Swissgrid Ltd
Bleichemattstrasse 31
P.O. Box
5001 Aarau
Switzerland

T +41 58 580 21 11
info@swissgrid.ch
www.swissgrid.ch

Master Thesis Proposal

Project title

Advanced Power Systems Modelling for Harmonic State Estimation

Project responsible and contacts

Dr. Asia Codino asia.codino@swissgrid.ch
Lokman Mheni lokman.mheni@swissgrid.ch

Project description

In modern grids, Transmission System Operators (TSOs) face growing challenges due to harmonic distortions caused by converter-based generation and nonlinear loads. Hence, effectively monitoring and identifying harmonic sources is essential to safeguard Power Quality (PQ) and ensure reliable system operation.

At Swissgrid as well, Power Quality is a topic that has become central. Indeed, Swissgrid, must comply with the Total Harmonic Distortion (THD) levels indicated by the Swiss Transmission Code. More importantly, the renewable share in the Swiss production is forecast to increase significantly. This indicates that the problem is likely to worsen in the short-term.
As a consequence, the first natural step is providing Swissgrid awareness of the harmonic penetration in its network, which translates into the implementation of a Harmonic State Estimation (HSE). As this application is theoretically challenging, the idea has arisen to collaborate with the Distributed Electrical Systems Laboratory (DESL) at École Polytechnique Fédérale de Lausanne (EPFL) to develop the tool.

Harmonic state estimation (HSE) is a process aimed to infer the harmonic state of a power system - namely, the nodal voltages at all buses of the grid, at each harmonic order -, allowing the identification and quantification of harmonic sources and their propagation through the grid. State estimation techniques, traditionally used for monitoring voltage and current conditions in power networks, are being extended to the harmonic domain to address the specific challenges posed by harmonic distortions [1].

At Swissgrid SAS Engineering team, a first Master Thesis was conducted from August 2024 to February 2025. The goal of this first work was to assess what can be achieved with the knowledge, equipment and measurements available at Swissgrid. The study validated the computational feasibility of the method and its effectiveness under simplifying assumptions (single-phase balanced power systems).
The second Master Thesis addressed the problem of HSE in unbalanced three-phase transmission networks, with a particular focus on advanced line modelling and electromagnetic couplings, applied to a more complex case study, including transmission lines organized in cascaded sections, with subsections shared between circuits (allowing to consider the coupling phenomena). A tensor-based formalism was developed to generalize the measurement model and to integrate both harmonic interactions and multi-conductor effects. The methodology was validated through a systematic set of test cases, each designed to assess the estimator under different measurement configurations and initialization strategies.

Tasks of the student

Several future tasks have been identified by the responsibles of the project, for a third Master Thesis to refine and improve further the power network model.

- Integration of transformers in the model. The goal of this step is to complete the network model and to expand the case study to a bigger and more complex subset of the Swiss high-voltage power grid, by introducing accurate modelling of power transformers. This would allow investigations on the harmonic coupling that can be caused by overloading of the transformers.
- Up-to-speed automated estimation. In a future perspective of an integration of the estimator in Swissgrid's SCADA system, it is important to optimize the code to make it run in a quasi real time fashion. A first step to achieve this is applying parallel computing tools [2]. It is recommended to convert the code from Matlab to Python.
- Virtual slack node method implementation. Given the NTP-based communication implemented in Swissgrid substations, and the limited availability in the market of measurement devices providing harmonic measurements based on PTP time synchronization, the measurements of the voltage phase angles are not always reliable. The goal of this step is to apply a methodology published by Ali Abur in 2022 [3] and 2024 [4] to 'get rid of' the need for angle measurements.
- Observability Analysis. We suggest formulating an optimization problem to find the optimal placement of the sensors [5] that we would install in a pre-defined subset of Swissgrid's power system used as a case study for a pilot project.

Required knowledge and skills

- Power systems modelling and analysis in steady state.
- Power transformers modelling.
- Power systems state estimation and bad data processing/assessment.
- Harmonic phenomena: injections and propagation.
- Accurate formulation of optimization problems.
- Proficiency in programming languages: MATLAB, Python.
- Proficiency in power systems simulation and analysis tools: EMTP-RV is a plus.

Location and time frame

The master thesis will be carried out at the Swissgrid headquarters in Aarau. It shall begin starting from March or April 2026, and last 6 months.

References

[1] Qin Lv and Fei Zhao. "A Review of Research on Power System Harmonic Detection and Its Suppression Methods". In: IEEE 2nd International Conference on Power Electronics and Energy Engineering (PEEE) 2019 (2019), pp. 1–6. doi: https://doi.org/10.1109/ITNEC48623.2020.9084832. url: https://ieeexplore.ieee.org/document/9084832.

[2] U. C. Yilmaz and A. Abur, "A Robust Parallel Distributed State Estimation for Large Scale Distribution Systems," in IEEE Transactions on Power Systems, vol. 39, no. 2, pp. 4437-4445, March 2024, doi: 10.1109/TPWRS.2023.3292552.

[3] U. C. Yilmaz and A. Abur, "A General State Estimation Formulation for Three-Phase Unbalanced Power Systems," 2022 North American Power Symposium (NAPS), Salt Lake City, UT, USA, 2022, pp. 1-6, doi: 10.1109/NAPS56150.2022.10012212.

[4] Ugur Can Yilmaz, Ali Abur, Specifying angular reference for robust three-phase state estimation, International Journal of Electrical Power & Energy Systems, Volume 158, 2024, 109945, ISSN 0142-0615, https://doi.org/10.1016/j.ijepes.2024.109945(https://www.sciencedirect.com/science/article/pii/S0142061524001662)

[5] U. C. Yilmaz and A. Abur, "Ensuring Solution Uniqueness in Three-Phase Power System State Estimation," 2024 56th North American Power Symposium (NAPS), El Paso, TX, USA, 2024, pp. 1-6, doi: 10.1109/NAPS61145.2024.10741772.