A HOLISTIC NETWORK PLANNING APPROACH: ENHANCEMENT OF THE GRID EXPANSION USING THE FLEXIBILITY OF NETWORK PARTICIPANTS

Lars JENDERNALIK
Dominique GIAVARRA
Westnetz GmbH
lars.jendernalik@westnetz.de

Christoph ENGELS
Univ. of Appl. Sciences Dortmund
christoph.engels@fh-dortmund.de

Johannes HIRY
Chris KITTL
Christian REHTANZ
TU Dortmund University
johannes.hiry@tu-dortmund.de

ABSTRACT

DSO's are facing significant challenges in network planning due to the integration of DER, Smart Grid technologies, E-Mobility, regulation and volatile market conditions. In previous work it was shown (A) how DSO's are able to optimize planning of network assets in the presence of high uncertainty [1] and (B) how to describe the interdependencies between all market participants in an agent-based fashion to derive forecasts of prices, generation & demand [3]. Here the integration of these solutions across all voltage levels by means of long-term network planning is presented. Thereby smart grid components extend the traditional grid planning process. This extension merges time-series based network planning approaches with models of active and reactive innovative network participants. This results in robust and future-proofed network planning.

INTRODUCTION

While there have been several publications in the past considering the optimal combination of asset strategy and network planning for upper voltage levels under uncertain conditions [1,2], as well as different ways of generating time series for grid planning, the presented approach creates added value by merging these two fields to improve the electricity grid planning process.

Previous work proposed an optimised planning procedure under consideration of assets' condition [1]. It provides functional valid grid structures in terms of asset condition and asset capacity (induced by the load and feeder) by means of replacement, enforcement and expansion of physical network elements. In contrast the dynamics of market participants also allow the utilization of flexibilities in terms of demand side management, adaptation of regulation frameworks, storage technologies and market mechanisms. Earlier work lead to an agent based simulation framework [3] capable of providing time series based grid utilization analysis. The combination of both approaches in the scope of "Agent.GridPlan" project allows for an integrated assessment of structural and operational measures and thus will result in more realistic and optimal solutions for holistic target grid planning.

APPROACH

This contribution is integrating the previous approaches across all voltage levels in following steps:

1. **Input:** The provision of global market conditions is complemented by regulatory rules. The expected energy mixture in terms of installed capacity is projected into the future. Weather and supply tasks describe a set of actual load and feeder situation in a specific hour which have to be applied to the network system.

2. **Analysis:** The usage of the actual network in terms of capacity, condition (age) and behaviour of market participants is analysed by means of agent-based-, asset- and power-flow simulation across all voltage levels using the input defined previously. The analysis leads to potential violations of the network capacities or asset conditions in a so called hotspot analysis.

3. **Fitness Restoration:** An optimal network adaptation is proposed by optimization techniques to balance the resulting future grid between the options of curtailment or structural change (e.g. the addition of (innovative) assets).

4. **Systems Results:** As an outcome the network planner is able to prioritize actions due to the probabilities of scenarios. Furthermore, he is able to compare the real network behaviour with the forecasted situations.

RESULTS

The Integration of the approaches has led to first results: The resulting planning & forecasting system across the voltage levels is shown in Figure 1.

A risk matrix (right-upper box) serves as a decision base for the prioritization of actions regarding the transformer between the high voltage and medium voltage level (black arrows): Actions in the lower-left quadrant must be executed, actions in the upper-right quadrant are unlikely to be applied. The necessary grid condition information is delivered by the underlying agent-based, distributed power flow calculation which provides technical information, e.g. nodal voltage (right-lower box), as well as information about the smart market and smart grid interactions.

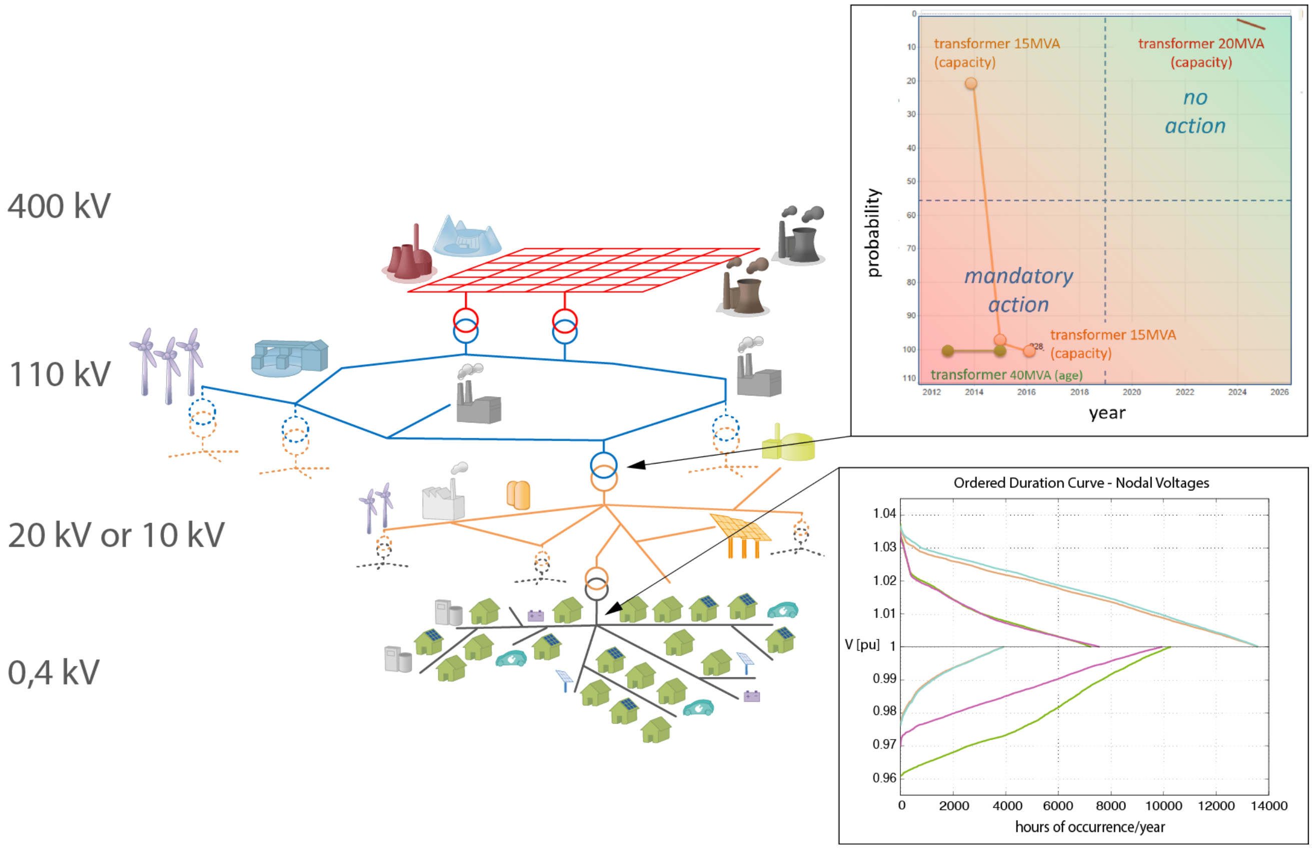

Figure 1: Scope of the integrated planning solution

Findings on system's state of the art

The **analysis stage** (step 2) is based on the current state of the agent-based simulation tool for an optimal grid extension planning (SIMONA) developed among others by Technical University Dortmund. As described by [3] the current state of SIMONA focusses on the medium and low voltage levels.

The agent based programming paradigm is designed to divide a large and complex problem (like a detailed voltage level integrated time series based distribution grid simulation) into smaller problems, which can be modelled very easy. In particular it aims to represent individual goals of distinct individual entities in an environment, where the entities are able to alter their own goals and behaviours during a negotiation process with other individuals [4]. One example could be the low level modelling of every single distributed generation (DG) plant. As the simulation framework's ability evolves to a voltage level integrated time series based simulation from high to low voltage level, the number of participants to be modelled and therefore the computational effort raises. Already in this early stage of the "Agent.GridPlan" project it can be noted, that, due to the use of the java agent developing framework JADE [5], there is a certain competition between modelling simplicity and computational efficiency. SIMONA is facing similar challenges considering the performance and scalability as presented in [6]. This challenge has to be addressed by innovative solutions to compute a large system in an acceptable time and with an acceptable computational effort.

One possibility to reduce the computational effort and in consequence accelerate the simulation is identified in the way of modelling DG plants. A simplified extract of SIMONA's overall system concept is shown in Figure 2. The DG agent communicates with a time agent, a market agent and a weather agent (all not depicted in Figure 2). The time agent announces the beginning of a time step and waits for the message of every grid agent, to ensure the load flow calculation of the given time step is finished. At the beginning of every time step the market agent informs all other agents about the current wholesale market price (spot market), whereas the weather agents broadcast information about the most relevant weather measures (solar irradiance, wind velocity and direction as well as temperature). All the described communication steps are performed by sending or receiving JADE messages. For further information on the overall system concept please refer to [1], [7]-[8].

The available level of detail of environmental data, among others, justifies that every single DG plant inherits the geo position from its point of common coupling. In consequence every DG plant (e.g. wind, photovoltaic panels, etc.) connected to the same node has the same geo location and therefore receives the same weather information. If every DG would be modelled as a distinct agent, the weather agent would send several messages containing the same information. In other words: no information surplus with more communicational effort. The increased message traffic would have a large impact on the run-time, if the SIMONA tool should be executed in parallel on distinct machines The interexchange over an added physical network would slow the overall performance. Even if the tool is running on a single machine, the same effects as presented in [6] are observable.

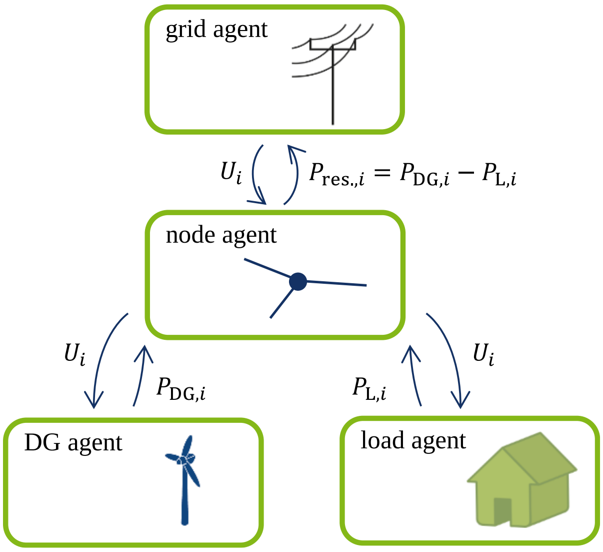

Figure 2: Extract of SIMONA's orverall system concept

To improve performance it is proposed to create only one DG agent per node that aggregates the functionality of several DG agents at the specific node. Hence, the new DG agent receives time, weather and market information. Following, it provides the sum of generated power to the environment. A new feature of this agent concept is a combination of intrinsic mathematical models, representing different generation technologies (e.g. PV and CHP plants), in a single agent implementation. With this aggregation of different plants and plant technologies their potential individual market driven behaviour is not aggregated. Only the interface to their environment is bundled. This quantity reduction of agents, and therefore the communicational effort, enables a distributed execution of the multi agent simulation (MAS) on distinct machines. Moreover it reduces the memory and CPU usage on every client of the computation cluster and therefore accelerate the simulation time even if a simulation is running on a single machine.

A second potential for performance enhancement is identified in the coupling between network nodes and network participants. The SIMONA simulation environment models every network node as a distinct agent, whose main task is the determination of residual nodal powers for a distributed load flow calculation by negotiations with the connected load and DG agents. It receives messages of the DG and load agents containing information about the current power infeed or consumption and provides the latest nodal voltage magnitude, which could be used e.g. to adjust the reactive power infeed in dependency of the given nodal voltage (cf. [9]). With raising voltage levels the nominal apparent power of DGs does also grow. Additionally special loads, like industrial consumers, often have specific requirements to voltage quality and to reliability. However, for grids at MV level or higher it might happen, that such significant consumers have a distinct point of common coupling, like a WEC farm being connected to the grid via its own secondary substation. From SIMONA’s modelling point of view, this means that these node agents only need to communicate to a single load or DG agent. In that case there is no advantage in splitting up the different agent’s functionalities. Here again a new aggregation stage is introduced.

The SIMONA user is given the possibility to choose up to which number of loads and DGs connected to a node their functionalities should be taken over by the node agent (cf. Figure 3). Those systems are further on called “offline systems”, because they are no longer modelled as a distinct agent. As of now the agents’ negotiations take place as an iterative process inside the node agent. By this the computational effort is further reduced, which helps in simulating a bigger amount of agents and thus enhances SIMONA’s capabilities, which is now able to perform time series based network state analysis for bigger grids across several voltage levels.

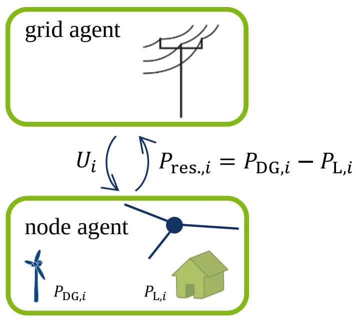

Figure 3: Concept of node agent with offline systems

First results on system integration

With the improved version of SIMONA, the analysis simulations to investigate the grid performance are executed. To do so, the input parameters of stage one are bundled to several future scenarios that should be investigated. These scenarios and their parameters are mainly based on different forecasts to ensure a range of likely future developments (e.g. [10], [11]). As a result of the simulation, different time-series of the grid utilization for each scenario for several years are generated. In the next step, these time series are taken to detect grid elements that will face critical situations in the future (e.g. violation of the (n-1)-criterion or an overload of a transformer). Not only the usage of time series identifies the critical situations, it also allows to determine the number of hours a violation of operational requirements and their exact occurrence. The result of this so called hotspot analysis are then used to optimize the existing grid.

As a third step of the proposed approach, a **fitness restoration** of the investigated grid is performed. To do so, the determined hotspots (critical grid elements) are investigated in detail and a problem analysis of the critical situation is performed. Then, a predefined catalogue of measures is used to remove all critical situations. These predefined actions are a user specific catalogue of operational (e.g. curtailment of the feed of RES) as well as structural (e.g. addition of (innovative) assets) possibilities to improve fitness of the grid. They have to be defined at the beginning of the optimization process.

The described optimization process not only restores the fitness of the grid but also estimates the expected costs resulting from the different operational and structural actions. Hence, an optimization problem with different restrictions (e.g. maximal costs allowed) is formulated and has to be solved.

As an outcome of the steps two and three, the network planner gets a full overview over the different scenarios, their impact on the grid utilization, possible issues that might occur in the investigated grid in the next years as well as a possible solution to prevent them. Furthermore, information about the estimated costs, depending on the considered scenario and the different operational actions and structural changes. These results will be accessible via a user interface which allows analytical visualization of simulated data even in big grids with large volumes of measures (e.g. load factors) in a multidimensional fashion. Technologically this is achieved by use of GeoJSON, Openstreetmap, Java and a Model View View Model (MVVM) concept in a four tier architecture. To ensure analytical efficiency the database layer provides NewSQL features like In-memory computing and columnar organization. A first mockup of a geographical representation is shown in Figure 4.

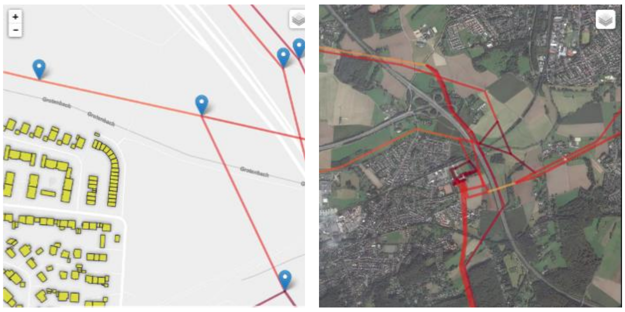

Figure 4: Blueprints of geographical HV-grid views

The values of resulting measures are represented directly using appropriate colour schemes or are accessible in dedicated views (e.g. load duration curves for individual assets). A schematic overview on the described four stage approach is presented in Figure 5.

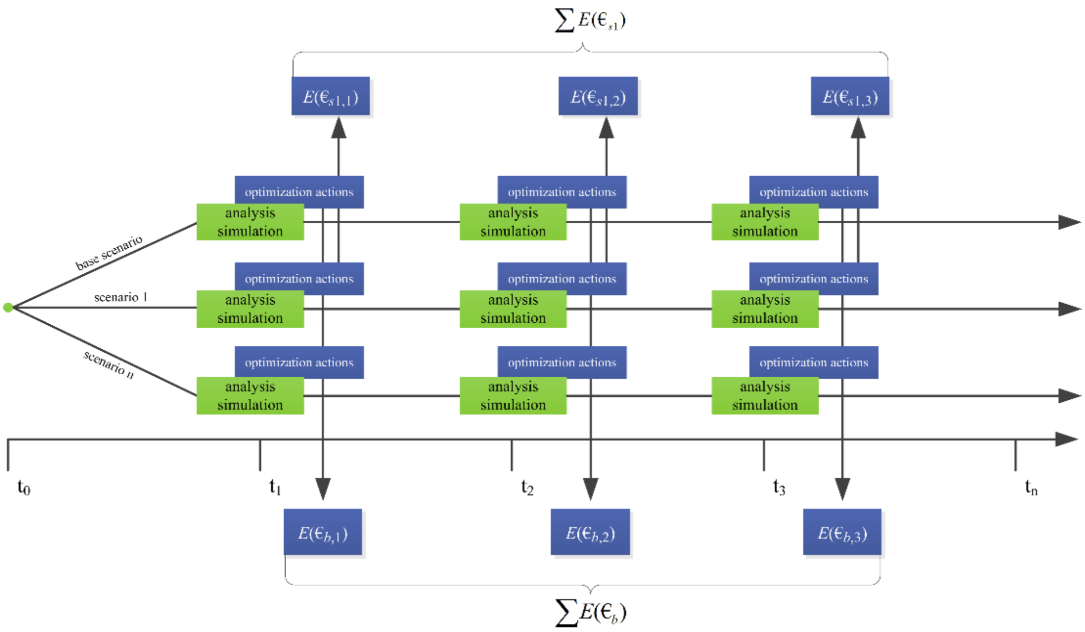

Figure 5: Schematic overview of the four stage approach

CONCLUSION

This paper presents an approach to enhance the distribution grid planning process while taking into account multiple voltage levels. With the widely discussed emerging volatility of grid loading and increasing (market oriented) interaction of distribution grid participants, the need for sophisticated, cross-voltage grid state analysis arises.
Such a detailed analysis can be carried out by a time series based multi agent simulation, which will produce a huge amount of data from which information have to be extracted. To achieve an optimal distribution grid planning process those resulting information have to be processed further, to derive adequate measures. Those steps can hardly be performed in a manual way.

The project "Agent.GridPlan" develops an approach for assisting distribution grid planners by integrating the agent-based grid analysis and simulation tool SIMONA and an optimized decision making process into an interactive system. The tool is either be capable of deriving adequate measures from sophisticated grid state analysis, as well as of giving a powerful visualisation module. Hence planning engineers would be able to understand given complex interdependencies and their resulting consequences.

The developed approach enables network planners to improve their network planning process due to

- multiple voltage level analysis in one step,
- consideration of different scenarios over multiple years,
- automatic optimization of the critical situations in the grid via a pre-defined measure catalogue with operational and structural actions,
- estimated costs of the different actions depending on the scenario and its occurrence which allows a financial evaluation as well as
- a state-of-the-art and user-friendly interface.

OUTLOOK

With the systems' integration and functionality enhancement some major challenges arise. With emerging voltage levels the number of network participants has to be taken into account. Thus the bidirectional interaction between market-oriented load and feed in systems with a wholesale market needs to be represented. The higher amount of individuals that have to be simulated also challenges computational and data efficiency. Here, adequate solutions have to be found in order to keep the simulation time and computational requirements in an acceptable size. As already mentioned, the planning engineer is challenged in analysing the gathered information. Here a suitable solution for human machine interaction has to be found.

ACKNOWLEDGEMENT

This project is supported by the European Regional Development Fund (ERDF).
See also http://www.agent-gridplan.net

REFERENCES

[1] L. Jendernalik, D. Giavarra, C. Engels, A. Maier; "Resilient and comprehensive network planning is key to a successful integration of renewable energy resources", 2016, *CIRED*, Helsinki.
[2] C. Engels, L. Jendernalik, J. von Haebler, S. Schimmeyer, A. Maier, D. Giavarra, "Smart Planning – Optimal Balance between Risk & Costs", *23th CIRED Intl. Conference*, 2015, Lyon.
[3] J. Kays, A. Seack, U. Häger, "The potential of using generated time series in the distribution grid planning process", 2015, *CIRED*, Lyon
[4] S. D. J. McArthur et al., "Multi-Agent Systems for Power Engineering Applications—Part I: Concepts, Approaches, and Technical Challenges", 2007, *IEEE Transactions on Power Systems, vol. 22, no. 4*, pp. 1743-1752
[5] "JADE v4.4.0." [Online]. Available: http://jade.tilab.com/. [Accessed: 12-Dec-2016]
[6] E. Cortese, F. Quarta, and G. Vitaglione, "Scalability and Performance of JADE Message Transport System," AAMAS Work. AgentCities, Bol., vol. 16, pp. 52–65, 2002.
[7] J. Kays, C. Rehtanz, 2016, "Planning process for distribution grids based on flexibly generated time series considering RES, DSM and storages", *IET Generation, Transmission & Distribution*, vol. 10, no. 14, 3405-3412
[8] J. Kays, A. Seack, C. Rehtanz, "Consideration of smart-meter measurements in a multi-agent simulation environment for improving distribution grid planning", 2016, *Proceedings IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT)*, 1-5
[9] A. Seack, J. Kays, C. Rehtanz, " Time series based distribution grid planning approach with decentralised voltage regulation", 2014, *Proceedings Power Systems Computation Conference*, Wroclaw
[10] German Federal Ministry for Economic Affairs and Energy, "Entwicklung der Energiemärkte – Energiereferenzprognose", Berlin, June 2014
[11] 50Hertz Transmission, Amprion, TenneT TSO, TransnetBW, "Szenariorahmen für die Netzentwicklungspläne Strom 2030 – Entwurf der Übertragungsnetzbetreiber", January 2016.