THE PLANGRIDEV DISTRIBUTION GRID SIMULATION TOOL WITH EV MODELS

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ABSTRACT

This paper presents a new simulation tool which studies the impact of the deployment of electric vehicles in distribution networks. The tool optimizes the operation of the system and is based on grid operation simulation, which takes the flexibility of controllable resources into account. The problem is tackled as an optimal power flow problem. The tool allows modelling the different kinds of distributed energy resources. *The different components of the model are first presented. Then, the inputs are described and some outputs are shown.*

INTRODUCTION

The roll-out of Electric vehicles (EVs) is gaining traction. EV charging will have an impact in the distribution grid, as it is a relatively high-power load and consumes a significant amount of energy. Furthermore, distributed energy resources (DER) such as roof-top photovoltaic (PV) systems are already widely rolled out today in a number of European countries. Distribution system operators have to manage the exploitation of the grid in accordance with standards such as EN50160, which defines minimum levels of quality of supply for end-users.

To assess the impact of the integration of EV and DER, and support the distribution grid planning process, new simulation approaches are being developed. Functionalities such as time-shifting of EV charging or modulation of charging power have historically not been modelled in commercial power flow simulation tools. Equally, reactive power control capabilities and (partial) curtailment of PV have not been taken into account typically. Using these capabilities may come at a cost to the owner or operator.

The distribution grid simulation tool that has been developed as part of the PlanGridEV project [1], to assess the issues detailed above, is the subject of this article. The overall objective of the PlanGridEV project is to develop new network planning tools and methods for European DSOs to support an optimized large-scale roll-out of electric vehicles whilst at the same time maximizing the potential of DER integration. The project aims to update tools and methods to address local load and congestion issues, based on the management of EV charging processes. A prototype tool is developed as part of WP4. The developed prototype builds upon the analysis, models and methods developed and published in public deliverables D4.1 and D4.2 [1].

SIMULATION TOOL

The PlanGridEV prototype tool performs a grid operation simulation, which takes the flexibility of controllable resources into account. This problem is tackled as an optimal power flow problem. Optimal power flow (OPF) problems are formulated to optimize power system related operational choices (*i.e.* decision variables). Next to unit characteristics, OPF problems take into account the physical behaviour of the grid.

The tool is built around a state-of-the-art large-scale multi-period AC OPF calculation core (static & balanced), focusing on radial grids for calculation speed advantages (exactness of convex relaxation under mild conditions [6]). It includes support for a library of flexible unit models for generic loads and generators, as well as a library of technology-specific models for PV, wind, EVs and stationary battery storage [2,3].

The OPF calculation core tackles both low-voltage and medium-voltage studies. The mathematical methods used are valid, robust, and have sufficient numerical performance for simulation of radial networks of varying voltage levels, with combinations of cables and lines, and for varying X/R ratios.

Unit modelling

A library of unit models is provided with the tool, including curtailable generators, sheddable loads, PV system models and EVs (including vehicle-to-grid). For DER and EV, the tool includes methods to generate representative behaviour, to simplify the setup of case studies by the user. The unit modelling aspects have detailed in [3,5]. Multiple units can be connected to a single node. The supported unit models in the tool are illustrated in Table 1.

Table 1 Classification of supported unit models.

unit model library						
consumer		generator			bidirectional	
buffer downstream	no buffer	no buffer			electricity storage	
EV	generic	generic	PV	Wind	EV V2G	BESS

Units have a unit-specific operational cost model. Generation and consumption costs are based on tariffs, but a cost for curtailment and load shedding can be used as well. For example, if the generator is curtailable, it means that the active power generation can be reduced, implemented in the tool in a continuous fashion. This means that there can be energy not generated, which represents an opportunity cost. This flexibility, albeit potentially costly, can then be used to stretch the limits of feasible grid operation.

EVs have a more detailed cost model, taking into account consumption and V2G injection, as well as using the range-extender. For the simulation models of wind & PV stochastic approaches have been implemented, which allows to generate representative generation profiles. For the EVs, the power consumption during driving as well as the mobility behaviour (sequences of locations) are modelled [4]. The EV model is similar to typical specifications of current vehicles, with 24 kWh of energy capacity, either 3.3 kW or 6.6 kW charging power, and a charging efficiency of 95 %. The EVs can alternatively be considered as plug-in hybrids / range-extended EVs, including the fuel cost of the operation of the internal combustion engine.

Grid modelling

A grid is composed out of grid elements. Each grid element connects two different nodes. Grid elements can be overhead lines, underground cables or transformers. Grid elements have an impedance representation determined by the technology and possibly the length. Table 2 illustrates the classification of the grid elements.

Table 2 Classification of supported grid elements.

grid elements				
overhead line		underground cable		transformer
impedance		impedance		impedance
technology	length	technology	length	technology

Internally, lines, cables and transformers, are represented as pi-sections. As depicted in Figure 1, it is assumed that shunt conductance is negligible. The user can define length-normalized technology-specific parameter sets for lines, cables and transformers. This allows the user to flexibly define specific sections and topologies.

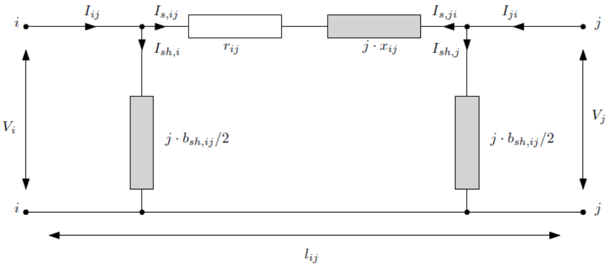


Figure 1 Pi-section representation of a grid element.

Cables and lines therefore have the properties of specific series resistance, specific series reactance, and specific shunt susceptance. Using the length of the section, the specific impedances are converted to absolute impedances. Transformers are defined straight-away through absolute impedance values. Separating the technology-specific and application-specific parameters allows for convenient re-use of parameter sets. Flow ratings can be given in the basis of apparent power and/or in the basis of current.

The topology of the network is defined by origin and destination of nodes. Between these nodes, the cables / lines / transformers which have been defined, can be used.

EV modelling details

Both domains are brought together in the prototype tool. Mapping of units to nodes occurs across time. While conventional resources such as power plants (*e.g.* CCGT, CHP) do not physically change location (grid node), the assignment of EVs to electrical nodes varies with time do to their mobility behaviour. Furthermore, as EVs can also leave the simulated grid area and charge at other locations, an *external node* is included to model the external charging actions. Furthermore, during driving, EVs are not grid-connected.

Finally, to model different levels of control freedom in the charging, ‘charging modes’ are defined. Table 3 illustrates the charging modes. The ‘conventional’ mode models typical user behaviour: charging as quickly as possibly when stopped and when charging infrastructure is available. Conversely, the ‘smart grid’ charging mode minimizes charging costs, while also being grid-friendly (not *causing* overloads/voltage problems). There is a distinction in this case between just charging and also using vehicle-to-grid. Depending on the mode (conventional, safe, proactive, smart grid), charging is on-off modulated or continuous.

Table 3 Definition of charging modes.

	conven-tional	**safe**	**proactive**	**smart grid unidir.**	**smart grid bidir.**
charge manag.	asap	asap except peak pricing	charg. cost min.	charg. cost min.	charg. cost min.
flow	on-off charg.	on-off charg.	on-off charg.	cont. charg.	cont. V2G

charg. = charging, min. = minimization, unidir. = unidirectional, bidir. = bidirectional, cont. = continuous, manag. = management

INPUT

The model is built directly in a spreadsheet input file, what is suitable to develop large distribution model containing lot of grid components.

There are number of requirements on case studies as a whole:

- radial grid structure in operation (open-loop);
- 1 grid : 1 slack bus : 1-to-n grid nodes;
- 1 grid node : 0-to-n units;

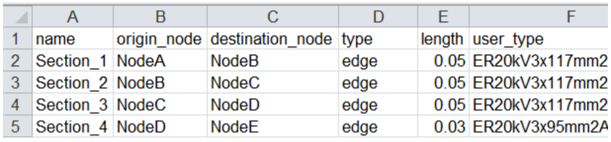
- series resistance nonnegative;
- time profiles:
  - can have different lengths;
  - the simulation time step will be in the range of 15 min to 4 h.

First, the "settings sheet" must be filled out (illustrated in Table 4). It contains the settings of the simulation, including the type of charging mode of the EVs (as specified here above). Simulation settings influence the results and can be used, without having to change data values. This functionality can be used to debug, compare with other tools, solve smaller case study to reduce waiting time, or to relax constraints.

Table 4 Simulation settings illustration.

case settings	example value
voltage limits applied?	yes
flow limit applied?	yes
apparent power limit applied?	yes
grid losses in cost objective?	no
EV charging mode (see Table 3)	conventional
operation horizon	5 days

Next, in the "simulation parameters sheet", the user specifies problem-specific parameters. The elements of the grid are defined in the cables/lines/transformers sheets and are used in the "topology" sheet where the grid is explicitly described. illustrates how a topology can be set up in the input template. Several additional sheets are dedicated to the definition of the DERs. In case of user-defined EVs, driving profiles as well as consumption profiles which must be defined in the "EV profiles sheet".



	A	B	C	D	E	F
1	name	origin_node	destination_node	type	length	user_type
2	Section_1	NodeA	NodeB	edge	0.05	ER20kV3x117mm2
3	Section_2	NodeB	NodeC	edge	0.05	ER20kV3x117mm2
4	Section_3	NodeC	NodeD	edge	0.05	ER20kV3x117mm2
5	Section_4	NodeD	NodeE	edge	0.03	ER20kV3x95mm2A

Figure 2 An easy-to-use spreadsheet input file - definition of a topology.

Stochastic methods

Distributed energy resources such as PV systems and wind turbines are modelled as generators, either generic generators or curtailable generators. The profiles for the PV, wind and EVs are obtained through stochastic methods.

Since one of the main objectives of the project PlanGridEV is to maximize the integration of DERs in power grids through EV roll-outs, methods for providing appropriate generation profiles from DERs has been an important part of the work within the project. It allows generating representative generation profiles. Figure 3 illustrates a PV generation profile generated as such.

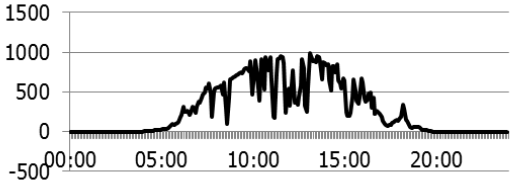


Figure 3 Example of generated PV profile (kW).

The stochastic nature of DER follows the general modular framework depicted in Figure 4. Measured weather data is used as input to the statistical model which, in turn, generates synthetic weather data with the respective statistical characteristics. A physical model uses the synthetic weather data to provide the resulting power characteristics. An aggregation model serves to model uncertainties and statistical effects of multiple spatially distributed DER units.

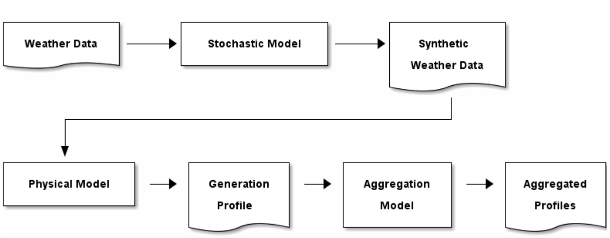


Figure 4 Modular DER modelling methodology overview.

Concerning the statistical generation of EV mobility profiles, a method was developed capable of addressing different environments in different countries, based on available mobility statistics. It generates a population of EVs within a given area, samples a travel chain and estimates the distance driven during the multiple travel segments of each EV.

OUTPUT

The DER profiles obtained through the stochastic approach, and used in the OPF, ultimately are also returned to the user, allowing the user to replicate results. Furthermore, for the sampled EVs, the mobility behaviour and power consumption during driving profiles are returned.

Due to the large-scale and multiperiod nature of the simulation, the tool returns a significant amount of numerical results. It is rather time-consuming to explore such results using conventional spreadsheet plotting methods. Therefore, to streamline the interpretation and analysis of the results, next to the numerical results, the tool returns a number of figures, all adhering to a common visualization approach. A modified box plot (Figure 5) is used to represent time profiles. The modified boxplot depicts the minimum value, the 5th percentile, the 25th percentile, the 75th percentile, the 95th percentile and the maximum value.

Figure 5 Definition of modified box plot. The values depict the percentiles of the profile.

Visualization approach

Five distinct figure types (png) are returned together with the numerical results (xls):

- input summary figure: nodes – units;
- grid element results: TF – line – cable;
- node results;
- unit results:
    - EVs separately;
    - consumer, generator, DER together.

The figures depict scalar values, discrete values (from finite sets) and profiles associated with the different elements (nodes, lines, units). Indexing (rows) is maintained across all the columns in one figure. The approach is the following:

- discrete values are depicted with dots;
- scalar values are depicted with bar plots;
- profiles are depicted with special box plots;
- labels on the leftmost and rightmost axis of the outmost figures are used for indexing.

Figure 6 illustrates the simulated power flows through four sections with the IDs depicted on the left-hand side. The active and reactive power flow in the depicted case is always in the same direction (positive flow from origin node to destination node). Only the current magnitude is depicted (the complex-valued currents can be found in the spreadsheet file). In case grid elements have shunt susceptance, the currents from origin to destination and vice-versa don’t mirror each other, therefore complex currents values for both directions are returned.

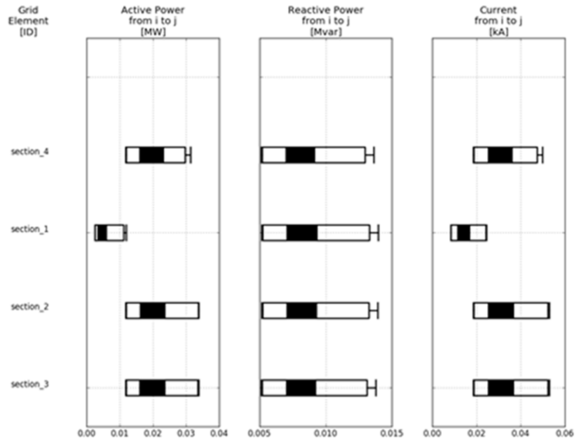


Figure 6 Box plot representation of time profiles (sets of continuous values) illustrated for the grid element results.

CONCLUSIONS

The paper proposes a new simulation tool. It studies the impact of EVs deployment in distribution networks. The tool optimizes the operation of the system and is based on grid operation simulation. The flexibility of controllable resources (decentralised generation, load and EVs) is considered in the optimization. The problem is tackled as a multi-period optimal power flow problem. Different kinds of distributed energy resources and EVs are supported by the tool. The tool includes stochastic methods to generate representative case study data, which simplify the data gathering aspects of case study development. Results of a case study developed within the PlanGridEV project and calculated with the tool are illustrated in companion paper [7].

ACKNOWLEDGEMENT

This work is part of European FP7 Project. The authors would like to thank the project partners for fruitful discussions during the project.

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement No. 608957.

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