ABSTRACT
A main part of operation expenditures for electrical networks results from non-electrical resources, e. g. field service personnel, agency staff, material and tools that are required for executing processes for maintenance, fault clearance as well as for investment projects. Consequently, network operators have to optimize their resource allocation strategy to increase their network operation efficiency and reduce costs.
This paper presents examinations on optimal resource strategies for operating high-voltage networks. With a new optimization method, that minimizes resource costs, dependencies between costs and outsourcing strategies are quantified for an exemplary network area. Further sensitivity examinations assess different strategies of resource assignment for fault clearance and predictable maintenance processes. It is shown that the newly developed method enables an objective cost evaluation.

INTRODUCTION
Due to the incentive regulation of the electricity market in Europe [1], network operators are facing new challenges. In order to earn adequate revenues in the future, potentials for increasing the efficiency of electrical networks need to be utilized. For realizing short-term efficiency improvements, the optimization of non-electrical resources needed for network operation is a reasonable approach.

Resources for the operation of electrical networks are:
- field service personnel of different qualification,
- external personnel (agency staff),
- material and
- special tools that are required for certain processes.

Degrees of freedom for minimizing costs related to those resources lie in the network operator’s resource allocation strategy.

In a recently finished research project at the Institute of Power Systems and Power Economics at RWTH Aachen university [2], a computer-based method for evaluating and optimizing resources for the operation of electrical networks has been developed. The objective function of optimization is to determine cost-minimal resources for operating a given network area. Boundary conditions of optimization are measures that have to be executed for network operation within one year as well as restrictions given by the availability of resources and uncertainties that influence network operation.
This contribution presents the functionality of the newly developed method and shows results of different examinations on optimal resource planning to quantify cost-influences.

RESOURCES FOR NETWORK OPERATION
During operation of electrical networks, numerous technical and organizational tasks have to be executed to ensure functionality of the electrical assets [3] [4]. These tasks which are also called processes include measures for maintenance, renewal and realisation of investment projects. Thereby, predictable processes like preventive maintenance measures can be distinguished from unpredictable processes that depend on uncertain influences like fault occurrences. Whilst the optimal point in time for execution of predictable processes can be determined considering availability of resources, unpredictable processes usually require a short time reaction of the network operator, and a preliminary planning of the resources has to be changed.
Degrees of freedom for optimal planning of resources are the decision what combination of resources (how many and what type of resources) should be used and the assignment between processes and resources.
In network operation, optimal resource planning is influenced by numerous uncertainties that have to be considered to minimize resource related costs. Restricted resource availability can make a cancellation of determined process executions necessary, e. g. because of vacation of staff members. Unexpected varying process durations may lead to overlapping processes. Missing external personnel, materials or impossible disconnection of equipment make execution of processes impossible. Fault occurrences or unexpected identification of defective network equipment cause additional processes for its restoration. Obviously, uncertainties during network operation influence planning of resources significantly. A method for determining cost-minimal resources has to respect all uncertainties so that practical resource combinations for network operation can be derived.
OPTIMAL RESOURCE PLANNING

The following sections overview the objective function of optimal resource planning and describe how it can be solved by a computer-based optimization method.

**Objective Function**

The objective of optimal resource planning is to minimize costs for required resources and thus for network operation. Therefore, the following objective function (OF) needs to be minimized:

$$OF = \min(K_{OR} + K_{EP})$$

where $K_{OR}$ are the costs for network operators resources and $K_{EP}$ are the costs for external personnel. As a constraint, the operation of all processes has to be assured.

A subordinate optimization problem within the determination of cost-minimal resources is their optimal capacity utilization. It can be maximized by an optimal allocation of given resources to the processes. Thereby, optimization variables for each process are the point in time when its execution is planned and the decision whether the process should be outsourced. The decision about use of external personnel has to be taken for each process which can be outsourced. Thereby, it depends on capacity utilization of networks operators staff if additional external personnel is necessary to execute all occurring processes. Additionally, it has to be considered that network operators may react to uncertainties which means an important degree of freedom during network operation.

**Optimization Method**

Figure 1 describes the newly developed computer-based method for calculating cost-minimal resources.

Due to the resulting problem size, a heuristic method which is based on Genetic Algorithms is used for the subordinate problem [5] [6]. With an integrated simulation of process execution the influence of uncertainties during network operation is evaluated and considered during optimization. The evaluation of different combinations of resources during searching cost-minimal resources identifies possible improvements of considered resource combinations that will be evaluated in the next iterative search step until cost-minimal resources are found.

**EXAMINATIONS**

In the following, the functionality of the method is shown and dependencies between costs and different resource strategies are examined on the basis of sensitivity analysis for an exemplary system.

**Considered System**

The exemplary system is based on a close to reality data set for maintenance and fault clearance processes for 65 high voltage substations in a network area of 5000 km². During one year, 2000 predictable processes have to be carried out. Additional workload is caused by an average of 260 fault clearance and restoration processes. The average workload of the system is 26340 man hours per year. The actual
workload varies due to stochastic effects like uncertain process duration or occurrence of unpredictable processes during network operation. These effects lead to a varying workload between 25500 and 27200 man hours per year. In the exemplary system a maximum of 15 % of the whole workload can be outsourced by costs of 120 % of the costs for using own staff members.

Cost-Minimal Resources and Optimized Capacity Utilization

The new optimization method determines cost-minimal resources for the considered system. For executing all processes 16 own staff members of different qualification and external personnel for 105 thsd. € per year are cost efficient (figure 2).

The planned capacity utilization includes the estimated capacity needed for predictable processes. It decreases from the beginning of the considered year to its end which leads to free resource capacities that may be used during network operation to react on occurring uncertainties. Finally, due to this free capacities all processes can be executed until the end of december despite uncertain influences like necessary fault clearance measures that are not known in advance.

The average used resource capacity during the period under consideration after optimization of resource allocation is higher than 90 %.

Cost Influences of Different Resource Strategies

In the following, dependencies between costs and efficient resource strategies are considered. On the basis of sensitivity analysis, cost-minimal outsourcing strategies are evaluated in reference to outsourcing costs. Further examinations assess different strategies of resource assignment for fault clearance and known maintenance measures and evaluate whether separate staff for fault clearance is profitable.

Dependencies between Resource Costs and Outsourcing Strategies

For the considered system outsourcing costs for single processes are 120 % of the costs for executing processes by own staff members that are working at full capacity. Nevertheless outsourcing of numerous processes is still cost efficient so that own staff members are free to react on uncertain events during network operation (figure 2).

For evaluating the influence of costs for external personnel on optimal resource strategies, costs for outsourcing are varied in the following examination. For ten different scenarios which are distinguished by relative costs for external personnel (between 70% and 200% of costs for own staff), cost-minimal resources and the assignment of external personnel are determined and compared (figure 4).

Figure 4 shows that optimal resource strategies strongly depend on costs for external personnel. Complete outsourcing (a maximum of 15 % of the whole workload) is cost-efficient in this example with costs for external
Outsourcing should be reduced with ascending costs for external personnel. At 200% of costs for own staff outsourcing becomes inefficient and all processes should be executed by own staff members.

Figure 5 compares this scenario to a resource strategy with execution of predictable processes and fault clearance measures by independent staff. This strategy has the advantage that predictable processes are less influenced by unpredictable fault clearance measures which make a short-term reaction of resources necessary. In this alternative resource strategy 14 own staff members and external personnel for 160 thsd. € are necessary for predictable processes and two more staff members are required for fault clearance which leads to a cost difference of about 4% between the scenarios.

The cost difference results from a reduced capacity utilization when executing predictable processes and unpredictable processes independently. With a combined execution of all processes, staff members which usually handle unpredictable processes can also be used for predictable processes. Figure 6 shows that a higher capacity utilization of resources can be realized thereby.

SUMMARY

Exemplary sensitivity analysis on optimal resource strategies show that an optimized outsourcing strategy can only be realized by a simultaneous consideration of resources and all possible processes. An outsourcing decision on the basis of a simple process consideration is not cost optimal. Further assessments on different resource strategies for fault clearance and predictable maintenance processes point out that separate staff for fault clearance and predictable processes is not cost efficient and that a maximum capacity utilization leads to minimum resource costs.

REFERENCES