Popular Abstract

The need for a transition of the energy system towards relying on renewable energy sources has caused a need for electrification in the transport and heating sectors and an emphasis on local distributed electricity generation. This tendency is expected to promote an increasing adoption of distributed energy resources (DER) technologies among actors in the electricity system. In particular, residential consumers are expected to widely adopt technologies such as personal electric vehicles, heat pumps, photovoltaic panels and residential storage batteries, which enable them to participate in the electricity system actively as prosumers. Furthermore, the adoption of the four DER technologies introduces new loads and generations in the electricity grid, possibly causing significant peak loads and power fluctuations. Parts of the existing distribution grid might not be sufficiently dimensioned to support future impacts from DER technologies, which concerns the distributed energy operators (DSO) who must ensure grid reliability and electricity security of supply. Determining the location, extent and characteristics of possible overloads in the grid due to DER adoption is therefore imperative for planning necessary actions to prevent overloads and grid faults. While several tools exist to analyse energy systems with residential DER technologies, the number of available tools that combine multiple different DER technologies with an electricity distribution system representation and an innovation adoption representation is limited.

Agent-based modelling and simulation methodology is employed to develop a simulation framework, DERInGrid, that can be used to analyse the complexity and reveal emergent electricity load and generation patterns caused by the operation of DER devices in the distribution grid. The development of the proposed simulation framework relies on an ecosystem mapping methodology where actors and objects in a system are identified along with their roles and relations and summarised in a mapping of the system. The entities from the mapped ecosystem are then translated into corresponding parts in the developed simulation framework in a convenient one-to-one manner. A cornerstone in the designed simulation framework is the use of the interface concept from object-oriented programming to define and restrict how agents in the framework interact with each other. This approach gives a flexible, modular and extensible simulation where the agents that implement the same interface can replace each other without changing other agents in the simulation framework.

The DERInGrid framework has been applied to three different case study distribution grid systems to validate its suitability to investigate the impact of DER technologies in distribution grids. For this purpose, six scenarios and a set of hypotheses have been established, each analysing how a particular parameter or property affects the power flow patterns that emerge in the case study systems. By using the results from the experiments performed using the simulation framework, the hypotheses have successfully been evaluated, and the DERInGrid has been validated as a viable solution for the analysis of how distribution grids are impacted by DERs. Furthermore, the agents in the DER module from the DERInGrid framework were replaced with a set of DER agents developed by a separate research team. By applying the established interfaces to this set of agents, it was possible to directly use them in the framework in place of the original DER agents. This revealed that the interface approach successfully provides modularity to the framework.

The contribution of the research and the developed DERInGrid framework presented in this thesis is twofold:

- Firstly, the framework can be used as a tool by DSOs for identifying parts of the distribution grid that are vulnerable to overloads due to the adoption of DERs and for analysing the characteristics of these overloads.
- Secondly, the framework serves as the first step toward a larger-scale framework that combines multiple sectors in the energy system in extended geographical, social and technological scopes.