

Trade Study of Alternative Controls and Power Distribution Architecture in Subsea Processing

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Abstract. This paper reports on a trade study of feasible concept alternatives for control and low voltage power distribution architecture for subsea process stations. Subsea gas compression is a new process station technology that is responding to the market need for extending the lifetime of existing subsea gas fields. These subsea process stations are deployed in deeper water, farther offshore and in harsher environments. The demand for a more efficient, less complex, and cheaper solution is pushing the technology development and screening for alternative concepts. The SPADE methodology has guided a trade study of concept opportunity exploration for alternative distribution architectures. The Pugh matrix demonstrated its ability to provide a simple overview of the multiple factors in a decision-making situation, with extensions for risk and opportunity assessment.

Introduction

This paper discusses the application of trade study method in the concept definition phase of a feasibility study within the subsea processing department in Aker Subsea. Aker Subsea is a Norwegian supplier of subsea systems to the international oil and gas industry, and part of Aker Solutions (AKSO). AKSO has been delivering successful subsea solutions for 50 years.

The research implements a systems approach to guide decision-making in concepts for a control and power distribution architecture. The concepts are developed for a study of a new subsea gas compression station system (NSGC). The system is based on a simplification of the recently executed subsea gas compression project (SGC), which was the first of its kind deployment.

Subsea gas compression is a new technology that is responding to the market need for extending the lifetime of existing subsea gas fields [16] [20]. This type of subsea process station consists of process modules that are retrievable units with functions such as gas compressing, separation or cooling that together make the compression station. Such subsea process stations need more power and more controls than the conventional subsea production systems like wellhead modules and pipeline manifolds. The architecture of controls and low voltage power distribution on subsea gas compression stations has been executed with a fully centralised system where controls and power are distributed from 1 or 2 subsea control modules (SCMs) and one large subsea module called controls and power distribution unit (CPDU). Stakeholders in AKSO controls system work groups have challenged the system architecture for controls and power distribution for an optimized architecture topology. This has triggered concepts of eliminating the CPDUs and SCMs from the compression station.

This concept suggests an interesting solution for this feasibility study and future processing stations, which is the reason for this research.

This paper examines the feasibility of alternative new system architectures for controls and power distribution. A trade study focused on the architecture concepts with the aid of SPADE methodology. The Pugh Matrix was selected as a suitable tool to support the decision making process for a possible project execution. Concept concerns are presented for conclusions with recommendations for future research.

Background

Gas compressors are used to maintain output as the reservoir pressure at gas-producing fields drops over time. While such compressors typically have been installed on platforms above sea level, placing them on the seabed and near the wellheads, Figure 1, is claimed to improve recovery rates and reduces capital expenditure (capex), and operational expenditure (opex) [3] [14] [21].

In 2015 the world's first subsea gas compression station was installed in a field off the shore of Norway. This will boost the falling gas pressures from neighboring satellite reservoirs, allowing stable production to continue, thereby enabling an additional 280 million barrels of oil equivalent to be recovered. Subsea compression will provide many benefits compared with the alternative of installing a new topside platform, including improved recovery, reduced capex and opex, smaller environmental footprint and safer operation [3] [14] [21].

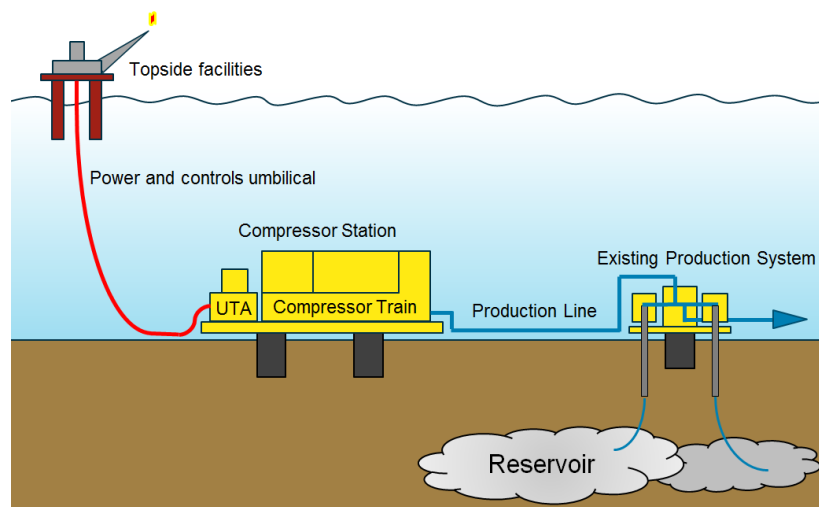


Figure 1 - System Field Overview

The development of the NSGC is based on the pilot project of Ormen Lange gas compression and is one of the most demanding technology projects aimed at improving reservoir recovery. With this new station, Statoil is one step closer to realising the vision of a subsea factory with subsea processing, and gas compression in particular, which is an important technology advance to develop fields in deep waters and harsh environments [14].

Subsea process control systems to date have generally involved centralized architecture; i.e. one or two SCMs gathering data from all process module instrumentation for electrical/optical communication through the umbilical termination. Power has been distributed from redundant CPDUs serving all process modules [8]. A CPDU is a modular subsea unit with circuit breakers for power electronic control, transmission, and distribution. Compressor and pump

motor power follows a completely segregated high voltage system. The electronic components in the CPDU are enclosed in a sealed enclosure filled with inert gas. This enclosure is integrated in a subsea modular unit for installation, intervention, and retrieval [17]. The main drawbacks of this solution are firstly the size of CPDUs as well as the complexity in engineering, testing, subsea hook-up connection, and downtime during maintenance [16] [17]. The mass and weight of the subsea enclosure increases with the sea depth and operation phase. This makes the conventional CPDU a complex and challenging unit to develop, especially for deeper sea conditions [16].

Next generation subsea process station need to be smaller, lighter, and less complex to be attractive for customers' investment. A report written by experts in AKSO [1] claim that the primary potential for optimisation for subsea process and control systems is to distribute both controls and power management across the subsea process modules. This will eliminate CPDUs and SCMs. Another proposed benefit is that the process modules will become standalone modules that are testable with its individual built-in control system. This will enhance final module reliability. The placement of controls equipment close to instrumentation will also improve layout optimization.

Customers vary in what they emphasize as important and have different priorities for the quality of the system. AKSO wants to develop the capability to deliver subsea compression systems for future projects. Could a subsea compression station without CPDUs and SCMs be a feasible and competitive solution? What are the trade-offs and opportunities? This research maps the concepts through a trade study to evaluate the best system architecture for customers. The concepts considered range from the conventional fully centralised power and controls to fully distributed controls and power. Each solution is analysed through the whole lifecycle with the holistic view to make arguments for alternative architectures in distribution of controls and power.

Research Methodology

AKSO established the NSGC study after completing the feasibility and concept phase process defined by AKSO's Project Execution Model, PEM. This process is shown in Figure 2. The PEM is a high level model, which directs the overall processes and defines how a project systematically moves from a concept through execution as explained in Byes thesis (2013) [6]. The stages describe briefly a list of project management activities and project execution activities to follow. These activities are constructed around AKSO main deliverables of more standard products and do not specifically facilitate advanced subsea technology development such as trade studies on new system architecture philosophies.

The concept phase of this system level is above the architecture of the control and power distribution, which suggests that architecture trade studies are meant to be carried out in the engineering phase, Phase 2, in AKSO. Phase 1 generally places less focus on screening alternative concepts.

The Feasibility and Concept phase allows for more customer interaction and could capture actual needs to tailor concepts in a trade study. This has been shown in Tranøys work [20] where he states that by implementation of need analysis, as a basis for system requirements definition, there is a potential for reducing a project's late design changes by 74%.

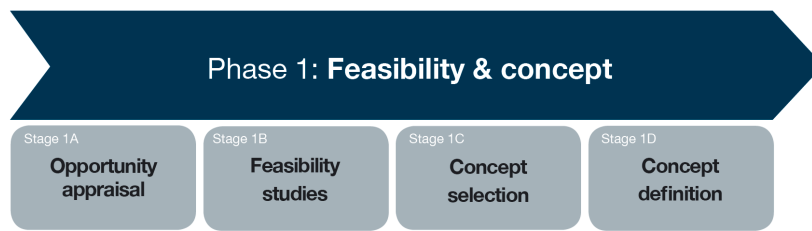


Figure 2 - AKSO PEM Feasibility and Concept Phase [6]

The research for this paper was executed following fundamental systems engineering principles using the SPADE methodology. SPADE is a simplified framework reformulated from the principles of systems engineering (SE). The acronym, graphically shown in Figure 3, is constructed from the SE activities Stakeholder identification, Problem formulation, Alternatives, Decision-making, and Evaluation [10].

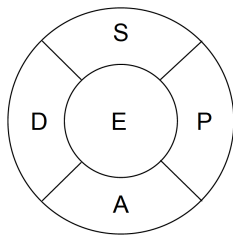


Figure 3 - SPADE Methodology/Framework Graphical Representation [10]

The research evaluates an existing system architecture compared to systems in a new architecture philosophy where data is gathered systematically by following the SPADE methodology. In this research, the system alternatives differ in the level of investments and risks such that the actual decision taken would affect the level of success on this project and define technology directions for further projects. Decisions at this level are taken by the upper management and customers and all relevant findings should be visible to inform an intelligent decision for success. A trade-off study is fundamental in all systematic decision making and should contribute to decisions that determine a future course of action and investment [12]. The importance of making a trade-off study for this research was to aid an informed decision focusing on providing a visual and readable assessment of the consequences and benefits of the different concept alternatives.

A trade study is an objective comparison of criteria that identify desirable and practical alternatives among requirements, technical objectives, design, risk, cost, functional and performance requirements. It documents the requirements, assumptions, criteria and priorities used for a decision [5].

The general process of a trade study approach is to first define scope and objectives and identify stakeholders. Next is to identify possible alternatives. Then selection criteria are established and evaluated for the scoring function relationship and the weighting. Last, all the information is summarised in a matrix where the results are evaluated for a report or presentation [12] [19]. To achieve these results no less than 9 interviews with 6 stakeholders were conducted over the course of the research period. The Pugh Matrix decision-making tool by Stuart Pugh [18] was selected to execute a systematic process of ranking alternatives in a visual frame where important criteria would get the attention needed from a multidisciplinary point of view. The Pugh matrix is considered effective both as an evaluation tool and as a visual communication tool for managers and customers [15], and satisfies the stated goals for this trade study research. Pugh claimed that in general, matrices are the best way of

formatting and representing an evaluation due to the structure and control during the concept selection process. The Pugh Matrix also allows simple sensitivity analysis to be performed, thereby providing some information as to the robustness of a particular decision.

Trade Study Results

Following the SPADE methodology, the research began by identification of stakeholders for the system. Next, the system needs were established from the stakeholders to frame the problem. Then the research explored and evaluated feasible alternatives for the system ending with two polar concepts and two concepts in between. The paper will close with a discussion of the results of the trade study analysis and how it might be useful to the ultimate decision-makers, and an evaluation of the choice of analysis method.

Stakeholder Identification. The feasibility study for the NSGC project was executed as an internal study anticipating a potential market need. Since all trade studies have a customer, the owner of project becomes the main customer stakeholder. AKSO will also contribute with a variety of experts on products, control systems, and key people from the legacy project. The feasibility study is aimed at a specific market and will take into account the relevant field requirements and limitations. The following stakeholder list was identified:

- Customer: Upper Management AKSO
- Project Systems Engineering Lead
- Control system work group
- World market need
- The legacy project Systems Engineering Lead
 - Installation lead
 - Structural lead
 - Product Responsible engineers

Problem formulation. The NSGC project emerged from the design generated by the feasibility study. Prior to the beginning this research, the system boundaries, and its impacts on the overall system were identified and defined [12]. Interviews and workshops were conducted with different engineers and stakeholders to capture the driving functions and goals of the controls and power distribution system. In addition, the FDR (Functional Design Requirement) from the legacy project were used as an important technical document for support. The new station, Figure 4, is based on the legacy SGC project and will take advantage of the technology developed during this project. The market need assessment and potential customers were involved early to investigate the possible integration of the new station in different field reservoirs.

The market and technology roadmap for AKSO points in the direction of smaller and lighter subsea boosting stations for deeper water and longer step out. Fulfilling the vision of this roadmap drives the NSGC project. The general architecture of the compression station train consists of a flow-base structure, a recycle module, and a compressor module. Adjacent to the train is an umbilical termination unit including subsea transformer units. Figure 4 illustrates the basics of the compressor station: process modules, CPDUs and an umbilical termination assembly.

At this early stage, the project executed a trade study on concepts for the main mission of the NSGC project. Objectives and principle requirements were defined in an overall operational context. The design basis for the feasibility study for the project considered the boosting process architecture only. The controls and power distribution architecture were identified as

a sub-system segregated outside the boosting process system and were therefore considered unproblematic and to be developed at a later stage in the engineering phase. In the case of the legacy system distribution architecture, this could be true, as this architecture has been integrated to boosting process system architecture before. Still, this is a dangerous assumption as it is unknown how new architectures for controls and power distribution may affect the process architecture. This could for example result in too little space or footprint on a module for equipment or cable connectors. An important interface between the control and power distribution system is the combined umbilical and umbilical termination. The size and weight of these termination units and connection transformer units would be affected by different need and input from power and controls typology.

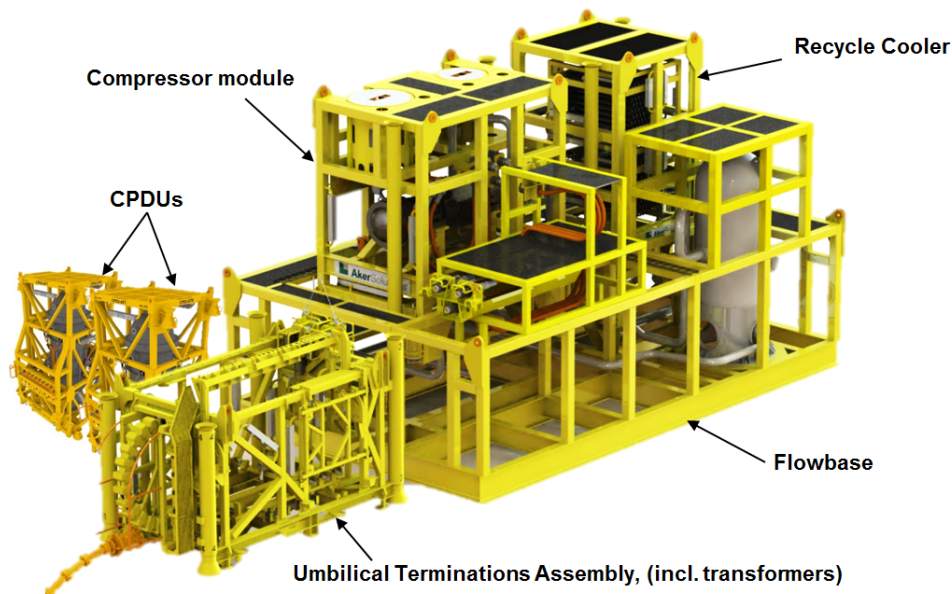


Figure 4 - Illustration of Compression Station [2]

The controls and power distribution system is a scope of work executed on the side of the core project team and lack the close communication with the main project group. Unknown dependences should be captured early between the work groups and the systems engineer provides the linkage that enables the different groups to function as a team [12]. The potential integration of a new typology architecture raises many opportunities but also creates a risk for the project. Both risk and opportunity should be handled and analysed by the system engineer in a supported structured approach. This analysis provides a documented rationale for decision-making and provides justification for stakeholders. It also facilitates the allocation of technology planning knowledge within the organisation. The researcher investigated the system independences between the project groups to keep within the given boundaries and requirements. An exploration of the system architecture opportunities and possibilities become the ultimate goal for the next generation compressor station optimisation.

Alternatives. The identification of alternatives was conducted through interviews and workshops with power and controls experts and system engineers from the legacy subsea compression project. Although the selection criteria are not chosen at this step the systems engineer should have an understanding of what discriminates the alternatives from each other [12]. Brainstorming in workshops is a good method for thinking outside the box and helps generate alternatives [12]. This session identified a variety of alternatives that were screened for their feasibility and differentiations. The concepts were designed to allow a full range of

functionality. No unrealistic concepts were further analysed, nor were concepts with minor differences in sub-system architecture or topology.

A controls and power umbilical is terminated adjacent to the station where power is transformed and sent to the CPDUs for further low voltage power distribution. Control signals are given to the SCMs for further distribution [21]. This is the case of the legacy system, which is one of the evaluated concepts in this research. There are two CPDUs for redundancy [8] as found in the conventional solution executed on the legacy system. The CPDUs supply electrical power at the desired voltage and frequency to the subsea process modules. This implies that this one compressor train has two enclosure units that both directly serve each process module on the compressor train. Optical connectors are hooked up from the umbilical termination to the SCM where signals are distributed throughout the train. This research established the simplified schematics, Figure 5, for the functional system architecture.

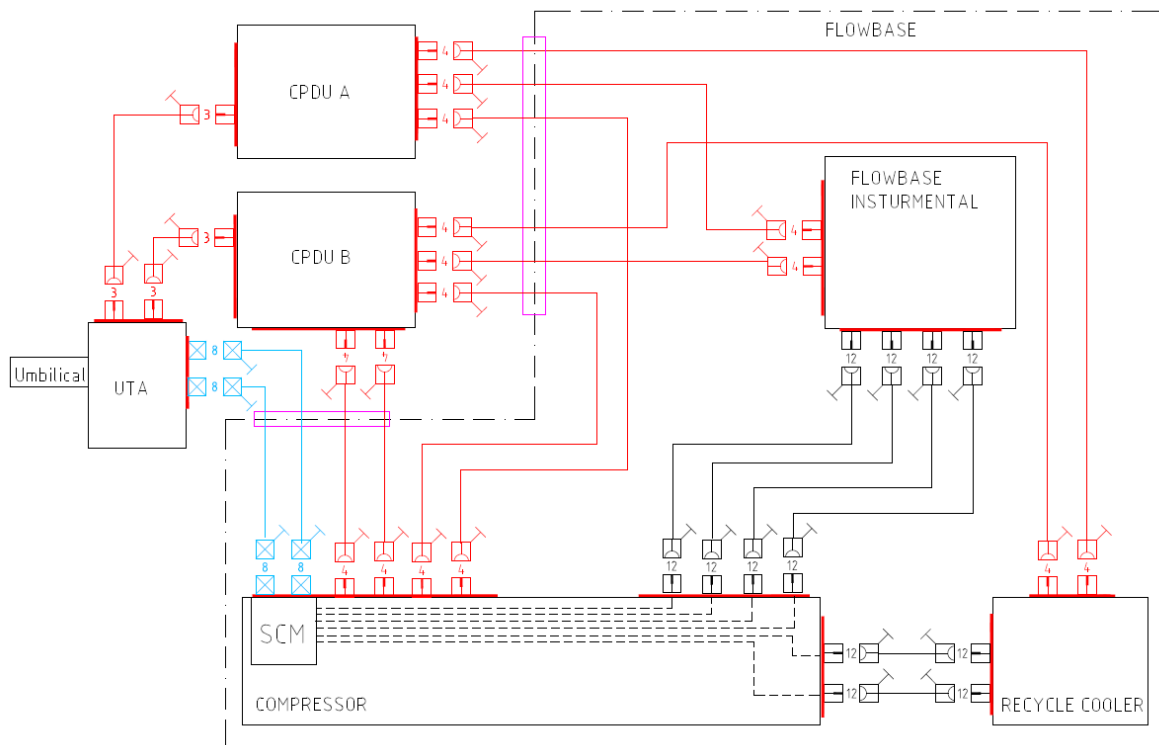


Figure 5 - Concept 1: Conventional Architecture of Controls and Power Distribution [2]

Experts within control and power distribution conducted a feasibility report on a new distribution philosophy [1]. This philosophy would aim at eliminating the CPDUs and SCMs from the test. Instead of centralised distribution, the individual modules on the compression train would distribute the controls and power. The researcher designed the philosophy and formed the architecture for fully distributing controls and power. The CPDUs and SCMs were both broken down into sub-systems in functional design analysis. Instead of collecting the internal components in one large enclosure, they were distributed in smaller units to accommodate operations at the location needed. This means that each process module would have control hubs and power hubs installed to serve its internal operational needs. The first process module will be connected to the umbilical termination and transformer and send both control and power to the next module as in a chain. This method is based on the Daisy-chain concept from electrical engineering. This topology would make each module a complete standalone module all connected in series where signals and power are passed from one

module to the next. An electrical fault in one of the modules could paralyze the complete system [16] so the solution runs two Daisy-chains from the umbilical termination to maintain the redundancy of having 2 CPDUs. The solution would be able to identifying a faulty module without disconnection [16] and replace a power hub or control hub without stopping production. This concept, Figure 6, was formed from the sub-system architecture created earlier in the concept exploration phase. The concept brought new interesting qualities for an alternate solution.

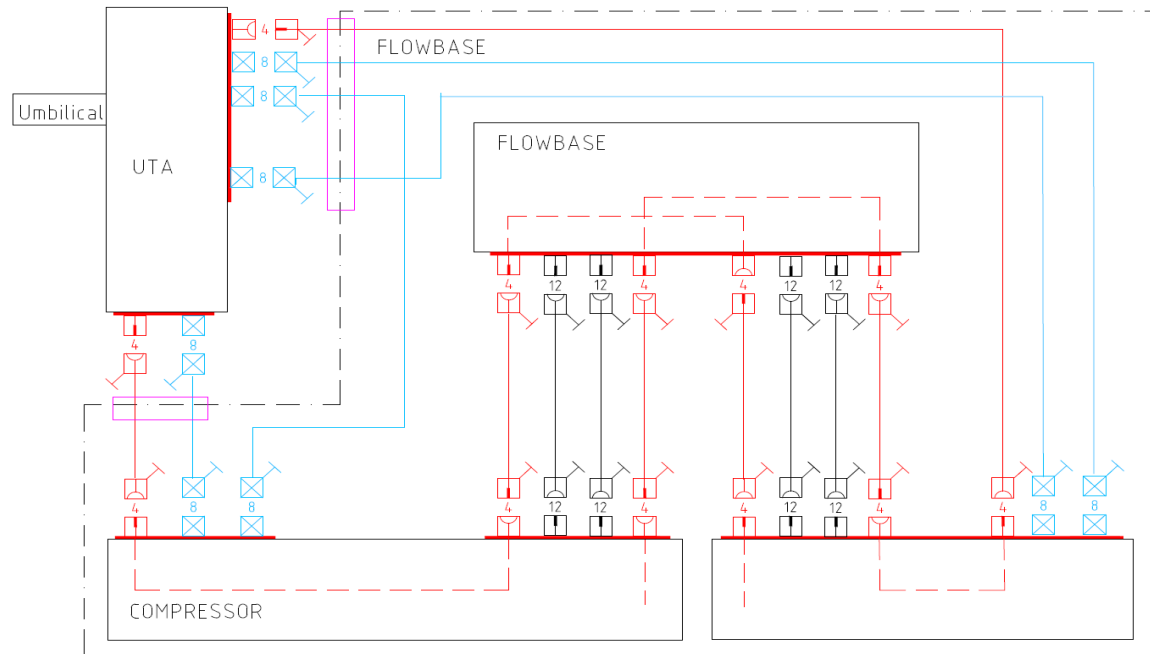


Figure 6 - Concept 2: Fully Distributed Control and Power Architecture [2]

The creative phase of exploring alternatives developed a concept of partial distribution of controls and power. The option with the minimum difference from the legacy system solution and still eliminate the CPDUs is to keep the conventional controls distribution through a SCM and distribute power in a Daisy-chain through power hubs as the fully distributed architecture. The research showed that keeping a SCM is also an attractive solution for some stakeholders due to a lower cost and risk in development. The research question has its foundation on the goal of a more optimal and less complex solution. Interviews and workshops with stakeholder resulted in a contradictory alternative to keep the centralised power distribution CPDU and to distribute the controls through controls hubs. A summary of the main architectural sub-systems were as followed:

- Controls distribution:
 - o Centralised controls
 - o Distributed controls
- Power distribution:
 - o Centralised power
 - o Distributed power

A summary of the results of all combinations of the above sub-systems are what this research refers to as the design concepts:

1. Fully centralised controls and power (Conventional solution)
2. Fully distributed controls and power (New suggested solution)

3. Centralised Controls and distributed power (Partial new combination)
4. Distributed controls and centralised power (Counter combination)

Identification of Criteria. In concept selection, a set of selection criteria is needed to differentiate between the alternative solutions [5] [12] [13]. Each criterion is to be an essential attribute of the system, related to one or more requirements. It is desirable that the criteria be quantifiable for an objective evaluation but this can be a difficult process. The researcher held interviews and workshops to evaluate all production scenarios, electrical load situations, cost-effective installation, testing and the project execution time and life cycle costs. Engineering, development, production and the whole life cycle of the system were considered. Operational philosophy, installation sequences and possible operational challenges were evaluated and possible impact on control system functionality and infrastructure was considered to comply with requirements [8]. The topic of development was an important topic as it considers the strategic approach on a higher level than the present system development. A criterion in strategy representing this gain in technology advances for future related project was established. The main cost differences are closely related to time and development with the uncertainties associated with technology maturity and development. Cost is usually a key criterion for any system. Reliability and maintainability are also usually important characteristics, but they must be quantified. In this case, the size and weight requirements are somewhat important criteria whereas technology maturity and reliability were judged to be most important.

All possible criteria were evaluated and this resulted in a list of 30 criteria. Only half these were to end up in the final matrix. The number of criteria used in a particular formal trade study can vary widely but usually ranges between 6 and 10 as in line with the theory that people can pay attention to 7 plus-or-minus 2 things at a time [12][19]. Fewer criteria may not appear convincing of a thorough study and more criteria could make the process unwieldy without adding value.

The concepts and all criteria found at this point were implemented in a spreadsheet provided in Figure 77. The inclusion and exclusion of selection criteria changed during the research as concepts evolved. The researcher ran several iterations to execute a convergence process that would close in on an optimum solution [9]. Some criteria were dropped because they did not discriminate among the alternatives and some because they were too difficult to evaluate precisely. In some instances, two closely interdependent characteristics did not contribute more discrimination than can be obtained by one of them with appropriate weighting. Through the iteration of criteria screening only the important few that would differentiate the concepts and provide relevant value to the matrix were retained.

Rating. Domain experts and stakeholders were involved in the weighting of the criteria and a suitable numeric scale of importance from 1 to 5 where 5 is most important was selected. Weighting the selection criteria can often provide an extra level of discrimination when making decisions. This absolute scale is simple to apply but leads to only the upper numbers 3 to 5 being used. This is because requirements or needs from stakeholders rated not important for the system would be eliminated from the list of criteria. As the criteria were more than 10, the criteria were for that reason sorted in a suitable number of categories to obtain an organised overview of the criteria. A weighting of categories has commonly been used in such matrices to fairly justify each criteria category, but in this case all criterion are evaluated with equal individuality. This was intended to keep the matrix as simple as possible.

Each concept was then evaluated for each criterion with the same scale from 1 to 5 where 5 is the best or most attractive solution. The results were calculated by adding all scores for all

concepts after multiplying each with its criterion weighting. Even as the matrix has incorporated a certain risk factor, it was desirable to visualise the difference in risk for concepts. This was done with coloured text boxes above each of the numeric solutions as presented in Bye's paper [6].

Sensitivity Analysis. A critical analysis was done to the trade study results to validate the robustness of the matrix. This is done by first performing a sanity check or engineering judgement to see if the outcome makes sense or feels right. A verification of the relative weights, attribute ratings and the numerical calculations are other ways to obtain more credibility [4] [13]. Validation of the result is very important especially when the outcome is an unexpected one. In this case the results were somewhat expected but a sensitivity analysis was perceived as especially important as the scores were close together. The conventional method of summing the individual scores is simple to use but has the unfortunate characteristic of underemphasizing low scores. A technique that does not suffer from this deficiency is to find a single figure of merit for a concept by calculating the geometric mean, rather than just the sum of the concept scores [12]. The Geometric Mean is a special type of mean or average where the n th root is calculated from the product of all the n scores multiplied. In this case n is 15 so the 15th root is calculated. This calculation was conducted with and without global weighting. The conventional method was calculated both with and without global weighting as well as the numerical means for the concept ratings. The resultant rankings of the options is presented in Table 1.

Table 1 - Matrix Calculation Method Results

Calculation Method	Concepts			
	1	2	3	4
Sum of scores (Conventional)	1st	2nd	3rd	4th
Sum without Global Weighting (GW)	1st	2nd / 3rd	2nd / 3rd	4th
Geometrical Mean with GW	2nd	3rd	1st	4th
Geometrical Mean without GW	2nd	3rd	1t	4th
Score Numerical Mean with GW	1st	2nd	3rd	4th
Score Numerical Mean without GW	1st / 2nd	1st / 2nd	3rd	4th

In each instance, removing all global weighting resulted in the same order based on the numerical values as for the weighted matrix. This provides a "rough and ready" robustness assessment. We can see a general trend in the different calculation methods result, which agrees somewhat with the conventional summing. The geometrical mean of concept 3 becomes a new numerical winner due to its mediocre satisfactory scores in all categories where both concept 1 and 2 have a mixture of high and low scores in the categories. A further examination of the scores for each criterion was conducted to test the invariance of the results to changes in the individual weighting factors and scores. One criterion after the other was set to zero before a recalculation for a numerical ranking. The mean of the 15 ranking results is shown in **Error! Reference source not found..** When such variations do not change the initial top choice, the procedure builds confidence in the result of the analysis [12] [13].

Table 2 - Criteria Zero Filling Results

Criteria Zero Filling Calculation	Concepts
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	1	2	3	4
Numerical Mean Ranking	1.96th	2nd	2.4th	3.63th

Summary. The criteria weightings can significantly affect the outcome quality of a Pugh Matrix, so it was important to perform a sensitivity analysis on the result [4] [12]. Concept 1, the numerical winner, and 2, second place, have the biggest advantages as well as big risks. This makes them two highly balanced opposites where the high ratings in concepts 1 are low ratings in concept 2 and vice versa. Both concept 3 and 4 have most scores in the middle score range. This makes them more stable but in general in a lower range than 1 and 2.

Discussion

Pugh Matrix. A decision analysis was found to be a valuable method to deal with the uncertainties, multiple stakeholders, and complexity in trade - off studies. Pugh's decision matrix method was executed to compute and visualise the decision analysis. The result of this research indicates a numerical ranking of the concepts with the conventional concept, option 1, as the winner. This was somewhat expected as new and unproven solutions for the subsea industry need to be integrated with great caution through strict qualification programs. However, the winner is close to a draw with both second and third options based on ranking. A decision based on such a tight margin is not the goal of this study.

The researcher further evaluated both risk and opportunity to deal with the uncertainties and the potential for the alternatives. Systems engineering should pursue all reasonable opportunities to solve problems and fulfil needs. Opportunities represent the potential for improving value and enabling creativity in resolving problems, which could affect the success of the project. Opportunities also usually carry risks and risks as potential problems should be avoided, if they cannot be mitigated. The new system architectures in this study are based on the pursuit of opportunities and it became an objective to achieve a proper balance between risk and opportunity [11]. Risk and opportunity were each included as an integrated row in the decision matrix to give a picture of the balanced uncertainties and potentials.

System Engineering Application. Three important findings of the trade study are particularly worthy of emphasis. Firstly, a strategic view should be taken to identify how the attractiveness of the technology development depends on both the internal and external environment. Secondly, stakeholder analysis should recognise that different stakeholders might impose different values to the alternate concept solutions. Thirdly, the time dimension should be considered by using technology roadmaps. Pugh Matrix is only a Systems Engineering tool to help extract the knowledge and experience from the study team, but the robustness of the result will still depend on the use of the tool as a process. A supported structured approach will provide a documented rationale for decision-making and provide justification for stakeholders. It will also facilitate the allocation of technology planning knowledge within the organisation [7]. The Pugh Matrix was found sufficient and effective toward both these objectives.

SPADE. The applied SPADE methodology worked as a framework that provided a structure for the analysis of activities. It helped maintain a focus on the system engineering principles instead of complex semi-relevant activity lists [10]. The model kept the researcher from taking ownership of trade study problems by systematically involving stakeholders as problems owners. This supports the ideology of applying an objective approach to evaluate a possible favourable concept or desirable criteria ratings. The SPADE activity of decision-

making was applied to the identification and rating of the decision criteria. Evaluation is an ongoing SE activity, as described throughout this paper, and especially in the performance of the sensitivity analysis.

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Architectural Concepts			1 - Conventional Solution		2 - New Suggested Solution		3 - Partial New Combination		4 - Counter Combination	
			FULLY CENTRALISED CONTROLS AND POWER		FULLY DISTRIBUTED CONTROLS AND POWER		CENTRALISED CONTROLS AND DISTRIBUTED POWER		DISTRIBUTED CONTROLS AND CENTRALISED POWER	
Category	Criteria	Global Weight	Offer	Rating	Offer	Rating	Offer	Rating	Offer	Rating
Strategy	Value to Aker Portfolio	5	Small step in roadmap development	2	Great advancement for further projects.	5	Some advancement for further projects.	4	Some advancement for further projects.	4
Cost, CAPEX	Development Time	5	Low	5	High	1	Medium	3	Medium	3
	Technology Maturity	5	Experience from execution in legacy project. No new technology	4	low maturity as new power and control Hubs need to be developed	1	Conventional controls distribution. Power distribution is unproven	2	Controls distribution is unproven. Conventional power distribution	3
	Fabrication / Production	3	Complex (CPDU)	1	Several new component	3	lesser new products to produce	4	Complex(CPDU)	1
Reliability	Total Number of Flying Lead Connection	5	Total 50 off. (Flowbase: 12, Compressor: 8, Cooler: 2, Station: 28)	4	Total 108 off. (Flowbase: 46, Compressor: 23, Cooler: 19, Station: 20)	1	Total 83 off. (Flowbase: 32, Compressor: 15, Cooler: 10, Station: 26)	2	Total 80 off. (Flowbase: 22, Compressor: 12, Cooler: 12, Station: 34)	3
	Installation Scope	4	CPDU installation	1	No CPDU.	5	No CPDU	5	CPDU installation	1
	Optimised Maintainability	3	No production during SCM maintenance/failure.	1	Production during single Control hub / Power Hub maintenance/failure.	4	No production during SCM maintenance/failure.	1	Production during single Control hub / Power Hub maintenance/failure.	4
Engineering	Scaleability for Adding Instruments	3	Easy to scale/expand. Limitation in SCM	5	Easy to scale/expand. Limitation in Control/Power hubs	2	Easy to scale/expand. Limitation: SCM	3	Easy to scale/expand. Limitation: Control hubs	3
	Scaleability for Adding Actuators	3	Limitation in CPDU capacity	4	Module internal: Additional batteries / flying leads from Power hubs.	2	Module internal: Additional batteries /flying leads from Power hubs.	2	Limitation in CPDU capacity.	4
Testing	Factory Acceptance Testing	4	More test equipment required	2	Individual early testing possible. Less equipment required	5	More controls test equipment required	3	Individual early testing possible	4
	System Integration Testing	4	Require CPDU and SCM to test	1	Individual and partly testable	5	Require SCM on compressor	3	Require CPDU to test	2
Structural	Added Weight of Architecture	3	3,5+25 = 28,5 tonne	2	19 tonne	3	13,5 tonne	4	9+25 = 34 tonne	1
	Footprint Needed on Modules for Retrievals	3	Total 11,5m ² . (Flowbase: 3m ² , Compressor:8m ² , Cooler: 0,5m ²)	4	Total 22,5m ² . (Flowbase: 9m ² , Compressor:9m ² , Cooler: 4,5m ²)	1	Total 20m ² . (Flowbase: 7m ² , Compressor:10m ² , Cooler: 2,5m ²)	1	Total 14,5m ² . (Flowbase: 5m ² , Compressor:7m ² , Cooler: 2,5m ²)	3
Installability	Complexity of Installation	3	Less equipment on module to protect	4	Most equipment on module to protect	1	Some equipment on module to protect	2	Some equipment on module to protect	2
	Number of Connectors to Hook Up a Station	3	Total 28 off. (Compressor: 12, Cooler: 4, UTA: 2, CPDU: 10)	2	Total 20 off. (Compressor: 7, Cooler: 7, UTA: 6)	3	Total 26 off. (Compressor: 15, Cooler: 7, UTA: 4)	2	Total 34 off. (Compressor: 8, Cooler: 8, UTA: 4, CPDU: 14)	1
Identified Risk		-	A postponement of deep sea solution development > 1000m sea depth.		Multiple Technology Qualification Programs (TQPs). Timeconsuming development of Power and control Hubs.		TQP: Development of power hubs.		TQP: Development of control Hubs.	
Opportunities		-	A more mature solution for a early project delivery.		Verifies a future deep sea power distribution		Verifies a future deep sea power distribution		Verifies an alternative control distribution architecture	

Conclusion and Future Research

The subsea domain is project oriented where execution time and cost creates programmatic pressure. This may cause engineering teams to skip preliminary steps in concept selection and place more emphasis on designing and delivering products. Incorporating practices, such as trade-off studies in Phase 1 of the PEM, could change the culture of project execution in AKSO and lead to more time allocated to considering innovative technology options.

The Pugh Matrix has demonstrated its ability to provide a simple overview of the multiple factors in a decision-making situation. Based on this, and prior research, the matrix has proven suitable for evaluating a new system architecture philosophy applied to an existing system. Extensions to the basic matrix structure supported concurrent visibility for assessment of Risk and Opportunities associated with each alternative.

Future work would point in the direction of detailing a concept for a fifth compromise solution for future exploration, and adoption of the Pugh Matrix as a SE tool for trade studies within AKSO.

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Biography

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