AUTOMATED EXPANSION PLANNING FOR DISTRIBUTION PRICING

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ABSTRACT

This paper presents findings of a part of the software project aimed at developing a comprehensive methodology and robust computation engine for automated expansion planning (AEP) of distribution networks and economic use-of-system charging at the extra high voltage (EHV) level. Two main objectives of the AEP module are (i) identification of network constraints and bottlenecks through an automatic check-up of the network compliance with the UK network planning standards, and (ii) carrying out minimum cost automatic network modifications to eliminate overloads. The AEP results are used as the first pass security assessment and for feeding into the pricing – charging models.

INTRODUCTION

Automated expansion planning of transmission and distribution networks searches for the best reinforcement plans by minimizing the overall cost while meeting various operation and reliability constraints [1,2]. The network expansion problem is usually tackled with the aid of an interactive approach in conjunction with a suite of power system analysis tools, or a comprehensive optimization model [3-7]. Network security and reliability constraints are often specified in terms of "n-k" security principles, where "k" is the number of components being simultaneously put on outage. However, no effort has been made so far to model the security concept "bigger outaged capacity – shorter permissible duration", which is the concept applied in the UK [8,9].

Recognising the need to automate distribution network expansion planning and to develop new distribution use of system (DUoS) charging models, "Electricity North West" (ENW) and "TNEI" have developed comprehensive software for expansion planning and pricing of distribution networks (Fig. 1). Expansion planning and pricing module can be run in one of two modes. The first is automatic check-up of the compliance with the UK network design standards [8,9]. Its main characteristics are analysis of the security requirements by demand groups and an in-detail modeling of the post-fault restorations. The results of this module are analyzed by the Planning Department who produce network solutions that are submitted to the Regulator. The other mode does the full network analysis in line with the security requirements and generates network reinforcements in a simplified way using a pre-specified set of rules. The network reinforcements so obtained are then fed into the pricing module, where nodal marginal charges are calculated using several developed pricing models.

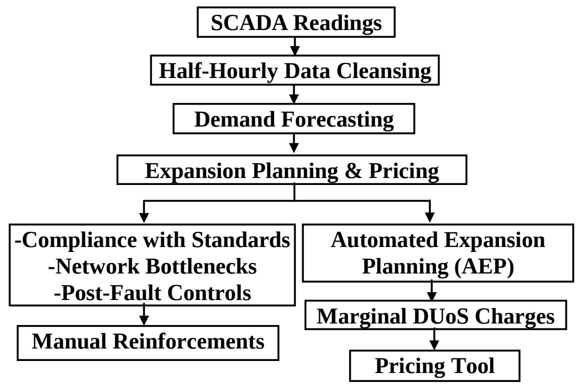

Figure 1 – "Expansion Planning & Pricing" (EPP) project

This paper presents the methodological aspects and software features of the AEP module. Global flowchart and the main building blocks are given first, which is followed by the software features, study results and conclusions.

AUTOMATED EXPANSION PLANNING

The AEP module is designed to give network reinforcements and/or replacements within the planning period which is typically 20 years (Fig. 2). Its main building blocks are the type of network analysis, expansion planning method and network modification procedure. Three network analysis approaches were developed. The first is analysis of the intact network only, where a single "security factor" is used to approximate contingent power flows. The next approach is (n-1) contingency analysis where all branches between tripped circuit breakers are outaged, while the most comprehensive approach employs the full "P2-6" contingency analysis as outlined in the UK planning standards [8,9]. The DC loadflow model is used in all approaches to study three characteristic operating regimes together with three loading scenarios. Winter peak, summer peak and summer minimum regimes are selected as typical operating conditions where distribution constraints are experienced. The loading scenarios are defined in line with the UK planning standards. For example, 33 kV networks are studied using the non-scaled primary and EHV customer peak (or minimum) loads, 132 kV network is analysed with the aid of loads scaled to match the 132/33 kV transformer (BSP) loadings, while x/132 kV grid transformers and 132 kV network are studied with all loads scaled to the peak (or minimum) loadings of the grid transformers (GSP).

Expansion planning and network modification are built as an integral module. Two planning methods are available here. The first is approximate "predictive planning" whereby each asset is looked at in isolation from all other assets and its reinforcement is triggered when the future (critical) flow reaches the branch rating. The second planning method studies the whole network as an integral entity on a yearly basis and a single network expansion is done at a time until all violated constraints are eliminated in the considered year. This method is described in more detail in the next section.

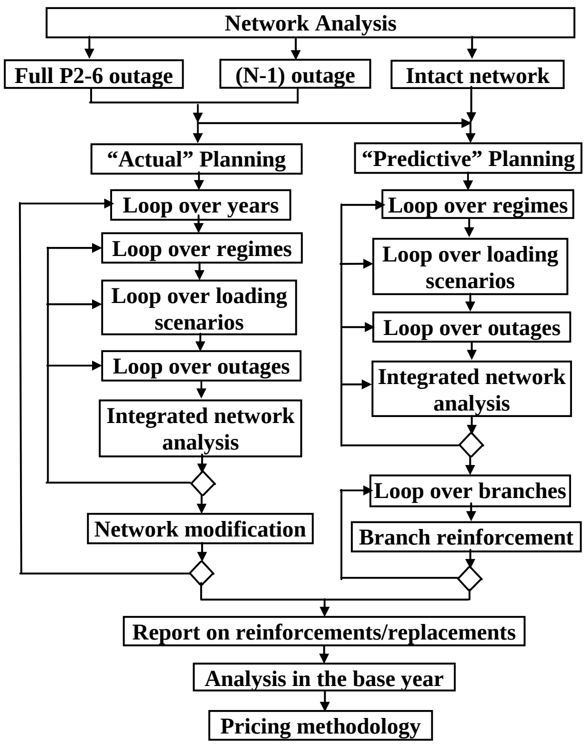

Figure 2 – Flowchart of the AEP module

NETWORK MODIFICATIONS

Analysis of contingency cases within all operating regimes and under different loading conditions gives the critical (ie highest) power flow in each branch. Critical power flows are then compared against the branch rating multiplied by (1 + *tolerance*), where *tolerance* can be defined separately for cable, lines and transformers. A prioritised list of overloaded branches is formed in the following way:

- All branches whose overload is more than x% greater than the rating are ordered by the magnitude of the MW power flow (x% is a user-defined setting).
- If there is no overload above (1 + x/100) times branch rating, all other overloaded branches are ordered using the highest MW power flow criterion.

The top branch on the prioritised list is selected for overload elimination. To do this, only a small part of the network surrounding the overloaded branch is analysed. Several mock branch modifications are done and the one with the least cost is finally selected for reinforcement or replacement. When the modification is completed, the entire network in the same year is studied again.

Modification of Underground (UG) Circuits

Following principles are applied to modify an UG circuit:

1. All UG circuit sections are modeled separately and the longest circuit section is called *dominant* section.
2. User-defined parameter defines whether reinforcement or replacement shall be done.
3. Branch reinforcement is addition of a parallel circuit:
   - It is either of the same size as the dominant section, or it is the first bigger size in the Component Catalogue if there is no match.
   - The new circuit is always a single-circuit and has unique cross-section. The newbuild cost is used.
4. Replacement of the cable is based on the following rules:
   - The next bigger cable is selected so that the overload is alleviated. A user-defined parameter can be used here to avoid frequent modifications in small steps. The entire circuit is of the same size, it is either single-circuit or double-circuit depending on the original branch configuration and the replacement cost is used.
   - If this is a single-circuit and an appropriate cable size cannot be found, the overloaded branch is replaced with a double-circuit and the corresponding replacement cost is calculated.
   - If the appropriate cable size cannot be found at all, a single parallel cable is added and the reinforcement cost is calculated.
5. The total replacement or reinforcement cost is made up of circuit and terminal costs. Circuit cost is calculated from the specific cost in £/km for that voltage (either single- or double-circuit) and the circuit length, while terminal cost is obtained from a look-up table with 132kV, 33kV and 11(6.6)kV switchgear and breakers. The letter cost is found by studying the branch ends.

Modification of Overhead Lines (OHL)

OHL are more complex to model because three types of modifications, namely reinforcement, refurbishment and "standard" rebuilding are envisaged, and there is an option to underground the OHL. Besides, cost entries are defined for OHL on towers and on poles and differentiation between single- and double-circuit towers shall be made. The main principles to modify an OHL are summarised below:

1. All OHL circuit sections are modelled separately and the longest section is called *dominant*.
2. Specific costs in £/km are found by identifying pole or tower type and single-circuit or double-circuit tower construction.
3. OHL reinforcement is based on the following rules:
   - If undergrounding is selected, a single parallel cable whose size is closest to the dominant section size is added. The newbuild cost is used.
   - If undergrounding is not chosen, an OHL whose conductor size is closest to the dominant section size is added. The new line is on double-circuit towers except in case where the existing single line is on double circuits. The newbuild, single-circuit or double-circuit cost is used.
   - An OHL on poles is always reinforced with another OHL on single-circuit poles.
4. Replacement of an OHL can be done either with

refurbishment or rebuild:

- If undergrounding is selected, a cable whose rating is bigger than the dominant cross section (overload must be eliminated) replaces the OHL. This can be either single-cable or double-cable and corresponding replacement cost is used.
- If there is no undergrounding, the OHL conductor size is determined so as to eliminate the overload. The tower type is either single-circuit or double-circuit and the replacement cost is calculated accordingly.
- If a replacement OHLor cable circuit cannot be found, a parallel circuit is added.

Modification of Mixed Lines

Where the branch under consideration consists of both UG and OHL sections, the algorithm needs to be modified:

1. The total UG and OHL section lengths are found and compared against the user-defined threshold (say 80%).
2. If the branch is predominantly UG, procedure for cable reinforcement/replacement is put in place.
3. If the branch is predominantly overhead, algorithm for OHL modification is applied.
4. If the branch is of mixed nature, the following is done:
   - If the OHL parameter is set to undergrounding, the new circuit will be all UG. Reinforcement or replacement is determined from the user-defined parameters and the UG costs are found as before.
   - If there is no undergrounding, the two sections are studied separately. If both sections are to be reinforced, a parallel circuit will have a UG and an OHL section. If one parameter is for reinforcement and the other is for replacement, the OHL parameter defines the modification type.
   - If replacement strategy is selected, the mock replacements of both sections are done. If this is a feasible solution, replacement is carried out. However if an appropriate OHL cannot be found, the branch is reinforced as before.

Modification of Transformer Branches

Transformers are classified by primary-side voltages and replacement costs are associated with individual sizes. The essential principles are:

1. Replacement or reinforcement is driven by settings defined for primaries, BSPs and GSPs.
2. Reinforcement is done with a transformer of the same size which is installed in parallel.
3. Replacement is done with the first bigger size if possible. If not, a transformer is added in parallel.
4. The total cost is the transformer and the terminal cost. The letter is cost of both bays if the transformer is in a substation, or cost of secondary-side bay in case of a feeder-transformer arrangement.

DEVELOPED SOFTWARE

The entire EPP software is developed around the base Interactive Power System Analysis (IPSA+) tool [10]. The original IPSA+ database contains data about power system components and they are extended with additional object attributes specific to the EPP project. The Catalogue of Power Components with appropriate costs is held in a separate set of tables in the database.

All configurable settings are loaded from the database into the forms and they should be saved alongside the study results. The AEP module is driven by several key settings, such as Network Analysis Type, Expansion Planning Method, Operating Regime and Scaling of Loads and Generations (Fig. 3). Group boxes in the left-hand side deal with modification methods for different types of assets (ie reinforcement, replacement, refurbishment, rebuild and undergrounding), while options for calculation of asset costs are displayed in the mid-part. The simplest option is to use uniform unit costs in £/km for linear assets and £/MVA for transformers, while more accurate approach is to apply generic asset costs whereby £/km and £/MVA are specified by voltage levels and asset types. The most accurate approach is to use the Catalogue of Power Components, where each individual asset type has appropriate specific cost. Additional parameters required by the AEP module are presented in the right-hand side. These settings are related to asset ratings and thresholds being used within network modification module.

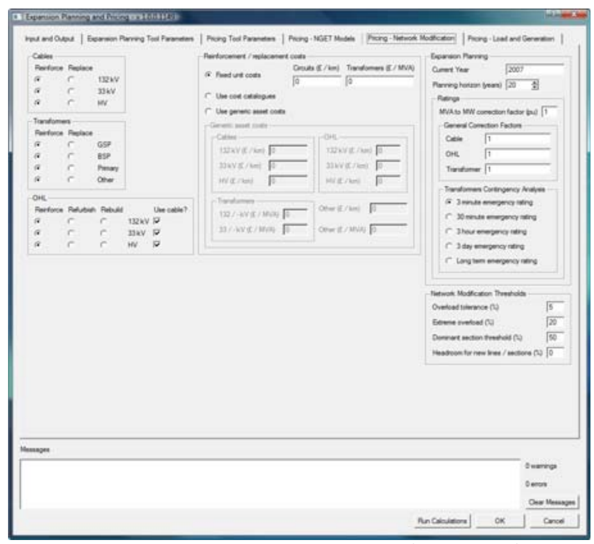

Figure 3 – "Pricing – Network Modifications" form

ILLUSTATIVE RESULTS

The EPP software was tested on the model of the entire EHV network consisting of a significant chunk of the 400kV and 275kV transmission networks, 132kV and 33kV networks down to 11(6.6)kV busbars. This network has around 3,000 nodes and more than 5,000 branches.

AEP results presented in Figures 4, 5 & 6 are for a "typical" distribution GSP supplying around 60 primary transformers. A comparison between two expansion planning strategies is given in Fig. 4. The more the network is meshed, the bigger discrepancy between the "actual" and "predictive" expansion planning. The presented case shows big difference in the mid part of the planning period, when interactions between individual reinforcements significantly

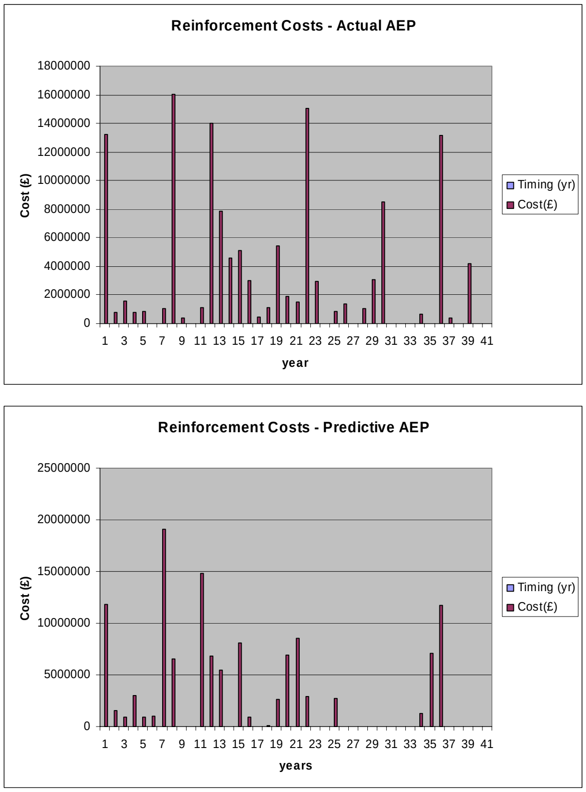

Figure 4 – "Actual" vs "Predictive" Reinforcement AEP

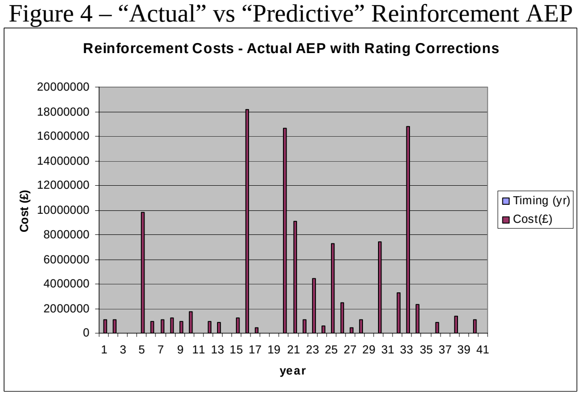

Figure 5 – Effect of asset rating increase

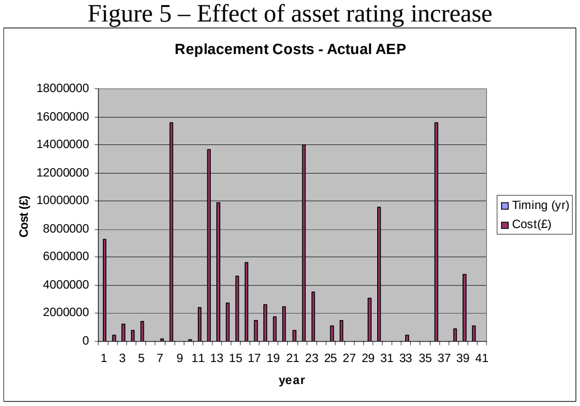

Figure 6 – "Actual" Replacement AEP

impact further network development. Impact of applying a positive generic correction factor to all asset ratings is presented in Fig. 5 indicating that there is a significant cost reduction at the beginning of the planning period. Finally, a different cost profile is obtained when replacing assets with bigger sizes rather then reinforcing them (Fig. 6).

CONCLUSIONS

This paper presents the developed methodology and software for the automated expansion planning of distribution networks. The results from the expansion planning are then fed into the pricing module, where calculation of nodal marginal charges is performed. The entire methodology is tested on the large-scale real-life EHV network. The automatically generated reinforcement/ replacement results line-up very well with the network solutions obtained using the standard "manual" approach to distribution network development.

REFERENCES

[1] V.A. Levi, M. Calovic, "A New Decomposition Based Method for Optimal Expansion Planning of Large Transmission Networks", *IEEE Trans. On Power Systems*, pp 937-943, August 1991.

[2] V.A. Levi, D.S. Popovic, "Integrated Methodology for Transmission and Reactive Power Planning", *IEEE Trans. On Power Systems*, pp 370-375, February 1996.

[3] E. Miguez et al, "An Improved Branch-Exchange Algorithm for Large-Scale Distribution Network Planning", *IEEE Trans. On PS*, pp 931-936, Nov 2002.

[4] M. Vaziri, K. Tomsovic, A. Bose, "A Directed Graph Formulation of the Multistage Distribution Expansion problem", *IEEE Trans. On Power Delivery*, pp 1335-1341, July 2004.

[5] P.C. Paiva, "Integral Planning of Primary - Secondary Distribution Systems Using Mixed Integer Linear Programming", *IEEE Trans. On Power Systems*, pp 1158-1165, May 2005.

[6] E.G. Carano et al, "Electric Distribution Network Multiobjective Design Using a Problem-Specific Generic Algorithm", *IEEE Trans. On Power Delivery*, pp 995-1005, April 2006.

[7] R.M. Fletcher, K. Strunz, "Optimal Distribution Sys tem Horizon Planning – Part II: Application", *IEEE Trans. On Power Systems*, pp 862-870, May 2007.

[8] *, "*Engineering Recommendation P2/5 – Security of Supply*", Energy Networks Association, UK, 1978, 2003

[9] *, "*Engineering Recommendation P2/6 – Security of Supply*", Energy Networks Association, UK, 2006.

[10] **, 2003, *IPSA Reference Guide*, www.ipsa-power.com