IMPACTS OF RENOVATION: PERSPECTIVES OF THE OWNER AND THE CUSTOMER IN THE ELECTRICITY DISTRIBUTION BUSINESS

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ABSTRACT

Renovation of electricity distribution networks is a current topic in today's electricity distribution business. Economic regulation of electricity distribution provides new opportunities to evaluate electricity distribution from the perspective of renovation. Operation and planning of electricity distribution networks have typically been carried out by minimising the total costs in the long term, which is a profitable approach from the perspective of national economy. However, the present regulatory model in Finland includes components that produce a different result with respect to an optimal network depending on whether the network is built from the perspective of the owner of the distribution network or the customer of the distribution network company.

INTRODUCTION

Ageing of the electricity distribution networks is a significant challenge in today's society. Thus, there is a need to significantly renovate the existing distribution networks. However, this can be also seen as an opportunity, because the networks can be rebuilt, and thus they can be optimised to meet the present requirements. An extra challenge for renovation is that authorities all over the world have started to regulate the distribution business [1]. For instance, interruptions may have a cost component of their own, and there are true incentives to decrease the operational costs, because they can have a straight effect on the allowed profit of the business. This extends the field of different alternatives in network renovation, and in addition to the owner's objectives, the viewpoint of customers has to be taken into account. Figure 1 presents the age distribution of wood poles in a Finnish distribution company.

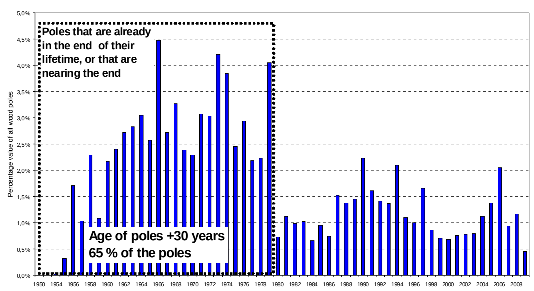

Figure 1. Age distribution of wood poles in a Finnish distribution network [2].

FINNISH REGULATORY MODEL

In Finland, the present regulatory model has been in use since 2008. It takes into account the influence of interruptions on the allowed profit. The influence of new or renewal investments is illustrated in Figure 2, which presents the basic properties of the regulatory model.

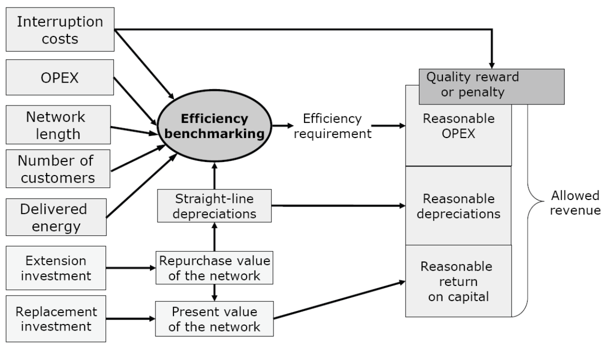

Figure 2. Outline of the Finnish regulatory model between 2008 and 2011 [3].

The regulation model is the basis of the present distribution business environment. It provides incentives for the owner to invest in the network asset, which can be seen for instance in a reward for quality (reliability) and also in the component of reasonable return on capital that is dependent on the investments. These methods ensure that the condition of the network will improve. However, the owner cannot ignore the needs of the customers, because they are a precondition for the distribution business. This factor can be assessed if the cost components that have an effect on the customer-related cash flow are considered. Therefore, large-scale investment programmes have to be analysed with care.

The cost components that are valued in the regulatory model and with respect to the allowed revenue are:

- Reasonable OPEX (operational costs from the maintenance and fault repair of the network)
- Quality reward or penalty (CENS savings)
    - o Reference level of outage costs, subtracted by the actual outage costs
- Reasonable depreciations
- Reasonable return on capital = Allowed profit

Table 1 lists the key features and drivers of the present regulatory model.

Table 1. Features of the regulatory model in the present time period (2008–2011) in Finland [3],[4]. WACC = weighted average cost of capital

Main features of the regulatory model	Drivers
• Allowed profit = Present value of the network * WACC • Reasonable depreciation costs = straight-line depreciations (= replacement value/lifetime)	• Investments may also have negative effects (straight-line depreciations in efficiency benchmarking)
• Outage costs, OPEX and straight-line depreciations included in efficiency benchmarking	• Strong incentives for quality improvement (on the other hand, penalties for reduced quality)
• Common and company-specific efficiency targets for OPEX	• Economic significance of major disturbance emphasised
• Outage costs have an effect on allowed return (quality incentive and efficiency benchmarking) • Standard compensations have an effect on allowed return	

Optimisation of the network

In this paper, it is studied how different investment and renovation strategies affect the cash flow of the owner of the electricity distribution company and the customer of the electricity distribution company.

The owner and customer perspectives are opposite to each other, which can be seen in the optimisation equations. Equation 1 gives a function for maximising the profit of the owner, while Equation 2 shows how customer-related costs can be minimised when the actual outage costs are also taken into account.

Maximisation of the profit of the distribution company's owner

$$\max Z = \sum_{t=0}^{T} \begin{pmatrix} \left(D_{\mathrm{ap}}(t) + D_{\mathrm{sld}}(t) + D_{\mathrm{OPEX}}(t) + C_{\mathrm{out,ref}}(t)\right) - \\ \left(C_{\mathrm{inv}}(t) + C_{\mathrm{OPEX}}(t) + C_{\mathrm{wd}}(t) + C_{\mathrm{out}}(t)\right) \end{pmatrix} \quad (1)$$

Minimisation of the costs of the customer with the outage costs included

$$\min Z = \sum_{t=0}^{T} \left(D_{\mathrm{ap}}(t) + D_{\mathrm{sld}}(t) + D_{\mathrm{OPEX}}(t) + C_{\mathrm{out}}(t)\right) \quad (2)$$

Where:
D = reasonable regulatory cost
C = actual cost

T = time-scale (years)
t = year
D_{ap} = allowed profit
D_{sld} = straight-line depreciations
D_{OPEX} = reasonable operational costs
$C_{\mathrm{out,ref}}$ = reference value for outage costs
C_{inv} = annuity of investment costs
C_{OPEX} = operational costs
C_{wd} = value of write down
C_{out} = actual outage costs

The boundary conditions that have to be met:

Back-up supplies in every situation (reserve power is used in the case of large-scale cabling)

Quality of voltage is within the limitation of standards

Controllable OPEX is defined from actual OPEX, when the company-specific and common efficiency requirements are taken into account. The efficiency targets are determined annually by the Finnish EMA. The reference value for outage costs (CENS) is the average of the past years. In the Finnish regulatory model (2008–2011) this is calculated from the years 2005–2008 [5].

COMPARISON OF NETWORK STRATEGIES

The study considers various renovation strategies from the perspectives of both the owner and the customer. The study is based on cost functions that are included in the optimisation equations. Some different renovation strategies that are based on maintaining the present overhead network structure and underground cabling are selected for the study; models for cabling have been presented for instance in [6]. The renovation strategies in this study are:

- 10a rolling cabling: Cabling with rolling strategy within a 10-year time period
- 20a cabling: Cabling starting from the oldest sections within a 20-year time period
- 40a cabling: Cabling starting from the oldest sections within a 40-year time period
- Poles 40: Replacement of the wood poles at the end of techno-economic lifetime (40 years)
- Poles 60: Replacement of the wood poles at the end of extended lifetime (60 years)

Current trends in the network development have been the criteria for the selection of the renovation strategies. In rural areas, electricity distribution networks have traditionally been built as overhead line (OHL) structures, but the direction is more and more towards underground cable (UGC) networks. The main reasons for this are better reliability in general, landscape issues and in particular, vulnerability of overhead lines during major storms. Yet another aspect to be taken into account is the demand for uninterrupted electricity supply, which will not decrease in the future.

Approach to the extended lifetime of network

Techno-economic lifetime defines the length of time that the network can be expected to be in use. An extension of lifetime has effects on costs that influence both the cash flow and the reliability of electricity supply. The influence on reliability can be minimised by intensified maintenance, which restricts the damages that occur in the network with an extended lifetime [7]. This principle is presented in Figure 3.

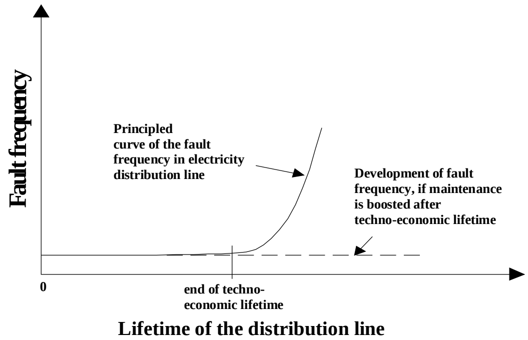

Figure 3. Effect of intensified maintenance on the development of fault frequency on an electricity distribution line.

Intensified maintenance and fault repair include extra control of the lines and replacing of broken insulators, cross-arms and single poles. The effects on costs can be assessed by setting a value that increases the operational costs each year when the techno-economic lifetime is exceeded. Thus, this also provides an opportunity to optimise the time when the line should be renovated. This can be illustrated by a simple example, where a 1-km OHL is at the end of its lifetime. If the renewal investment of the line and the annual maintenance and fault repair costs are known, the life cycle costs can be determined. The life cycle costs are shown in Figure 4.

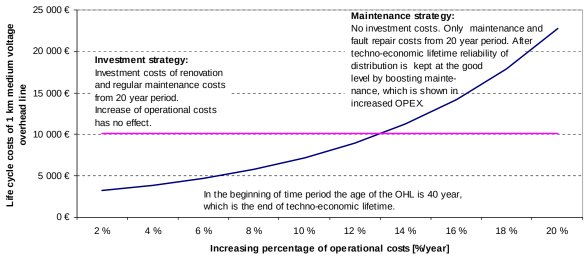

Figure 4. Costs of a 1-km OHL in the cases of investment strategy and maintenance strategy. The reference period is 20 years and the interest rate is 5%. The investment sum of the line is 7500 € and the operational costs are 212 €/year before the end of the techno-economic lifetime.

Figure 4 shows that if the increase in the operational costs is less than 13%/a, the intensified maintenance and fault repair strategy is more profitable than the investment strategy. If the reference period is extended to 40 years, the intersection of the curves moves to 6%/a, with the same cost structure as presented in Figure 4.

Calculation parameters

Processing of renovation investments, reliability analysis and asset management require a large number of parameters, which have to be carefully chosen so that they correspond with the statistics. For instance, definition of fault rates and switching times requires statistics from several years. Table 2 lists parameters gathered separately for each conductor type. Table 3 shows other parameters needed in the calculation.

Table 2. Individual parameters for each conductor type and some typical values for the parameters.

List of parameters	Typical values
Fault frequencies: forest, field, roadside	0.05 faults/km
Repair times: forest, field, roadside	2 h/fault
Repair costs: forest, field, roadside	100 €/km
Maintenance costs: forest, field, roadside	100 €/km
Conductor prices	25000 €/km (99mm^2 OHL)

Table 3. General parameters for the reliability and asset management studies

List of parameters	Typical values
Switching times:	
remote controlled disconnector	10 min
manually controlled disconnector	60 min
Secondary substation prices (20/0.4 kV)	7500 €
Excavation prices for underground cables	5000–10000 €/km
Compensation of earth fault currents	2000–3000 €/km
Price for pole changing	500–700 €/pcs
Interruption unit costs	€/kW, €/kWh

Unit prices of the components are based on the guidelines of the Energy Market Authority of Finland (EMA) [8]. The fault frequencies are based on actual data gathered from the distribution network studied in this paper. The interruption unit costs have been determined by EMA [5], and they have been considered in [3]. Other parameters are based on the results of a collaborative research project of the universities and distribution companies.

RESULTS

The renovation strategies considered in this paper provide an opportunity to compare different alternatives for guidelines for the future. The studied network is a part of a Finnish distribution company, and most parts of the network are at the end of their lifetime.

Owner's perspective

From the owner's perspective, distribution network renovation involves many cost components that have to be taken into account. These cost components are shown in Figure 5, where the cost structure of two different strategies is presented.

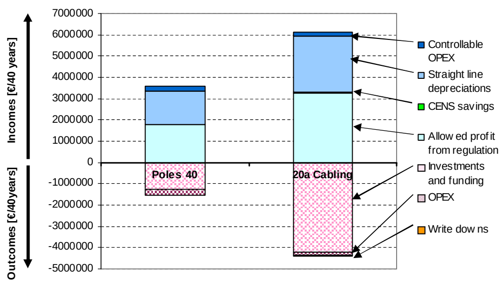

Figure 5. Structure of the owner's cash flow, which includes incomes and outcomes within a 40-year period in the following strategies: 20 year underground cabling and pole replacement at the end of 40 years' lifetime.

Figure 5 shows that the cash flows of the strategies can be significantly different, and therefore variation in the outcomes and incomes can also be substantial. Figure 6 shows the profit and cash flow of the company with studied strategies within a 40-year period.

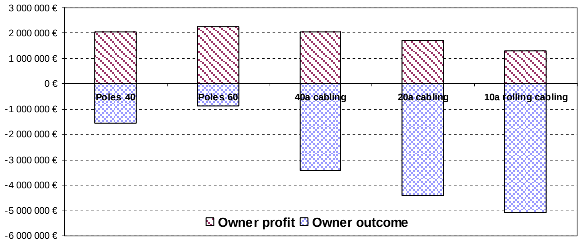

Figure 6. Negative bar shows the outcomes from investments and financing, operational costs and write downs. The bar on the positive side is the profit that remains in the company, when outcomes have been deducted from incomes (Profit = Incomes - Outcomes).

Figure 6 shows that although the regulatory model provides incentives to invest in and develop the network, the methods for renovation should be considered with care. For instance, the owner's profit will be at the same level when the pole strategy and 40a cabling strategy are considered. However, the costs caused by different strategies will vary significantly. This can be seen, for instance, from the owner's outcomes. The cost level of the pole strategies is approximately 1000 k€, when the level of 40a cabling is over 3000 k€.

Customer's perspective

Figure 7 presents the amount of payments that can be collected from the customers, the outage costs (CENS) and the average distribution tariffs within the 40 year period in the studied strategies.

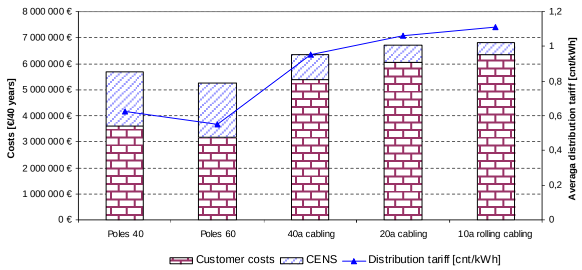

Figure 7. Costs that are allowed to collect from customers added by CENS. The curve presents the distribution tariff in the studied area.

It is shown in Figure 7 that the customer outage costs (CENS) level out the differences between the OHL strategies and the UGC strategies, which would be much more significant if CENS were ignored. However, Poles 60 is the most profitable strategy, if the customer costs are the parameter for renovation. Consideration of the distribution tariff provides almost the same results as the comparison of the customer costs. In this case, pole replacement strategies are more profitable compared with the UGC strategies. Nevertheless, the results are sensitive to variation of parameters such as unit prices of the components and fault rates, which can easily turn the results around.

CONCLUSIONS

Renovation of electricity distribution networks is a challenging subject. The profitability of a renovation strategy depends strongly on the function to be optimised. Therefore, the result of optimisation may vary significantly. The present regulatory model in Finland does not give an unambiguous answer to the question of the best renovation option. This is explained by the parameters, which are not the same in every function. The parameter that causes the largest variation in the compared alternatives, that is, the owner and customer approaches, is the interruption cost parameter, CENS.

The perspectives of the owners and customers have to be assessed with larger feeder groups in the future; these approaches have also to be compared with the traditional cost functions of long-term distribution system planning.

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