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A Review on Power Generation for Subsea Loads and the Economic Implication for Future Projects

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Abstract:

The application of clean energy for power generation and transmission to subsea loads for subsea processing, compression and boosting processes have been identified to reduce the emission of CO₂, CO and other hazardous gases to the environment. Subsea all-electric systems have also been identified as a better option due to size reduction, lower weight, its low power requirement and consumption. This review paper focused on Power Generation models with emphasis on generating the power onshore as one option and with the use of clean energy options like wind, solar etc. this power generation models will help to reduce the size and weight of offshore oil and gas production Platforms. The power transmission to the subsea sea loads was considered using high voltage transmission cables and an economic model to guide future investment in subsea project development was considered

Keywords: Clean energy, power generation, power transmission, subsea loads, economic model

1. Introduction

The processing and boosting of produced fluids in the offshore industry have been initiated subsea (on the seabed) so as to reduce challenges in flow assurance and the cost effectiveness for any subsea projects in the oil and gas industry. (McClimans & Fantoft, 2006), defines subsea processing as an active handling treatment of produced fluid at the seabed or down hole. Attention has been focused to cases of multiphase boosting/pumping, separation process, and wet-gas boosting/compression.

There is a desire to improve oil and gas discovery from satellite wells which are in the range from 30 – 40% compared to dry wells (topside wells) which are in the range of 50 – 70%. Subsea processing technology has been a great contributor to improve recovery. The most matured technology within subsea processing is the subsea boosting system. The pumping technology either single or multiphase have been deployed since 1990 and is today field proven with over 25 systems in operation (Jahnsen & Storvik, 2011). The focus of this paper is to look at some field experiences of subsea separation and boosting and a review of power transmission to the subsea loads and a consideration of economic model that will guide investment for subsea project for future development since the discovery of oil and gas these day are in very difficult environment and at the same time the engineering applications should be environmentally friendly, hence this review.

2. Field Experiences of Subsea Separation and Boosting

At about year 2000, the Troll pilot 3-phase separation was the first subsea separation installed in the Norwegian continental shelf. This system has the produced water re-injected in the reservoir and the produced oil and gas flow to the topside. Other subsea process system inexistence is the Tordis 3-phase separation, installed in 2007, also with water injection and an addition to boosting the multiphase flow of oil and gas up to the Gulfaks C platform. In Brazil, the first subsea process technology installed was the Vertical Annular Separation and Pumping system (VASPs) in the Marimba field. In West Africa, the Pazflor gas-liquid and boosting system was installed in Pazflor field development in Angola.

The impact of Subsea boosting on deep water field was identified by (Ribeiro, Camargo & Paulo, 1996), showing results of subsea bosting systems as a reliable tool in cost reduction of subsea deep-water development. As at this time prediction was that about 50 percent of unexploited resources were located in ultra-deep-water areas, which has been the driving force for Petrobr as since its future in the production of oil and gas is linked towards deep water resources. (Skiftesvik & Svaeren, 2000), noted subsea pressure boosting as a technology that helps for accelerated production of oil and gas with reduced production time. Subsea processing has been identified to reduce offshore production platform based on size and cost. Saving cost for production platforms that benefits subsea processing include: Subsea processing with re-injection of produced water which will increase oil production, Subsea water treatment and removal could eliminate or reduce the need for water treatment topside and will also help to eliminate water injection risers, production from marginal fields

will be performed using very simple floating production platforms, reduce the risk of hydrate formation and minimize the use of chemicals for injection. Removing the water will reduce the flow and the specific gravity of the fluid; this will in turn reduce the static head and the flow resistance will decrease, which will reduce cost by using smaller pipelines and risers (Skiftesvik & Svaeren 2000).

Nakashima, Oliveira & Caetano (2004), described subsea boosting as a vital technology required for enhanced oil and gas recovery. Nakashima et.al (2004) compared the boosting of oil and gas using the gas lift and the subsea multiphase pumping system. Results of its analysis proved that in the first year of its production, the heat and electricity which comprises of the total energy consumed in each case is slightly higher with the gas lift, which is as a result of the high flow rate that is a consequence of the lift gas re-circulation. The heat consumption with the Subsea multiphase pumps (SMPs-60) which was meant to be the highest value due to the high oil and gas flow rate was observed to have a reduction in the first year owing to the high shaft speed and friction power inside the pump. From this analysis, in 2020, the volumetric flow decreased as a result of reduction in shaft speed and friction power as the heat consumption raises.

The Jubarte field with its subsea equipment operated at a water depth of 1400 meters is an example of field experiences which uses an Electrical Submersible Pump (ESP) configuration compared to the gas lift method. The Electrical Submersible Pump allows a production bypass and pump retrieval without the removal of the Christmas tree and associated well completion set. In 2001 associated failure that arises in the use of the Electrical Submersible Pumps that causes loss time in production and a high cost of intervention was addressed by installing the Electrical Submersible Pumps system set out of the well and this made both installation and recovery easier (Rodrigues, Soares, Matos, Pereira & Ribeiro 2005).

Statoil Operating the Tordis field in the North Sea installed the subsea separation, boosting and injection systems (SSBIs) in 2007. The system was installed with focus on simple technical solutions using equipment's with track records of success in operations both in subsea and topside applications. The Subsea Separation, Boosting and Injection project used a technology qualification programme to qualify and document performance of new components (Fantoft, Hendriks & Elde 2006).

In the Gulf of Mexico, the BP King oil field used a multiphase boosting. This field has three wells which have been producing since 2001. The King D5 and D6 started producing before King West D3 started producing in 2003. The wells are located at a depth of between 1520 to 1625 meters. A tieback approach was applied in this field, with all the wells tied to the Marlin field Tension Leg Platform (TLP) located at a distance of 27km away. BP initiated means to boost production as the pressure in the reservoir begins to decline. The mode of structural approach applied by BP was based on its stage gate process (Davis, Kelly, Kierulf, Eriksson, Normann & Hormstvedt, 2009). These processes include:

Figure 1: Structural Approach for BP Stage Gate Process (Davis Et.Al, 2009)

After considering different oil recovery methods, subsea boosting came out favourable in this evaluation.

For subsea process technology to be fully employed, there are value drivers that needs to be considered. Aside from the Account aspect or accounting indicator that creates value, economic indicators of value creation and the market indicator of value creation, most oil and gas company adopt most frequently the category of performance variable known as value driver and this value driver are measured using Key Performance Indicators (KPI). These drivers were identified for both brown and green field applications. An example of a typical KPI in this aspect could represent the required Capital Expenditure (CAPEX) and Operational Expenditure for the development of these fields (MacClimans & Fantoft 2006).

3. Power Generation and Transmission to Subsea Loads

Power generated to be utilized offshore or transmitted to subsea loads can be generated by wind turbine, solar systems, gas turbine on offshore platforms and by also connecting from national grid to supply offshore and subsea systems. The focus of this paper is to look at cleaner energy options where the power generated will reduce or eliminate the emission of CO, CO2 and other Hazardous gases that have negative effect on our environment.

The industry presently is driving towards the reduction of equipment size, weight and low power consuming equipment. This drive is towards reducing cost in offshore exploitation and production.

Floating production platforms and Tension Leg Platforms (TLPs) have been the order of offshore platforms over the years, but with issues of high cost of renting a floating production vessel, environmental impacts of oil and gas exploration and production, High power demand for offshore production, flow assurance issues etc., these issues can be resolved based on the use of systems with lower power consumption, so as to reduce the amount of power needed offshore.

The major problem of analysing subsea systems is that every project has its own design specification of its components and facilities. For this reason, equipment's are qualified based on a particular project instead of having a common standard. To solve this problem, the Joint Industry Project which brought together most of the big players in the industry comprises of Total, Shell, Petrobras, Exxon Mobil, Woodside and chevron, came together to work on the subsea electric power standardization (SEPs) (Steiner, Micheal, Edouard, Cornelia, Diego & Stephen 2013).

The Joint Industry Project (JIP) on the electric power standardization for subsea equipment published an international industry standard on the design, testing and qualification of subsea power transformers. This standard will reduce the cost of future subsea field development by creating uniformity in the oil and gas industry projects (Oil and Gas Journal 2016).

The predominant use of Gas turbines on offshore platforms has increased the emission of Co₂, NO_x other hazardous gases to the environment, for this reason better options that are less hazardous will be adopted in the industry. Jorun, Erik & Magnus (2002), designed a model using wind turbines as the alternative source for power generation for four offshore platform to be used in the Norwegian region. For this model, the high voltage Alternating current (HVAC) will be used for shorter distance of transmission while the high voltage direct current (HVDC) cable will be used over a long distance. Another option is the supply of power to subsea loads from power generated onshore from national grid. The transmission of power from onshore have advantages such as high level of availability (approximately 99%), increased length of life (approximately 30 years), increased efficiency in fuel to electric power conversion, less maintenance and shorter down time (Marcio, Carlos, Bruno, Diego & Mauricio 2014). Audun & Nils (2014), analysed power supply to subsea loads by generating the power on the topside, although this is the trend in the industry, where Gas turbines are located topside, for power generation and transmitted via the umbilicals to the subsea loads. An alternative to this can be the use offshore wind turbines on offshore platforms although this is a cleaner energy but the size of the offshore platform will be increased due to the size of a wind turbine and also issues of safety on offshore platform will also be a concern.

3.1. Power Transmission Model

Power transmission models in this paper will focus on models that can be adopted with different generation modules. Power can be generated either by wind turbine, solar panels, gas turbines, tidal energy, national grid etc., but the mode of transmission could either be expensive or cost effective. Lai, Zhang, Dong, Song, Todorovic, Gupta, Garces, Gunturi, Wijekoon, & Sihler (2014), designed the modular subsea direct current system for power transmission to subsea processing systems i.e. Subsea loads. The modular system was designed to have reduced size, high reliability, flexibility and a reduced installation weight. The system has a sending end, where the power generated is sent to a converter station that's converts the AC power to DC power before transmission via a high voltage direct current cable to the receiving end converter station that converts the DC power to AC power before transmission to the subsea loads. Depending on the application of the load demand from subsea process systems, pumps and compressors, the power rating of different fields can be addressed by using this system since it gives flexibility and can be adapted notwithstanding the power demand of a field. The system has a by-pass switch that creates a continuous process despite the fault of any of the system. The modular Subsea Direct current system concept is Shown in Figure 2.

Figure 2: The Modular Subsea Direct Current System Concept (Lai Et.Al 2014)

The step-up and step-down transformers in the figure will be applied based on the power requirement of the field and the size of the transmission cable.

Having a DC power source can help to reduce cost by eliminating the AC to DC converter. High voltage DC cables are more preferable for long distance transmission due to less losses involved in DC Transmission.

Figure 3: Power Transmission with DC Power Source

Figure 3 shows a dc power source and transmission via HVDC cable. The DC power source model using HVDC cable is preferred for long distance transmission. Having a Power transmission with DC power source will reduce cost of using a converter station. A DC source like the solar cells will transfer power in DC directly but the cost of the solar panels will have to be compared with that of an AC source with AC to DC converter at the sending end.

For shorter distance AC power is more preferable depending on the power requirement. Figure 1.4 shows a typical AC power source model applicable for short distances.

Figure 4: Power Transmission with AC Power Source

From figure 4, PCDM represents the Power Control and Distribution Module. This module was introduced here to regulate the power used by the subsea loads depending on the demand of the field and the power from the sending end. The PCDM can be applied at the sending and receiving end as the case may be.

A model for a subsea development project can be selected based on the power source and field development. New subsea projects have its own economic challenges based on the type of model to apply for a particular subsea field development, taking subsea economics into consideration will give investors an insight on the merits and demerit of undertaking new projects.

4. Economics of Subsea Development

The advantage of having a subsea model that will bring about cost reduction in the production of oil and gas is very important. This cost reduction can be achieved by having a model that shows a cost reduction trend or potential cost to encounter in the course of investment into subsea systems and field developments.

(Euphemio, Kuchpil, Figueiredo, 2009) identified power transmission losses in transmission cables increases with increasing tieback distances. To minimize these transmission losses, larger diameter cable maybe used as this will likely add to the increase in cost for subsea installations or in a different scenario voltage are stepped up and currents reduced at the source before transmission as the case maybe. The use of subsea transformers will be required to step-down the voltage before distribution to individual component at the receiving end of the main power cable. Losses on transmission cables are quoted at about 3% percent per 1000km, depending on the voltage level and construction details of the cable. (Erlend, 2002), stated the improvement in field economy will be made possible by applying subsea processing because it has a significant processing ability and carries a manageable risk. At this stage (Erlend, 2002) noted that the results and experience from subsea processing proved to be good as used in the industry. Subsea processing also identified as a technology for the improvement of field economics in both producing fields and new field developments in the various areas; increased production and recovery, improved flow performance and flow assurances, accelerated and improved production, enable offshore fields with long tie-backs, enable development of marginal fields, reduce the dependence and use of chemicals and inhibitors, minimize power consumption etc.

Flexibility in the design stage is a method of recognizing and understanding the effect of uncertainty (de Neufville & Scholtes, 2011). It is important for the design engineers to identify and implement flexible solutions in the early phase. This will allow for the integration of systems in a cost-effective manner (Erlend, 2002).

The growth of oil and gas production from deep water field through the use of subsea production has been made possible using novel technology including mudline two/three phase separation, subsea multiphase and liquid pressure boosting. A life cycle cost approach which includes an "unforeseen" Operational expenditure element gives the following economic model (Giovanni & Remi, 2000).

$$\text{PROFIT} = \text{REVENUE} - \text{CAPEX} - \text{OPEX}_{\text{PLANNED}} - \text{OPEX}_{\text{UNPLANNED}} \quad (1)$$

The life cycle cost (LCC) was estimated as

$$\text{LCC} = \text{CAPEX} + \text{OPEX}_{\text{PLANNED}} + \text{OPEX}_{\text{UNPLANNED}} \quad (2)$$

A simple cash-flow diagram for a typical field development

Figure 5: Basic Cash Flow Diagram For A Typical Field Development
Source: Giovanni & Remi 2000

The simple cash flow diagram gives an insight of the need to consider basic economic factors like the net present value (NPV), internal rate of return (IRR) and cash flow before an investment.

Subsea systems ranging from high power systems for power transmission to the subsea loads are being optimised to meet with the present-day field requirement in offshore field development to make subsea projects very economical since most discoveries these days are located in difficult offshore environment.

The size of subsea trees has shown reduction in size as new technologies tends to design smaller systems that will still meet with the demand in subsea fields even in the most difficult environment. These systems are meant to operate with the lowest level of down time so as to keep production going and save cost on maintenance. (Ersdal & Hornlund, 2008), (Pires, morais, Freitas & Monteiro, 2016) noted that most offshore production facilities are operated beyond their service life or are close to their design service life. Hence the need for flexibility during design phase of subsea facilities should be considered so as to produce systems with high reliability and availability.

The power consumption of subsea trees has reduced over the years from the use of electro-hydraulic subsea trees to the present day all-electric subsea trees. This reduction in such power consumption is a positive indication of the economics of subsea as it proffers lower operation cost in the industry. Hence the gap between the subsea production equipment operated by hydraulic control systems to that operated by all-electric as the later shows to be of more economic value. The reduction of weight and size of subsea systems which will play a major role in economics of subsea systems have been in continuous work process for decades. The equipment used in the industry over the years is shown in table 1.1.

S/N	Year Range	Equipment Used
1	1961 - 1969	Direct Hydraulic
2	1971 – 1985	Sequenced Hydraulic
3	1985 - 2012	Electro-hydraulic
4	2008 – present day development	All-electric

Table 1.1: Equipment Used Over the Years
Source: Berven, 2013

The evolution of these systems has come about through research and development with field experiences on a global view. Subsea systems are often designed based on a range of diverse conditions which include: weight, size, production capacity, health, safety and environment (HSE), economics, reliability. These are factors that are mostly considered in the design of subsea system and field developments projects (Berven, 2013).

5. Conclusions

This review presents the need of a cost effective and clean energy option to the offshore oil and gas industry as identified by the advantages of subsea processing, boosting and compression and having a wide application of an all-electric system that has shown a positive indicator towards enhance oil recovery and reduced power consumption. From the power generation and transmission model analysed, depending on the field requirement and distance from source of power generation a field requirement can be met based on power generation notwithstanding the size of the subsea development. The economic model in this review identifies unplanned expenditure as a tool to be considered in the life cycle cost of a project. From this review, a subsea development project can be carried out in order to save cost in capital and prepare for unforeseen circumstances and expenses in field operations having in mind the use of low power consuming equipment and a clean energy power source.

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