Agent-based framework for simulating evolution of DER in energy systems

PhD project - Magnus Værbak - Center for Energy Informatics, University of Southern Denmark

SDU

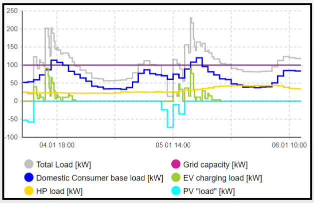
Background and purpose

The need for renewable transition of the Danish energy sector necessities a transition of the heating and transportation sectors to rely on electricity, which can conveniently be produced from mature renewable technologies, such as wind turbines and photovoltaics. Part of this transition comprises residential actors' adoption of electric vehicles, heat pumps and possibly small-scale electricity generation and storage equipment, hence allowing them to act as prosumers, offering demand and generation capacities to the electricity system. However, the adoption of these distributed energy resource (DER) technologies has given rise to concern among distributed electricity system operators whose grids have been established in the past where the development in DER usage could not be foreseen, and hence lack the capacity to support the increased load magnitudes that DERs might cause. Before any actions, such as grid extensions, are carried out, it is necessary to model and investigate these potential overloads caused by DERs.

However, complex systems, such as an energy system with decentral actors, are difficult to model and analyse using “classic” approaches, e.g. equation systems or linear programming. Three major aspects that cause this complexity are:

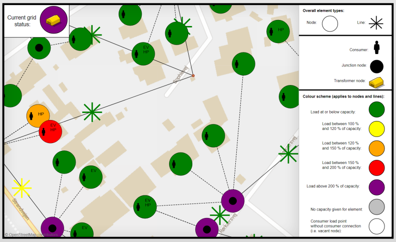
- **Self-organization:** A system does not always contain a leader/controller who coordinates the overall behaviour of the actors. Instead, actors might organize themselves spontaneously in a way that causes order in the system.
- **Non-determinism:** Individual actors in the system only possess, and can only respond to, partial knowledge about the system. Furthermore, a considerable of randomness arise due to the individual actors' spontaneous behaviour.
- **Dynamic system topology:** The behaviour of individual actors in the system and their influences on each other might change radically depending on certain conditions. Actors might be appear and disappear entirely.

The multi-agent modelling approach can help model the dynamics of a system that features the above properties. Simulation is more intuitive and treats the individual agents (or populations hereof) as separate objects who interact and affect each other and their environment, each agent following their own set of rules.



Distributed system transformer sub-station loads monitored during simulation run-time

Objectives



Simulation model topology representation - nodes are connected and change colour depending on their magnitudes of overload, along with DER technologies adopted by consumers

The objective of the research conducted in this thesis is to investigate the characteristics of overloads in low-voltage electricity distribution grids that are caused by DER adoption among residential electricity consumers connected to the grid.The timing, magnitude and cause of these overloads are analysed, and the overloads are furthermore divided into three levels depending on where in the grid they occur:

- **Electricity consumer connection points** - the electricity load capacity that is allocated to each single residential consumer
- **Distribution grid sub-components** - the components found within the electricity distribution grid, e.g. cables and junction boxes
- **Transformer sub-station** - the sub-station that connects and feeds in electricity to the entire distribution grid

Investigated scenarios include various prevalences of the following distributed energy resources:

- **Electric vehicles**
- **Heat pumps**
- **Roof-top photovoltaics**

While not the main focus of the research per se, the emergent impact of changes to the logic of the individual consumer or technology agents, e.g. by introducing flexibility schemes, can be investigated as well by adding this changed logic to the existing agents as sub-components.

Based on the overload patterns that emerge in different scenarios, a subsequent objective is to produce information on whether a specific grid is resilient to future DER adoptions, where and when grid extensions become necessary, and whether such extensions can be postponed or reduced by using flexibility/consumer demand-response schemes.

Methodology

The multi agent-based software simulation platform, AnyLogic, is used for the modelling. This platform is quite versatile as it also provides System Dynamics and Discrete Event modelling functionality which can be combined with the agent-based modelling.

The simulation modelling methodology comprises a structured set of steps that can be summarised as follows:

1. The system to be simulated is mapped as a network (or ecosystem) of actors that each assumes a certain set of roles. Based on these roles, the actors interact with each other through specific types of relations.
2. The actors and roles from the system mapping are turned into agent types and object-oriented programming interfaces, respectively. The interfaces are furthermore given sets of methods that reflect the services they are going to provide in the simulation.
3. Relations are established between the agent-types based on their interfaces, and the ownership hierarchy between the agent types is furthermore implemented.
4. The logic of the individual agent types is defined.

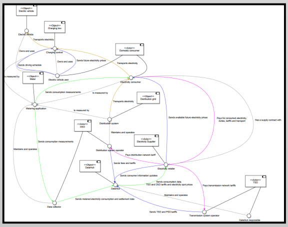
A central aspect pertaining to the methodology is that all interactions between agents are based on the roles, i.e. the interfaces, assumed by the agents. This ensures proper encapsulation between agents, allows different agent types to assume the same role and provide the corresponding services, and it furthermore promotes reusability of certain components in the simulation models.

The simulation model used for investigating the distribution system grid overloads currently comprises agents which can roughly be grouped as follows:

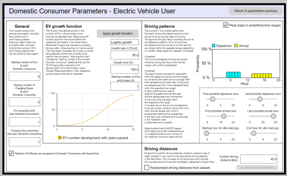
- **Central actor agents:** Large actors that maintain the grids or trade electricity on the market and sell it to the consumers. The distribution system operator belongs to this group.
- **Decentral actor agents:** Small actors that are often numerous and who perform autonomous decisions and actions with limited knowledge and concern of the overall system. The residential electricity consumer belongs to this group.
- **Service appliance/object agents:** Appliances that provide certain comfort, convenience or services needed by the owners. Electric vehicles and (heated) residential building spaces belong in this group.
- **Electricity appliance agents:** Appliances that consume and/or produce electricity to the grid, usually fuelling service appliance/object agents in the process. Electric vehicle charging boxes, heat pumps and roof-top photovoltaics belong in this group.
- **Grid component agents:** Components that constitute the electricity grid which transport electricity from the top-level transformer sub-station to the load appliance agents. Cables, junction nodes and transformer sub-stations belong in this group.

A notable feature of the model is that it automatically generates a topology representation of the simulated electricity distribution system and its residential consumers connections based on input information pertaining to the components and consumer connection points in the grid. Electricity loads and productions that commence in the lowest level of the grid, is then aggregated upwards in the grid topology, with the transformer sub-station that connects the distribution grid to the rest of the electricity system being the highest leveled node, hence aggregating all loads and generations in the grid.

Finally, a user interface is provided where numerous paramters pertaining to the agents can be set before simulations are run, hence allowing for convenient testing and evaluation of different proposed scenarios. These parameters include functions that determine the adoption of DERs over time among the residential consumers.



Mapping of ecosystem actors, roles and relations of modelled energy ecosystem



User interface for electric vehicle user role parameters

Collaboration and contributions

TREFOR

FED FLEXIBLE ENERGY DENMARK

anylogic

CENTER DENMARK

The PhD research project is part of Flexible Energy Denmark, a joint effort between distribution system operators, industrial actors and universities/research institutes to promote digitalisation of the Danish electricity sector and employ demand-side flexibility to efficiently exploit intermittent renewable electricity generation. The project includes a shared data-lake (Center Denmark) that contains data on the electricity distribution grids maintained by the partner distribution system operators and the consumers connected to those. The simulations performed as part of this research therefore use characteristics and electricity and heat consumption data of real residential consumers, and grid topology information of the grids to which they are connected. The outputs gained from the simulations can therefore be used to give realistic recommendations to the distribution system operator, in this particular case TREFOR.

The long-term contribution expected from the research is a decision-making simulation tool that can be applied by distributed system operators to evaluate how their existing grids perform when consumers adopt new electricity consuming and producing technologies and/or change their use behaviour pertaining to those technologies. The operator can then use the simulation outputs to plan how future grid extensions or consumer flexibility incentive schemes should be executed.

PhD poster - Author: Magnus Værbak - Supervisor: Bo Nørregaard Jørgensen - Co-supervisors: Zheng Ma, Yves Demazeau - PhD period: 2018 to 2022
University of Southern Denmark, The Mærsk McKinney-Møller Institute, Center for Energy Informatics