STUDY OF ALTERNATIVE STRATEGIES FOR RURAL AREA DISTRIBUTION NETWORK DEVELOPMENT

Mika MARTTILA
Tampere University of Technology
Finland
mika.marttila@tut.fi

Janne STRANDÉN
Tampere University of Technology
Finland
janne.stranden@tut.fi

Jussi ANTIKAINEN
Tampere University of Technology
Finland
jussi.antikainen@tut.fi

Pekka VERHO
Tampere University of Technology
Finland
pekka.verho@tut.fi

Matti PERALÄ
Koillis-Satakunnan Sähkö Oy
Finland
matti.perala@veo.fi

ABSTRACT
Network planning methods will be changed in future because of the economic regulation and importance of reliability of electricity distribution. Usually rural area networks are carried out with overhead lines but overhead lines are vulnerable to faults caused by the weather and therefore new strategies are needed to develop rural area networks.

Reliability increasing actions could be profitable if interruptions are taken into account as outage costs. With the advanced reliability analysis tool, the effect of different strategies of rural area network development can be studied. The calculations show that traditional strategies are no longer profitable.

In future climate change and major storms might have bigger influence on the reliability of electricity distribution. In this paper the impact of major storms has been taken into account and some calculations have been made with different climate change scenarios.

INTRODUCTION
Importance of power quality and dependence on electricity distribution has been increased and therefore the methods of network planning have been changed. At the same time power quality has started to influence on network companies’ profits due to the regulator of Finland, which means that increased investments could be reasonable due to the costs of reliability [1].

Rural area distribution networks are typically carried out with overhead lines. Weather is the main reason for disturbances in the overhead line networks and climate change might further increase this failure rate and the possibility of major storms. [2]

Interruption time and the number of customers experiencing outage could be reduced with dividing medium voltage network feeders into smaller sections with new HV/MV substations or circuit breakers. Weather-related interruptions and voltage dips are responsible for a major portion (over 50 %) of all interruptions in the medium voltage network in Finland [2]. With the efficient protection against weather-related disturbances reliability of electricity distribution could be increased substantially [3].

In this paper several strategies for improving reliability of electricity distribution of rural areas are combined and the economic profitability of them is evaluated.

INTERRUPTIONS IN RURAL AREA NETWORKS

In Finland interruption statistics are collected from distribution system operators (DSO) and these statistics are published yearly collectively. According to the interruption statistics 2007, 81 % of all interruptions in the medium voltage network occurred in overhead lines and 84 % of total interruption time were caused by interruptions occurring in overhead lines. 49 % of all interruptions were caused by natural phenomena and the rest were caused by technical reasons, external reasons and planned interruptions. [2]

According to these statistics main focuses in rural area network development are reducing weather-related interruptions and different more reliable network structures.

STRATEGIES FOR RURAL AREA NETWORK DEVELOPMENT

Existing strategy (base)
Existing strategy is the base for network development. This is the way how medium voltage network have been built in network used in this study. In this strategy medium voltage network is mainly built with overhead lines and lots of spark gaps are used to protect network equipments against lightning overvoltages.

Sectionalisation of medium voltage feeders and light modular substation (new base)
In future there will be new light modular substation (LMS) in the network under consideration and some medium voltage feeders will be divided into smaller sections with circuit breakers. Because of that, it is reasonable that this strategy is the starting point for the other strategies developed in this study. This new base is used to compare...
economic benefits of different strategies. Economic benefit of this new base is also calculated and reasonableness of investments is proved.

**Increased overvoltage protection (strategy 1)**

In this strategy small (<200 kVA) distribution transformers are equipped with current limiting arresters (CLA) and bigger (≥ 200 kVA) transformers are equipped with metal-oxide arresters (MOA).

Because all spark gaps are replaced with CLAs or MOAs short interruptions and voltage dips are clearly reduced. Long interruptions are also reduced but the influence is relatively small. [4]

**Boosted forest maintenance (strategy 2)**

Wind and snow are responsible for major portion of all weather-related interruptions and the main reasons for failures caused by wind and snow are fallen and bent trees. In this strategy forests nearby overhead lines are coppiced more than normally. Trees are growing stronger and therefore trees are not bending and falling as easily as before the boosted forest maintenance. [3,5]

**Allocated cabling (strategy 3)**

Underground cable network is the only way to build weather-proof network. Of course, for example frost could cause interruptions in the underground cable network but the failure rate of these faults is negligible and therefore it has been left out in this study. [3]

In the network used in this study cabling of whole medium voltage network is clearly unprofitable because of high investment costs [3]. There are only a few small urban areas in the network and these are now carried out with overhead lines. In this study only urban areas are cabled and the economic benefit is calculated.

**Covered conductors in urban areas (strategy 4)**

Bare overhead lines are vulnerable for faults caused by conductors touching each other or trees and tree branches touching conductors. Covered conductors (CC) are not vulnerable for these faults because of thin insulation layer covering bare conductors. [6] However, after storms CC lines have to be inspected and fallen trees cleared. Therefore CC lines were assumed to be as vulnerable as bare overhead lines for major storms. In this strategy only urban areas are built with CC lines.

At 2007 failure rate for CC was only 0.38 faults/100km/year and at 2006 failure rate was 0.4 faults/100km/year. Failure rates for bare overhead lines were 6.14 and 7.76 faults/100 km/year. [2,7]

**FUTURE SCENARIOS**

**Climate change**

In future the climate change could increase the number of faults caused by wind, snow and lightning. In reference [8] have been predicted that climate change could increase the interruptions costs significantly.

In this study the effects of the climate change have been simulated by increasing the failure rates caused by wind, snow and lightning. It is assumed that the increase of failure rates caused by wind snow and lightning are equal.

**Major disturbances**

Usually abnormal events such as major storms have been left out from statistics and those are not taken into account in network planning. This might exclude some profitable network investments. [9]

In this study calculations are made in two ways, with and without major storms. Wideness of outage times of major storms based on statistics and it is assumed that major storm occurs once every ten years. It is also assumed that the climate change will increase the wideness and seriousness of the major storms.

**NETWORK STUDIES**

**Reliability based network analysis**

At Tampere University of Technology models for reliability based network analysis have been developed and implemented as a part of a network planning software. In this advanced reliability based network analysis tool failure rates are based on the “partial failure rates” due to certain failure causes. For example, 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 roadside) and on the neutral earthing method of the overhead line feeder.

The reliability analysis results in the expected number and duration of outages at each load point in the network as well as the overall reliability indices (SAIFI, SAIPI, CAIDI and MAIFI). The load point specific information can further be used as an input for outage cost modeling. The evaluation of the outage costs experienced by customers is based on the value of non-distributed energy, which is determined by the outage cost parameters of different customer groups. Costs like production losses are taken into account in the definition of inconvenience costs for a customer. In this connection customers are divided into five groups: residential, agricultural, industry, public and commercial.

The outages are divided into four categories: unexpected outages, planned maintenance outages and short auto-reclosing occurrences (i.e. < 1 second and < 3 minute). The cost model has two parameters that assign a cost to the interrupted demand, (€/kW), and to the unsupplied energy, (€/kWh). For auto-reclosings (AR) there are separate values. Table 1 shows the input data for the outage cost definition described in more detail in reference [10].
Table 1. Interruption cost parameters for different customer groups [10]

<table>
<thead>
<tr>
<th></th>
<th>Unexpected outage</th>
<th>Planned outage</th>
<th>High speed AR</th>
<th>Delayed AR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>€/kW, €/kWh</td>
<td>€/kW, €/kWh</td>
<td>€/kW</td>
<td>€/kW</td>
</tr>
<tr>
<td>Agriculture</td>
<td>0.43, 5.10</td>
<td>0.23, 2.63</td>
<td>0.13, 0.57</td>
<td></td>
</tr>
<tr>
<td>Industry</td>
<td>4.19, 29.09</td>
<td>1.64, 13.65</td>
<td>2.61, 3.41</td>
<td></td>
</tr>
<tr>
<td>Public</td>
<td>2.25, 17.94</td>
<td>1.58, 8.74</td>
<td>1.77, 2.78</td>
<td></td>
</tr>
<tr>
<td>Commercial</td>
<td>3.15, 35.56</td>
<td>0.26, 27.15</td>
<td>1.56, 2.90</td>
<td></td>
</tr>
</tbody>
</table>

The basic idea of the developed modern reliability based network analysis is described in more detail in reference [10].

Network
Test network is real network and the length of medium voltage network is almost 1500 kilometers. There are almost 1200 distribution substations and over 15000 customers. Total Electric energy consumption was almost 180 GWh in 2007.

Results
Using the reliability based network analysis tool, the total long-term costs of different strategies were calculated. The study period was 20 years. Calculated costs are not real costs for DSO but these can be used to compare different strategies. The regulator also uses cost parameters of the same kind.

Figure 1 shows the long-term costs when the reliability of electricity distribution of existing network is increased with light modular substation (LMS) and sectionalisation of medium voltage feeders.

As can be seen in figure 1 both investments are profitable and the economic benefit of new base is proved.

Figure 1. Long-term costs of different strategies.

The total long-term costs of different reliability increasing strategies are shown in Figure 2. In these calculations it was assumed that the present situation is new base. This is why investments are not taken into account in new base. Other strategies were compared to this new base and only additional investments of different strategies were taken into account.

If major storms are not taken into account strategy 1 (“full” overvoltage protection) is the most profitable way to improve the reliability of electricity distribution. Strategy 1 and 2 together is also profitable, but boosted forest maintenance (strategy 2) is not profitable alone.

Figure 2. Long-term costs of different strategies without major storms.

If major storms are taken into account all strategies but allocated cabling (strategy 3) and CC in urban areas (strategy 4) are profitable. It can be also noted that the difference between strategies 3 and 4 is not very big when major storms are taken into account. Results are shown in Figure 3. The most profitable strategy is strategies 1 and 2 together.

Figure 3. Long-term costs of different strategies with major storms.

In previous calculations it is assumed that the existing overhead line network is not at the end of the lifetime. If it is necessary to renew the network of the urban areas the situation is totally different as can be seen in figure 4. If major storms are taken into account the investments of allocated cabling are profitable. It can be also noted that without major storms the most profitable strategy is CC in urban areas. If major storms are taken into account CC in urban areas is the second best strategy.
Impact of climate change has been simulated by varying failure rates caused by wind, snow and lightning. Long-term costs have been calculated with four multipliers and results are shown in Figure 5. As can be seen the only change in the order of superiority happens when the multiplier for faults caused by wind, snow and lightning is approximately 1.6. In this point strategy 3 (allocated cabling) becomes more profitable than strategy 4 (CC in urban areas).

**CONCLUSION**

The development of rural area network is quite challenging task because the weather is the main reason for faults in medium voltage networks. Climate change and possible major storms might have great influence on economic benefit of different development strategies. Also the model of regulation will change in future and it is also significant factor in network development.

According to this study, increased investments for improving the reliability of the electricity distribution are profitable in most cases in used network. Only radical strategies, such as cabling and CC in urban areas, are unprofitable way to improve the reliability of electricity distribution. It is also important to take major storms into account when the costs of interruptions are calculated. If it is necessary to renew whole parts of existing network, underground cable and CC in urban areas are more profitable strategies than renewal of the existing overhead line network. Prices of underground cable network equipments have also decreased in recent years.

**REFERENCES**


