# A QUEUE THEORY APPROACH TO OPTIMISE CONTROL CENTRE ORGANISATION

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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 under increasingly complex conditions. Therefore questions concerning process analysis and process improvement are getting more and more into focus since some years.*

*This paper presents a full control centre operation model for High-/Medium-/Low-Voltage-grids (HV-/MV-/LV-grids) in combination with a grid operation model. The new model allows to optimise the number of control centres including the number of control stations with regard to the amount of planned (maintenance) and un-planned (incidents, outages) work in the grid.*

## INTRODUCTION

Current power grids are highly complex and require sophisticated, precise operation and control. Starting with the European recommendation (20-20-20-agenda) that 20% of Europe's energy should obtain from renewable sources by the year 2020, new issues have occurred in power systems. Due to the high penetration with renewable energy sources, the secure and reliable operation of modern power grids in Europe represents a competitive task. Monitoring and controlling such systems is becoming more and more difficult and control centres will be more than ever before the central nerve system of the new smart power grid. But the benefits of the evolution of the smart power grids towards more operational flexibility will mainly depend on the ability of the control centre staff to operate as quickly and effectively as possible. 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 could lead 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-, afternoon- and night-shift) and the number of available SCADA-system workstations (control stations). Furthermore the size of the grid areas of responsibility for incident clearance and planned work has an important impact on the resulting availability too.

This paper proposes a detailed power system control centre operation model for control centres of high-/medium- and low-voltage grids. The model is based on a time-driven queuing network, which is combined with a full HV-/MV-/LV-grid operational model presented in former papers [1, 2]. This combination allows analysing interdependencies between the organisation and configuration of control centres on the one hand and the grid operation workforce for planned work and incident clearance on the other hand. Furthermore it's possible to quantify the process interdependencies between separated high-voltage and medium-voltage control centres. The new model is able to simulate the complete control centre processes starting with daily switching planning, switching actions for planned work in the grid and -most important- clearing of randomly occurring incidents and outages.

This new control centre model is used in a comprehensive case study of a large distribution grid operator in Germany, who operates high-, medium- and low-voltage grids. Crucial results of this case study are presented in this paper too.

## CONTROL CENTRE OPERATION MODEL

Beside resources on site the control centres are in particular the key player in the re-supply process. The control centre is responsible for the entire operation management up to 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 [4, 5, 6], the aim of the research work is to create a simulation-model for the main processes of planned work and incident clearance in HV/MV/LV control centres. 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 1. 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 work between control stations is possible.

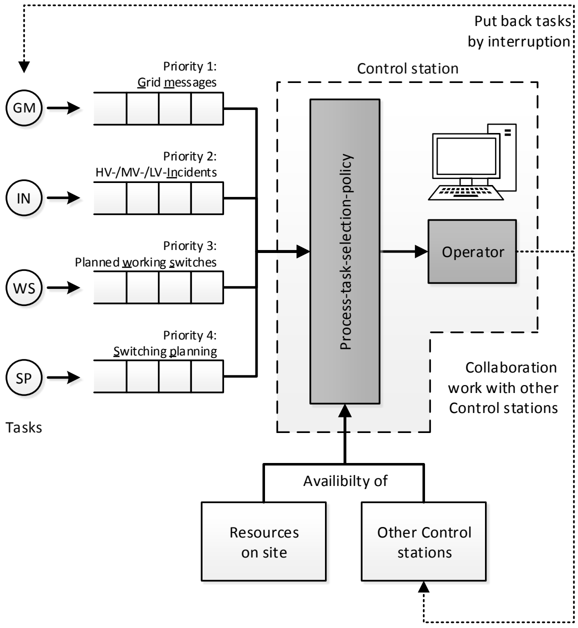


**Figure 1:** Schematic view of the control station model

Tasks 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. 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. They are prioritized according to their importance. Incidents with the highest priority are served first and those with lower priority have to wait. 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. The next priority class contains schedule processing of planned switching actions. The lowest priority class contains processes of daily switching planning and other administrative tasks. The process-task-selection-policy addresses the question which waiting open task is served next, if more than one task is waiting for the operator. The process task selection rules model in detail the operational practice of HV/MV/LV control centres.

The model incorporates control stations with different areas of responsibility, which can possibly overlap (Figure 2). The areas of responsibility are time-dependent and allow to differentiate between periods of day (morning- and afternoon-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.

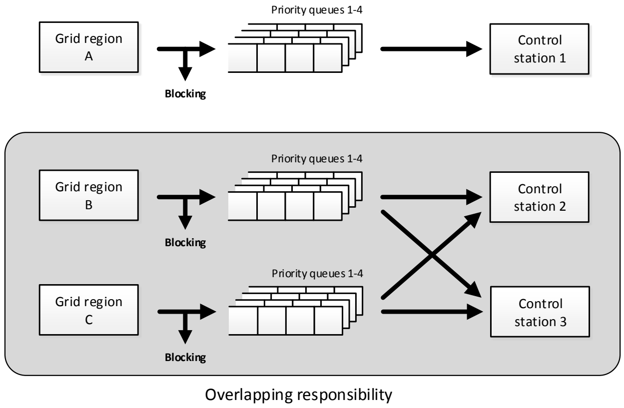


**Figure 2:** Schematic view of the queuing model

## 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. The graph (nodes and edges) of an example grid supply area is shown in [2].

## Process modelling of the control centre

The core process of the control centre is to coordinate and manage the grid operation tasks (planned work and incidents). This new approach extends former work [1, 2, 3] 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. 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. 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.

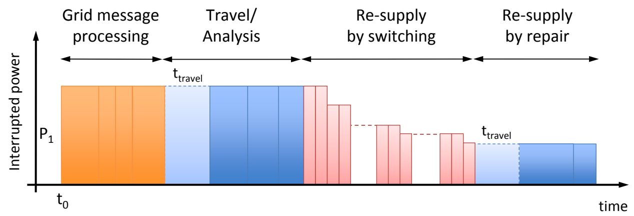


**Figure 3:** Profile and process stages of an incident with interruption of MV-supply

As an example for a control centre process for the typical proceeding of MV-incidents with power interruption is depicted in Figure 3. Based on the concept of the grid operation model, incidents are characterized by the place and time of occurrence ($t_0$), the affected power ($P_1$) and the duration of the restoration process on-site, complemented with the process durations of the control centre. In particular the processing of the re-supply process in the four process stages grid message processing, analysis, re-supply by switching and re-supply by repair are represented in detail.

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

- Grid message clearance
- HV-/MV-/LV-incidents with or without supply interruption
- Operations without grid incident
- Switching actions for maintenance work in HV-/MV-grids
- Switching planning and other administrative tasks

Input data for all kind of processes and process stages can be estimated based on extensive analyses of historical data.

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 of 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 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.

## CASE STUDY

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.

### Grid data and organisation schemes

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

| scenario set | number of incidents | | | Planned working tasks |
|---|---|---|---|---|
| | other | MV | LV | |
| Normal (7 days) | 32 | 38 | 116 | 157 |

**Table 1:** Scenario set of the exemplary week

The parameters of the organisation schemes of the control centre are given in Table 2. Five organisation schemes with different numbers of control stations are analysed. In all schemes the grid areas of responsibility for the control stations are overlapping.

| organisation scheme | number of control stations | | |
|---|---|---|---|
| | morning | afternoon | night/ weekend |
| O1 | 3 | 3 | 2 |
| O2 | 2 | 2 | 2 |
| O3 | 1 | 1 | 1 |
| O4 | 2 | 1 | 1 |
| O5 | 2 | 2 | 1 |

**Table 2:** Organisation schemes

### Results

As a first example Figure 4 shows the empirical distribution function of the delay time of incidents for all incidents for organisation schemes O1 to O3. With organisation scheme 1 (O1) 90% of all incidents have a delay time of at most 9 minutes in processing by the control stations. The total delay time due to the unavailability of the resources on site is 53 minutes for 90% of the incidents. With a reduced number of available control stations (O2 – O3) the delay time in 90% of the incidents rises. Organisation 2 (O2) results in a delay time of 21 minutes and organisation 3 (O3) results in a delay time of 107 minutes for 90% of the incidents.

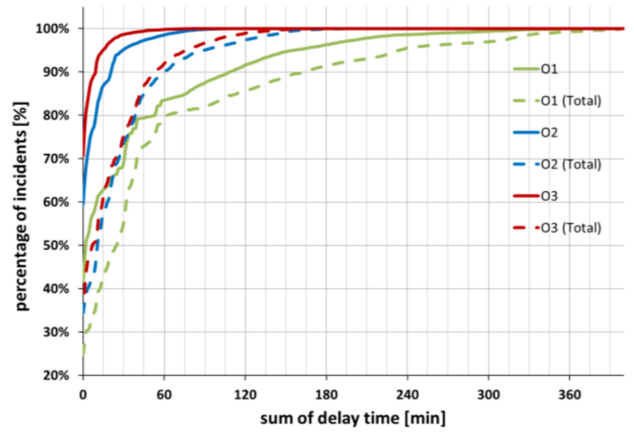


**Figure 4:** Empirical distribution function of the total delay time of incidents and the partial contribution of the control centres for organisation schemes O1 to O3

The results indicate a significant influence of the number of available control stations at day and at night on the delay time. Due to the moments of simultaneous interruptions, incidents of lower priority have to wait in the queue for being served. The resulting delay time increase with reduced number of control stations. In comparison to O1 the influence of the control centre organisation on the total delay time in O3 is larger. The bottleneck in O3 is the single control station with the largest share in the total delay time, while in O1 and O2 the unavailability of resources on site has the largest share in the total delay time.

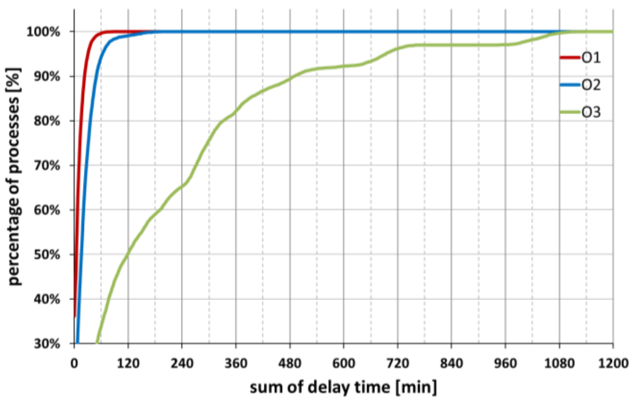


**Figure 5:** Empirical distribution function of the delay time of planned work for organisation schemes O1 to O3

The empirical distribution function of the expected delay time of planned working switches for the calculated organisation schemes is shown in Figure 5. Organisation scheme O1 results in a delay time of 22 minutes with the probability of 90 % and organisation schemes O2 results in a delay time of 48 minutes with the same probability. Organisation O3 leads to excessive delays of 484 minutes in 90% of the cases.

In contrast to incidents the delay time of planned working switches is longer than for incidents and the influence of the number of available control stations on the delay time is significantly larger. 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 delay times of planned switching tasks in the queue.

Beside the number of available control centres the delay time of planned working switches is influenced by the number of simultaneous tasks during the day. Figure 6 shows for one exemplary day the workload of the control stations and the queue length of the queuing system for organisation scheme 2 (O2). In **scenario 1** all planned working tasks start in the period between 7:00-9:00 h (this means one task every 5.5 minutes). In **scenario 2** the tasks starts in two separated time slots (7:00-8:40 h, 9:40-10:40 h) and in **scenario 3** the tasks starts in 12 time slots every 30 minutes between 6:30-12:30 h.

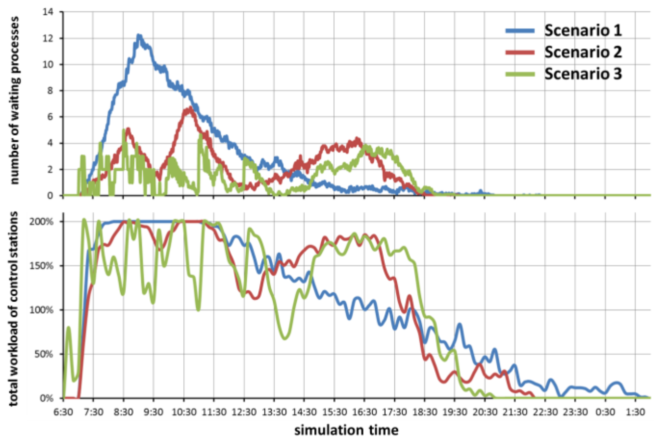


**Figure 6:** Workload and waiting time optimisation with time slot management for organisation 2 (O2)

The results for scenario 1 show in Figure 6 that the workload grows rapidly with the beginning of the planned tasks and the two control stations are not able to process the incoming tasks fast enough. This leads to a rapidly growing queue length and till 12:00 h many processes have to wait to be served by the control centre. Due to the large delay during the morning the last processes finished at night at 1:30 h.

With the implementation of time slot management methods in scenario 2 and 3 the control station utilisation can be optimized and the extremely large delays in scenario 1 can be avoided. In comparison to scenario 1 the moments of a high utilisation of the control stations can be reduced and the number of waiting processes in the queues is significantly lower. In scenario 3 only 5 processes need to wait during the processing for a short period of time in the queue for the control centre and the last tasks finished with a relatively short delay at 20:30 h.

Figure 7 shows the correlation between the daily workload for switching actions and the resulting average waiting time for planned switching tasks. The results are based on different simulations of 61 operating scenarios of planned working switches without incidents. For organisation scheme 3 (O3) a total workload for planned switching processes of 360 minutes/day results in an average delay time of 32 minutes/process (1) and a daily workload is up to 720 minutes/day the average delay time is 155 minutes/process (2).

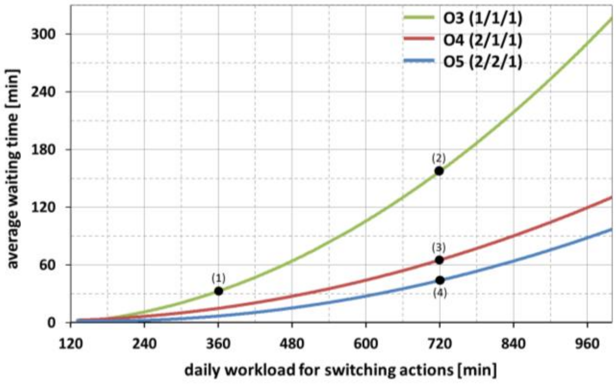


**Figure 7:** Expected average waiting time depending on the daily workload for switching actions for organisation schemes O3 to O5

This shows a significant and disproportionate influence of the daily total workload on the resulting expected average waiting time, since a higher daily workload increases the probability of simultaneous processes increases too. With the support of a second additional control station during the morning shift (O4) the average delay time can be reduced to 65 minutes/process (3). If there is a second control station during the afternoon shift (O5) the average delay time can be reduced to 43 minutes/process (4).

## CONCLUSION

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.

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