REGROW: Renewable Energy Generation Risk from Outlier Weather

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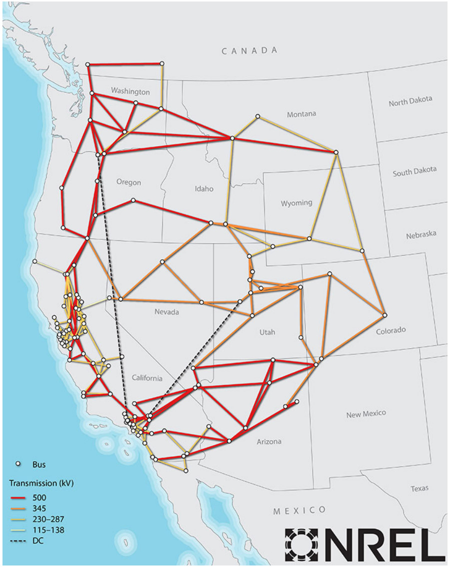
Overview

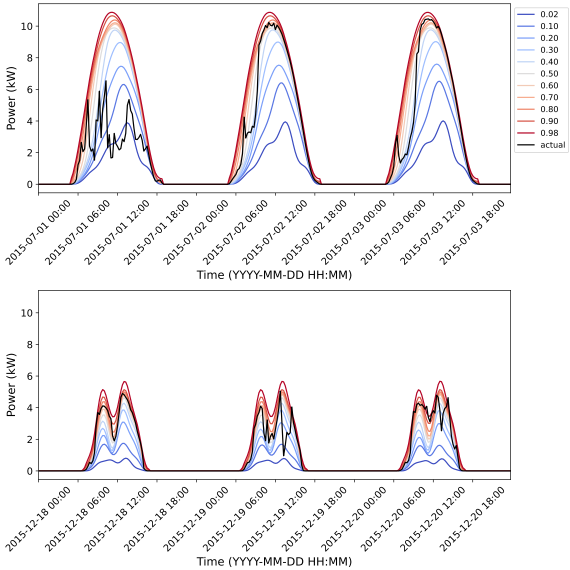
- **motivation:** 2020 CAISO blackouts caused by
  - extreme weather: very high energy demand
  - high renewable penetration: ‘duck curve’ effect
  - day-ahead electricity market: supply challenges
- **objectives:**
  - estimation of correlated losses and fat tails
  - robust model predictive control of the grid
  - counterfactual reasoning for different scenarios
- **model:** white-box ML model based on convex optimization for
  - joint probability distribution of load and renewable generators
  - efficient, tractable and robust planning

Dataset curation and grid modeling



- curate datasets covering historical abnormal weather patterns
- obtain multidimensional data covering grid conditions, renewable generation, and weather
- **example datasets**
  - NREL PVFleets
  - NREL 144-bus model of WECC electrical grid
  - NOAA extreme weather

Risk modeling

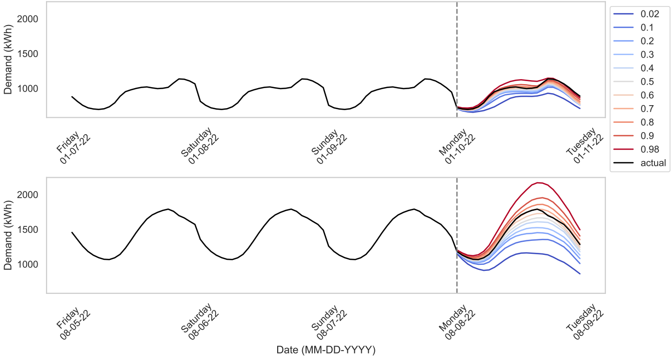


- develop risk models of renewable generator underperformance and outages
- capture correlations between generators and ambient meteorological conditions
- make a ‘nightmare scenario generator’
- figure shows estimated quantiles for power generation of a residential PV system

Robust control

- model predictive control (MPC) consisting of
  - **forecast:** predict stochastic future values
  - **plan:** solve optimization problem assuming forecasts are correct
  - **execute:** take first action in plan
  - **repeat**
- works extremely well in practice (*e.g.* to land rockets)
- can be specified as a convex optimization problem
- tractable and can be solved efficiently and robustly

Multi-forecast MPC



- incorporate uncertainty and information patterns via multiple scenarios
- can be conditioned on historical and future information
- figure shows net load forecast for Rhode Island

Implementation

$$
\begin{array}{ll}
\text{minimize} & -q_T + \kappa\|c\|_1 + \sum_{t=1}^T \phi(g_t) \\
\text{subject to} & q_1 = Q^{\text{init}}, \\
& q_{t+1} = q_t + c_t,\ t = 1, \ldots, T, \\
& 0 \preceq r^{\text{curt}} \preceq r, \\
& c + r^{\text{curt}} + g = l, \\
& 0 \preceq q \preceq Q\mathbf{1}, \\
& 0 \preceq g \preceq G\mathbf{1}, \\
& |c| \preceq C1.
\end{array}
$$

convex optimization problem that can be solved efficiently and robustly

```
import cvxpy as cp
c = cp.Variable(T)
q = cp.Variable(T + 1, nonneg=True)
r_curt = cp.Variable(T, nonneg=True)
g = cp.Variable(T, nonneg=True)
obj = -q[-1] + kappa*cp.norm1(c) +
        alpha*cp.sum(g) +
        beta*cp.sum_squares(g)
cons = [q[0] == Q_init,
        q[1:] == q[:-1] + c,
        r_curt <= r,
        c + r_curt + g == l,
        q <= Q, g <= G,cp.abs(c) <= C]
mpc = cp.Problem(cp.Minimize(obj), cons)
mpc.solve()
```

can be implemented in only a few lines of code

Impact

- **current paradigm:** we need fossil energy sources for grid resilience during extreme weather events
- **hypothesis:** extreme weather events are not a barrier to large-scale renewable integration provided that we have the right planning tools
- **potential benefits:** enable high-penetration of renewables and decarbonize the grid
- **transfer of knowledge:** use well-known techniques from finance and portfolio optimization to mitigate risks in the energy sector