INNOVATIVE PLANNING METHOD FOR DERIVING NEW RULES FOR FUTURE NETWORK PLANNING

Julia ZIEGELDORF
FGH e.V. – Germany
julia.ziegeldorf@fgh-ma.de

Sören PATZACK
FGH e.V. – Germany
soeren.patzack@fgh-ma.de

Max HOVEN
FGH e.V. – Germany
max.hoven@fgh-ma.de

Albert MOSER
FGH e.V. – Germany
albert.moser@fgh-ma.de

Hendrik VENNEGEERTS
FGH e.V. – Germany
hendrik.vennegeerts@fgh-ma.de

Robert FRINGS
INFRAWEST GmbH - Germany
robert.frings@infrawest.de

ABSTRACT

Planning methods for low and middle voltage networks (LV and MV) have to be adjusted due to the new challenges for the distribution network operator like the increasing amount of distributed renewable energy sources (DRES) and especially for urban networks innovative loads like e-mobility. Besides conventional solutions (e.g. line expansion) innovative operation equipment (e.g. MV/LV-transformers with variable transmission ratio) and communication technology can help the network operator to face these challenges. Since the day-by-day planning process has been usually subject to the application of planning rules in order to handle the high amount of planning decisions efficiently, these rules must be updated considering the innovative aspects.

In this paper, we present an innovative planning method for long-term LV- and MV-network optimization that can be used to answer the question if –regarding the big challenges and related uncertainty - new and innovative planning rules can be applied at all and – if yes – how they could be defined in detail.

INTRODUCTION

Network planning process in the past

In the past, the network planning process was generally affected by the connected load. The day-by-day-planning process was based on several planning rules with the aim to enable fast, efficient investment decisions for typical planning tasks without the need of detailed analysis of every single load or maintenance measure. One exemplary planning rule for the dimensioning of the LV-grid substation transformer is to take the number of household connections as a dimensioning parameter.

Present and future network planning process

Present and future network planning processes have to face new challenges: The DRES-development has become one of the main triggers for network expansion planning. In the MV- and LV-networks the costumers become prosumers (producer and consumers) especially due to photovoltaic installation. Also the usage of micro combined heat-and-power plants (CHP) or heat pumps as well as the additional load of electro-mobility vehicles result in new load profiles and therefore higher network loads. In addition to conventional planning options the use of innovative operating equipment can help to resolve these new challenges efficiently. For this new and more complex network planning task, new planning methods are necessary that consider both conventional and innovative solutions.

Therefore we present a new planning method that optimizes a given network structure using innovative elements regarding the new load and generation situation. The presentation of the methodological approach is the focus of this paper. A second aim is to apply this method to a wide range of characteristic network structures to derive new and innovative planning rules for the day-by-day planning process.

PROBLEM ANALYSIS AND MODELLING

The aim of long-term network planning is to find optimal networks structures for future scenarios of supply tasks. That is, when looking 10-20 years ahead, the identification of optimal adaptions of the present network structures to the new supply task and generation situation.

Economic evaluation

The term “optimal” refers to the optimization’s objective function. In long-term network planning typically the focus lies on the minimization of the network costs (annuity), that are (Equation 1) the one-time investment cost for conventional and innovative operating equipment (*CAPEX*) and the yearly operation costs (*OPEX*), e.g. for maintenance, losses and regulatory discounts. The annuity is derived by assuming typical spans of life-time for the operating equipment (*T*) and interest rates (*i*).

$$\dot{K}_{ges} = \sum_i \dot{a}_i * K_{CAPEX,i} + \dot{K}_{OPEX,i}$$

Equation 1 – Cost evaluation

With $\dot{a}_i$=annuity factor of cost term i, considering the real interest rate and usual life spans of the equipment.

Technical constraints

Typically in planning of German distribution networks, the following constraints must not be violated.

Voltage range: According to standard EN 50160 the permitted voltage range is given by $\pm 10\% U_n$ for each network node. For the voltage rise due to DRES in Germany additionally the "2%-rule" and "3%-rule" must be considered (Figure 1). If no tap-changed transformer MV/LV is used, the available voltage range has to been divided up between the MV- and LV-network.

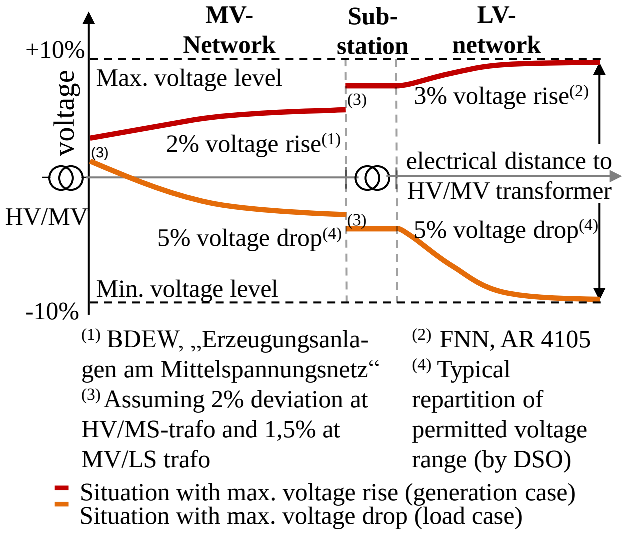

Figure 1 Permitted voltage range [1][2][3]

Overloading of lines/transformers: For all operation equipment the actual power flow S_j at element j must not exceed the rated power S_r

Short circuit: $S''_{sc,i}$, the actual value of the initial symmetric short circuit apparent power at bus i must not exceed equipment rating.

Degrees of freedom

Figure 2 shows the various options a network operator has in the context of smart-grid and innovative planning methods. These are the degrees of freedom considered in the developed optimization method.

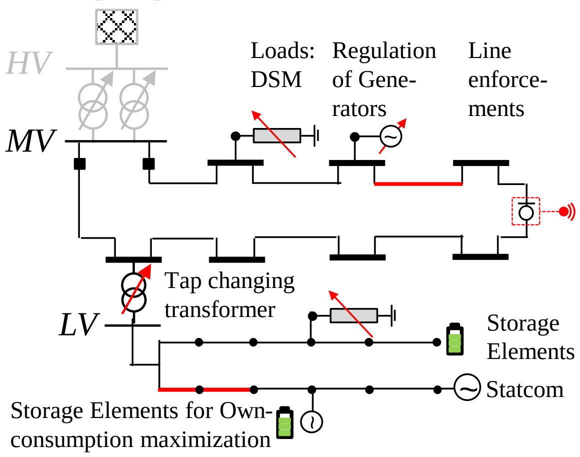

Figure 2 – Degrees of freedom

Apparently some planning options complement others in their capacity of resolving violations of the technical constraints (e.g. tap-changed transformer for voltage control, DSM to control the overloading), whereas other are mutually exclusive. To capture these inter-dependencies the "Smart Operators" of the presented algorithm were developed.

METHODOLOGY

Figure 3 shows the basic procedure of the methodology.

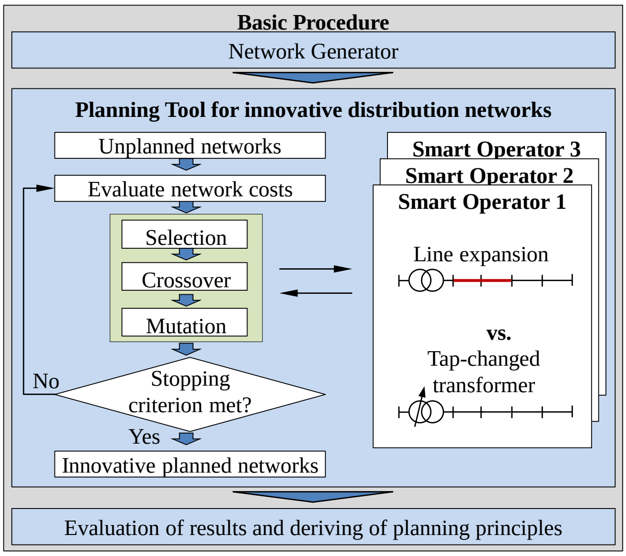

Figure 3 Methodology using genetic algorithm

In a first step various synthetic network structures with different characteristics that represent different supply tasks and generation situations are produced with a network generation tool and supplemented with characteristic parts of real networks.

Then the developed planning method is applied to all networks with the aim to derive conventional and an innovative optimal solution for each network's reinforcement and expansion decisions.

Then the two solutions (innovative vs. conventional) can be compared and the influence of different parameters (e.g. load density, generation density, length of lines) on the investment decisions can be estimated.

These findings are then generalized and transferred –if possible – in rules for the day-by-day planning process.

INNOVATIVE PLANNING TOOL

Network generation and analyzing

The "Network Generator" for the generation of synthetic network structures is an additional tool developed in context of the new planning method. It is based on statistical parameters derived from real networks.

Optimization with Genetic Algorithm

The Genetic Algorithm (GA) is a nature derived optimization method, which means that the course of the algorithm is based on the micro-evolution process in nature. It is a heuristic approach, so there is no guarantee that the global optimum is found. Heuristic approaches are necessary when the optimization problem turns out to be too complex for exact solving. In case of the described network planning problem the solution space is very high because of the wide variety of investment options. The use of GA is often used in network planning, so the basic idea of the presented approach is based on existing approaches [4].

Problem modeling in Genetic Algorithm

At the start, the existing network with all its investment options is encoded ("translated") into the syntax of the GA. Table 1 sums up the important elements.

Reality	Modeling	GA
One investment decision	One degree of freedom	One gene-value
One network with investments	One solution	One individual
Set of possible net-work configurations	Set of solutions	Population

Table 1 Syntax of genetic algorithm

One solution, which means one configuration of operating equipment for the network, is encoded as a so-called individual. This individual, a so-called gene-string, contains one gene for every investment decision. Therefore different individuals represent different combinations of investments with each individual enabling network operation without constraint violations.

Out of a large number of individuals (solutions) the algorithm aims to find the best one. This group of individuals is called the "population". Before creating the population a pre-analysis (e.g. placing of storage units only near the substation) is made to determine which parts of the network are violated or not. Thereby, solution space and run-time of the algorithm can be reduced. The decision which individual is the best out of a group of many can be made by the calculation of the fitness value, which represents the network costs.

Approach of the algorithm

The GA is running stepwise (iterative) and tries to improve the quality (fitness) of the individuals in every iteration. For each step a new population is derived by applying genetic operators (typically mutation and cross-over) to the existing population, so the evolution is simulated.

The mutation-operator selects an individual randomly and modifies the gene-string in order to produce an individual with lower costs. After that, a load-flow calculation (simulating one high-load and a high-feeding-case) validates if the individual causes network constraint violations. If that is the case, the individual is repaired by expansion of additional lines or is set back to the initial state before the mutation.

The crossover-operator randomly selects two individuals and crosses them in order to generate better solutions. Individuals with a high value of objective function are adopted from the new population, while the others are neglected.

By using these genetic operators, the quality of the overall population improves. The iterative process ends if a stopping criterion (e.g. max. number steps or no more improvement) is met.

Smart Operators:

One disadvantage of the GA is the mostly random search process. The standardized mutation operator selects a random gene and changes it randomly to a new value. By using this approach, the finding of an optimal solution is uncoordinated and not very efficient. In order to improve this process, more efficient operators, the so called "Smart Operators", were implemented. These operators search faster due to a more intelligent modification of existing solutions by considering pre-implemented rules. These rules define combination of genes, where good solutions with low costs are suspected. This approach shall be demonstrated with an example:

In an existing LV-network with huge voltage-constraint violations, the GA will search for a solution by mostly extending lines, as they are the major part of the individual. The usage of a MV/LV-tap-changed transformer could be a valid, cost efficient solution too, but there are several more genes for a line extension than for the transformer. Therefore the standardized mutation operator will work through a great number of iterations, extending and removing lines, until finding the perhaps most efficient solution by coincidence.

In contrast, one of the Smart Operators – called "MV/LV-tap-changer vs. line extension" – tries to dissolve the voltage constraint violation by targeted combining of a MV/LV-tap-changed transformer in addition to the withdrawal of all extended lines. This approach is motivated due to the rule, that voltage constraint violations can be handled by using a MV/LV-transformer. By using this Smart Operator, this possible valid solution is found faster than using the normal mutation operator.

Other Smart Operators for the usage of storages, STATCOM or the substitution between two types of operating equipment were implemented. To prevent the algorithm converging into local optima, the Smart Operators are only used for a certain, definable ratio (e.g. 20% of the whole mutation operator).

EXEMPLARY RESULTS

The following two exemplary investigations should demonstrate the functionality of the presented algorithm.

Exemplary network - Down-Town-City area

As the rural network structures have been in focus in recent research [5] we like to stress the challenges for urban network operators, that differentiate from rural networks in the amount and type of distributed generation, the penetration with new and flexible loads as well as special demands for power quality. To ensure, that the developed methodology is able to solve real network planning problems, a real LV-down town city network structure has been chosen. For the year 2030 two different scenarios for the networks usage were derived.

Best-guess-scenario: On the one hand the evaluation of solar potential power maps[6], studies considering the development of micro-CHP plants[7], energy policies of the German Federal Government especially regarding the development of e-mobility [8] as well as the network operator's expectations lead to a best-guess scenario for the future use of network (see Table 2 "best-guess").

Over-estimated scenario: On the other hand an over-estimated scenario regarding the growth of PV generation is tested (see Table 2 "over-estimated").

Table 3 shows the characteristics of the chosen network area before enforcements and extension:

Characteristics \ Scenario	Best-guess	Over-estimated
Conventional Load [MW]	2.2	2.2
Load by e-mobility [MW]	1.6	0
Generation – PV [MW]	1.1	5.5
Generation – micro CHP [MW]	0.4	0.2
Load density [MW/km^2]	25	14
Generation density [MW/km^2]	10	38

Table 2 Scenarios for load and generation development

Characteristics	Value
No. house connections (0.4 kV)	245
No. nodes	636
No. MV/LV- transformers	14
Sum of capacity of transformers [MVA]	5.9
Length of lines in LV [km]	10

Table 3 Network characteristics of exemplary network

Further assumptions

Cost-scenarios

The cost assumptions for the planning options are shown in Table 4. First, one extreme cost-scenario is examined to validate the functionality of the proposed method. This scenario lacks realistic assumptions and is only used for demonstration purposes. After that, results for a realistic scenario with accurate cost assumptions for future down-town-city areas are presented.

Costs \ Scenario	Ex-treme	Rea-listic
Line enforcements, single [€/m]	100	100
Line enforcements, double [€/m]	120	120
Line enforcements, quadruple (both side of the street) [€/m]	200	240
Transformer enforcement, 1 MVA [€]	8000	12000
Tap changed transformer, 1 MVA [€]	12000	30000
Storage, 30 kVA [€]	9000	75000
STATCOM, 72 kVA [€]	4000	18000

Table 4 Cost assumptions [own assumptions], [7]

Technical limits

In addition to the technical constraints discussed above, the limit for line or transformer loading is set to 66% of $S_{nominal}$, based on the network operator requirement, that every group of three transformers should provide reserve for one another in case of line or transformer outings.

Results

Case 1: Over-estimated scenario with extreme assumptions for cost relations

The following figures each show a small part of the optimal conventional and innovative solution for the network structure presented above. These solutions show clearly the effectiveness of the proposed method. When enabling only conventional equipment, line extension is used for dissolving constraint violation (see Figure 4).

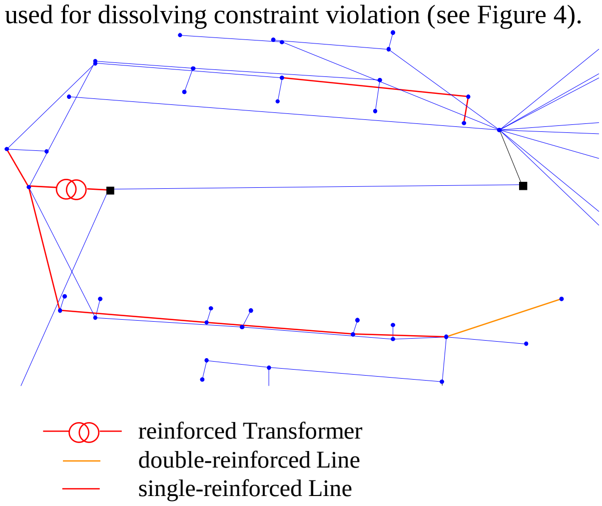

Figure 4 Conventional solution

When considering innovative operating equipment the optimal solution changes. Figure 5 for example demonstrates the usage of a tap-changed transformer for the substitution of line enforcement.

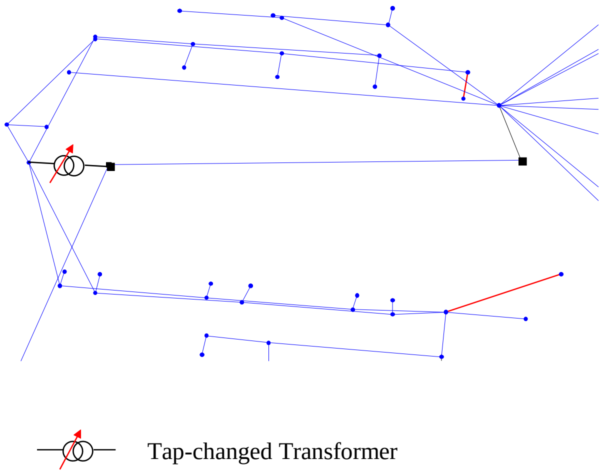

Figure 5 Innovative solution using tap-changed transformer

Figure 6 compared to Figure 7 showing another part of the presented network, demonstrates how line enforcement is substituted in the innovative solution with the placing of storage elements. In case of the presented storage capacity, the part of double-enforced lines can be reduced or rather substituted by single-enforced lines and the storages. The enforcement of the substation transformer cannot be substituted by placing storage-elements because the storage capacity is not high enough. Consequently, the storage-elements in this case are only necessary for the voltage stability.

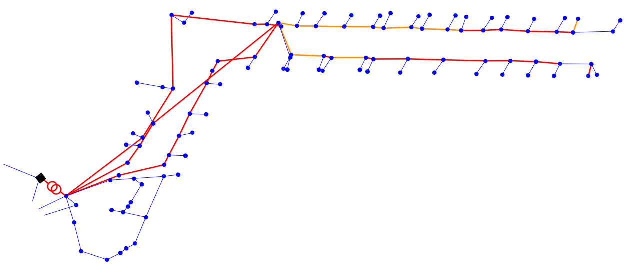

Figure 6 Conventional solution

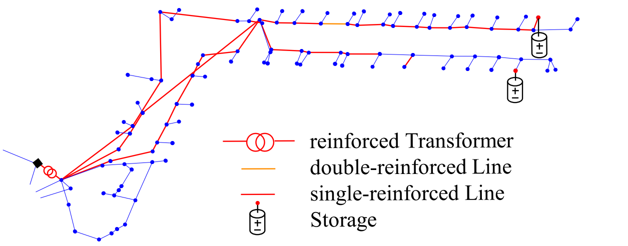

Figure 7 Innovative solution using storage elements

Case 2: Best-guess scenario with realistic assumptions for cost relations

Table 5 shows the reinforced elements for the conventional and innovative planning solutions under consideration of the realistic cost scenario. Line as well as transformer enforcements are part of the optimal solution but no tap changing transformer or STATCOM is used.

Solution / Element	Conven-tional	Inno-vative
Single-enforced lines [m]	243	243
Double-enforced lines [m]	0	0
Reinforced transformer	1	1
Tap-changed transformer [No.]	0	0
STATCOM	0	0

Table 5 Overview – network enforcements

The analysis shows that with realistic cost relations no innovative operating equipment will be used to solve the network's criticalities when facing the future supply task. As down-town city area typically show reserves for the integration of additional load as a result of the previous or current planning rules, in the best-guess scenario only single lines or transformers must be enforced. There is no need for voltage drop controlling equipment. However this does not rule out any efficient application of intelligent network equipment, since uncertainties of local customer behavior are high and also the quality of service can be improved by innovative operations equipment.

SUMMARY AND OUTLOOK

In this paper, we propose a new innovative planning method for the planning of LV- and MV-network structures under consideration of innovative operation equipment such as tap-changed transformers, voltage control elements as well as storages or DSM.
The exemplary results show the functionality of the new planning method, based on a genetic algorithm approach with proposed "Smart Operators" integrated in the standard genetic methods (mutation, crossover).
With this method, a large amount of networks can be automatically planned and the comparison of the conventional and innovative solutions can be performed. This will give the opportunity to identify new planning rules using innovative equipment and methods based on statistical evaluations of the results generated with this planning method. The presented optimization method will be updated by implementing optimized modifications of the LV-structure, e.g. new positioning of substations.

NOTIFICATION

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