NREL Analysis: Cost-Effective and Reliable Integration of High-Penetration Solar in the Western United States

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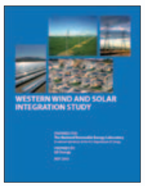
SYSTEMS INTEGRATION

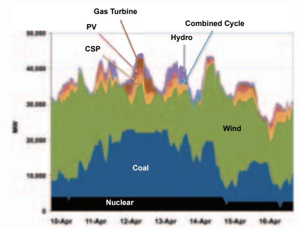
Objective

The **Western Wind and Solar Integration Study** (WWSIS) is one of the largest regional wind and solar integration studies to date. It was initiated in 2007 to examine the operational impact of up to 35% penetration of wind, photovoltaic (PV), and concentrating solar power (CSP) energy on the power system. The goal of the Western Wind and Solar Integration Study is to understand the costs and operating impacts caused by the variability and uncertainty of wind, PV, and CSP on the grid.

The Western Wind and Solar Integration Study Phase 1



In the Western Wind and Solar Integration Study Phase 1 (WWSIS1), solar penetration was limited to 5%. Utility-scale PV was not included because of limited capability to model sub-hourly utility-scale PV output. System dispatch for the worst week of the 3 years analyzed is shown at right. High wind and solar output cause coal and other generators to cycle on and off and ramp more frequently. Utilities and policymakers have asked NREL to delve into the details of the impacts of cycling and ramping on wear-and-tear costs and emissions.



The Western Wind and Solar Integration Study Phase 2

New techniques allow the Western Wind and Solar Integration Study Phase 2 (WWSIS2) to include high penetrations of solar—not only CSP and rooftop PV but also utility-scale PV plants. WWSIS2 examines:

- What are the wear-and-tear costs of cycling and ramping of coal and gas plants?
- What are the emissions impacts of cycling and ramping of coal and gas plants?
- How should operators re-optimize unit commitment and economic dispatch with these impacts taken into account?
- How do solar impacts compare with those of wind?
- What mitigation options are available?

WWSIS2 Input Data

Wear-and-Tear Cost Data

Intertek-APTECH provided the following wear-and-tear cost data for seven categories of fossil-fueled plants:

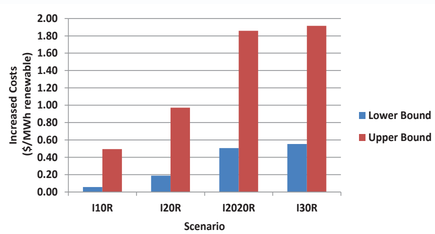
Data inputs include:

- Costs of hot, warm, and cold starts
- Costs of ramping down to minimum output
- Forced outage rate impacts
- Long-term heat rate degradation.

Ceiling on Wear-and-Tear Costs

GE Energy applied these wear-and-tear data to the original dispatch results from WWSIS1. Because these wear-and-tear costs were not explicitly modeled in WWSIS1 but will be in WWSIS2, the revised dispatch of WWSIS2 is likely to show less ramping and cycling. Therefore, GE Energy's analysis gives a ceiling on wear-and-tear impacts.

Results (right) show that cycling costs in the high-renewable scenario have a ceiling of \$0.55–\$1.90/MWh of renewables produced, which is a reduction in the value of the renewables of up to 2.4%.



Emissions Data

NREL used the Environmental Protection Agency's Continuous Emissions Monitoring (CEM) data set to analyze hourly emissions from nearly every fossil-fired plant in the U.S. NREL determined incremental emissions of CO_2, NO_x, and SO_2 caused by startups, ramping, and partial loading.

Emissions Re-Analysis for WWSIS1

NREL applied these detailed startup, ramping, and part-loading emissions of NO_x and CO_2 to the dispatch results of WWSIS1. In this re-analysis, generic emission rates, not plant-specific rates, were used for simplicity. The impact of the startup, ramping, and part-loading emissions was relatively small and not always a negative benefit. Avoided CO_2 emissions are 1.7% less, considering the detailed impacts, with the largest impact coming from the part-loading. Avoided NO_x emissions, on the other hand, were 3.3% better because of the lower NO_x rates at part-loading.

Production Simulation Modeling

These refined wear-and-tear cost and emissions data are being used in the WWSIS2 production simulations of the Western Interconnection using the PLEXOS security-constrained unit commitment and 5-minute economic dispatch model.

WWSIS2 Preliminary Results

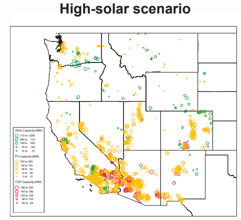
Scenarios and Transmission

Four scenarios will be run for WWSIS2 in PLEXOS:

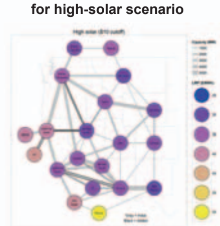
- High solar (15% PV, 10% CSP, 8% wind)
- High mix (16.5% solar, 16.5% wind)
- High wind (4.8% PV, 3.2% CSP, 25% wind)
- Reference (8% wind, 3% solar).

NREL sited the scenarios and ran PLEXOS to expand transmission to bring resources to load.

High-solar scenario



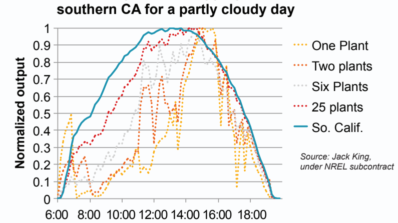
Transmission expansion for high-solar scenario



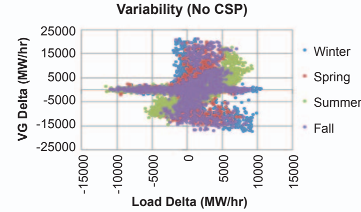
Statistical Analysis

Extensive statistical analysis was conducted on the variability of the load, net load, and solar and wind data for each scenario. As the upper left plot shows, geographical aggregation reduces PV variability. The other three plots on the right are scatter plots showing the hourly change in load versus the hourly change in variable generation (VG). The points in the bottom right quadrants, where the load is increasing and the VG is decreasing, are the challenging hours for system operators.

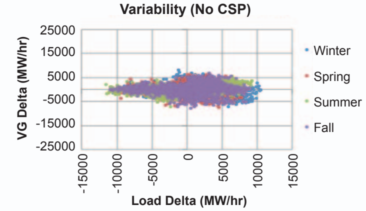
Increasing PV plant aggregation in southern CA for a partly cloudy day



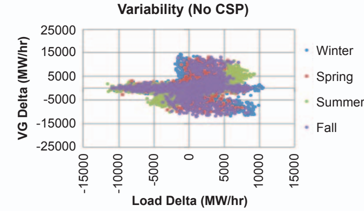
High Solar Scenario – Footprint VG Variability (No CSP)



High Wind Scenario – Footprint VG Variability (No CSP)



Intermediate Scenario – Footprint VG Variability (No CSP)



Next Steps

NREL is currently running PLEXOS simulations for each of the four scenarios. GE Energy will help identify and design mitigation options, which will be run subsequently. A report on these results will be produced by the end of FY12.

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