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Smart Grid Resilience – Security of Supply 2.0

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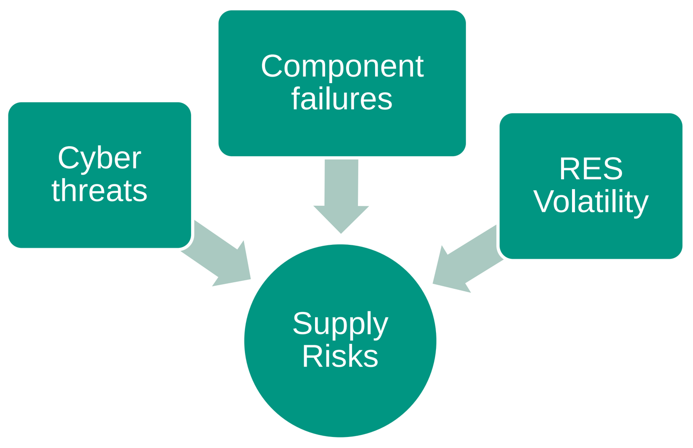
Smart Grids & Infrastructures

Motivation

Power distribution system **increasing dependencies** on

- ICT-infrastructures and
- Renewable Energy Sources (RES).



Advanced Metering Infrastructures and Smart meters allow **fine grained power distribution management strategies**.

Find **suitable power distribution strategies** in times of **power shortage** by exploiting the advantages of an advanced metering infrastructure and smart meters.

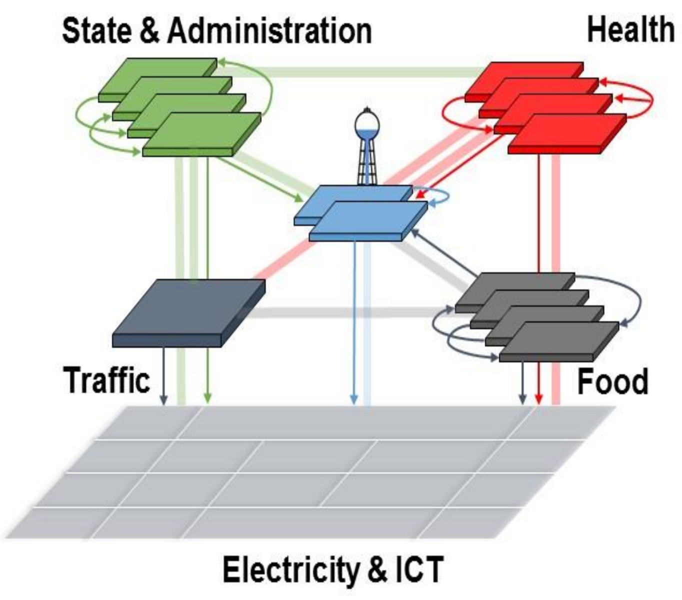
Quantities

Disruptions of an infrastructure $\boldsymbol{x_i}$, caused by power shortage, may lead to **negative consequences** for the population that can be measured by its **criticality** $\boldsymbol{c_i}$ see [OMS2018].

An infrastructure $\boldsymbol{x_i}$ may possess

- **Process Flexibility or**
- **Coping Capacities**

that allow to specify a *power demand interval* $[\boldsymbol{P^i_{D,min}}, \boldsymbol{P^i_{D,max}}]$, where $\boldsymbol{P^i_{D,max}}$ is the power demand for *normal process* mode and $\boldsymbol{P^i_{D,min}}$ the power demand for at least running *some essential subprocesses.*



Distribution Heuristics

Setting

$\boldsymbol{v_l} := (P^l_{D,min}, P^l_{D,max}, c_l)$ *power demand and criticality,*

$\boldsymbol{SP_l}$ *suppliable power* for infrastructure $\boldsymbol{x_l}$,

$\mathfrak{S} := \{[a,b] \mid a,b \in \mathbb{R}, 0 \leqq a \leqq b\} \times [0,1]$

$\mathfrak{F} := \mathfrak{S} \times \mathbb{R}^+_0$

Similarity

$\boldsymbol{s}: \mathfrak{S} \times \mathfrak{S} \to \mathbb{R}^+_0$,

a demand and criticality similarity measure

I. If $\boldsymbol{v_i = v_j \Rightarrow s(v_i, v_j) = 0}$

e.g. $\boldsymbol{s(v_i, v_j)} = \|\boldsymbol{v_i - v_j}\|_2$

Fairness

$\boldsymbol{f}: \mathfrak{F} \times \mathfrak{F} \to \mathbb{R}^+_0$,

a fairness similarity measure

II. If $\boldsymbol{s(v_i, v_j) = 0 \Rightarrow f\left((v_i, SP_i), (v_j, SP_j)\right) = 0}$,

e.g. **if** $\boldsymbol{s(v_i, v_j)} = \|\boldsymbol{v_i - v_j}\|_2 = \boldsymbol{0 \Rightarrow SP_i = SP_j}$

Criticality Based Optimal Power Flow applied to the IEEE 33 Bus System

Scenario: 75% coverage of default power demand

Supply Index

Let

$$\boldsymbol{SI} = \sum_{i \in I} \tilde{c}_i \, q_i(SP_i),$$

be a *supply index*, where $\tilde{c}_i = \frac{c_i}{\sum_{j \in I} c_j}$, is the *weighted criticality* and q_i a *certain linear* function measuring the **quality of supply**.

Test case: **32** infrastructures/prosumers and one power generator - demand and criticality data as in Fig-4,5.

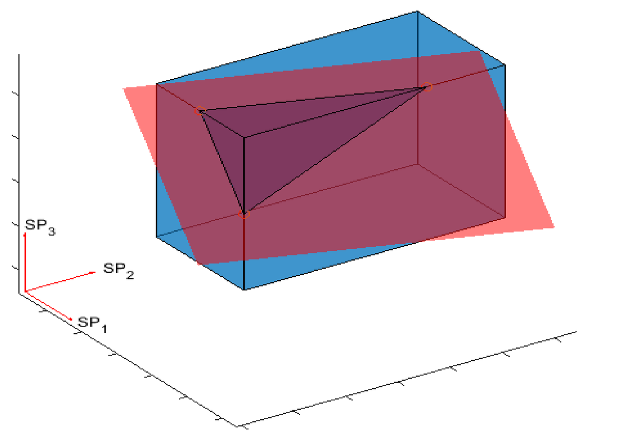


Fig-1: Power demand domain (blue) truncated by the power shortage constraint (red)

Global Maximum of $\boldsymbol{SI}$

Finding a global maximum $\boldsymbol{M}$ of $\boldsymbol{SI}$ within a *truncated power demand domain*, see Fig-1, can be used to assess the quality of **fair power distributions**, see Fig-2.

The dual-simplex algorithm applied to our test case: $\boldsymbol{M = 0{,}993}$ but the found solution is **not fair** - i.e. *relatively big differences* in similar cases occur.

Evolutionary Algorithms and Optimal Power Flow

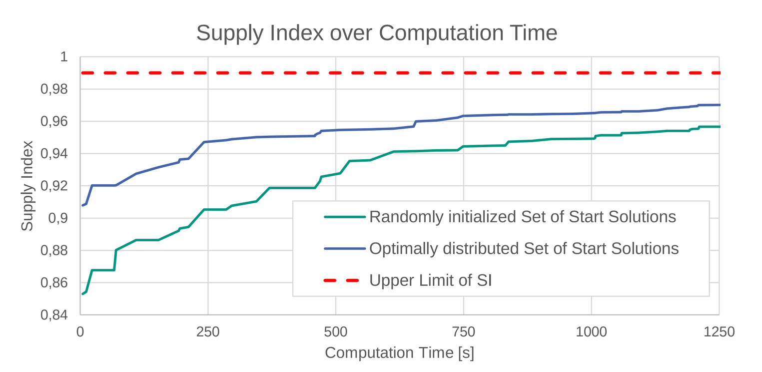


Fig-2: Increase of the achieved supply index SI in the course of an optimization run for a set of randomly (green) and optimally distributed (blue) start solutions. The value of SI depicted here always refers to the fittest solution in the set

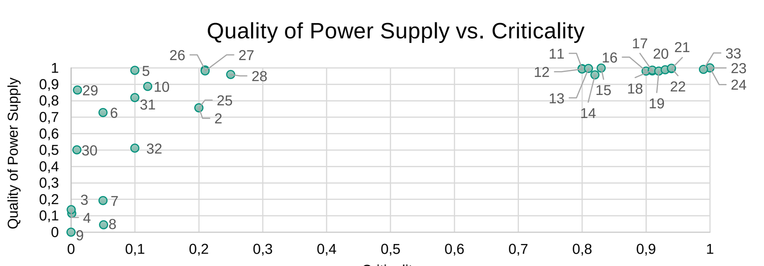


Fig-3: Values of q_i for the criticality values c_i of the busses the investigated network consists of

The determination of a **fair power distribution** while maximizing the **supply index** $\boldsymbol{SI}$ becomes an increasingly difficult problem with a growing number of consumers. Hence, a **global optimization** procedure, specifically an **Evolutionary Algorithm (EA)**, is applied. An EA improves a set of solutions by replicating the mechanisms of biological evolution (heredity, mutation, and survival of the fittest). Due to the algorithm's stochastic nature, different optimization runs may show different behavior and therefore may require varying run times to obtain sufficiently good solutions.

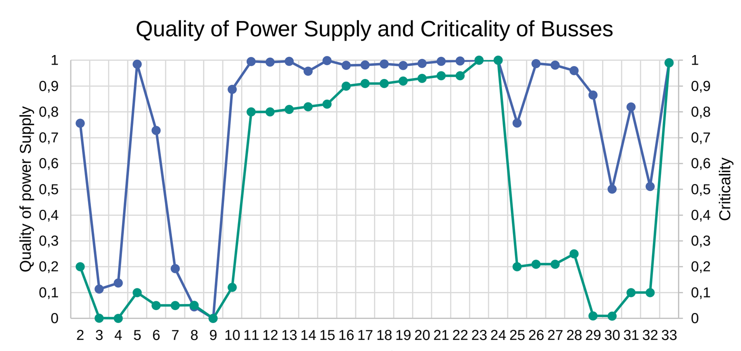


Fig-4: Values of q_i (blue) and c_i (green) for all the network's busses

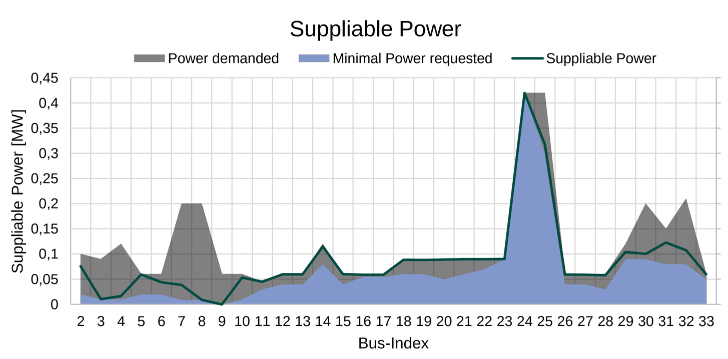


Fig-5: Power demanded $P^i_{D,max}$, minimally requested power $P^i_{D,min}$ and suppliable power SP_i for the busses

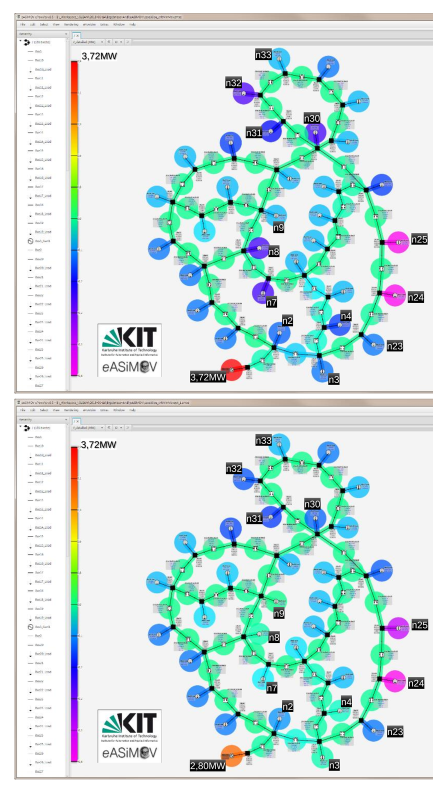


Fig-6: Power supply of a distribution grid with 32 prosumers: 100% coverage of power demand (top) and 75% (bottom).

Next Steps

- More detailed and larger use cases, e.g. urban power distribution grids including critical infrastructure models are in preparation.
- Current work aims at increasing the performance of the EA through an improved gene model and an extension to a memetic algorithm.
- Extension of the power grid models with photovoltaics and battery storage for transient simulation [KCKH2017].

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References

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[KCKH2017] *Kyesswa, M., Çakmak, H.K., Kühnapfel, U., Hagenmeyer, V.: A Matlab-Based Dynamic Simulation Module for Power System Transients Analysis in the eASiMOV Framework, EMS2017 – UKSim - AMSS DOI 10.1109/EMS.2017.36, pp.157-162, 2017.*