Dynamic Simulation and Stability Limits of Large-Scale Transmission Systems with Renewables

SCCER-FURIES Annual Conference (Virtual)

Dr. Alexander Fuchs (ETH Zurich, Research Center for Energy Networks)

Oct 28, 2020
Summary

- Dynamic stability future Continental ENTSO-E system with high share of converter-based renewable energy sources (RES)
- Assessment of large disturbances, in particular islanding scenarios
- New dynamic simulation framework: modular, flexible, robust initialization, fast
- Comparison of different converter models and impact on stability
- Simulation for a wide range of generation distribution and RES-shares
- Results:
  - Computation of stability contours for assessment of expected disturbance impact
  - Simple converter models systematically underestimate impact on dynamic stability
  - Insights in complex dynamic couplings and cascaded outages
Agenda

Dynamic simulation of large transmission grids

RES modeling

Results for secure power system operation
Background: Risk from transients in the transmission grid

- Scenario: System split into multiple synchronous areas (similar to 2006 event)
- Challenge: Loss of multiple GW of import or export in each area

- Background:
  - Dynamic power system stability of large disturbances in the future Continental ENTSO-E system
  - Challenges and potential support from converter-based generation

- System parameters:
  - Continental ENTSO-E dynamic model
  - Share of converter-based renewables
  - Initial load flow distribution
  - Converter control approaches
Simulator Framework

- Modular framework combining symbolic and numerical methods.
- Runs approximately realtime for large Continental ENTSO-E dynamic model (≈ 10’000 buses and 1’000 generators).
Simulation Workflow

- Definition and symbolic differentiation of component equations (only structure)
- Parameterization of components and assembly of network model
- Two-step initialization approach (important for feasible Voltage/reactive power setpoints)
  1. Solve OPF problem (with bounds on PG,QG,VG)
  2. Solve dynamic initialization problem (with bounds on AVR,Turbine,Generator)
- Post-processing, computation of performance metrics, visualization
System split of Continental ENTSO-E Base case

- Performance metric of interest: Rate-of-change of frequency (ROCOF) approximated with swing-equation
  \[ R = \dot{\omega} = \frac{P_{\text{gen}} - P_{\text{load}} - P_{\text{losses}}}{2H} = \frac{\Delta P}{2H} \]

- ROCOF estimated in simulation over 2000ms time window

- Loads are fixed, shift of generation power between regions (up to ±15GW)

- New RES is included by reducing synchronous machines an adding converters
Agenda

Dynamic simulation of large transmission grids

RES modeling

Results for secure power system operation
Modeling of converter based generation

- Three types of common converter models
  - **IMP**: Impedance models of converter (simplified static model, often used)
  - **CCC**: Current-controlled capacitor model (PV-converters without storage)
  - **VSM**: Virtual synchronous machine model (converters with battery storage)

- IMP is simple to simulate and often used for simulation in large systems
- *How accurate are simulation results with IMP compared to realistic CCC models?*
- *What are the benefits of using VSM with dynamic grid support?*
• Several controllers for grid support, similar to synchronous machine.

• Model and tuning based on:
Kundur system: ROCOF and RES

- Shift of generation to RES reduces inertia: \( R = \frac{\Delta P}{2H} \)
- Simulation with varying shares of IMP, CCC and VSM
- Increase rate depends on converter type

- ROCOF increases with RES
Computation of a ROCOF premium for different RES models

- Roughly linear dependence on RES generation share: \( R = R_0 + K \cdot P_{\text{RES}} \)
- For IMP, \( K_{\text{IMP}} = 0.37 \text{mHz/sec per MW renewables} \)
- Estimate of ROCOF premium:
  \[ K_{\text{CCC}} = 2.6 \cdot K_{\text{IMP}} \]
  \[ K_{\text{VSM}} = 1.5 \cdot K_{\text{IMP}} \]
- IMP systematically underestimates the ROCOF, confirmed for a wide range of load flow distributions
- Can use ROCOF premium to update existing results (also from other projects) obtained with with IMP models
Agenda

Dynamic simulation of large transmission grids

RES modeling

Results for secure power system operation
Continental ENTSO-E: varying power balance and RES-share (IMP-type)

- **Mean ROCOF values** in South-West as a function of generation power added to the region. Case with 0% and 40% RES.

- Shift of generation to RES reduces inertia, generation shift changes power balance:
  \[ R = \frac{\Delta P}{2H} \]

- Similar pattern in other regions (but different slopes, depending on power balance and generation settings)
Estimation of impact of converter types

- Plot confirms the roughly linear dependence of ROCOF on RES share and power balance (also seen in smaller systems) as predicted from Swing-equation.
- **Linear interpolation** allows update coefficients for ROCOF computation.
- ROCOF can be estimated for different shares and types of RES-models (CCC, VSM) without further simulation.
Application: Stability contour for the grid operator

- Results allow fast mapping of current and future operating points
- Informs the grid operator when the system approaches a risky state (e.g. $R > 1\text{Hz/s}$)
- Can be used for monitoring of the dynamic security through the grid operator
- Can be created for a wide range of load flows and events, and intersected accordingly
More insights: emerging synchronous clusters

- Cascaded split: For higher generation, after the initial split, South-West separates into multiple synchronous zones.
- Simulation-based identification of regional frequency clusters (robust, system constraints accounted for)
Summary

- Dynamic stability future Continental ENTSO-E system with high share of converter-based renewable energy sources (RES)
- Assessment of large disturbances, in particular islanding scenarios
- New dynamic simulation framework: modular, flexible, robust initialization, fast
- Comparison of different converter models and impact on stability
- Simulation for a wide range of generation distribution and and RES-shares
- Results:
  - Computation of stability contours for assessment of expected disturbance impact
  - Simple converter models systematically underestimate impact on dynamic stability
  - Insights in complex dynamic couplings and cascaded outages
Thank you for your attention!

FEN - Research Center for Energy Networks

ETH Zentrum SOI
CH-8092 Zurich

Dr. Alexander Fuchs
Sonneggstrasse 28
Tel: +41 44 632 28 60
Fax: +41 44 632 13 30
E-mail: fuchs@fen.ethz.ch
Web: www.fen.ethz.ch