ADJUSTMENT OF RESTORATION STRATEGY AND TELECONTROL SYSTEM IN MV NETWORKS

A. Kox, H.-J. Haubrich
Institute of Power Systems and
Power Economics (IAEW) of
Aachen University of Technology
Schinkelstr. 6, D-52056 Aachen, Germany
Tel.: + 49 241 807691, Fax: + 49 241 8888197,
e-mail: kx@iaew.rwth-aachen.de

J. Nachtkamp
STAWAG
Stadtwerke Aachen AG
Postfach 500155, D-52058 Aachen, Germany
Tel.: + 49 241 181402, Fax: + 49 241 181868
e-mail: info@stawag.de

SUMMARY

Today, reliability considerations in network planning often take into account the operational options for restoration of supply, the restoration strategy, and the facilities of telecontrol systems only in an insufficient way. This paper presents a new method to calculate reliability indices for individual substations by simulating the process of fault localisation and restoration of supply and optimising the restoration strategy. The investigations of representative scenarios show remarkable potentialities of cost reduction by adaptation of network structure, telecontrol system and restoration strategy without reducing the reliability of supply.

INTRODUCTION

For failure management after short circuits in medium voltage networks fault-locating crews have to drive along the substations of the faulted feeder. Fault indicators show the fault direction and by means of switching operations the fault can be isolated and supply can be restored to all consumers in a step by step manner [1]. Today, reliability considerations in network planning do not take into account the operational options for restoration of supply, i.e. the influence of the access order of substations (the restoration strategy) on the individual restoration time of each substation. Besides, telecontrol is only used in very few cases to support failure management because of the additional cost, especially for communication equipment, and for lack of methods to calculate its benefit with sufficient accuracy.

Increasing economical forces by the liberalisation of the markets of electric power in whole Europe and individual customers' demands for different levels of reliability of supply lead to new tasks for network planning [2]. In addition technological progress in communication systems enables new and less expensive solutions for simple telecontrol functions [1,3,4]. The question arises, how reliability of supply can be provided to individual consumers by simple and inexpensive network structures using simple telecontrol functions in a few substations and choosing an optimised restoration strategy [5,6,7].

For this purpose a new method has been developed to calculate individual reliability indices for each substation by simulating the process of fault localisation and restoration of supply and optimising the restoration strategy.

FAILURE MANAGEMENT

Short circuits in open operated MV networks lead to interruption of supply of the whole feeder by tripping of the circuit-breaker in the substation HV/MV. To localise the fault mobile fault-locating crews have to drive along the substations and read the local short-circuit indicators. The indicators show whether the fault current has passed the station or not and so the fault location can be determined to be behind (towards the normally open switches to neighbouring feeders) or before the present substation (towards the substation HV/MV). The access order of the substations has got a big influence on the restoration time in general and the restoration time of each individual substation in particular. There are some basic strategies in practise (fig. 1):

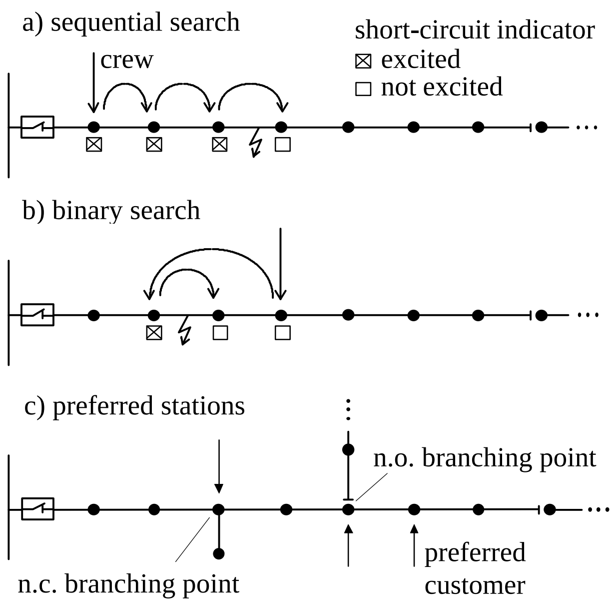

Fig. 1: Basic strategies for fault localisation

a) With sequential search the stations are accessed in their topological order starting at the beginning or at the end of the feeder.

b) With binary search the faulted part of the feeder is divided into halves in every step.

c) Some stations may be preferred like branching points with normally closed (n.c.) or normally open (n.o.) switches (to get more information about the fault direction or to restore supply) or stations supplying preferred customers (e.g. with specific contracts guaranteeing a maximum restoration time).

Beside these basic strategies the accessibility of the substations, depending on their geographic position and their type (compare packaged substation with outside indication and vault substation), has got a big influence on the access order and the restoration time. Often this substation is accessed next which is the next reachable one.

Is the fault location limited to a single line between two substations or to a substation itself, it has to be isolated at the neighbouring substations by opening the n.c. switches and supply can be restored to the faultless substations by closing the tripped circuit-breaker and the n.o. switch (fig. 2a).

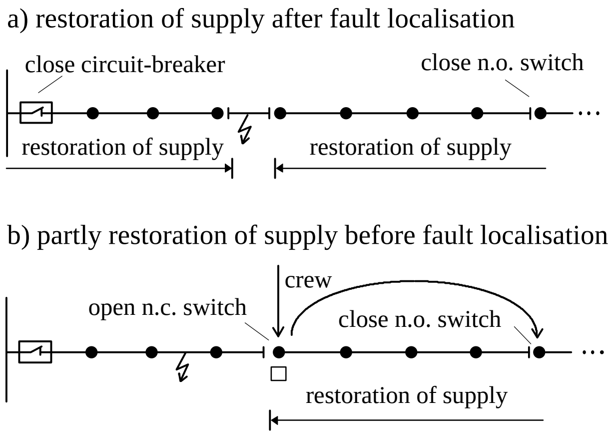

Fig. 2: Restoration of supply

To accelerate the restoration of supply of single substations, faultless parts of the feeder can be disconnected from the remaining faulted part in an early step and supply can be restored to the belonging substations before the fault localisation continues (fig. 2b).

Network automation functions can support the process of fault localisation and restoration of supply. In a first step single short-circuit indicators can be teletransmitted and so the fault can be roughly localised. This information can guide the crew in the first step closer towards the real fault location (fig 3a). By remote control of the normally open (n.o.) switch (or the circuit-breaker at the substation HV/MV) long driving ways can be saved and the (partly) restoration of supply can be supported (fig. 3b).

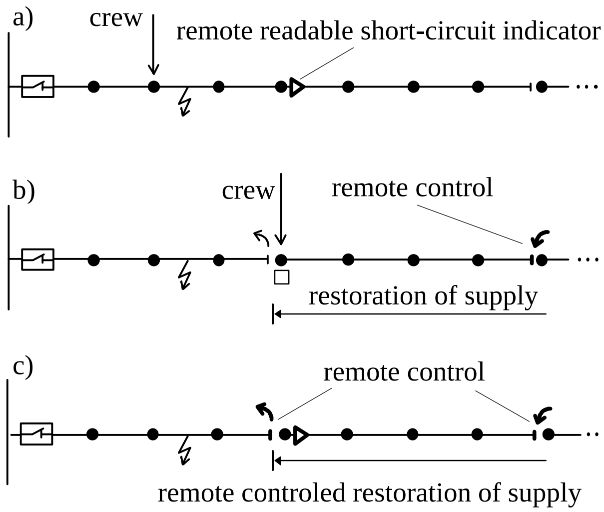

Fig. 3: Simple network automation functions to support fault localisation and restoration of supply

Finally by combination of remote readings and remote control faultless sections may be determined and supply may be restored to them very quickly without any local operation (fig. 3c).

Notice that the required telecontrol functions are very simple. It is not necessary to install expensive automation units with complex metering, calculation and signalling functions. Transmitters that have only to send a binary signal in case of excitation of the short-circuit indicator and receivers to receive the binary open/close signal for the telecontroled switch, e.g. with energy store for one open/ close cycle, are sufficient. For communication standard mobile phone facilities are sufficient and affordable.

DEVELOPED SIMULATION METHOD

For optimal adjustment of network structure, telecontrol system and organisation of the fault-locating crews a computer based method has been developed at the Institute of Power Systems and Power Economics (IAEW) of Aachen University of Technology in co-operation with STAWAG Stadtwerke Aachen AG. Fig. 4 provides a survey of the new method.

The investigation scenario has to be defined by

- network structure,
- telecontrol system, i.e. substations with remote readable short-circuit indicators and substations with remote controlled switchgear,

- geographic data, especially distances and driving times between substations and accessing times at the substations, and
- the number of fault-locating crews.

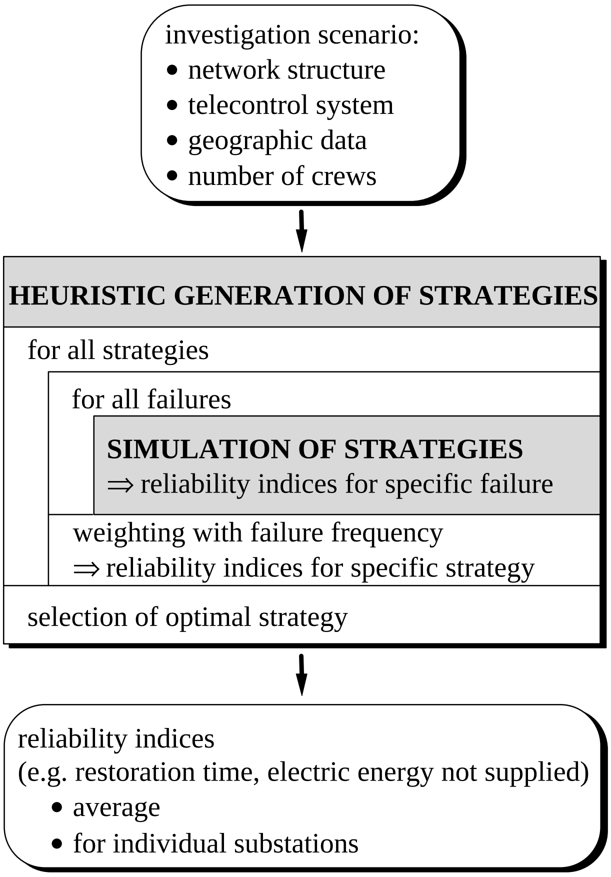

Fig. 4: Survey of the new method

Goal of the new method is to value the scenarios with regard to failure management. For this purpose all restoration facilities of the network structure, supported by the telecontrol system, have to be used in the best way. Therefore the core of the new method is the optimisation of the restoration strategy.

For this optimisation task a heuristic approach is chosen. By combination of the basic strategies (fig. 1) and permutation of access orders a large number of different strategies is generated, defined by specific decision criteria. After their generation all strategies are simulated for each possible fault location. Simulating the individual driving and switching actions of the fault-locating crews in a step by step manner allows regarding the changing circuit state of the network and so calculating the individual restoration time for every substation for each specific failure. These values are weighted with the failure frequencies and so reliability indices for the specific strategy are calculated. After the simulation of all strategies this one can be chosen which leads to the best value of an optimisation criterion that can be selected, e.g. minimum average restoration time or minimum restoration time of one single preferred substation [8].

The practicability and plausibility of the generated strategies, including the optimal use of telecontrol functions, is ensured by continuous assistance by operating personnel during the whole process of development and proven by comparison to real failure cases. For the first time this new method allows to quantify the benefit of single specified telecontrol measures with high accuracy.

WITH TELECONTROL TO NETWORK SIMPLIFICATION

As a first application of the new method an area of nine feeders of the urban 10 kV cable network of STAWAG, supplying 81 substations MV/LV, is investigated. Today's network structure is marked by six unit substations, connected by 10 kV transmission lines, where the feeder lines start with selective protection. All substations have short-circuit indicators. A few of them are remote readable (fig. 5).

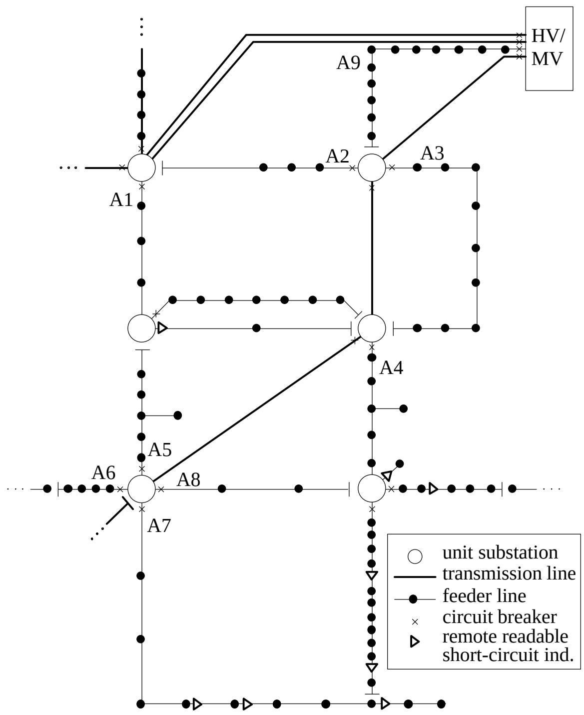

Fig. 5: Former network structure

Because of ageing and new regulations many switches have to be exchanged and some stations have to be rebuild. To minimise the investment cost the area is planned to be restructured to six larger feeders, removing five of six unit substations and thus saving 12 circuit-breakers (fig. 6). The question is how the restructuring influences the restoration times, if failure management is continued being performed by one single crew.

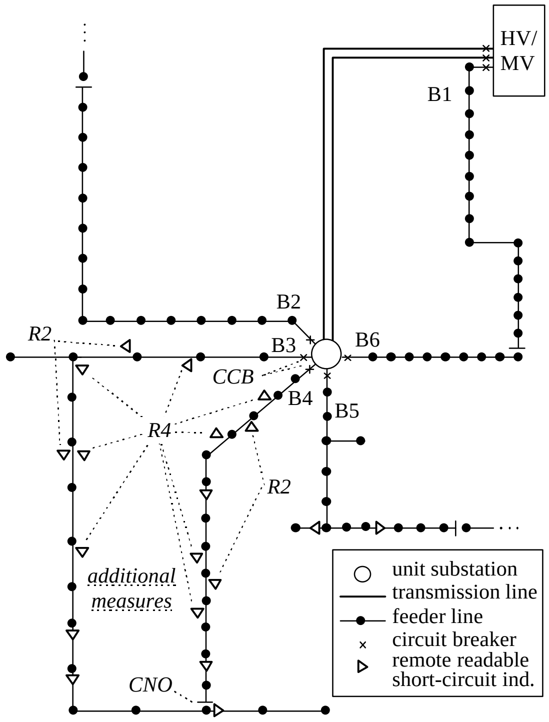

Fig. 6: Network structure after reconfiguration

First, the restoration times for the nine feeders A1 to A9 of the former network structure are calculated. Because of big differences in length and number of substations supplied the values vary very strongly (fig. 7). As this level was accepted in the past by all customers the maximum values of average and maximum restoration time shall be taken now as demanded limits for the restructured network.

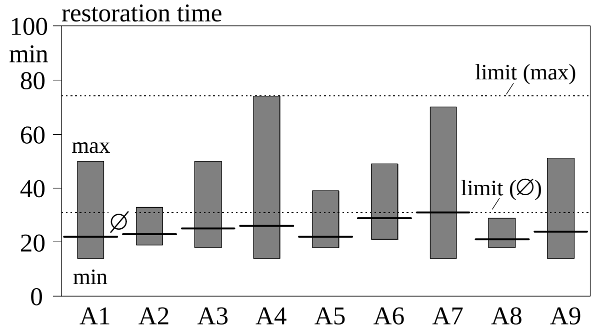

Fig. 7: Restoration times for the former network structure

The calculated restoration times for the restructured feeders B1 to B6 are shown in fig. 8. Most values of average and maximum restoration time increase slightly because of longer feeders with more substations supplied. But there are limit violations only for the two neighbouring feeders B3 and B4.

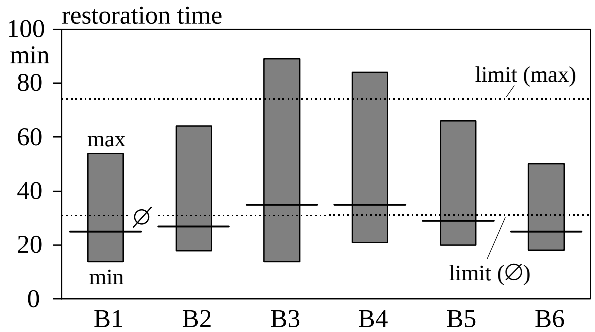

Fig. 8: Restoration times for the restructured network without additional measures

For these two feeders B3 and B4 the following telecontrol measures, in addition to the existing remote readable short-circuit indicators, have been investigated to compensate the rising restoration time (fig. 6):

R2: remote reading of 2 short-circuit indicators each;

R4: remote reading of 4 short-circuit indicators each;

CCB: remote control of the circuit-breakers;

CNO: remote control of the normally open (n.o.) switch;

C2: remote control of circuit-breakers and n.o. switch.

Fig. 9 shows that additional remote readings for feeder B3 are less effective than for feeder B4. The existing remote readable short-circuit indicators at feeder B3 are already placed very well so the benefit of the additional ones is only small. Here the demanded limiting values can only be achieved by remote control of the circuit-breaker or the n.o. switch. For feeder B4 the additional remote reading of two short-circuit indicators can be regarded as sufficient. For both feeders the remote control of circuit-breaker and n.o. switch can reduce the restoration times additionally very strongly. Indeed this measure is not necessary to comply with the required limits.

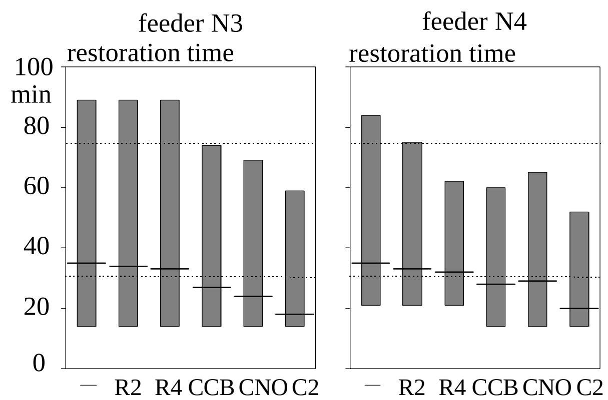

Fig 9: Effect of the additional telecontrol measures

This investigation is a representative example how primary equipment is substitutable by secondary equipment. Similar results could be derived from different further investigations.

ORGANIZATION OF THE FAULT-LOCATING CREWS

During working hours the fault locating crews are busy, e.g. with maintenance or construction work, either at the utility's site or in the field. At night they mostly have to be alarmed from home. Depending on the number of stand by crews each is responsible for a more or less big area supplied.

A present development at almost all utilities is the reduction of personnel and thus an enlargement of these areas. Longer reaction times and less familiarity with the local situation result.

To quantify the influence of these tendencies the next investigation has been carried out for a model ring network structure supplying 20 substations with n.o. switch in the middle. To cover the range of imaginable rationalisation developments the simulation method has been performed with a parameter variation for:

- reaction time - time between fault indication and the crew reaching the first substation of the faulted area;
- access time - time to enter the substations.

The influence of an increase of these values by 50 % or 100 % on the restoration time has been calculated and possible compensating telecontrol measures, similar to the example above, have been investigated:

R5: remote reading of 5 short-circuit indicators in each feeder (every second substation);

CCB: remote control of the circuit-breakers;

C3: remote control of circuit-breakers, n.o. switch and another substation in the middle of the feeder.

Fig. 10 shows how strongly the increasing time parameters influence the restoration times (without compensating measures) though the driving times were assumed to be constant. If the increase of reaction and access time (e.g. by reorganisation) can be limited to 50 % the more simple compensating measures like remote reading of short-circuit indicators (R5) or telecontrol of only one switch (CCB) might be taken as sufficient. In case of doubling the parameters (e.g. very strong personnel reduction with shut down of utility sites) more telecontroled switches, with the possibility of complete telecontroled restoration of supply of some substations (C3), are necessary to keep the restoration times of the reference scenario.

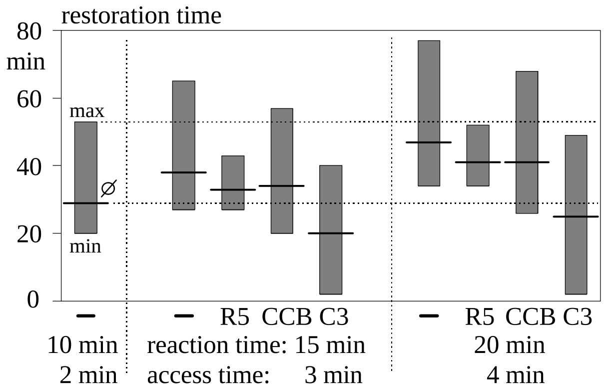

Fig. 10: Effect of increasing reaction and access times and compensating telecontrol measures

It should be mentioned that this model investigation just can show tendencies and demonstrate how this kind of questions can be answered by application of the new developed simulation method. For the evaluation of real reorganisation processes the individual conditions have to be regarded.

INDIVIDUAL RELIABILITY BY ADAPTED RESTORATION STRATEGY

In case of individual demand for high reliability of supply of only one single customer a preferred restoration of supply for this customer might be sufficient to limit its average or maximum restoration time. This may make telecontrol measures unnecessary which always provide higher reliability to more customers. This possibility is investigated for a specific substation of the feeder illustrated in fig. 11 supplying 17 substations MV/LV of the urban 10 kV cable network of STAWAG.

For this scenario the strategies for minimal average restoration time (strategy A) and for minimal restoration time of substation N (strategy B) are compared. Fig. 11 demonstrates the different procedures for an exemplary fault on the line between substation J and K.

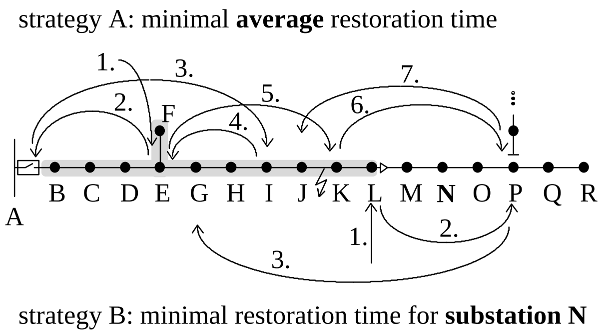

Fig. 11: Strategies for minimal average and minimal individual restoration time

The possible fault location is limited by the remote readable short-circuit indicator (▷) to the section before substation L. Strategy A carries out a kind of binary search with partly restoration of supply after each step of fault localisation (compare fig. 1 and fig. 2). To substation N supply is only restored in a late step. Alternatively strategy B disconnects the faultless section L to R in the first step from the rest of the feeder and restores supply to the belonging substations (including substation N) via the normally open switch in substation P before starting the search along the rest of the feeder.

Fig. 12 shows the strongly reduced average restoration time for station N if its restoration of supply is preferred for all failure cases (strategy B). However, the average restoration time of all stations rises slightly up consequently. Maximum and minimum restoration time (over all stations and all possible faults) are unchanged.

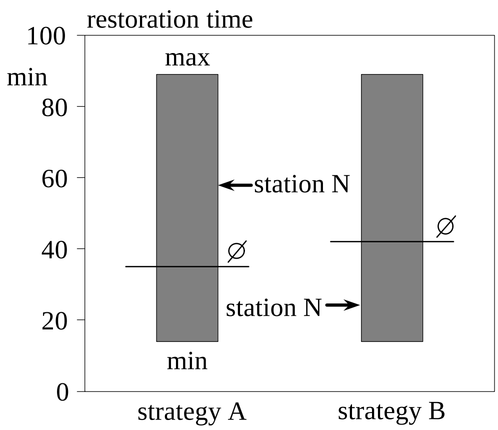

Fig. 12: Average and individual restoration time with or without preference of station N

CONCLUSION

Today, reliability considerations in network planning only consider the operational options for restoration of supply and the facilities of telecontrol in an insufficient way. This paper describes a new method to calculate the reliability of supply of individual substations depending on network structure, telecontrol system and organisation of the fault-locating crews by simulation and optimisation of the restoration strategy.

The investigations of representative scenarios show that simple telecontrol functions at certain substations may allow savings of remarkable amount in primary equipment and personnel without reducing the reliability of supply. To enhance the reliability of supply of only one single or a few customers an adapted restoration strategy with preferred restoration of supply of the specific substation might be sufficient.

Notice that all investigation scenarios are urban scenarios. For rural areas the absolute (and accepted) restoration times are often much higher than the values discussed here. Further investigations show that in these cases often much more benefit can be achieved by single telecontrol functions because of the longer distances between the stations. In rural areas remote readings or remote control can save even longer driving ways.

The developed method, designed as an planning tool, as well can be used to support the fault-locating crews by suggestion of an optimised strategy, at today's state e.g. for training purpose. For on-line implementation the further development towards an interactive decision support system with data exchange to geographical information systems (GIS), routing systems and satellite navigation systems (GPS) is intended.

REFERENCES

[1] G.C. Schoonenberg, W.M.M. Menheere and F. Jansen, "Increasing the Availability of the Medium Voltage Network in the Netherlands", CIRED 97, paper 4.2

[2] T.M. Taylor, H.L. Willis and M.V. Engel, "New Considerations for Distribution Network Planning and Design", CIRED 97, paper 6.1

[3] J.R. Formby, R. MacMillan and P. Snowdon, "Improving MV Network Reliability and Plant Utilisation by Remote Switching using Distribution Line Carrier and Radio Communications", UNIPEDE Distribution Conference „Information Systems in Distribution“, Rome, October 1993, paper 934en1.9

[4] CIRED Ad-Hoc Working Group 2, "Distribution Automation: functions and data", CIRED 95, session 4

[5] J. Maegaard and E.F. Pedersen, "Cost Benefit Monitoring - Real Values", Proceedings DA/DSM 94 Europe, Paris, September 1994, Vol. 2, pp. 501-514

[6] M. Lehtonen and S. Kupari, "A Method for Cost Benefit Analysis of Distribution Automation", IEEE, Catalogue No. 95TH8130, 1995

[7] UNIPEDE, Distribution Study Committee 50.04.DIS-NET, "Distribution network configuration and design - Applied practices, likely trends and evaluations of technical solutions", UNIPEDE, Ref.: 05004Ren9540, Paris, 1995

[8] A. Kox, "Planung von Mittelspannungsnetzen unter Berücksichtigung betrieblicher Freiheitsgrade bei der Störungsbeseitigung", Dissertation RWTH Aachen, Aachener Beiträge zur Energieversorgung, Band 53, Aachen, 1998