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Risk Investigations in Investment Planning under Consideration of a Supply Interruption Insurance System

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***Abstract*--This paper presents investigations of an insurance approach against supply interruptions as an enhanced model of monetary valuation of supply interruptions. Results of praxis relevant risk-based investigations for different investment measures for medium voltage systems considering the supply interruption insurance system are presented. The upgrading of the protection system, improving of restoration strategy and the conversion from radial to open loop system structure are considered. The behaviour of a cable and an overhead line power system is compared. Different parameters such as different observation periods and insurance tariffs are taken into account.**

***Index Terms*-- power supply reliability, insurance system, reimbursements, investments, risk management.**

I. Introduction

THE liberalisation of the electricity market is accompanied for the system operators by the need of reducing costs which may lead to a long-term reduction of supply reliability due to the actual regulation rules in Germany. In February 1998, the German Federal Supreme Court decided that utilities are legally liable to normal and special tariff customers up to 5000 DM resp. 2556 Euro and in the case of gross negligence only [1], [2]. In contrast customers, especially industry customers, are becoming more and more sensitive to supply interruptions, which may lead to huge damage costs.

An insurance model could lead to economic solutions (e.g. [3], [4]). Today different insurance models which guarantee the customer financial compensation of interruption costs are offered world-wide ([1], [5]). The insurance approach used here [3], [4] is a new method of monetary valuation that does not include the disadvantages of conventional monetary valuation of customers' damage costs ([6]-[9]).

The idea of the insurance model is to offer financial compensation in case of supply interruptions if the customer pays an extra quality fee. This way the customer sets economic indicators. Using probabilistic reliability assessment the financial risks associated to the insurance approach for both system operator and customer can be determined and handled.

Thus risk management methods must be used in order to avoid financial drawbacks. Risk is defined as the product of the probability and the consequences of a damage causing event [10]. The economic risks of power system investments can be estimated quantitatively. They can be justified if the probability for expected savings in reimbursements exceeding the investments for a given observation period is high enough. This evaluation is based on the calculated reliability level and the tariffs selected by the customers.

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II. Investigation Basis

A. Insurance Model

The basic idea of the insurance model of [3], [4] which is embedded in the existing tariff system is to involve the customer directly by choosing tariffs fitting to his/her individual situation. Thus, the customer has to pay the prices for the minimum connection and operational costs as well as an insurance fee for the additional reliability (see Fig. 1). The insurance fee guarantees financial compensation by the system operator in the case of supply interruptions. Given the offer of a tariff system with different insurance fees and reimbursements, the customers can determine their individual optimum by themselves.

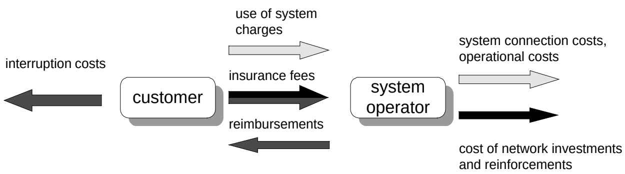

Fig. 1. Tariff systems including the insurance model [4]

In addition to the advantages for the customer, the model offers substantial advantages for the system operator. The knowledge of the customer's choice of tariff classes in a power system area facilitates the system operator to optimise the sum of investment costs, operational costs and reimbursements. Thus automatically a reliability level is given, which leads to an economic optimum for customers and system operators, assuming correct proceeding. It should be noticed, that the approach does not lead inevitably to an "optimal" reliability level. For example, situations are possible, where the customer due to sensitive production processes wishes a high supply reliability. However it can be more economic for the system operator, to pay high reimbursement charges, instead of upgrading the supply reliability by investment measures.

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The expected yearly amount of customer reimbursements can be estimated by means of probabilistic reliability analyses. The transformation of probabilistic indices into real costs implies financial risks with respect to the creation of a tariff system with uniform insurance fees and reimbursements for each tariff class [4] as well as the taking of decisions for power system investment planning.

Financial risks that arise in investment planning under consideration of the proposed supply interruption insurance system are mainly from stochastic risks, if the knowledge of the customer's tariff class choice is assumed. The stochastic risks arise from the nature of uncertainties of stochastic rare occurring events, such as supply interruptions [4]. This leads to reliability indices with large statistical variances. So reimbursements to be paid during one year can be much higher than the expected value. The stochastic risks depend on the life and number of contracts, customer's tariff class choice and most important the fortuitousness of outage occurrences.

B. Reliability analyses assumptions

A time sequential Monte-Carlo simulation method is used in order to determine the distribution functions of reliability indices besides the expected values.

The reliability parameters of Table I are based on [9], [11]-[14]. The distribution functions of the component outage duration are assumed as log-normal distributed with a relative standard deviation $\sigma_r(T_f) = 200\%$.

The duration of executing manual switching actions is, except section III.B, assumed to be $T_s = 1$h.

TABLE I
RELIABILITY PARAMETERS

OM	CP	H_f	T_f	p_f
SO	OL	0.0828	4.0	
	CB	0.0189	15.0	
	T	0.0015	8.0	
	SB	0.0002	3.2	
	SLT	0.0001	3.2	
	MS	0.006	6.5	
ME	OL	0.003	4.0	0.00077
	CB	0.013	13.4	0.0033
MP			1.0	0.009
UPO			1.0	0.00013

Legend: OM - outage models: SO - single outage; ME - multiple earth fault (operation with resonant grounding); MP - malfunction of protection device; UPO - unnecessary protection operation (unnecessary opening);

CP - components: OL - overhead line; CB - cable; T - transformer; SB - switchbay failures causing the outage of the busbar; SLT - switchbay failures causing the outage of the adjacent line or transformer; MS - medium voltage substation;

Parameters: H_f - failure frequency; T_f - outage duration; p_f - conditional probability of failure;

Units: $[H_f] = km^{-1}a^{-1}$ (OL, CB), a^{-1} (T, SB, SLT, MS); $[T_f]$ = h;

$[p_f] = km^{-1}$ (ME), 1 (MP, UPO);

C. Significance test for comparison of results

In order to compare reliability parameters such as the reimbursements of two power system variants, a significance test can be used by considering the cumulative distribution function $F_2(x)$ and the distribution function $f_1(x)$. Eq. (2) describes the mathematical function, Fig. 2 illustrates the significance test.

p_{sig} is defined as the probability of the realization x_2 of a stochastic variable being higher or equal to the realization of a stochastic variable x_1 [13], as shown in Fig. 2.

$$p_{sig}(x_2 \geq x_1) = 1 - \int_0^{\infty} f_1(x)\ F_2(x)\ dx \qquad (1)$$

In the case of identical distribution functions, the probability p_{sig} is 50%. In [13] an enhanced approach is proposed, by calculating the significance probability $p_{sig\ d}$ of the realization x_2 of a stochastic variable being higher or equal to the realization of a stochastic variable x_1 plus a value Δx. The probability $p_{sig\ d}$ is given by eq. (2):

$$p_{sig\ d}(x_2 \geq x_1 + \Delta x) = 1 - \int_0^{\infty} f_1(x) F_2(x + \Delta x) dx \qquad (2)$$

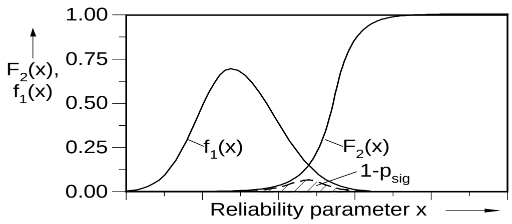

Fig. 2. Significance test acc. to eq. (1)

D. Tariff classes

The value of guaranteed reimbursements in the case of supply interruptions is oriented towards supply interruption costs of customers. Thus, tariff class specific reimbursements R_i consist of interrupted power specific reimbursements and energy not delivered in time specific reimbursements [4]:

$$R_i = (r_P + r_E\ T_i)\ P_i \qquad (3)$$

with R_i: reimbursements, T_i: interruption duration, P_i: interrupted power, r_P: interrupted power specific reimbursement factor, r_E: energy not delivered in time specific reimbursement factor.

Table II gives an overview of the reimbursement factors of investigated tariff classes.

TABLE II
TARIFF CLASSES

Name of tariff	r_P in Euro/kW	r_E in Euro/kWh
tariff 01	0	5
tariff 02	0	10
tariff 04	0	20
tariff 10	5	0

III. INVESTIGATIONS

A. General

Since the presented investigations contain several investment measures for resonant grounded MV systems such as the upgrading of protection system, improvement of restoration strategy and the conversion from radial to open loop system structure, different test systems I to IV are used, which are described in the respective sections.

B. Improvement of the restoration strategy

Fig. 3 shows the test-system I consisting of one openly operated loop supplying 20 customers C_{A1}-C_{B10}. The power demand of each customer is 0.1 MVA and the length of each line is 0.65 km (total 13.65 km). At the outgoing lines from the MV busbars the circuit breaker and the definite-time overcurrent-time protection relays are placed. The MV loop is fed by the 110-kV-power system, which is assumed 100% reliable.

For the base variant (variant 1), the duration of executing manual switching actions including fault location is assumed to be T_s = 1h. If telecontrol measures such as remote reading of short-circuit indicators are considered, the duration of fault location and restoration can be reduced [15] from 1h to 0.5h (variant 2) if e.g. every second substation is equipped with a remote reading of a short-circuit indicator.

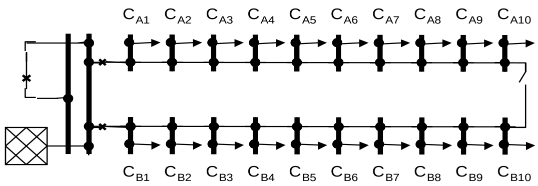

Fig. 3. Test-system I

Fig. 4a shows the cumulative distribution curves of reimbursements. The observation period is assumed to be T_{obs}=20a. Fig 4b illustrates the comparison of reimbursements of the variants using the significance test acc. to eq. (2). Since the upgrading of the telecontrol only influences energy not delivered in time specific reimbursements acc. to eq. (3), it is assumed that all customers of the test system are insured with tariff 01.

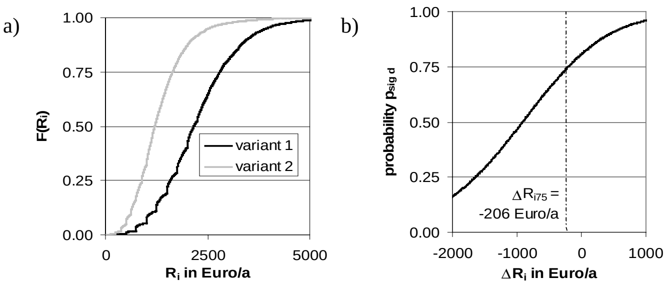

Fig. 4. Comparison of reimbursements for variants with improvement of the telecontrol (reducing switching duration from 1h to 0.5h), l_{line}=0.65 km, tariff01, T_{obs} = 20a, R_i acc to eq. (3).
a) Distribution functions
b) Significance probability $p_{sig\ d}$ acc. to eq. (2)

Knowing the customer's tariff choice, variant 2 can be compared monetarily to the base-variant 1, determining the value of the difference in reimbursements ΔR_i, where the significance probability of eq. (2) has a chosen value, which expresses the risk in the investment planning.

For identical distribution functions, the probability for $\Delta R_i = 0$ equals $p_{sig\ d}$ = 50%. Thus, the power system operator will choose a value of the significance probability higher than 50%. The investments for an upgrade of the power system can be justified if the reimbursement difference at the chosen probability is higher than the investment costs of the upgraded variant compared to the base variant. The higher the chosen probability value is, the less risk the system operator will take, because definite investment costs are compared to scattering reimbursements which base on the fortuitousness of supply interruptions. In order to avoid financial losses, for the investigations the risk value of $p_{sig\ d}$ is chosen to be 75%. For the example of Fig 4, the investment costs for an upgrade of the power system can be justified if they are lower than the reimbursement difference of the two variants ΔR_{i75}= -206 Euro/a.

The observation period has a major influence on the variances of the distribution functions. The longer the duration, the lower the relative standard deviations are [4]. As Fig. 5 illustrates this effect also influences the significance probability acc. to eq. (2). The probability curve becomes more discontinuous with a decreasing observation period T_{obs}. This results in high values of reimbursement differences ΔR_{i75} for short observation periods, means that the differences are smaller to justify the investments or that they even cannot be justified for positive values of ΔR_{i75} (e.g. for T_{obs} = 2a and T_{obs} = 5a in Fig. 5).

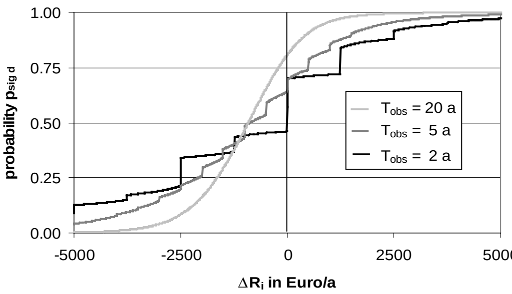

Fig. 5. Significance probability $p_{sig\ d}$ for variants with improvement of the telecontrol (reducing switching duration from 1h to 0.5h), l_{line}=0.65 km, tariff01, different observation periods T_{obs}.

In Fig. 6 the significance probability curves for a variation of the customer's tariff choice are illustrated. The figure shows, that an increase of the reimbursement factor r_E results in a linear distension of the curves with the same increasing factor. Thus the curves can be used to determine a minimum value of insured customer power resp. a minimum value for the reimbursement factor, as of a given investment measure can be justified.

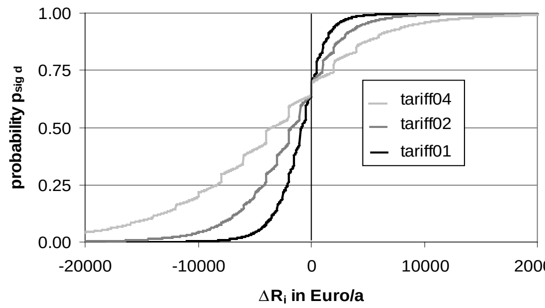

Fig. 6. Significance probability $p_{sig\ d}$ for variants with improvement of the telecontrol (reducing switching duration from 1h to 0.5h), l_{line}=0.65 km, T_{obs} = 5a, different reimbursement factors r_E

Since the exact value of reducing the restoration duration due to the use of remote reading of short-circuit indicators is not known, additional investigations are performed, if the switching duration can be reduced from T_s=1h about ΔT_s=0.25h to T_s=0.75h.

Table III shows the comparison of investment costs, ΔR_{i75} for tariff01 and the minimum value of the reimbursement factor $r_{E\,min}$ to justify the investments, assuming that all customers are insured with the same tariff.

For investment costs yearly annuities are determined with a rate of interest q of 6 % p. a. To compare the annuities directly to the reimbursement savings, it is assumed, that the reimbursements are equal distributed within the observation period T_{obs} and thus the several reimbursement cases do not have to be valued with the rate of interest q. This assumption is true, if the component reliability parameters are constant in T_{obs} resp. no time depending effects like ageing have influence on the reliability input data. The lifetime of the short-circuit indicator remote reading system is set to be 10 a. The investment costs for the remote reading of short-circuit indicator are assumed to be 7500 Euro, including 10 remote readable short-circuit indicators (every second substation) and remote reading unit and mounting.

TABLE III
RESULTS FOR IMPROVEMENT OF THE TELECONTROL
(REDUCING SWITCHING DURATION T_S), TARIFF01

T_{obs} in a	l_{line} in km	ΔR_{i75} in Euro/a		$r_{E\,min}$ in Euro/kWh		Investment-costs in Euro/a
		ΔT_s =0.5h	ΔT_s =0.25h	ΔT_s =0.5h	ΔT_s =0.25h	
5a	0.65	493	991	-	-	1019
	1.30	5	883	-	-	
	2.60	-806	796	6	-	
20a	0.65	-206	311	25	-	
	1.30	-719	137	7	-	
	2.60	-1817	-280	3	18	

An increasing line length l_{line} and thus an increase of reliability indices leads to decreasing reimbursement differences ΔR_{i75} and in case of negative values for ΔR_{i75} the decrease of the minimum reimbursement factors $r_{E\,min}$. It can be stated, that in principal the investment costs can justified only for long observation periods and an effective reduction of the switching duration of ΔT_s = 0.5 h due to the telecontrol. Furthermore only for the two cases of T_{obs}= 5 a with ΔT_s= 0.5 h and T_{obs}= 20 a with ΔT_s = 0.25 h for long line lengths l_{line}=2.6 km the values of ΔR_{i75} are negative. Customer interruption costs conventionally are in a range up to r_E= 25 Euro/kWh for r_P=0 [6]-[9]. Thus it can be seen, that the minimum values of reimbursement factors for the cases with positive values of -ΔR_{i75} are in a comparable to customers interruption costs range.

C. Upgrade of the protection system

In comparison to section III.B the protection system is improved. This improvement is investigated. Fig. 7 shows the test-system II with the upgraded protection system. Mainly the customers C_{A1}-C_{A5} and C_{B1}-C_{B5} in front of the additional protection relays are affected by this measure. Thus the following monetary investigations are performed for these customers only.

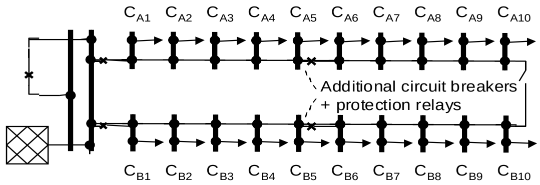

Fig. 7. Test-system II with upgraded protection system

Fig. 8 shows the significance probability of the comparison of the reimbursements of the two test-systems I and II for energy not delivered in time specific and interrupted power specific reimbursements and different line lengths. The positions of the curves for identical line lengths but the two different tariff classes are nearly equal. This is because most supply interruptions do not last longer than one hour due to the execution of manual switching actions within T_s = 1h. This means that in case of one hour lasting supply interruptions, the interrupted power specific reimbursements and the energy not delivered in time reimbursement are equal, if the specific reimbursement factors r_P and r_E are the same.

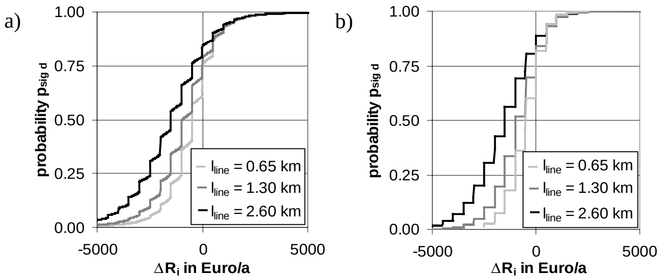

Fig. 8. Significance probability $p_{sig\,d}$ for variants with improvement of the protection system, different line lengths l_{line}, T_{obs}=5a
a) Tariff 01
b) Tariff 10

Furthermore it can be seen, that the curve shapes are different. The shapes of the curves of interrupted power specific reimbursements are absolute stepped due to the fact, that the interruption frequency has discrete values in a given observation period only. For energy not delivered in time specific reimbursements the curves are more unruffled, because the component outage duration T_f (see Table I) is continuously log-normal distributed.

Table IV shows the comparison of investment costs, ΔR_{i75} for tariff01 resp. tariff10 and the minimum value of the reimbursement factor $r_{E\,min}$ resp. $r_{P\,min}$ to justify the investments.

The investment costs for one of the two additional switch bays is taken to be 42000 Euro including protection system, telecontrol, mounting and attributable costs for buildings. The lifetime for the switch bays is assumed to be 20 a. Again it can be seen, that an increasing line length l_{line} and thus an increase of reliability indices leads to decreasing reimbursement differences ΔR_{i75} and decreasing minimum reimbursement factors $r_{E\,min}$ (in the case of negative ΔR_{i75}). It can be seen, that only in the cases with long line lengths and high observation periods, the minimum values of reimbursement factors are in a range of high customer interruption costs. In all other investigated cases the investment costs in principal cannot justified because of positive values of ΔR_{i75} or the minimum values of reimbursement factors are too high to compare them to interruption costs.

TABLE IV
RESULTS FOR IMPROVEMENT OF THE PROTECTION SYSTEM TARIFF01 RESP. TARIFF10

T_{obs} in a	l_{line} in km	$-\Delta R_{i75}$ in Euro/a		$r_{E\,min}$ in Euro/kWh	$r_{P\,min}$ in Euro/kW	Investment-costs in Euro/a
		tariff01	tariff10			
5a	0.65	9	3	-	-	7325
	1.30	3	1	-	-	
	2.60	-501	-497	73	74	
20a	0.65	-119	-246	308	149	
	1.30	-371	-491	99	75	
	2.60	-914	-1005	40	36	

D. Conversion from radial to open loop

The conversion from radial to open loop structure for customer CB5 is investigated in this section. Fig. 9 shows parts of the two test-systems under consideration. The test systems are differing from test-system I in the connection of customer C_{B5} to the power system only. In test system III the customer is radialy fed, while in test system IV C_{B5} is connected in the open loop structure. Due to the fact, that mainly customer C_{B5} is affected by the conversion measure, the following monetary investigations are performed for this customer only. Furthermore mainly interruption duration and thus energy not delivered in time are different for test systems III and IV. Therefore only energy not delivered in time specific reimbursements acc. to eq. (3) are considered. The investigations are performed for tariff 01.

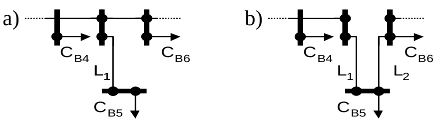

Fig. 9. Parts of test-systems III and IV
a) Test-system III: Radial feeding of C_{B5}
b) Test-system IV: Connection of C_{B5} into open loop structure

Fig. 10 illustrates the significance probability of the comparison of the reimbursements of the two test-systems III and IV for different line length for L_1 and L_2 and different observation periods with l_{L1}=l_{L2}. The figure shows, that ΔR_{i75} is in most cases nearly zero or even positive (compare T_{obs} = 5a).

Investment costs for cables vary in a wide region because of different types of ground surfaces like tarmac or natural ground. The investment costs for the additional cable L2 are assumed from 35000 Euro/km for cable laying by cable ploughing up to 110000 Euro/km for laying in a standard ditch in tarmac. The costs are comprising costs for the cable, mounting and cable accessories like cable joints and cable sealing ends. The lifetime for cables and overhead lines are assumed with 40 a. The comparison of the radial and open loop structure shows, that ΔR_{i75} is only negative in the case of long observation periods T_{obs} = 20a and long line length l_{line}=5.2 km. In this case the values of r_{Emin}.are dependent on the different cable investment costs in a range from 1890 Euro/kWh up to 5940 Euro/kWh.

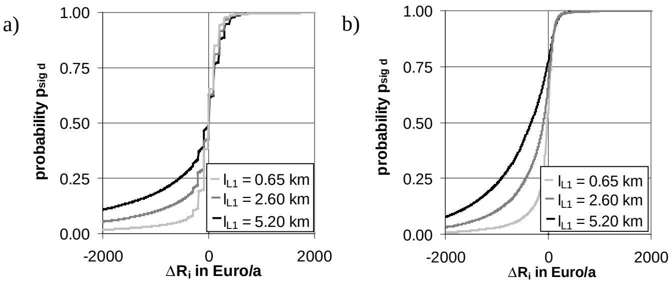

Fig. 10. Significance probability $p_{sig\,d}$ for conversion of radial to open loop structure, different line lengths l_{L1}= l_{L2}, tariff01
a) T_{obs}=5a
b) T_{obs}=20a

E. Results for overhead lines systems

This section summarises the results of the investment measures for the improvement of restoration strategy, an upgrading of the protection system and a conversion from radial to open loop structure, analogous the sections B-D. The only difference in the investigated test systems is, that overhead lines are taken instead of cables with differing reliability parameters (see Table I).

Due to the higher value of failure frequency of overhead lines, the values of $r_{E\,min}$ for the improvement of the telecontrol or the protection system are lower than for the cable-test systems, even with identical investment costs for the measures (see Tables V and VI). Thus the measures can be justified for lower insured power for overhead line systems, than for cable systems. The values of $r_{E\,min}$ are within the range of conventional customer interruption costs.

TABLE V
RESULTS FOR IMPROVEMENT OF THE TELECONTROL (REDUCING SWITCHING DURATION T_S), TARIFF01, COMPARE TABLE III

T_{obs} in a	l_{line} in km	ΔR_{i75} in Euro/a		$r_{E\,min}$ in Euro/kWh		Investment-costs in Euro/a
		ΔT_s =0.5h	ΔT_s =0.25h	ΔT_s =0.5h	ΔT_s =0.25h	
5a	0.65	-993	752	5	-	1019
	1.30	-3026	112	2	-	
20a	0.65	-1969	-363	3	14	
	1.30	-4496	-1424	1	4	

TABLE VI
RESULTS FOR IMPROVEMENT OF THE PROTECTION SYSTEM TARIFF01 RESP. TARIFF10, COMPARE TABLE IV

T_{obs} in a	l_{line} in km	ΔR_{i75} in Euro/a		$r_{E\,min}$ in Euro/kWh	$r_{P\,min}$ in Euro/kW	Investment-costs in Euro/a
		tariff01	tariff10			
5a	0.65	-2961	-2940	12	12	7325
	1.30	-6504	-6486	6	6	
20a	0.65	-3878	-3753	9	10	
	1.30	-7913	-7883	5	5	

Because of high overhead line failure frequencies but lower outage duration the results for conversion from radial to open loop structure of the test systems III and IV for overhead lines are similar to the results of the cable systems. Only in the case of long observation periods T_{obs} = 20a and long line lengths l_{line}=5.2 km the values of ΔR_{i75} are negative. If investment costs for overhead lines are assumed to be 40000 Euro/km including material and mounting, these parameters lead to a value of r_{Emin}=705 Euro/kWh.

IV. Summary Of Results

The results show that in the case of improvement of the restoration strategy by the usage of remote reading of short-circuit indicators, the investments can be justified, if the customers are insured with a energy not delivered in time specific tariff acc. to conventional interruption costs, especially for overhead line power systems, long observation periods and long line lengths. The investments for upgrading the protection system can be justified in most cases for the overhead line power systems. They can only be justified for cable systems, if the line lengths and the observation period are long and the customers are insured acc. to high interruption costs. Due to the upgrade of the protection system interrupted power specific as well as energy not delivered in time specific reimbursements are decreasing. The conversion from radial to open loop system structure cannot be justified due to low differences in reimbursements and high investment costs in any case.

V. Conclusions

The subject of the paper is the insurance against supply interruptions as an enhanced model of monetary valuation of supply interruptions. A short description of the model is given. The financial risks in investment planning for the system operator given by stochastic uncertainties are regarded. The paper presents risk-based investigations for different investment measures for MV systems, considering the supply insurance system. Considered measures are the upgrade of the protection system, improvement of the restoration strategy by investments for telecontrol and the conversion from radial to open loop system structure. The results are a good base for checking investment plans for their financial risks. So the proposed insurance model as well as the accessed risk analyses are important measures to be used in the liberalised environment.

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VII. Biographies

Dipl.-Ing. Armin Sorg (1971) studied Electrical Engineering at the Technical University of Darmstadt / Germany. He has worked as a research assistant on reliability since 1996 at the Forschungsgemeinschaft für Elektrische Anlagen und Stromwirtschaft e. V. Mannheim (FGH) on different projects such as “Time Sequential Probabilistic Outage Simulation.”

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Dr.-Ing. Wolfram H. Wellssow (1957) studied Electrical Engineering at the University of Stuttgart/ Germany and received his Dr.-Ing. degree at the Technical University of Darmstadt. He joined the Forschungsgemeinschaft für Elektrische Anlagen und Stromwirtschaft e. V. Mannheim (FGH) in 1984 as head of the Computer Applications Department. From 1996 to 1997 he was a full Professor for electric power systems at Siegen University. Since 1997 he is director of FGH.