NREL
NATIONAL RENEWABLE ENERGY LABORATORY

The Western Wind and Solar Integration Study




The Effects of Wind and Solar Power–Induced Cycling on Wear-and-Tear Costs and Emissions

Results From the Western Wind and Solar Integration Study Phase 2

The electric grid is a highly complex, interconnected machine. Changing one part of the grid can have consequences elsewhere. Adding variable renewable generation such as wind and solar power affects the operation of conventional power plants, and adding high penetrations can induce cycling of fossil-fueled generators. Cycling leads to wear-and-tear costs and changes in emissions.

Phase 2 of the Western Wind and Solar Integration Study (WWSIS-2) was initiated to determine the wear-and-tear costs and emissions impacts of cycling and to simulate grid operations to investigate the detailed impact of wind and solar power on the fossil-fueled fleet in the West. It was a follow-up to Phase 1 (WWSIS-1), released in May 2010, which examined the viability, benefits, and challenges of integrating high penetrations of wind and solar power into the western grid. WWSIS-1 found it to be technically feasible if certain operational changes could be made, but it raised questions regarding the impact of cycling on wear-and-tear costs and emissions.

Frequent cycling of fossil-fueled generators can cause thermal and pressure stresses. Over time, these can result in premature component failure and increased maintenance and repair. Starting a generator or increasing its output can increase emissions compared to noncyclic operation. And operating a generator at part-load can affect emissions rates. Utilities are concerned that cycling impacts can significantly negate the benefits that wind and solar power bring to the system. To plan accordingly, power plant owners need to understand the magnitude of cycling impacts.

To calculate these wear-and-tear costs and emissions impacts, NREL designed five hypothetical scenarios to examine up to 33% wind and solar energy penetration in the western United States and to compare the impacts of wind and solar:

- **High Wind: 25% wind, 8% solar**
- **High Solar: 25% solar, 8% wind**
- **High Mix: 16.5% wind, 16.5% solar**
- **TEPPC[1]: 9.5% wind, 3.5% solar**
- **No Renewables: 0% wind, 0% solar**

Emissions Data

NREL used the Environmental Protection Agency's Continuous Emissions Monitoring system data set to analyze hourly emissions from nearly every fossil-fueled plant in the United States. NREL determined incremental emissions of carbon dioxide (CO_2), nitrogen oxide (NO_X), and sulfur dioxide (SO_2) caused by starts, ramping, and partial loading.

Analysis

The data was incorporated into commercial software that simulates operations of the western grid (including the United States, Canada, and Mexico) on a subhourly basis, because variable renewable generation can change within the hour. Results were based on the specific characteristics of the western grid and key assumptions, including an average natural gas price of $4.60/MMBtu, significant balancing authority area cooperation, and least-cost economic dispatch and transmission usage.

Key Findings

The study found that the high-wind and high-solar scenarios reduced CO_2 by 29% to 34% across the Western Interconnection, with cycling having a negligible impact. Cycling actually improved the NO_X reduction by 1% to 3%, so that NO_X was reduced by 16% to 22% in the high-penetration scenarios. This is because the average coal plant in the West has a lower NO_X emissions rate at partial output than at full output. Cycling lessens the SO_2 reduction by 2% to 5%, so that SO_2 was reduced by 14% to 24% in the high-penetration scenarios (see Table 1).

Table 1. Emissions Avoided per MWh of Wind and Solar—Considering Part-Load, Ramping, and Start Impacts

Scenario	Avoided CO_2 (lb/MWh)	Avoided NO_X (lb/MWh)	Avoided SO_2 (lb/MWh)
High Wind	1,190	0.92	0.56
High Mix	1,150	0.80	0.44
High Solar	1,100	0.72	0.35

From Lew et al., *Western Wind and Solar Integration Study Phase 2*, 2013.

1 Transmission Expansion Planning Policy Committee of the Western Electricity Coordinating Council

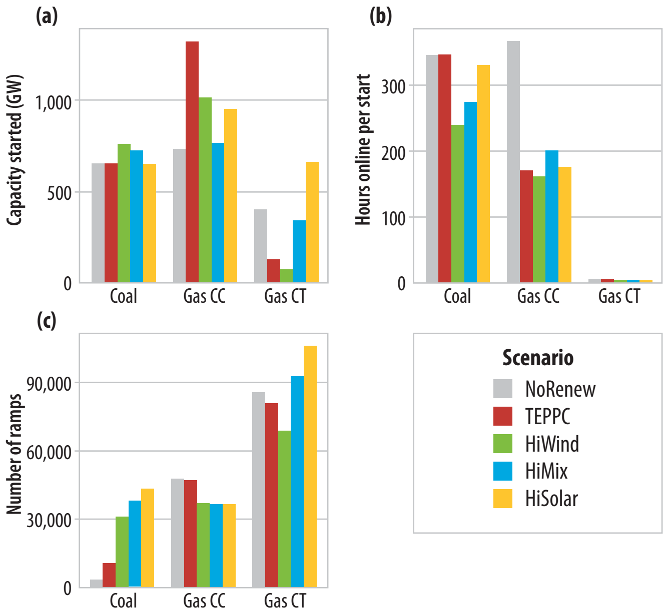

Figure 1. (a) Capacity started, (b) average number of hours online per start (must-run CTs were excluded), and (c) total number of ramps for each plant type by scenario for one year

Figure 1 shows the cycling impacts to coal, combined-cycle (CC), and combustion turbine (CT) gas plants for the scenarios considered in the analysis. Using our study assumptions, 4 MWh of renewables would displace 1 MWh of coal generation and 3 MWh of gas, on average. The biggest cycling impact would be to significantly increase the ramping of coal units. Wind tends to reduce generation from, starts of, and ramps of combustion turbines. Solar tends to increase starts and ramps of gas combustion turbines to meet the system peak that occurs as the sun is setting.

Figure 2 shows cycling cost by plant type. Combustion turbines are found to have the most significant wear-and-tear cost impacts, although these costs actually decrease under low-wind and low-solar penetration scenarios. In the scenarios that included high penetrations of variable renewable generation, fuel costs were reduced by approximately $7 billion per year across the West, while cycling costs of $35 million to $157 million were incurred per year. For the average fossil-fueled plant, this would result in an increase in operations and maintenance costs of $0.47 to $1.28 per megawatt-hour of fossil-fueled generation. From the perspective of wind and solar power, these additional cycling costs are $0.14 to $0.67 per MWh of wind and solar generated compared to fuel cost reductions of $28 to $29 per MWh, based on the generator characteristics and modeling

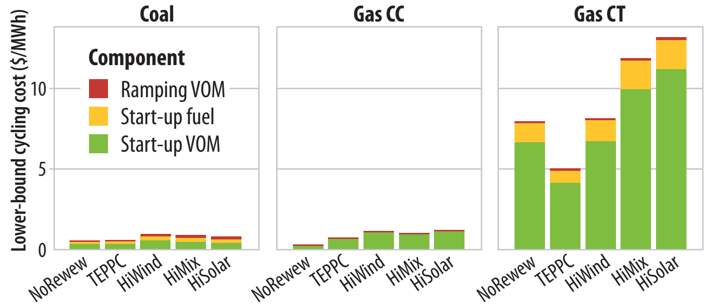

Figure 2. Lower-bound cycling cost for (left) coal, (center) gas CC units, and (right) gas CTs (excluding the must-run CTs) for one year

assumptions described in the study. These costs are operational costs, because WWSIS-2 did not consider capital costs of construction of the studied levels of wind and solar power plants or any additional gas-fired generation, transmission, or other measures to accommodate them on the grid.

Conclusions

Variable renewable generation can lead to changes in the amount of cycling associated with powering up and down fossil-fueled plants. Although cycling has an impact on costs and emissions, those impacts are small in terms of fuel savings and displaced emissions.

Associated Publications

D. Lew, G. Brinkman, E. Ibanez, B.-M. Hodge, M. Hummon, A. Florita, M. Heaney, G. Stark, J. King, N. Kumar, S. Lefton, D. Agan, G. Jordan, and S. Venkataraman. (2013). *The Western Wind and Solar Integration Study Phase 2*. NREL/TP-5500-55588. Golden, CO: National Renewable Energy Laboratory.

GE Energy. (2010). *Western Wind and Solar Integration Study*. NREL/SR-5500-47434. Work performed by GE Energy, Schenectady, NY. Golden, CO: National Renewable Energy Laboratory. Accessed September 2013: www.nrel.gov/docs/fy10osti/47434.pdf.

More Information

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See our website at www.nrel.gov/electricity/transmission/.

Photos (from top)*: photo by Ruth Baranowski, NREL 21204; photos by Warren Gretz, NREL 10618, 06392, 10926*

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