Subsea Production Control Systems

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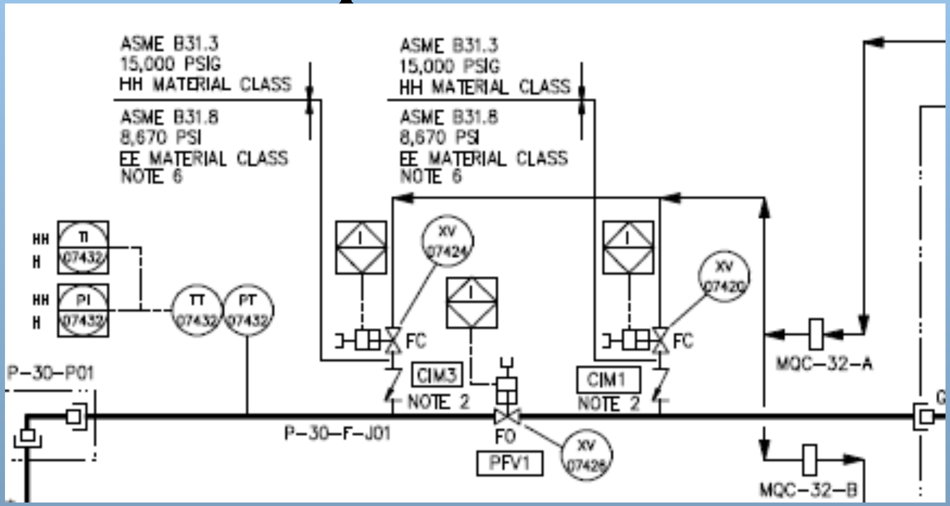
Lesson objectives

- **Define criteria for subsea controls**
- **Examine types of subsea control systems**
- **Give examples of valve and choke actuation**
- **Discuss an overview of electrical systems**
- **Examine and analyse hydraulic systems**
- **Identify topsides hydraulic controls interfaces**
- **Identify topsides computer/master control station (MCS) interfaces**
- **Illustrate shutdown systems and control logic**
- **List industry standards and BP codes**

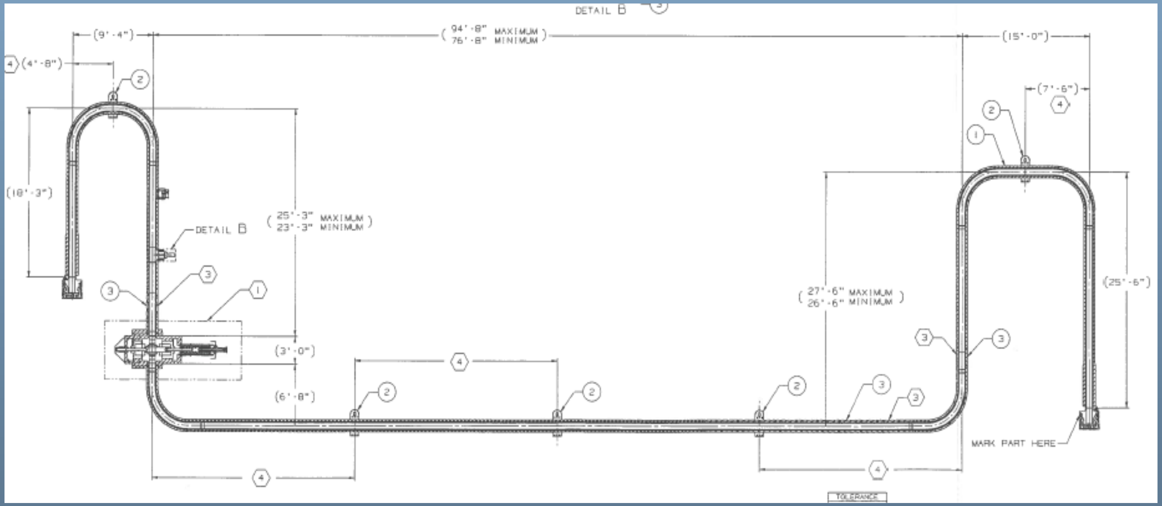
Lessons learned – Thunder Horse

Jumper construction – P30-F-J01

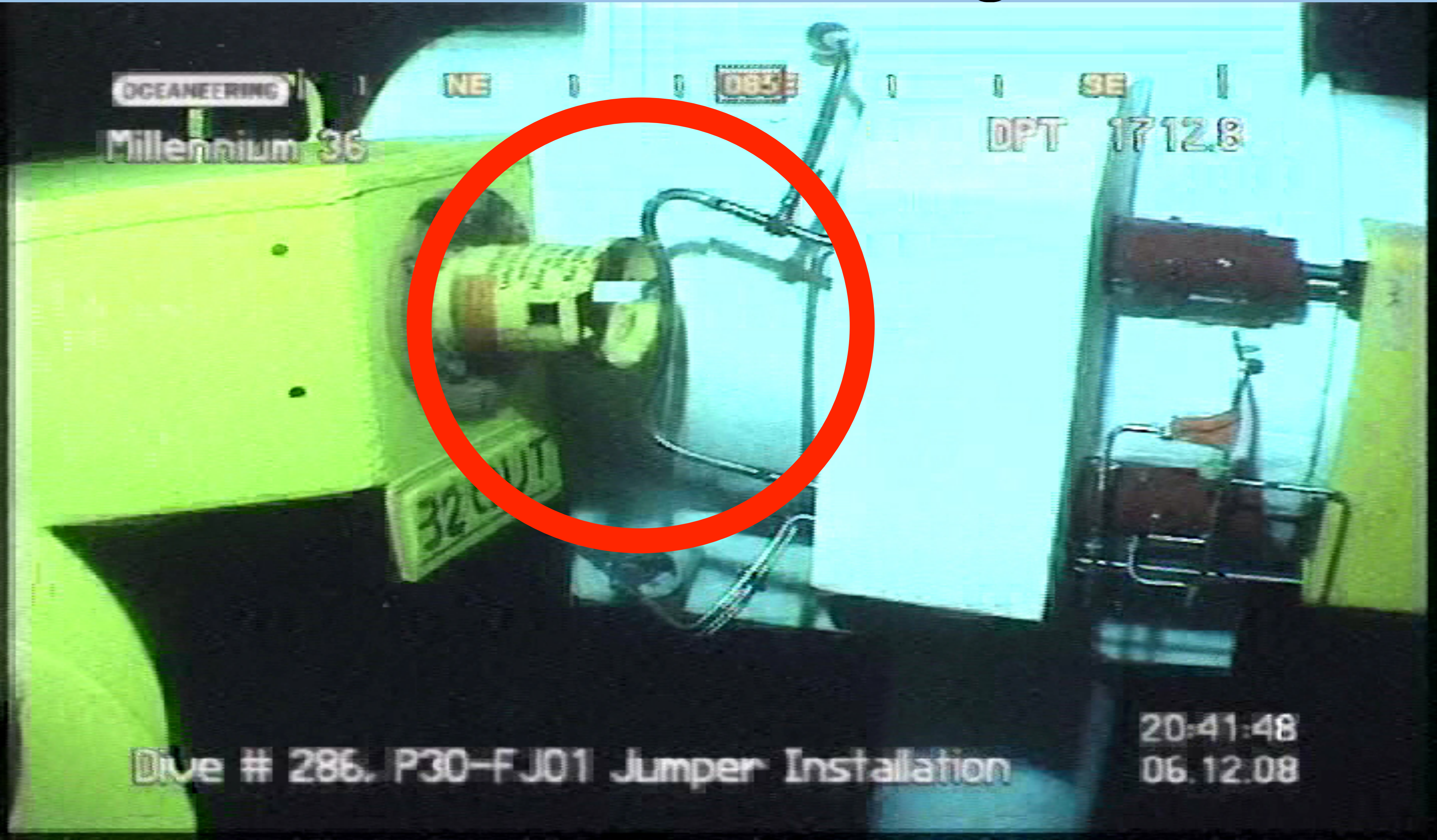


DC 32 Manifold

Extract from P&ID

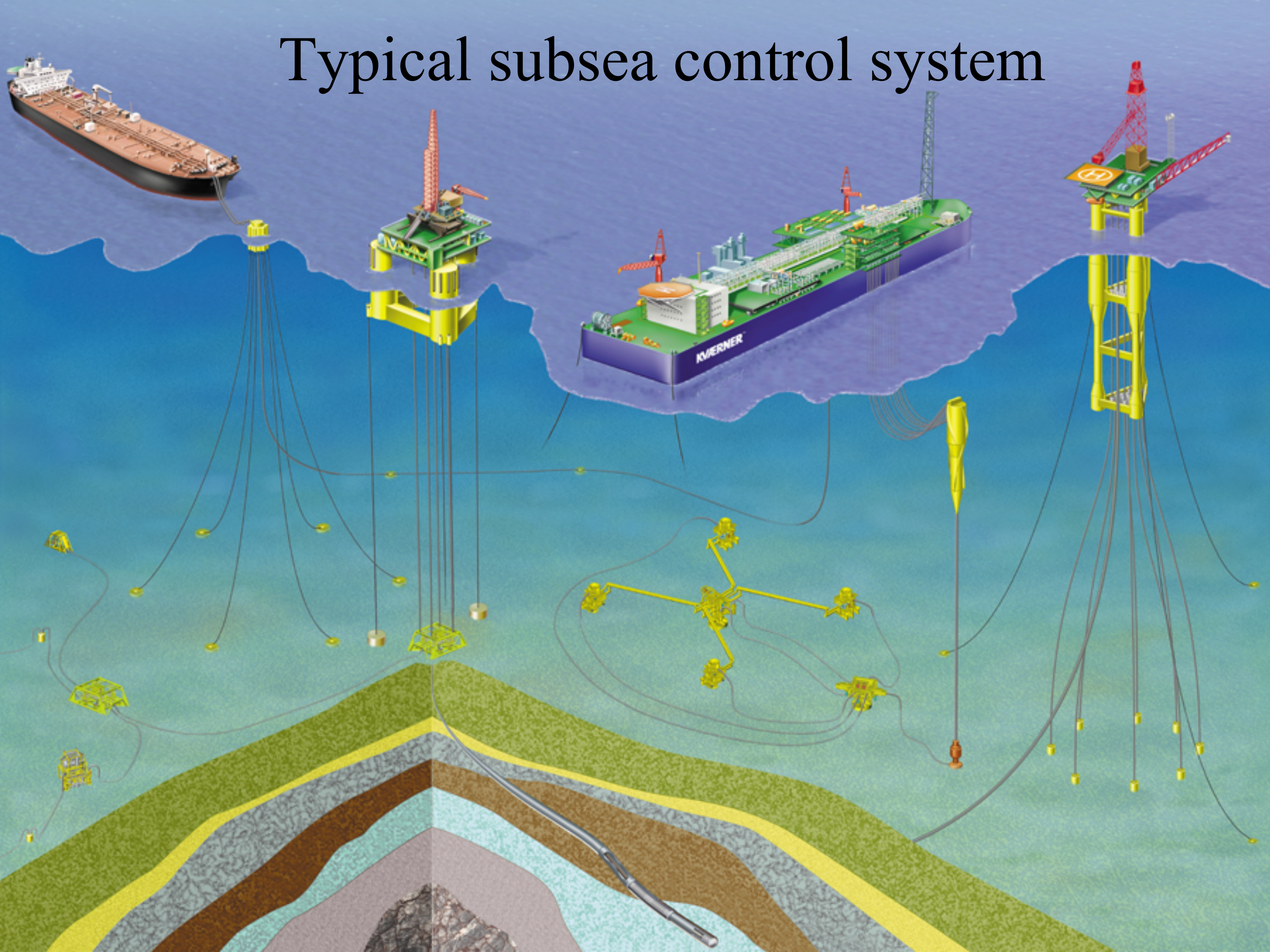


What went wrong?



Design Criteria for Subsea Controls

Typical subsea control system



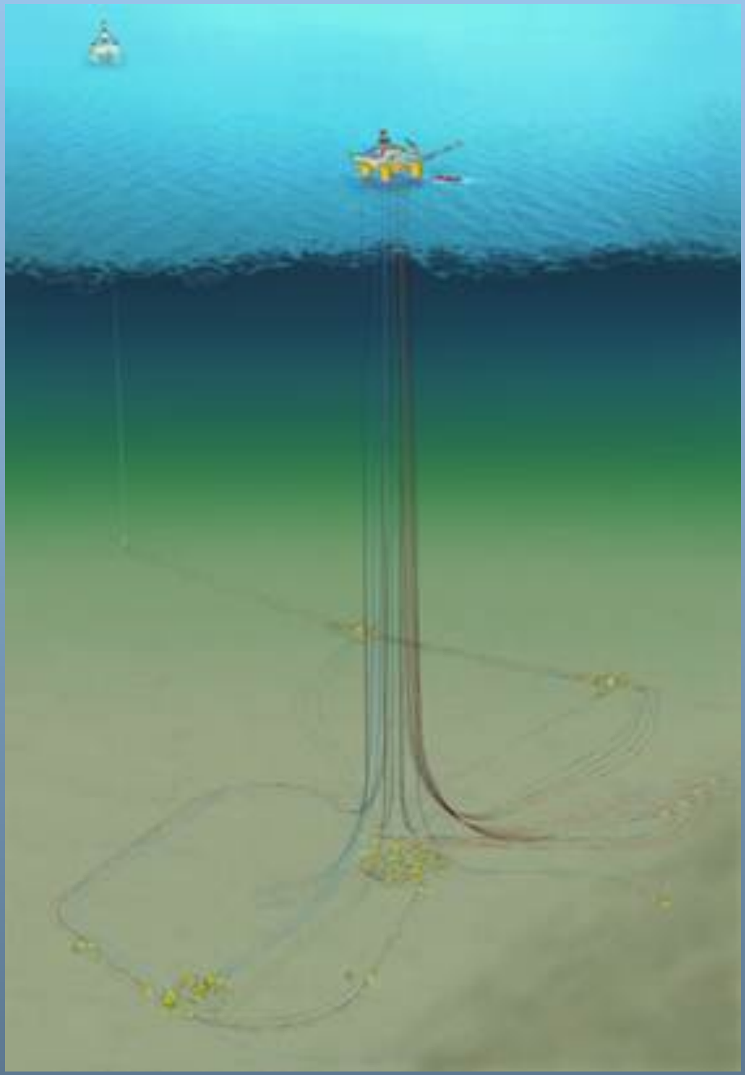
Design criteria

Factors to be considered during system design
Distance to reservoir
Reservoir geography
Reservoir pressure and temperature
Water depth
Number of wells
Well type (oil, gas, water injection)
Type and number of functions to be monitored

Design criteria

Typical subsea items to be controlled:

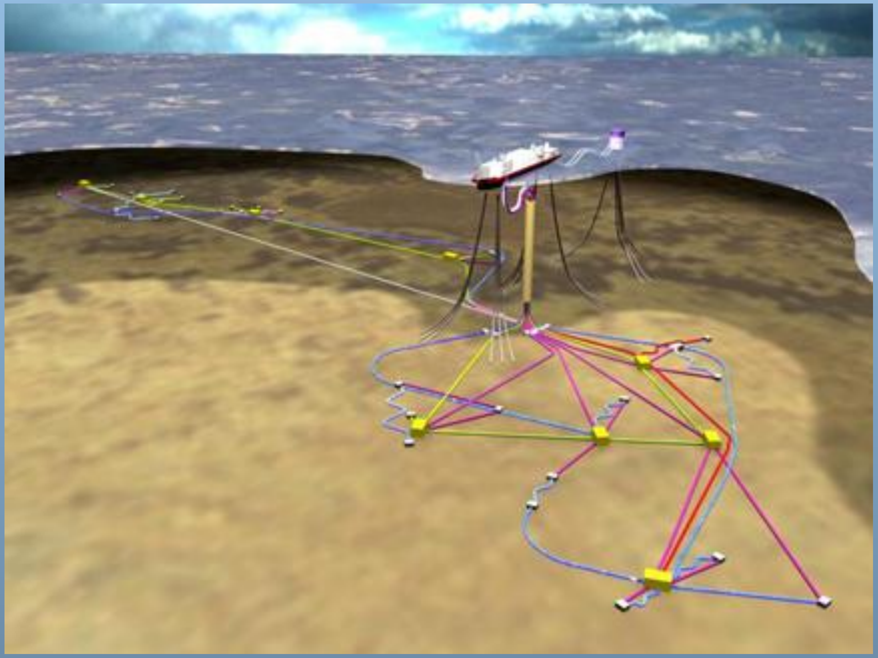
- **Tree valves**
- **Chokes**
- **Downhole safety valves**
- **Manifold valves**
- **Subsea isolation valves (SSIVs)**
- **High integrity pressure protection systems (HIPPS) barriers**
- **Subsea processes:**
  - **Separators**
  - **Pressure boosters**
  - **Subsurface multilateral valves**



Design criteria

Typical measured variables in a subsea production system:

- **Pressure**
- **Temperature**
- **Flow rate**
- **Valve position**
- **Choke position**
- **Sand production rate**
- **Pig detection**
- **Control system housekeeping:**
  - **Hydraulic supply pressures**
  - **Electrical supply voltage and current**
  - **Communications error rates**



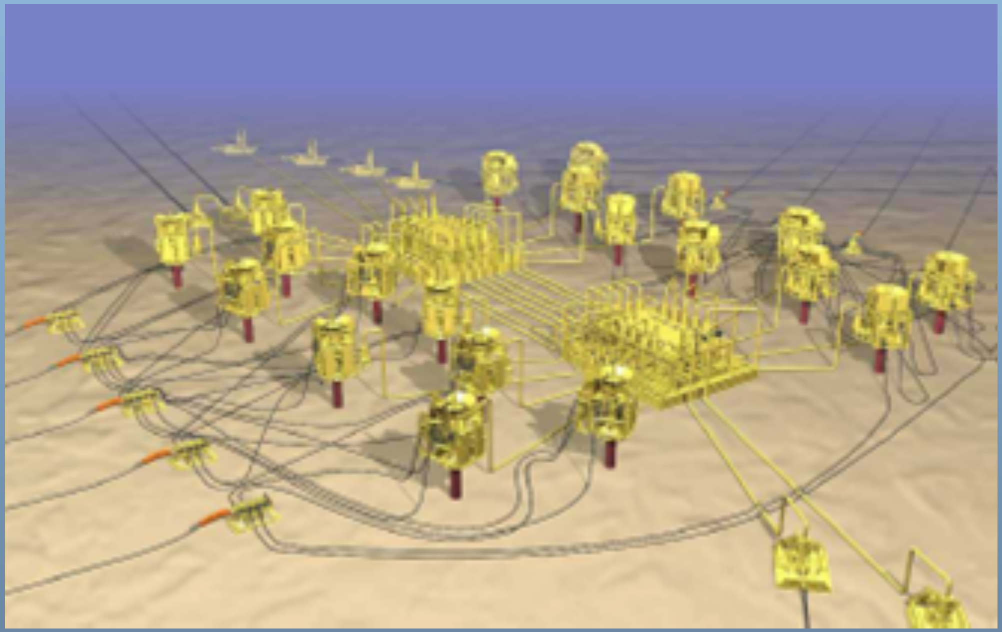
Design criteria

Typical items controlled by subsea production control system
Tree valves • 5 to 15 per tree, depending on well type and tree complexity
Chokes • One or two per tree
Manifold valves • Project dependent
Operations • Open/close • Production flow control • Water injection and gas lift flow control • Chemical injection control and metering

Design criteria

Type of surface facilities:

- **Semi-submersible**
- **Spars**
- **Buoys**
- **Fixed platform:**
  - **Manned**
  - **Unmanned**
- **Floating, production, storage and offloading (FPSO)**
- **Land based**



Design criteria

Considerations for deciding the most appropriate control system
Project life • **Weeks** • **Years**
Distance to the controlled items • **Feet/metres** • **Miles/kilometres**
Required response time • **Seconds** • **Minutes**

Types of Subsea Control

Types of control systems

A. Direct hydraulic

B. Piloted hydraulic

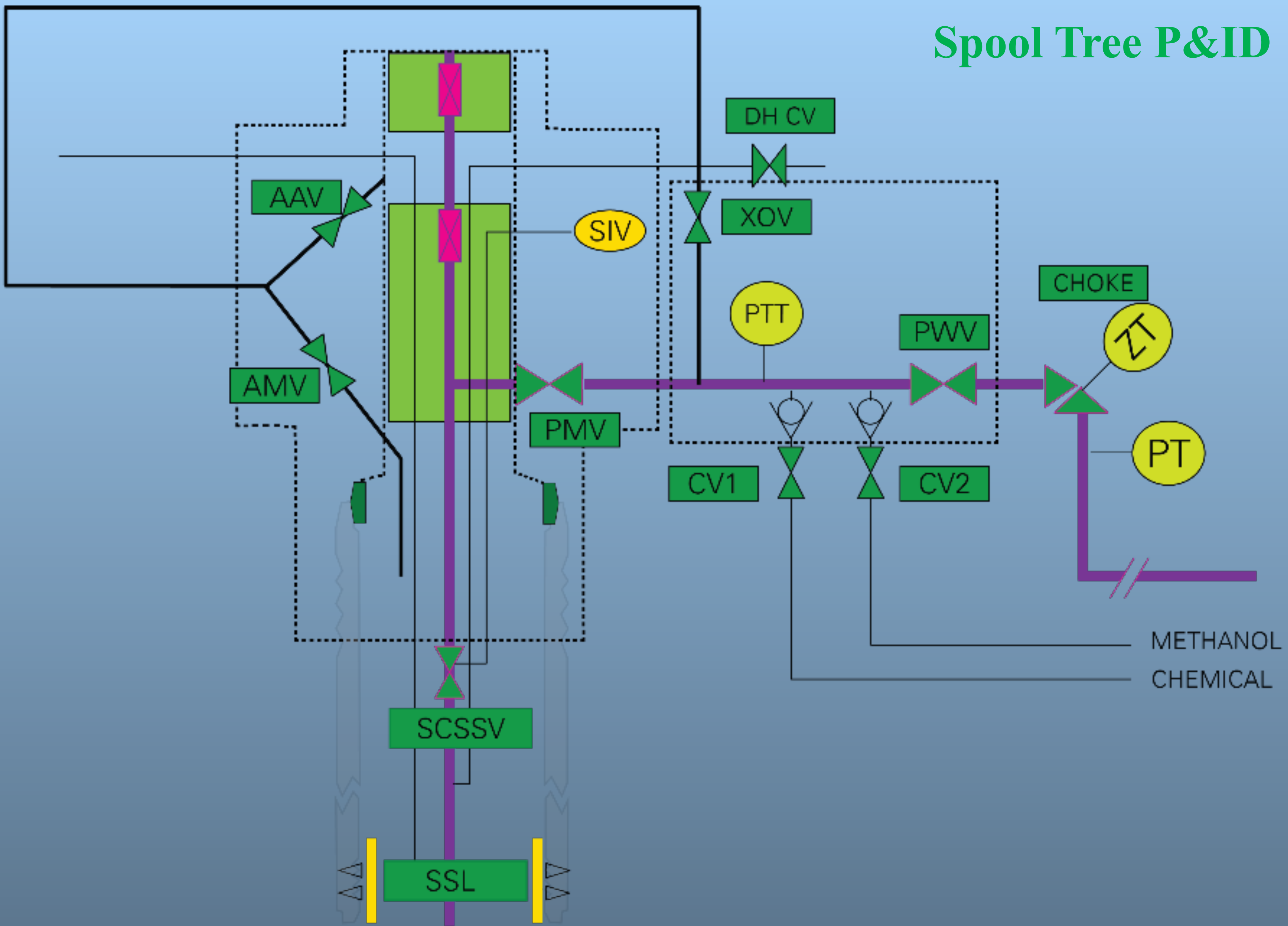
C. Sequence hydraulic*

D. Electro-hydraulic*

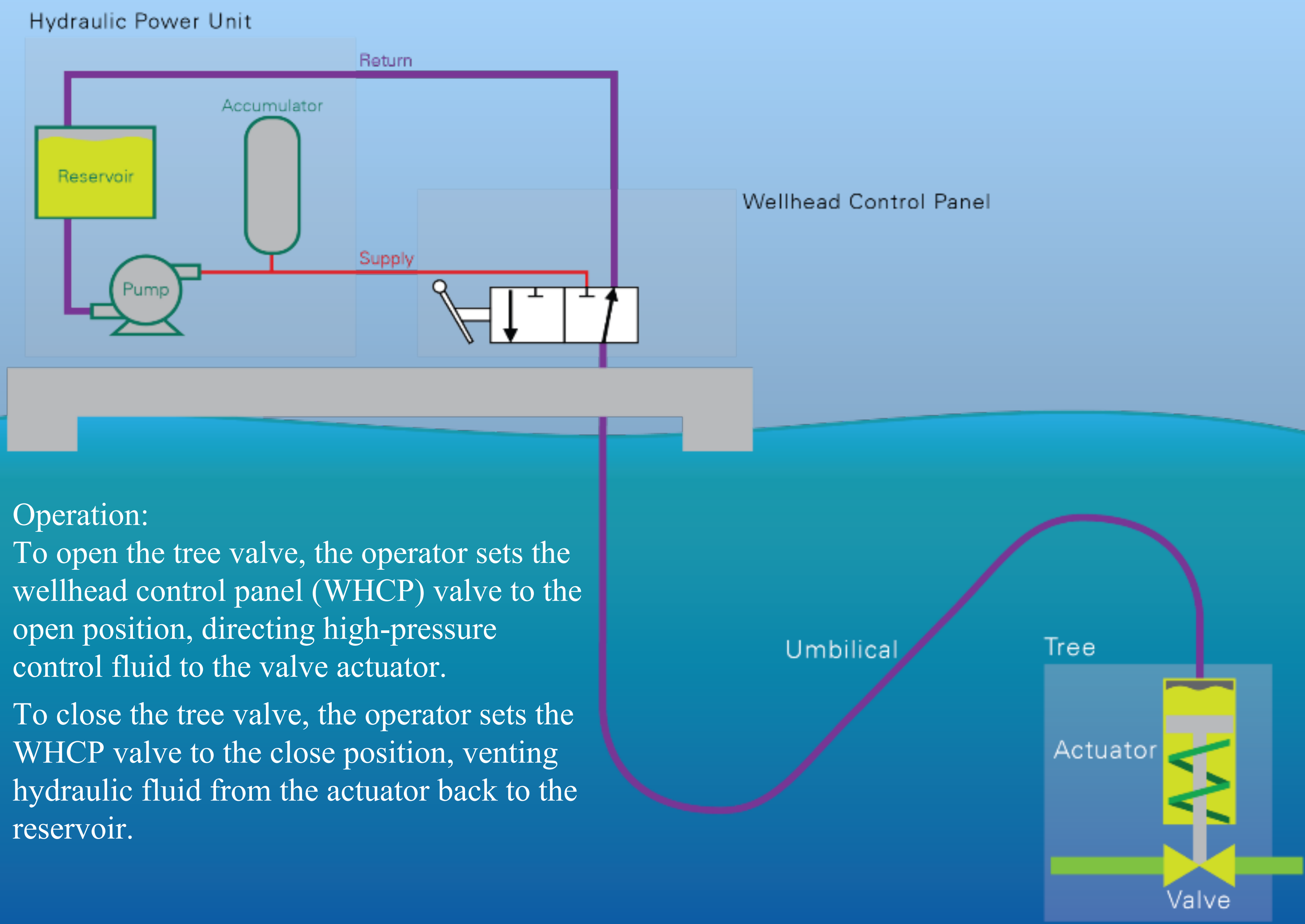
E. Multiplex electro (optical) hydraulic

*Not discussed in detail.

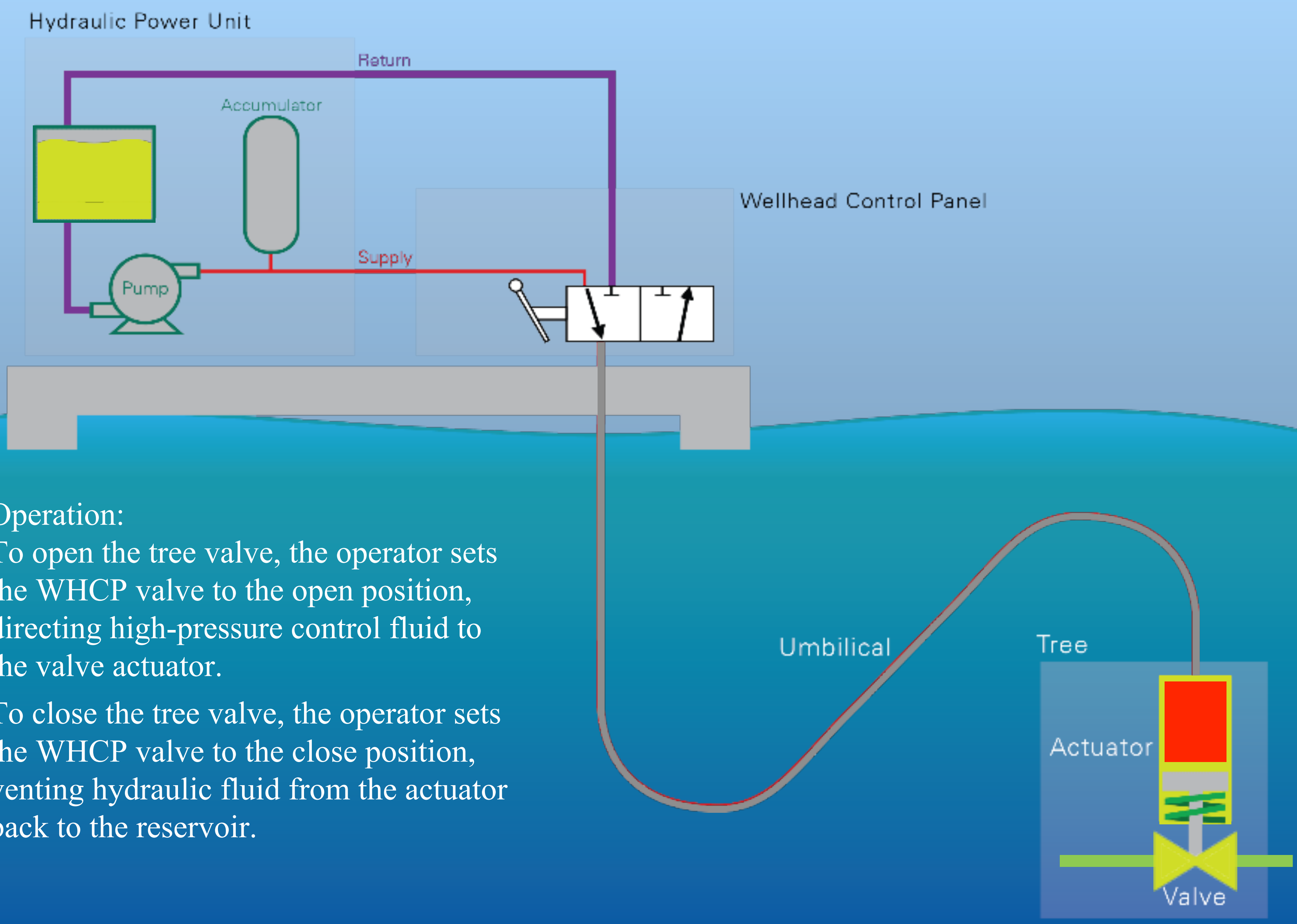
Spool Tree P&ID



Direct hydraulic control



- Operation:
  To open the tree valve, the operator sets the wellhead control panel (WHCP) valve to the open position, directing high-pressure control fluid to the valve actuator.
- To close the tree valve, the operator sets the WHCP valve to the close position, venting hydraulic fluid from the actuator back to the reservoir.



- Operation:
  To open the tree valve, the operator sets the WHCP valve to the open position, directing high-pressure control fluid to the valve actuator.
- To close the tree valve, the operator sets the WHCP valve to the close position, venting hydraulic fluid from the actuator back to the reservoir.

Direct hydraulic control

Direct hydraulic control

Summary

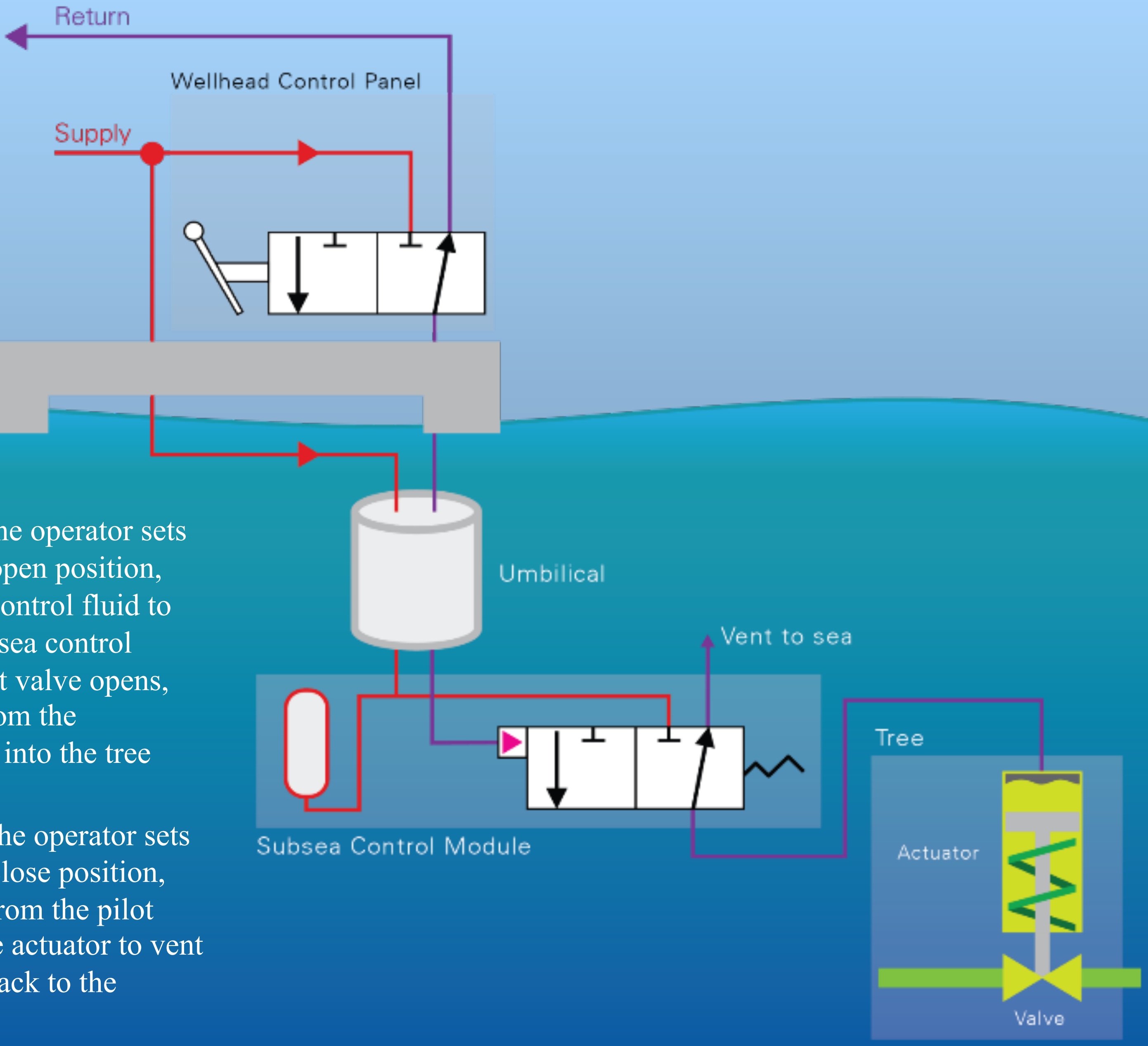
- Simplest of all control systems
- Dedicated hydraulic hose for each subsea function being controlled
- Control supplies are attached directly to the valve being actuated
- Typically used for workover applications and small systems

Advantages

- Low cost
- Reliability is high due to the critical components being on the surface
- Maintenance access is very good; all critical components are on the surface

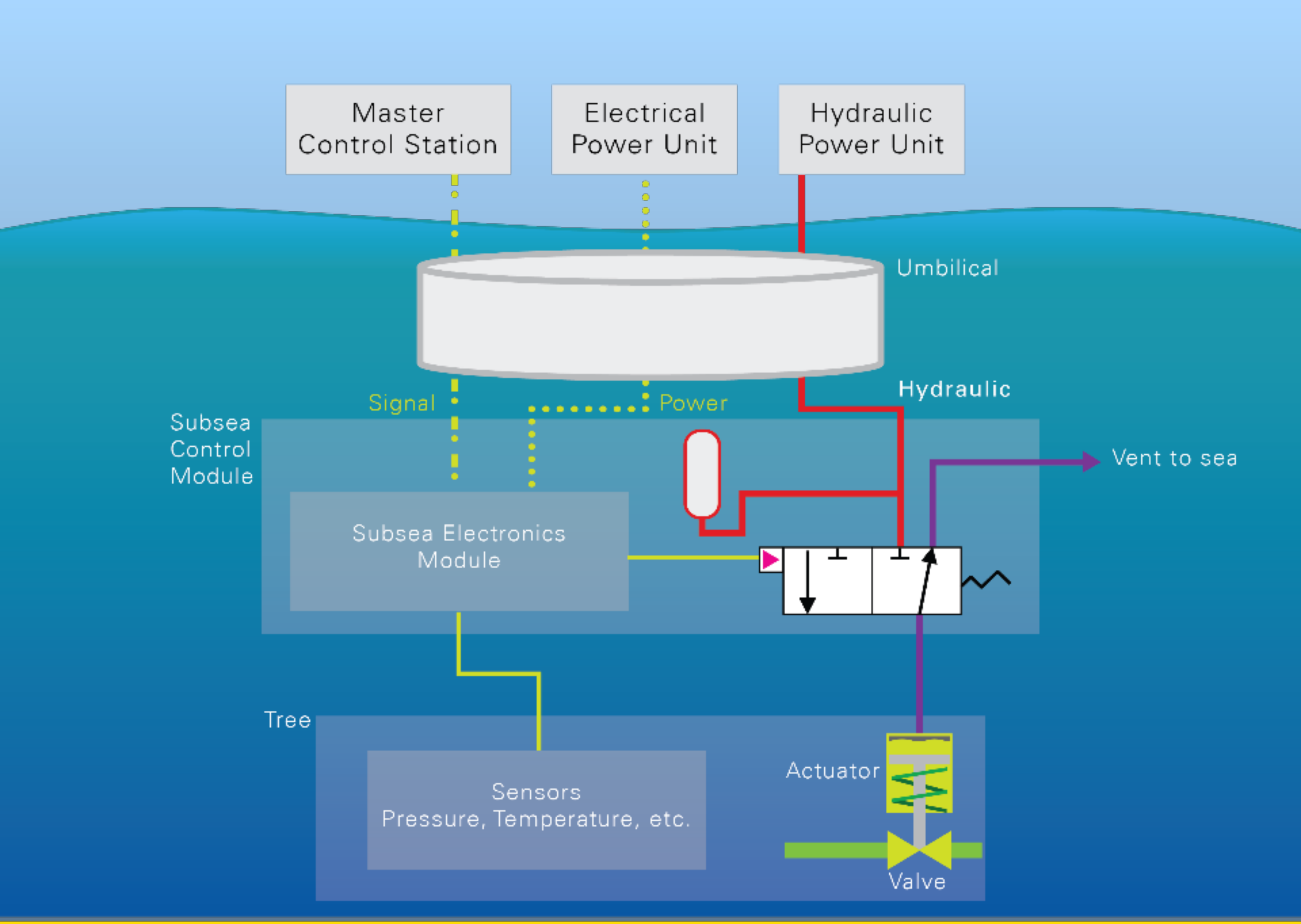
Disadvantages

- Very slow
- Large number of hoses (one per function)
- Dump valves can be used to speed up tree valve closure time
- Limitation in distance (10,000ft/3km) due to slow response
- No subsea monitoring due to no electrical signals

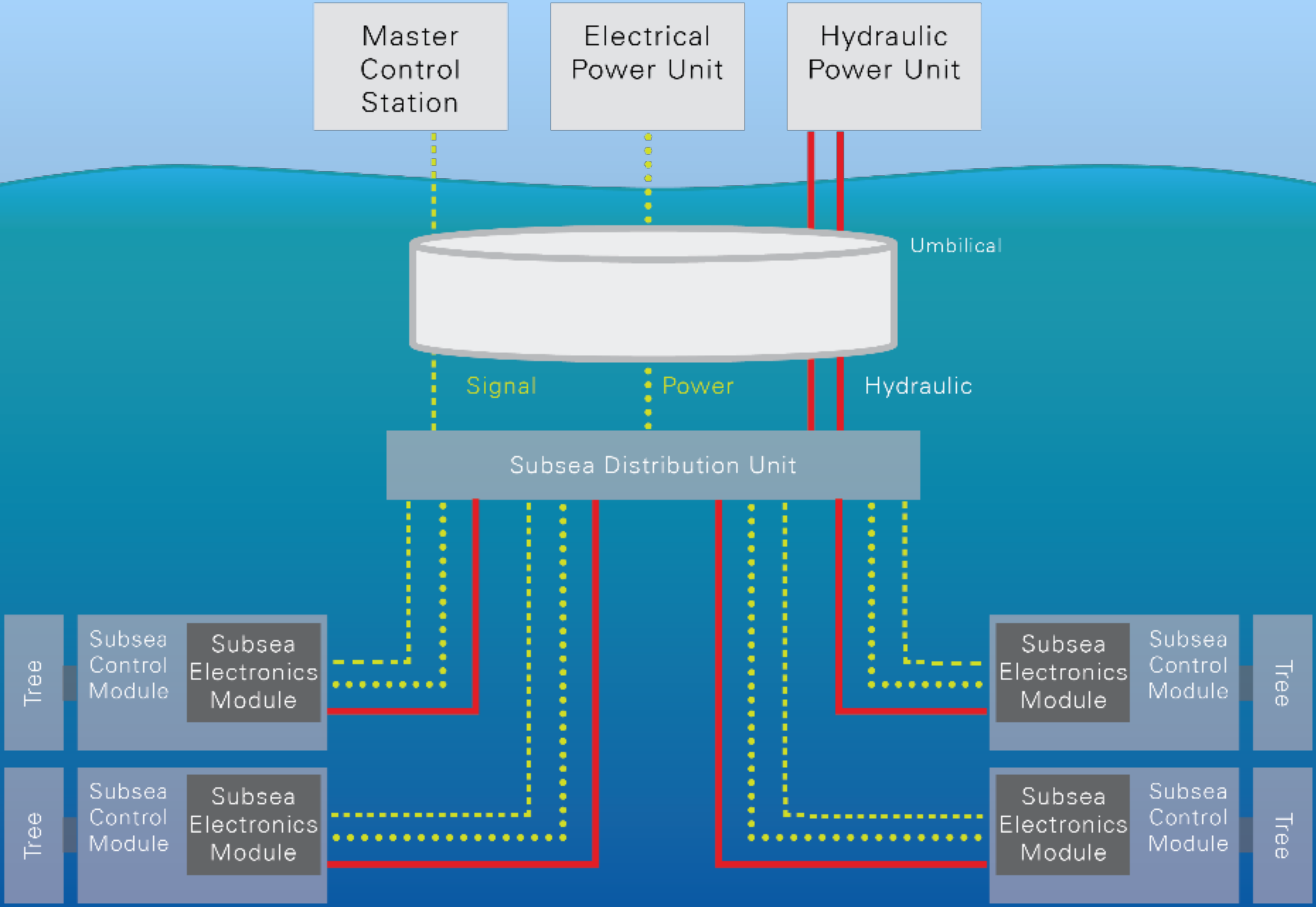


- Operation:
  To open the tree valve, the operator sets the WHCP valve to the open position, directing high-pressure control fluid to the pilot valve in the subsea control module (SCM). The pilot valve opens, allowing fluid to flow from the accumulator in the SCM into the tree valve actuator.
- To close the tree valve, the operator sets the WHCP valve to the close position, venting hydraulic fluid from the pilot valve, allowing the valve actuator to vent through the pilot valve back to the reservoir.

Piloted hydraulic



Multiplexed electro-hydraulic



Multiplexed electro-hydraulic

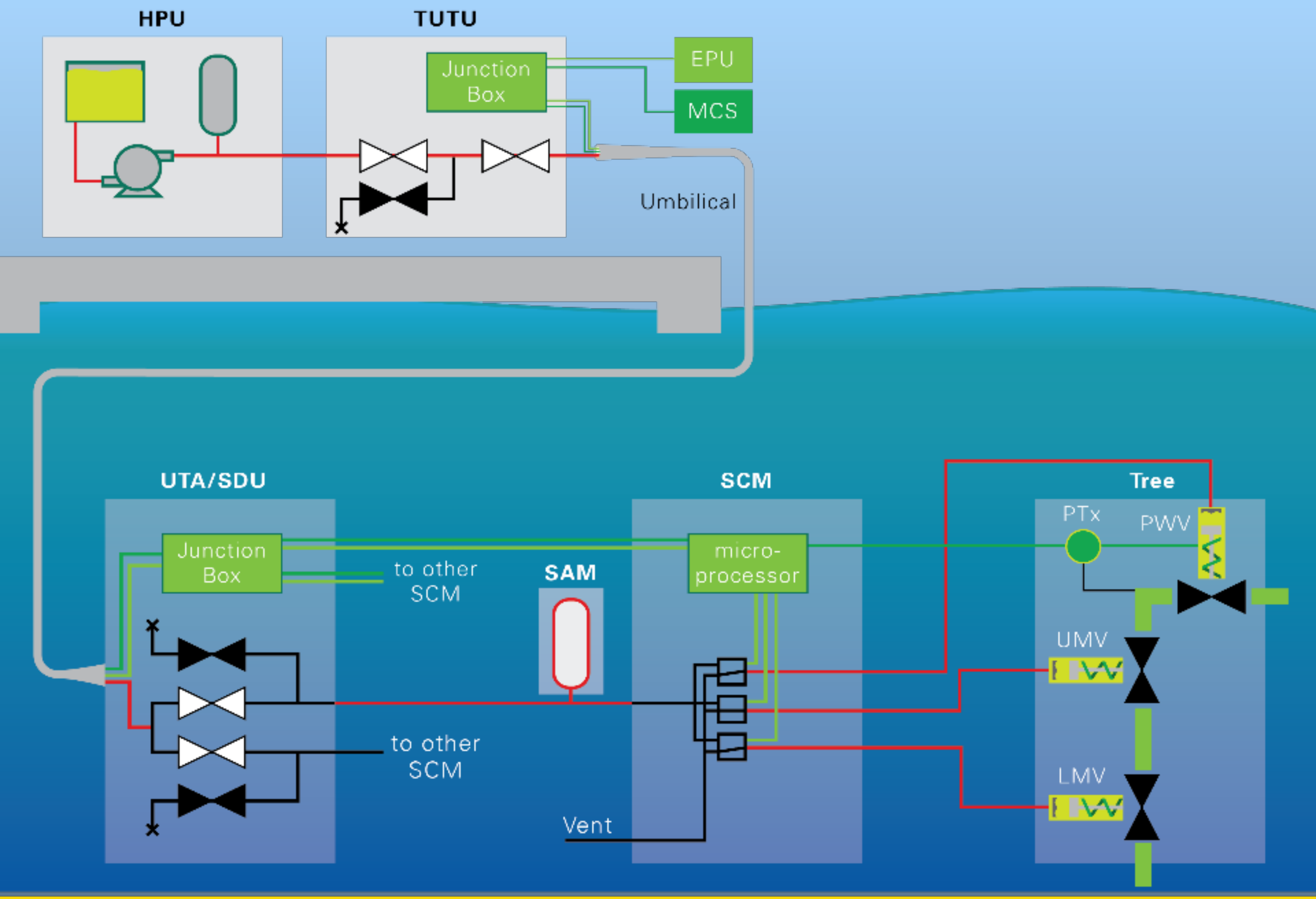
Multiplexed electro-hydraulic

Advantages

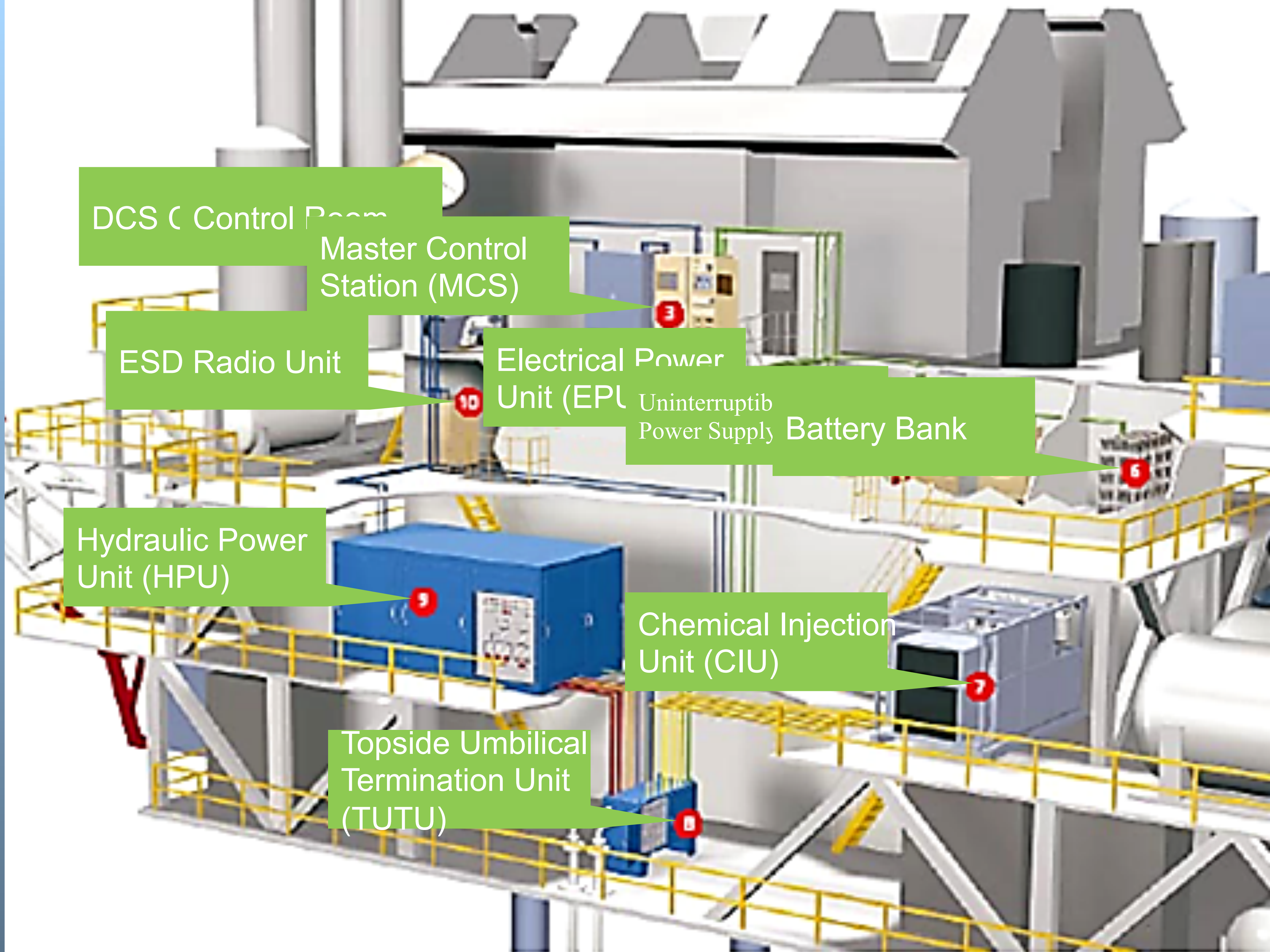
- Operates over large distances
- Faster response times
- Smaller umbilical diametre
- Allows control of many valves/ wells via a single communications line
- Redundancy is easily built in
- Enhanced monitoring of operation and system diagnostics
- Ideal for unmanned platform or complex reservoirs
- Able to supply high volume of data feedback

Disadvantages

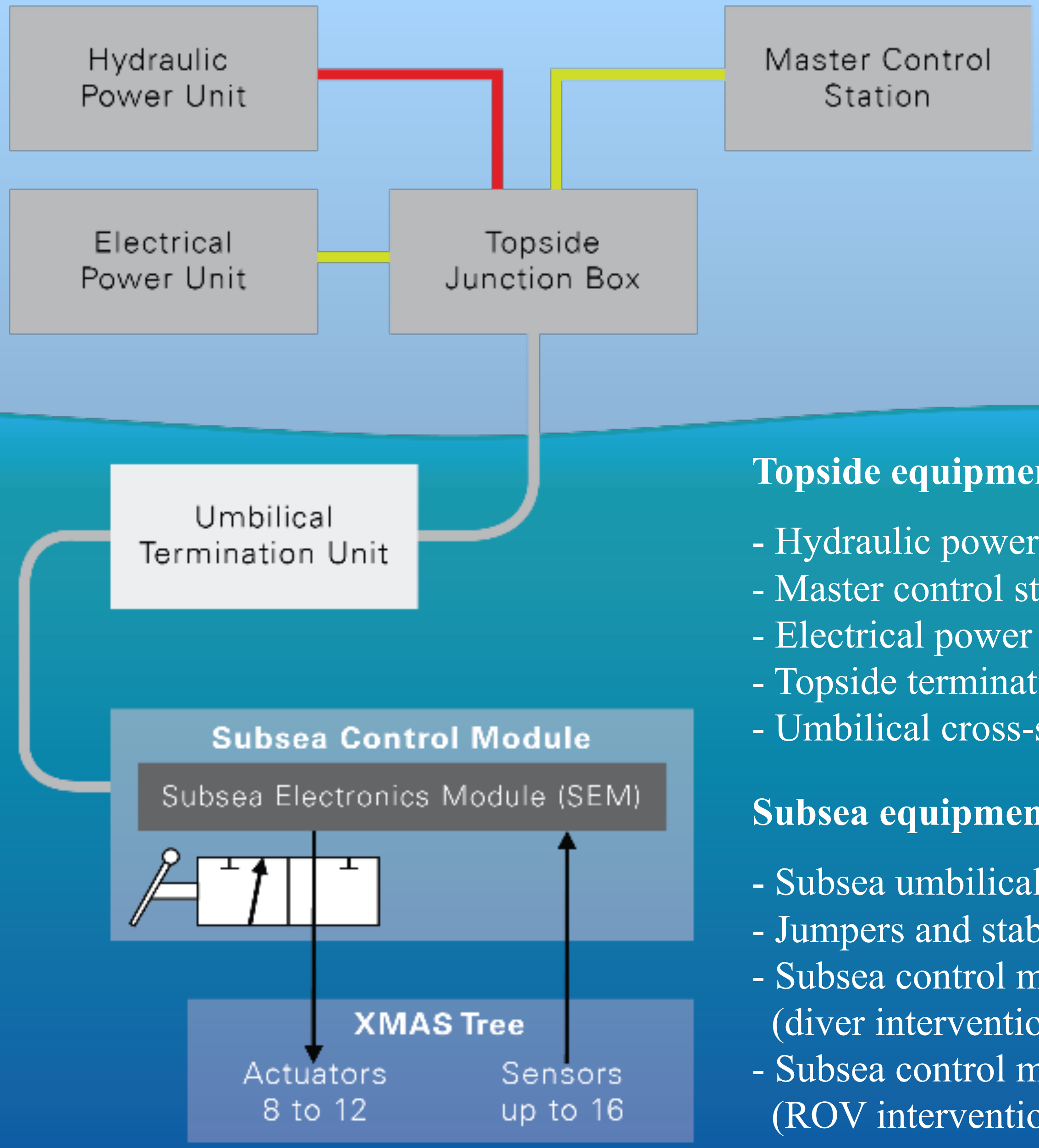
- Cost is high due to:
  - Electronics within the SEM
  - Addition of a computer topside
  - Addition of computer software
- The above costs balance against smaller and less complex umbilicals and advancing technology reducing the cost of the electronics.
- Reliability critical due to:
  - Critical components are used subsea within the SEM
  - Electrical connections
  - Sensors



Typical multiplexed electro-hydraulic system


DCS (Control Room
Master Control Station (MCS)
ESD Radio Unit
Electrical Power Unit (EPU
Uninterruptib Power Supply
Battery Bank
Hydraulic Power Unit (HPU)
Chemical Injection Unit (CIU)
Topside Umbilical Termination Unit (TUTU)
3
10
6
9
7
8

Valve and Choke Actuation



Topside equipment

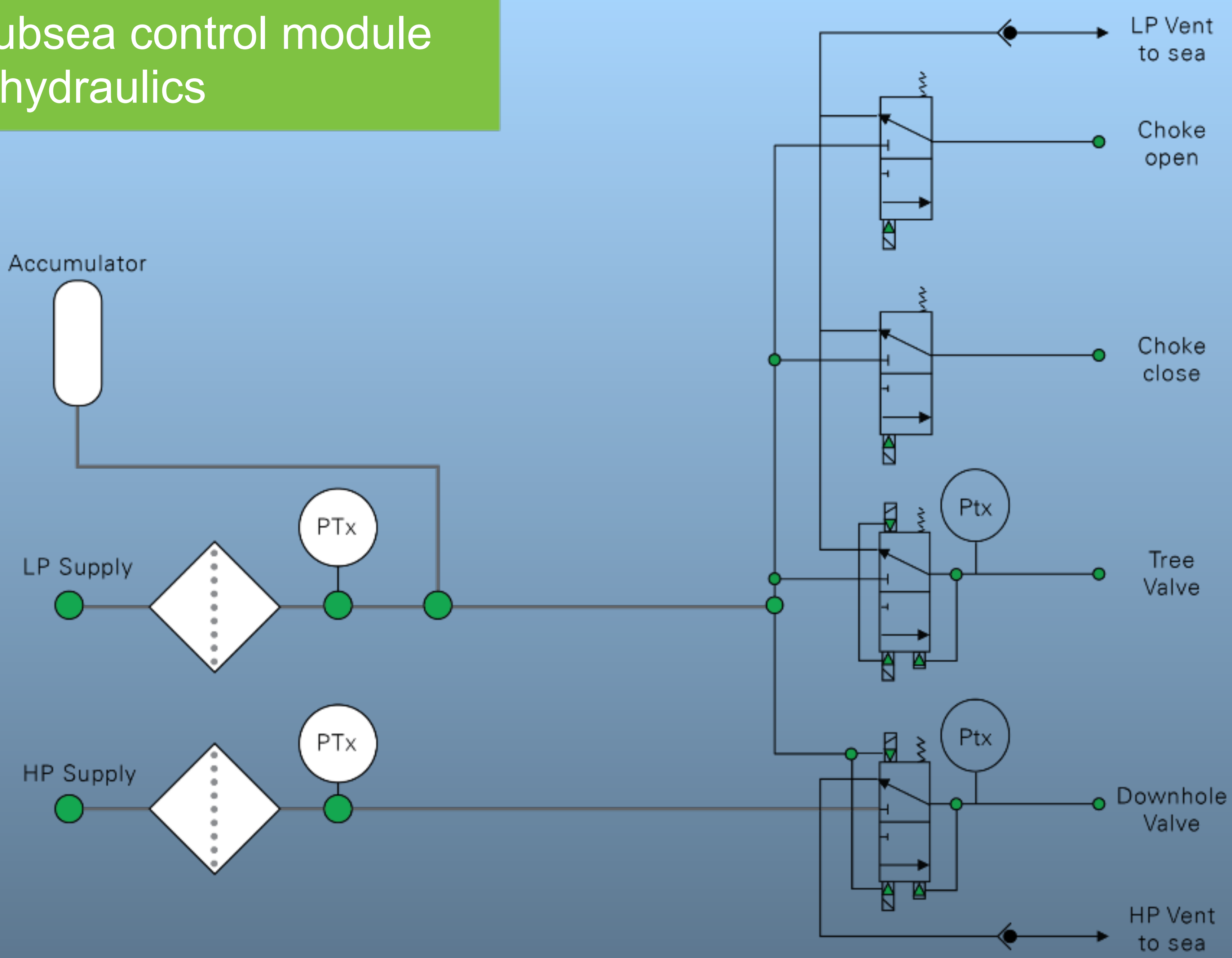
- Hydraulic power unit
- Master control station
- Electrical power unit
- Topside termination unit
- Umbilical cross-section

Subsea equipment

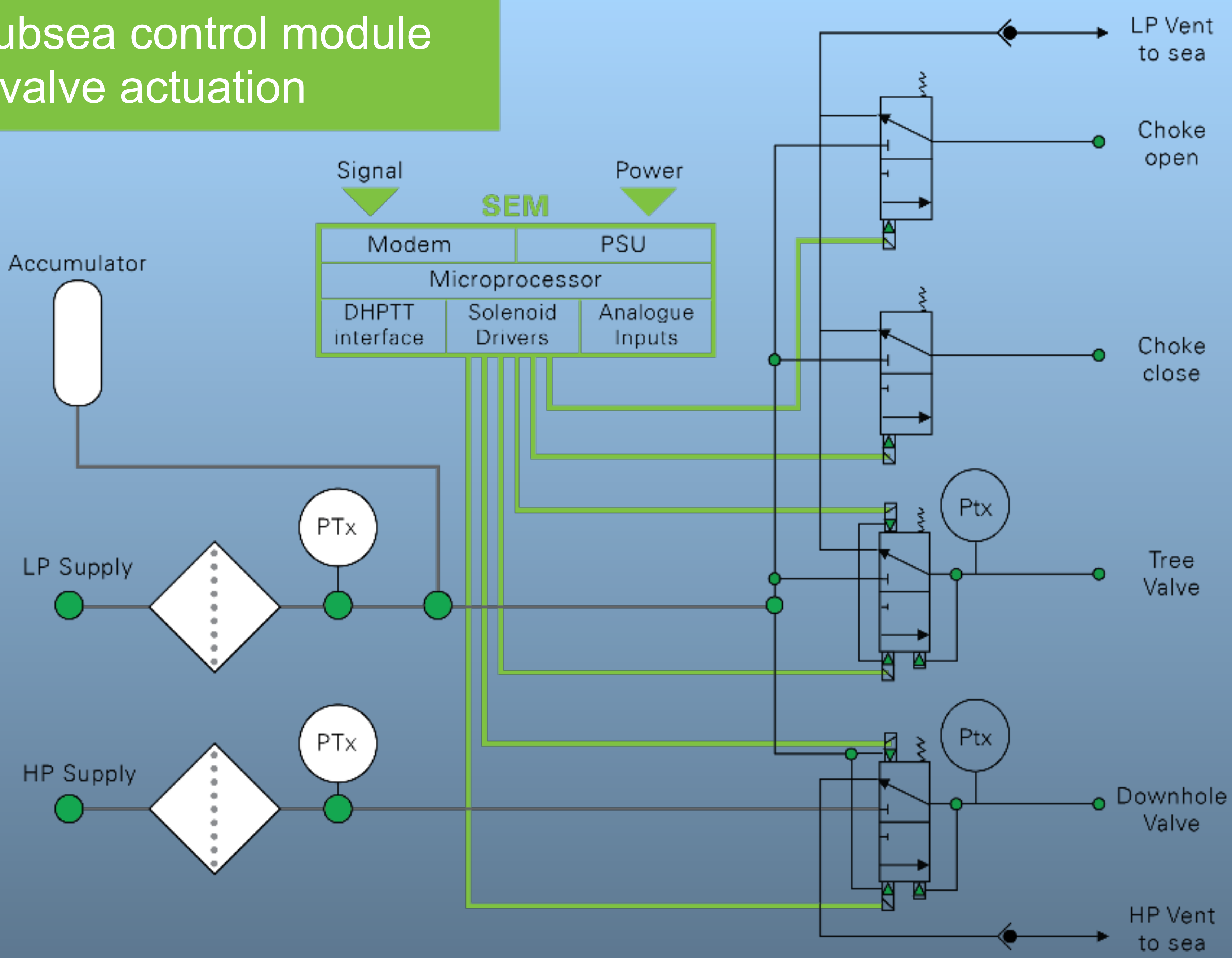
- Subsea umbilical termination
- Jumpers and stabplates
- Subsea control module (diver intervention)
- Subsea control module (ROV intervention)

Typical field equipment – MUX electro-hydraulics

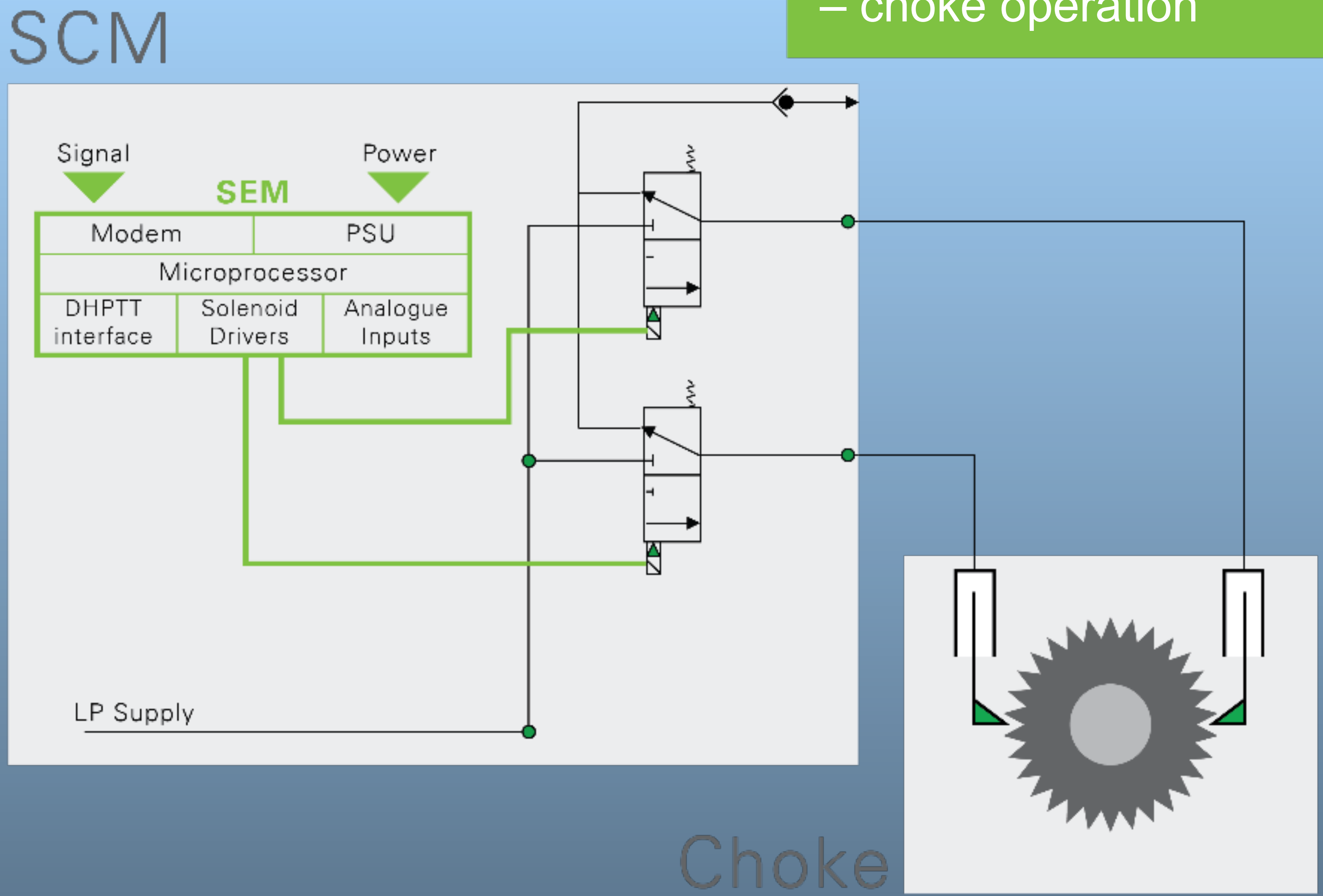
Subsea control module – hydraulics



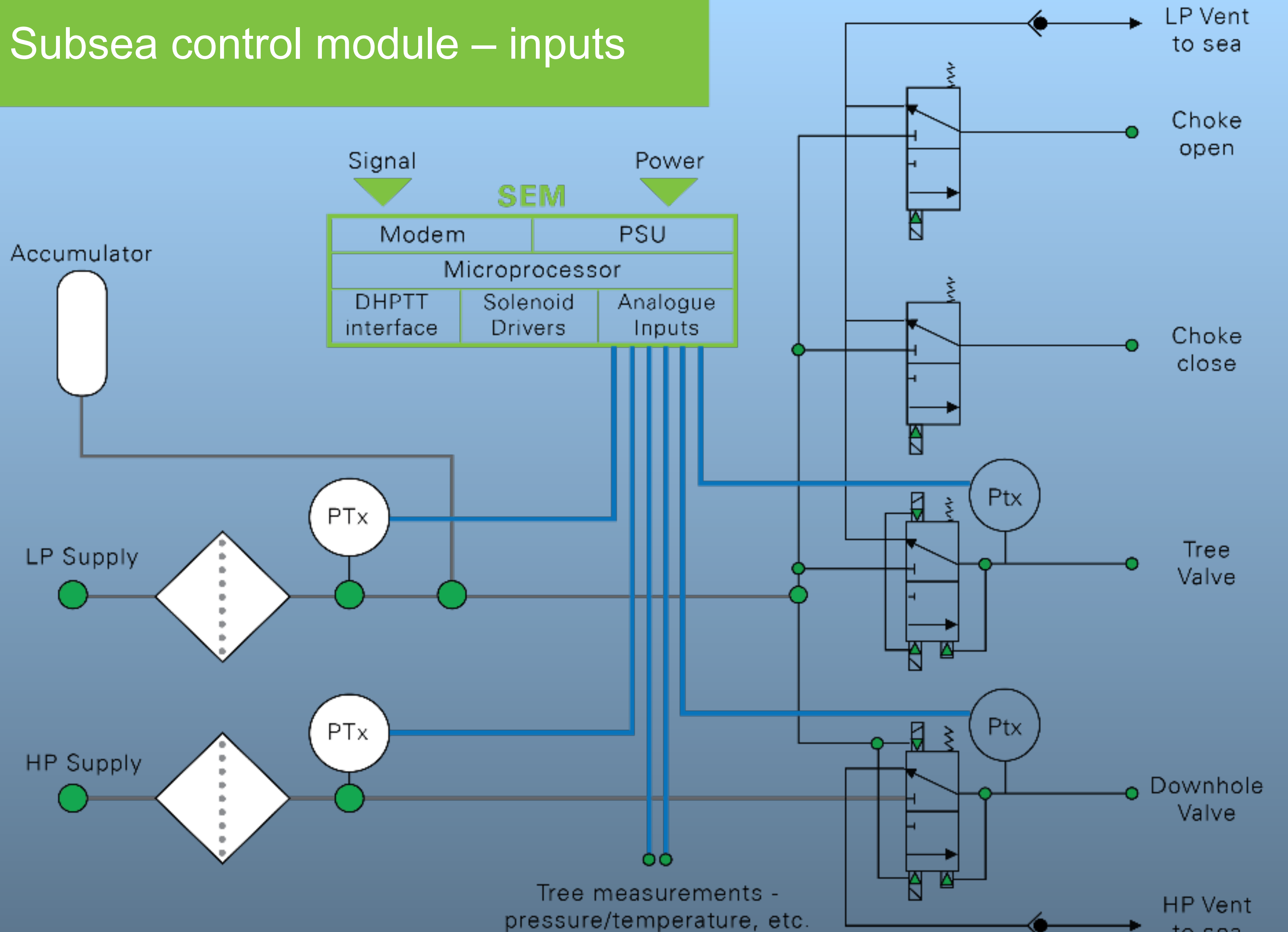
Subsea control module – valve actuation



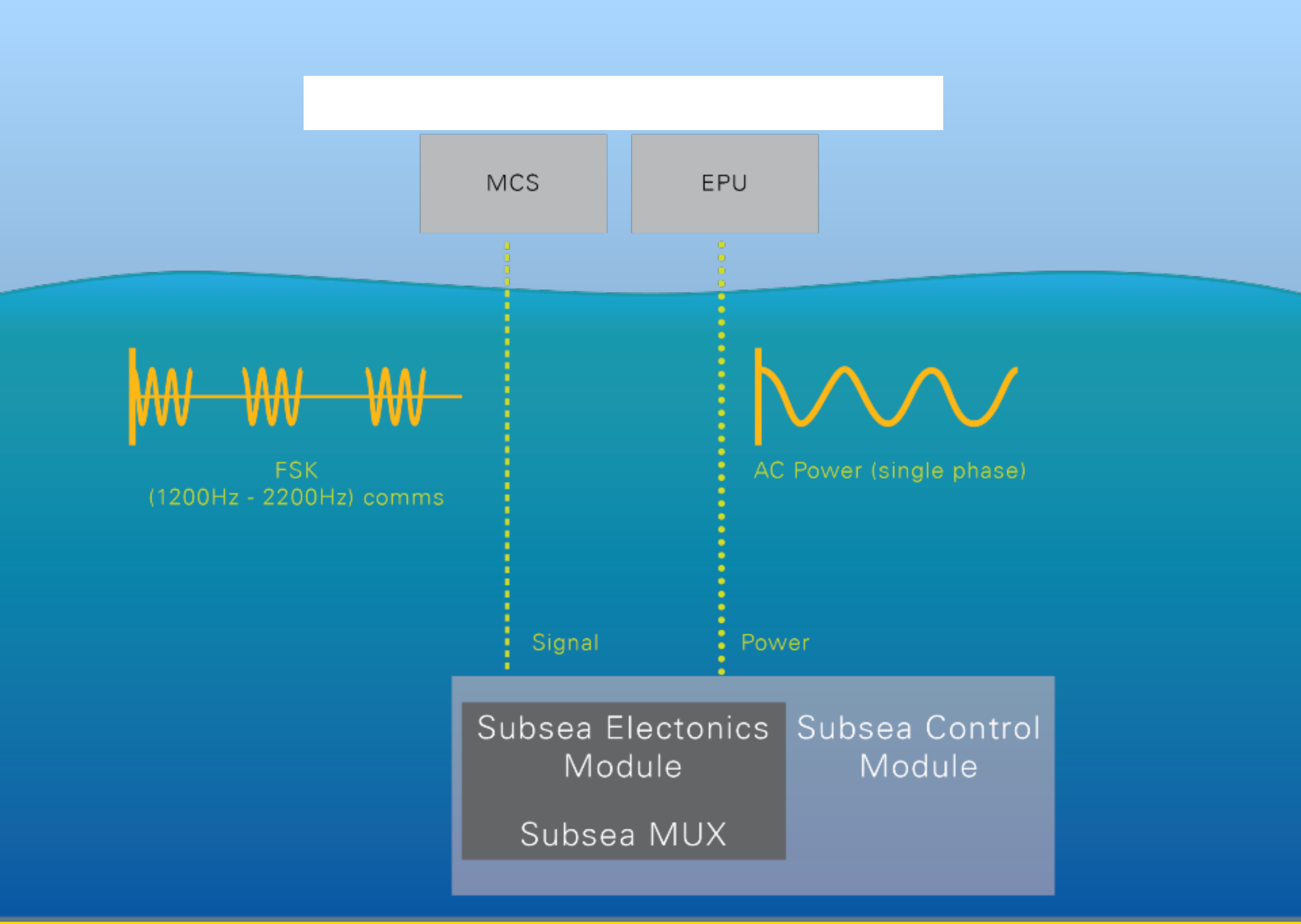
Subsea control module – choke operation



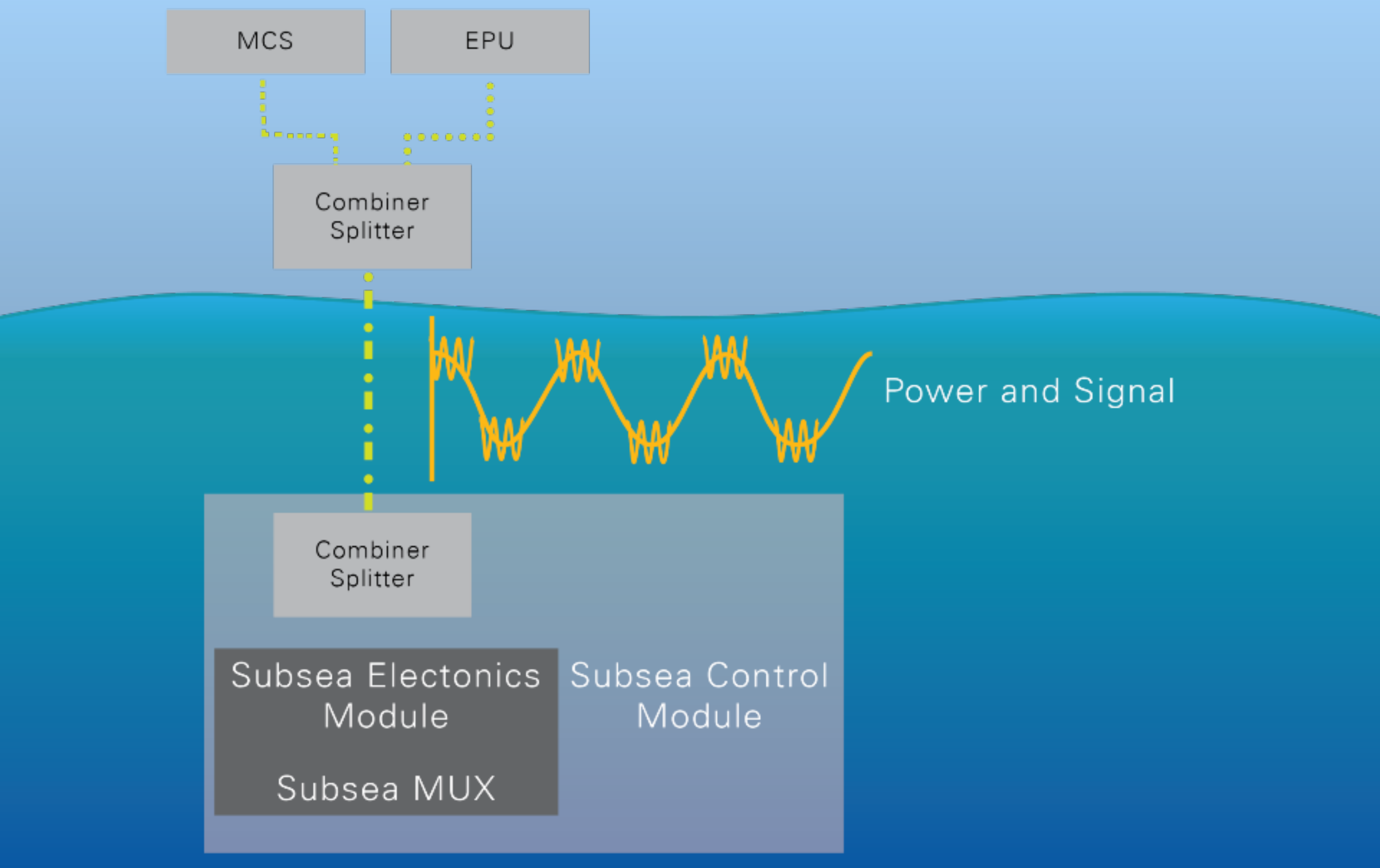
Subsea control module – inputs



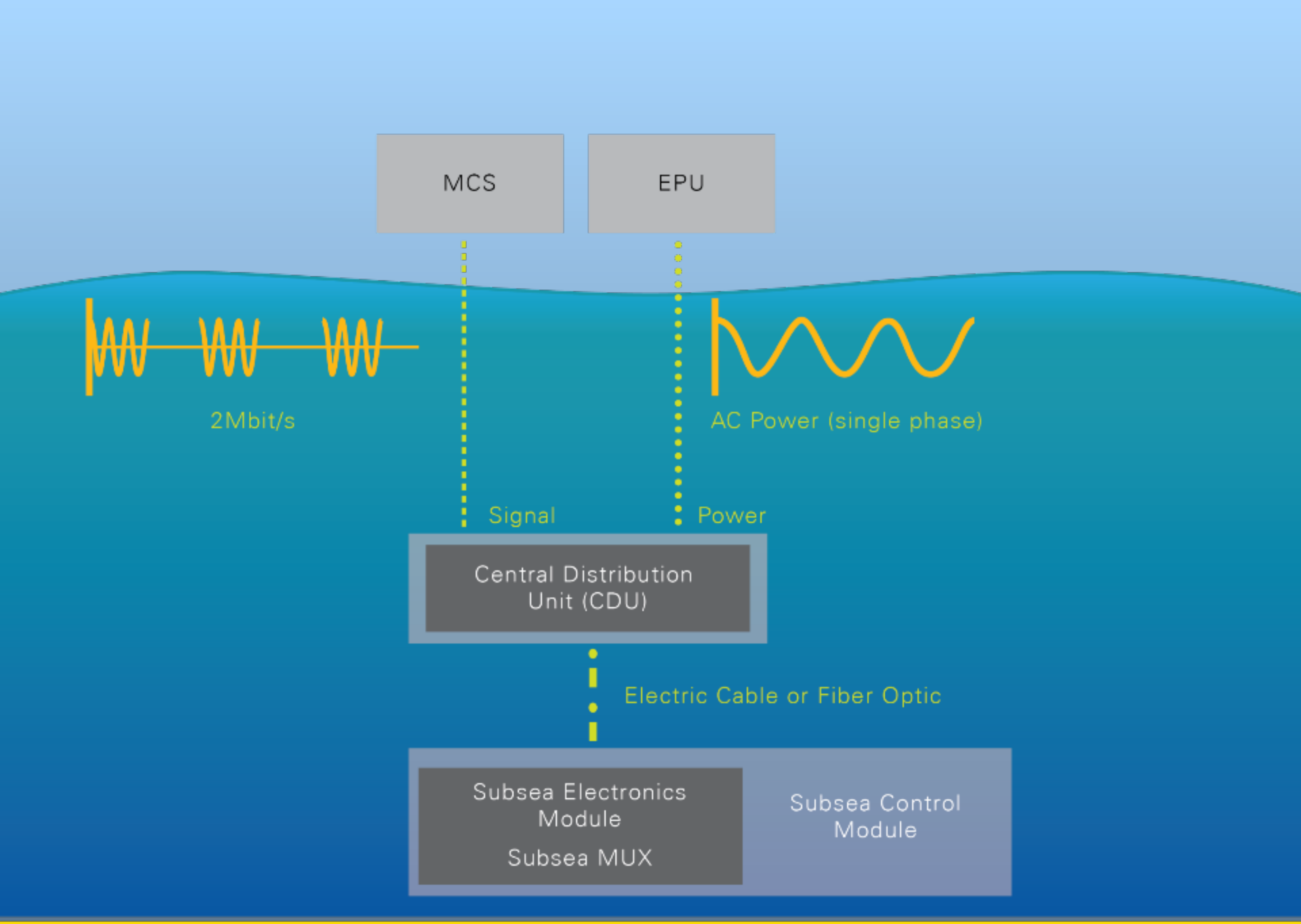
Overview of Electrical Systems



Control options – separate electrical power and comms



Control options – combined electrical power and comms

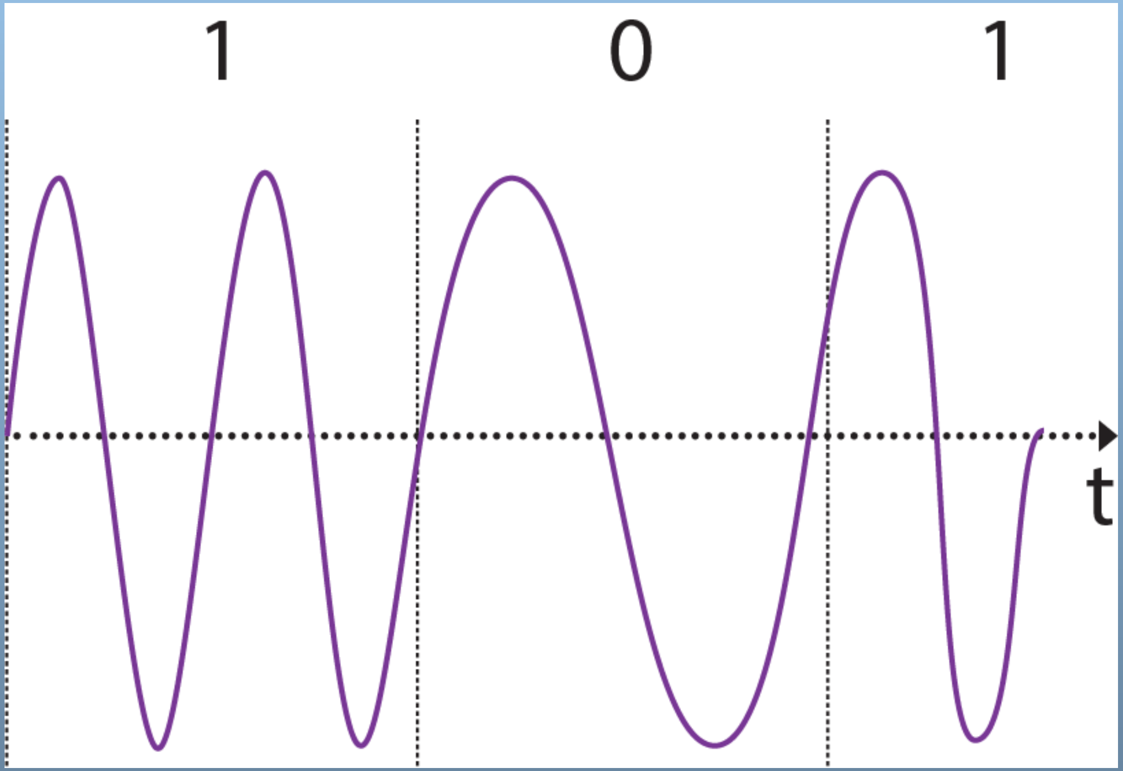


Control options – separate electrical power and comms (fibre)

Electrical Analysis - Communications

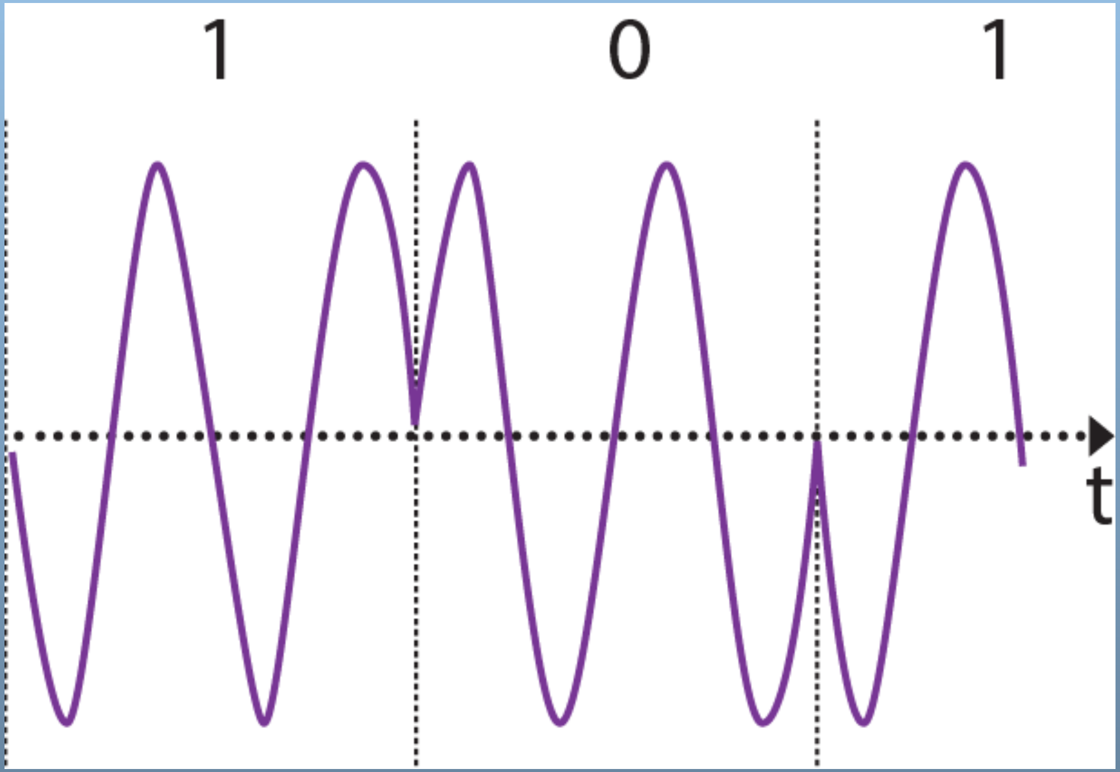
Frequency shift keying (FSK)

- Binary FSK (BFSK): One frequency for 0 and one frequency for 1.
- One frequency designated as ‘Mark or 1’; other frequency designated as ‘Space or 0’.



Phase shift keying (PSK)

- Binary PSK (BPSK) One phase for 0 and one phase for 1.
- One frequency designated as ‘Mark or 1’; other frequency designated as ‘Space or 0’.

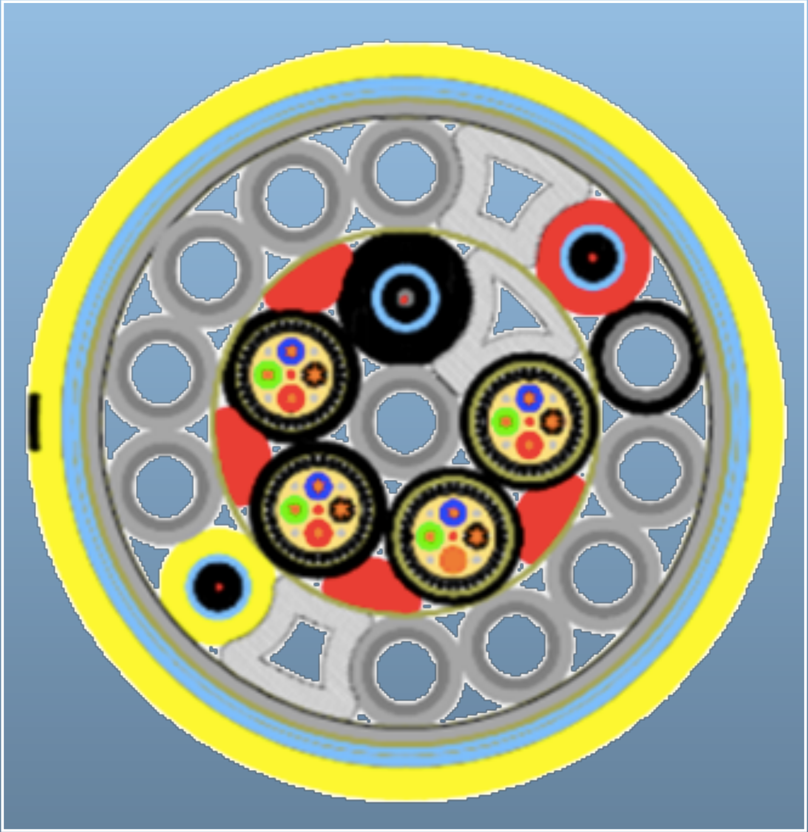


Factors affecting communication analysis

- **Major concern**
  - Signal attenuation
  - Distortion and unintended harmonics in waveform to/from Subsea power and communications unit (SPCU) to Subsea electronic modules (SEMs)
  - Crosstalk
- **Goal**
  - Reduce bit error rate. Reduce Crosstalk.

Factors affecting communication analysis

- Umbilical length: longer offsets have higher attenuation losses
- Minimum refresh rate for data from subsea sensors
- Speed of response to subsea emergency shutdown (ESD) commands
- Umbilical cable size
- Field layout and distance
- Communications super-imposed on power vs. separate communications and power



Optical budget for fibre optic systems

Transmitter Optical Power Output: AA (dBm)

Receiver Optical Power Threshold: BB (dBm)

Goal: **Tx – Losses > Rx**

Fibre Optic Losses

Fibre Loss = αL (dB) ; where α is the fibre attenuation (dB/m) and L is the length (both static and dynamic)

Patch Points/Connector Losses = *# of connects*Loss per connector* (dB)

Device attenuation = *# of devices*Loss per device* (dB)

Safety Margin = *defined per project* (dB)

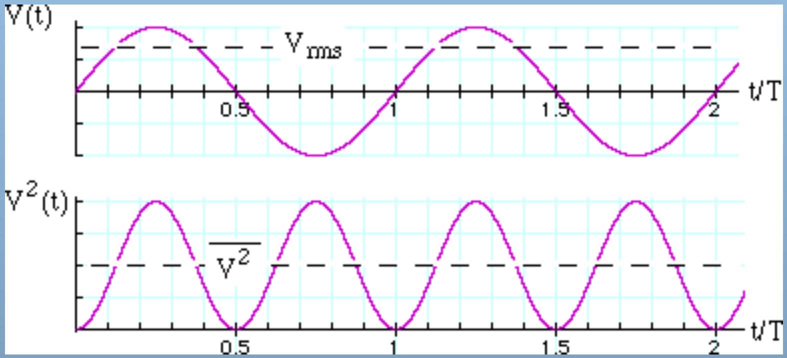
$$\text{Attenuation (dB)} = 10 * \log {}^{input\ signal\ (W)}\!/_{output\ signal\ (W)}$$

Electrical Analysis - Power

AC single phase power

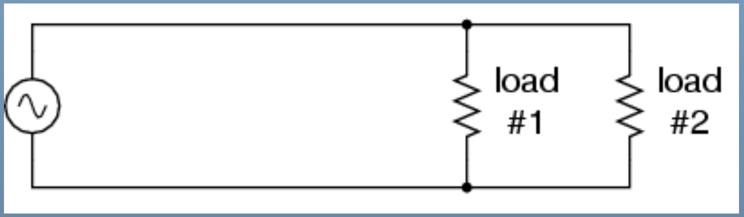
Description:

- Single sinusoidal voltage source
- Voltage goes to zero twice every cycle
- Frequency = 50–60 Hz
- Two wires (pairs)



Single phase power is used for:

- Low-to-medium voltage (250–690 VAC)
- Short-to-medium tie-back distance (~15 miles)
- Small loads (watt to kilowatt range)
- Can be used for most deepwater projects



DC power

Description:

- Constant voltage and current
- One or two wires in umbilical

Used for:

- Long-distance transmission of HV power
- Large loads (e.g. subsea processing, all electric systems)

Advantages:

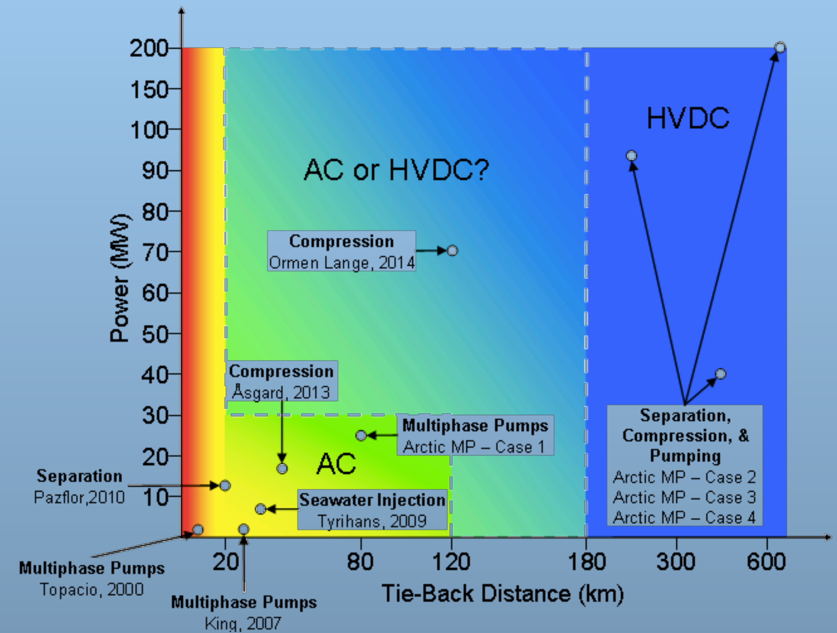
- Less expensive transmission cable
- Improved voltage stability
- Less power loss
- Better efficiency over long distances

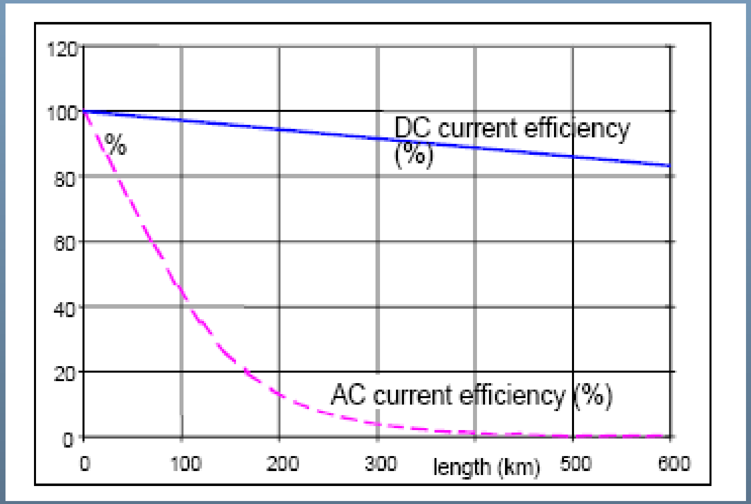
Disadvantages:

- Cannot use transformers
- AC/DC conversion equipment cost?

Examples of future projects using DC power

- Long distance Arctic tie-backs (20-200 MW, 80-600 km)

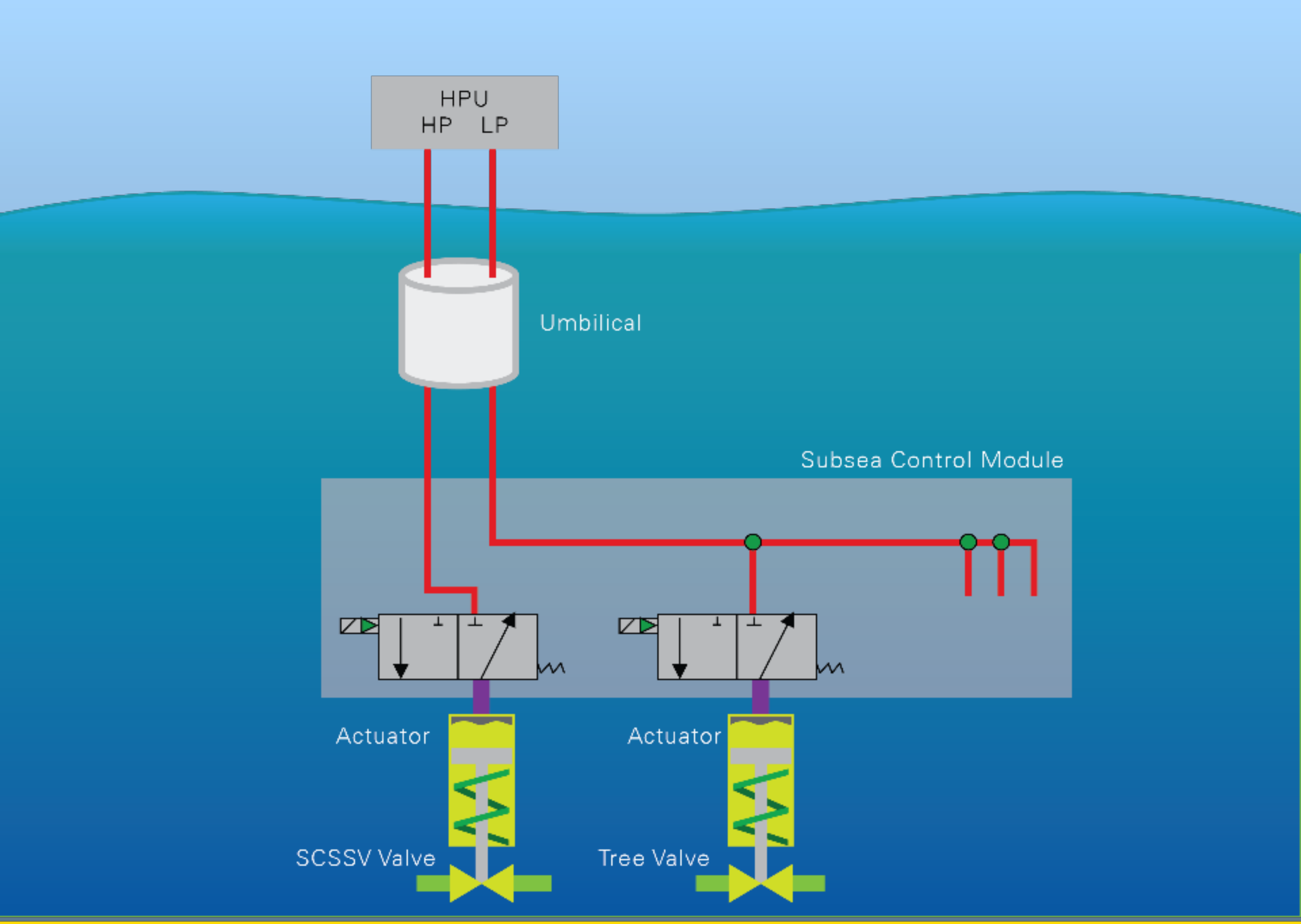




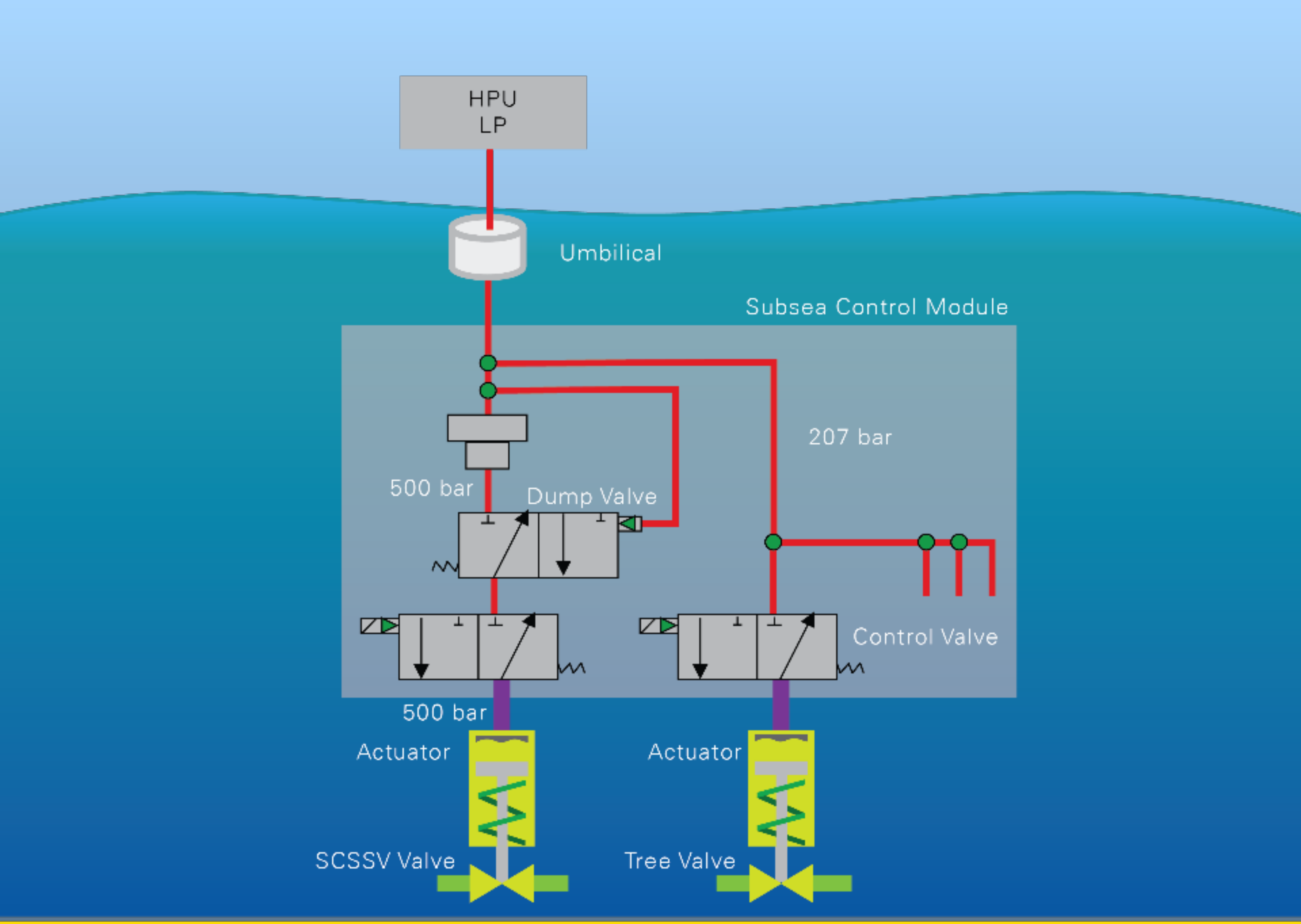
Factors involved in power analysis

- Cable attenuation, impedance, DC resistance, capacitance, inductance, and conductance at system operating frequencies
- Minimum load analysis
  - Finds the EPU voltage which gives maximum SCM voltage at min system load
- Maximum load analysis
  - Finds the EPU voltage which gives minimum SCM voltage at max system load
- Voltage analysis
  - SEM voltage at max and nominal EPU voltage at full load
- Maximum and minimum load current demand using information from sMPFM, compressors, separators, DHPT sensors, SEMSs, SCM housekeeping.
- Maximum and minimum power demand
- EPU power rating ($P = V_{max}I_{max}$)
- Power factor analysis

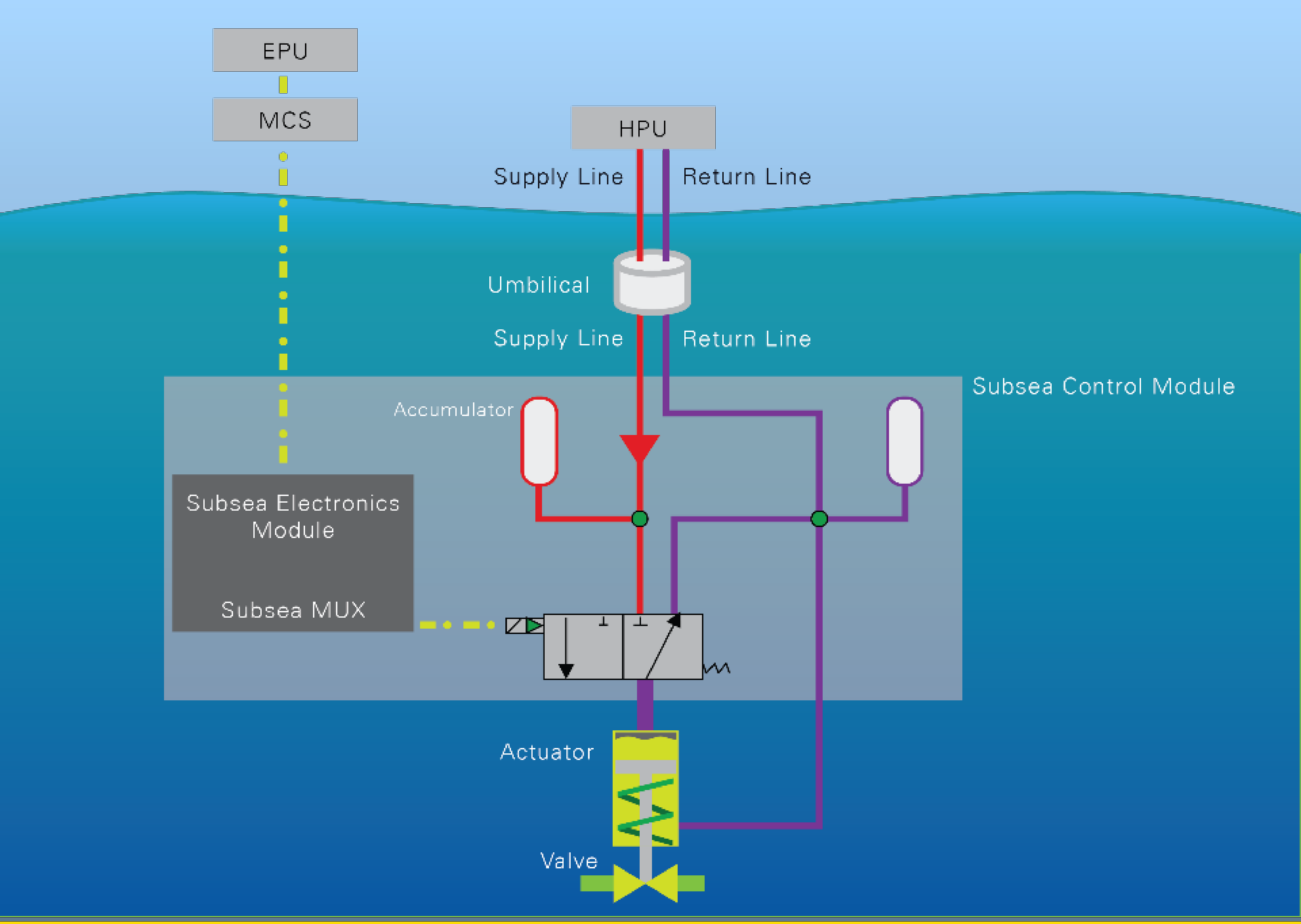
Overview of Hydraulic Systems



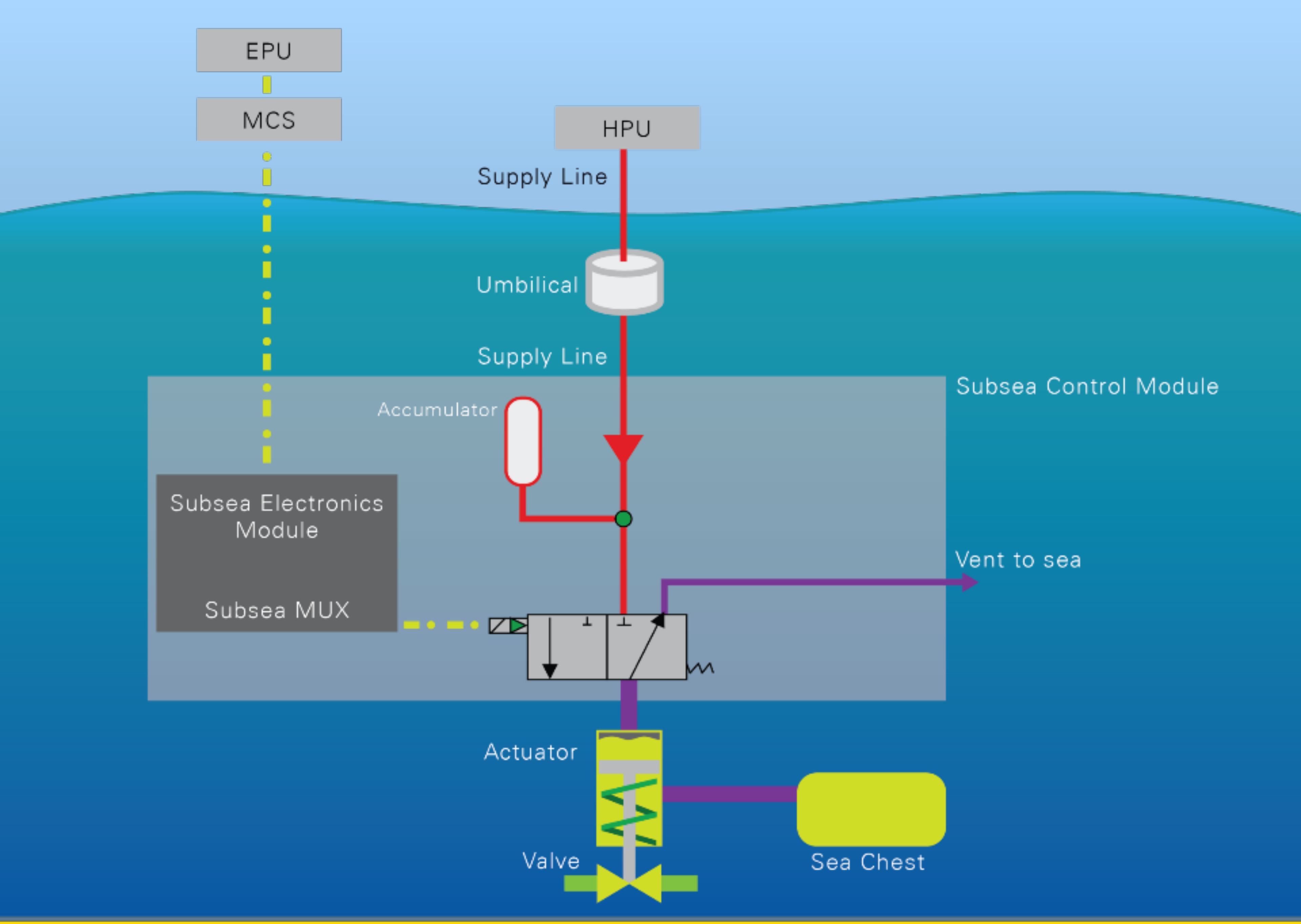
Control options – dual hydraulic pressure distribution



Control options – single intensification



Control options – closed loop hydraulics



Control options – open loop hydraulics

Hydraulic Analysis

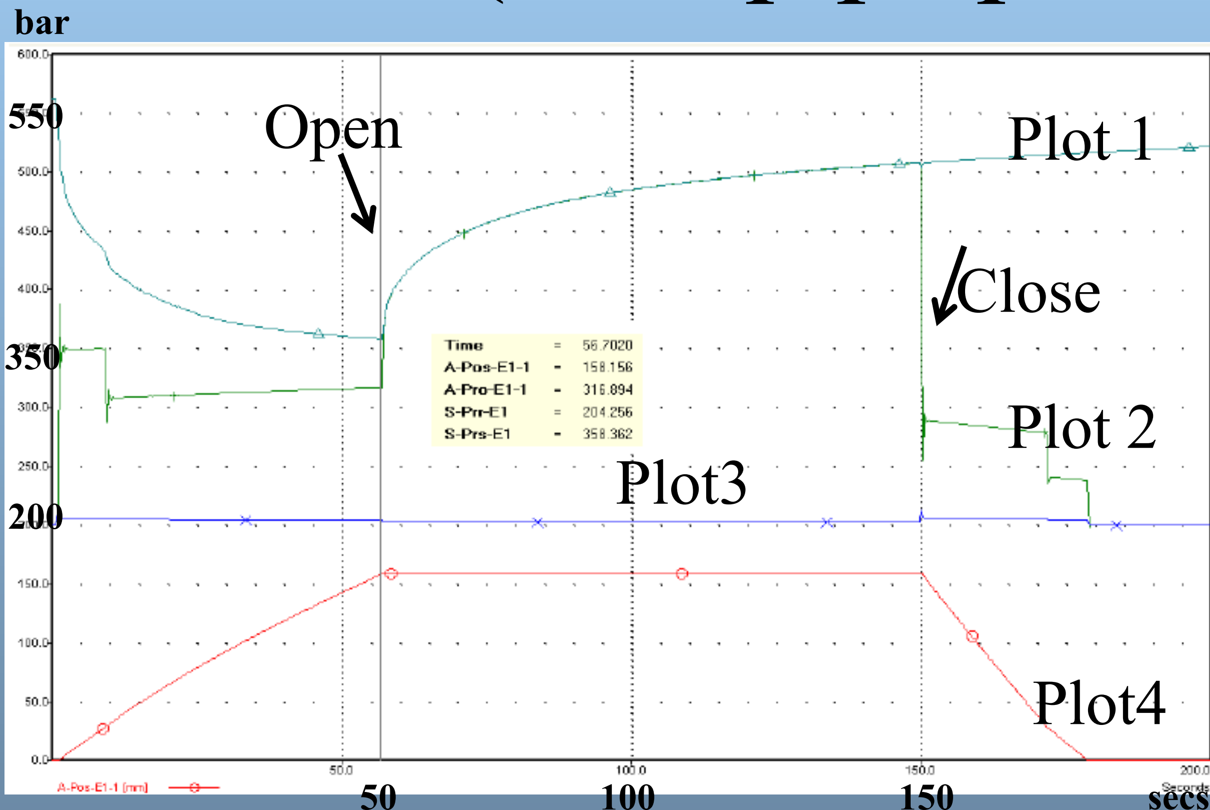
System requirements

- Type of hydraulic system
- Reliability and redundancy
- Water depth and hydrostatic head
- Frictional losses
- Emergency shutdown philosophy
- Operating pressures (minimum and maximum)
- Subsea hydraulic boosting
- Valve closure time requirements
- Need and sizing of accumulators (subsea and topsides)

Key analysis outcomes

- Opening and closing response times of the process valves under conditions of minimum and maximum process pressure
- Time for the pressure to recover following a process valve opening
- Time to carry out a sequence of valve openings, such as the opening of a tree (neglecting choke valve operation)
- Stability of opened process valves to pressure transients caused by operation of other control and process valves (sympathetic control valve delatching, process valve partial closing, etc.)
- Response time to close process valves in the event of a common close command, such as an ESD ventdown at the surface, venting off hydraulic control valves via supply lines, subsea quick dump
- Time to prime the hydraulic system from a depressurized state
- Stability of opened downhole control and safety valves to pressure transients caused by operation of other safety or IWCS valves (sympathetic control valve delatching, process valve partial closing, etc.)

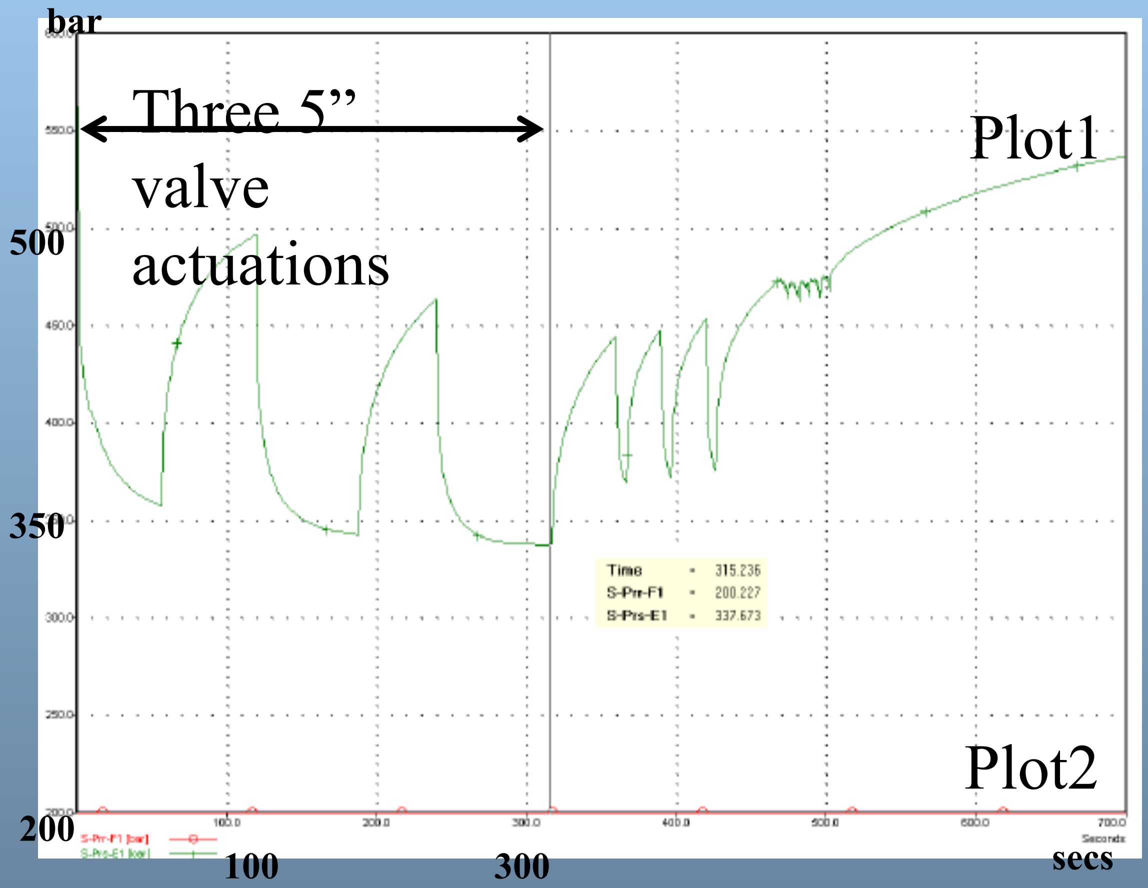
5” valve open and close (min. pipe pressure)



Success criteria: LP supply line pressure – 127 bar > Return Line

Plot 1: LP Supply line pressure, bara
Plot 2: Actuator opening cavity pressure, bara
Plot 3: Return line pressure, bara
Plot 4. Valve piston position

Sequential valve operation

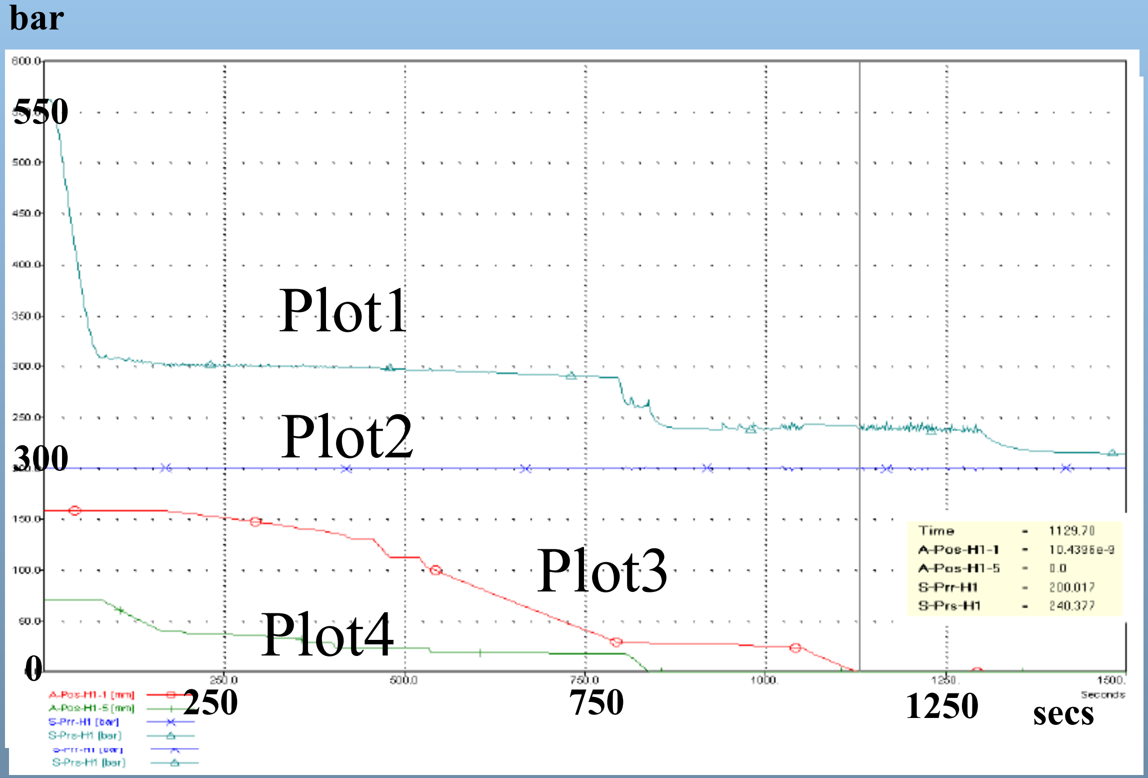


Success criteria: LP supply line pressure – 127 bar > Return Line

Sequence:
5" valve opened at t=1s, 120s, 240s;
2"valves open at t=360s, 390s, 420s;
Choke actuated from t=470s to 502s

Plot 1: SCM Supply Line Pressure
Plot 2: SCM Return Line Pressure

ESD LP vent for 5” and 2” valves



Plot 1: LP Supply Line, bara

Plot 2: LP Return Line, bara

Plot 3: 5” actuator piston position

Plot 4: 2” actuator piston position

Topsides Hydraulic Controls Interfaces

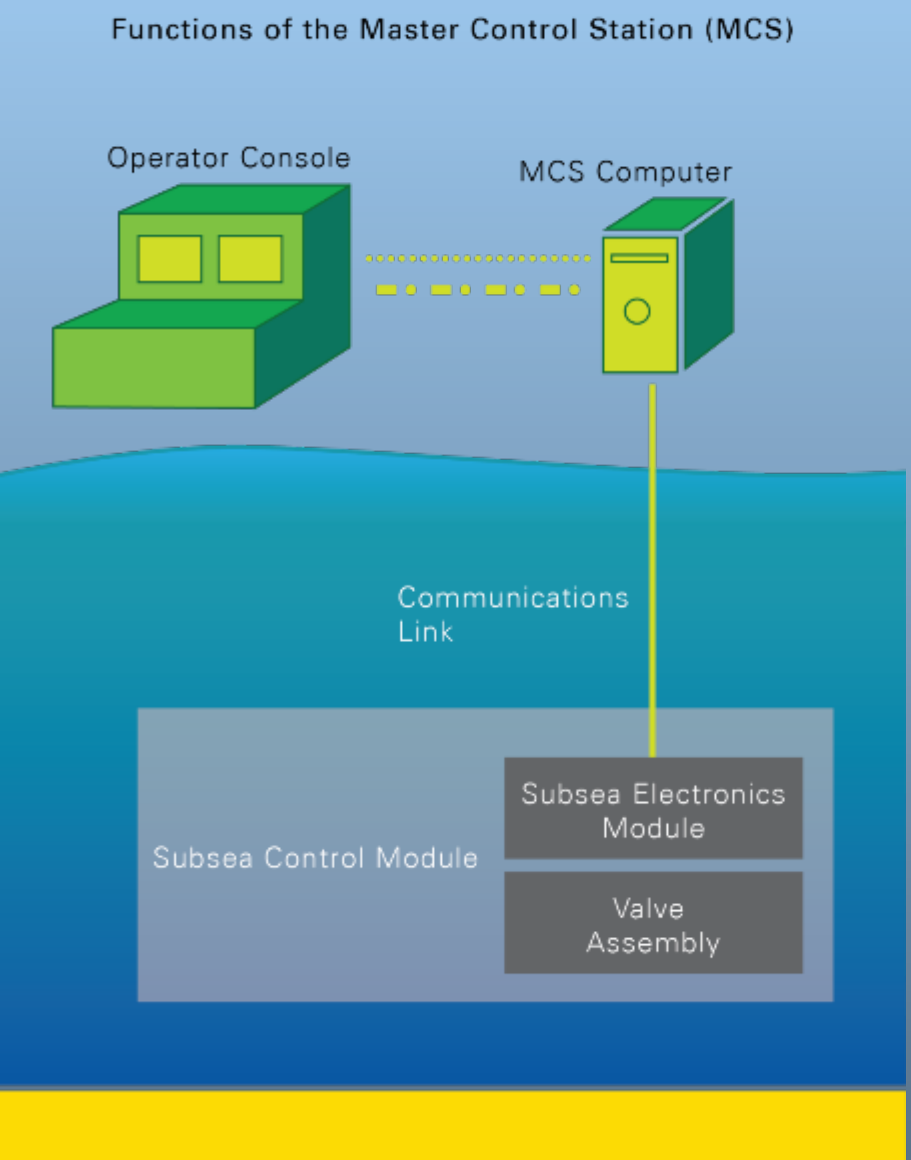
Hydraulic power unit (HPU)

- Hydraulic control fluid to operate subsea actuators, valves, and downhole SCSSVs
- Stand-alone unit with local programmable logic control system (PLC) controls
- Unattended operational design
- Class 1, Division 2, Group D hazardous environment suitability – Applicable to GoM
- Dual-redundant 10,000 psi and 5,000 psi pumps for hydraulic supply
- Hardwire ESD feature for hydraulic ESD pressure dump with high-pressure delay for SCSSV closure
- Interface with platform or FPSO’s DCS, ESD/PSD fire and gas system via pneumatic shutdown valve
- Single-skid mounted assembly with crane lift and deck tie-down capability
- Recirculation pumps and filters to ensure fluid cleanliness

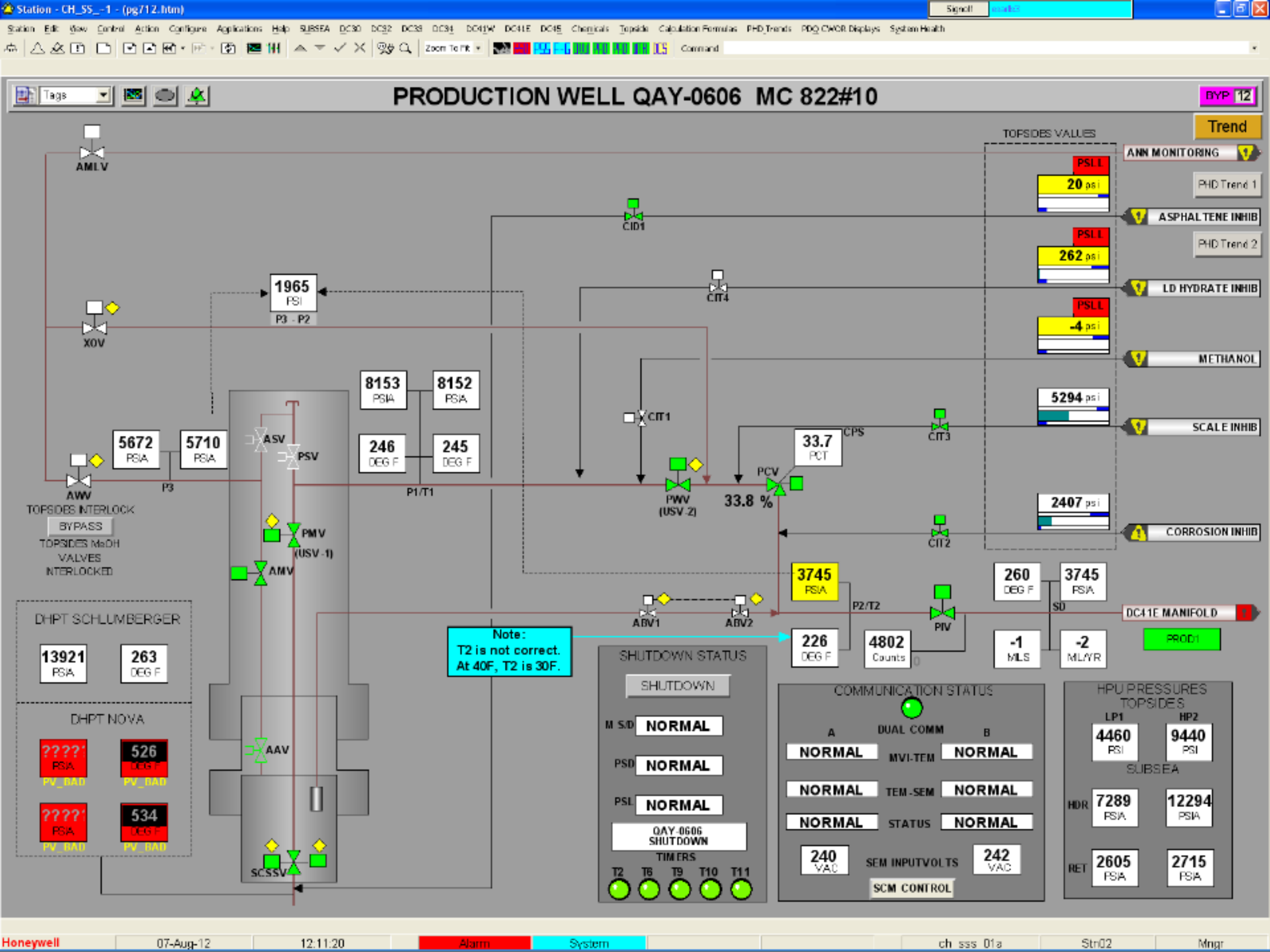
Picture Credit: FMC Technologies and Bardex Corporation

Topsides Computer/MCS Interface

Computer interface



- Provides operator interface to the subsea control system.
- Primary functions:
  - Provide a communications interface to subsea equipment.
  - Display current state of control system components.
  - Display process, pressure, temperatures, etc.
  - Provide a means of controlling these elements.
  - Perform automatic and operator-initiated shutdowns.
  - Inform the operator of any process upsets.

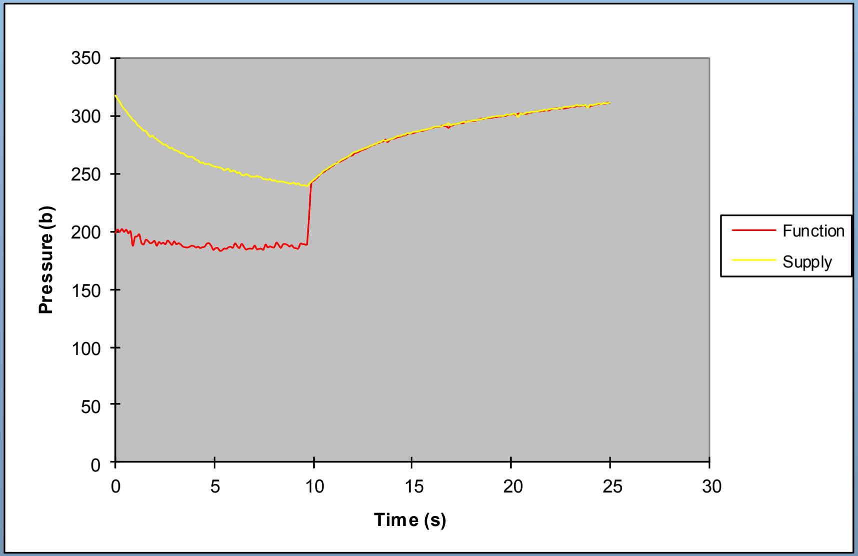

Station - CH_SS_-1 - (pg712.htm)
PRODUCTION WELL QAY-0606 MC 822#10
BYP 12
Trend
TOPSIDES VALUES
ANN MONITORING
PHD Trend 1
ASPHALTENE INHIB
PHD Trend 2
LD HYDRATE INHIB
METHANOL
SCALE INHIB
CORROSION INHIB
DC41E MANIFOLD
PROD1
PSLL 20 psi
PSLL 262 psi
PSLL -4 psi
5294 psi
2407 psi
AMLV
XOV
AWV
TOPSIDES INTERLOCK
BYPASS
TOPSIDES MeOH VALVES INTERLOCKED
1965 PSI P3 - P2
8153 PSIA
8152 PSIA
246 DEG F
245 DEG F
P1/T1
5672 PSIA
5710 PSIA
P3
ASV
PSV
PMV (USV-1)
AMV
AAV
SCSSV
CID1
CIT4
CIT1
CIT3
CIT2
CPS
33.7 PCT
PWV (USV-2)
PCV
33.8 %
3745 PSIA
P2/T2
226 DEG F
4802 Counts
ABV1
ABV2
PIV
260 DEG F
3745 PSIA
SD
-1 MLS
-2 ML/YR
Note: T2 is not correct. At 40F, T2 is 30F.
DHPT SCHLUMBERGER
13921 PSIA
263 DEG F
DHPT NOVA
????? PSIA PV_BAD
526 DEG F PV_BAD
????? PSIA PV_BAD
534 DEG F PV_BAD
SHUTDOWN STATUS
SHUTDOWN
M S/D NORMAL
PSD NORMAL
PSL NORMAL
QAY-0606 SHUTDOWN
TIMERS
T2 T6 T9 T10 T11
COMMUNICATION STATUS
DUAL COMM
A B
NORMAL MVI-TEM NORMAL
NORMAL TEM-SEM NORMAL
NORMAL STATUS NORMAL
240 VAC SEM INPUTVOLTS 242 VAC
SCM CONTROL
HPU PRESSURES TOPSIDES
LP1 4460 PSI
HP2 9440 PSI
SUBSEA
HDR 7289 PSIA 12294 PSIA
RET 2605 PSIA 2715 PSIA
Honeywell 07-Aug-12 12:11:20 Alarm System ch_sss_01a Stn02 Mngr

Computer interface – pressure profiling

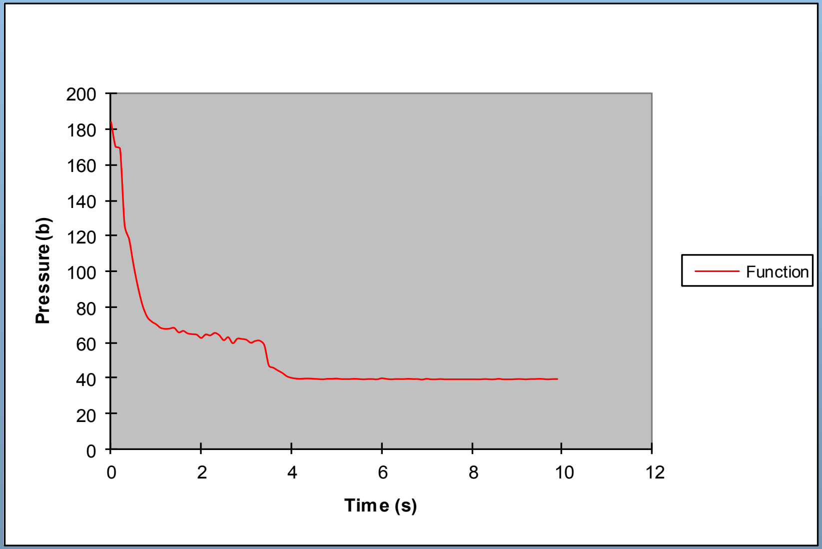
- Sometimes referred to as valve footprinting
  - A technique which is used to assess the performance of the tree valve and actuator.
- Valve operation
  - The pressure in the hydraulic function line from the SCM to the actuator is measured by the SEM with a fast sampling rate for (typically) 10 seconds.
- Data is passed back to the MCS
  - May be displayed graphically and a visual assessment may be made of the valve/actuator performance.

Pressure profiling

Wing Valve Opening

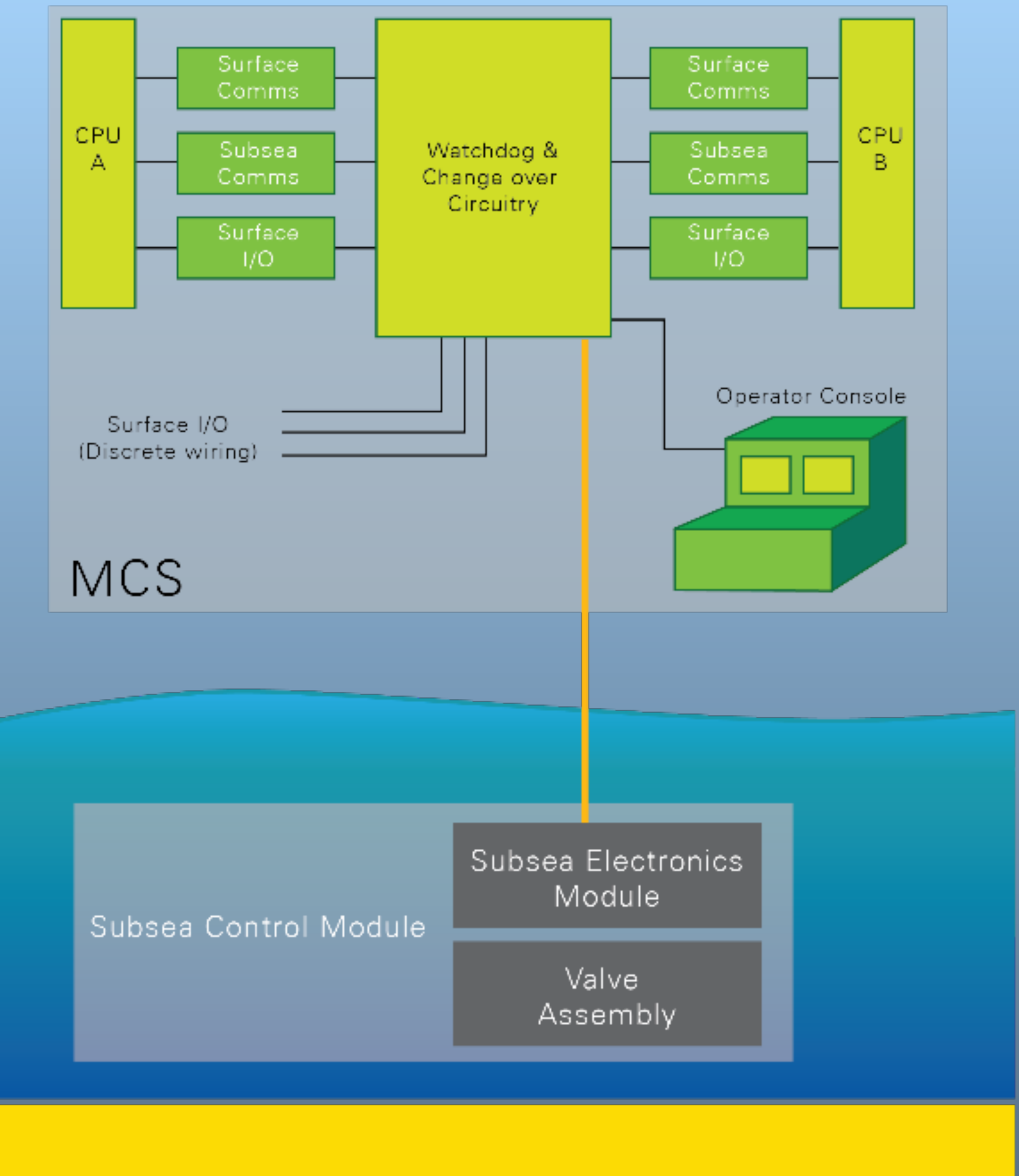


Wing Valve Closing



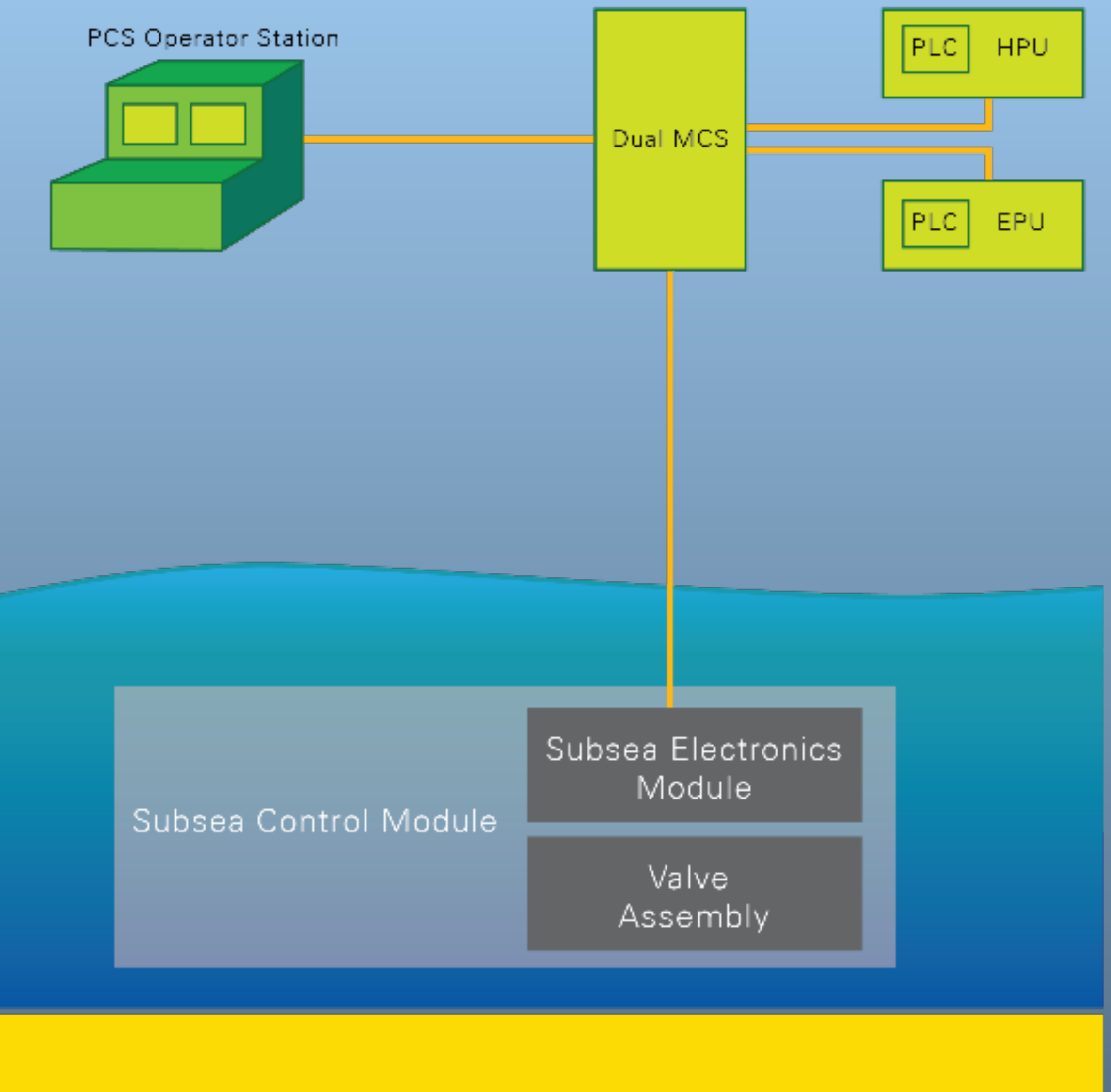
Note: These traces were taken from a system that uses a hydraulic supply pressure of
5,000 psi (345 bar) for tree valve actuators.

Stand alone Dual MCS (hot standby - local I/O)



- Advantages
  - Increased reliability
  - Off-line system can be maintained while producing
  - Modifications can be made on off-line systems
- Disadvantages
  - More expensive than single in terms of both hardware and software
  - More complex software increasing possible maintenance costs
  - Platform cabling costs may be high

Stand Alone Dual MCS (distributed I/O)



- Advantages
  - Good saving in installation costs, particularly if the surface I/O count is large
  - HPU pumps, etc. can be locally controlled by PLC
- Disadvantage
  - PLCs add to system hardware costs

Applicable industry standards and BP codes

Industry standards:

- API 17F/ – Design and Operation of Subsea Production Systems; Subsea Production Control System
- API 17E – Subsea Umbilicals

BP codes:

- GP 78-18 – Design and Operation of Subsea Production Control Systems
- GP 78-09 – Subsea Safety Instrumented Systems
- GP 78-16 – Subsea Control Fluid Selection
- GP 78-05 – Testing of Subsea Equipment: FAT, EFAT, SIT, and FIT

Questions