Power Grid Resilience against Natural Hazards

Salman Mohagheghi, PhD
Electrical Engineering Department
Colorado School of Mines
Power Grid and Natural Disasters

- Natural disasters are the second biggest cause of large-scale outages in the US

- Where is the Challenge?
  - Uncertainties about the event, its spatial (and sometimes temporal) scope, its severity and its consequences
  - Assets are likely to be already operating close to their designed limits
  - In the case of weather-induced hazards, renewable energy resources are affected more
  - Traditional view of critical versus non-critical loads is not appropriate anymore
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- What Can Be Done?

Hazardous Event

Event Starts

Preventive Measures

Corrective Measures

Restorative Measures

- Asset Management
- Distributed Resources
- Redundant Designs
- Capacity Expansion
- Risk-Based Dispatch
- Self Healing Mechanisms
- Service Restoration
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- **Case Study:** A wildfire is approaching the power distribution system
- **Objective:** Find the most economical energy for dispatch of DER, DR and Microgrid resources that minimizes the probability of lost load
- **Approach:** 2-stage stochastic optimization: purchase reserves before the onset of the event based on its expected impact, and dispatch them during the course of the event
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\[ R \cdot I_{C,f}^2 + Q_s + Q_{r,f} = Q_r + Q_c \]

\[ \Rightarrow I_{C,f} = \sqrt{\frac{Q_r + Q_c - Q_s - Q_{r,f}}{R}} \]

Variation in conductor ampacity based on different ambient temperatures and different wind speeds. For more information see: M. Choobineh, B. Ansari and S. Mohagheghi, “Vulnerability Assessment of the Power Grid against Progressing Wildfires,” Fire Safety Journal, vol. 73, pp. 20–28, April 2015.
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Problem Formulation:

\[
\begin{align*}
\min & \quad \sum_{s \in S} \sum_{t \in T} \sum_{m \in M} \left( \sum_{g \in G_m} c_{m,g,t}^{res} \cdot P_{m,g,t}^{res} + \sum_{d \in D_m} c_{m,d,t}^{res} \cdot P_{m,d,t}^{res} \right) + \sum_{s \in S} \sum_{t \in T} \sum_{m \in M} \left( u_{m,t,s} \cdot \left( \sum_{g \in G_m} c_{m,g,t}^{gen} \cdot P_{m,g,t}^{gen} + \sum_{d \in D_m} c_{m,d,t}^{DR} \cdot P_{m,d,t}^{DR} \right) + [1 - u_{m,t,s}] \cdot c_{t}^{LR} \sum_{l \in L_m} P_{m,l,t} \right) + M \cdot \sum_{s \in S} \sum_{l \in L} (1 - v_{l,t,s}) \cdot \alpha_l P_{l,t} \\
\text{Subject to:} & \\
\forall s, \forall t : & P_{s,t}^{sub} + \sum_{m \in M} \left( \sum_{g \in G_m} P_{m,g,t,s}^{gen} + \sum_{d \in D_m} P_{m,d,t,s}^{DR} \right) = \sum_{l \in L} v_{l,t,s} \cdot P_{l,t} \\
\forall s, \forall m, \forall t : & (1 - u_{m,t,s}) \cdot \left( \sum_{g \in G_m} P_{m,g,t,s}^{gen} + \sum_{d \in D_m} P_{m,d,t,s}^{DR} \right) \geq (1 - u_{m,t,s}) \cdot \sum_{l \in L_m} P_{m,l,t} \\
\forall s, \forall m, \forall g, \forall t : & 0 \leq P_{m,g,t,s}^{gen} \leq P_{m,g,t}^{max} \\
\forall s, \forall m, \forall d, \forall t : & 0 \leq P_{m,d,t,s}^{DR} \leq P_{m,d,t}^{max} \\
\forall s, \forall l, \forall t : & S_{l,t,s}^2 = P_{l,t,s}^2 + Q_{l,t,s}^2 \leq (S_{l,s}^2)^2
\end{align*}
\]
Fire approaching line 53-54, which affects a large section of the network. $\lambda$ represents the ratio of available line capacity to maximum capacity. For more information, see: B. Ansari and S. Mohagheghi, “Optimal Energy Dispatch of the Power Distribution Network during the Course of a Progressing Wildfire,” *International Transactions on Electrical Energy Systems*, vol. 25, no. 12, pp. 3422–3438, December 2015
Concluding Remarks

- Difficult problem to solve when time horizon extends beyond a day or two, or if there is a need for granular dispatch
- Exact problem is almost always nonlinear mixed-integer
- Incorporating reactive power into the formulations makes the problem quadratic and sometimes non-convex
- The problem is typically multi-objective with usually contradictory functions, and Pareto optimality need to be ensured
- Success depends on having “reasonable” uncertainties