Intermittent Renewables & Dynamic Stability in Distribution Grids

Sabine Auer

Work with Frank Hellmann, Paul Schultz, Anton Plietzsch, Casper Roos, Jobst Heitzig and Jürgen Kurths

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The Future Power Grid
1. Motivation & Overview

Overarching question:
How can we optimize the overall design of the future power grid for the dynamically stable integration of renewable energies?

What are the novel dynamics we can expect?

What is the relationship between structural and dynamic properties?

Measures for transient & asymptotic stability analysis:
- e.g. survivability, basin stability, exceedance

How can we integrate flexibility options?

Smart Grid Control:
- e.g. simple heuristics for Decentral Smart Grid Control

Features our conceptual models need to capture:
- e.g. power electronics, delayed reaction, intermittency

build models
analyze
new concepts
Dynamic Stability in Distribution Grids

2. Distribution Grid Modeling

\[ H_i \dot{\omega}_i = P_i - D_i \omega_i - \sum_j K_{ij} \sin(\phi_i - \phi_j - \alpha_{ij}) \]

Network Structure

- Lossy lines
  \[ \alpha_{ij} = \arctan(G_{ij}/B_{ij}) \]
- Tree like networks
  \[ K_{ij} \text{ sparse} \]

Node Dynamics

- Intermittency
  \[ P_i(t) \]
- Inverters
  \[ \text{low inertia } H_i \]
  \[ \text{low damping } D_i \]
  \[ \text{delays} \]

Agents

- Active Consumers
- Smart Grid Control
  \[ \text{demand } P_i(t) \]

Distribution Grids
- P. Schultz et al., EPJ ST (2014)

Distributed Renewables (DR)

Auer et al., IEEE ISGT (2016)

Sabine Auer, RD IV Transdisciplinary Concepts and Methods
Dynamic Stability in Distribution Grids

3. Model Cases

1. Mid-Voltage (MV) Grid Model
   99 MV nodes
   • same demand & production
   • difference injected into grid
   • 1 heavy node (slack bus)
   • power balance: negative sum over power in-feeds and losses

2. Microgrid Model
   • 50 producers, 50 consumers (±0.1MW)
   • no connection to upper grid level

Intermittency
   • time series generated by model of Langevin Equation plus Jump process
   • Solar and wind model provided by Mehrnaz Anvari, O. Kamps & K. Schmietendorf

![Power Spectrum](image1)

![Correlation in Time](image2)
**Dynamic Stability in Distribution Grids**

3.1. Single Node Fluctuations in MV Grids

**Exceedance** (survival function, sum of tail): $\text{mean}(p_i(|f| > 0.01 \text{ Hz}))$
**Dynamic Stability in Distribution Grids**

3.1. Single Node Fluctuations in MV Grids

**Resistive distance** (ohmic shortest path from disturbed node) to slack bus dominates dynamic stability
Dynamic Stability in Distribution Grids

3.2. Single Node Fluctuations in Microgrids
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3.2. Single Node Fluctuations in Microgrids

![Graph showing exceedance mean vs. closeness centrality with Pearson correlation]

- Pearson $r = 0.45$; $p = 3.2 \times 10^{-6}$
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3.2. Single Node Fluctuations in Microgrids

pearsonr = 0.45; p = 3.2e-06
With losses:
- Non-trivial relationship between closeness centrality and exceedance

Without losses:
- Anti-correlation
What's next

- Improve understanding of single node fluctuations
- Compare stochastic stability measures with deterministic measures (for single node perturbations)
- Investigate multiple node fluctuations and optimal inertia/balancing placement for such a case study
- Improve performance analysis of different heuristics for electric vehicles (with increasing number of EVs) → Master thesis Casper Roos (Paper in prep.)
References

- S. Auer, F. Steinke, W. Chunsen, A. Szabo, R. Sollacher“. Can Distribution Grids Significantly Contribute to Transmission Grids’ Voltage Management?”. submitted to IEEE ISGT.
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4. Related Work: Smart Grid Control

Special grid charges should be adjusted in the interest of greater demand side flexibility
- Permit flexibility serving the needs of the market and/or grid (e.g. BDI, BEE, BNE)
Dynamic Stability in Distribution Grids 4.
Related Work: Smart Grid Control

Renewable generation & react with simple heuristics

- Frequency fluctuations
- Measure frequency

Solar power

Time

Charging power (%)

Grid frequency (Hz)

Renewable generation & react with simple heuristics

Measure frequency

Charging power (%)

Grid frequency (Hz)
Power Spectrum Renewables
Two ways to perceive inverters
1) first leads delayed differential equations
2) other approach from Schiffer et. al. IEEE, 2013

droop control for frequency stabilization

\[ P_{M,i}(t) - P_{d,i} = -\frac{1}{k_{P_i}}\omega_i(t) \]

\[ H_i\dot{\omega}_i(t) = -D_i\omega_i(t) + P_{d,i} - P_i(t) \]

with \textit{virtual inertia} \( H_i = \tau_{P_i}/k_{P_i} \) and damping \( D_i = 1/k_{P_i} \)

low pass measurement (acts as integrator)

\[ \tau_{P_i}\dot{P}_{M,i}(t) = -P_{M,i}(t) + P_i(t) \]

\( P_{M,i} \)- measured active power
\( P_{d,i} \)- desired active power setpoint

\( P_i = \sum_j K_{ij} \sin(\theta_i - \theta_j - \alpha_{ij}) \)
Exceedance correlated or anti-correlated with Hurst exponent (time correlation)