of a breach in the rotor circuit. When it occurs a breach there will be induced both a negative and positive stator flux as a result of asymmetry in the rotor circuit. To analyze the current supply frequency components there can be used FFT. With FFT or DFT the signal can be converted into the frequency domain where the frequency components of the signal can be analyzed. Comparing the signal with a healthy motor will show which components that stand out.

An analysis and optimization method is presented to show alternative methods that can be used for analysis and optimization problems. For analysis and optimization problems there need to be a kind of detection method that can be used.

With System Identification a model can be created of a physical process. Once having a model it can be improved by evaluating and performing a strategy with an Observer so the right parameters can be found.

For controlling a process output MPC can be used. MPC have the ability to predict future response of a process plant and can be used to find the optimal control.

For fault detection when doing diagnostic and performance monitoring it was in the case rotor fault detection recommended to compare the current signal of a healthy motor against a broken motor. In that way anomalies behavior can be detected. It has been shown that with having a real process a model can be identified using different techniques. When a model is being created, it can be used to compare. A model deviating from the original equipment will indicate anomalies behavior. Detection of rotor fault in an electric motor can be one case in an offshore installation that can be used for remote processes. Deciding who will take the responsibility for doing the diagnostic and performance monitoring is up to the oil company's staff to decide. Again there is a question about knowledge and experience.

9 Discussion

The problem description is based on a literature study. Different approaches have been discussed along. The study is based on communication between on-offshore. Generation 2 of IO concern vendor support and 24/7 support. The result shows that the contents in this thesis have captured the important aspects of G2. With implementation of G2 it is no doubt that it follows many challenges regarding, organizational challenges, work processes and human factors. Utilizing vendor expertise demands a need for clearly defined responsibility tasks. All common sense says that utilizing each other's competence will improve efficiency.

G2 is all about remote processes. ICT and IT security will therefore be critical for implementation of G2. Work procedures and guidelines have been proposed in this thesis to have a secure and successful implementation of IO. It still cannot be emphasized enough how important it is to assess IT security and all the complexity that follows remote processes. The impact of misuse can be fatal. At the end it is no doubt that if those facts mentioned above are solved, G2 will contribute to maximize profits and reduce risks.

Transferring functionalities to land involve reducing the manning requirement offshore. What consequences this will have for people and their jobs is not mentioned in this thesis but would have been interesting to be looked into. It is mentioned to rotate onshore and offshore workers. This is done for the benefit of securing people with valuable experience and knowledge within the company. If all those employees losing their jobs offshore are offered a position onshore is uncertainness. How the manning situation will continue in the future where more work tasks will be transferred to land and atomized will remain an unanswered question.

The reason why the experiment with rotor fault detection in an electric machine was not carried out in practice was that the circumstances did not allow it. It would not be essential for this thesis because proving a method for detecting failures will not be the right responds to this thesis. The aim is to highlight the functionality and challenges of IO that concerns defining and present data for analysis and optimization.

In this thesis there is much focus on mindset and methods. The theoretic example with diagnostic and performance monitoring of an asynchronous motor, was chosen to highlight a typical case that involve analysis and optimization. Such a case is exactly one type of functionality that can be transferred to onshore centers. If the monitoring and diagnostic case is profitable the future will show.

Concerning analysis and optimization methods there are mentioned some techniques. Analysis and optimization point towards research centers and vendor support. For analysis and optimization it is a need for historical data. This is opposite of 24/7 support that require real-time data to make decisions.

Having a replicate historian database located onshore will give external parts greater opportunities to perform analysis and avoid all the bureaucratic layers that external parts need to pass when accessing the SCADA system for the platform .

10 Conclusion

In this thesis it is accomplished a study of the challenges of IO focusing on IO G2 that involve vendor and 24/7 support. The aim of G2 is to gather competence and experience to higher the level and improve the value creation on the Norwegian continental shelf.

Based on the results, the complexity of IO seems to be a challenge that is captured by highlighting organizational, work processes and human and technical factors. The challenges related to organizational and work processes are not the same challenges that other companies face within an organization. For IO it concerns connecting people across different geographical areas, for collaboration between work disciplines and for sharing knowledge and experience. That IO involves collaboration across geographical areas shows that it is necessary to relate to new people. To achieve better and more effective ways of operating it is vital that one utilizes each other's competence. User and roles are therefore important with IO, not only regarding human factors but also for technical parts.

Access to an industrial system offshore shows that it is necessary to consider risk involving external parts UI. It was questioned how data can be accessed between onshore and offshore. This is by establishing remote access. To have remote access there is a need to be a network infrastructure that provides an entry path through the industrial network. Remote access is the solution since external parts can be located at any geographical area.

Consequences and vulnerabilities follow with providing an entry path into the industrial system. It must be provided a secure entry path that prevents abuse and attacks from outsiders. It is obvious that IT security must be considered with high priority since an offshore installation consists of many critical parts.

Obstacles that always will be present are human failures. The results show that it is considered how to prevent human failures when accessing the industrial system. This is important to quality assure HMIs.

It is obvious that requirements and delimitations account for much of the risk picture.

The guideline for preparing experiment can be a benefit when defining tasks towards research centers onshore. The case with diagnostic and performance monitoring of an asynchronous motor is a typical example that can be utilized for remote processes. Detecting rotor fault with MCSA is proven theoretically in this thesis. In different articles it has been proven both theoretically and practically that MCSA is a method that can be used. It can be considered to use rotor fault detection in future remote processes concerning onshore centers.

Analysis and optimization methods presented are among many methods that can be used. Having models that can describe a physical process is important to have for analysis and optimization tasks. In the case of rotor fault detection it shows having a model of a healthy motor can be a benefit for detecting faults. Fault indications will clearly separate from a healthy machine since the amplitude in sidebands will increase dramatically.

10.1 Suggestion to further work

Suggestion for further work could be to use one of the analysis and optimization methods presented for a real optimization problem to support the methods. But then a practical example from the oil industry must be available to be genuine.

Another suggestion for further work can be looking into an already implemented case of diagnostic and performance monitoring towards onshore centers. Starting from vendor access to an HMI used for configuration and control will give an overall view of a remote process.

Many vendors for equipment do also offer monitoring environment solutions and their own application for controlling and configuration but still access and decisions will rely on the operator companies. Utilizing such solutions can be relevant for further work.

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Appendices

Appendix A: Task Description

Telemark University College

Faculty of Technology

FMH606 Master's Thesis

Title: **Integrated Operations - Define and present data necessary for analysing & optimization**

TUC supervisor: David Di Ruscio

External partner: Aker Solutions AS

Task background:

Aker Solutions AS is one of the world’s leading providers of oilfield products, systems and services. Our knowledge and technologies span from reservoir to production and through the life of a field. Integrated Operations towards Oil & Gas Industry is commonly associated with operative connection between sea and land. With Integrated Operations follows many risk assessments that cause challenges to be solved .New concepts within reservoir management, searching, drilling, operational solution and logistics will be one of many challenges. Information and Communication Technology are one of the most important changes in progress in the petroleum activity in form of Integrated Operations.

Task description:

The aim of this thesis is to study how raw data from a process/equipment on a platform can be handled, stored and presented. The purpose of this is to use this data through Integrated Operations so that expert personnel onshore can trend, analyse and do what's necessary for optimize today's operational solution.

The thesis will include the following tasks:

1. Study integrating operations in oil and gas industry
2. Handling and Present data
3. Information and communications technology
4. Control System
5. Risk assessments

<u>Student category</u>:

Reserved student: Christian Aanning

<u>Practical arrangements</u>:

The work with the thesis will be held at Aker Solutions/TUC.

<u>Filename</u>:

Master_thesis2013_CF_Aanning

<u>Signatures</u>:

Student (date and signature): Christian Aanning (071116@student.hit.no)

Supervisor (date and signature):