

Impact of uncertainties on strengthening power system resilience to extreme weather: where, when, how

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Table of contents

- 1) Introduction
- 2) Overview
- 3) Application examples
- 4) Results
- 5) Discussion
- 6) Conclusions

Introduction

- Actions needed for climate change adaptation in power systems
- Climate change adaptation in power systems can be achieved with improvements in resilience to extreme weather events
- Uncertainties in power systems and extreme weather events bring uncertainties to power system resilience enhancements

Overview of uncertainties

Where?

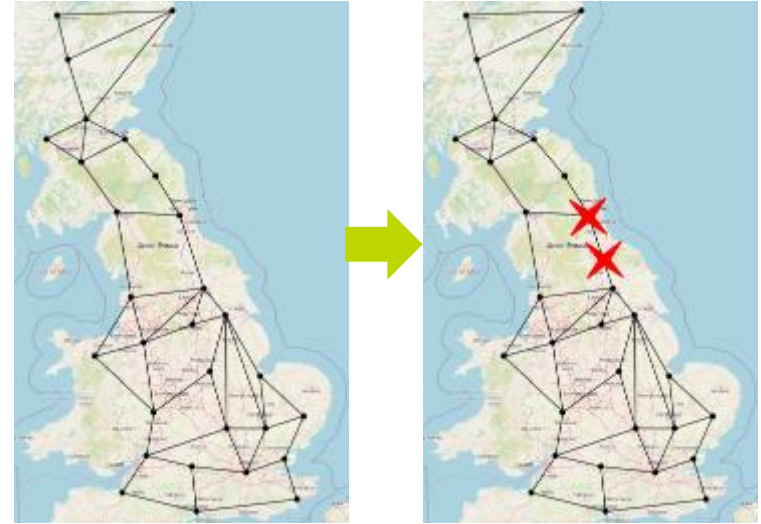
- Affected locations
- Out-of-service power system components
- Cascading effects

When?

- Occurrence time
- Time to prepare

How?

- Alternatives to improve resilience



- Disabled line or substation?
- In 1 h or 1 day?
- Underground line or reconfiguration?

Overview of uncertainties

- Dealing with uncertainties
 - Stochastic optimization
 - Monte Carlo simulations
 - Chance constraints
 - Deterministic optimization
 - Worst-case scenario
 - A range of representative scenarios

Application examples

- Description
 - 29-bus GB transmission system
 - 29 buses: aggregated generation and transmission loads
 - 99 lines: 49 double circuits, 1 single circuit
 - Operation in a stormy day
 - weather data (forecasts) define affected locations
 - power outages: (coincident) line tripping triggered by permanent fault
 - out-of-service lines affect the system's ability to supply loads
 - preventive generation dispatch to minimize lost loads
 - 24 h time horizon with reliable weather forecasts 6 h ahead
 - Objective: minimize energy not supplied subject to power flow constraints



Application examples

- Optimization problem

$$\min_t \sum_{k \in K} \sum_{i \in I} D_{t,k,i} - d_{t,k,i}$$

- Subject to

$$\begin{aligned} 0 &\leq d_{t,k,i} \leq D_{t,k,i} \\ 0 &\leq g_{t,k,i} \leq G_{t,k,i} \\ f_{t,k,l} &\leq M(1 - A_{t,k,l}) + B_{t,k,l}(\theta_{t,k,OR(l)} - \theta_{t,k,DE(l)}) \\ f_{t,k,l} + M(1 - A_{t,k,l}) &\geq B_{t,k,l}(\theta_{t,k,OR(l)} - \theta_{t,k,DE(l)}) \\ \sum_{l \in L | OR(l)=i} f_{t,k,OR(l)} - \sum_{l \in L | DE(l)=i} f_{t,k,DE(l)} &= g_{t,k,i} - d_{t,k,i} \end{aligned}$$

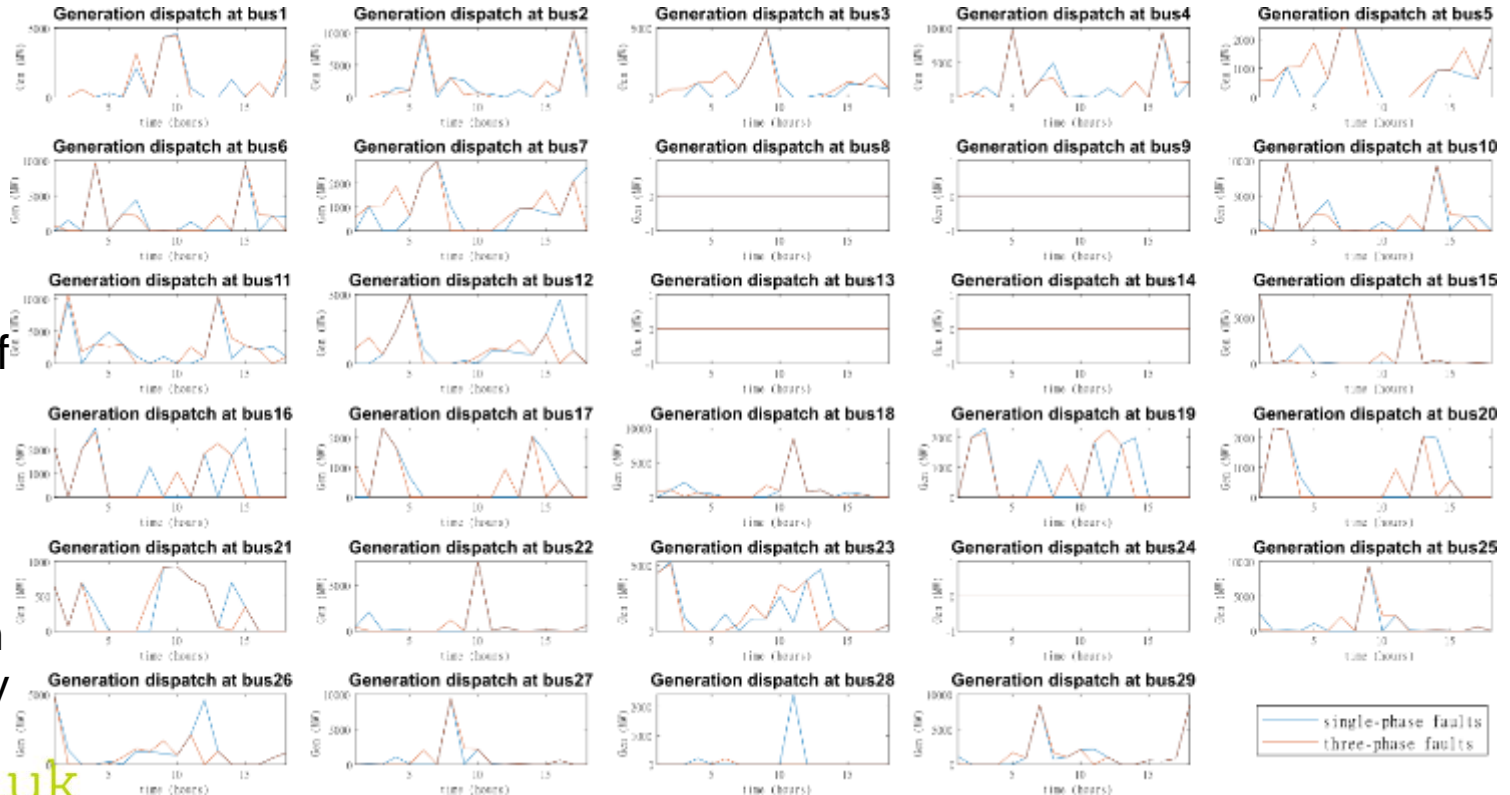
- Case studies

- Impact of extreme weather is worse than expected: disabling of all phases instead of a single-phase
- Extreme weather hits the grid before or after forecast time: effect on power outages
- Random number added to load demand: maximum variation of $\pm 10\%$

Results

- Impact of extreme weather is worse than expected: disabling of all phases instead of a single-phase
- Generation dispatch by bus

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Results

- Extreme weather hits the grid before or after forecast time
 - Changes in out-of-service lines
- Random number added to load demand: $\pm 10\%$
 - Changes in total load demand and power imbalance



Interval 1
Disabled Lines: 20 out of 99
Gen Available: 76,281.72 MW
Gen Calculated: 53,324.73 MW
Load Projected: 54,524.73 MW
Load Calculated: 53,324.73 MW
Load Actual Min: 51,034.18 MW
Load Actual Max: 56,134.13 MW
Balance: -2,809.40 -- 2,290.25 MW

Interval 2
Disabled Lines: 22 out of 99
Gen Available: 79,135.21 MW
Gen Calculated: 53,345.06 MW
Load Projected: 54,345.06 MW
Load Calculated: 53,345.06 MW
Load Actual Min: 50,605.60 MW
Load Actual Max: 56,213.84 MW
Balance: -2,867.78 -- 2,740.46 MW

Interval 3
Disabled Lines: 8 out of 99
Gen Available: 81,341.58 MW
Gen Calculated: 51,885.33 MW
Load Projected: 51,885.33 MW
Load Calculated: 51,885.33 MW
Load Actual Min: 48,734.98 MW
Load Actual Max: 54,455.05 MW
Balance: -2,570.72 -- 3,150.35 MW



Interval 4
Disabled Lines: 6 out of 99
Gen Available: 78,580.27 MW
Gen Calculated: 44,155.13 MW
Load Projected: 44,155.13 MW
Load Calculated: 44,155.13 MW
Load Actual Min: 42,118.65 MW
Load Actual Max: 46,074.30 MW
Balance: -1,916.17 -- 2,036.27 MW

Interval 5
Disabled Lines: 8 out of 99
Gen Available: 80,240.57 MW
Gen Calculated: 39,594.39 MW
Load Projected: 39,594.39 MW
Load Calculated: 39,594.39 MW
Load Actual Min: 38,090.76 MW
Load Actual Max: 41,737.46 MW
Balance: -2,143.09 -- 1,503.63 MW

Interval 6
Disabled Lines: 0 out of 99
Gen Available: 77,393.80 MW
Gen Calculated: 37,294.82 MW
Load Projected: 37,294.82 MW
Load Calculated: 37,294.82 MW
Load Actual Min: 35,574.33 MW
Load Actual Max: 39,344.21 MW
Balance: -2,049.39 -- 1,720.49 MW

Discussion

- Enhancements in power system resilience to extreme weather are affected by uncertainties
- The selection and implementation of preventive measures for power system resilience enhancements to extreme weather depend on
 - operating conditions of the grid
 - severe weather conditions
 - accurate information
 - constraints
- Power system resilience enhancements are limited if prepare for one scenario and it does not occur

Conclusions

- Uncertainties in power system operation and severe weather conditions make an influence on the selection of resilience enhancement measures in different ways
- Deterministic impact assessment of extreme weather events on the grid over a range of scenarios
- Optimization problem aimed at minimizing the energy not supplied defines appropriate resilience enhancement strategies
- Power system resilience enhancements are limited if prepare for one scenario and it does not occur

Thanks for your attention.

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