OPTIMAL RESOURCE PLANNING FOR MAINTENANCE OF DISTRIBUTION NETWORKS

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INTRODUCTION

Yearly resource planning for distribution grid operation is often based on average values of the past. However, a more detailed model of distribution networks is indispensable if grid operators’ decisions regarding operation and structure of the network have to be evaluated. In addition, scheduling of human and material resources have to be taken into account to compare different strategies of network operation and its influence on costs.

Within a first study the authors used a newly developed simulation and optimization approach to determine minimum resources for maintaining distribution grids. This methodology was used to evaluate minimum operation costs considering relevant technical and organizational characteristics of typical medium and low voltage distribution grids.

In this paper an overview on the methodology used is given and some of the results achieved are shown.

OPERATION COSTS OF DISTRIBUTION GRIDS

Operation costs of distribution grids are mainly determined by the resources (personal and material) required for planned maintenance of components and measures to overcome incidents in the grid. The first depend on the operation strategy and on the kind and number of components used (e.g. cable versus overhead-lines). Most of these measures can be planned without time restrictions, whereas some measures have time dependent restrictions: e.g. cutting of trees is allowed only during the winter period from Oct. to March.

Incidents happen accidentally, but some annually and daily variations have to be regarded: Incidents caused by lightning are more likely to occur during the summer period, whereas storms happen more frequently during the winter period.

Since automation is not commonly used in medium and low voltage grids, switching and earthing actions by mobile personnel have a relevant influence on the effort needed to prepare lines and substations for maintenance or for the fault clearance. Thus, not only component related measures but also network related measures to prepare and post-process components have to be regarded.

The aim of this paper is to introduce the newly developed methodology which allows quantifying the annually required resources (personnel and material). In addition some of the results of its application on two typical grid areas of RWE are shown.

The result is a human resource allocation for network operator’s own maintenance department and costs for external personal (Outsourcing). The most appropriate outsourcing strategy can be obtained with this tool. The influence of variations of the operation strategy can be studied.

DETERMINATION OF RESOURCES REQUIRED

For each component of the grid maintenance measures are modelled considering its type (component related maintenance measures) and its function in the network structure (network related measures). In the following the models used are introduced.

Component Related Maintenance Measures

These measures depend on the maintenance strategy and the stochastic behaviour of the components. Data are obtained from statistics (e.g. [1,2]). These measures are modelled by the following characteristics:

- Frequency of each singular action (maintenance or fault),
- required human resources (number, duration and qualification of staff members),
- required costs for materials and spare parts,
- required costs for external personnel (outsourcing), only for preventive measures:
  - possible period of time for carrying out measures,
  - necessity for disconnection of component to carry out measures,
  - only for incident based measures: type of fault.

Since incident based measures are carried out immediately after the incident, a specification of a time period for carrying out these measures is not necessary.

Network Related Measures

Network related measures are simulated regarding the function of a component in the network structure; this means switching and earthing measures for maintenance or fault clearing. This simulation is only necessary for MV-component. In LV Structures are very simple, so estimating average values is sufficient. Within this simulation a differentiation between network related preparation and post-processing of preventive and incident based component related maintenance measures is made. Incident based
measures are furthermore differentiated by the following types of faults which cause the component related measures:

- short circuit faults: cause tripping of protection devices and thus require fault location and restoration;
- earth faults in compensated and isolated networks: require immediate fault location and disconnection;
- non-electric faults: are discovered during inspection or by third parties and require immediate disconnection.

In addition, reserve measures to compensate the unavailability of a component during maintenance, like installation of emergency power generators, are simulated.

To obtain the resources required, methods, which have been developed for optimization of fault clearance, are applied [3-5]. Subject of these methods are MV-feeders.

The methods allow a detailed modelling of typical cable and overhead line networks. Operation processes, like movements of staff in the network area, switching actions, earthing actions as well as inspections and measurements, are simulated. A quantification of the human and material (for running emergency power generators) resources thus is possible.

**Combining Maintenance Measures**

To meet time constraints for carrying out maintenance measures, single network related and component related measures are combined to packages. For this purpose, the following heuristic methods are applied to each component classified by its type and its function in the network structure.

**Preventive Measures**

Fig. 1 shows the method applied for combining preventive measures to packages of component related and network related measures. If no disconnection of a component is required, measures can be carried out independently, network related resources do not have to be considered. If disconnection of component is required, the component related measure is part of a maintenance package with component related and network related measures which have to be carried out in one sequence. In some cases it can be more efficient to integrate more than one component related measure within the stage of disconnection even though the scheduled frequencies for the combined component related measures are different.

Within the heuristics used, multiple component related maintenance measures are combined to packages if total costs for maintenance measures are lower due to the total reduction of network related maintenance effort.

**Incident Based Measures**

Fig. 2 shows the method applied for combining incident based measures to packages. For each component related incident the network related requirement for resources is determined by type of fault (short circuit faults, earth faults in compensated and isolated networks and non-electric faults) and by the damage that is caused by the incident.

**Requirement Of Resources In The Period Of Time Considered**

To obtain the resource requirement for the network to be considered in the considered time period, the resource requirement which has been determined for each component (classified by type and function in the network structure) is multiplied with the frequency the measures and packages of measures have to be carried out and with the number of component of that type and function in the network.

**OPTIMAL RESOURCE ALLOCATION**

Requirement for resources can be covered using staff employed in grid operator’s own maintenance departments, which causes yearly costs for each staff member or by outsourcing measures which causes costs for each measure outsourced.

When planning resource allocation, grid operators have to decide whether a measure is carried out by their own maintenance department or if it is outsourced. With employing staff it is to decide how many staff members of what qualification the maintenance department should have. These decisions have to fulfill the following constraints:

- some maintenance measures have to be carried out in a restricted period of time,
- maintenance measures require a minimum qualification of staff,
- staff of maintenance departments has a limited capacity,
• maintenance measures within packages have to be carried out in a sequence and
• maintenance measures, which have to be carried out several times within a year have to have minimum time periods in-between.

The resource allocation is described as an optimization problem which can be solved using mixed integer programming (MIP), since decisions can be mathematically described by integer variables and objective function (minimum costs for staff and outsourcing) and constraints can be transformed into linear equations. The problem is solved using the “branch and bound” method, which allows to obtain results regarding optimal numbers of staff members to be employed in the maintenance department, optimal times for maintenance measures to be carried out and optimal outsourcing strategies for each maintenance measure.

RESULTS

The results shown are calculated using a suburban and a rural MV and LV grid structure which is typical for RWE Rhein Ruhr. The total number MV/LV substations is about 1,400 (suburban: 700, rural: 500), the total MV-line length is about 900 km (cables: 70%, overhead lines: 30% suburban: 550 km, rural: 350 km) and the total LV-line length is about 2,200 km (cables: 80%, suburban: 1,400 km, rural: 800 km). The period of time considered is one year, the minimum time unit considered is one month. In the following, some of the results regarding requirement for resources and costs for maintenance of the networks considered are shown.

Required Resources

Using the newly developed models, it is possible to determine monthly resource requirement. The human resource requirement is shown in fig. 3 and fig. 4. Since the results for the suburban and the rural area are similar, the diagrams show results for the suburban area only. The man-hours required monthly are related to the maximum of man-hours required in one month if suburban and rural area were considered as a whole. The diagrams show the relation between maintenance effort caused by MV and LV networks and for MV networks the relation between the effort caused by network and component related measures.

Fig. 3 shows resource requirement for preventive maintenance. Measures which can be carried out during a period of several months are evenly spread to this period of time.

Resource requirements for preventive maintenance is mainly caused by MV-component. Due to maintenance measures at the outside of substations (substation grounds) and at overhead lines (OHL), maintenance resources required during the summer time are quite higher than during the winter time.

Fig. 4 shows resource requirement for incident based maintenance. In contrary to preventive maintenance it is dominated by LV-component. Due to external influences (e.g. thunderstorms) requirement for human resources during the summertime is noticeable higher than during the rest of the year.

Altogether, in the considered MV-grids about 10% and in the considered LV-grids about 35% of maintenance effort is caused by incidents.

In MV-grids, a remarkable percentage of maintenance effort is caused by network related measures: in the grids considered it is about 20%. Thus, considering the grid structure is indispensable when evaluating maintenance costs.

To verify this statement, fig. 5 shows the effort required for network related measures if a substation is to be maintained depending on the grid structure it is installed in. Especially after incidents, human resources required for preparing component related maintenance measures at a substation in a typical rural feeder of the considered networks is much higher than human resources for a substation in a typical suburban feeder.

If maintenance resource requirement were covered in the months it is distributed to in fig 3 and fig. 4 a very uneven and unrealistic utilization of staff would result. Thus, to quantify minimum maintenance costs, optimal maintenance staff allocation with the method described before is appropriate.
Optimal Strategy Regarding Maintenance Staff

With optimal resource allocation about 75% of the total maintenance costs are caused by covering human resource requirement (fig. 6). The optimal strategy regarding maintenance staff and thus total maintenance costs depend on the size of organizational units. If the maintenance department for rural and suburban area were one unit, total costs for covering human resources would be about 2.5% lower than if the maintenance department would be divided into two independent units.

![Diagram of maintenance costs depending on organization of maintenance departments](image)

fig. 6: maintenance costs depending on organization of maintenance departments

Not only the costs but also the optimal number of staff members of the maintenance department is influenced by the size of the network areas to be maintained: dividing the maintenance department into two units results in an optimal number of staff members which is some 20% lower, therefore a different ratio of costs for outsourcing and maintenance staff leads to minimum overall costs depending on the network size.

Optimization of human resource allocation can achieve a very constant and also high utilization ratio of maintenance staff as shown in fig. 7 (maintenance department as one unit).

![Diagram of optimal maintenance scheduling and outsourcing strategy](image)

fig. 7: optimal maintenance scheduling and outsourcing strategy

To reach minimum maintenance costs, the optimization tool recommends an optimal monthly maintenance schedule for measures and packages of measures which are not completely outsourced (time dependant measures). Measures which are completely outsourced can be carried out within their individual possible time period without influencing costs, since it was supposed that outsourcing costs do not depend on the amount of man-hours outsourced and the time of the year.

In the example shown in fig. 7 the large amount of outsourced man-hours in November (time dependant measures) is due to the low number of measures which have necessarily to be carried out in this month. Thus, for the maintenance department, November should be used for preparing outsourced maintenance measures like cutting trees along overhead lines.

CONCLUSIONS

The newly developed methodology allows detailed investigations to quantify the influences of individual grid characteristics and grid operator’s strategies on maintenance costs. By applying it in order to analyze influencing factors on maintenance costs of typical German MV- and LV-distribution grid structures it has been proved, that a detailed modelling of maintenance processes is indispensable, since on the one hand network related measures for preparing and post-processing component related maintenance and on the other hand organizational aspects like choosing an optimal outsourcing strategy have strong influence on maintenance costs.

In addition it was shown, that the optimization approach, which is part of the newly developed methodology, can determine optimal resource scheduling for maintenance measures and thus be used as a planning tool in order to minimize maintenance costs.

REFERENCES


