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Impacts of quality improvement incentives on automation investments in the Finnish new regulation model

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During the second regulatory period of 2008-2011 incentives are included into the Finnish regulation model which allows higher profits for the network owners for properly allocated network investments leading to lower operation and interruption costs. In this paper the economical benefit and payback time of different automation schemes in two typical Finnish rural medium voltage (MV) distribution feeders are studied. The electricity distribution reliability indices, total outage cost, outage cost saving and payback time for different automation schemes with different numbers and locations of automated distribution substations were calculated.

INTRODUCTION

Finnish rural MV distribution feeders are usually protected by the reclosers of the primary distribution substation only. Centrally located branching points of the feeders may be equipped with remote controlled switches to reduce fault locating, isolation and restoration times. Using remote controlled circuit-breakers instead of switches also allows feeders to be sectionalised. Sectionalisation means dividing a feeder into sections in order to isolate faults and minimize the section of the feeder circuit that is put out of service. Thus the cost of non-delivered energy (NDE) and autoreclosing (AR) are reduced.

This integration of remote control and protection is achieved by using ABB's compact three-phase vacuum recloser OVR-3, which is remotely controlled over a General Packet Radio Service (GPRS) connection. The earth-fault current is derived from the residual current of the three phase-currents. A remote monitoring and control unit type REC 52_ is used for remote and local control of the line recloser and for protection, fault indication, condition monitoring and supervision of the downstream feeder section. According to the performed laboratory tests, an earth-fault protection sensitivity of 1.2 A primary value is achieved, which is of the same order as the sensitivity of the substation recloser earth-fault protection.

The new Finnish regulation model

According to the guidelines for the Finnish second regulatory period of 2008-2011 the quality of the electricity distribution influences the economy of distribution companies in two ways. First, the regulation authority sets a company-specific efficiency improvement obligation, which consists of a company-specific and a general improvement target. Second, the regulation authority calculates a reasonable profit level for each distribution company, thus regulating the price setting of the companies. Thus incentives are included into the Finnish regulation model, which allow higher profits for the network owners who allocated network investments properly, leading to lower operation and interruption costs.

The zone concept

Apart from sectionalisation the zone concept includes several other means of increasing the number of protection zones within the distribution areas of a primary distribution substation. By increasing the primary distribution substation density with light 110 kV substations the effects of interruptions and voltage dips are restricted and the magnitude of the earth-fault currents is reduced. By increasing the number of protection zones with switching substations and line reclosers auto-reclosings are carried out deeper in the network and the protection zones diminish. Creating new protection zones by using the 1000 V distribution system limits the influence of faults located on the feeder laterals to the laterals. Enhancing feeder automation with fault location capability reduces fault duration. Increasing remote control of switches in distribution substation results in enhanced fault restoration. In this paper the economic benefit of integrated protection and remote control is investigated in a case study.

CASE STUDY

Two feeders in the distribution area of Vaasan Sähköverkko, a distribution company on the Finnish west coast, were chosen for the case study. Details of the studied feeders and the main calculation parameters are presented in Tables 1-4. Electricity distribution reliability indices, total outage cost, outage cost saving and payback time for different automation schemes with different number and location of automated distribution substations were calculated. The results were calculated for feeders with no automation, with current remote control facilities and with current remote control facilities and possible future costeffective sectionalisation schemes. The benefits of possible future automation schemes were evaluated with regard to the improvements of the distribution substation reliability indices T-SAIFI and T-SAIDI and the payback time of the automation investments, of which the most cost-effective solution was chosen for the pilot installation.

Feeder	W	P	L	UGL	DSS/	No.
	GWh	MW	km	%	km	NOPs
F1	12.5	1.4	54.5	7.8	0.84	3
F2	9.4	1.1	68.6	6.6	0.93	5
Finland			31.6	4.0	1.0	

Table 1. Characteristics of the two feeders studied compared to average values for Finnish rural area distribution feeders. Abbreviations: UGL= undergrounding level, DSS= distribution substation, NOP= normally open point.

Feeder	Forestry	Frequency 1/100 km, year		
		HSAR	DAR	Sust. Interrupt.
F1	15 %	48.4	3.0	8.6
F2	20 %	37.5	2.5	6.2
Finland	28 %	37.2	8.7	5.4

Table 2. Forestry level and outage-related data compared to average Finnish rural area feeder values.

NDE		HSAR	DAR
€/ kW	€/ kW	€/ kW	€/ kW
1.19	11.9	0.59	1.19

Table 3. Unit costs of NDE and AR [1].

Property	Component	Value
Fault frequency, 1/100 km, year	OHL	5.37
	OHL, open field	2.94
	OHL, forest	10.0
	UGC	1.76
	COC	2.0
	DSS	0.88
Switching time, h	manual	1.0
	remote	0.1
Repair time, h	OHL, COC	3
	UGC	24
	DSS	4

Table 4. Used calculation parameters. Abbreviations: OHL= overhead line, UGC= underground cable, COC= coated overhead cable.

Zone design

Natural locations for line reclosers are downstream of loadcentres, at the interface between underground cables and overhead lines, in the beginning of branches or laterals and at current remote control sites. According to the principle of location the studied feeders were divided in 4-5 zones (Figure 1), and then the characteristics of the zones were calculated (Table 5). The automation schemes studied are presented in Table 6.

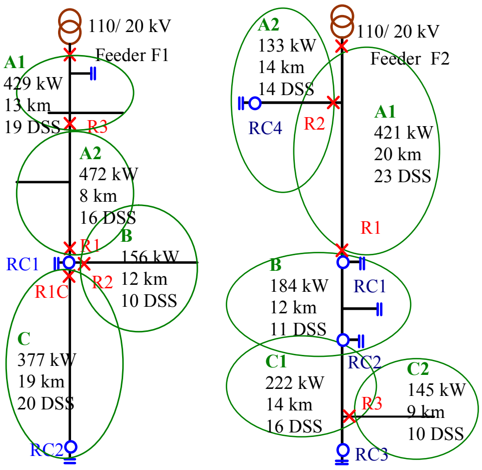

Figure 1. Circuit configuration, zone design and characteristics of feeders F1 and F2.

Feeder	Zone	Forestry	P	Length, km			No. of DSS
		%	kW	OHL	UGC	COC	
F1	A1	10	428	9.9	0.84		19
	A2	30	472	8.2	0.93		16
	B	10	156	12.5			10
	C	10	377	19.6	0.2		20
Sum	4		1434	50.2	4.3		65
F2	A1	20	421	19.8	0.1		23
	A2	20	133	9.5	4.4		14
	B	25	184	12.4			11
	C1	20	222	11.8		2.1	16
	C2	20	145	6.6		1.9	10
Sum	5		1104	60.1	4.5	4.0	

Table 5. Characteristics of the zones of the feeders.

Automation	Symbol	Description
Remote controlled switches	RC1	Remote controlled distribution substation RC1
	RC2	Remote controlled distribution substation RC2
	RC12	Remote controlled distribution substations RC1 and RC2
Remote controlled line recloser	R1	Remote controlled line recloser R1
	R2	Remote controlled line recloser R2
	R3	Remote controlled line recloser R3
	R12	Remote controlled line reclosers R1 and R2
	R1-3	Remote controlled line reclosers R1, R2 and R3

Table 6. Applied automation schemes and symbols.

Results

The chosen feeders for the study were among the worst performing feeders of the distribution company partly because both the studied feeders cross bird areas. Both feeders included remote control of switches the influence on the economy of sectionalisation of which was one key task in the study.

System-level indices are used, which are based on the number of distribution substations affected by the interruptions. This is shown by adding the prefix T before the indices, e.g. T-SAIFI, T-SAIDI and T-MAIFI.

As Figure 2 shows, Vaasan Sähköverkko has been able to considerably improve T-SAIDI of the studied feeders. By adding remote control to the switches, the T- SAIDI value has been cut to about a half of the value of the original feeders with no remote control. There still remains a potential to improve the reliability indices, especially TSAIFI and T-MAIFI by implementing sectionalisation (Figure 3, Table 7).

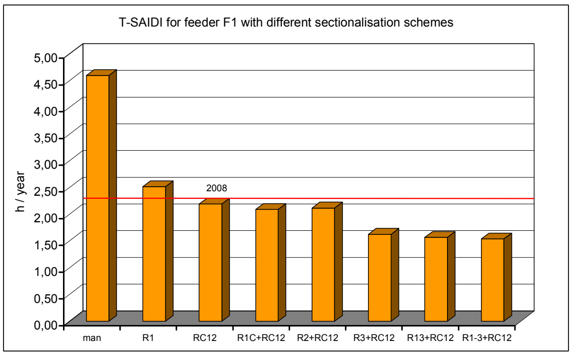

Figure 2. T-SAIDI of feeder F1 with different automation schemes.

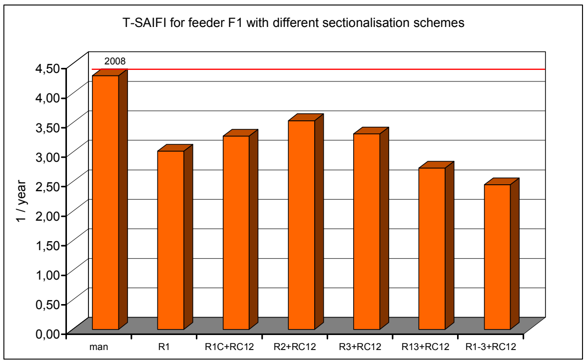

Figure 3. T-SAIFI of feeder F1 with different automation schemes.

The most cost-effective line recloser at the T-branch in feeder F1 is R1 while the most cost-effective recloser along the main line is R3. The payback time of the first recloser (R3) is 1.3 years in feeder F1 and 2.6 years (R1) in feeder F2. With a maximum payback time of two years the costeffective number of line reclosers on feeder F1 is one and on feeder F2 zero. With a maximum payback time of 3.5 years the number is two on feeder F1 and one on feeder F2. Due to the cost of AR the optimum location of the first line recloser is upstream of the middle of the feeders.

Property	Without automation	With RC	With line recloser	
			First	Second
T-SAIFI, 1/y				
-F1	4.3	4.3	3.3	2.7
-F2	3.7	3.7	2.7	2.2
T-SAIDI, h/y				
-F1	4.6	2.2	1.62	1.57
-F2	3.7	1.65	1.55	1.12
T-MAIFI, 1/y				
-F1	25.8	25.8	19.8	15.7
-F2	24.0	24.0	16.3	14.6
Out. cost red., %				
-F1		35	31	18
-F2		36	24	20
Payback time, y				
-F1			1.3	3.2
-F2			2.6	4.1

Table 7. Reliability indices and cost reduction improvement potential with feeder automation.

CONCLUSION

As has been seen line reclosers may be cost-effective even in homogenous feeders with current automation. The economy depends on several factors, such as current degree of automation, feeder load, length, load type, degree of undergrounding, forestry and expected payback time for the investment. With unit costs corresponding to those of the second Finnish regulatory period potential locations for line reclosers are feeders with a line length of at least 30 km and an average load of at least 500 kW. Due to the complexity of calculation a calculation tool is needed to find the feeders where line reclosers are cost-effective enough.

Typical cost-effective implementations are given in Figure 4. Potential recloser locations depend especially on important loads or load centres in the network. Also the location of generators affects the siting of reclosers. Recloser should also be installed in places where an underground network changes into an overhead line network or just in front of long lateral lines.

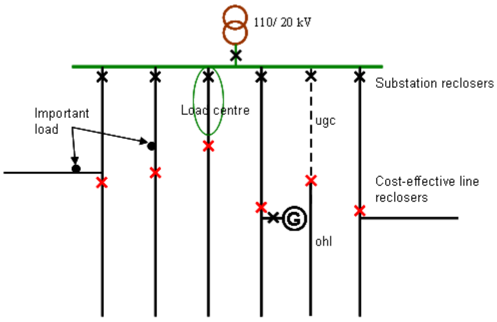

Figure 4. Cost-effective implementation of line reclosers.

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[2] Lakervi E, E.J. Holmes, 1996, Electricity distribution network design, Second edition. Peter Peregrinius Ltd., London, UK, 70-79.

APPENDIX: Equations used in calculations

Reliability indices

$T-SAIFI=\Sigma mpk_i\ /\ mp$, where

mpk$_i$ = number of distribution substation areas that are influenced by outage i
mp = total number of distribution substation areas in the distribution area

$T-SAIDI=\sum_{i=1}^{n}\sum_{j=1}^{x} mpk_{ij}\times h_{ij}\ /\ mp$, where

n = number of outages
x = number of different outage durations related to a certain outage
mpk$_{ij}$ = number of distribution substation areas in the areas where the outage duration was h$_{ij}$
mp = total number of distribution substation areas in the distribution area

$T-MAIFI=\Sigma mpk_i\ /\ mp$, where

mpk$_{ij}$ = number of distribution substation areas that are influenced by the momentary interruption i
mp = total number of distribution substation areas in the distribution area

Cost, savings and payback time

The cost of NDE is calculated by means of the cost of the power and energy not supplied C$_{NDE}$ [2]:

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

λ$_i$ = average outage rate
a$_j$(t$_{ij}$) and b$_j$(t$_{ij}$) are the per-unit cost values for the power and energy not supplied to the load point j when the outage time is ij t (e.g. €/kW and €/kWh)
P$_j$ = average power not supplied

The cost of AR C$_{AR}$ is:

$C_{AR}=\sum\lambda_H\times L_i\times P_i\times c_H+\sum\lambda_D\times L_i\times P_i\times c_D$, where

c$_H$ = HSAR unit price
c$_D$ = DAR unit price
λ$_H$ = HSAR frequency per unit length of line
λ$_D$ = DAR frequency per unit length of line
L$_i$ = line length of zone i
P$_i$ = average power of zone i

The total outage cost C$_{INT}$ is:

$C_{INT}=C_{NDE}+C_{AR}$

The economic benefit of an automation scheme i is:

$B_i=\left[\left(C_{j_0}-C_{j_i}\right)+\left(C_{AR0}-C_{ARi}\right)\right]$, where

C$_{j0}$ is the cost of NDE for the basic feeder 0 without automation
C$_{ji}$ is the cost of NDE for the feeder with automation scheme i
C$_{AR0}$ is the cost of AR for the basic feeder 0 without automation
C$_{ARi}$ is the cost of AR for the feeder with automation scheme i

The payback time T$_i$ with the remote controlled line recloser scheme i is:

$T_i=K_i/\left(C_{INT1}-C_{INTi}\right)$, where

K$_i$ is the investment cost of recloser scheme i
C$_{INT1}$ is the total outage cost in year 2008
C$_{INTi}$ is the total outage cost with recloser scheme i

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