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Investigation of offshore thermal power plant with carbon capture as an alternative to carbon dioxide transport

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ABSTRACT

Carbon Capture and Storage (CCS) technology is considered as one option to reduce CO_2 emissions in order to mitigate climate change. The conventional CCS technology has its own complications including high costs and risks for storing CO_2. This paper introduces the concept of Offshore Thermal Power Plant with CCS (OTPPC), which eliminates the needs for transporting CO_2 and therefore reduces the complications of the whole system. A general design selection process for the OTPPC is established. A case study is carried out to demonstrate the application of OTPPC and the cost-effectiveness of this concept is evaluated by calculating the Levelised Cost Of Energy (LCOE) for both the OTPPC and conventional CCS technology for an onshore power plant with assumption that CCS is necessary.

1. Introduction

Carbon Capture and Storage (CCS) is considered as one option in the portfolio for mitigating climate change that is mainly caused by the large anthropogenic emissions of CO_2 from burning fossil fuels (IPCC, 2005, 2007a, 2007b, 2007c, 2007d). According to the International Energy Agency (IEA), fossil fueled power generation accounts for 41% of the total emissions of CO_2 (IEA, 2011). Therefore, many researches focus on the capture of CO_2 emitted from power generation and the subsequent transport and storage of CO_2.

However, the conventional CCS technology has its own complications, such as high energy penalty, high costs, technology immaturity, the complexity of transporting CO_2 and uncertainties in the long-term storage of CO_2 (IPPC, 2005). Although transportation of CO_2 does not contribute to the largest part of the total costs, it increases the complexity of the whole system and therefore increases risks for leakage. In addition, the current CCS technologies mainly focus on the pursuit of CO_2 storage in onshore geological formations, which may lead to the concerns from the public towards the safety of storing CO_2 underground. However, the concept of Offshore Thermal Power Plant with CCS (OTPPC) may eliminate the above problems, which moves the power plant offshore to facilitate storing CO_2 into offshore geological formations.

The concept of offshore thermal power plant is not really new in the literature. Many companies have shown interest in developing this concept in order to reduce the need for lengthy permitting applications that are needed for conventional land based power plants (Waller Marine, 2011). In addition, the Gas to Wire (GTW) concept provides an attractive solution for marginal gas fields and stranded gas. Instead of transporting the natural gas from marginal gas fields to an onshore terminal, it generates electricity offshore and then transmits the electricity via subsea power cables to onshore electricity grids, which generates a higher thermal efficiency compared with the conventional approaches (HITACHI, 2011). The concept of combining an offshore power plant with CCS has been addressed previously when considering power generation for offshore installations since the 1990s (Bjerve and Bolland, 1994). A more recent concept is by Hetland et al. (2008). The SEVAN GTW concept, developed by SEVAN MARINE and Siemens is a cylindrical platform equipped with a combined cycle power plants with four blocks, each consisting of two gas turbines and one steam turbine. These are connected to an amine based carbon capture system (Hetland

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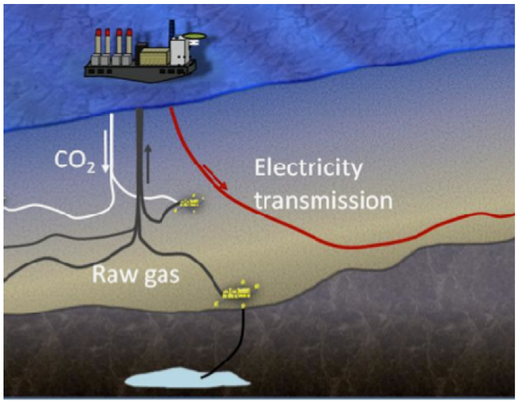

Fig. 1. Schematic of offshore thermal power plant with inclusion of CCS.

et al., 2009). However, the cost benefits of this concept have not been investigated before. This raises the question whether OTPPC is cheaper than the conventional CCS technology for power plants.

Hence, the main purpose of this paper is to illustrate the concept of offshore thermal power plant with CCS, establish the corresponding design selection process and evaluate this concept in terms of availability for application and cost-effectiveness.

The concept of an OTPPC involves integrating power generation equipment, gas processing equipment, carbon capture systems and electricity transmission modules onto one offshore platform (Windén et al., 2011). As with the GTW concept, OTPPC can be applied in marginal gas fields where the high costs of production and transportation of gas make such developments non-viable. Compared to onshore power plants, offshore power plants have the advantages of shorter construction periods (Waller Marine, 2011) and ease of mobility. In addition, the cost of natural gas may be significantly reduced since natural gas can be directly supplied from the existing offshore gas fields as shown in Fig. 1.

Different from conventional CCS technology for power plants, this concept eliminates the need for long distance transportation of CO_2 via pipelines or ships by directly capturing CO_2 from fuel gases and injecting it into offshore geological formations. The generated electricity can either be transmitted to onshore electricity grids via subsea power cables or be used to support other offshore operations (Hetland et al., 2009).

This section has introduced the concept and features of an OTPPC, the design process of which is discussed in Section 2. A case study, discussing the cost-effectiveness of an OTPPC is given in Section 3. Finally, concluding remarks are given in Section 4.

2. Design selection process

Like the other offshore platforms, the OTPPC has to be capable of operating and surviving in the offshore location for a long period. Therefore, it is important to evaluate the environmental load effects based upon a given site in the design stage. Design codes and regulations that are applicable for offshore platforms may also be adapted to guide the design of the OTPPC. However, the OTPPC has its own complications and limitations. By integrating different systems onto one platform, the complexity of the overall system increases. In addition, the capacity of the power plant is limited by the deck area and storage capacity of the supporting platform. Before implementing this concept, a variety of factors that govern the design of the OTPPC need to be evaluated.

The engineering design process is an iterative decision making process where a system is devised to meet the required needs. It involves several stages including concept design, a feasibility study, preliminary design, detailed design and production design (Ertas and Jones, 1996). The purpose of this section is to describe the process by which the concept design and the associated feasibility study of the OTPPC can be carried out. In general terms, it must be decided what type of vessel should be used, if a single or multiple vessels are to be used and what equipment goes on board (Hill et al., 2002).

The more specific design selection process and the associated feedback loops may differ depending on the motivation for implementing an OTPPC. Three motivations can be distinguished: power output, exploitation and CO_2 storage. Fig. 2 shows the design selection process for the motivation to produce electricity. The power output determines the configuration of the OTPPC that then decide where the location is so that the gas supply can be matched to the power output requirement (Hill et al., 2002). Based on the chosen location and the capacity of the OTPPC, the CO_2 storage option can then be determined. The electricity transmission system is designed based on a combination of power output and offshore distances.

The second motivation is to explore marginal gas fields or stranded gas. Here the gas field location is fixed, which determines the capacity of gas fields and offshore distances. The configuration of the OTPPC, electricity transmission system and CO_2 storage option can be adjusted accordingly as shown in Fig. 3.

The third motivation is to pursue the storage of CO_2 into offshore geological formations. This then fixes the location and an appropriate power output is chosen based on the gas supply as illustrated in Fig. 4. This can also depend on how much CO_2 can be stored in the storage site since if CO_2 sequestration is the primary

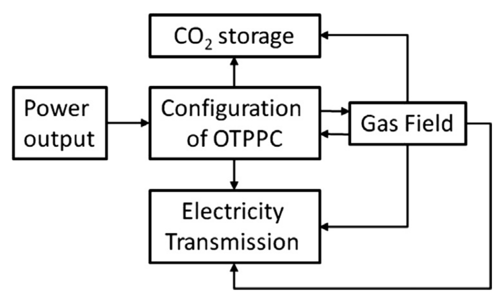

Fig. 2. Design selection process for producing electricity.

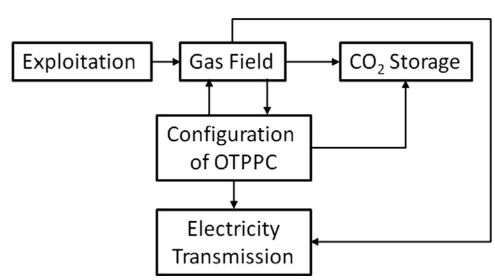

Fig. 3. Design selection process for exploiting gas fields.

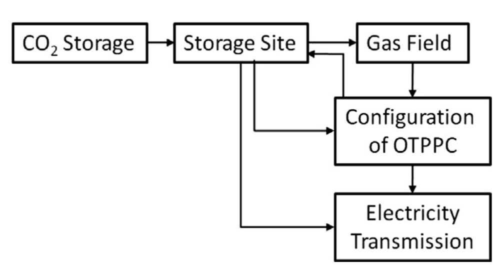

Fig. 4. Design selection process for storing CO_2.