OPTIMAL LEVELS OF AUTOMATION AND UNDERGROUND CABLING OF FINNISH MV NETWORKS IN THE NEW LEGISLATION AND REGULATION ENVIRONMENT

Henry Lågland
University of Vaasa (UVA) – Finland
Henry.Lagland@uva.fi

Lauri Kumpulainen
UVA – Finland
Lauri.Kumpulainen@uva.fi

Kimmo Kauhaniemi
UVA – Finland
Kimmo.Kauhaniemi@uva.fi

Ari Salo
Vaasan Sähköverkko Oy – Finland
Ari.Salo@vaasansahkoverkko.fi

ABSTRACT

The Finnish Electricity Market Act (EMA) [1] imposes on Distribution System Owners (DSO) an obligation to develop their networks so that an outage caused by snow or storm does not last more than six hours in urban areas and 36 hours elsewhere by 2028. The regulation period of electricity distribution network operations in 2016-2019 introduces new incentives to carry out reliability improving investments [2]. The main task of this study is to find a cost-effective strategy to address the demand for better security of supply set up by the EMA.

INTRODUCTION

To fulfil the demands in the EMA the DSOs have to find a cost-effective investment strategy. The two main methods to do this is to use optimal levels of feeder automation (FA) and underground cabling (UGC) in the given operational environment (OE, Figure 1). Questions to be addressed are then:

- How to fulfil the demands in the EMA at the different review times as cost-effective as possible
- Finding cost-effective targets of FA and underground cabling
- Optimal use of present infrastructure
- Optimal utilisation of the regulation incentives

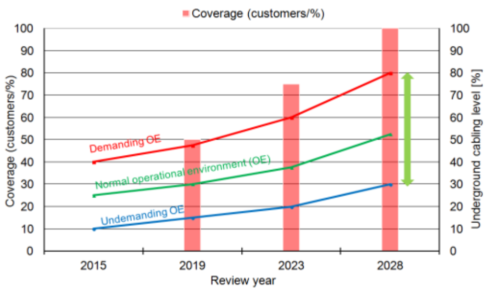

Figure 1. The demands of the EMA regarding the coverage of the maximum outage times at the different review years (2019, 2023 and 2028).

The research was performed as a part of the Sundom Smart Grid project in collaboration with the local network company Vaasan Sähköverkko Oy which provided a case study in its network. By including reserve power and five feeder automation schemes a set of network configurations was generated. The underground cabling level of the five feeder alternatives was 15 % -100 %. The studied five feeder automation schemes included current technology as well as novel distributed protection based solutions. On a network company level the task was also studied based on data from a previous research.

1. THE CASE STUDY

The impact of the investment date was studied by choosing three alternative investment years 2015, 2020 and 2028 (Table 2). Combining five feeder alternatives (Table 1), five feeder automation schemes (Figure 2, Table 3) and the three investment dates a wide range of alternative investment options was accomplished. The effect of the operational environment was addressed by varying the number (0-4) of major events.

Table 1. Main features of the case study feeder alternatives. UGCL = underground cabling level in percent. BPA = Building plan area.

Feeder	UGCL %	Special feature	Prot. zones	Length km
MF15	15		3	27.2
MF55	55	UGC in BPA	3	24.8
MF55RP	55	Reserve power 2x410 kVA	3	24.8
MF60	60	Trunk line 100 % UGC	3	24.8
UGC100	100	100 % UGC	2	22.4

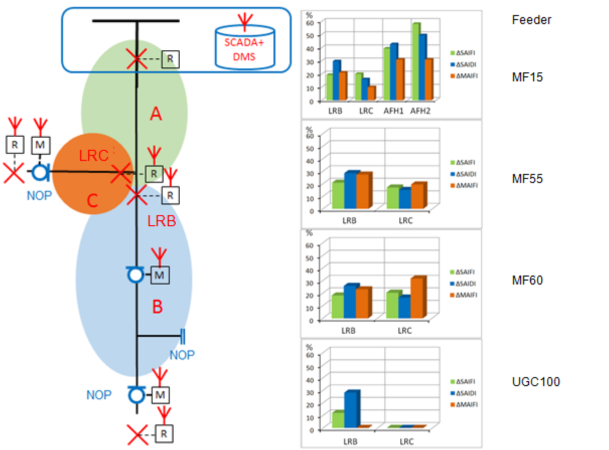

Figure 2. Studied FA schemes of the case study feeder. To the right FA scheme quality indices relative improvement of the different feeder alternatives. For feeder and FA abbreviations see Table 1 and 3.

Table 2. Development of the main features of the case study feeder in time. BPA = Number of building plan areas. SDS = number of secondary distribution substations

Study/in-vestment year	Development of features in time				
	Reg. period	BPA	Power kW	SDS	Custo-mers
2015	3	1	1228	35	935
2020	4-5	2	1765	41	1161
2028	5-6	2	1923	43	1287

Table 3. Studied automation levels of the case study feeder, see Figure 2.

Feeder automation level		Benefits
Sche-me	FA equipment control-led by SCADA/DMS	
RC	Remote controlled line switches in line and normal open points (NOPs)	Speed up of the fault handling process. Comparison level.
LRB	RC + remote control-led line recloser downstream of main branch	Separation of faulted network downstream of the line recloser.
LRC	RC + remote control-led line recloser in main branch	Separation of faulted main branch line.
AFH1	RC + remote control-led line recloser downstream of and in main branch	Separation of faulted main branch and faulted network downstream of the trunk line recloser.
AFH2	AFH1 + remote controlled line reclosers also in NOPs	Only the faulted protection zone is separated.

To find the optimum level of underground cabling and FA the reliability indices, the total annual outage cost and the annual total cost of the five feeder alternatives with different levels of FA was calculated. The impact of the regulation incentives was calculated both on an annual and write-off period level.

1.1 Reliability indices

Underground cabling improves all the reliability indices of the network (Figure 3). Remote controlled line reclosers improve all the indices upstream of the line reclosers. The improvement potential of the automatic fault handling schemes is about twice that of a single remote controlled line recloser scheme (Figure 1, right). The performance of the different automation schemes regarding SAIFI and MAIFI depends on the used technology, while the performance regarding SAIDI also depends on the performance of the repair crew in the fault handling process. It is assumed that the crew acts in accordance to minimize the total outage cost.

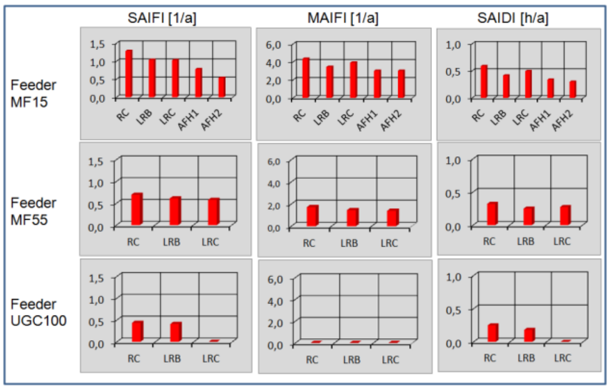

Figure 3. The reliability indices of three underground cabling levels (UGCL) in the case study feeder.

1.2 Annual total outage cost

The annual total outage cost depends on the underground cabling level, number of major events during write-off period , appreciation level of the per-unit cost value for the outaged power and energy (year), average power of the feeder (year) and feeder area (zone). The appreciation level of the per-unit cost value for the demand and energy was 50 % up to 2015 but it is now 100%. The annual total outage cost of zone A is low due to a high underground cabling level and the closeness to the feeding primary distribution substation (Figure 4). Zone B has by far the highest annual total outage cost due to a high average power, a low underground cabling level and a location far away from the feeding primary distribution substation. Increasing the underground cabling level of zone B reduces effectively the annual total outage cost of the feeder.

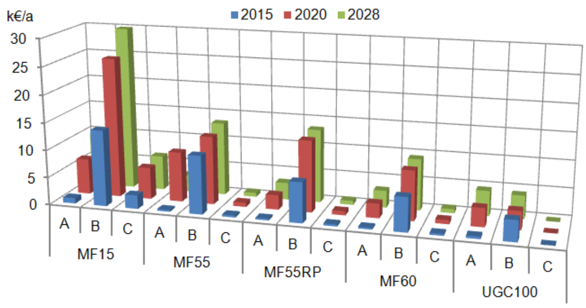

Figure 4. Distribution of the annual total outage cost in the feeder zones (A, B and C) according to underground cabling level and study year.

1.3 Annual total cost

Underground cabling is an efficient way to reduce the number of outages and effects of major events in electricity distribution networks. By feeding building plan areas with weather-proof underground cabling routes either directly or by alternative pathways the demands in the EMA can be fulfilled. By increasing the underground cabling level of the network the distribution company reduces its marginal costs, such as the operating, repair, maintenance, loss and quality costs. By underground cabling the most fault susceptible sections of the network company a reasonable cost-effectiveness is achieved. The optimum underground cabling level depends on the operational environment of the distribution company and is the underground cabling level with which the network company can fulfil the demands of the EMA. The impact of the number of main events was studied by varying the number between zero and four during the write-off period. In the operational environment of the network company one main event on average is feasible (Figure 5).

The importance of feeding building plan areas with weather proof lines or spare feeding routes can be seen in Figure 5 (right top) where the annual total cost of the feeders are calculated with the assumption that an alternative weather proof line is not available in year 2020.

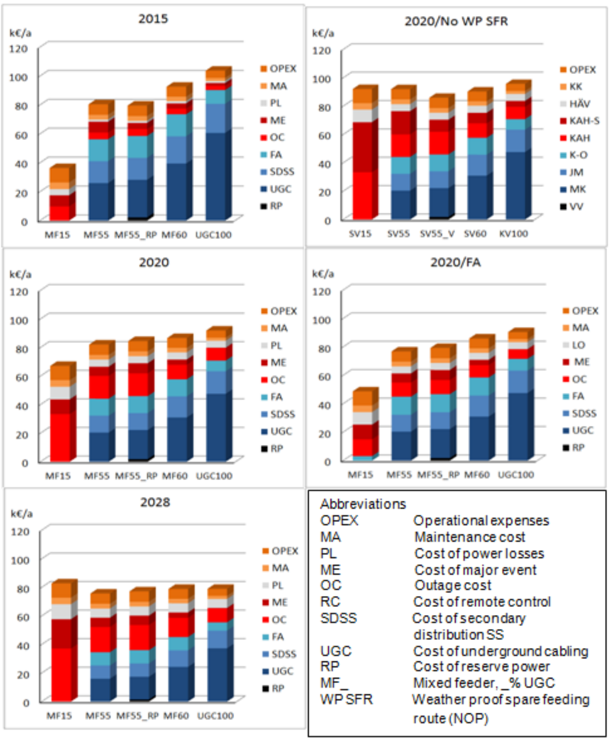

Figure 5. Annual total cost of the different feeders when investment is performed in 2015, 2020 and 2028. For feeder abbreviations see Table 1.

The annual total cost reduction potential of FA is remarkable, especially in mixed feeders (Figure 5, right middle). In the present MF15 feeder distributed protection based automatic fault handling reduces the annual total cost by 27 % while application of FA in the other feeder alternatives reduces the annual total cost by a few percent. This is due to the fact that in the present regulation environment the per-unit outage cost values for power and energy do not justify the use of advanced FA schemes in networks with a high underground cabling level.

1.4 Impact of regulation incentives on reliability improving network investments

The annual impact of the four incentives calculated in this example is 7.7 % of the replacement value of the network (Table 4). The total impact during the write-off period is 36.2 %. As the present value of the network is about 50 % of the replacement value, the impact of the incentives is about 72.4 % or almost three fourths of the present value of the network. The underground cabling and feeder automation investments also improve the technical standard of the new network. The impact of the innovation and unit cost incentives were not studied here because the utilisation of them is case-specific.

Table 4. The impact of the regulation incentives on an annual and write-off period (WOP) level.

Incentive	Impact		
	k€/a	%/a	%/WOP
Quality incentive	31.1	1.9	7.6
Investment incentive	28.2	1.8	12.6
Reliability incentive	32.8	2.0	2.0
Efficiency incentive	32.4	2.0	14.0
Sum	124	7.7	36.2

2. THE NETWORK COMPANY LEVEL STUDY

The network of the distribution company was analysed according to data available from an earlier research [4]. Of the 105 feeders of the network company 52 had registered outages during the study period 6 years.These feeders are positioned on the national outage cost per feeder length unit chart (Figure 6).

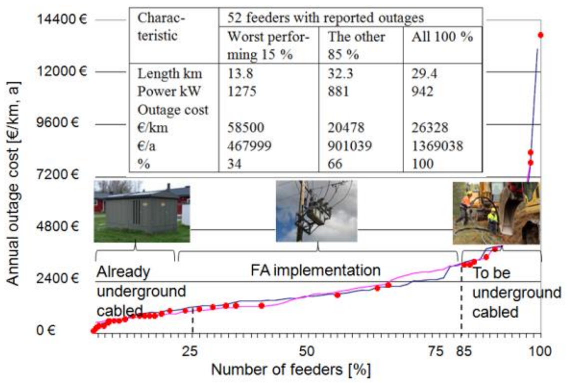

Figure 6. Investigated feeders positioned on the national outage cost per feeder length unit chart [5].

Of the 52 feeders with registered outages 8 (15 %) have poor performance regarding outage cost per feeder length unit. A further cost analysis reveals that the payback time of most of the feeders is rather long even if only the cost difference between underground cabling and overhead line is regarded as investment cost (Table 5). The annual total outage cost of these worst performing feeders accounts for

34 % of the annual total outage cost of the network company. The eight feeders account for 6 % of the total network length of the distribution company at that time. So by underground cabling 6 % of the network the annual total outage cost of the distribution company can be reduced by one third.

Table 5. A cost analysis of the 15 % worst performing feeders. CSF = Case study feeder. VSV Oy = Network company.

Feeder	kW/km	Outage cost		Payback time a
		%	€/kW, a	
F1	13	12	1075	2
F2	376	2	22	4
F3	83	4	93	4
F4	139	5	27	8
F5	144	2	22	10
F6	153	1	19	11
F7	39	6	71	11
F8	82	2	34	11
CSF	45	(2.4)	27	26
VSV Oy	31	100	30	34

3. AN ALTERNATIVE INVESTMENT STRATEGY

Based on the results achieved in the case and the company level study an alternative investment strategy to large scale underground cabling was formed. The main principles of the strategy are:

a) To maximize the allowed return on investment of the remaining life time of overhead lines extended use of feeder automation is preferred

b) Urban areas and lines feeding them are underground cabled or alternatively equipped with weather proof spare connections

c) Weather proof lines are used as spare connections for urban areas in neighbouring feeders

d) In remote urban areas and archipelagos where weather proof feeders can't be applied mobile and/or fixed reserve power is used jointly by several neighbouring feeders

e) Repair crew organisation capacity is properly sized to handle major events outside urban areas within 36 hours

f) If the organisation is not capable to do a) to e) the degree of underground cabling is increased or the capacity of the repair crew organisation is increased.

g) The operational environment, e.g. frequency of major events, is the main parameter determining the ratio between investment in underground cabling, feeder automation and crew capacity.

With this investment strategy large scale underground cabling is avoided and the incentives of network investments are appropriate for the network company to allow a reasonable revenue.

4. THE REGULATION SYSTEM

The network companies compensate outages to their customers by paying standard compensation for major events lasting over 12 h. At the end of the four year long regulation period the annual total outage costs of the network companies are totalled. A reasonable revenue level is calculated for each network company where the outage cost is one input. If the network company has charged too much it has to compensate the customers by reducing its prices in the next regulation period. Thus the network companies may have to compensate the customers twice for poor electricity distribution reliability. In forest areas the outage cost of major events in stormy years may be higher than for normal years. As the occurrence of major events depends on the operational environment, including weather conditions, of the distribution companies the impact of major events differs substantially. A direct relation between performed network investments and reduced total outage cost is seldom established even within a four year regulation period. Taking into account 100 % of the outage cost instead of 50 % ends in even more altering annual outage costs in the network companies. Thus, due to different operational environments the inclusion of major events into the regulation system does not treat the network companies in a neutral manner.

5. CONCLUSIONS

The study suggests the establishment of primary application targets for underground cabling and feeder automation to optimize the cost effectiveness of underground cabling and the allowed return on capital of overhead lines. Another output of the study is the establishment of an alternative investment strategy to wide scale underground cabling. The strategy utilizes the cost-effective primary application targets of underground cabling and feeder automation as well as sizing of the staff resources to meet the demands in the Electricity Market Act. As the network companies pay standard compensation to customers in outages longer than 12 hours and the operational environments vary the major events are suggested to be excluded from the annual total outage cost calculation in the regulation model.

REFERENCES, in Finnish only

[1] The Parliament, 2013, Electricity market act. http://www.finlex.fi/fi/laki/alkup/2013/20130588

[2] The Finnish Energy Authority, 2015, Regulation methods 2016 - 2023.

[4] K. Nykänen, 2009, Determination of the present state and development plan of Vaasan Sähköverkko Oy network company from a supply security perspective.

[5] The Finnish Energy Authority, 2008, Report on electricity supply security 2007.