"SMART PLANNING" – FIRST PRACTICAL RESULTS OF THE INTEGRATED APPROACH FOR GRID DEVELOPMENT AND STRATEGIC ASSET MANAGEMENT*

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ABSTRACT

The basic idea of an integrated evolutionary approach for grid development and strategic asset management was presented during CIRED 2013 [1]. This paper deals with the experience of the implementation phase and with first practical results of this new approach.

The synergetic combination of strategic Asset Management (based on age and conditions) and capacity-based Network Development (expansion planning) leads to an additional level of technical and economical optimization potential. The investment strategy is linked to the main technical drivers: condition and functional demands. The adaption to uncertain future requirements is based on the analysis of a variety of different load and feed-in scenarios. This approach enables the optimization of future grid structures combining (n-1) contingency analysis, asset simulation and a hybrid evolutionary algorithm. Additional benefits could be achieved.

INTRODUCTION

Which synergies should be identified by a "Smart Planning" system? If we look at an underlying asset (e.g. transformer station, transformer, line,…) which has reached the end of its lifetime in year t and enters a critical condition this asset has to be replaced in time.
Normally such a replacement is done 1:1. If new renewable generation is added or demand is changing in year $t+\Delta t$, which exceeds the capacity of this 1:1 replaced asset, the original investment has to be depreciated in total. "Smart Grid Planning" should be able to avoid such situations and include uncertainty in form of multiple scenarios to find a target grid with a minimum of investment and operational costs within the planning period.

METHODOLOGY

The requirements of an integrated approach are combined by means of a target function oriented evolutionary optimization method based on a rule-based Genetic Algorithm. Figure 1 shows the principle process of the basic rule-based Genetic Algorithm, see [2].

On one hand both long-term regional feed-in and load forecasts and assumed probability distributions are used to generate scenarios. On the other hand the status quo is represented by the actual basic grid.

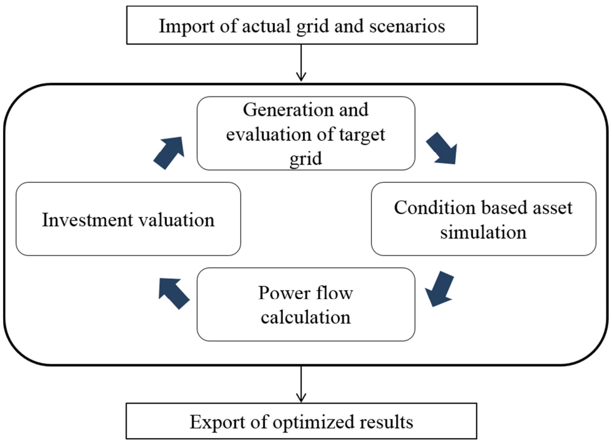

Figure 1: Basic rule-based Genetic Algorithm

Both descriptions are integrated as input parameters of the calculation model. The Genetic Algorithm performs a variation of the basic grid based on the grid planning rule-set as well as stochastic mutation and recombination. This calculation leads to a practical target grid candidate. The sub-modules „condition based asset simulation" [3] and „power flow calculation" [4] check the validity of this candidate for proper age conditions as well as for sufficient grid capacity regarding the selected scenarios. Valid target grid candidates are evaluated by a cost or result oriented investment analysis. Key figures and network measures of the candidate with minimized costs (resp. revenues) are prepared as a detailed report for the grid planning staff.

EXPERIENCE OF THE IMPLEMENTATION PHASE

The implementation phase revealed the complexity of the possible solution space and the necessary boundary conditions. For instance the assumptions of 10 transformer stations, 15 planning years and 10 transformer types (reflecting different capacities) will lead to $10^{(10x15)} = 10^{150}$ possible combinations ignoring other network elements, e.g. transmission lines or different development scenarios. Therefore an important task of the implementation phase was the definition of boundary conditions limiting the number of possible optimization steps without cutting the practically needed search space.

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Planning Ruleset

To reduce the complexity of the search space planning rules are introduced. These rules are defined by planning experts and describe all feasible replacements and expansions and their interdependencies.

Figure 2 shows the application of two different planning rules to expand a transformer station by additional 20 MVA. Rule 1 simply adds a new transformer with a capacity of 20 MVA to the station while rule 2 first foresees a transfer of the 20 MVA transformer from 1970 to the transformer pool and adds a new transformer to the station with 40 MVA capacity. For sake of simplicity, this example is reduced to two rules only. In contrast in this project phase the implemented system provides a set of 56 rules in total.

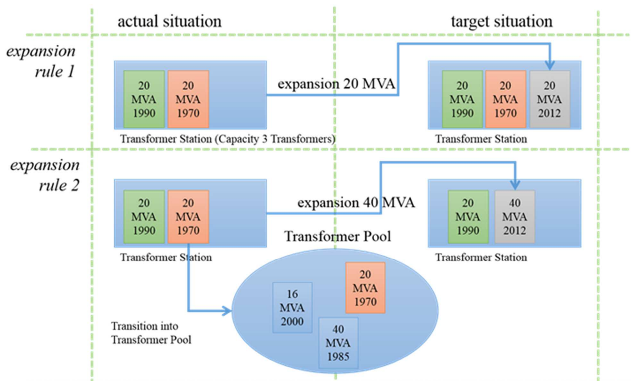

Figure 2: Example Planning Rules

The application of such a set of rules enables the optimizer to find global solutions in reasonable computing time.

Scenario Generation

The underlying scenarios are derived from long-term studies and forecasts that describe the expected regional future developments for different generation technologies (wind, PV, biomass) and demand. Typically these studies provide three possible future paths; an optimistic path with high increase of installed capacity, an expected path and a pessimistic extension path with a low increase of installed capacity. The three paths spread a kind of scenario funnel for each of the considered technologies. In order to take into account the uncertain future development the expected values are extended by a normal distribution. The planner has to determine appropriate standard deviation parameterization for each technology. In this project the optimistic as well as the pessimistic path of the study are assumed to represent the higher and the lower edges of the normal distribution respectively. The resulting distribution functions of each technology are combined to four dimensional scenarios for each time step of the planning horizon. The quantity of x discretisation intervals of the normal distribution lead to $s = (x + 1)^4$ scenarios for each time step.

Figure 3 shows a two-dimensional extract of a four-dimensional example. The x- and y-axis represent two generation types (e.g. wind and PV) and the squares on the z-axis give the probability for a certain generation scenario. The maximum of this function reflects the scenario which equals the combination of the expected values of both technologies.

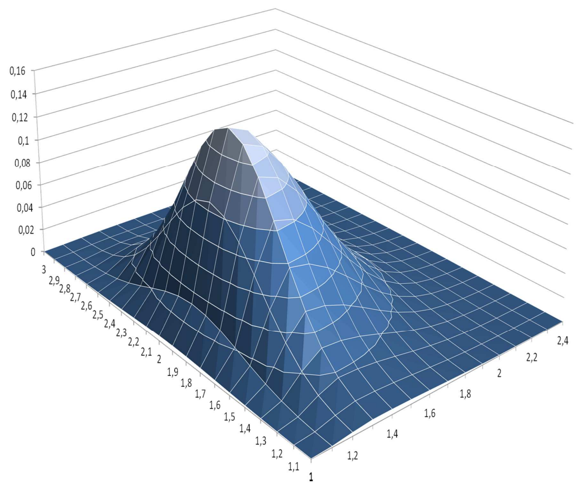

Figure 3: Scenario sampling

In this project two discretisation intervals are defined that lead to $s = 3^4 = 81$ different four-dimensional scenarios for each time step. The final results are weighted by their probability (z-axis value).

Power Flow Analysis

The grid under investigation entails a high complexity and level of detail in its technical description. To increase the significance of the planning approach, the grid has been reduced as low as possible. For the power flow analysis, the grid is described by a network topology containing information about the electrical circuits representing the transmission lines (several segments build one circuit), transformers (including three winding transformers), switches, busbars and its bus-ties. The entire 110 kV grid is analyzed including the equipment of the 110, 30 and 10 kV voltage levels.

The network is assumed to be in the normal condition (N-0). This comprises a base setting of switches and bus-ties in the network configuration (open or closed). In order to perform a contingency analysis, the single outage conditions ((N-1) events) have to be determined. In a (N-1) case due to a failure of a single network element, two options have to be considered: If the network is separated into two disconnected parts (isolated networks), the grid must be merged again by switching actions. Switching actions close to the failure

location restore the network structure. The appropriate actions are identified by a graph analysis algorithm before the contingency analysis is done. If the grid shows congestions in the (N-1) case there is the option of reducing the injected power generation. A first implementation includes a fix reduction of the power generation. A second approach foresees an optimal reduction pattern found by solving the following optimization problem: Minimize power generation constrained by the power line limits using power transfer distribution factors (PTDF) [4].
The determination of the (N-1) topologies including the switching actions is done stepwise for each (N-1) event. The process consists of three main parts: the determination of the relevant (N-1) events and two algorithms identifying isolated networks and feasible switching actions. The latter two parts include for each line outage i that causes an isolated network a number of N_{Si} switching actions. As a result, $\boldsymbol{T_i}$ network topologies have to be evaluated in the contingency analysis.

The power flow analysis is implemented in a DC Load flow model in MATLAB [5]. Input parameters are:

- Nodal balance of installed generation and load (Scenario parameters)
- Network topologies of the (N-0) and (N-1) cases

The power flow is performed for each topology. The grid is dimensioned for two worst case situations representing possible combinations of load and generation feed-in. A fix generation reduction in the (N-1) condition considers a reduction of RES generation to zero. Hence, a contingency analysis is only performed for a high load and low level of power generation (s. Table 1).

Table 1. Grid dimensioning: Relevant load flow cases

		RES high	RES low
Load	high	-	N-1
Load	low	N-0	-

The results contain information about the line loading and, if an overloading occurs, the failed network element for the respective (N-1) case. For the critical topologies, calculations are performed for all topologies $\boldsymbol{T_i}$ of the switching operations N_{Si}. A topology is valid if the line loadings are within the limits for at least one switching operation.

PRACTICAL RESULTS

Test Problem

A working prototype is already available. To verify the functionality of the system a test case including only two scenarios with 192 asset elements has been applied simultaneously and successfully: In year $t_0 = 2013$ a line segment between region "A" and region "W" must be replaced due to its critical state (conditional trigger) while at $t_1 = t_0 + \Delta t = 2016$ the capacity of the new line segment is exceeded in one of the considered scenarios (with probability of 90%) as a result of the power flow calculation (functional trigger), see Figure 4.

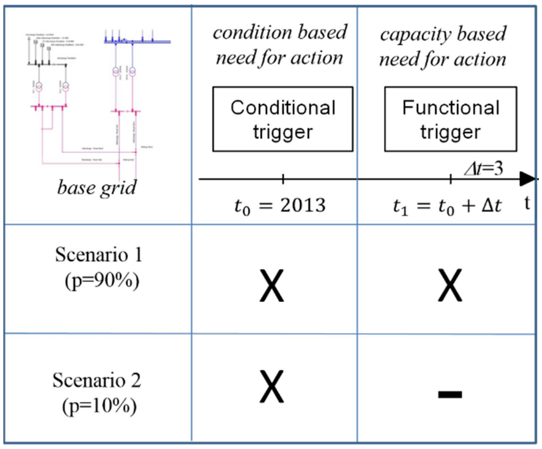

Figure 4: Action triggers & scenarios

Optimization

The tailored Genetic Algorithm is applied using 500 generations including 100 individuals in each population. Conditional or Functional triggers are resolved by replacement or extension of the affected asset. The resolution can be applied for all scenarios (for instance in the case of the Conditional trigger in the test problem at t_0) or for a subset of scenarios only (in the case of the Functional trigger at t_1).
The objective function combines the contribution of CAPEX for replacement or extension actions of each scenario weighted by its probability and OPEX. Figure 5 shows the process of optimization: The x-axis represents the 500 generations, the y-axis shows the TOTEX of the grid candidate solution (individual). The lower bound represents the best solution found so far.
This function is minimized by optimization and should lead to synergies between conditional and functional driven actions: Instead of adding an additional asset in year t_1 (strategy without synergy) the optimizer should propose a well dimensioned line segment already in year t_0 which also satisfies the capacity constraints in year t_1(optimal strategy).

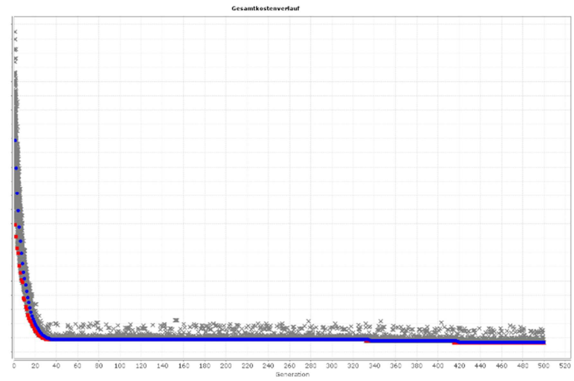

Figure 5: Convergence

Figure 6 shows the course of optimization on the test problem. On the y-axis the number of actions are drawn while the x-axis represent the number of generation. The upper line shows actions which are applied to all scenarios while the lower line reflects the number of actions which are used by one scenario only. It can be seen that at the end of the optimization (right part of the figure) the number of actions in a single scenario goes to zero and there is one action left which is applied to both scenarios. This situation corresponds to the desired outcome where the synergetic action should be identified.

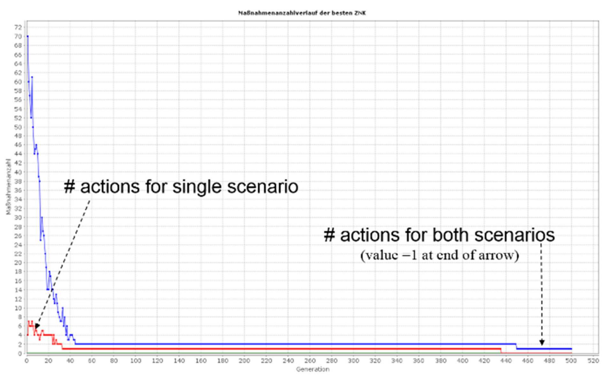

Figure 6: Number of actions throughout optimization

Results

The investment analysis leads to the following results:

(A) **Strategy without synergy:** The calculation of the discounted TOTEX results in 1.377 TEUR. The TOTEX consists of 389 TEUR for the conditional replacement of the old line segment by a new one with identical capacity including a special amortization (278 TEUR) in 2016 in the scenario with need for capacity expansion. Furthermore 988 TEUR for the new line segment with a higher capacity has to be considered.

(B) **Optimized strategy:** Optimization leads to a discounted TOTEX of 1.017 TEUR as a result of building the new line segment with the higher capacity already in 2013.

The comparison of the discounted TOTEX between both asset strategies shows a difference of 360 TEUR (= 1.377 TEUR – 1.017 TEUR) which can be saved in this case with an optimized strategy for one single asset only.

SUMMARY & OUTLOOK

The challenges of the German « Energiewende » can only be overcome by an integrated optimization approach. This approach minimized CAPEX. Due to problem complexity the inclusion of expert knowledge from network planners is mandatory. Uncertainty can be addressed by probabilistic scenarios.

The system is currently applied to real network topologies showing a variety of results which are investigated and validated at the moment.
In a next step the number of scenarios is increased to 81, the accuracy of the powerflow calculation (n-1 criteria) is improved and asset simulation functionality will be refined.

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