INTEGRATED OPTIMIZATION OF DISTRIBUTION SYSTEM PLANNING AND TRANSITION INTO NEW GRID STRUCTURES

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ABSTRACT

The research project IO.Netz(*) aims to improve the current process of long term distribution system planning. Analysing and planning today's distribution systems is still characterized by isolated software tools so that network planners have to deal with a list of shortcomings. Furthermore they have to deal with an increasing complex environment and have to include additional aspects (e.g. uncertainty for the investment decisions with lower budgets; development of renewable sources). The challenge to embed decentralized renewable energy sources into the distribution network implies a tight integration of the software tool chain for planning decision support. This paper proposes to raise the synergies between the replacement strategies in asset management and investments driven by the inclusion of renewable sources. Our central approach estimates the realization probability of new decentralized generation sites, simulates grid development by a system dynamics approach, calculates investments under uncertainty and applies multi-criterial optimization based on the simulation model.

INTRODUCTION

Network planners have to deal with a list of shortcomings applying the current planning approach:

- no quantitative evaluation of uncertainty for the investment decisions
- no representation of network topologies within technical asset management
- isolated congestion analysis

The integration of regional distributed renewable energy sources is going to challenge the planning processes of distribution systems. It implies a structural and functional transition from distribution power grids to regional transmission networks. Present planning tools only cover a subset of process steps and show a lack of integration and support the tasks of:

- asset management simulation including automatical optimization of asset strategies [1]
- geographical planning of grid structures [2,3]
- scenario-based congestion analysis and risk management [4]

INTEGRATION OF LONG TERM DISTRIBUTION SYSTEM PLANNING

The project IO.Netz(*) aims to improve the current process of long term distribution system planning (see Fig. 1):

1. Description of current grid infrastructure as a starting point.
2. Identification of the future target structure of the grid with respect to the expected evolution of generation and consumption patterns including technical and structural interrelations.
3. Simulation of different transition paths starting from the current asset base and structure ending in target structures of different representative scenarios.
4. Identification of an optimal transition strategy applying multi-criterial and robust optimization methods with respect to the competing design measures CAPEX and security of supply. Beside the establishment of an optimal technical solution the investment decision based on the probability weighted set of scenarios is included. For a financial investment evaluation, a real option evaluation technique based on a fuzzy pay-off method [5] is applied. This approach also includes regulatory constraints and technical constraints, i.e. the availability of system components.

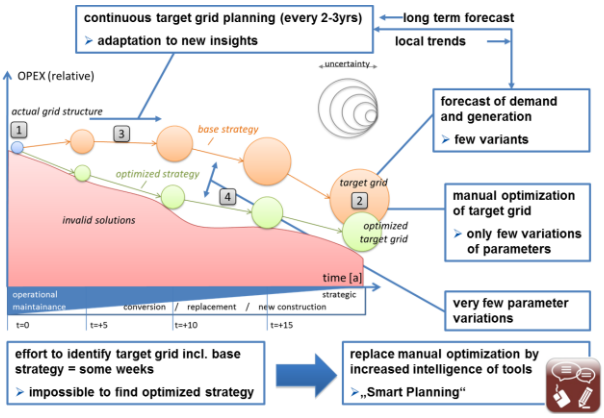

Figure 1: Scenario analysis and development of optimal strategies for long term distribution system planning

FUNCTIONALITY AND PROCESS STEPS

The proposed system within the project IO.Netz(*) is organised along two different aspects of functionality and process steps:

Integration of Functionality

A major task in distribution system planning is related to the integration of different tools and requirements. Each of these functions is associated with a certain objective in distribution network planning. Our architecture builds a platform (see Figure 2) where

- the state of assets is estimated in a probabilistic manner (Objective: "Young and lean" network structure).

(*) **This work has been supported in the R&D project "IO.Netz" funded by BMWi, grant no.: 03ET1071**

- grid topology is represented on an appropriate geographical level of detail which is given by the district level here (Objective: Enable connection of renewable sources to the distribution grid).
- a probabilistic investment model reflects the financial impacts under uncertainty in supply (Objective: Minimal capital allocation).
- the scheduling of actions for grid adaptation is documented (Objective: Feasibility of replacement and / or construction of assets).
- congestion analysis helps to guarantee reliability within the grid (Objective: Availability of supply).

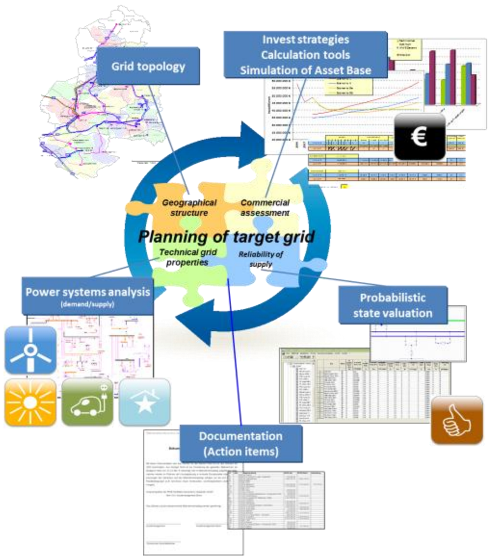

Figure 2: Functions in target grid planning

IDENTIFICATION OF TARGET STRUCTURE

One essential step to implement such an approach is given by the extension and integration of the current efficient methods and tools as well as the experience of a local distribution system operator. As depicted in Figure 2, the target grid planning problem has become a complex task. Besides the power system analysis, the practical planning process incorporates geographical information about the grid topology, commercial instructions from the investment strategies, reliability aspects derived from probabilistic models valuating the asset condition as well as internal processes of the grid operator. The modern distribution system planning works with a set of different tools developing the grid towards a "young" asset base and a "lean" grid structure [2]. In general, determining investment alternatives and its timing have to be done from a technical and economical point of view in order to develop the current asset base according to its future requirements.

A brief view on the process is given in Figure 3. Relevant information is the asset base allowing an evaluation of investment alternatives upon the condition, the technical age and the costs of the present equipment. The next input factor and strictly spoken the important one for the grid development is given by the uncertain environment. Available information about the development of generation capacity and the load determines the efficiency and the optimal timing of investments. Especially the long term prediction of scale and location of renewable energy sources but also of the load points have become a difficult task. Hence, deriving realistic scenarios is one of the important challenges of this research projects as it represents the basis of a probabilistic evaluation of optimal strategies.

Besides the uncertain variables, the target grid planning must include the technical and geographical information about the present grid infrastructure such as the topology represented by nodes and branches, the electrical parameters and the operational concept. The latter involves the technical constraints at the normal operation point of the system (i.e. voltage magnitude, voltage angle and line loading) as well as the security concept (i.e. switching, n-1 constraints) influencing the system reliability and finally the design of the grid.

The power system analyis uses this information to assess different investment alternatives from a technical perspective. This includes expansion, reinvestment, modification (up- and downgrading) and dismantling of the grid structure. Power flow and reliability simulations are performed to identify the need and determine the efficiency of different projects.

In a further step, the projects have to be evaluated using technical and financial criteria. The determination is one of the important issues as it helps to improve the present planning tools (i.e. automation, speed) and enables an appropriate consideration of technical aspects within the probabilistic investment model of this research project. At present, different approaches are investigated to find criteria that fit to the project's objectives. One example is the application of a probabilistic load flow model [3] that enables to analyse the need and efficiency of investment projects towards the uncertain development of electrical load and generation capacity. Finally, the planning process foresees an optimal decision that is subject of the following paragraphs.

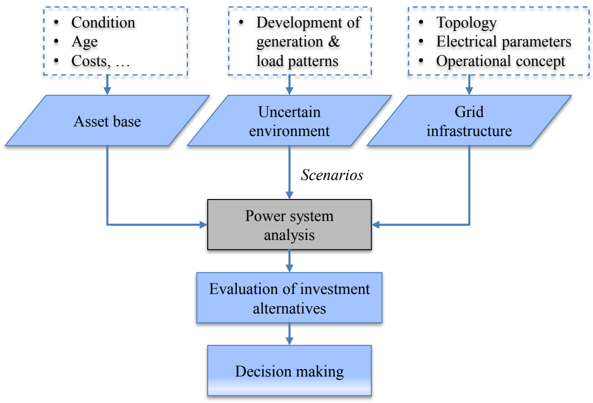

Figure 3: Process of target grid planning

SIMULATION OF TRANSITION PATH

Causal Loop Diagrams serve as the basis for a simulation model using a system dynamics approach, therefore the use cases within the IO.Netz project are displayed in a cause effect diagram modelling essential causal relations between the different parameters (see fig. 3). Thereby, the asset respectively the asset mix always builds the centre of the analysis.
Previous asset simulations have only been able to mark the demand for a structural grid change approximatively (indirect) by the adaption of the amount of an asset type, which was a flow into the asset simulation as a result of the grid development process.
Within the research project IO.Netz decentralized net information as well as external boundary conditions shall become a direct part of the asset simulation and lead to optimization of asset scenarios.
According to this enhanced approach the following three main drivers have a competing impact on the asset mix:

1. The state of the means of production and the renewal and maintenance strategy as a result from it
2. The structural changes caused by new grid requirements (e.g. by the increased input of renewable energy or the demographic change)
3. Asset demand caused by unpredictable incidents

Furthermore, budget limitations require the prioritization of the measures derived from the analysis for ensuring optimal use of the invested capital taking the effect on the required service of supply into account. The cause effect diagram shown above describes an overview of the use cases and the overall objectives of the IO.Netz project. In the forthcoming project phases the relations of the cause effect diagram will be described in detail and will be the basis for configuration of the solution.

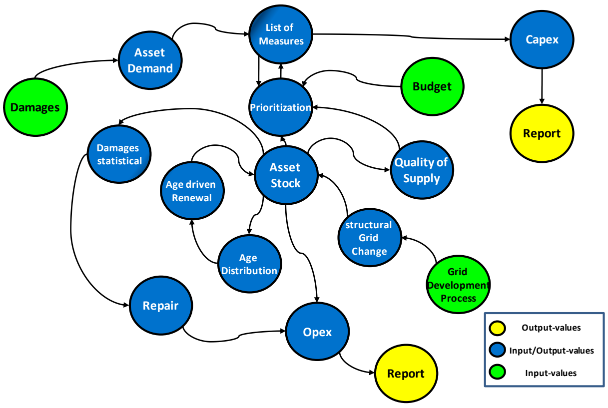

Figure 4: Causal Loop Diagram as the bridge between grid planning and asset management.

Asset management simulation and optimization has to include topological descriptions and multi objective optimization methods. Optimization methods have to incorporate uncertainty in form of real option valuation as well.

PROBABILISTIC INVESTMENT MODEL

Real option valuation describes a common approach to find the best decision for the time to invest in expensive projects [6]. In contrast to classical real option valuation the moment in which the project is realized is defined externally here by the installation of new renewable generation capacity in the supply zone.
Therefore we propose to use a variation of the real option approach called Fuzzy Payoff method [5].

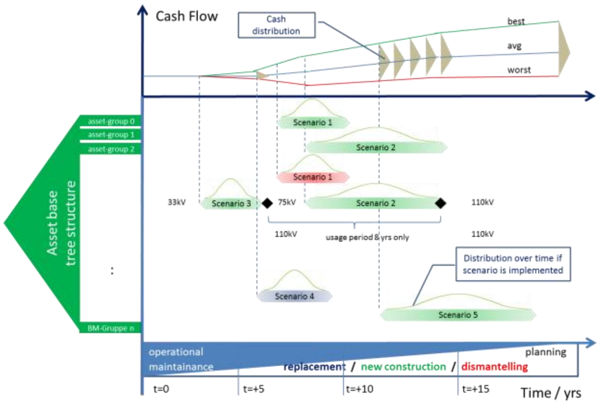

Figure 5: Transformation of scenarios into probabilistic cash flows

Figure 5 shows the dependency between the asset base and their organisation in groups (triangle left) and the probabilistic time series of cash flows (upper x-axis). The asset manager initially creates a variety of scenarios which reflect different options to cover the capacity constraints induced by the input feed of renewable projects. These scenarios contain uncertainty in terms of begin of power production and in terms of construction at all. This uncertainty has to be estimated by the DSO by providing probability distributions (for simplicity Gaussians are assumed here) [5]. These scenarios are linked to certain asset groups which are included in actions restructuring the grid (different rows belonging to the lower x-axis). The approach proposed here will derive probabilistic cash flows from the different combinations of scenarios to reflect the worst, average and best cash situation. Based on the cash flow distribution (here triangular shaped) the Fuzzy Payoff method will be applied to find the best investment decision under this uncertain information.

MULTI OBJECTIVE OPTIMIZATION

As seen in the introduction the different functionalities are associated with different objectives. The main challenge remains to find a sound compromise between these objective (usually in conflict with each other, for instance grid quality against CAPEX & OPEX). We propose multicriterial optimization techniques based on evolutionary algorithms [7] for solving these conflicts. As a result we expect a solution space in form of a pareto curve, see Figure 6.

Since the best solutions are proposed automatically by the system based on the simulation model (which is a simplification of reality) and optimization functions a reality check by human experts is required. The set of best solutions on the pareto frontier can be analysed by the end user and lead to enhanced usability and acceptance of the resulting solution (green large square).

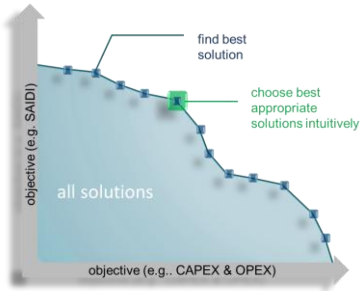

Figure 6: Pareto-front as a result of multi-objective optimization

The drawback of this approach results in the complexity of computing power which is needed to calculate a large variety of solutions to form the pareto frontier, which is addressed by distributed computing here.

PILOT APPLICATION

This approach is based on the current target planning process of a large regional distribution system operator. The enhancements are going to increase the quality and efficiency of the planning process. Practical studies of actual distribution grid scenarios will give a proof of concept:

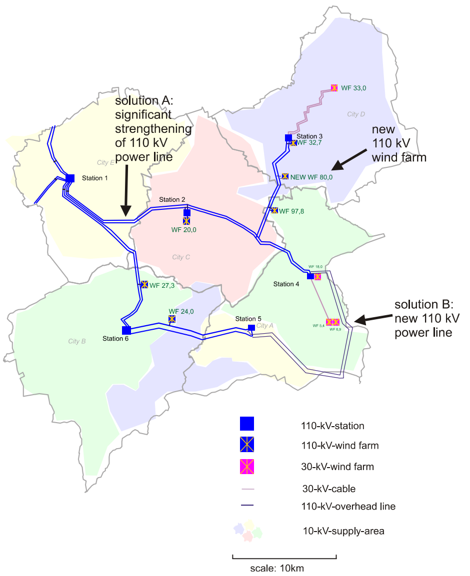

Figure 7: Practical case study

A first case example is defined by the following situation: An investor considers to build a new wind farm or to re-power an existing one in the supply zone of a DSO within the period of 5-7 yrs (see Figure 7).

The connection of this site will need additional power line capacity (for instance a 110kV line). The probability that this investment will be made is estimated with 50%. On the other hand the grid structure in this part of the supply zone is outdated and will not be able to provide an adequate capacity for the mentioned wind farm. So asset management has to decide whether to replace the asset by a line with higher capacity or to build a new 110-kV-line directly.

SUMMARY AND OUTLOOK

The objective of this research project is devoted to the improvement of the distribution system planning process. To solve the planning problem, an approach has been developed incorporating the expert knowledge of different disciplines. The paper outlines the general idea and gives an insight about the methodology and the major model parts: the assessment of investment alternatives using practical and new methods for the target grid identification, a system dynamics approach for the asset management process, a probabilistic investment model applying real option evaluation and an optimization tool for a multi-criteria decision making.

The next challenge of this project will be the modelling of the interrelations among the model parts and the development of realistic scenarios for the probabilistic technical and financial evaluation. For this purpose, a stylised study model has been presented and will be the starting point for the following application, testing and evaluation of the model parts.

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