VISIONARY DEVELOPMENT OF DISTRIBUTION NETWORKS

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ABSTRACT

In this paper some scenarios dealing with power distribution will be presented and evaluated. Special attention is paid to reliability parameters, such as failure rate and outage costs. With assumptions of some set of scenarios long term planning case studies have been carried out using an advanced IT-tool. The studies show that profitability of investments to more reliable network depends strongly on the reliability parameters used.

INTRODUCTION

The long term planning of distribution networks is increasingly challenging task for utilities. The owners put strong pressure to be profitable, but on the other hand the customers and regulator require higher and higher reliability. In addition the development of the society and the changes in climate as well as the forms of energy production and use have strong effect to the operation environment. The paper presents history and scenarios dealing with reliability parameters. With assumptions of some set of scenarios long term planning case studies have been carried out and evaluated in the paper.

RELIABILITY PARAMETERS

In long term planning of distribution networks there is need to forecast future development in order to select the right parameters to be used in network analysis. Traditionally the most important parameter has been rate of load growth, but from reliability point of view the development of reliability parameters is of great importance. In this section some important reliability parameters are presented as well as their development in the coming decades. The forecasted development can be seen as a scenario, which can be used in studying the alternative solutions for future network.

Failure rate development

Typically failure rates used in reliability analysis have been determined using the historical data. It is also typical that when one value has been determined is used in the analysis of the future development. However, based on the most recent historical data, it can be seen that there is rising trend in failure rates in distribution network. At least this has happened in rural networks in which overhead lines are mainly used. The trend has also been recognized by the experts who has a long experience on the operation of distribution networks. One example on that is shown in Figures 1 and 2. In Figure 1 the 15-year development of number of permanent failures (accidental long interruptions) in medium voltage network in one Finnish utility (Koillis-Satakunnan Sähkö) has been shown. The rising trend can easily be seen in the picture.

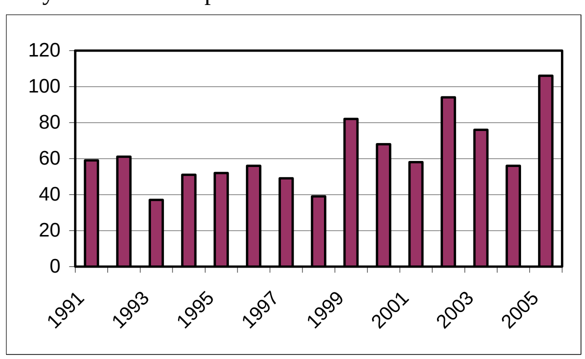

Figure 1. Number of permanent failures in one Finnish utility during period 1991-2005 (Main storms excluded)

The rising trend can be seen even if the main storms happened in 2001 and 2003 were not included in the statistics. Those are included in figure 2, which shows that the big storm in 2001 dominates the graph. It is justified to present the picture without it, but in evaluation of the failure rate development the storms should be taken into account.

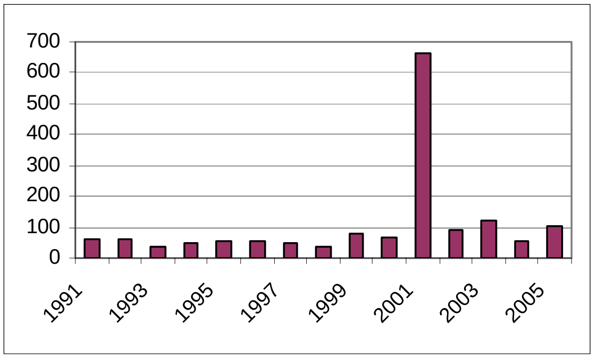

Figure 2. Number of permanent failures in one Finnish utility during period 1991-2005 (Main storms included)

The fundamental reason for the rising trend in not totally clear, but the cause of the rising rate are weather based faults e.g. wind and snow together with trees. One explanation to the development could be climate change, even if the change is so far quite minor compared to the forecasts. In any case the coming climate change will increase the probability of extreme weather conditions. Based on that it can easily be forecasted that the failure rate of aerial distribution lines will be increased significantly during the coming decades. As a scenario it could be assume that the failures due to the wind, snow and thunder will be at least duplicated.

Development of outage cost modelling

In order to have possibility to optimize total costs in the long-term network planning the consideration of the reliability must be done by using outage costs accompanied with reliability analysis. In modeling outage costs a combined cost model (CCM) can be used. The basic idea in the CCM approach is to model interruption costs as a sum of two components: one is a function of the interrupted load demand; another is a function of the unsupplied energy. The combined cost model has two parameters that ascribe a cost to the interrupted demand, A [€/kW], and to the unsupplied energy, B [€/kWh]. For the auto-reclosings there are separate values.

In Finland, several surveys in order to determine the values of CCM for different customer groups has been carried out in past decades, for example [1]. Table I presents the values of the earlier studies..

TABLE I – Interruption cost parameters for different customer group based on earlier surveys

	Unexpected outage		Planned outage		High speed AR	De-layed AR
	A	B	A	B		
Residential	0.068	0.61	0.034	0.3	0.034	0.088
Agriculture	0.54	4.9	0.18	1.6	0.25	0.70
Industry	2.6	8.7	0.80	3.8	1.1	2.9
Public	0.65	3.4	0.23	1.5	0.23	0.73
Commercial	1.9	11	0.8	7.2	0.95	2.1

In order to update the values Helsinki University of Technology and Tampere University of Technology (TUT) and several Finnish distribution network companies carried out project in 2004-2005 [2]. Based on the results of the survey the outage cost parameters Aand B has later been determined in TUT. The resulting values are presented in table II.

TABLE II – Interruption cost parameters for different customer group based on recent survey

	Unexpected		Planned		High-speed AR	Delayed AR
	A	B	A	B		
Residential	0.17	2.01	0.09	1.03	0.09	0.32
Agriculture	0.35	7.25	0.18	3.71	0.26	0.68
Industry	2.16	15.00	0.84	7.04	1.91	2.50
Public	1.48	11.77	1.04	5.74	1.91	2.60
Commercial	2.27	25.53	0.19	19.49	1.84	2.97

Based on the results some further modification to the values has been made in TUT in order to be correctly used in network analysis and network business regulation. The modification is based on the following factors:

- peak demand has been used in the normalizing of the reliability worth parameters but average power is used in reliability evaluation and calculation of interruption costs (=> increase to the values)
- only certain part of the interruptions happens during most harmful time (=> decrease to the values)
- auto-reclosings occur often during less harmful time and within short time period (=> decrease to the auto-reclosing values)

The modified values are presented in table III and these values are also the basis of the studies in the following chapter.

TABLE II1. The modified reliability worth parameters

	Unexpected		Planned		High-speed AR	Delayed AR
	A	B	A	B	A	A
Residential	0.36	4.29	0.19	2.21	0.11	0.48
Agriculture	0.45	9.38	0.23	4.80	0.20	0.62
Industry	3.52	24.45	1.38	11.47	2.19	2.87
Public	1.89	15.08	1.33	7.35	1.49	2.34
Commercial	2.65	29.89	0.22	22.82	1.31	2.44

When compared the results of the latest survey [2] and also the modified values to the previous Finnish one [1], reliability worth parameters have at least doubled during a decade. It can be expected that this progression continue, which can be seen as a scenario in the analysis of future network.

Outage costs as part of network business regulation

The deregulation of power market opened the market in middle 1990's in Finland. However, the network business remained as a natural monopoly, which is regulated by the Finnish Energy Market Authority. The consideration of power quality as part of regulation is challenging task, which have been developed in several projects in co-operation between Lappeenranta University of Technology (LUT) and TUT and the regulator [3]. Now, it seems to be natural that the outage costs will be somehow part of the regulation in the future, which means that the consideration of them is not only socio-economic utility thinking, but also part of real business.

RELIABILITY STUDIES

This section presents some results of the studies, which have been done using data of one Finnish utility, Koillis-Satakunna Sähkö. The main idea is to compare the total long-term costs of existing type network and fully cabled network. The comparison is done both using existing reliability parameters and using parameters based on scenarios presented in previous section. Before the studies the software tool used is briefly presented.

Reliability analysis software

At Tampere University of Technology models for reliability based network analysis have been developed and implemented as part of a network planning software. First version of the reliability analysis was developed already in 1980s and it has been used e.g. for studying the optimal number and location of remote controlled disconnectors. In the earlier analysis, failure rates were constant for similar components (e.g. 6 failures per year and per 100 km for all overhead lines) without taking into account any other factors influencing to the reliability of the components. In reality, the operational environment affect to the failure rate. In the developed more advanced reliability based network analysis failure rates are based on the "partial failure rates" due to certain failure causes. E.g. for a transformer the overall failure rate for permanent faults is a sum of partial failure rates due to lightning, animals and other fault causes. Partial failure rates are, in turn, dependent on one or more weight factors. For example the partial failure rate due to wind and/or snow for overhead lines is dependent on the surroundings of the line (forest, field or next to road) and on neutral earthing method of the overhead line feeder. Defined partial failure rates and weight factors are based on failure statistics collected from several network utilities and Finnish failure statistics. In addition to statistics, engineering judgment was used when enough adequate failure data was not available.

The reliability analysis in radially operated distribution networks is quite straightforward, but the difficulty is in the determination of the outage time in different parts of the network. Some parts of the network can be restored in few minutes by using remote controlled disconnectors, but some other parts must be restored manually, which will take some tens of minutes. In a fairly small part of the network the outage time is the same as the real repair time. In the reliability model several different switching times are applied and each outage time depends on how faulted component, load point and remote controlled and manually operated disconnectors are situated.

The reliability analysis results in the expected number and duration of outages each load point in the network as well as the overall reliability indiced (SAIFI, SAIDI, CAIDI and MAIFI). The load point specific information can further be used as an input for outage cost modelling presented in the previous section.

In addition of the reliability analysis the software calculates the expected number and the depth of voltage dips for each load point. In order to include the dips also to the overall cost calculation the cost of dip should be evaluated. Because a deep voltage dip is like short interruption from a customer point of view it is natural to use the cost of fast autoreclosing also to dips. In the studies presented below the dips in which the residual voltage is less than 60 % causes the same cost as the short interruption due to fast-auto-reclosing.

The developed reliability based network analysis has been implemented into a network planning software. In the implementation network information system (NIS) with interface to customer information system (CIS) has been used as a platform. The basic idea of the developed modern reliability based network analysis is depicted in more detail in reference [4].

Alternative network studies

There is strong pressure to power distributors to improve the reliability of supply. After big storms in Nordic Countries and the consequent long interruptions the fully cabling has been arisen to be the only possibility in the future to avoid long interruptions and provide required reliability level. The opposition claims that fully cabling is is too expensive. However, for example Vattenfall has announced that their future strategy is to move into weather-proof power distribution, which in practice would mean mainly cabled medium voltage network. In the following brief study dealing with the cabling is presented: First using the existing reliability parameters and then using parameters based on future scenario.

In the studies the total lifetime costs of the alternative network structure is analyzed. The first case means rebuilding of the network using the same solutions as used in existing network. The alternative solution is fully cabling of medium voltage network. The low voltage network is not taken into account, because cabling is nowadays at least as inexpensive as building aerial lines at low voltage level. The study period is 40 years and the interest rate 5 %. For both network solution the costs for the entire network over the study period were calculated, including reliability costs

e.g. expected outage costs. In the studied network there is about 1500 km medium voltage lines (20 kV), of which most are nowadays overhead lines.
The results of the analysis using existing reliability parameters are presented in table IV. As can be seen in table the cabling is very unprofitable solution comparing with the existing solution.

Table IV. The result of the study using existing reliability parameters

Cost component (k€/a)	Existing type of network	Fully cabled network
Investments	1820	3175
Maintenance	352	123
Losses	21	115
Unexpected interruptions	253	60
Planned interruptions	28	28
Temporary interruptions	259	0
Total costs	2733	3501
SAIFI	2.16	0.43
SAIDI (h)	1.43	0.34
CAIDI (h)	0.66	0.74
MAIFI	25.37	0

Another study has been done using scenario based reliability parameters (Table V). In the study the following changes has been made to the parameters:

- Weather based failure rates will be duplicated
- The outage costs will be duplicated
- The costs due to voltage dips is taken into account

Table V. The result of the study using scenario based reliability parameters

Cost component (k€/a)	Existing type of network	Fully cabled network
Investments	1820	3175
Maintenance	352	123
Losses	21	115
Unexpected interruptions	906	120
Planned interruptions	56	28
Temporary interruptions	704	0
Voltage dips	440	5
Total costs	4299	3566
SAIFI	3.88	0.43
SAIDI (h)	2.56	0.34
CAIDI (h)	0.66	0.74
MAIFI	46.49	0

The result shows that the cable solution is very profitable when analyzed with the scenario based parameters.

DISCUSSION

The results presented in the previous chapter can easily be criticized. At first, the reliability of existing network can be improved remarkable by using quite inexpensive measures e.g. by adding more distribution automation. Additionally the value of outage costs can be separated in urban areas and in rural areas, which may lead to lower optimal reliability in rural areas. This development is accompanied with trend of increasing use of reserve power devices in rural areas.
On the other hand the extremely big storms have not usually been included into the reliability analysis. In order to always avoid the long interruptions (e.g. some days) the only possibility is to increase dramatically the amount of cable. This fact speaks for increased cabling. However, is should be noted that the natural network reliability improvement uses the existing network to the end of the lifetime, which mean that cabling would take for very long time. If it would be done in accelerated time it would lead to notably increased financial cost, which were not included in the studies presented in this paper.
Even if there is lot of criticism regarding with the results of the study, the scenario based evaluation of the calculation parameters should be part of the planning process. This kind of thinking should be included to the mobilization of the new IT-tool in utility: In order to be successful futurology based scenarios should be understand by everybody who is involved in the planning process.

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