Highly flexible zero-carbon electricity generation using an innovative oxy-fired supercritical CO2 power cycle

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Abstract

Along with renewables and nuclear power, carbon capture and storage (CCS) is expected to play a vital role in decarbonising electricity production. In future electricity systems, CCS power plants will be required to respond to the fluctuating supply of renewable energy by varying their output and through rapid shut-downs and start-ups [1]. This concept of flexible operation - initially proposed by academics at the University of Edinburgh [1, 2] - allows CCS plants to time-delay the financial and energy output penalty of carbon capture processes. Whilst the concept was developed for conventional fossil fuel power cycles with post-combustion capture, this project is the first to apply it to the Allam Cycle, a recent breakthrough in low-carbon energy generation.

The Allam Cycle is an oxy-fired supercritical CO2 power cycle, currently undergoing pilot scale testing as part of a $140m scheme led by NET Power [3]. It is designed to produce zero carbon electricity at competitive efficiency and costs compared to unabated fossil fuel plants, thus exhibiting a step-change in performance compared to state of the art CCS power generation. In the Allam Cycle, shown in Figure 1, an Air Separation Unit produces oxygen which is combusted with natural gas, producing a high-pressure working fluid above 90% supercritical CO2 in volume, which is then used to drive an electricity generating turbine. Most of this CO2 is then compressed and fed back into the cycle, while surplus is removed at the required pressure and quality for pipeline transport. Thus, the cycle inherently captures all CO2 produced, without the expense of an add-on capture system.

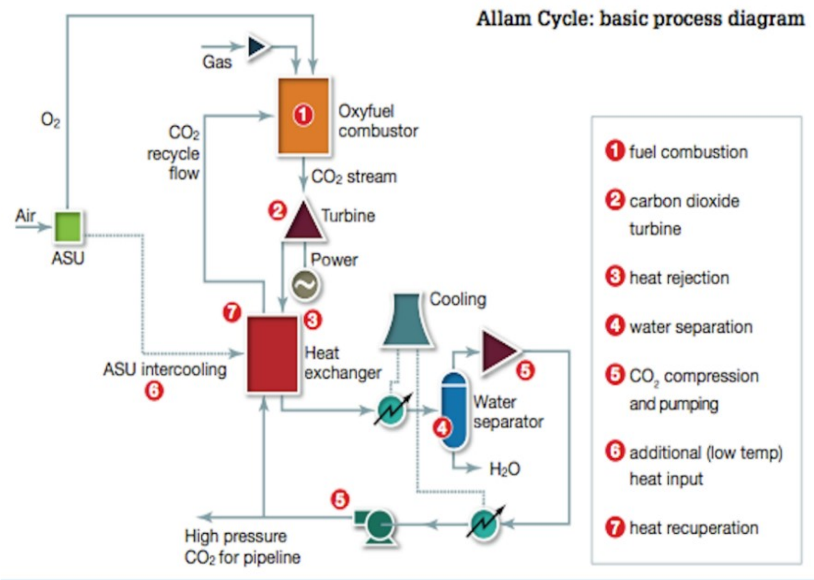

Figure 1 - Simplified Allam Cycle Schematic [4]

The potential for enhanced operational flexibility in the Allam Cycle arises from the opportunity to decouple the highly energy intensive step of oxygen production from power generation. The limiting factor for operational flexibility in the current embodiment of the cycle is the Air Separation Unit, with long start-up times – for example, 6-8 hours after a 24 hour shutdown – and a ramp rate of 3% per minute that is much lower than the 10% per minute achievable by modern combined cycle gas turbine plants [5].

Introducing interim storage of liquid oxygen would mitigate the impact of the Air Separation Unit's slow dynamics on plant performance, and allow electrical energy to be stored as chemical energy during periods of low electricity demand. Oxygen would be produced either by powering the Air Separation Unit with surplus electricity imported from the grid, or by operating the cycle with no net electricity output to the grid by reducing the load of the power cycle to match the electricity demand of the Air Separation Unit. The stored energy would be returned to the grid during periods of high electricity demand by bypassing the power requirement of the Air Separation Unit and discharging liquid oxygen.

Additionally, there is potential for Allam Cycle plants to balance flows in future CO2 transport and storage systems. This is due to flexible operation strategies resulting in prolonged periods of CO2 production, which would smooth the variability of CO2 flows entering transport and storage systems. This smoothing effect could mitigate the occurrence and financial impact of problems currently associated with flow variability in CO2 networks, as evidenced in [6] and a separate submission by Spitz et al. from the University of Edinburgh to this conference.

At GHGT-14, optimised configurations of Allam Cycle plants incorporating liquid oxygen storage, developed using gPROMS process modeling software, will be presented. These will demonstrate the flexible operation concept through several novel modes of operation with varying outputs of electricity, liquid oxygen and CO2 for storage. The technical requirements for implementing a liquid oxygen storage scheme will also be discussed.

The potential value of flexible Allam Cycle plants in future UK grid scenarios with high levels of wind and solar capacity will be explained, by building on a methodology using a Unit Commitment Economic Dispatch (UCED) model developed at the University of Edinburgh [7]. The model works to find the least-cost dispatch of available generation resources and determine their optimal output. Allam Cycle gas plants will be added to the model, which presently incorporates gas CCS plants, unabated gas plants, nuclear plants and wind and solar aggregated generation curves from historical UK weather data. For a range of target grid CO2 intensities, and for permutations with varying penetrations of renewable energy, the UCED model will be able to predict the optimal operation of the Allam Cycle fleet. The key outputs of the model are the plants' operational profits and the volume and variability of CO2 that they produce. Therefore, the model is expected to demonstrate the additional profit to Allam Cycle plants that interim liquid oxygen storage facilitates, as well as the Allam Cycle plants' capability to balance CO2 networks.

References

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