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2018 Annual Conference
October 22nd, 2018

Quantitative comparison of cascading failure models for risk analysis in power systems

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Introduction & Motivation

- Accurate risk assessment of power system operations crucial for decision makers such as transmission system operators to ensure a stable and reliable supply of energy to customers and prevent component overloads or even blackouts due to cascading failures
- Computational cost of power flow simulations, in particular cascading failure analysis, increasing with increasing model complexity
- Exclusive use of more expensive modelling methods not necessarily needed if similar conclusions can be drawn from the output of a less complex model

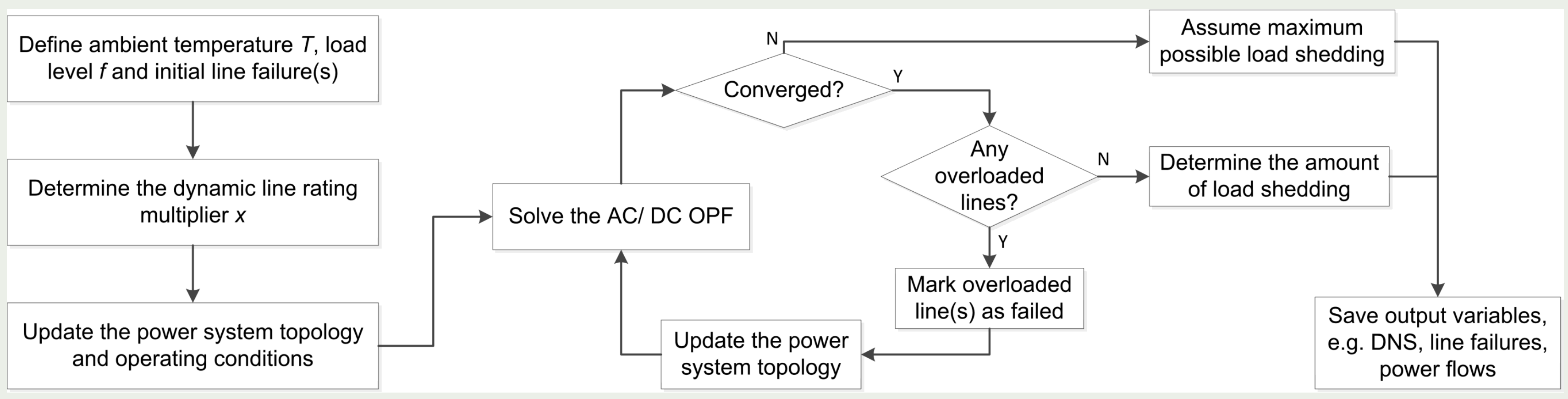
→ Comparison of the AC OPF-based Manchester model with the computationally less expensive DC OPF-based OPA model to determine if and under what circumstances the two models lead to diverging results

Cascading failure modeling

Both the Manchester model and the OPA model were created for cascading failure analysis and are modified to incorporate external influencing factors, i.e.,

- variable demand (by multiplying all bus loads by a factor f)
- temperature dependent transmission line capacities (dynamic line rating)

In each simulation the following sequence of actions is carried out:



Dynamic line rating

Dynamic line rating is determined as a function of solar irradiance q, ambient temperature T_{amb} and maximum tolerable line temperature T_{line}^{max}. Using the equation of thermal equilibrium the highest possible current flow through a conductor at reference conditions can be computed:

$$I(T_{ref})^2 = \frac{\overbrace{P_{conv}(T_{ref}, T_{line}^{max})}^{\text{natural convective cooling}} + \overbrace{P_{rad}(T_{ref}, T_{line}^{max})}^{\text{radiative cooling}} - \overbrace{P_{sun}(q_{ref})}^{\text{solar heating}}}{\underbrace{R(T_{ref})}_{\text{resistivity of the conductor at reference temperature}}}$$

$$T_{ref} = 20°C$$
$$T_{line}^{max} = 80°C$$
$$q_{ref} = 900 \frac{W}{m^2}$$

The relative decrease or increase in ampacity w.r.t. the reference conditions is then computed by the ratio $\boldsymbol{x = I(T_{amb})/I(T_{ref})}$.

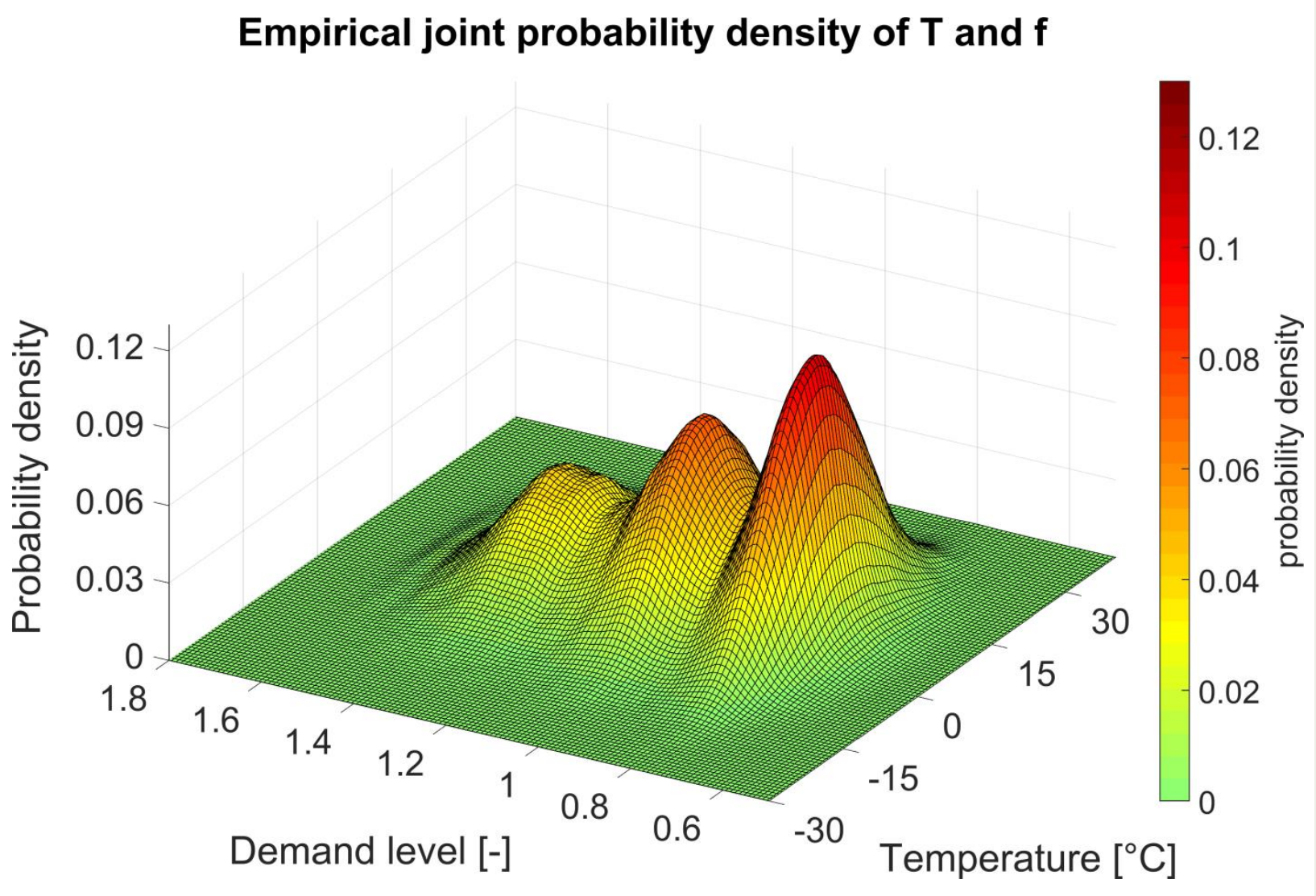
Case study

Power flow simulations based on the IEEE-24 bus RTS at different operating points:

parameter		min	max	
ambient temperature	T [°C]	-30	40	in 2°C steps
bus load (w.r.t. base load)	f [%]	50	180	in 2% steps

Case 1: no initial line failures considered

Case 2: study including initial line failures


Empirical joint probability density of T and f

Definition of random line failures

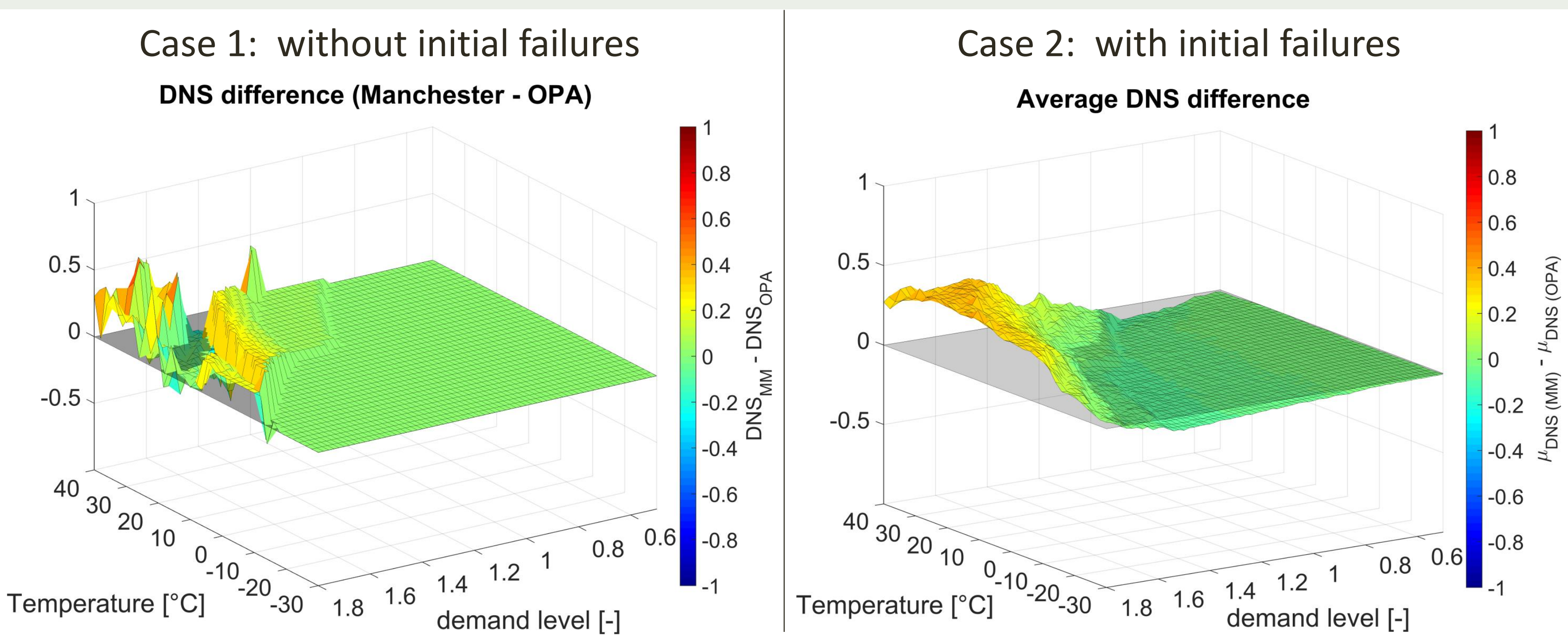
In addition to assessing the zero-failure-case

- consideration of all the possible single line failures (38)
- sampling of 961 (n-k)-contingencies with k>1

→ 1000 model evaluations for each operating point, leading to 36 · 66 · 1000 = 2’376’000 simulation runs of each model

Comparison results

Demand not served (DNS)


Case 1: without initial failures
Case 2: with initial failures

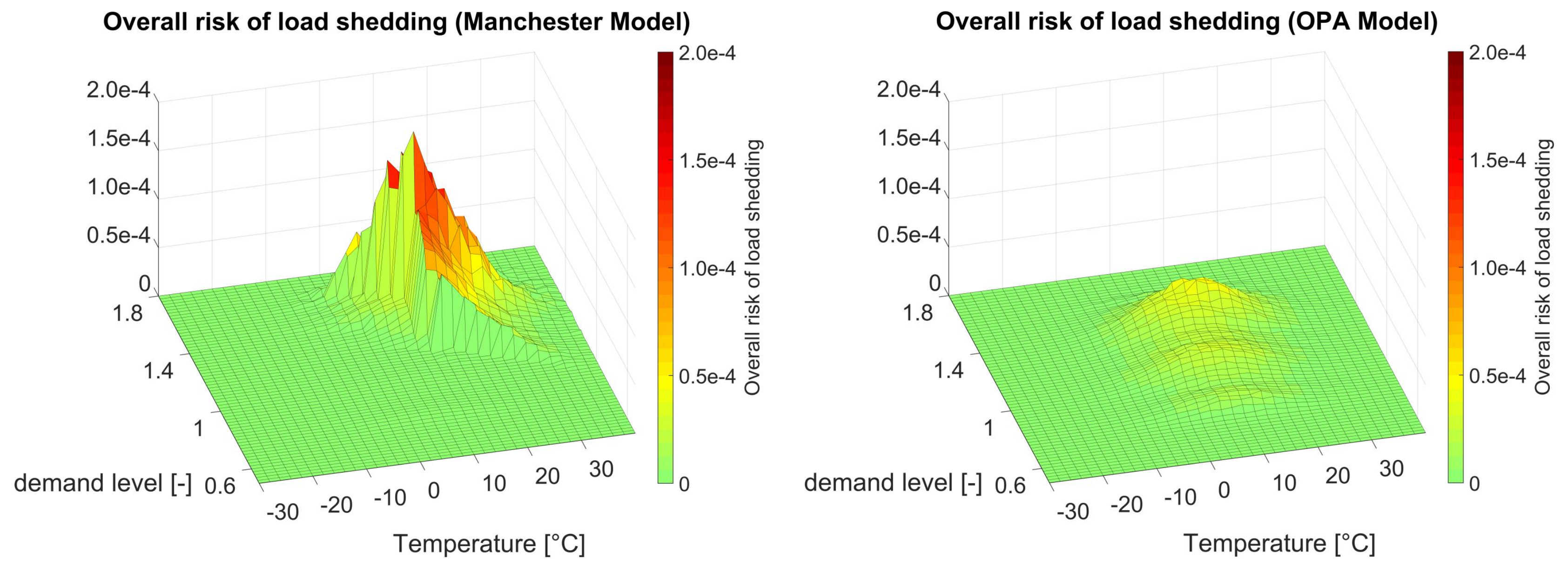
- Manchester model predicting more input conditions with DNS>0 in Case 1
- OPA model indicating higher average DNS in Case 2 except at very high T and f

Overall risk of operation $\Re$ (Case 2)

- ➢ Computed by multiplying the joint probability $\hat{P}(T,f)$ by the expected DNS at a certain temperature T and demand level f
- ➢ $\hat{P}(T,f)$ determined from an empirical joint PDF based on historic data

$$\Re(T,f) = \hat{P}(T,f) \cdot \sum_i DNS_i(T,f) \cdot (0.01)^{n_{fail}^i}$$

DNS_i … DNS at contingency i
0.01 … single line failure probability
n_{fail}^i … number of line failures



- OPA model predicts elevated risk for a larger fraction of the input space (1024 vs. 593 out of 2376 points) due to higher average DNS at lower temperature and demand levels
- elevated risk area includes almost all points identified by the Manchester model
- for those points, the Manchester model shows noticeably higher risk values than the OPA model

Line Criticality

most frequently failed lines (by ID) immediately after an initial failure

Rank	1	2	3	4	5	6	7	8	9	10
Manchester Model	10	11	23	28	18	17	12	5	7	6
OPA Model	11	23	28	10	18	3	17	36	37	29
***Overlap** (indep. of rank)*	***100%***					***20%***				

- perfect overlap in the five most vulnerable lines (if the order is neglected)
- conformity rapidly decreasing beyond that

Conclusions

- Identification of the same five most critical lines by both models
- OPA model results indicating larger area of elevated risk than Manchester model in Case 2
- Manchester model assigning significantly higher risk within the detected area
- Manchester model showing higher fraction of DNS>0 points in Case 1

Acknowledgement

The authors acknowledge the CTI - Commission for Technology and Innovation (CH), and the SCCER-FURIES - Swiss Competence Center for Energy Research - Future Swiss Electrical Infrastructure, for their financial and technical support to the research activity presented in this poster.