A CONTROL CENTRE PROCESS SIMULATION MODEL

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Abstract – Grid service companies in today's liberalized electrical energy markets face the key challenge to balance cost efficiency and quality of supply. Therefore questions concerning process analysis and process improvement are getting more and more into focus since some years.

This paper presents the first approach to model a full control centre process for Medium-/Low-Voltage-grids (MV/LV-grids) in combination with a grid operation model. The model allows to optimise the number of control centres including the number of control consoles with regard to the amount of planned (maintenance) and unplanned (incidents, outages) in the grid.

Keywords: control centre process simulation, multiclass queuing model, Monte Carlo, optimisation of organisations

1 INTRODUCTION

As a consequence of today's regulation of grid fees and the regulation requirements grid operators have to analyse the essential business processes very accurate in order to find the optimal balance between fulfilling the quality standards given by regulator on the one hand and the corresponding costs to satisfy them on the other hand. In particular all optimisation efforts concerning cost reduction without losing quality of supply are getting more and more into focus [1].

The central core business process concerning the quality of supply by coordination of planned and unplanned work (incidents, outages) is the power system control centre process.

In most cases planned work in the grid like maintenance, renewal and grid building projects need switching actions by the control centre. Moreover incidents in medium-voltage and low-voltage power grids and the resulting outage clearance as well as the re-supply process are organized by the control centre, too, of course with a much higher priority than the planned work. This means that a bottleneck in control centres' availability does not only lead to a delay in the re-supply process and therefore influences the quality of supply indices. Furthermore such a bottleneck influences the schedule processing of planned work and leads to operating delays and as a consequence to higher costs.

The availability of control centres is influenced by several parameters of the organisation of the control centres' staff. First of all it is influenced by number and qualification of the employees during the different shifts (in general: morning-, day- and night-shift) and the number of available control stations. Additionally the size of the grid areas of responsibility for incident clearance and planned work has an important impact on the resulting availability.

Power system control centres like other business processes can be modelled using queuing theory. In this paper we propose a detailed power system control centre operation model using queuing theory, which is combined with a full grid operational model presented in former papers. This combination allows analysing interdependencies between the organisation and configuration of control centres and the grid operation tasks (planned work and incident clearance). The new model is able to simulate the complete control centre process starting with daily switching planning, switching actions for planned work in the grid and -most important- clearing randomly occurring incidents and outages. The model allows analysing different organisation schemes of control centres and field operation staff with reference to the resulting quality of supply. Furthermore it offers the possibility to evaluate the workload of the control centre staff and the resulting delay in the planned work.

The paper presents the simulation model for control centres in detail as well as the interdependencies with the grid operation model. First simulation results of a case study with different control centre organisation options of a large grid operating company are given.

2 CONTROL CENTRE PROCESS MODEL

During former conferences a grid operation model for electrical power grids was presented [2]. This model allows to simulate the operational processes for restoration of supply after interruptions. The attention of the grid operation model focuses on the analysis of the relation between the organisation and employment of field operation staff (called resources in the following) and the corresponding quality of supply.

Beside resources on site the control centre is a key player in the re-supply process, because it is responsible for the process control of the re-supply process. Also the control centre is responsible for the assignment, activation and management of the resources on site. All switching actions during the re-supply process are executed directly by remote control or indirectly ordered to resources on site.

Based on the principal ideas of priority queuing-models of call centres [3, 4, 5], the aim of the research work is to create a simulation-model for the main processes of planned work and incident clearance in MV/LV control centres. In combination with a grid operation model for MV/LV-grids it is possible to describe the interdependencies between the operation processes and the control centre processes.

2.1 *Power grid model*

Based on the concept of the grid operation model, the supplied area and the associated power grid are modelled by a sufficiently large number of nodes. Each node is aggregating all the electrical grid equipment of its corresponding geographical area. With this representation all grid operation and control centre tasks (planned work, planning activities and incidents) are related with tasks in the corresponding node. The nodes are connected by a set of edges, which represent the spatial structure and characteristics of the supply area. The edges are described by the estimated travel time between two edges. The travel time inside a node accounts for the average travel time between the electrical equipments for switching actions on site in the grid. It's assumed, that the resources for planned working tasks are on site, when they start working clearance for maintenance. The graph (nodes and edges) of an example grid supply area is shown in Figure 1.

Figure 1: Example grid supply area and the corresponding graph model

2.2 *Queuing Model*

The control centre is modelled as a multichannel queuing system with four different priority classes. A schematic view of the modelling approach is given in Figure 2. The number of parallel queuing channels refers to the number of parallel control stations in one control centre. Each control station has four priority queues according to the number of priority classes. Depending on the organisation, the model allows to switch tasks from one control station to another, so that collaboration between control stations is possible.

Processes with the highest priority are grid messages, coming from the power grid itself by remote monitoring or with a delay from customers by failure acceptance centres. Other possible information is coming by the resources on site during the re-supply process. All grid messages need to be served directly, because they are containing important information about the actual grid state. One priority lower are incidents with or without supply interruptions. The next priority class contains schedule processing of planned switching actions. The lowest priority class contains processes of daily switching planning.

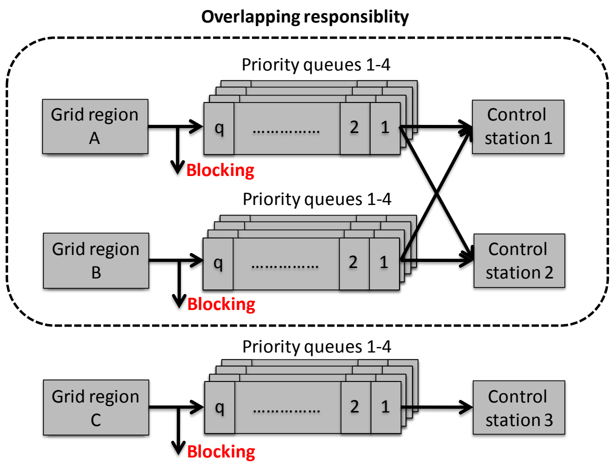

Figure 2: Schematic view of the queuing model

For simple queuing systems it is possible to develop analytical models. One example of a non-pre-emptive *N* class priority model with assumed poisson distributed input processes and equal exponential process times can be described as followed [6].

Let W_k be the steady-state expected waiting time in the queue system (including the process time) for a process of priority class *k*. Then the waiting time can be calculated with:

$$W_k = \frac{1}{A B_{k-1} B_k} + \frac{1}{\mu}, \text{ for } k = 1, 2, \ldots, N \tag{1}$$

where

$$A = s! \frac{s\mu - \lambda}{r^s} \sum_{j=0}^{s-1} \frac{r^j}{j!} + s\mu, \tag{2}$$

$$B_0 = 1, \tag{3}$$

$$B_k = 1 - \frac{\sum_{i=1}^{4} \lambda_i}{s\mu}, \text{ for } k = 1, 2, \ldots, N \tag{4}$$

with $s =$ number of control stations,
$\mu =$ mean process rate per busy control station,
$\lambda_i =$ mean arrival rate for priority class i,
for $i = 1, 2, \ldots, N$,

and

$$\lambda = \sum_{i=1}^{N} \lambda_i, \tag{5}$$

$$r = \frac{\lambda}{\mu}. \tag{6}$$

Due to the complex characteristics of the process mechanisms, the different queue disciplines and the system design with the grid operational model it is impossible to develop a complete analytical queuing model of control centres. In this case it is necessary to simulate the control centre process model by Monte Carlo simulations [3].

The developed queuing system is completely described by the routing policies, the characteristics of the process stages for the different processes and the interdependencies with the restoration process of the grid operation model.

2.3 *Queue routing policies*

There are two kind of routing policies describing this system: Control-station-selection-policy and process-task-selection-policy.

2.3.1 *Control-station-selection-policy*

Based on the definition of responsible areas for the control station, the control-station-selection-policy describes how a task is routed upon its responsible control station. In case of a large number of simultaneous incidents, e.g. due to a storm or affected by heavy thunderstorms, the number of parallel processes for one control station can reach a certain limit and the control station needs to block new upcoming processes with lower priority. To keep control of the parallel re-supply processes, no further new incident is being served by the control station until some current processes are completed. This concerns in particular planned switches and new incidents of lower priority. New grid messages are still served with the highest priority. If possible new or open tasks of planned switches can be served by another control station with the same responsibility for this area.

2.3.2 *Process-task-selection-policy*

The process-task-selection-policy addresses the question which waiting open task is served next, if more than one task is waiting, when a control station completes a process stage or is waiting for an external resource to complete a process stage. During this waiting time the control station can finish the process stage of another task. The process task selection rules differ for the different priority classes. Grid messages, planned working switches and switching planning tasks are served according to the First-Come-First-Served rule. Incidents are prioritized according to their importance. Incidents with the highest priority are served first, those with lower priority have to wait, independent of their time of arrival into the system. In cases where the necessary on site resource is not available, e. g. because it is travelling to the node of failure, the control station looks for the next incident in the priority order, where the necessary resource is waiting on site to be served by the control station. A schematic view is given in Figure 3.

If possible, an upcoming new process will be served immediately by the first responsible control station. If the first responsible control station is busy, but a second (back-up) responsible control station is available, the back-up station serves the upcoming task. If all possible responsible control stations are busy, the upcoming task joins the queue, if the actual task of the control station has a higher priority. If the priority of the new task is higher, it depends if the actual task is in this moment pre-emptive for new tasks with a higher priority. In the pre-emptive case the actual task stops and the upcoming task is served immediately. After finishing the process with the higher priority, the control station continues with the pre-empted processes from the point of pre-emption or starts new. In non-pre-emptive cases there is no interruption allowed and the highest priority task just goes to the head of the queue to wait his turn.

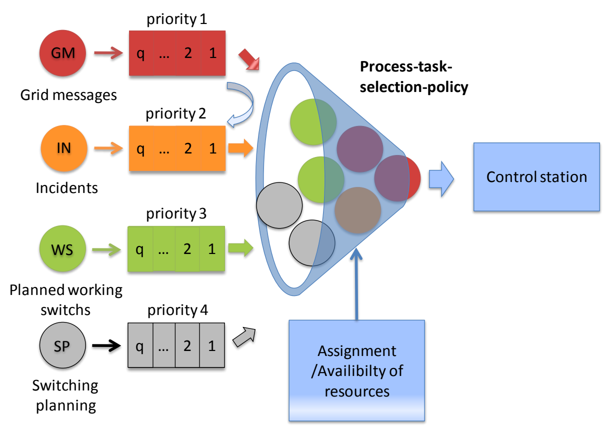

Figure 3: Schematic view of the process-task-selection-policy

2.4 *Organisation of control stations*

The model incorporates control stations with different areas of responsibility, which can possibly overlap. The areas of responsibility are time-dependent and allow to differentiate between periods of day (morning- and day-shift) and night (night-shift). So it's possible to vary the number of available control stations for one area of responsibility during different shifts.

Under normal conditions incidents and normal tasks of planned switching actions are assigned to one fixed control station. This decision is made at the beginning of the assignment of the task to a possible control station. During proceeding of the process the assignment does not change. If one control station is getting busy because of a large number of parallel processes of incidents and rejects new jobs or stops planned working processes, it's possible to switch open or new planned working processes to other possible control stations.

2.5 *Characteristics of processes and process stages*

The core process of the control centre is to coordinate and manage the grid operation tasks (planned work and incidents). The grid operation model focuses on the optimal organisation of resources on site and aggregates the different re-supply processes in MV/LV-grids by a generic profile. Other work [7] describes very detailed the optimal restoration processes and focuses on the optimal scheduling of the restoration steps for incidents of supply.

This new approach extends former work by much more detailed description of the re-supply process in these parts, where the control centre is directly process participant. Also the processes of planned working switches and switching planning are modelled detailed in different separate process stages with the interaction between the control centre and the external resources.

At all six different processes are defined to describe the interaction between control centres and field resources according to their priority:

- Grid message clearance
- MV-incident with or without supply interruption
- LV-incident with or without supply interruption
- Action without grid incident
- Switching action for planned work
- Switching planning

For all process and each process stage the average duration, the necessary process participants and rules for pre-emption are defined.

Especially the process stage of switching actions needs to be modelled very detailed, because in this process stage numerous interaction between the different process participants (control centre, resource on site and other superior control centres) takes place. Often during switching actions on-site or when resources travel between two switching actions, the control station is not needed to continue the process in this moment and there is the possibility to change to other waiting tasks in the queues. The model is able to simulate complex switching programs with remote controlled switches, on site switching actions and coordinated switching actions with other superior control centres.

Based on the concept of the grid operation model, incidents are characterized by the place and time of occurrence, the affected power and the duration of the restoration process on-site, complemented with the process durations of the control centre. Input data for all kind of processes and process stages can be estimated based on extensive analyses of historical date.

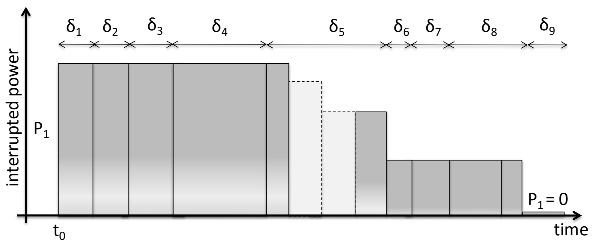

Figure 4: Profile and process stages of an incident with interruption of MV-supply

As an example for a control centre process in Figure 4 the typical proceeding of an MV-incident with power interruption is shown. Every incident in the model starts with one or a set of grid messages. This grid messages need to be examined and the status of the power grid to be determined by the control station (duration δ_1). After this step the control centre needs to activate an on-site resource (duration δ_2) and send it to the place of incident (duration δ_3). During the fault location and analysis on site proceeds, continually information must be exchanged between the control station in the control centre and the resource on site (duration δ_4). Due to the meshed construction of the medium voltage grids, most customers can usually be re-supplied by switching actions. During the switching period (duration δ_5) a permanent process interaction between the control station and the resource takes place. In cases, where not all customers can be re-supplied by switching actions, specialized resources are needed to repair additional components. They need to be activated by the control station (duration δ_6) and travel to the place of incident (duration δ_7), too. After re-supply the last customers by repairing components or with the help of mobile power units (duration δ_8), the event finally needs to be reported in the data systems by the control station (duration δ_9).

2.6 Evaluation

The complete time recording of all tasks during the simulation allows a comprehensive performance analysis of the processes and organisation. It's possible to calculate the desired workload of the control stations with the resulting delays all defined processes. The combination with the full grid operation model and the individual modelling of each interruption of supply allows determining the resulting quality of supply. The following key indices are calculated:

- Workload per unit of time for each control station
- Duration to dispose an incident to field resource
- Duration until arrival of filed resource on site
- Delay times of all incidents
- Customer average interruption duration index, CAIDI, according to [8]
- System average interruption duration index, SAIDI, according to [8]
- Minimum and maximum interruption duration of every incident
- Energy not delivered in time
- Delay times of all process stages of planned tasks

The calculated key indices can be used to analyse different organisation schemes of control centres and field operation staff. By comparing the key indices the most adequate organisation with respect to the given requirements can be determined.

3 CASE STUDY

3.1 Grid data and organisation schemes

In this section we show exemplary results of a case study with the model for different control centre organisation options, based on an existing supply area. The aim is to illustrate how the relation between different configuration of control centre organisation options and the desired key indices can be analysed qualitatively and quantitatively.

The investigated region has an approximate size of 2.900 km² and includes both rural and urban zones. The corresponding grid consists of approximately 6.800 km of MV distribution network, 12.600 km of LV distribution network and 8.100 substations MV/LV. In the model, this area is represented by 63 nodes, each covering a zone with a diameter of approximately 8 km. The nodes are connected by 179 edges with an average travel time of 21 minutes.

In this case study we simulate one exemplary month based on historical data. Table 1 shows the key data of the scenario.

scenario sets	number of incidents			Planned working tasks
	other	MV	LV	
Normal (30 days)	58	21	103	259
Extreme (12 hours)	22	6	26	--

Table 1: Scenario set of the exemplary month

The simulation includes two typical sets of incidents. The normal incident set has a rate of 1 incident per 3.8 hours. In the middle of the month there is an extreme weather scenario, due to a large thunderstorm front, with a large rate of incidents of 1 incident per 13.3 minutes. Not every incident leads to an interruption of supply, since ground-to-earth faults without interruption, voltage dips or short-term interruptions are included.

The average rate of planned switching tasks for planned maintenance work is 6 planned tasks per weekday. Additionally there are between 4 and 8 switching planning tasks per day.

organisation scheme	number of control stations	
	day	night
1	3	3
2	2	2
3	2	1
4	1	1

Table 2: Organisation schemes

The parameters of the organisations of the control centre are given in Table 2. The grid areas of responsibility for the control stations are overlapping. Four organisation schemes with different numbers of control stations are analysed. In organisation scheme 3 only one control station is available in the night and two control stations are available during day time.

3.2 Results

Exemplary evaluations for the following key figures are presented:

- Delay time of the re-supply process in case of incidents
- Waiting time for the field resources in case of planned work
- Workload of control stations

3.2.1 Results for organisation scheme 2

As a first example Figure 5 shows the empirical distribution function of the delay time of incidents and planned working switches for the organisation scheme 2.

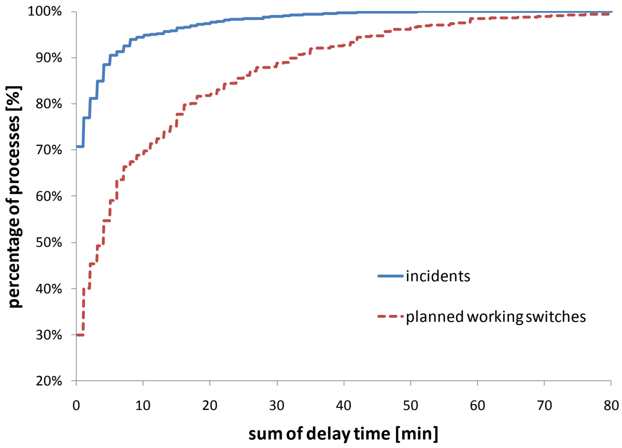

Figure 5: Empirical distribution function of the delay time of tasks (incidents and planned switching actions) for organisation scheme 2

First of all it's to remark, that the most incidents (70 %) have no delay time and so are served immediately after occurring. This is caused by the small number of simultaneous incidents during most time of this exemplary month. Only during the extreme weather scenario there are a large number of simultaneous incidents, which lead to waiting times in the service of the control centre or to a bottleneck of resources in the field..

In contrast to incidents only 30% of all planned working switches have no delay time, while 90% of all planned working switches have a delay time of at least 32 minutes. This is due to two reasons: First, most planned working switches start at the beginning of the day shift of the field resources. So a large number of planned switches are overlapping in the same time period, causing delays in the morning. Second, due to the lower priority of planned working switches to incidents, planned working processes are pre-empted, when an incident occurs and the control station first serves the incident. This leads to waiting times of planned switching tasks in the queue.

3.2.2 Impact of the number of control stations on the delay time of incidents

Figure 6 depicts the empirical distribution function of the delay time of incidents for all incidents of the example scenario for all calculated organisation schemes.

With organisation scheme 1 (O1) 90 % of all incidents have a delay time of at most 3 minutes. With a reduced number of available control stations (O2 – O4) the delay time in 90% of the incidents rises. Organisation 2 (O2) results in a delay time of 5 minutes, organisation scheme 3 (O3) in a delay time of 10 minutes and organisation scheme 4 (O4) results in a delay time of 16 minutes for 90 % of the incidents. The results indicate a significant influence of the number of available control stations at day and at night. Due to the moments of simultaneous interruptions, some incidents of lower priority have to wait in the queue for being served. The resulting delay time increase with reduced number of control stations.

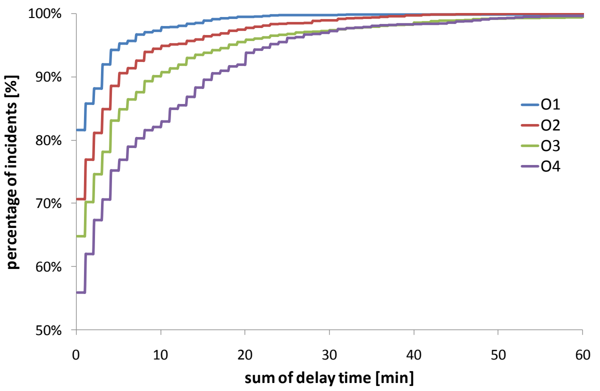

Figure 6: Empirical distribution function of the delay time of incidents for organisation schemes O1 to O4

3.2.3 Impact of the number of control stations on the delay time of planned working switches

The empirical distribution function of the expected delay time of planned working switches for the calculated organisation schemes is shown in Figure 7.

Organisation scheme O1 results in a delay time of 25 minutes with the probability of 90 % and organisation schemes O2 and O3 in a delay time of 32 minutes with the same probability. Organisation O4 leads to heavy delays of 84 minutes in 90% of the cases. There is no difference between organisation scheme O2 and O3, because during day time, where all planned working switches taking place, the number of control stations is equal.

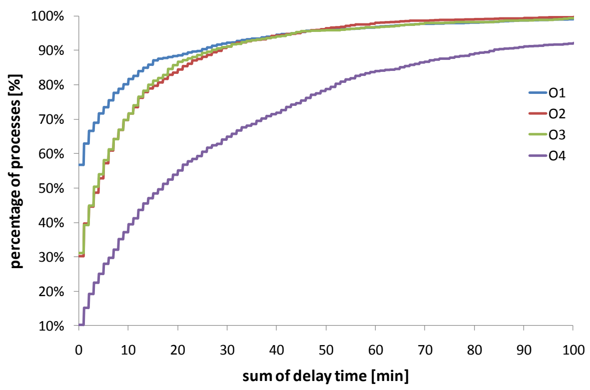

Figure 7: Empirical distribution function of the delay time of planned working switches for organisations schemes O1 to O4

Due to the reasons explained before (lower priority), the delay time of planned working switches is longer than for incidents. For planned working switches the results indicate a significantly influence of the number of available control stations on the delay at day. The reduction of control stations in the night has no impact to the delay time of planned working switches, because the tasks mainly occur during the day.

3.3 Workload of control stations

Figure 8 shows the resulting total workload for the organisation schemes O1, O2 and O4 during the extreme weather scenario in the middle of the exemplary month.

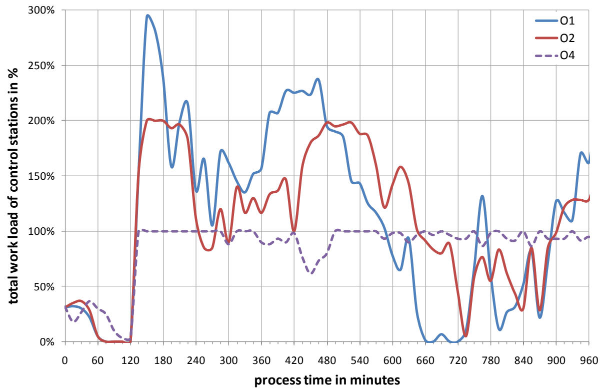

Figure 8: Total workload of the control stations for organisation schemes O1 to O4 during the extreme weather scenario

The results show, that with the beginning of the thunderstorm (ca. 120 minutes after the start of the simulation of this period) the workload grows rapidly with the number of incidents. In the first hour of the storm up to every 2.7 minutes a new incident (with or without interruption of supply) occurs in the system and needs to be serviced by the control stations. In organisation scheme O1, most incidents are cleared after 8 hours (ca. 660 min) and the resulting workload is heading down. In organisation scheme O2 it takes more or less one hour more to clear all incidents. Due to the significantly reduced number of control stations during the night shift, organisation scheme O4 needs more than 14 hours and is still servicing the incidents, when the planned working switches occurs in the beginning of the morning shift (after ca. 720 minutes). In this case planned processes have to wait, until all incidents are finished in the late afternoon. In comparison organisation scheme O1 and O2 are ready to service the planned working processes in the next morning.

4 CONCLUSIONS

With regard to today's regulation requirements grid operators need to focus considerations of optimisation in all parts of the organisation. Special attention must be paid to all business processes concerning the quality of supply. Control centres are -beside the field operation staff- the main player in the re-supply process with significant contribution to the resulting quality of supply.

The combination of a full grid operation model and the presented new control centre model allows to analyse the impact of different organisation schemes of control centres and field operation staff on the quality of supply and the resulting delay in the planned work for the first time. The simulation model supports strategic decisions concerning the configuration and number of necessary control station of control centres

Due to the detailed modelling of the control centre processes and their interaction with the field operation staff it's possible to quantify these correlations. Concerning legal, regulatory or internal requirements, the optimal organisation of control centres and field operation staff can be found. Based on this results grid service companies can generate competitive advantages.

Further research effort will be spent on detailed modelling of control centres for high-voltage grids, and their process coupling to assigned MV/LV-control centres.

REFERENCES

[1] C. Friedrich, M. Guarisco, S. Kueppers, A. Schweer, "Grid Operation in the Contrary Regulation Challenge of Cost Reduction and Supply Quality", Proceedings of the 19th International Conference on Electricity Distribution (CIRED 2007), Vienna, Austria, May 2007.

[2] M. Guarisco, C. Friedrich, M. Laumanns, M. Zdrallek, "A grid operation model: resource demand for an adequate quality of supply", Proceedings of the 16th Power Systems Computation Conference (PSCC), Glasgow, Scotland, July 2008.

[3] D. Gross, C. M. Harris "Fundamentals of Queueing Theory", New York, Wiley, 1985, ISBN 0-471-89067-7.

[4] S. Helber, R. Stolletz "Call Center Management in der Praxis", Berlin, Springer-Verlag, 2004, ISBN 3-540-00100-X

[5] R. Stolletz, S. Helber "Performance analysis of an inbound call center with skills-based routing", OR Spectrum, Vol. 26(3), pp 331-352, 2004

[6] F. S. Hillier, G. J. Liebermann, "Introduction to Operations Research", New York, McGraw-Hill, 2009, ISBN 0-077-29834-9

[7] M. Theil, G. Theil, "Reliability Assessment of Medium Voltage Networks with Simulation of the Restoration Process", Proceedings of the 14th Power Systems Computation Conference (PSCC), Sevilla, Spain, June 2002

[8] "IEEE Guide for Electric Power Distribution Reliability Indicies, IEEE Std 1366-2003 (Revision of IEEE Std 1366-1998)", 2004.