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Improving reliability in an urban network

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ABSTRACT

This paper describes various developments to improve reliability in urban power distribution networks. Actual implementation of different methods is addressed. The benefits are calculated according to the benefits achieved through regulatory incentives and through benefits obtained in asset management. The actual implementation in Helsinki presents both traditional and advanced smart grid implementations. The network supervision and control was previously limited to transmission and primary substation level only. Now with the implementation of both distribution automation and 100% coverage of smart meters, the entire grid from transmission to customer level is monitored and controlled. The impact of the chosen development methods on reliability indices in Helsinki is described. The future smart grid actions in Helsinki are also included.

The main contribution of the paper is the holistic view on reliability improvement in urban distribution networks and the description of the actual implementations. The results show that with well planned and implemented actions the customer interruption costs and SAIDI in urban networks can be reduced by 50%.

1. Introduction

Modern society is increasingly dependent on the critical infrastructures of ICT and electricity distribution. Electricity is essential for individual users everywhere, but also collectively especially in the urban society where the functions are heavily interlaced. When the service of electricity comes to a halt, most processes stop immediately or with a minimal delay, being contingent on other processes. This accumulation is evident in the valuation of uninterrupted electricity. The value of customer interruption costs has been evaluated in many studies, for ex. in [1–5]. In general, the customer interruption cost (CIC) values have doubled from the 1990 level [6]. On average the cost of interruptions for commercial customers is about tenfold compared to households [1]. Since commercial and public services are significant in urban areas and they are the dominant customer groups [7] in the urban core, the value of uninterrupted electricity supply is especially appreciated in city networks.

The paper first considers theoretical aspects of improving the reliability in power distribution networks. The paper then presents an analysis of reliability improvements and the implementation of different improvement methods in real urban network circumstances in the case of Helsinki. The scope is in optimizing different improvement methods as well as in creating a holistic view for improving system reliability in real urban network circumstances. The successful achievement of cutting SAIDI by 50% in Helsinki is described. The future large scale smart grid projects in Kalasatama district of Helsinki are also presented.

This paper describes and integrates the analyses and the results of the applications of the methods presented in previous papers [8–12]. The main contribution is to create a comprehensive reliability improvement solution for urban distribution networks utilizing modern technologies and models. A proof of concept of the solution is presented in a real urban network case. The presented optimization methodology and the real case results show that significant reliability improvements can be achieved in urban power networks. With a holistic and systematic approach the costs of reliability improvements can be lower than the savings in the economic losses achieved.

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Nomenclature

ΔC	change in annuity (€/a)
CAIDI	customer average interruption duration index
CIC	customer interruption costs (€/kWh)
CIC_{actual}	customer interruption costs, actual (€/kWh)
CIC_{ref}	customer interruption costs (€/kWh)
ΔCIC	change in customer interruption costs (€/a)
CML	customer minutes lost
DA	distribution automation
DMS	distribution management system
DSO	distribution system operator
Helen	Helen Electricity Ltd.
k	number of DA secondary substations on feeder j excluding NOP
LV	low voltage (kV)
MV	medium voltage (kV)
NOP	normally open point
ΔOC_j	change in outage cost on feeder j (€)
oce	outage cost energy parameter (€/kWh)
OHL	overhead lines
SAIDI	system average interruption duration index
SAIFI	System average interruption frequency index
T_{swa}	average switching time with automation (h)
T_{swm}	average manual switching time
T_{swsm}	average manual switching time of a on substation outages (h)
T_{swsa}	average switch time with automation in substation outages (h)
λ_j	interruption rate on feeder j
IC(s)	sectionalizing device installation cost
MC(s)	sectionalizing device annual operation and maintenance cost
CI(s)	sectionalizing device capital cost
$L(j, k, f)$	average load of the kth-type customers located at the jth loadpoint of feeder f
$C^{d_{ij}}(i, j, k, f)$	customer damage function continuous decision variable which depends on customer type, duration of interruption d_{ij} etc.
$\lambda(i, f, t)$	failure rate of distribution elements grouped together on feeder f
q	annual load increase rate
T and t	sectionalizing switch life time and year index
DR	annual discount rate
$X(s, f)$	binary decision variable which is equal to 1 if a sectionalizing switch is installed on the sth location of feeder f
N_f	total number of feeders.
NC_f	total number of possible fault locations on feeder f
NL_f	total number of load points on feeder f
CT_f	total number of customer types
N_s	total number of installed sectionalizing switches.

2. Reliability monitoring

2.1. System reliability indices

The factors that are characteristic to distribution reliability are: frequency, duration and the extent of the interruption. Frequency refers to the number of interruptions during an analysis period, duration is the length of the interruption and extent refers to how many customers are interrupted [13].

The generally accepted reliability indices are defined in standard IEEE-P1366 [14]. System Average Interruption Duration Index (SAIDI) is the most used system reliability index and it is typically calculated by yearly basic. Customer Average Interruption Duration Index (CAIDI) describes the average length of the interruption once it happens and System Average Interruption Frequency Index (SAIFI) describes how many times in a year an average customer in the system experiences an interruption. Besides these established reliability indices, a new index CIC/kWh, in which total customer interruption costs (CIC) are divided by total customer Energy consumption, has introduced [15,16]. The effect of various ways of improving reliability could then be evaluated by the impact they have on reducing customer damage.

2.2. Customer-based reliability monitoring

The indices explained above measure the performance at the system level. From the customer point of view they are average or expected values. No target levels for these indices are given. The progress has been based on comparisons between distribution system operators (DSO) and their general striving for improvement. To raise the importance of the customer point of view, customer based indices have been used.

In 2010 the Finnish Energy Industries gave a recommendation for the reliability planning criteria [17,18]. The recommendation takes the perspective of an individual customer. Earlier it had already been generally accepted that the quality level is different depending on the conditions of the DSO (rural, urban, city). This recommendation gives a justified basis for the differentiation between areas which makes it possible to focus the investments in a cost–effective way. To city area the target levels are more demanding, so the DSOs in urban area need advanced methods to fulfill the reliability targets.

2.3. Regulation and legislation

Ex-ante regulation model is applied by the Finnish Energy Market Authority. The methodology of reasonable pricing is confirmed before each regulatory period. After the four-year regulatory period, compliance is monitored for each DSO and the allowed profit is confirmed by the regulator [19].

The Finnish regulation scheme includes incentives to minimize the total cost of network operations. Although the customer interruption costs are not included in the financial statements of the DSO, in the regulation model, the outage costs are included in the total costs in addition to capital costs and operational costs. Therefore, by minimizing this total cost, the economic losses of the customer and the reciprocity of the cost elements are taken into account. Outage costs are evaluated using the customer interruption costs. Thus the CIC values are officially approved as the basis for network optimization. The average values on national level are applied in the regulation scheme. The DSOs may use more detailed CIC values (for each customer group and geographical area) to prioritize their own actions to improve the quality of supply.

The incentives in the Finnish regulation scheme reward the improvements in the system level performance, since the outage costs affect directly to the allowed profit of the DSO. The company's own historic data is used as a reference. The actual outage costs are compared to this reference value and quality bonus or sanction is determined depending whether there is an improvement in the outage costs or not. To create benefit to both the customer and the DSO, the annual reward is split 50/50 between these two. Therefore the quality bonus (increasing the allowed total costs) is 50% of the difference between actual outage costs, CIC_{actual} and the reference level CIC_{ref}.

$$\text{Quality bonus} = (CIC_{ref} - CIC_{actual}) x\, 0,5 \quad (1)$$