Test Case tutorial: EU grid operations

Tom Schoolmeesters

6 augustus 2025

Project Structure and Resources

The following documents and repositories are part of the tutorial and the thesis:

- **EU_grid_operations_thesis**: GitHub repository containing the main project code.
- **PowerModelsACDC**: A customized version of the original GitHub repository, adapted for this project.
- **Test Case Tutorial**: A step-by-step guide on how to install and use the code.
- **Code Documentation**: Detailed explanation of the inputs and outputs of the various functions in the EUGO model.
- **Thesis**: *"Filtering Relevant Candidates from Transmission Network Expansion Planning: Application to the North Sea"*.

Framework Overview and Software Guide

This tutorial accompanies the thesis *"Filtering Relevant Candidates from Transmission Network Expansion Planning: Application to the North Sea."* The thesis introduces a scalable, transparent, and reproducible framework that significantly enhances transmission network planning. By integrating data-driven candidate filtering with detailed power system modeling, it provides essential decision support for advancing Europe's renewable energy transition and achieving climate targets.

The framework relies on two Julia packages: `EU_grid_operations` and `PowerModelsACDC`. Both packages have been modified to include the necessary functions and input data structures required by the thesis. The changes made to `EU_grid_operations` are documented in the included documentation, which becomes available after downloading the GitHub repository.

Accessing the Documentation

To explore the documentation for the `EU_grid_operations_thesis` package:

1. Download the repository and unzip the folder.
2. Navigate to the `docs/build` directory.
3. Open the `index.html` file in your preferred web browser.

From the homepage, you can browse all documentation pages, which include information on the implemented functions and the test case.
Additionally, the source code contains inline comments next to each custom function to clarify their purpose and usage.

Modifications to the `PowerModelsACDC` package involve the formulation of an optimization problem that accounts for a representative time series set. In this formulation, each timestep represents a specific number of real hours within a year. This weighting factor is incorporated into the objective function to ensure accurate cost evaluation over time. **Important:** If a new dataset is generated, the weighting factor must be manually updated in the `PowerModelsACDC` source code to ensure correct time representation.

This modification should be made in the `objective.jl` file located in the `src/core` directory. Specifically, the update needs to be applied within the functions `objective_min_cost_repr` and `objective_min_cost_acdc_repr`, where `repr` refers to "representative timeseries". Within these functions, the weighting factor can be adjusted and then saved.

Preparing the test case

To reproduce the results of the thesis, you'll need to run a predefined test case using two customized Julia packages: `EU_grid_operations_thesis` and a modified version of `PowerModelsACDC`. Both packages can be downloaded from the following GitHub repository.

After downloading, place both packages in the same directory on your local machine. Additionally, make sure to download the required FEATHER input files and move them into the `data_sources` folder of the `EU_grid_operations` package. See *data_sources/download_links.txt* for download links.

Gurobi Solver

Before running the code, ensure you have a valid Gurobi license, as it is required to solve the optimization models.

Next, navigate to the `thesis` directory inside the `EU_grid_operations_thesis` package. This folder contains the scripts necessary to run the test case.

Finally, you need to register your local version of `PowerModelsACDC` in your Julia environment. This can be done by executing the following commands in the Julia REPL:

```
using Pkg
Pkg.develop(path="INSERT_PATH_TO_YOUR_FOLDER")
```

Once this is complete, you are ready to execute the test case and reproduce the results presented in the thesis.

Test Case Description

The test case analyzed in this project corresponds to the Distributed Energy (DE) scenario for the simulation year 2040 and climate year 2008. You can change the parameters to analyse other scenarios and years if you want. It is composed of three main modeling stages, followed by a comprehensive set of post-processing visualizations and analyses.

1. Zonal Optimal Power Flow (OPF)

Script: `run_zonal_opf.jl`
This model represents the entire European electricity system using a simplified zonal network—approximately one node per market zone. This abstraction allows efficient computation of cross-border electricity flows, with a specific focus on the North Sea region. The model constructs:

- an **input dictionary** (grid topology and parameters), and
- a **scenario dictionary** (time series for demand and renewable generation),

using updated TYNDP input data. It then applies PowerModels' `NFA PowerModel`, a network flow approximation (active power only), to solve hourly dispatch problems. Results are stored in a structured result dictionary.

2. Nodal Optimal Power Flow (OPF)

Script: `run_nodal_opf.jl`
A detailed nodal OPF is performed for the North Sea countries:

- Belgium (BE)
- Germany (DE)
- United Kingdom (UK)
- Netherlands (NL)
- Western Denmark (DK1)

Boundary conditions are set using the cross-border flows obtained from the zonal OPF, which enables detailed intra-zonal analysis without modeling all of Europe in nodal resolution. Key features include:

- Detailed internal grids for congestion modeling
- Adapted offshore wind layouts reflecting realistic infrastructure constraints

3. Transmission Network Expansion Planning (TNEP)

Script: `run_nodal_tnep.jl` This step focuses on filtering and selecting the most impactful investments from a large pool ($>$ 50,000) of expansion candidates. The aim is to improve scalability and result quality in the TNEP model.

Filtering approach:

- **PTDFs**: to evaluate physical flow impacts
- **Nodal price differences**: to estimate economic potential
- **Benefit-to-cost ratios**: to prioritize high-value options

Advanced data techniques are applied:

- Principal Component Analysis (PCA)
- k-means clustering (spatial and technical diversity)

The resulting filtered candidates feed into a linearized OPF formulation for hybrid AC/DC networks. The objective is to minimize total system costs, including:

- Generation costs
- Load shedding penalties
- Investment expenditures

4. Post-Processing and Visualizations

The framework provides detailed geospatial and temporal insights into system behavior. Key visualization and analysis functionalities include:

Geospatial plots:

- Nodal prices
- Grid loading levels

Generation/load dynamics:

- Generation by type
- Demand profiles
- Installed capacity

Component-level diagnostics:

- Buses, branches, generators

Network performance indices:

- Congestion index (hourly and annual)
- Saturation index

Curtailment and shedding detection:

- Renewable curtailment
- Load shedding (overall and per hour)
- Electrical congestion identification

Line flow analyses:

- Loading levels over time

These visualizations are essential for interpreting the results of the simulation and assessing system reliability, bottlenecks, and the effectiveness of proposed reinforcements.