Development of ZEUS – Zero - Emission Unmanned power Station

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ABSTRACT

Ongoing climate changes and environmentally friendly pledges at governmental levels are driving the global energy transition worldwide. One of the critical sectors for decarbonization is the offshore oil & gas industry, where natural gas will still play a central role in the predictable future. Supercritical CO_2 as a working fluid is one of the enabling technologies incorporated in an innovative CO_2 free offshore power plant burning gas with pure oxygen. This solution, known as ZEUS (Zero Emission Unmanned power Station) utilizes a recuperative indirect sCO_2 power cycle with a high-pressure oxy-fueled combustor as its heat source and it is intended to be used offshore. The high-pressure exhaust gas, primarily composed of steam and CO_2, when is cooled, facilitates the liquefaction of combustion products, allowing for direct re-injection into a suitable reservoir nearby. The short version of the paper presents the ZEUS concept along with its advantages followed up with sCO_2 turbine description for the anticipated 5 MWe demonstrator plant scheduled for completion in 2027.

INTRODUCTION

Environmentally driven carbon reduction targets pose challenges for energy-intensive industries, including offshore oil & gas. This situation is catalyzing the deployment of innovative technologies, such as supercritical CO_2 (sCO_2) power cycles investigated and demonstrated in several projects [1]. Using carbon dioxide as the working fluid (WF) in conventional power cycles enables more compact plants and even higher thermal efficiency than their steam-based counterparts. These advantages are particularly significant for offshore applications. Application of sCO_2 based technology for power cycles is comprehensively presented in [2], whereas a report from 2018 [3] outlines still valid technological gaps, TRLs of associated components and research needs. Another unique feature of sCO_2 power cycle, is the viable possibility of using additives, such titanium tetrachloride ($TiCl_4$), what allows to obtain a chemically tailored working fluid for a given application. CO_2-blends as a WF are mainly investigated with reference to concentrated solar power plants to tune up the critical point parameters what helps managing efficient heat rejection from the cycle while increasing cycle thermal efficiency [4].

In that respect, sCO_2 power cycles are favorably investigated and used for a vast number of different applications outperforming steam cycles and providing all advantages of compact design. Therefore, sCO_2 technology is selected for the ZEUS concept introduced in the next section.

ZEUS CONCEPT

The ZEUS concept, Zero Emission Unmanned power Station, produces electrical power by burning natural gas and pure oxygen offshore, close to the production wells, onshore, on a topside, on floating production, storage and offloading units or subsea. The oxygen is provided by an Air Separation Unit (ASU) placed onshore or offshore. The burner design made in platelet design technology with hundreds of intricate flow channels for fuel, oxygen and diluent offer very large fuel flexibility in terms of fuel gas composition allowing very high CO_2 content. This feature allows that ZEUS plant can use any gas as feedstock, including associated gas, methane hydrates, CO_2-rich gas and stranded gas, what realizes lower levelized costs of electricity. Early indications show that ZEUS is very cost competitive with other carbon capture alternatives. The combustion is done at high pressure (> 85 bar), obtained for free from the wells. The high pressure ensures that when cooled, the exhaust is liquified instantly and can be re-injected by pumps directly into suitable formations in the vicinity and is enhancing production rate over the reservoir life. The proposed concept gives short-traveled gas, short-traveled CO_2, and only a cable running to shore or to offshore installations. The overall ZEUS plant is depicted in Fig. 1.

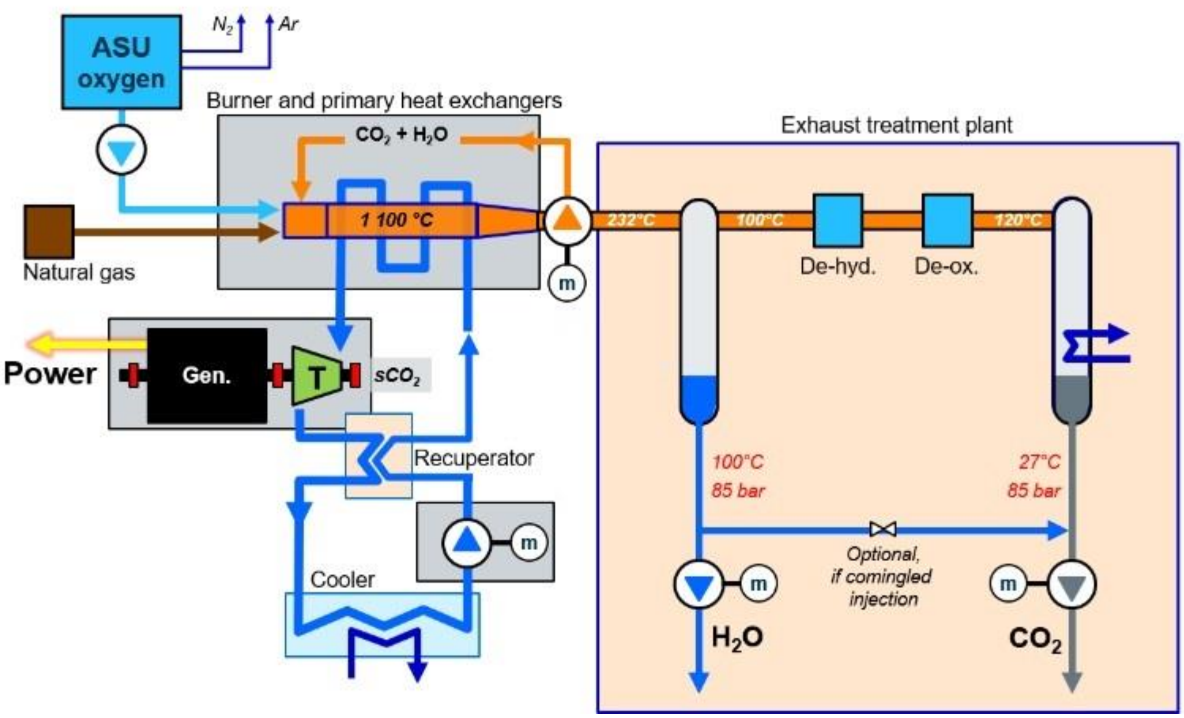

Figure 1. Layout of the ZEUS concept.

sCO_2 TURBINE AND ZEUS DEMONSTRATOR

The ZEUS layout features a sCO_2 indirect, recuperative bottoming cycle. To demonstrate and document the performance of the ZEUS concept, a 5 MWe electric demonstrator plant is scheduled for completion by 2027. Currently, pre-FEED study is finished in 2023 and engineering study is ongoing in 2024. The main premise is to demonstrate applicable technology anticipated for commercial ZEUS unit with power output (between 50-200+ MWe). The demonstration plant will be installed in a suitable location with access to gas and where the CO_2 can be safely disposed. Additionally, the demonstration plant is planned to demonstrate economic benefits through enhanced oil recovery, confirming the appeal of the ZEUS concept.

The power loop along with corresponding points on T-s diagram are depicted in Figures 2 and 3, respectively.

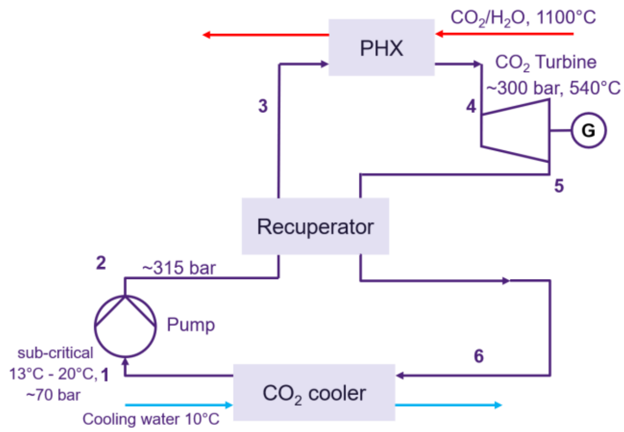

Figure 2. 5 MWe sCO_2 indirect power loop in ZEUS plant demo.

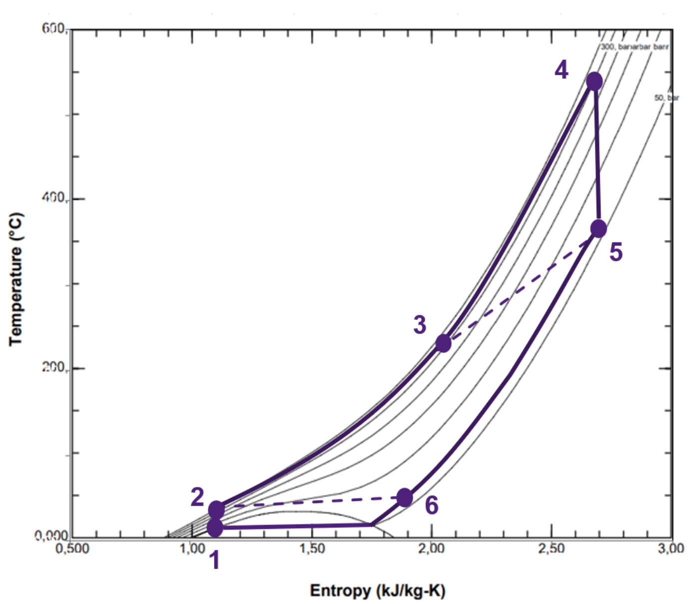

Figure 3. sCO_2 power cycle for ZUES demonstrator plant.

An essential component is the primary heat exchanger (PHX) accommodating two streams at high pressure and temperature, i.e. hot exhaust gas and sCO_2, thus linking the power loop with heat source. Appropriate technology solutions and partners are being engaged for providing compact and robust design for both oxy fuel burner and PHXs. Recuperator and CO_2 cooler are mature components for which suppliers are reviewed. The sCO_2 feed pump will be developed by a market leading pump vendor. The exhaust treatment plant (ref. Figure 1) will be investigated in another demonstrator project founded by Norwegian sponsor body.

A vital component for power cycle is the turbine and generator set. The 3-dimensional model of 5 MWe sCO_2 turbine along with generator is depicted in Figure 4.

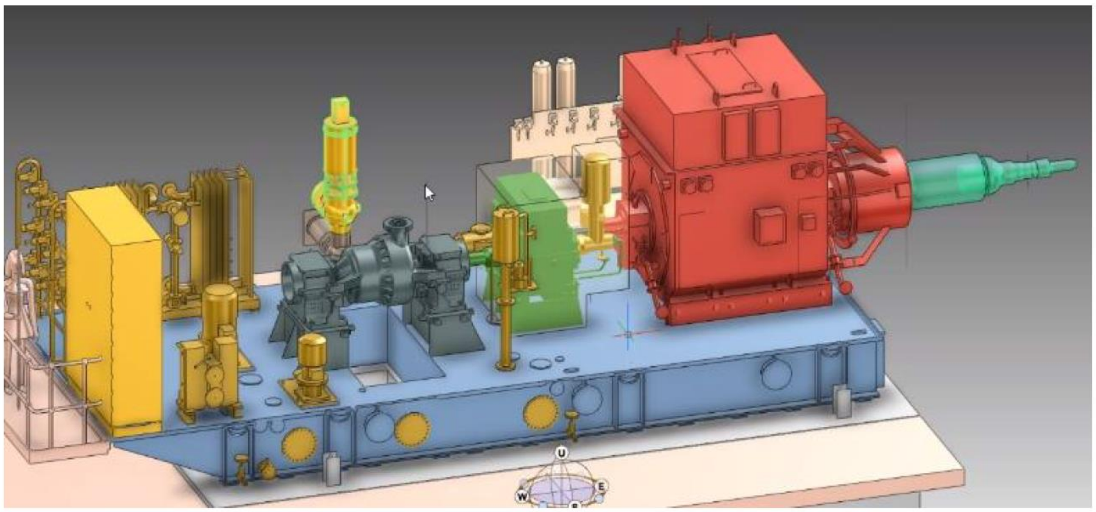

Figure 4. 5 MWe sCO_2 turbine and generator installed on skid by Siemens Energy.

Both the turbine and generator will be supplied by Siemens Energy. For the sCO_2 turbine the heritage design philosophy of high-pressure barrel type steam turbine is applied. Similar fluid working conditions in comparison to steam cycles allow usage of well-established alloys with proven durability and supply chain. The basic design of the demonstrator sCO_2 turbine allows easy scaling up to more than 200 MWe for the finally intended commercial application.

SUMMARY

The ZEUS concept addresses many practical challenges faced by industrial stakeholders. Although, most of the incorporated individual blocks are relatively mature, the way of integrating them for offshore ZEUS amplifies the remaining research needs. To address this, the 5 MWe demonstrator plant is scheduled for completion in 2027. While seeking for partnership in this entrepreneurship some technology providers and vendors are reviewed to establish strategic partnerships for all building components.

The presented ZEUS concept could make natural gas not only affordable and reliable but also sustainable. In addition to that, the mapping of various possible business cases proves benefits of tying ZEUS to offshore wind as power balancing unit, contributing positively to energy transition worldwide.

REFERENCES

[1] Martin T. White, Giuseppe Bianchi, Lei Chai, Savvas A. Tassou, Abdulnaser I. Sayma, Review of supercritical CO_2 technologies and systems for power generation, Applied Thermal Engineering, Volume 185, 2021, https://doi.org/10.1016/j.applthermaleng.2020.116447.

[2] Fundamentals and applications of supercritical carbon dioxide (sCO_2) based power cycles. K Brun, P Friedman, R Dennis. Woodhead publishing, 2017. 414, 2017.

[3] Dogan, Omer N., Weiland, Nathan T., Strakey, Peter A., Lawson, Seth A., Black, James B., Jesionowski, Gary A., and Gioia, Chris J.. Direct Supercritical CO_2 Power Cycle Technology Research and Development: Technology Gaps and Research Needs. United States: N. p., 2018. doi:10.2172/1603329.

[4] F. Crespi, P. Rodríguez de Arriba, D. Sánchez, A. Ayub, G. Di Marcoberardino, C.M. Invernizzi, G.S. Martínez, P. Iora, D. Di Bona, M. Binotti, G. Manzolini, Thermal efficiency gains enabled by using CO_2 mixtures in supercritical power cycles, Energy, Volume 238, 2022, https://doi.org/10.1016/j.energy.2021.121899.

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