"Smart Planning" – Optimal Balance between Risk & Costs

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ABSTRACT

The German "Energiewende" enforces structural adaptions on the distribution grid which require significant investments. Finding cost optimal measures and synergies between state based and capacity based grid adaption under given uncertainties offers an obvious solution in this transition process. A prototype has been presented in [1] showing a proof of concept using scenario techniques, power flow and age simulation, expert planning principles and memetic evolutionary optimization.

While these results are deployed in a DSO planning process the available annual budgets and the state or capacity based investment have to be aligned on a risk based assessment. The proposed Smart Planning workflow is complemented by a risk matrix where measures are prioritized due to their time horizon and probability support of the underlying scenarios.

INTRODUCTION

The Smart Planning approach belongs to the category of Big Data applications in producing large volumes of data due to the variety of scenarios, the combination of installed capacity and real power injection, the complexity of the underlying grid structure, the (n-1) cases and the planning horizon. To control this data complexity and to preserve transparency for the grid planner the information has to be organized along a workflow and visualized by appropriate reports following usability rules.

The system architecture developed in [2] has been transferred into a Smart Planning workflow, see Figure 1. Based on long-term forecasts different future developments for demand, wind-, photovoltaic- and biomass-production are assumed in terms of probabilistic scenarios. An evaluation of the actual grid structure by contingency analysis and asset age simulation leads to potential "hot spots" in different scenarios indicating a need for action. An optimal set of actions is identified by applying a memetic evolutionary algorithm following formalized expert planning guidelines for a maximum of transparency of the optimization output.

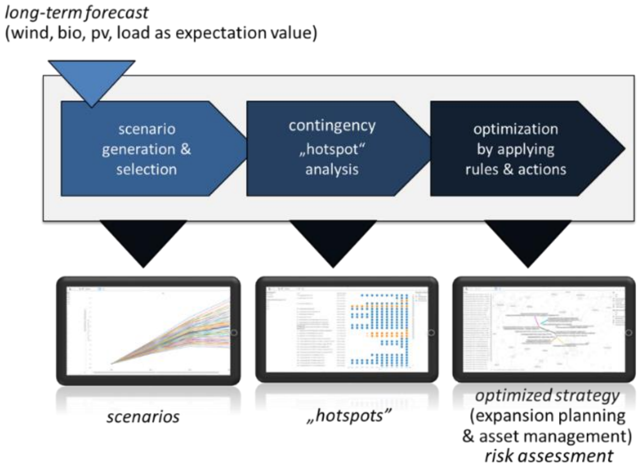

Figure 1: Smart Planning Workflow

The resulting measures are mapped onto a "hot spot" list, age distribution charts, financial charts, a geographical map and a risk matrix (see Figure 2) reflecting the time line and the probability of the underlying scenarios.

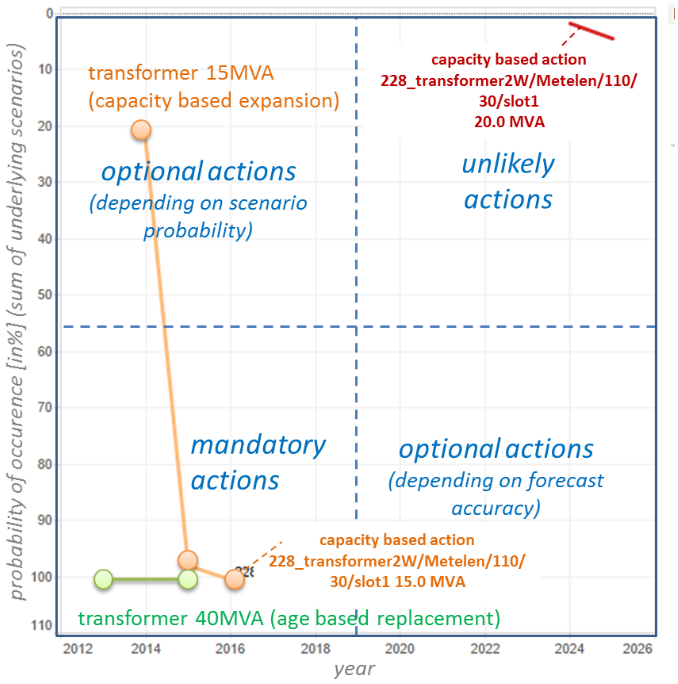

Figure 2: Risk Matrix

The system enables network planners to preserve a maximum of flexibility in their decisions and find a balance between risk and costs.

PLANNING WORKFLOW

Scenario definition

Starting from the expectation values of long-term forecasts for renewable generation and load on the basis of installed power per region the approach defines different variations resulting in a set of 81 scenarios. Figure 3 depicts a projection of the development of all different scenarios over 15 years (x-axis). The y-axis is given as the product of all contribution factors (wind, photovoltaic, biomass and load) here for reasons of visualization. As it can be seen directly uncertainty is increasing over time.

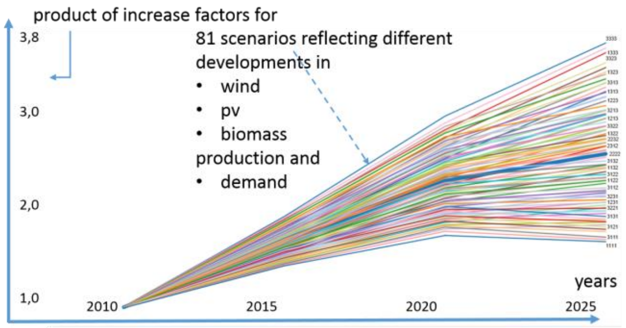

Figure 3: Scenario development over time

The number of scenarios defined here allows a description of a very rich set of future developments. On the other hand this variety increases the complexity of the planning process significantly. Therefore the system must provide support for automatic and powerful calculation processes (in terms of asset simulation and power flow simulation) and evaluation of results by interactive visualization as well.
Each scenario gets a relative probability value in order to show its relevance within this distinct scenario set. In general the single scenario reflecting the combination that is derived from the baseline load and feed-in prognosis gets the highest value. The probability values for all other scenarios can be calculated by the assumption of typical distribution functions. This probability distribution enables the development and a subsequent evaluation of all necessary grid measures and projects.

Load Demand Combinations

The next step translates the installed capacity into the real load by assuming different generation / load combinations for (n-0) and (n-1) cases. Additionally a differentiation between pure hot spot analysis and optimization is shown in
Figure 4. The results for a 60 node network on the 110kV level show, that the critical cases occur in a weak load / high generation situation (middle column). In contrast the high load / weak generation situation remains in a safe state since this load describes the case for which the network structure has been designed for originally (left column).

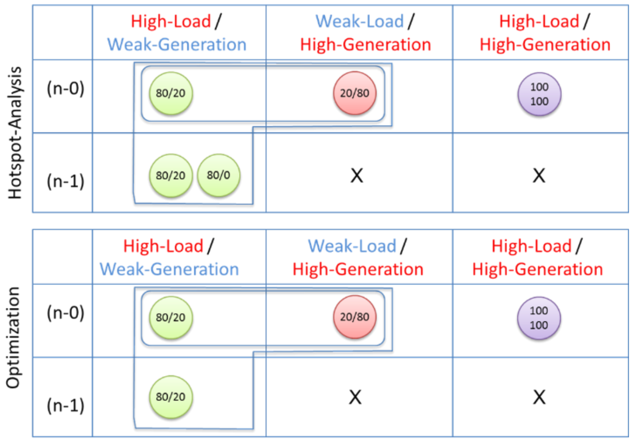

Figure 4: Utilization cases of installed capacity

In the weak load / high generation combination the (n-1) case is not investigated because in such an exceptional situation the DSO is allowed to shut down critical power generation sites to remove any (n-1) contingencies without undergoing any financial penalties.

Hot spot Analysis

After the definition of load scenarios the system allows an assessment of the actual network structure which is called "hot spot analysis". Due to the multidimensional characteristic of the scenarios in space and time the analysis is supported using different views.

Time course of "Hot spots"

Figure 5 shows those assets (rows) over time (columns) which are affected by conditional or capacity based action triggers: The dark dots indicate a need for an age based replacement while the light dots represent contingencies on dedicated assets. The diameter of the light dots are showing the cumulative probability of the underlying scenarios causing the capacity problem.

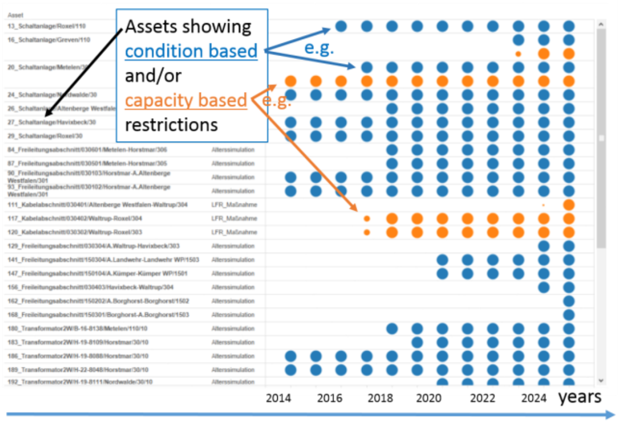

Figure 5: Hot spot analysis on a yearly basis

Geographical distribution of ”Hot spots”

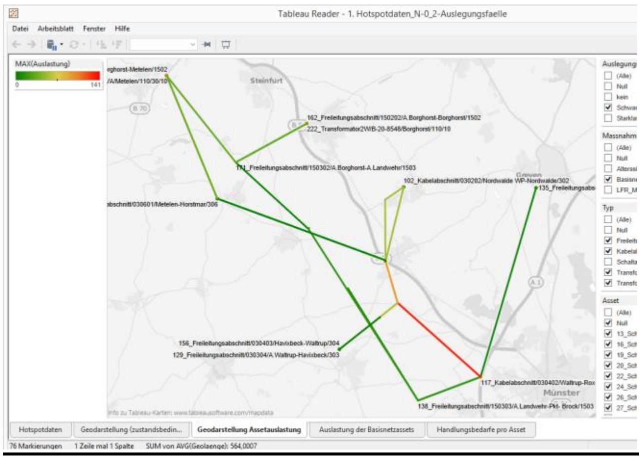

Figure 6: Hot spot analysis on a geographical basis

To visualize action triggers and their topological neighborhood a geographical view is provided by the system.
Figure 6 shows a part of a real area of the network under investigation.

Optimization

A genetic optimization including a memetic variation is applied to find synergies between conditional based and capacity based actions. As a result potential actions are prioritized in terms of planning horizon and support of scenario probability.

Risk Matrix

Figure 2 depicts a risk matrix as a result of the optimization process where the potential future actions for a site containing a transformer with 40MVA in the base year 2013 (dot in the left lower corner) can be analyzed: The x-axis shows time in years while the y-axis represents the cumulative probability of scenarios [Remark: The scale is shown in an inverse fashion to build risk quadrants. Zero probability is located in the most upper line of the chart!]. This cumulative value is a sum of the single probability values of the different scenarios reflecting their importance within the complete scenario set.

In 2014 additional capacity of 15MVA is needed in 20% of scenario support (dot in the upper left corner). In 2015 this requirement increases to 97% while in 2016 all scenarios support the need for these extra 15MVA. Also the original 40MVA transformer must be replaced due to age based conditions. Since 40MVA is defined as the maximum capacity for transformers a common action combining the 40MVA replacement and the 15MVA extension is not feasible. In 2024 the capacity is exceeded again in 5% of the scenario support (line segment in the upper right part). A prioritization of all potential actions can be derived from this kind of risk matrix:

(1) If the proposed actions fall into the **lower left** quadrant they must be seen as mandatory.

(2) If the result is located in the **upper right** quadrant it can be ignored.

(3) If the action is part of the **upper left** quadrant the probability support of the underlying scenarios should be investigated.

(4) If the result is part of the **lower right** quadrant the forecasting quality is responsible for a potential decision.

The risk matrix and the preceding workflow and processing steps turn out to be a valuable tool set for decision support in network planning as postulated for asset management support in [3]:

“The increasing complexity in Asset Management requires a broad and integrated system based decision support. This includes a broad acquisition and processing of business and technical asset data and their aggregation and evaluation via KPI and management dashboards as well. Additionally these data have to be processed automatically using a variation of parameterization. This is done on the basis of simulation based network planning instruments, software solutions for optimization of invests and projects and programs for conditional and risk oriented maintenance.”

The risk matrix allows for risk identification and assessment as postulated in the asset management standard PAS55 [4]. The probability of credible events and their consequences are covered.

Reduction of Complexity

As pointed out in [1] an integrated optimization of age based and capacity based grid planning actions describes a complex task which is computational NP-complete. For this reason a reduction of the search space of possible actions has been introduced by obeying planning rules defined by network planning experts.
Additionally the complexity is now reduced by a variation of the initialization of the evolutionary optimization process: The original implementation of the genetic algorithm starts with a random choice of actions applied to the actual base network. The elitism parameter determines the number of best individuals which are transferred unchanged to the population of the next generation. Originally this elitism value has been set to 1 and a random initialization for all individuals has been chosen. This approach leads to start solutions with high variation compared to the actual base network. As a result the number of iterations needed to converge to a good solution is high and is time consuming. Figure 7 shows the first 1.300 iterations (x-axis) with a final objective value of about 850

Mio. (Composite objective function value shown as the lower bound value of the iteration series).

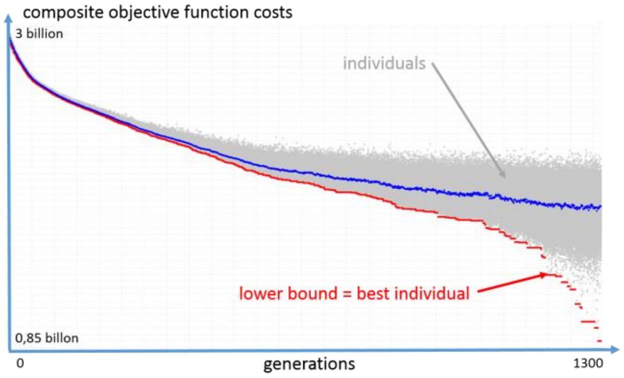

Figure 7: Convergence with elitism = 1

The inclusion of an original actual base network in the first population after the initialization process preserves a reasonable structure which contains some past planning considerations from planning experts. The probability of a survival of this actual base network during the first iterations of the optimization process is very high (due to its objective function value which is usually low compared to randomly initialized individuals) and is further enhanced by increasing the elitism parameter to the value 2. This leads to an acceleration by a magnitude. Figure 8 shows 430 iterations and final costs of approximately 750 Mio.

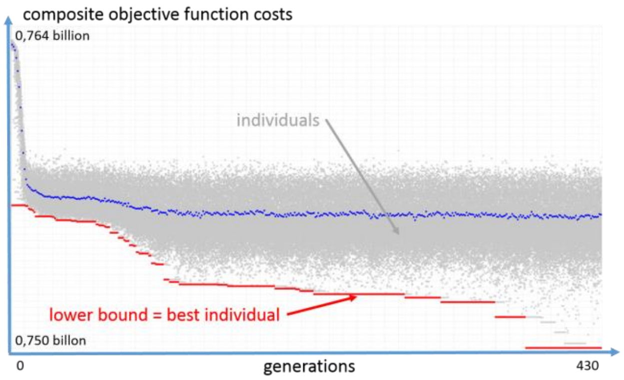

Figure 8: Convergence with extended elitism = 2 and initial actual base grid

Since evolutionary optimization is based on randomness and there is no common stop criterion available for the convergence process, the structures of the final network solutions of the two approaches cannot be compared directly. Instead the solutions are characterized by their objective function value and the computational costs:
The latter optimization strategy which uses an elitism value of 2 finds a better solution (objective function value differs by 11,5%) than the first approach in only 1/3rd computational time.

Hence the inclusion of actual knowledge of planning experts describing:

- the actual (and partially planned) network structure
- the set of potential planning rules (as introduced in [2])

builds a crucial source for the reduction and controllability of optimization complexity.

The planning guideline rules designed by planning experts can be established in an incremental fashion starting with a coarse set of rules which is refined after evaluation of a first optimization run. Such interaction allows optimized planning guided by planning experts.

SUMMARY & OUTLOOK

The network planner is able to access the decision critical and optimized results in a direct way in different views.

The restrictions in investment budgets and the need for a transition into new network structures fulfilling the requirements induced by the "Energiewende" can be balanced using the proposed risk matrix.

The feedback and first experiences of DSO planning experts working with the solution show the improved efficiency and productivity in planning support. In a next step the system will be transferred from a prototype in a product status while the variety of file formats will be enhanced, simulation performance will be increased and the scenario creation process will be designed in a more flexible manner.

The remaining tasks and challenges are:

- Using an even more realistic scenario generation approach, e.g. by application of agent-based simulation.
- An extension of the system to multi-voltage levels
- An improvement of the power flow calculation in terms of performance
- Adding standard file formats for network models to ease the exchange with other tools
- System workflow support for incremental definition of planning rules and actions.

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