Pushing the Limits of the Grid:
Aggressive Wind Energy Penetration Scenarios

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Motivation and Assumptions

The intermittency of both wind and solar resources has proven to be a strong argument against their rapid integration on the to grid. This study attempts to quantitatively address this concern by considering both the wind and solar resource in California together. A series of power flow solutions are found for the Western Interconnection over the course of a day with very large upgrades to current and planned wind farms and solar thermal plants throughout California.

A number of assumptions are made for this initial set of calculations. We assume the addition of high voltage transmission lines from the proposed generation to the nearest 500-kV busbar and we neglect voltage requirements, assuming that the appropriate power electronics are installed to maintain appropriate voltage levels throughout the day. This study is a first attempt at establishing a methodology for identifying wind and solar generation expansions that best supply the daily fluctuations in the California load.

Day-long Power Flow Simulations

The Western Interconnection[5] is modeled as a power flow system, where each transmission line has a known admittance, y_{ij}, and connects two busbars at unknown voltages, V_i and V_j. Busbars connected to a generator or a load also have a specified injected power, S_i, and injected current, I_i. The state of the system is determined by solving the power flow equations below, where $\mathbf{Y}$ is a matrix constructed from the line admittances. This non-linear system is solved using the Newton-Raphson method with the PowerWorld Simulator.

$$I_i = \sum_{k=1}^{n} Y_{ik} V_k \qquad S_i^* = V_i^* I_i$$

Optimization Scheme: Wind and solar plant sizes are determined by maximizing the installed capacity subject to the constraint that on a summer day, the additional renewable power in the vicinity of each swing bus never exceeds the local natural gas generation in the base case. The resulting installed capacities are shown in Table 1.

Day-long simulations consist of scaling the California loads proportionally to match a seasonal daily load profile from the CAISO OASIS database[6] and scaling natural gas generation according to the demand (Current/Base Case) and renewable generation (High-Renewable Penetration Case) according to the available resource. Maps with the average power output by technology type[7] are shown in Figures 3 and 5 and the hourly power generation in California is shown in Figures 4 and 6.

Table 1. Wind and solar plant installed capacities from optimization

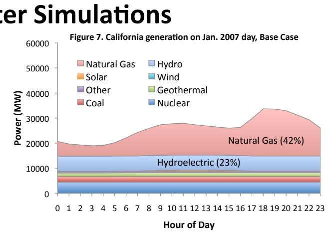
Proposed Plant	Capacity (MW)
San Gorgonio Wind	6,140
High Winds	7,715
Pacheco Pass Wind	6,649
Beacon Solar	13,732
SES Solar Two	2,494
Harper Lake Solar	3,464
Victorville Solar	3,464
Carrizo Solar	15,017

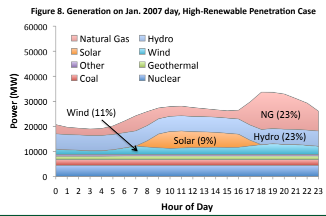
Winter Simulations

Day-long hourly simulations were performed for a January day in 2007 assuming the same installed capacities as the July 2016 simulations. Results are shown in Figures 7 and 8.

Since the installed capacities are optimized for the summer daily load profile, the percentage of renewable energy used over the course of the day is significantly reduced compared to the summer 2016 case. Optimization with the annual load, wind, and insolation profiles is expected to reduce this discrepancy, but may also reduce the summertime renewable power output.

Even in this non-optimal case, renewable power still accounts for over 40% of California generation during the winter day.





References

[1]*MM92: The 2-megawatt power plant with 92 metre rotor diameter*. REPower (2004). <http://www.repower.de/fileadmin/download/produkte/PP_MM92_uk.pdf>
[2]Masters, G. (2004). *Renewable and efficient electric power systems: Appendix C: Hourly clear-sky insolation tables*. Stanford, CA: John Wiley & Sons.
[3]*Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors.* National Renewable Energy Laboratory (1994).
[4]*Large Solar Energy Projects,* California Energy Commission. <http://www.energy.ca.gov/siting/solar/index.html>.
[5]Power flow cases containing line admittances, loads, and generators obtained from the WECC, December, 2007.
[6]*Oasis: system load reports*, California Independent System Operator (2007). <http://oasis.caiso.com>.
[7]Maps produced with GIS substation, transmission line, and power plant layers from Platts. McGraw Hill (2008).

Wind and Insolation Data

Hourly wind data for the months of January and July were obtained using a mesoscale meteorological model. Power output at each farm was calculated using the power curve for the 2MW REPower MM92 turbine and is shown in Figure 1.[1]

Figure 1. Power output per turbine at proposed wind plant sites

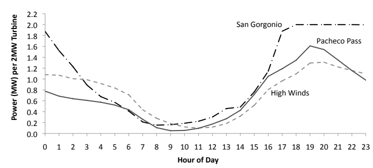
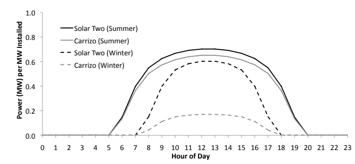


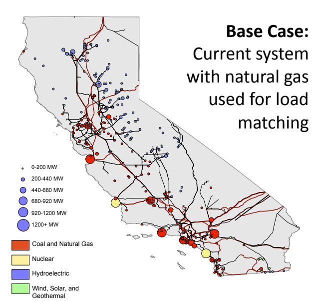
Figure 2. Power output per MW-installed at proposed solar plant sites



Insolation data were obtained by scaling clear-sky insolation data by latitude and tracking scheme[2] to average monthly insolation data[3] at locations near the proposed sites. Proposed sites were obtained from the California Energy Commission's list of Proposed Large Solar Projects.[4] Hourly output was calculated using reported capacity factors for existing concentrating solar thermal plants and is shown in Figure 2. All resource data represents monthly averages, which filter out some real-time fluctuations. This simplification was made only for these initial calculations, in which the focus was developing a methodology for evaluation of the resources with respect to the regional load.

Summer Simulation Results

Figure 3. Average power generation by source on July 2016 day, Current/Base Case



Base Case: Current system with natural gas used for load matching

Figure 4. California power generation on July 2016 Day, Current/Base Case

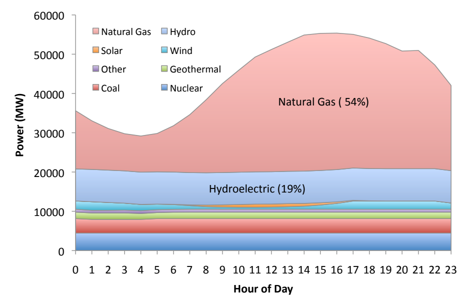
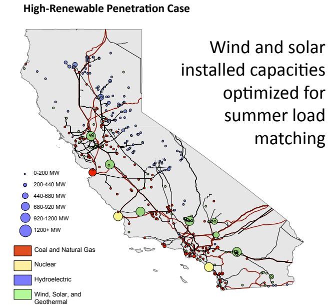
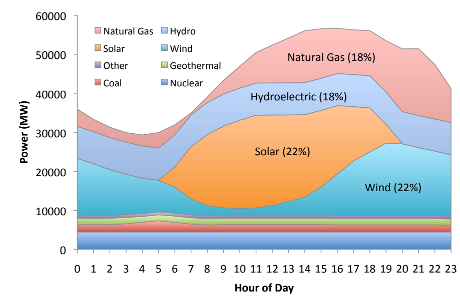


Figure 5. Average power generation by source on July 2016 day, High-Renewable Penetration Case



Wind and solar installed capacities optimized for summer load matching

Figure 6. California power generation on July 2016 Day, High-Renewable Penetration Case



Conclusions

- In this study we have established an initial methodology for exploring aggressive wind and solar penetration scenarios based on an optimization scheme that accounts for fluctuations in both the renewable resources and the load.
- Initial power flow calculations suggest that with construction of the proper high-voltage transmission lines and addition of the necessary power electronics, generation from renewables in California may be able to provide 70% of the power used on a summer day in 2016.
- Power flow simulations also led to the identification of four regions within the California grid that operate somewhat independently. These regions will provide the basis of a simplified four-busbar approximation of the California grid to be used in the next optimization scheme.

Future Work

- Repeat calculations with wind and insolation point data to remove smoothing due to averaging
- Expand optimization to account for seasonal load fluctuations – this may increase the proportion of renewable power utilized in winter months, but may also decrease the renewable power used in summer months
- Include sub-hourly fluctuations and real-time resource data to provide more information regarding the dispatchable generating capacity necessary to accommodate intermittency
- In order to comment on grid stability, worst-case power flow calculations and fault calculations must be performed with attention to voltage limits.