RELIABILITY BASED ASSET MANAGEMENT FOR INVESTMENT STRATEGIES AND DECISIONS

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INTRODUCTION

In Europe the electricity network business is facing large investment needs in the coming years, due to the increased requirements for quality as well as the fact that a major part of the electric network, especially in the rural areas, is coming to the end of its lifetime. There is therefore a need to be able to analyze the network in order to find the right locations for investment, i.e. the right parts of network to be renovated or reconstructed, in order to maximize the improvements of network with optimal investments. More and more attention is also put on the quality issues, minimizing outages.

In order to be able to do the right decisions, all the possible known aspects should be taken into account, i.e. as many as possible information sources should be used. There are several sources of information available; Network information systems have been widely in use since 90's and there are national statistics available about outages and the reasons for them. Also condition information for network components have been collected for some years in many network companies. There has however not been any system in use utilizing the available data extensively in a way that support the decision making in network companies.To be used for the first order headings.

BACKGROUND

In order to study the possibilities to enhance the existing network information systems (NIS) with needed functionality, a cooperation project was started in Finland in 2002. Participants in the cooperation project were eleven Finnish network companies, Tampere Technical University, VTT Technical Research Center of Finland and three NIS vendors, Tekla Corporation as one of them.

The cooperation project included a research phase where earlier published research results were evaluated, a specification phase where the needed functionality and methods were specified and in the later part of the project also workshops where the defined methods were tested on a real network data using prototype software developed during the project.

One of the cooperation project's main targets was, instead of just handling traditional failure rates, to model them to be depending on the location, condition etc. of the component in question. The components, which were chosen to be modeled, were overhead line section, covered conductor line section, underground cable, aerial cable, secondary substation, disconnector and "other component", which can be any type of component. For each component the essential fault reasons were introduced and the fault frequency and essential factors for them defined. For example, the main fault reason of overhead line are fallen trees due to wind and the main factor effecting to this basic fault frequency is the location of line section (whether the line section locates in treeless area, edge of the forest or forest). In this work the statistics from participating companies as well as the national Finnish outage statistics were used.

The modeling was done separately for sustained and momentary faults. Also the short circuit and earth fault failure rates were modeled separately in order to have input data for voltage dip analysis.

In addition to the fault frequency model the analysis of effects of failure is needed. This analysis will for each consumption site return the mean interruption frequency and outage duration.

During the cooperation project also a method for calculating voltage dips caused by short-circuits was developed. The results of this calculation are the number of voltage dips in each consumption site into a number of depth levels.

In order to utilize the results of the reliability analyses in cost calculation, a model for fault and outage costs was developed. The direct costs for a network company are the costs for labor and material and in case of overlong interruptions also the direct compensations to the customers. The outage costs on the other hand are fictive costs of the inconvenience because of interruption but by including outage costs in the total costs the optimal solution should lead to economical optimum as a whole.

In order to get an overall view a mechanical condition index of a network component was created based on components existing inspection data. In the same way an index describing the technical goodness of the network was created based on the power system analysis results.

The cooperation project outcome was a detailed specification of the algorithms and methods to be used. The project was finished in the beginning of 2005. [1]

SYSTEM IMPLEMENTATION

When the implementation into Tekla Xpower network information system started, special effort was put on making the system as general as possible, suitable for not only Finnish network companies, but more generally for network companies using Tekla Xpower globally. All basic values used in the system are for example parameters defined in database, totally about 400, which then can be easily changed to suite the local situation.
Since the methods defined were based on the information generally existing in the databases of the participating eleven network companies there was a need to improve the methods and information used as base for the methods. One example is the environment information for overhead lines, which was specified in percentage units for the line section to indicate the percentage of line sections locations in treeless area, edge of the forest, in forest and in high risk forest. This information was defined to exist among inspection data. In the implemented system the information is defined per line element, i.e. per span (between two poles), giving much more precise information. The method was also changed so that the information is taken from a forest mask produced with remote sensing. This mask, a raster picture with 25 m resolution, includes 45 classes of forest (3 different forest types, 5 classes of height, 3 classes of timber volume per hectare). On top of this information there are information about fields, water, roads and built-up areas. The environment information is then saved in the database linked to component, and is used when analyzing the reliability of the network. This gives the possibility to develop analysis further to take into account local variations in forest type.
Another example of improvement done was the support of low voltage (LV) networks. This was not included in the original project but was modeled during implementation in similar ways as for medium voltage (MV) networks.

SYSTEM DESCRIPTION

Tekla Xpower RNA&AM (Reliability based Network Analysis & Asset Management) is totally integrated into network information system Tekla Xpower, having the same database and user interface as Tekla Xpower. This means that all the functionality and data available in Tekla Xpower is also available to be used by the application internally or by the user. It also means that all the normal functionality of Tekla Xpower is available with RNA&AM, such as network planning and simulation in an environment supporting long transactions.
The inspection data stored in Tekla Xpower Maintenance Management System (MMS) is used for three type of components; secondary substations, disconnectors and poles, from which the information is connected to the overhead-line elements connected to the pole. From the inspection information an overall condition index (0 to 4) is calculated, where value 0 is meant for a basically new component and value 4 a component that should be replaced. The condition index is used for the fault frequency calculation in the reliability calculation.

Reliability calculation

The central basic value of the reliability calculation is the calculation of fault frequency for each component. This is basically done with formula:

$$\lambda_{F,i} = \sum_{j=1}^{N_i} \left(\prod_{k=1}^{M_j} K_{F,i,j,k} \right) \cdot \lambda_{PF,i,j} \cdot L_i$$

The component i has N_i circumstances and with circumstance j there are M_j circumstance fault factors. $K_{F,i,j,k}$ is the circumstance fault factor k for component i and $\lambda_{PF,i,j}$ is the partial fault frequency j for component i. L_i is the length of the conductor, for other components L_i = number of components per 100.
For example the fault frequency of a secondary substation is depending on the following three partial fault frequencies and their circumstance fault factors (different factors within brackets):

- Thunder
  - Location or way of protection (In cable network, surge arrester, spark gap, no protection)
- Faults caused by animals
  - Animal protection (On cover, No animal protection)
  - Jumper isolation (Isolated, Un-isolated)
  - Bird protection (Bird spikes exist, No bird spikes)
- Other faults
  - Mechanical condition (OK – inspected within last 2 years, OK – inspected earlier, Not inspected, Not OK – inspected within last 2 years, Not OK – inspected earlier)
  - Load (Normal load, Overloaded)

As an example of calculating the fault frequency of a conductor, the fault frequency of a MV overhead line is calculated from the following two partial fault frequencies:

- Wind or weather conditions
  - Forest / environment information (Treeless area, Edge of the forest, Normal forest, High risk forest)
  - Maintenance (More frequent, Normal, Less frequent)
- Other faults
  - Mechanical condition (Condition index 0 to 4)
  - Type factor (Reliable, Normal, Bad)

Due to the fact that the smallest area a fault can affect is an isolation area (i.e. the network until the closest disconnectors) the calculation can be done based on the fault frequency of each isolation area, which is calculated as the sum of the fault frequencies of the components belonging to it.
In order to calculate how an outage affects the network as a whole, each isolation area is analyzed:

- How the isolation area can be isolated (manually /

remotely)
- How the feeding to other isolation areas fed through this can be restored (manually / remotely)

The result of the analysis is different duration for fault isolation and restoration of supply to other isolation areas. Usage of fault location in the feeder reduces the time for fault isolation.

For repair times less than 5 hours there are some typical faults modeled (cable replacement with backup system, replacing MV/LV transformer, repair of overhead-line). For longer repair times (5-8 h, 8-12 h, over 12 h) proportions and standard repair times are used. Also planned interruptions are modeled, but in a straight forward way using parameterized frequencies and durations. The auto-reclosings (High speed and delayed) are also modeled and evaluated. The input data is similar as for the fault frequency described above for secondary substation and MV overhead line.

Voltage dip calculation

As the whole network model is existing in the system, and there are information about the probability of faults in different locations of the network it is possible to analyze how the faults affect other networks from voltage dip point of view, as the short-circuit is seen as a voltage dip in other feeders.

Voltage dips can also affect neighboring primary substations via the feeding regional (HV) network. This is also supported in the voltage dip calculation if the regional network is documented. The result from voltage dip calculation is how deep voltage dip caused by a short circuit in each line section occurs in each secondary substation or consumption site. It is also possible to color the network according to the voltage dip depths caused by a short circuit in a selected location in the network.

Results from reliability analysis

The results of the reliability calculation are always shown in two ways: what a certain network component causes and what a consumption site or secondary substation suffers. In this way it is possible easily to find out which parts of network are causing the most problems. It is possible to navigate in the list of results in a hierarchical way; on MV side main transformer – MV feeder – overhead line / cable and on LV side secondary substation – LV feeder – overhead line / cable.

The results include a lot of information; for example for each transformer, feeder or overhead line / cable the following groups of results are shown concerning what the network or component is causing:
- General information about the network and component, totally 20 columns of results
- Statistics about the network or component from reliability basics point of view, totally 58 results
- 5 general indices (Overall criticality, Electrical goodness, Mechanical condition, Safety, Reliability)
- Fault information, totally 10 results
- Standard outage indices (SAIFI, SAIDI, CAIDI, MAIFI)
- Planned outages, totally 7 results
- Auto-reclosings, 4 results
- Voltage dip calculation, 14 general results and additionally 14 results per consumption type
- Costs for faults, planned outages, auto-reclosings and voltage dips, 8 results

All results are also saved in relational database. They can be used for example to create thematic maps with Tekla Xpower Theme & Statistic Analysis or to create alphanumeric reports with a reporting tool like Microsoft Access.

Asset management results

With Asset Management part of the system, the different costs of planned improvements are evaluated and can be compared to for example present situation. Costs can be costs for network company, i.e. real costs and end customers' costs, due to for example outages. The following network company costs are handled:
- Construction and land use costs
- Maintenance costs (inspection, service and repair)
- Losses
- Cost of outages
  - Costs for energy not supplied
  - Costs for overlong interruptions

In addition to these costs, also the end customers' costs are presented:
- Cost of sustained interruptions
- Costs of momentary interruptions
- Costs of voltage dips

Calculation can be performed over a number of years and all the costs can be discounted back to present time.

SYSTEM IN REAL USE

Tekla Xpower RNA&AM have been in active use since August 2006 in Vattenfall Distribution Finland, and have been used in some projects in order to collect experience and to fine-tune the parameter sets. Below there are two examples of real cases from this network company the second of which have been carried out and the are checked against the calculation results from Tekla Xpower RNA&AM.

Case 1, Evaluation of new light primary substation

A new light type primary substation is planned in the middle of the areas supplied from two existing primary substations. The usage of these new, by Vattenfall Distribution Finland developed primary substation is a strategic decision in order to be able to increase the number of primary substations in a cost effective way. The goal for this improvement is to reduce the number of sustained and momentary interruptions. The original situation is already quite good in the area, with remote controlled disconnectors.

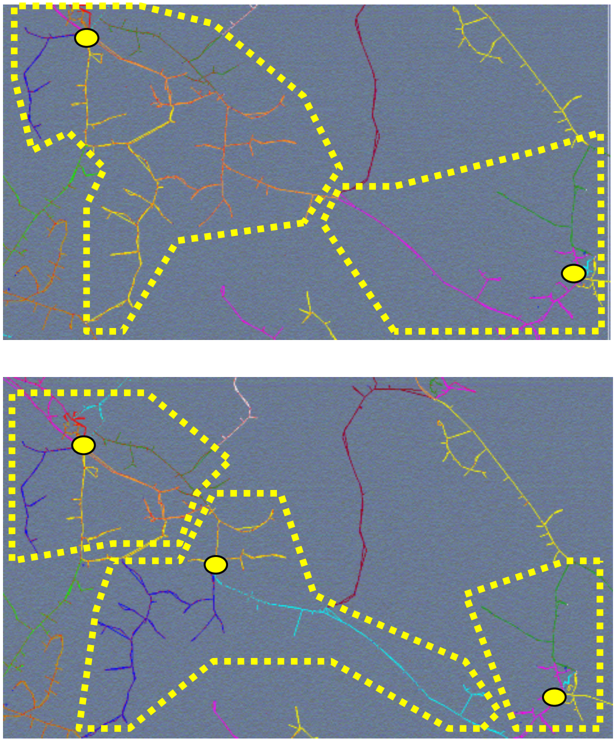

Figure 1: Situation before (upper) and after (lower) the primary substation is realized

Table 1: Cost calculation

Utility (k€, a)	**Original**	**Light substation**
Investment	0	29
Losses	2,2	0,9
Inspection	2,4	2,4
Service	3,9	3,9
Repair	3,6	3,6
Sum utility	12,1	39,8
Customers (k€, a)		
Unplanned interruptions	27,5	18,2
Planned interruptions	1,1	1,1
Momentary interruptions	51,3	24,7
Sum Customers	79,9	44
Sum Grand total	**92**	**84**

Table 2: Results from reliability calculation

Feeders originally	3
Feeders finally	6
Line length (km)	209
Customers	1237
Outages (pcs)	9,13
Reclosings	250,6
SAIFI, original	3.04
SAIFI, final	1,47
SAIFI, difference	**-1,57**
SAIDI, original	154
SAIDI, final	148
SAIDI, difference	**-6**
MAIFI, original	87
MAIFI, final	43
MAIFI, difference	**-44**

In table 1 the costs for the project have been compared to the costs of the present situation. This shows that with the value put on customer interruptions, the investment is economically profitable over 20 years. In table 2 the results from the reliability calculation shows that the biggest changes are in SAIFI and MAIFI, which will be about half of the original situation. There is no big change in SAIDI, due to the fact that the situation was already quite good in the area, as sustained outages were quickly isolated with the remote controlled disconnectors in strategic locations.

Case 2, Enhanced protection

The project for enhanced secondary substation protection has been started already before implementation of RNA&AM and was calculated with RNA&AM in order to check the algorithms used. The project included that a feeder, 124 km 20 kV overhead line with 690 customers, was renovated, in the way that all spark gaps were replaced with surge arresters and all MV/LV transformers were equipped with mechanical protection against animals.
In table 3 there are the results from Tekla Xpower RNA&AM calculation and in figure 2 there is the real number of sustained interruptions and momentary interruptions in the network during the first 7 months of 2005 (Original network) and 2006 (Improved network). From the results it can be seen that the trend in the calculation results is the same as in the real values; No real change in number of sustained interruptions but the number of momentary interruption has dropped to about half of the original number.

Table 3: Cost calculation

Utility (k€/100km, a)	**Original**	**Improved**
Investment	0,0	5,7
Losses	0,7	0,7
Inspection	2,4	2,4
Service	2,4	2,4
Repair	1,6	1,5
Sum (utility costs)	7,1	12,7
Customers (k€/100km, a)	**Original**	**Improved**
Unplanned interruptions	13,7	13,5
Planned interruptions	0,3	0,3
Momentary interruptions	13,2	8,1
Voltage dips	23,5	16,5
Sum Customers total	50,7	38,4
Sum Grand total	**58**	**51**

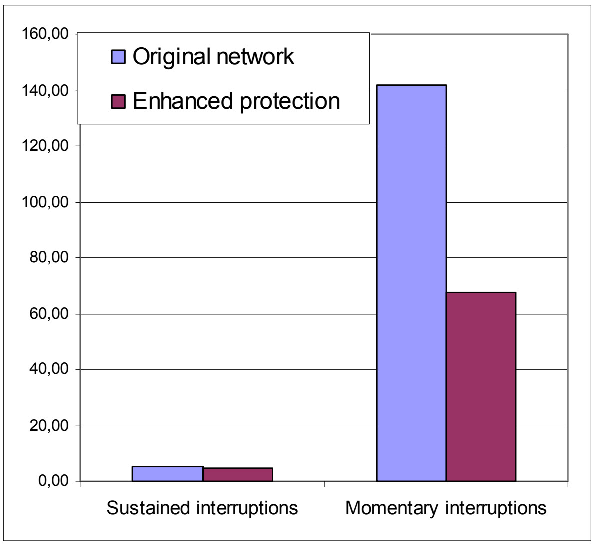

Figure 2: Real number of interruptions

CONCLUSION

This system has already proven to be a good tool for both analyzing the network and analyzing planned improvements, and will be used as a tool for decision making in Vattenfall Distribution, Finland. It has also been noticed by other Tekla Xpower users and there are few more pilot projects started for implementing Tekla Xpower RNA&AM.

The model as such is also quite straight forward, making future improvements to the model, such as implementing additional fault factors or circumstances to already analyzed component types, quite easy. This will make the results more reliable in regions with other or additional important fault reasons.

REFERENCES

[1] P. Verho, J. Pylvänäinen, J. Järvinen, M. Oravasaari, S. Kunttu. "Luotettavuuspohjainen verkostoanalyysi (LuoVa) – projektin loppuraportti", Research report 2005:6 Tampere University of Technology, Institute of Power Engineering. *(In Finnish)*