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Investigating exhaust gas recirculation (EGR) to enhance carbon capture in natural gas combined cycle (NGCC)

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Abstract

The Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Working Group III report (AR6 WGIII) on climate mitigation assessed several scenarios to keep global warming below 1.5°C with "no or limited overshoot." WGIII identified seven pathways, named "Illustrative Mitigation Pathways" (IMPs), summarizing different decarbonization strategies. The WGIII report emphasized the importance of carbon capture and storage as a critical decarbonization strategy in most of the identified pathways. Historically, fossil fuels have produced a substantial percentage of electricity, with natural gas combined cycle power plants (NGCC) playing a significant role. NGCC is the largest segment of the operational gas turbine fleet. These plants primarily meet low-cost base load and, intermediate load and peak load -following electric power demands. As environmental concerns grow and the necessity for energy diversification rises, countries are continually investing resources in renewable energy sources, alternative fuels, and decarbonization technologies. GE Vernova is collaborating with our customers and partners to develop solutions to improve the CO_2 intensity (electricity generated per mass of CO_2 emitted) through various solutions including but not limited to increasing plant efficiency, decreasing the carbon content in fuel by utilizing low-carbon fuels such as hydrogen, as well as employing carbon capture and storage/utilization technologies [1]. There are currently no full-scale NGCC power plants in operation anywhere in the world which employ post-combustion carbon capture. Even pilot studies conducted under NGCC flue gas conditions are limited. As a result, there is a lack of data on the carbon capture plant (CCP) under typical conditions of commercial NGCC. Therefore, most of the information that is currently available is mainly dependent on the insights obtained from Front End Engineering Design (FEED) studies. These FEED studies provide a framework for the configuration, performance, cost analysis, and operation.

The paper focuses on the integration of a NGCC and a solvent based post combustion CCP, considering both greenfield and retrofit sites where the Exhaust Gas Recirculation (EGR) integration with NGCC is studied.

EGR is a technology used to reintroduce a portion of the exhaust gas into the gas turbine's inlet after appropriate cleaning and conditioning. The EGR flow is mixed with the fresh ambient air prior to the compressor inlet. EGR provides two major advantages. The directed flue gas to the CCP is proportionally decreased with the EGR rate. The

reduction in flow to the CCP reduces the physical size of CCP components, resulting in a decrease in both footprint and CapEx of the CCP. Secondly, EGR increases the concentration of CO_2 and a resulting higher CO_2 partial pressure in the flue gas.

The ratio of recirculated flue gas to stack gas flow is known as the EGR ratio.

$$EGR\ ratio\ = \frac{returned\ gas\ flow\ to\ GT\ inlet}{Stack\ gas\ flow}$$

The EGR gas flow interacts with sprayed water through a packing, leading to the cooling of the EGR flow and the condensation of a fraction of its water vapor. Following the exhaust flow's exit from the EGR direct contact cooler, it proceeds to the gas turbine inlet mixer. An EGR mixer must be installed within the inlet gas turbine filter house that mixes the EGR flow with the intake air of the gas turbine, **Error! Reference source not found.**.

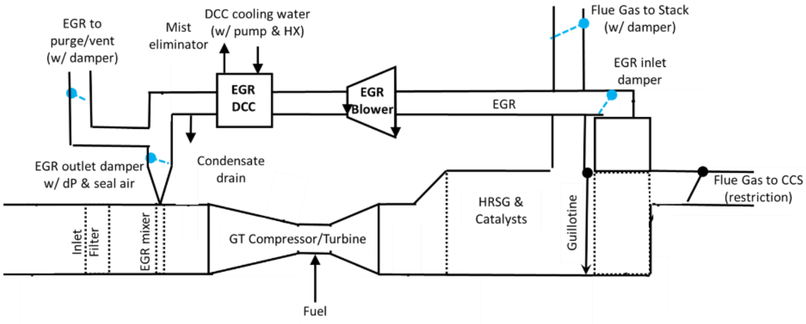

Figure 1: EGR layout.

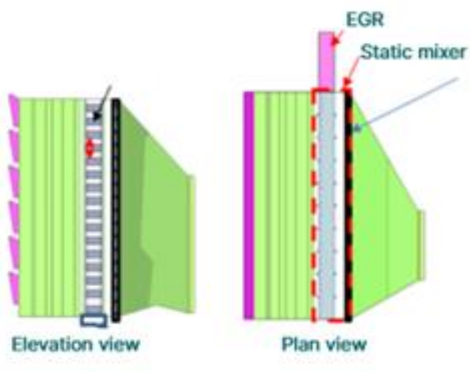

Figure 2: EGR gas turbine inlet filter.

Reduced CAPEX of the carbon capture plant

The significant reduction in CCP size with EGR is primarily in the direct contact cooler system (DCC) and absorption system. The DCC and absorber systems are built according to the volumetric flow of flue gas. The volume of the columns and column packing decreases proportionately with the EGR ratio, leading to a substantial decrease in both direct and indirect costs related to DCC and absorber equipment, including materials, construction, installation, engineering, and labor. The potential CapEx reduction of the absorption system and total plant cost including EGR cost, is illustrated in the figure. The absorption system CapEx reduction at 30% EGR is approximately 25%, while the total cost reduction of the CCP, which includes the absorption system, regeneration system, and CO_2 compression train, is approximately 15% when compared to the non-EGR scenario. The total cost savings for the NGCC with CCP plant, which includes EGR cost is approximately 7%. These figures are subject to change depending on the site location, engineering and project management contingencies, and the CCP configuration.

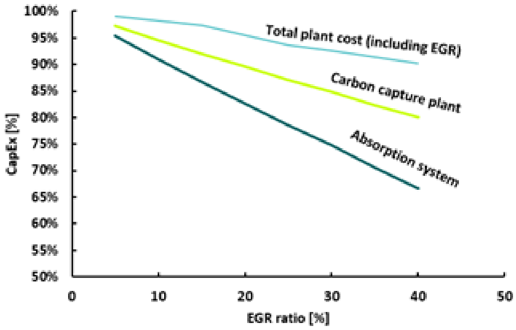

Figure 3: CapEx reduction as function of EGR.

EGR offers substantial advantages in improving CCP performance, configuration and cost reduction. The paper studies three different scenarios improved CCP performance, improved CCP capture rate, reduced absorber height.

Scenario 1: CO_2 concentration increase in the gas turbine exhaust flow with increased EGR ratio. The CO_2 concentration increases by almost 45% at 30% EGR which reduces the amount of work required by the carbon capture plant. The specific reboiler duty (SRD) reduces by almost 12% at 30% EGR ratio which as consequence reduces steam extraction while improving the electrical output of the steam turbine.

Scenario 2: The CO_2 capture rate of CCP can be boosted if the CCP is configured with EGR and the reboiler duty remains constant in comparison to the scenario without EGR. The CCP's CO_2 capture rate can be increased by approximately 2% points, from 95% up to 97%, while maintaining the same boiler duty and 30% EGR. The CO_2 rich loading is increased by EGR, which in turn increases the cyclic capacity. Therefore, it enables an increase in the capture rate, provided that the heat supplied to the reboiler remains constant.

Scenario 3: EGR raises the amount of CO_2 in the flue gas that is sent to CCP. Rich solvent CO_2 loading rises with increasing CO_2 concentration, allowing the absorber height to be reduced for a fixed capture rate and reboiler duty.

GE Vernova (GEV) completed a DOE-funded FEED study titled "Retrofittable Advanced Combined Cycle Integration for Flexible Decarbonized Generation." The study focused on retrofitting Southern Company's James M. Barry Electric Generating Plant in Bucks, Alabama, with CCS technology capable of capturing up to 95% of the plant's CO2 emissions. The FEED analysis examined the plant's performance and demonstrated the techno-economic analysis of NGCC integration with CCP evaluated retrofitting two 7F.04 GE NGCC totalling 565 MW with a carbon capture plant that included 40% EGR. The FEED study demonstrated a total plant cost savings of around 4% with 40% EGR as compared to the non-EGR scenario [2].

Keywords: Exhaust gas recirculation (EGR), carbon capture, NGCC

References

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