Subsea - Building Blocks

Subsea Production Control Systems

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Module structure

- Section 1 – Introduction to control systems
  - Scope of control systems engineering
  - Basic control systems
  - Realising the control system

- Section 2 – Subsea control systems
  - Introduction
  - Commonly used terms
  - Methods of control
  - System selection criteria

- Section 3 – Control system components
  - Overview
  - Surface components
  - Subsurface components

- Section 4 – Connection systems
  - Communication systems
  - Umbilicals
  - Infield connections
  - Multi-bore connectors
  - Jumpers
  - Connectors and Penetrators

- Section 5 – Instrumentation
  - Introduction
  - Basic instrumentation
  - Advanced instrumentation

- Section 6 – Topside Control Systems
  - Offshore control systems
  - Integration
Learning objectives

By the end of this module you will be able to….

- Understand the how a subsea control system is implemented
- Understand why
- Understand how a subsea control system relates to other systems
- Understand what is meant by of SIL and how it affects a subsea system
- Understand how the subsea production control system fits into the process control system

But not….

Design one
Section 1 – Introduction to control systems

- Basic control systems
- Realising the control system
Section 2 – Subsea control systems

- Introduction
- Commonly used terms
- Methods of control
- System selection criteria
Section 2 – Subsea control systems

- What is the definition of a subsea control system?

- ISO 13628-6 says……..
  - “control system operating a subsea production system during operation”

- More useful….
  - “To safely maintain the flow of hydrocarbons from a subsea facility”

- What are a subsea control systems two main requirements?
Subsea control systems

- Does a control system fulfil its primary requirements?
  - Safe operation
    - 2003 HSE Report into valve failures that resulted in a hydrocarbon release showed:
      - 43% of failures were from inadequate design, materials, etc
      - 0% from control systems
  - Availability
    - 2003 HSE Report into valve failures that resulted in downtime showed:
      - 43% of failures were from inadequate design, materials, etc
      - 24% of failures were from the control system
  - The cost per failure?
    - Average of 100 hours downtime
Root cause of the failures

- An unrelated HSE report found 44% of failures in a safety-related control system were due to wrong requirements/specifications.
Commonly used terms

- **Closed loop system**
  - The hydraulic fluid is returned to the hydraulic power supply reservoir (tank)

- **Open loop**
  - The hydraulic fluid is vented either to sea or to a recoverable subsea storage vessel

- **Directional control valve or valve**
  - Controls the flow of the hydraulic fluid
  - Can be discrete or continuous

- **Solenoid**
  - Electrical coil that controls the control valves position
Commonly used terms

- **Fail safe**
  - Returns to a safe condition in a fault condition, can be fail open, fail close or fail as is.
  - Usually controlled by a mechanical spring

- **Hydraulic accumulator**
  - Pressure vessel used to store hydraulic fluid under pressure

- **Latched function**
  - A function where the control signal does not need to be continuously applied
Methods of control

- Direct Hydraulic
  - Low tech solution
  - High level of reliability
  - Easy to understand
  - Easy to fault find
  - Easy to service
  - Cheap

- Platform

- Umbilical
  - Best suited to shallow water
  - Slow to respond
  - Large umbilical

- Valve
Methods of control

- Piloted Hydraulic

  - Subsea accumulation
  - Mechanical or electrical pilot valve operation
  - Valve sequencing can be used

- Not suited for ultra-deep water or long step outs
- Slow to respond
- Large umbilical
Methods of control

- Direct Electro Hydraulic
  - Smaller umbilical
  - Faster response
  - Simplified control pod

- Not suited for ultra-deep water or long step outs
- Increased number of subsea electrical connections
- Requires separate electrical umbilical or multicore umbilical
Methods of control

- Electro Hydraulic Multiplexed

- Long step out and deep water
- Faster response
- Simplified umbilical
- Capable of complex control
- Improved surveillance

- Increased number of subsea electrical connections
- Higher voltage connections
- More complex subsea components
- More difficult to support
Methods of control

- All Electric

- Ultra deep water and extremely long step outs
- Zero emissions
- Suitable for harsh environments
- Subsea processing
- Easily expandable
- More autonomous?
- Lower operating and maintenance costs?
- Complex electro-mechanical devices
- Power electronic devices subsea
- High voltage distribution systems
- Harder to control failure modes
- Greater level of technical support
- Higher Intervention costs?
- Installation costs?
## Choice of system

<table>
<thead>
<tr>
<th>System Type</th>
<th>Cost</th>
<th>Maintenance /reliability</th>
<th>Flexibility</th>
<th>Step out</th>
<th>Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Hydraulic</td>
<td>Low</td>
<td>Low technical threshold. Most components topside.</td>
<td>Limited</td>
<td>Short</td>
<td>Shallow</td>
</tr>
<tr>
<td>Piloted Hydraulic</td>
<td>Low</td>
<td>Low technical threshold. Most components topside.</td>
<td>Limited</td>
<td>Short</td>
<td>Shallow</td>
</tr>
<tr>
<td>Direct Electric</td>
<td>Low</td>
<td>Increased complexity.</td>
<td>Limited</td>
<td>Short</td>
<td>Shallow</td>
</tr>
<tr>
<td>Electro Hydraulic Multiplex</td>
<td>High</td>
<td>More complex, subsea equipment.</td>
<td>Expandable</td>
<td>Long</td>
<td>Deep</td>
</tr>
<tr>
<td>All Electric</td>
<td>High</td>
<td>More complex, subsea equipment.</td>
<td>Expandable</td>
<td>Very Long</td>
<td>Ultra Deep</td>
</tr>
</tbody>
</table>
Selection criteria

The choice of system can depend on more than just the depth and step out distance.
Selection criteria

The type of development can effect the control system employed

- Floating production storage and off-loading (FPSO)
- Floating production unit (FPU)
- Control and Riser Platform (CRP)
- Subsea to shore
- Re-development
- New development

Cost is also a consideration!
Selection criteria

- For each of the following systems define the main requirements for the control system:
  - Re-development, shallow water, production lifetime ≈ 5 years.
  - New rapid development, deepwater, long step out, possible late stage enhanced recovery, possible field tie-ins, production lifetime ≥ 15.
  - Extension to existing facility, deepwater, short step out, production lifetime ≤ 10 years.
  - Arctic development including compression, sub-ice, long step out, production lifetime ≥ 15.
Section 3 – Control system components

- Overview
- Surface components
- Subsurface components
System components overview

- Typical systems components can include:

- Surface
  - Topside Umbilical Termination Unit (TUTU)
  - Hydraulic Power Unit (HPU)
  - Electrical Power Unit (EPU)
  - Subsea Control Unit (SCU)
  - Master Control Station (MCS)

- Subsea
  - Umbilical Termination Assembly (UTA)
  - Subsea Distribution Assembly (SDA)
  - Subsea Distribution Unit (SDU)
  - Communications Interface Unit (CIU)
  - Subsea Electrical Junction Box
  - Subsea Control Module (SCM)
  - Subsea Electronics Module (SEM)
Where does it all fit?

Hydraulic Power Unit
Process Control System
Master Control Station
Hydraulic Power Unit
Chemical Injection Unit
TUTU
Subsea Umbilical (Hydraulic, Electrical Power and Fibre Optic)

Electrical Power Unit

Umbilical Termination
In-field Umbilical (Hydraulic, Electrical Power and Fibre Optic)

Subsea Distribution
Electrical and hydraulic jumpers

Subsea Control Module
Electrical and hydraulic jumpers

Christmas Tree
Downhole

Background courtesy of STATOILHYDRO AS
Surface equipment
Subsea or master control unit

- Can act as a stand-alone control station or integrated in to the PCS
- Interfaces to subsea equipment, HPU, EPU
- Provides operator and engineer access to the system
- Acts as a gateway for third party equipment
- Expandable

AKS SCU
Electrical power unit

- Semi-conductor based power supply system
  - Variable voltage output

- Can house the communication on power modem

- Provides monitoring of the umbilical system.
  - Under and over voltage protection
  - Over current protection
  - Line insulation monitoring

- Communicates to the SCU

For Subsea to Shore developments this can be replaced by a high voltage transmission system. This consists of a high voltage step-up surface transformer connected by subsea distributions umbilicals to subsea high voltage stepdown transformers.
Hydraulic power unit

- Self contained unit provides high and low pressure hydraulic supplies for the subsea controls (sometimes HP hydraulics is derived from LP supply subsea)
- Provides surface accumulation
- Redundant motor pump sets
- PLC monitoring and control
- Interfaced to the SCU

FMC HPU

AKS HPU
Topside umbilical termination unit - TUTU

- Hydraulic, electrical and fibre optic termination
- Electrical terminations in internal junction boxes
- Individual block and bleed valves for each hydraulic line
- Individual pressure gauge per hydraulic line
Master control station

- Operator and Engineering access to the system
- HMI graphical interface to the system
- Stand-alone system or
- Integrated into DCS system
- Remote repeater stations
- Can be local or remote
Subsurface equipment
Subsea termination assembly

- Terminates and distributes the umbilical
- Electrical, hydraulic and chemical distribution
- Multi-bore connectors
- ROV mateable jumpers
- Configurable arrangement using crossover caps and or jumpers
Subsea distribution assembly /unit

- Similar to UTA
- In-field distribution of hydraulic and electrical supplies and communication signals
- Subsea electrical junction box
- Local transformation of power supplies (step-down transformers)
- Fibre to copper converters (CIU)
Subsea control module

- Can be installed on SDUs, SDAs, PLEM and XTs
- Controls and monitors subsea instrumentation and actuators (valves, etc)
- The SCM normally consist of:
  - Hydraulic and electric operated valves
  - Subsea Electronic Module
  - Couplers for electrical cables and hydraulic lines.
  - Valves contained in an oil filled pressure compensated housing
  - SEM in a one atmosphere pressure vessel
- Retrievable
Subsea electronics module

- One atmosphere pressure vessel
- Cards for control signal handling and communications
- Supports various communication protocols
- Power supplies for instrumentation and actuators
- Intelligent, able to perform local control
Section 4 – Connection systems

- Communication systems
- Umbilicals
- Infield connections
- Multi-bore connectors
- Jumpers
- Connectors and Penetrators
Communication systems

- Surface to subsea
  - Higher bandwidth
  - Copper or fibre optic
  - Redundant

- Subsea
  - New SIIS defined (CANbus)
  - IWIS (downhole instruments)
  - Lower bandwidth
  - Copper
  - Redundant
Communication systems

Surface to subsea communication

- Based on TCP/IP protocols
- Older systems used bespoke communication protocols
  - Based on standards RS protocols
- Dumb systems with no intelligence subsea are limited to either analogue or digital signals (voltage or current)
  - Digital voltage signals
    - Discrete events (limit switches, pressure switches)
    - Normally DC voltages
  - Analogue current or voltage signals
    - Continuous measurements (pressure transmitters, temperature transmitters)
    - Normally 4-20mA
- Communication protocols are now being specified by some companies to ensure the openness or a system and help to avoid lock-ins.
Fibre optic communications

- There are two main types, single mode and multi mode. The mode refers to the frequency of the light.

- Surface to surface communication uses single mode fibre optics.
  - Long distance
  - Harder termination
  - More complex connectors
  - Glass fibre
  - Cheap fibre, expensive transceivers
Copper communications

- Normally serial or bus protocol
- Separate communication conductors or a communication on power system can be used
  - High frequency communication signal superimposed on to the power conductors at the transmitter end
  - Power supply filtered at the receiver end to extract the communication signal
- Lower bandwidth
- Simpler and cheaper connections
- Cheaper modems
- Frequently used as a back-up communication method
# Comparison of fibre to copper

<table>
<thead>
<tr>
<th>Fibre</th>
<th>Copper</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pros…</strong></td>
<td><strong>Pros…</strong></td>
</tr>
<tr>
<td>- High speed</td>
<td>- Cheaper modems</td>
</tr>
<tr>
<td>- Gigabits of information</td>
<td>- Easier terminations</td>
</tr>
<tr>
<td>- Video and audio</td>
<td>- Simpler connectors</td>
</tr>
<tr>
<td>- Noise immune</td>
<td></td>
</tr>
<tr>
<td>- Light weight</td>
<td><strong>Cons…</strong></td>
</tr>
<tr>
<td>- Sophisticated diagnostic tools</td>
<td>- Heavier umbilical</td>
</tr>
<tr>
<td><strong>Cons…</strong></td>
<td>- More expensive umbilical</td>
</tr>
<tr>
<td>- More fragile</td>
<td>- Susceptible to noise</td>
</tr>
<tr>
<td>- Harder to terminate</td>
<td>- Lower data rates</td>
</tr>
<tr>
<td>- More elaborate connectors, especially subsea</td>
<td>- Shorter distance</td>
</tr>
<tr>
<td>- Expensive transmit and receive equipment</td>
<td></td>
</tr>
</tbody>
</table>

Ideally fibre optics should be used for all systems, however for simple shallow water applications it may be harder to justify.
Umbilical systems

- The choice of umbilical can depend on the application and the type of system deployed

- Types of umbilical available includes:
  - Direct hydraulic
  - Multiplexed electro-hydraulic
  - Integrated production umbilicals (IPUs)
  - Dynamic umbilicals
  - Subsea to shore
Direct hydraulic umbilicals

- Older design
- Large cross section
- Lots of hydraulic lines (one per function)
- Limited electrical connections
- Difficult to handle and terminate
Multiplexed electro-hydraulic umbilicals

- Smaller cross section
- Steel tubes
- Common hydraulic supply
- Chemical injection lines
- Fibre optic and copper signal conductors
- Power conductors
Integrated production umbilical

IPU technology puts services and production flowline all in one line.
Dynamic umbilicals

CONDUITS, PVC
CENTER LINE
ELECTRICAL CABLES
HYDRAULIC TUBES
OUTER SHEATING
METHANOL TUBES
WIRE

LEAD
CENTER LINE

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Dynamic umbilicals

Nexans’ dynamic umbilical for the Thunder Horse project in Gulf of Mexico installed in 2005.
Subsea to shore umbilical

- Single integrated umbilical
- High voltage cable
- Low pressure hydraulic line (HP hydraulic supply generated locally, where needed)
- Chemical lines
- Optical fibres

Inadequate requirements in ISO 13628-5 for electrical cables. Relies on general IEC standards for cables rated 1kV to 3kV IEC 60502-1 and for cables rated 6kV to 30kV IEC 60502-2.

Åsgard 26/45/(52)kV
Ormen Lange 18/30(36)kV

Nexans’ umbilical for Statoil's Snøhvit Field in the Barents Sea (single length 145km long)
Connecting it all together

- Multi-bore connectors
- Jumpers
  - Hydraulic
  - Optical fibre
  - Electrical
- Couplers
- Connectors
- Penetrators
Multi-bore connectors

- Used to make the in field connections from the UTA to the SDAs and SDUs
- Electrical connections
- Fluid connections
  - Hydraulic control
  - Chemical
- Fibre optics
- Production flowlines

FMC multi-bore connectors (collet type)
Jumpers

- Used to distribute electrical, optical and hydraulic signals and supplies
- Oil filled pressure compensated hose
- Terminated with either a wet mateable connector, coupler or penetrator
- ROV installable
- Can be used to reconfigure the system

ODI electrical jumpers
Couplers

- ROV or diver operable, quick release style connector
- Wet mateable – poppet mechanism seals on release
Electrical connectors

- Wet and dry mate subsea
- Low voltage for signal
- High voltage for power supplies
  - 12KV Tyrihans
  - 36KV Ormen Lange
- Can be very problematic

ODI electrical connectors
Fibre optic connectors

- Wet mateable
- ROV or diver operable
- Limited number of mates and de-mates
- Fine tolerance
Penetrators

- Fibre optic or power (very high voltages)
- More reliable than connectors
- Made up dry and they are not serviceable subsea
- Usually used to terminate one end of a power cable
- Can be used as a barrier between oil and water, gas and oil and gas and water

Bennex penetrator assembly
Section 5 – Instrumentation

- Introduction
- Basic instrumentation
- Advanced instrumentation
Instrumentation

The subsea control system will generally include the following:

- Subsea and downhole transducers measuring temperature, pressure, valve position, sand production, multiphase flow, well parameters and the condition of the subsea control system equipment

- Control system variables and housekeeping parameters such as hydraulic fluid pressures, communications status and system voltages are also recorded for analysis at the surface

- Other parameters which can be monitored include:
  - Corrosion
  - Vibration
  - Strain
  - Movement (riser monitoring)
  - Ocean Current (riser monitoring)

- In a modern system almost any variable in the control system can be made available to the Process Control System
Instrumentation

- Simple pressure and pressure instruments tend to use analogue communications normally 4-20mA.

- More sophisticated instruments can use protocols such as ModBUS or TCP/IP based.

- Downhole instruments use the IWIS protocol.

- Work is on going to develop a standard for subsurface instrumentation (SIIS).

- High bandwidth communication systems have allowed for the development and deployment of very complex instruments.
Instrumentation - basic

- Temperature (TT)
- Pressure (PT)

The pressure and temperature transmitters can be combined into a single instrument called a PTT.

Both temperature transmitters (TT) and Pressure transmitters (PT) can be used to monitor either the process or the control system.

- Sand
  - Intrusive type measures the erosion on a probe inserted into the process flow
  - Non-intrusive are based on acoustic devices

- Valve position
  - Continuous measurement by LVDT or similar
  - Discrete measurement by proximity switch
  - Inferred from other measurements
Instrumentation - advanced

- **Corrosion**
  - Intrusive sensors penetrating the process flow, usually at the well head
  - Non-intrusive, normally fabricated as a section of pipeline

- **Hydrocarbon**
  - Capacitive sensor

- **Flow meters**
  - Normally mounted in-line

- **Multiphase flow meters**
  - In-line ROV retrievable devices
  - Measuring the fractions of gas, oil and water in the process stream.
  - Older subsea systems were not very accurate (~20%), newer systems more complex promise better results
  - Also measure, density, salinity, mass and volumetric flow rate, pressure and temperature
Section Six

- Offshore control systems
- Integration
Offshore control system

- Platform/Process Control System
  - DCS System

- Safety Systems
  - Fire and Gas System
  - Process Shutdown System (PSD)
  - Emergency Shutdown System (ESD)

- Subsea Production Control System
Where does it all fit?

[Diagram of system integration]

Background courtesy of Emerson DeltaV
Where does it all fit?

- Subsea Production Control System and DCS usually interfaced at the supervisory network level
- PCS can be integrated into the DSC
- Third party systems interfaced at the supervisory network level, e.g.
  - Flowmeters
  - Downhole sensors
- Modern systems use OPC to facilitate external interfaces
  - Open standard
  - Transparent database
Future developments

- All electric field
- Sub-ice operations
- Increased sophistication of subsea processing units
  - Faster, more complex control loops
  - Increased instrumentation (process and condition monitoring)
- Remote and integrated operations
- Greater use of information
  - E-field systems
- Increased Complexity
  - Harder to test
- Increased attention to software quality systems, security and systems integration
  - TickIT, CMMI
  - Requirements engineering
Safeguarding life, property and the environment

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