RWTH AACHEN UNIVERSITY

E.ON Energy Research Center
ACS | Institute for Automation of Complex Power Systems

Master Thesis / Diplomarbeit:

Validation of representative distribution networks based on Sensitivity Analysis

Validierung repräsentativer Verteilnetze auf Basis der Sensivititätsanalyse

The context

Because of the major changes undergoing in modern power systems, traditional transmission system applications (e.g., fault detection, state estimation, voltage control, etc.) are being introduced at the distribution grid level. The increasing complexity of distribution systems requires grid models to develop and validate the emerging algorithms, as well as to test and simulate the emerging applications. However, there is often an evident difficulty to obtain the required data for building such grid models, due to proprietary concerns and security issues. In this context, there is an impelling need to adopt test networks which can be considered as '*representative networks*' (RNs), i.e., test grids able to appropriately represent the behavior of (a set of) real distribution systems. Given their nature, these representative networks could be effectively and flexibly used for a plethora of applications, simulations and analyses in the power system domain.

The challenge to tackle

There exists different tools and philosophies to build such representative networks [1]. The most straightforward method is simply selecting an actual feeder from a real distribution network and anonymizing it to remove private or sensitive data. Other families of methods involve building synthetic networks ex-novo (using real networks as basis) by employing clustering techniques, manual design, planning tools, etc.

Alternatively, if building RNs ex-novo is not a primary scope per se, there might still be the need to select/adopt a valid – already existing – RN that is able to be "representative" of the network area under study.

Overall, irrespective of whether the RNs have to be (i) built from scratch or (ii) chosen out of a pool of already available RNs, the validation of a specific RN from the "representativeness" point of view is far from being univocally formalized. In fact, the evaluation of whether – and to which extent – a given RN is really "representative" of a certain real distribution network area of interest often turns out to be based on subjective criteria or limited to the computation of aggregated topological indicators [2].

A possible approach

To tackle the problem of RNs validation, Sensitivity Analysis (SA) could be a viable solution. Concisely, SA can be defined as "the study of how the uncertainty in the output of a model can be apportioned to different sources of uncertainty in the model input". Given its complex nature, the distribution network can be seen as a black-box model. The model inputs may be both topological (e.g., number of lines, number of substations, etc.) and electrical (e.g., line parameters, loads and generation sources etc.) and its outputs may be specific to the use case under study to represent the system response of interest (e.g. number of voltage violations, hosting capacity etc.). Loosely speaking, the intrinsic variability (or the *uncertainty*) in the model inputs make the model output *uncertain* too. In this context, the SA can effectively quantify the contributions of each model input to the variability (or the *uncertainty*) in the model output. This way, it is possible to extract the specific "sensitivity pattern" or "footprint" of the model (Figure 1).

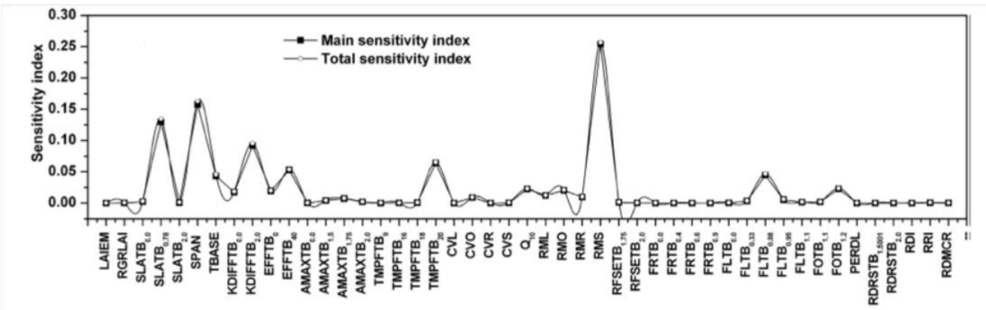

Figure 1 Example of "sensitivity pattern" of a model output with respect to a set of model inputs (x-axis). By computing main and total sensitivity indices, only a few model inputs reveal to be important in driving the model output variability.

The SA could be logically applied to the problem of validating, in a robust manner, a specific RN. Assuming that we have one real distribution grid and a set of "candidate" RNs (generated by one algorithm or already available in the literature), the validation problem can be intuitively translated into the question: "which RN shows the most similar sensitivity pattern with respect to that of the real grid?". In fact, the "most suitable" RN and the real distribution grid would be similarly sensitive to a specific set of model inputs (i.e., reacting in the similar way to the same perturbations).

The idea behind this SA-based validation approach is intuitively depicted in Figure 2. After applying this SA-based validation approach, by looking at the "sensitivity pattern" the analyst can take an informative decision on which RN best represents the real grid/network area under study. On the other hand, not only can the "most suitable" RN be chosen in an objective manner, but also the "boundary of applicability" of the "selected" RN can easily emerge by knowing its specific sensitivity pattern.

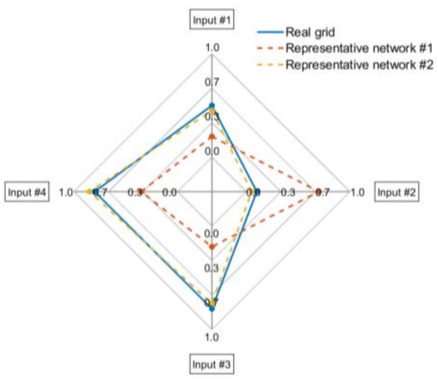

Figure 2 Intuitive visualization of the SA-based validation approach of two hypothetical RNs with respect to a specific real network. Along each of the four axes are reported the values of the sensitivity indices of the model output to four model inputs. After extracting the sensitivity pattern of the three networks (real grid, RN#1, RN#2), the RN#2 reveals to be the most suitable candidate for effectively representing the behavior and the characteristics of the real grid.

The overall goal of this thesis work is, after familiarizing with the RNs and SA topics, the development and testing of the SA-based validation framework presented above, as well as its comparison with other possible validation approaches already available in the literature.

Your tasks (and therefore the skills you will acquire):

- Literature review regarding RNs for distribution systems and state-of-the-art methods for their validation
- Analysis of suggested literature regarding SA
- Familiarize with one openly-available platform for generating RNs from a set of selected real distribution grids
- Familiarize with selected tools for power system analysis (e.g. MatPower in MatLab or Pandapower in Python)
- Familiarize with one selected tool for performing SA
- Elaboration and development of the SA-based validation approach
- Interface the SA tool with the power system analysis tools (in MatLab or Python)
- Test the SA-based validation approach with some real distribution grid models and compare it with other available approaches

Your profile:

- RWTH master student of Electrical Engineering (but students coming from other RWTH faculties or other universities are welcome to apply)
- Basic (but effective!) skills of MatLab or Python
- Previous knowledge of power system analysis as well as general knowledge of statistics is a plus
- Basic knowledge about distribution systems

Notes
The supervision will be done in English.

References

[1] Postigo Marcos, F.E.; Mateo Domingo, C.; Gómez San Román, T.; Palmintier, B.; Hodge, B.-M.; Krishnan, V.; De Cuadra García, F.; Mather, B. A Review of Power Distribution Test Feeders in the United States and the Need for Synthetic Representative Networks. *Energies* **2017**, *10*, 1896. https://doi.org/10.3390/en10111896

[2] Prettico G., Gangale F., Mengolini A., Lucas A. and Fulli G. ; DISTRIBUTION SYSTEM OPERATORS OBSERVATORY: From European Electricity Distribution Systems to Representative Distribution Networks; EUR 27927 EN; 10.2790/701791

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