Effect of Cryogenic Carbon Capture (CCC) on Smart Power Grids

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Increased electricity demand and stability concerns for existing grids have led researchers to seek for power generation systems that can relieve the pressure from the existing grid while also satisfying environmental concerns. The smart grid is considered to be a new strategy to achieve this goal [1]. While there is not a universal definition for smart grids, it usually includes data collectors, data displayers, information-based controllers, and technologies that can produce and store electricity or reduce the demand [2]. More specifically, smart grids consist of advanced metering infrastructures [3], advanced electricity pricing [4], demand response [5], distribution automation [2], microgrids [6], and distributed storage systems [7]. These technologies stabilize power grids and enable them to accommodate more renewable power sources [2]. Smart grid technologies attract more attention when CO_2 emission regulations become stricter because CO_2 removal systems consume a significant fraction of the power plant output. While management of consumer demand is often considered in smart grid studies, this strategy may be applied once or twice a year for a few hours where there is peak electricity demand [8]. Supplier load management applies the same idea and has the potential to be used throughout the year, especially when the continuous operation of CO_2 removal systems is considered. This strategy can therefore deliver more power to the grid during peak hours and stabilize it without overriding consumer choice.

Cryogenic Carbon Capture ™ (CCC) is an example of a CO_2 removal system that stabilizes the grid by storing available excess energy and using it during peak hours [9]. This process primarily includes fast-responding equipment such that it can follow the high fluctuations of the intermittent renewable power sources. This energy storage incorporates renewable sources into the grid by storing them when they are available [10]. Therefore, the excess energy can originate either from baseline power production or from renewable power sources. In this process, the electricity required to run the CO_2 removal plant during peak hours is supplied from the stored energy during off-peak hours. The stored energy can also be used in meeting the residential demand. Therefore, the energy storage capability of the CCC process will not only relieve excess stress on the grid during peak hours but also relieves the pressure from it by delivering the stored power to the grid. The importance of such multi-functional plants significantly increases when the restrictive regulations for CO_2 emissions become effective. Thus, technologies such as CCC require detailed attention.

In the CCC process, CO_2 is removed from the flue gas by desublimation. To provide the cooling for the desublimation process, two refrigerants are used in the CCC process. Most of the energy consumption of the CCC process is attributed to the compression cycles. However, this process has the potential to produce excess refrigerants when electricity demand is low or when excess energy is available and store them in grid-scale insulated vessels. Liquefied Natural Gas (LNG) is the refrigerant used in this study to run the CCC process in energy storage/recovery modes. The storage/recovery modes of the second refrigeration cycle is not considered. LNG is produced in excess during low electricity requirement and stored in the tank. Then, during peak hours, stored LNG is taken from the tank to run the CCC process. Running the CCC process with stored LNG means that refrigeration compressors are run at the minimum load which saves compressor power demand. After going through the CCC process, LNG becomes a vapor as a result of removing heat from the flue gas. The excess natural gas produced inside the plant during peak hours is partially combusted in a gas turbine to provide electricity for both the CCC process and residential consumers. The rest of the natural gas can be either exported to the pipeline to avoid processing it during peak hours, further saving electricity for the grid, or can be recirculated to the LNG production plant to supply a fraction of the LNG for the CCC process. Therefore, the storage capability of the CCC process helps stabilize the grid during peak hours by providing excess power and reducing the parasitic loss of the CO_2 removal system.

In this case, dynamic optimization and integration of the CCC process with fossil-fueled power plants and wind power plants is considered. The coal-fired power plant has a 900 MW capacity while the power output from the gas turbine is 480 MW. The wind power comes from ten stations in California and reaches a maximum of 300 MW. Dynamic optimization results show that the assumed grid-scale energy storage tank manages the electricity load of the CCC process such that approximately 80 MW excess power for about 12 hours of the day is available for the grid during peak hours. In addition, approximately 570 MW power is also produced from the natural gas produced inside the plant (gas turbine and combined cycle), again for about 12 hours. The operational profit obtained from the system increases by 122% compared to the same system without energy storage. The excess revenue obtained from the storage tank is enough to pay for the cost of construction of the CCC plant [11].

[1] “Electrical Engineernig Portal.” Available: http://electrical-engineering-portal.com/an-overview-of-smart-power-grid.

[2] “Smart Grids and Renewables; A Guide for Effective Deployment”, *International Renewable Energy Agency (IRENA)*, 2013.

[3] H. Farhangi, “The Path of the Smart Grid”, *Power and Energy Magazine, IEEE* , vol.8, no.1, pp.18,28, Jan.-Feb. 2010.

[4] S. Shao, M. Pipattanasomporn, “Impact of TOU Rates on Distribution Load Shapes in a Smart Grid with PHEV Penetration”, *Transmission and Distribution Conference and Exposition*, 2010 IEEE PES , vol. 1, no. 6, pp. 19-22, Apr. 2010.

[5] A. Mahmood, M. N. Ullah, S. Razzaq, and E. Al., “A New Scheme for Demand Side Management in Future Smart Grid Networks”, *Procedia Computer Science*, vol. 32, pp. 477–484, 2014.

[6] H. Kanchev, D. Lu, F. Colas, and B. Francois, "Energy Management and Operational Planning of a Microgrid With a PV-Based Active Generator for Smart Grid Applications", *Industrial Electronics*, *IEEE Transactions*, vol.58, no.10, pp.4583,4592, Oct. 2011.

[7] P. M. Connor, P. E. Baker, D. Xenias, et. al., "Policy and regulation for smart grids in the United Kingdom", *Renewable and Sustainable Energy Reviews*, vol. 40, pp. 269–286, Dec. 2014.

[8] "Enernoc", Available: http://www.enernoc.com/our-resources/term-pages/what-is-demand-side-management.

[9] "Sustainable Energy Solutions", Available: http://sesinnovation.com/.

[10] M. J. Jensen, D. Bergeson, D. Frankman, L.L. Baxter, "Integrated Rapid Response Energy Storage with CO_2 Removal", *PowerGEN*, 2012.

[11] S. M. Safdarnejad, J. D. Hedengrena, L. L. Baxter, "Grid-level Dynamic Optimization of Cryogenic Carbon Capture with Conventional and Renewable Power Sources", *Applied Energy Journal*, submitted.