OUTAGE COST COMPARISON OF DIFFERENT MEDIUM VOLTAGE NETWORKS

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ABSTRACT

In this paper the costs of non-delivered energy (NDE) of a collection of generic distribution network models are compared. The network models are especially developed in order to enable detailed studies of the effects of high-speed automatic reclosing (HSAR) and delayed automatic reclosing (DAR) on the costs of NDE. Also the influence of using different levels of automation and sectionalisation on the outage costs of the different network layouts are studied.

INTRODUCTION

Distribution network structures differ locally and from country to country. Electricity market liberalisation increases competition and the need to utilize distribution networks more efficiently. As a result of this the utilization ratio of the network equipment is rising. Furthermore, the use of smart components enables loading levels to be pushed towards their limits. To maintain electricity distribution reliability more contingency zones are needed. As a result the layout and configuration of distribution networks has to be checked as the loading level of equipment is raised.

Switching and automation reduces outage time by permitting service to be restored in advance of repair thus improving System Average Interruption Duration Index (SAIDI). Sectionalisation uses equipment that is automatic and nearly instantaneous to isolate faults and malfunctions and seeks to minimize the number of customers interrupted when an outage occurs improving also System Average Interruption Frequency Index (SAIFI). When calculating the benefit/cost ratio of different investment alternatives the cost of NDE is often used. In this paper the cost of NDE for the customers is calculated for different generic feeders with different automation and sectionalisation schemes. At first the studied network alternatives are introduced. Then the used automation and sectionalisation schemes are presented. After that there is a chapter demonstrating the cost calculation methods. Finally the results are presented.

STUDIED NETWORK ALTERNATIVES

When designing the generic network models statistics from the Finnish utilities was used [1]. The basic layout of the studied network feeders consists of an open ring 20 kV network for the urban area combined with a radial network for the rural area (Figure 1). The open ring network is an underground cable network consisting of two feeders connected to each other by a normally open point (N/O). The reliability level for a typical urban supply is achieved by this arrangement. The share of customer groups is different for the urban and rural area according to table 1 and the transformers are loaded up to 65 % of their rated power. The lines of the networks are dimensioned to carry their economical loading.

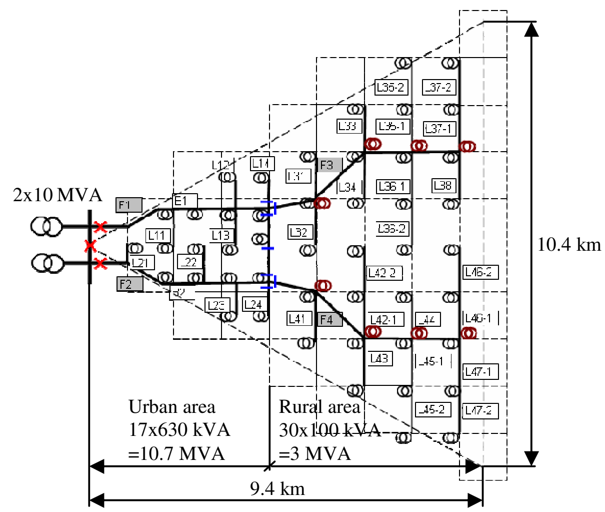

Figure 1. An example of the investigated feeders, the hybrid open ring and 1000 V radial distribution system.

Table 1. The share of customer groups for the urban and rural parts of the feeder and the cost of AR for different customer groups [2].

Customer group	Share/ %		Cost € / kW HSAR	Cost € / kW DAR
	Urban	Rural		
Residential	40	40	0.068	0.088
Free-time	0	5	0.068	0.088
Agriculture	0	10	0.540	0.700
Service	20	10	1.900	2.100
Public	27	15	0.460	0.730
Industry	13	20	2.100	2.900

The average number of secondary substations per km feeder length is 1.3 in the urban area and 1.0 in the rural area. The size of the secondary substations is 630 kVA and 100 kVA while the number of secondary substations is 17 and 30 (Figure 2, 3 and 4). The construction of the rural area part of the network models is varied with respect to the layout and line type (Table 2).

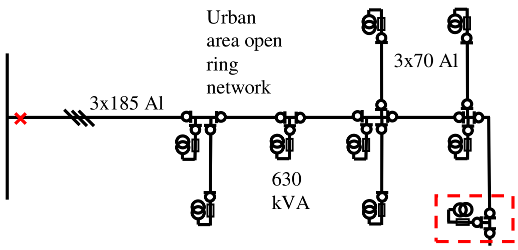

Figure 2. A detailed layout of the upper half of the urban area underground cable open ring feeder. x = Circuit-breaker/recloser, = switch-disconnector, = fused switch-disconnector, = secondary distribution transformer.

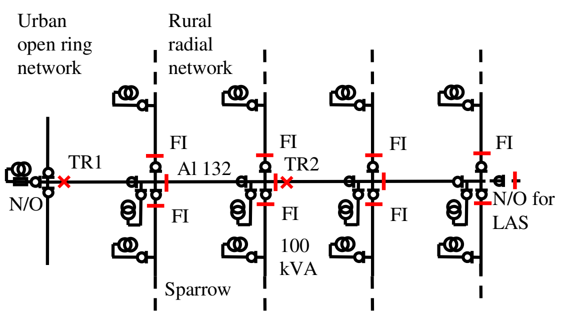

Figure 3. A detailed layout of the rural area overhead line one branch radial feeder with rural area trunk reclosers TR1 and TR2 and fault indicators FI.

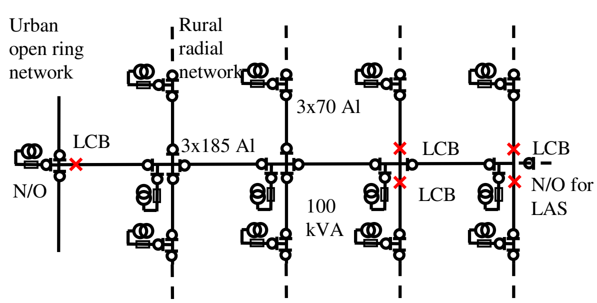

Figure 4. A detailed layout of the rural area underground cable one branch radial feeder with line circuit-breakers LCB (Sectionalisation LRa, table 1).

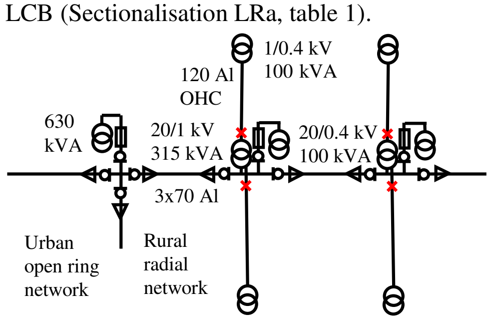

Figure 5. A detailed layout of a part of the hybrid open ring and 1000 V radial rural area distribution system.

Table 2. Studied hybrid layout feeders.

Name	Rural line	ID	Protection[1)]
Open ring and radial one branch	OHL	OR_R1b_ohl	SS R, L R, F
Open ring and radial one branch	UGC	OR_R1b_ugc	SS CB, L CB, F
Open ring and radial two branches	OHL	OR_R2b_ohl	SS R, L R, F
Open ring and radial two branches	UGC	OR_R2b_ugc	SS CB, L CB, F
Open ring and link arrangement system	OHL	OR_LAS2b_ohl	SS R, L R, F
Open ring and link arrangement system	UGC	OR_LAS2b_ugc	SS CB, L CB, F
Open ring and satellite	UGC	OR_SAT2b_ugc	SS CB, L CB, F
Open ring and 1000 V rural	UGC/ OHC	OR_R2b_1kV	SS CB, L CB, F

[1)] F= fuse, SS R= substation recloser, SS CB= substation circuit-breaker, L R= line recloser, L CB= line circuit-breaker

In the Figure 5 the last alternative of table 2 the hybrid open ring and 1000 V rural network is presented. The 1000 V voltage is used between the 20 kV medium voltage network and 400 V low voltage network. The 1000 V line is more economical compared to medium voltage lines in rural areas where power is relatively small (less than, e.g., 80 kW) and line length is only few kilometres [2].

AUTOMATION AND SECTIONALIZATION

Automation

Electricity distribution continuity can be improved even after a fault has occurred by eliminating a transient fault or limiting the influence and duration of a permanent fault by using distibution automation. Automatic loop sectionalizing, automatic switching of supply and remote control are such automation possibilities. Technology limitations (IT) and high costs compared to the benefits have restricted the use of automation in improving the electricity distribution reliability of rural areas. Technological progress, privatization, quality awareness and a greater dependence on continuous electricity distribution have created pressures for improving electricity distribution quality also in rural areas. In this paper the influence of different feeder automation levels (Table 3) on the cost of NDE has been studied.

Sectionalisation

In this study several levels of sectionalisation are examined. The two main aspects are sectionalisation of the feeder trunks and sectionalisation of the laterals. Regarding the sectionalisation of the trunks the first stage is to add a recloser between the urban open ring feeder and the rural feeder. The second stage is to add a second recloser in the middle of the rural area trunk. The sectionalisation of the laterals is studied in three different cases (Table 4). The influence of these different sectionalisation schemes on the cost of NDE has been analysed.

Table 3. Studied automation levels.

Automation level	ID
No automation	man
Manual operation and fault indicators in the rural network	man+fi
Manual operation and remote read and operated fault indicators in the rural network	man+rfi
Remote control of the secondary substation between the urban and rural networks and remote read and operated fault indicators in the rural network	rc+rfi
Automatic operation of the secondary substation between the urban and rural networks and remote read and operated fault indicators in the rural network	auto

Table 4. Analysed sectionalisation levels.

Sectionalisation level	ID
A recloser in the beginning of the rural network	TR1
A recloser in the beginning of the rural network and a second recloser in the middle of the rural network	TR12
A recloser in the beginning of the rural network and reclosers in 50 % of the rural laterals	TR1+LRa
A recloser in the beginning of the rural network and reclosers in all the rural laterals	TR1+LRb
Reclosers in the rural laterals	LR

OUTAGE COSTS

In Finland the values of the cost of NDE for different customer groups has been investigated by a survey in 2005 [4]. In the calculations presented here the lower limits of these values have been used. In Table 5 typical values of the cost of NDE in some other countries are presented, as well. In this study the outage costs considered are the customer cost of NDE, the cost of HSAR and DAR.

Table 5. Typical values of the cost of NDE for different customer groups in Finland, Norway and The Netherlands.

Customer group	**Finland** [3]				**Norway** [4]	**The Nether-lands** [5]
	Cost €/ kW		**Cost €/kWh**		**Cost**	**Cost**
	1 h	**12 h**	**1 h**	**12 h**	**€/ kWh**	**€/kWh**
Residential	3-10	25-60	3-7	2-5	0.98	16.4
Free-time [1)]	2-20	48-81	2-17	4-7		
Agriculture	3-16	50-120	3-13	5-11	1.83	3.9
Service	4-60	25-270	4-47	2-25	12.07	7.9
Public	5-35	60-450	5-30	5-41	1.59	33.5, gov.
Industry	7-22	50-190	7-20	4-15	1.59-8.05	0.3-33.1

[1)] This value should be multiplied with the utilization degree of the free-time residence.

For the calculations the feeder is modelled as large component groups as possible considering that all the included components are acting in the same way regarding the reliability.

For permanent faults, the outage times t_{ij} caused by a given component can include either equivalent switching times or repair times. The equivalent switching time caused by a component depends on how the faulted component, the load point, network protection, controlled disconnectors, and reserve connections are situated in relation to each other [6]. The cost of NDE is calculated by means of the costs of the power and energy not supplied. C_j

$$C_j = \sum \lambda_i \times \left[a_j(t_{ij}) + b(t_{ij}) \times t_{ij} \right] \times P_j \ ,$$

where $a_j(t_{ij})$ and $b_j(t_{ij})$ are the per-unit cost values for the power and energy not supplied for the load point j when the outage time is t_{ij} (e.g. €/kW and €/kWh). The average outage rate is λ_i.

For the calculation of the cost of AR the cost of one HSAR and one DAR is calculated for the whole feeder, both urban and rural area of the feeder and the laterals (Table 6). Used statistics regarding AR are [1]: 51 earth faults/100 km, year; faults cleared by HSAR = 73 %; faults cleared by DAR = 17 %; permanent faults = 10 %.

Table 6. Outage costs for the studied feeder system (two branches rural feeder).

Customer group	Average P/kW	Interr. C €/h, interr.	Interr. C €/HSAR [2]	Interr. C €/DAR [2]
Urban	**3686**			
Residence	1474	4423	100	130
Free-time	0	0	0	0
Agriculture	0	0	0	0
Industry	737	5160	1548	2138
Public	995	4975	458	726
Service	479	1916	910	1006
Sum	**3686**	**16474**	**3016**	**4000**
Rural	**975**			
Residence	390	1170	27	34
Free-time	49	29	3	4
Agriculture	98	293	53	68
Industry	195	1365	410	566
Public	146	731	67	107
Service	98	390	185	205
Sum	**975**	**3978**	**745**	**984**
Feeder	**4661**	**20452**	**3761**	**4984**

The costs of AR are:

$$C_{AR} = \sum_i 0.51 \times L_i \times c_{hsar_i} + \sum_i 0.27 \times 0.51 \times L_i \times c_{dar_i} \ ,$$

where C_{AR} are the costs of AR, L_i is the total length of the conductors, c_{hsar_i} is the cost of one HSAR, c_{dar_i} is the cost of one DAR of the protection area i (Table 6).

RESULTS

In Figure 6 the annual outage costs for the different feeder types with no automation or sectionalisation are given. The influence on the costs of different automation levels is presented in Figure 7 and the influence of different sectionalisation schemes in Figure 8. When calculating the influence of sectionalisation on the cost of NDE no automation is used and vice versa.

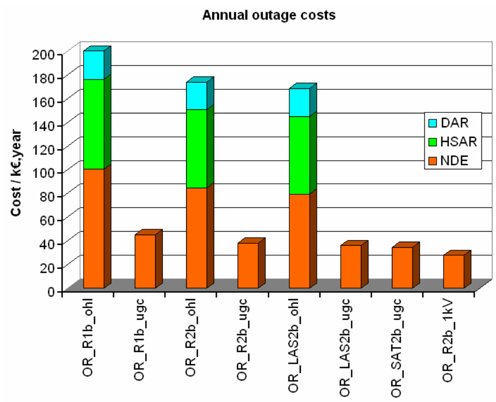

Figure 6. Annual outage costs with no automation or sectionalisation (Table 2).

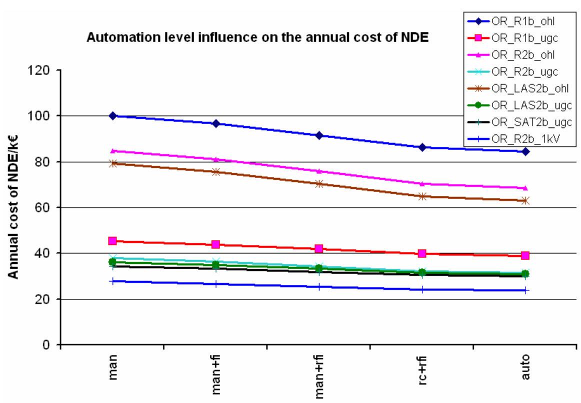

Figure 7. The influence of automation level on the annual outage costs (Table 2 and 3).

CONCLUSION

The cost of NDE for OHL networks is more than twice that of UGC networks and the cost of AR is the same as that of NDE. Therefore, whenever possible, feeders with different reliability levels (OHL and UGC) should not be combined. By using the various automation schemes SAIDI can be improved and the cost of NDE and AR are reduced. When sectionalisation is applied both SAIFI and SAIDI can be improved. Sectionalisation is a very powerful tool in improving outage cost of OHL networks. As the worth of outage costs tend to rise with time more than other costs, they will play a more and more important role in electricity network design in the future.

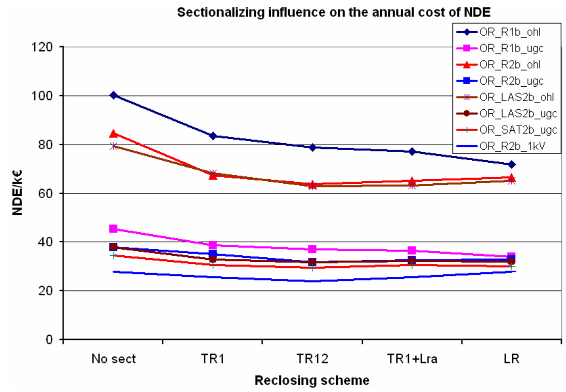

Figure 8. The influence of sectionalisation level on the annual outage costs when no automation is used (Table 2 and 4).

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