FUNCTIONAL SCALABILITY AND REPLICABILITY ANALYSIS FRAMEWORK FOR DISTRIBUTION GRIDS

Sergio Potenciano Menci[1], Roman Schwalbe[1], Clemens Corner[1] Barbara Herndler [1], Johannes Kahtan[1], Christoph Gutschi[2], Thorsten Gross[3]*

[1]*Austrian Institute of Technology AIT, Giefinggasse 2, Vienna, Austria*
[2]*CyberGrid, Weimarer Strasse 119, 1190 Vienna, Austria*
[3]*Avacon Netz GmbH, Schillerstr. 3, Helmstedt, Germany*
* *barbara.herndler@ait.ac.at*

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Abstract

The current increase of renewable energy sources (RES) connected within medium voltage (MV) and low voltage (LV) networks, along with their system integration, is expected to continue to expand and increase their presence for the foreseeable future. It is therefore necessary not only to analyse the potential impact of the integration of these sources into the network but also to quantify their impact in combination with their respective control strategies which will be implemented when the devices are deployed at MV or LV. The Austrian Institute of Technology (AIT), therefore, aims to present a scalability and replicability framework to provide a standardized approach. This framework is a product of the developments acquired from various projects in which AIT participated as the leader of the scalability and replicability analysis (SRA) in distributed networks for the European projects, InteGrid and InterFlex, and the national funded project in Austria, LEAFS.

1 Introduction

In recent years, the distribution grid has experienced massive changes. The current and increasing large scale integration of renewables as described in [1], current digitalization of the metering assets and the introduction of new actors, such as Virtual Power Plants (VPP), are the drivers for change when developing a smart grid. These changes bring new challenges to the different actors in order to find diverse solutions to operation, integration, interconnection and maximization of the assets in order to create a more resilient and prosperous grid. In Europe, these challenges have been continuously addressed from different perspectives which cover the smart grid deployment. The European Commission aims to address these challenges through several projects [2]. The main conclusions derived from these projects is not only to create a concept but provide a solution where the set of functions developed can be scaled to production areas and replicated in many areas to maximize the potential of the solution and implement it in other networks, either nationally or internationally. Hence over the last years, European projects such as InteGrid [3] and InterFlex [4] have dealt with the topic of creating scalable and/or replicable solutions which can be realised within the future networks thereby extending beyond demonstration sites as potential deployment areas. The use of the Smart Grid Architecture Model (SGAM) [5] as a standard reference framework to provide an explanation of the solutions integrated in those projects provides a simplistic overview of the complexity which the smart grid is comprised of. It is no longer just a question as to whether the developed algorithms perform correctly or whether the components can communicate, it is in addition, a question of scale and whether the solution can be replicated elsewhere. Several methodologies have been developed and are continuously being improved in order to target and assess the scalability and replicability analysis (SRA) of Smart Grids as in InterFlex, InteGrid and LEAFS [6]. In these cases, the SRA methodologies usually distinguish between a technical and non-technical area. The technical areas are, the Functional-oriented, dealing with network impact and network logic, and the Information and Communication Technologies (ICT)-oriented, which targets the communication network and lastly, Economic-oriented, using cost benefit analysis. The non-technical analysis considers the Regulatory aspects and focuses on the international/national regulation.

In this paper, the framework which AIT has been developing and adapting to perform the functional oriented technical analysis is introduced. Additionally, the methodology and results obtained from the implementation of this framework within various SRA oriented projects, in which AIT participated, is presented. Therefore, section 2 considers the internal functional approach which AIT has been developing during the last years. Section 3 exposes some of the performed evaluations of such a framework within several projects, i.e. InteGrid,

InterFlex, and LEAFS. Section 4 provides a brief conclusion and perspective for future developments of the functional framework as per AIT's objectives.

2 AIT'S SRA framework

AIT's framework has been developed based on the requirements for each individual project considering the type of network analysis required. Some of the analyses include targeting the hosting capacity, network reinforcement, curtailment statistics, flexibility maximization provision, grid management, compiled in [7]. Given the diverse types of analyses and the versatility of them, the best strategy to re-use and keep adapting and improving certain techniques for network simulations was to consider a unified approach encapsulated within a framework. This framework is reflected in Figure 1, which provides a simple representation of the current status of AIT's functional framework developed for assessing the functional oriented SRA. Since all the analysis types require, at minimum, adequate network data, which is exclusively owned by the distribution system operators (DSOs), this data must be made available in addition to the functions they provide.

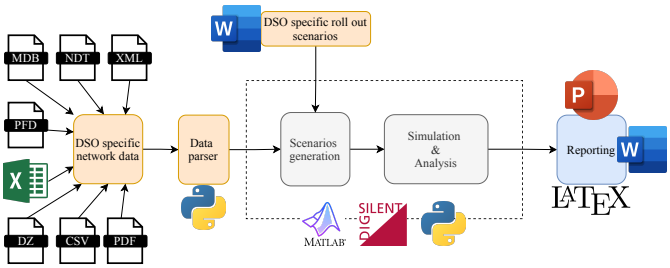

Fig. 1. Simplified functional SRA methodology developed.

However, currently, there is no standardized specification for technical data but rather each DSO has its own internal proceeding. Due to this fact, one of the first steps is to implement functions to parse and validate the received data. From the experience acquired over several international and national projects, this step is considered to be the most time consuming. However, the automation tools created for data parsing help reduce the time invested. Additionally, specific roll out scenarios for the DSO are created considering the interest of the DSO towards devices such as electric vehicles (EVs), inverters, batteries, heat pumps (HPs), etc. All the information gathered through community of practices [8] or direct meetings in addition to the roll out scenarios' definition, is then used for creating the scenarios in the frameworks used for the simulation. This significantly depends on the set of tools and devices which are to be included in the SRA. In most cases, the simulation is executed by means of DIgSILENT PowerFactory, which is a well-known tool to simulate and analyse electric grids and is capable of providing many inside features as mentioned in [9]. In other cases, specific tools developed are tested with Python or MATLAB. Once the results of the simulations are obtained, they are processed with python scripts in order to have a clear visualization of the results. Typically, after the necessary simulations and analyses of the corresponding results, reports are issued. The reports visualize the entire analysis in specific detail in order to present all relevant information obtained from the simulations.

3 Framework implementations

3.1 InterFlex

InterFlex is an EU Horizon 2020 project which focused on the local use of flexibilities when increasing the share of renewables within the distribution grid. The project incorporated the use of various smart grid technologies in order to facilitate the integration of renewable energy sources (RES), electric vehicles (EV), battery systems, cross energy carriers and grid automation. These concepts were demonstrated within real networks across five locations in Europe. In this context, the SRA encompasses all four focus areas of the SRA (functional, ICT, economic and regulatory). Due to the significant interest of DSOs with respect to the functional area, AIT's framework is used in this focus area for the analysis of the impact of several smart grid functions on the network. Although the analysis was conducted within all five demonstrations as presented in [10], the results of the German analysis are selected as it provides a DSO based solution with no aggregator or market involvement. The DSO uses flexibility for its network operation through feed-in management and demand response techniques. Hence, the analysis of the potential implementation of a large scale roll out of controllable devices, photovoltaic (PV); night storage heaters (NSH); heat pumps (HP) over an entire year with the potential of being used as flexibility sources was necessary. During this analysis, the control of flexibilities is achieved through the use of the $cos\phi(P)$ function integrated within PV inverters, as per the German LV Grid code [11], an on-off delta function was used for the NSH and a peak interval reduction function was used for the control of HP. The set of solutions is heavily tested in the demonstration's real rural LV network, which is composed of a total of six feeders and a total of 123 customers using quasi-dynamic power flows. An example network is shown in Figure 2 .

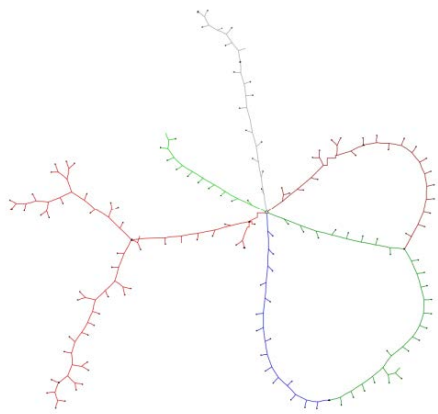

Fig. 2. Local DE demo area analysed.

The SRA uses as a baseline the status quo conditions of the demo and then compares the results of monte-carlo simulations with 50% and 100% of customer involvement whether they can be activated or not. On the one hand, the scalability analysis focuses on the increase of flexibility sources, the number of them, their size, or their controllability. On the other hand, the replicability analysis focuses on the seasonal impact since the devices are seasonally dependent. Figure 3 exposes one of the key performance indicators (KPIs) calculated, maximum line loading per feeder. This KPI identifies the maximum loading of each line within a feeder and establishes whether the network limit (100%) is violated. The set of solutions clearly reduces the maximum line loading when implemented, although, in one of the feeders it is heavily loaded, which would lead to smart curtailment in order not to exceed the threshold limit.

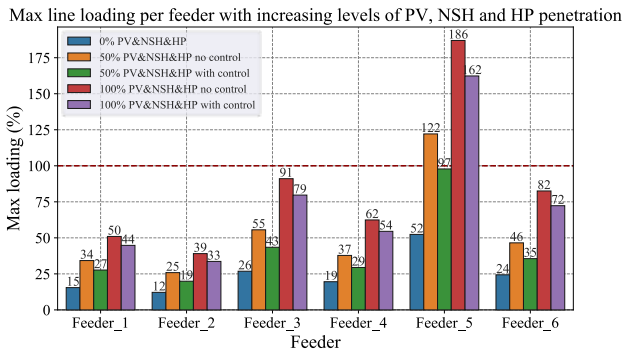

Fig. 3. DE demo InterFlex max loading.

During the replicability analysis, the mean values over each day are used to highlight the feeder loading per day. This is shown in Figure 4 and Figure 5, which represent the worst-case scenario with a full roll out scale without control and with control respectively. The results clearly show the impact of non-controllable devices and how the issues can be mitigated through the introduction of smart solutions, as the demand on the winter season gets reduced.

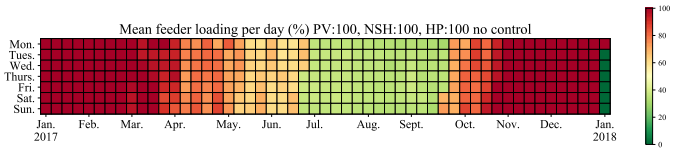

Fig. 4. Mean loading per day with no control functions.

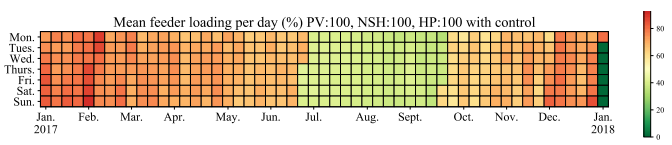

Fig. 5. Mean loading per day with control functions.

3.2 *InteGrid*

InteGrid is an EU Horizon 2020 project with demonstrations in Portugal, Sweden and Slovenia, with two main focus areas. The first area focuses on the role of the DSO as a system optimizer and as a market facilitator for the use of flexibility products. The second, on the integration of single solutions, while examining the scalability and replicability. Hence, the SRA plays a major contribution to the project as it is an essential component in providing a deeper view from the different focus areas of the SRA (Functional, ICT, Economic and Regulatory), of which are further presented in [12] and [13]. AIT's framework helps target the Functional oriented SRA. The analysis is divided into clusters due to the necessity of providing a deployment context for the interactions of the integrated solutions. These clusters consider a variety of devices to integrate, which range from home energy management systems (HEMS) to large scale batteries or residential batteries, wind farms, solar panels or the inclusion of a water treatment plant. However, in this paper focus is given to cluster 3 in order to demonstrate the flexibility of the framework. This cluster is demonstrated in Slovenia and consists of a Virtual Power Plant (VPP) which provides flexibility offers for tertiary reserve and a Traffic Light System (TLS) that validates these offers in day-ahead and intraday. The network is a real semi-rural MV network with 720 nodes, 710 branches and 339 customers, represented in Figure 6.

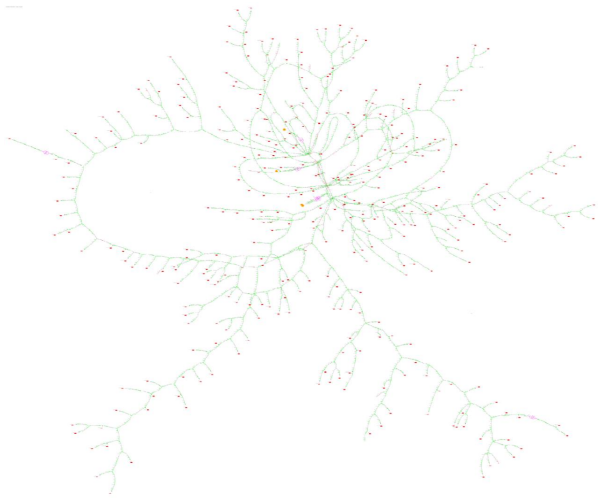

Fig. 6. Slovenian network graph.

In this network, the flexibility bids from the VPP are analysed making use of power flow and optimal power flow simulations conducted to observe during the week and weekend days in one season using the multi-period optimal power flow (MPOPF) developed in the project. In this set up, an evaluated is made from a scalability point of view as to how much flexibility can be introduced into the grid without causing violations and varying the network sizes to test the performance of the TLS. From a replicability point of view, bid prices (economically driven) versus distributed generation location (technically driven) are compared in addition to the extension of electric

vehicles and wind turbines into the network and different network types (urban and rural). The results obtained are partially represented in Figure 7, which shows the results of the TLS evaluation of the maximum total flexibility of upwards (generation) versus downwards (loads) for a weekday based on the cases where it is economically driven (the OPF tries to curtail flexibilities with high prices first) versus technically driven (flexibilities with location where the impact is the highest, are curtailed first). Figure 7 compares the results of a technically driven simulation with an economic scenario where flexibilities at the end of the feeders are cheaper and the ones closer to the primary substation are more expensive. The plot shows the relative change of flexibility volume which can be activated in each feeder between the technical and economic scenario. The results for the downward evaluation are comparable. However, for downward flexibilities up to 2.5% less flexibility volume can be activated in some feeders. For the opposite case (economically driven), where cheaper flexibilities are located close to the primary substation and more expensive flexibilities at the end of the feeders, the results of the upward evaluations are similar and the feeders can accommodate less flexibilities in the downward case.

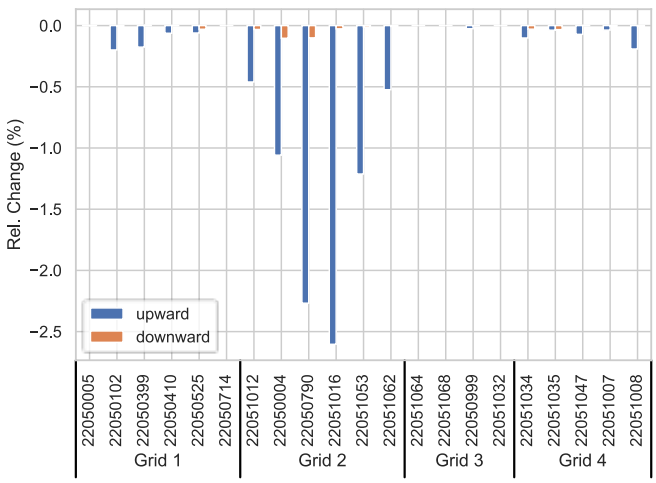

Fig. 7 Comparison of the maximum total flexibility of the units connected to feeders between a technical and an economic scenario.

The mere activation, per se, of the current flexibilities has almost no impact, thus can be neglected by the DSO. However, when upscaling the flexibility penetration and their quantities, more challenging situations arise which could result in primary substation loading, line loading or voltage band violations. In exactly these scenarios the TLS provides a solution. The TLS is a system which supports the DSO in the evaluation of flexibility bids and suggests to the grid operator possible curtailment options in order to avoid the potential problems. The TLS considers the following points when evaluating the flexibility bids 1) it tries to increase the total quantity of flexibility volume in the grid 2) by also considering the prices of the bids and selecting preferably cheaper bids. In the case of the SRA the developed framework which assessed the impact of the incorporated TLS system demonstrated the success of the system in large scale networks.

3.3 LEAFS

The LEAFS project is developed under the Energy Innovation Austria framework which targets three locations in Austria. In it, the impact of new network devices such as PV, EV, HP, central and home storage systems on distributed low voltage grids was analysed. Additionally, since there was a growing interest in the flexibility potential of such new devices in the network, device flexibility was analysed and demonstrated in field testing. The SRA was used to quantify the impact of an increase in PV and EV and their control strategies under mainly the functional and, secondarily, the economic focus areas. The penetration of these devices was increased by vast numbers for the LV networks of two major Austrian DSOs which account for 20% of Austria's distribution network. These networks in total are comprised of approximately 15.000 customers, with more than 46.000 feeders and nearly 1.1 million connection points (metering points) ranging from rural, to semi-rural or sub-urban networks. From the overall data provided, around two third of the grids were suitable for calculations, the rest had to be excluded for various reasons. One main outcome of the calculations is that the analysed future PV penetration scenario is suitable to fulfil the Austrian mission 2030 PV target [14] and no major challenge were identified based on the results of the analysed LV grids. In contrast to this, the analysed future EV penetration scenarios might lead to a significant reinforcement demand. Nevertheless, the results strongly depend on the chosen parameter assumptions. By using AIT's functional oriented framework in addition to some economic inputs, it was possible to determine the necessary grid reinforcement demand for transformers and lines for each grid in detail under the given parameters and assumptions used within the simulation. The results obtained can be a starting point for full economic SRA where future trends are incorporated. The calculations of the future scenarios are based on symmetric three-phase power flow calculations of the two worst-case use-cases commonly used in power system planning (namely the high-load-no-infeed and the low-load-high-infeed scenario).

Figure 8 shows the grid reinforcement calculation for approximate 3500 grids to enable future EV home charging (11 kW) scenario with 100% penetration (each household with an EV) and a 0.5 coincidence factor. The grey boxes show the existing transformer count of the respective apparent power (x-axis). The coloured boxes show the transformers that need to be upgraded to a higher apparent power rating to solve grid constraints evoked by the analysed future EV scenario. For instance, from 486 existing 100 kVA transformers, 178 have to be upgraded to 160 kVA and 99 have to be upgraded to 250 kVA. From these numbers, it can be concluded that the 100% EV penetration scenario with 11 kW charging with a coincidence factor of 0.5 might be a considerable challenge for low voltage grids if it is applied to the existing status of the grid.

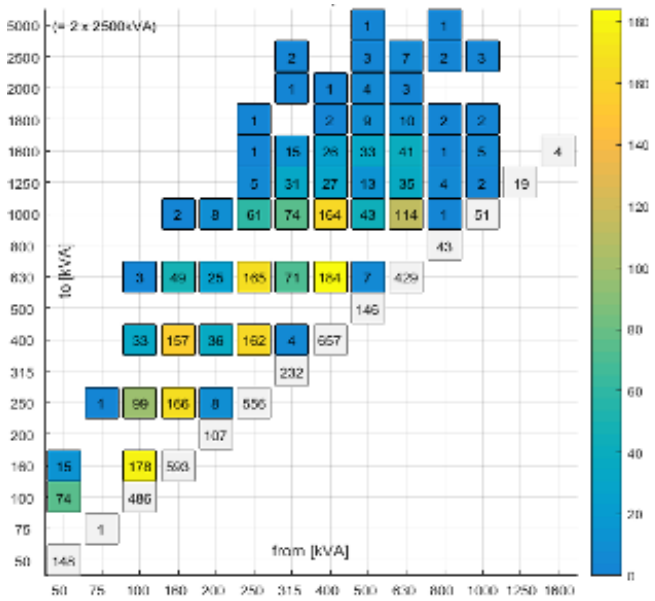

Fig. 8. Necessary transformer upgrade for future EV scenario.

4 Conclusion & Future work

As exposed through the different examples for the Functional oriented SRA using AIT's framework, many technical outputs can be achieved due to its modularity and adaptability to the requirements of each system and stakeholder. Although the framework is technically proven, it is consistently and continuously being further developed. Achieving an even more modular framework and incorporating standardization i.e., network data exchange, will further enable the automatization process and boost the quick and efficient use case description and testing. This will result in the ability to perform investigations of larger scope with more variations to offer even higher degrees of analysis. Hence, AIT's practically proven framework, with ongoing developments, seeks to provide a standardized and modular approach to be adapted to DSO specifications. The framework also provides a potential solution to the upcoming data handling issue, where data privacy creates some inconvenience as this framework can be run as an external service for the DSO. Additionally, the framework is able to run large number of simulations in a reduced timeframe while offering standardized and adjustable reporting for ease and clarity of results in order to facilitate knowledge transfer.

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