MULTI UTILITY GRID OPERATION: AN ORGANISATION STUDY

Markus ZDRALLEK
University of Wuppertal – Germany
zdrallek@uni-wuppertal.de

Marcus STÖTZEL
University of Wuppertal – Germany
marcus.stoetzel@uni-wuppertal.de

Volker STAUFERT
RheinEnergie AG – Germany
v.staufert@rheinenergie.de

Michael ANGENEND
Rheinische NETZGesellschaft mbH – Germany
m.angenend@rng.de

ABSTRACT

As a consequence of today's regulation of grid fees and the regulation requirements grid operators have to analyse the essential business processes with the most influence on the quality of supply. The goal is to find the optimal balance between fulfilment of the quality standards given by the regulators on the one hand and the corresponding costs to satisfy them on the other hand. The most important business process concerning the quality of supply is the outage clearance and restoration process on which the optimisation efforts focus more and more. A developed multi utility grid operation model allows to optimise an integrated organisation structure for all kind of grids.

INTRODUCTION

On former conferences a grid operation model for electrical power grids was presented [1, 2]. In the meantime this model was basically re-engineered and extended for multi utility grid simulations. The new model is now able to simulate grid operation processes in Medium-/Low-Voltage-grids (MV/LV-grids) as well as in Gas- and Water-grids. Furthermore it is possible to analyse dependencies between the operation processes of the different grids and even to simulate an integrated organisation structure for all kind of grids.

This new "multi utility grid operation model" is used in a case study of a large urban grid operator in Germany who operates electricity, Gas and Water-grids. In the case study the outage clearance and re-supply process for the different grids is simulated and optimised. Therefore different organisation options are calculated and compared with respect to the resulting quality indices. The requirements of the different grids for the operation staff organisation are quite different. While for the optimisation of MV/LV-grids the common and well established reliability indices like customer minutes lost are used to compare organisation schemes, an equivalent for Gas- and Water-grids is missing. However in these grids the assured arrival time on site in case of incident information by the customer in a specific, given time is extremely important. For example in Germany for gas leakage information an arrival time of 30 minutes for grid operating staff on-site has to be assured in any case. Therefore the requirements of the different grid processes have to be balanced in the integrated operation management organisation. The new "multi utility grid operation model" allows to quantify all the corresponding effects.

MULTI UTILITY GRID OPERATION MODEL

The idea of the model is to simulate the operational processes after incidents. A schematic view of the modelling approach is given in Figure 1. The model is mainly driven by the demand for grid operating staff (called resources in the following) on the one hand and the available resources on the other hand. The demand for resources is determined by a set of incidents, and the availability of resources is given by the organisation structure. After the assignment of the resources to the incidents the indices for the quality of supply and accessibility of the supplied area are calculated. In the following, the components of the model will be described in more detail.

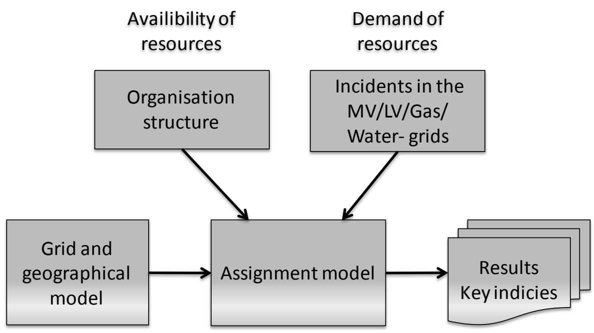

Figure 1: Schematic view of the multi utility grid operation model

Grid and geographical model

The supplied area, the electrical power, gas and water grids are modelled by a sufficiently large number of nodes. Each node is aggregating all the grid equipment of its corresponding geographical area. With this representation all grid operation tasks 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 travelling of the resources is restricted to the graph defined by the pre-mentioned nodes and edges. Figure 2 depicts the graph (node and edges) of an exemplary supply area.

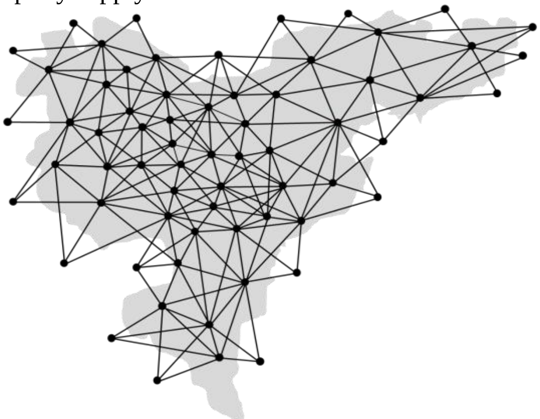

Figure 2: Graph of an exemplary supply area

Modelling of incidents in MV/LV-grids

Based on very detailed models for the re-supply processes and the associated tasks, the interruption of supply and the clearance process is described in this model by a generic profile. This profile is characterised by the place and time of occurrence, the interrupted power and the duration of the restoration process. As an example the proceeding for MV-incidents with power interruption is shown in Figure 3.

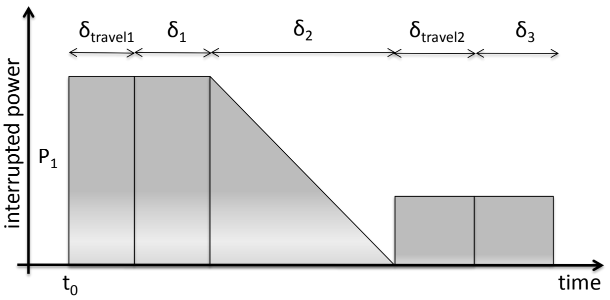

Figure 3: Profile of an incident with interruption of MV-supply

In the interruption profile, the time of occurrence is denoted by t_0 and the initially interrupted power by P_1. As soon as possible, an on-site resource is activated and sent to the place of the interruption (duration $\delta_{travel1}$). If no resource is directly available, the travel time includes in this case the delay time too. After arrival on site the incident has to be analyzed first and no power can be restored (duration δ_1). Due to the meshed construction of MV-grids, customers can usually be re-supplied by switching actions (duration δ_2). To simplify the computations, the decreasing outage power is approximated by a linear function. 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 and travel to the place of incident (duration $\delta_{travel2}$), too. After repairing the components (duration δ_3) the last customers can be re-supplied and the incident is cleared.

Modelling of incidents in Gas-/Water-grids

Whereas electrical energy interruptions of supply can be characterized by the interrupted power, the incidents in Gas- and Water-grids need to be specified by a pre-given importance. Therefore different importance-classes are defined in the model. With this importance classes it's possible to prioritize the different types of incidents, e.g. gas leakage, fire, supply interruption or metering failures.

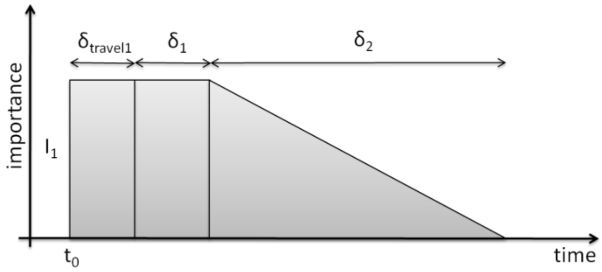

Figure 4: Profile of an incident in Gas-/Water-grids

According to the same principle as the description of the incident in MV/LV-grids, the incident clearance in Gas- and Water-grids is described by a generic profile (shown in Figure 4). The profile is characterized by the place and time of occurrence, the importance class and the duration of the incidents clearance process. Due to the characteristics of Gas- and Water-grids in most cases of incidents the supply is still ensured. Most important are these incident, where the clearance needs to prevent an immediate danger by cases of e.g. fire, gas or water leakage. In these cases the fastest arrival on site is extremely important and an available resource is sent immediately on site. The first task after arrival is to analyse the situation on site and initiate security measures if necessary (duration δ_1). After finishing this process stage the incident is cleared by repairing the failed components. Depending on the type of incident, sometimes the restoration time to clear the incident lasts for a long time and special resources are required additionally. During the repair process the importance of the incident decreases for long lasting repair work. To simplify the computations, the decreasing importance is approximated by a linear function too.

By analysing historical data, the failure rates of different types of incidents and the probability distributions of the necessary input parameters (interrupted power, importance classes and durations of the different process stages) of the model have been estimated. The types of incidents are differentiated by section (e.g. electrical power, gas and water), voltage level, type of component, grid design and state. The travel times and possible delay times depending on the availability of resources are calculated within the model by Monte Carlo simulation.

Assignment model

At the moment a new incident occurs, the currently available resources are assigned again to all actual incidents regarding their priority. Due to the direct influence on the quality of supply, incidents with interruptions of supply in MV/LV-grids are generally prioritized by the interrupted power. For incidents in Gas- and Water-grids the incidents are prioritized by the importance classes. In cases from an integrated operation management organization it's necessary to compare simultaneous incidents in MV/LV- grids and Gas-/Water-grids with reference to their priority. To capture this relation and to compare incidents in the different grids, a comparison factor $f_{classes}$ has to be specified for each importance class, so that the incidents with electrical power interruption are considered equally as the important classes in Gas-/Water-grids. Since emergency incidents always have the highest priority, for this class the comparison factor is $f_{emergency} \rightarrow 0$.

For an incident j is defined the power equivalent $\tilde{P}_j(t)$

$$\tilde{P}_j(t) := \begin{cases} P_j(t) & \text{for electrical grids} \\ \dfrac{I_j(t)}{f_{classes}} & \text{for Gas- or Water-grids} \end{cases} \qquad (1)$$

$P_j(t)$ denotes the (remaining) interrupted power of incidents j with power interruption at time t and $I_j(t)$ the (remaining) importance of incident j in Gas- and Water-grids. The power equivalent $\tilde{P}_j(t)$ allows now to prioritize incidents in the different types of grids according to their impotency.

The efficiency w_{ij} of assigning resource i to incident j is defined as

$$w_{ij} := \frac{\tilde{P}_j(t)}{d_{ij} + \delta_j(t)} \qquad (2)$$

where d_{ij} denotes the travel time of resource i to incident j. For incidents in MV/LV-grids $\delta_j(t)$ is the remaining duration of the incident. For normal incidents in Gas-/ Water-grids $\delta_j(t)$ is either the remaining duration of the incident. Only for incidents in Gas-/Water-grids with a extremely high emergency (e.g. gas leakages) $\delta_j(t) = 0$, in order to ensure that in every case the incident is directly assigned to the closest available resource.

The value w_{ij} can be interpreted as marginal restoration efficiency as it indicates the amount of power equivalent which can be restored per time unit. The efficiencies w_{ij} are used to decide the priorities of the incidents to be processed in a case of a shortage of resources as well as to select the nearest resources in case of a surplus of resources.

The assignment of resources to incidents is calculated by maximizing the total marginal restoration efficiency. Details are published in [3]. So incidents with a higher power equivalent are generally prioritized and so in cases of a shortage of resources, the incidents with the least efficiencies will not be assigned and will be delayed. According to the assignment decision, the resources travel to their assigned incident start with the restoration process.

CASE STUDY

In this section we show exemplary results of a case study with the model for different organisation options of a large multi utility grid operating company. The aim is to illustrate how the relation between different configurations of resources and the desired key indices can be analyzed qualitatively and quantitatively.

The grid operating company supervises an area with the size of approximate 750 km² and about 1.3 million inhabitants. In the model, this area is represented by 64 nodes, each covering a zone with a diameter of approximately 4 km. The nodes are connected by 270 edges with an average travel time of 16 minutes (compare Figure 2).

In this case study one typical scenario of incidents is simulated based on historical data. Table 1 shows the key data of the scenario

utility division	number of incidents		
	other	MV	LV
electricity grids	388	136	1000
	gas	water	high emergency
pipeline grids	3303	805	357

Table 1: Scenario set of incidents

In the MV/LV-grid the scenario corresponds to a typical set of incidents (with or without interruptions of supply) during one year and has a rate of 1 incident per 5,7 hours. Not every incident leads to an interruption of supply, since ground-to-earth faults without interruptions are included. The scenario of the Gas- and Water-grid has a rate of together 1 incident per 2,0 hours. Also in this scenario not every incident means a interruption in the supply of gas or water. Many causes of failure (e.g. pleasure problems, gas or water leakages, metering failures) don't affect the supply with gas or water and are included in the simulated scenario.

For the MV/LV-grid five different organization schemes of resources are considered, each with a varied number of resources during periods of normal work (n_r) and stand-by service (n_s). For Gas- and Water-grids three different organisation options are compared. The key parameters of the organization schemes are given in Table 2.

organisation schemes	MV/LV-grid		Gas-/Water-grid	
	n_r	n_s	n_r	n_s
O1	1	1	1	1
O2	0,7	0,7	0,7	1
O3	0,5	0,7	0,7	0,5
O4	0,3	0,3		
O5	0,2	0,7		

Table 2: Organisation schemes with the number of resources given as a ratio to the current number of resources

As small example of a large case study the following two different key figures are presented.

Non-availability of supply

The non-availability of supply for MV/LV-grids is measured by the well-known system average interruption duration index (SAIDI). Figure 5 shows the total SAIDI (MV+LV) for the different organisation schemes O1 to O5) related to the current level.

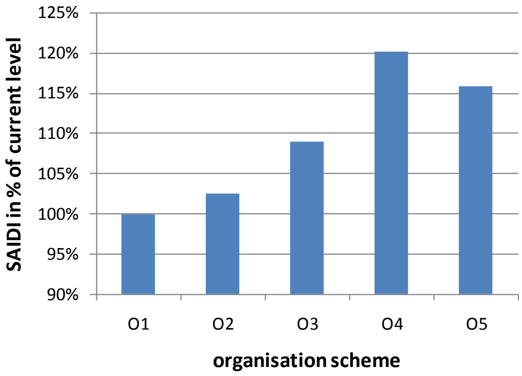

Figure 5: Total SAIDI (MV+LV) for organisation schemes O1 to O5

All five organisation schemes influence the resulting non-availability of supply. It can be concluded, that the number of resources during normal working time and stand-by service leads to this effect. In cases of simultaneous incidents and less available resources than incidents, interruptions with lower priority have to wait until resources become available. Due to the small number of simultaneous interruptions and the prioritization of MV-interruptions, reducing resources (O2 - O5) does not affect the SAIDI very much as seen in Figure 5.For example even a heavy reduction of the number of resources down to 30% (O4) causes only 20% increase of the SAIDI.

Duration until arrival on site

The duration until arrival on site is defined as the time between occurrence on the incident and the first time a resource arrives on site. The duration until arrival on site is an important performance measure especially for the Gas- and Water-grids.

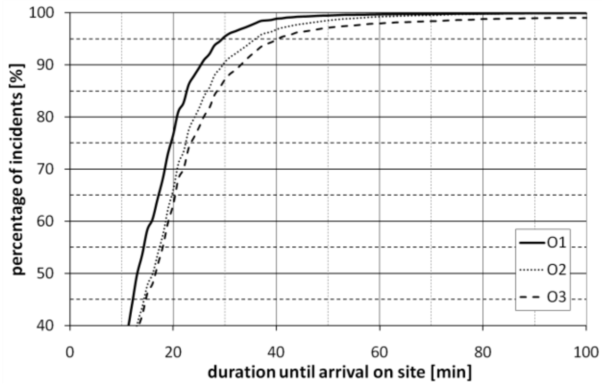

Figure 6: Empirical distribution function of the duration until arrival on site for organisation schemes O1 to O3

Figure 6 shows a part of the empirical distribution function of the duration until arrival on site for all incidents in the Gas- and Water-grid. Whereas with organisation O1, 95% of all incidents are reached on site in 30 minutes, O2 leads to an arrival-duration of 36 minutes and O3 to an arrival-duration of more than 40 minutes. The results show a significant influence of the number of resources during normal work time and stand-by service. Because of the shortage of available resources more incidents are delayed and the duration until arrival on site is worse. This relates only the incidents with less importance. Incidents with a high importance are assigned first and reached in the pre-given time.

CONCLUSIONS

With regard to today's regulation requirements grid operators need to optimise particularly the relation between organisation of resources and quality of supply. The extended multi utility grid operation model allows to quantify this relation for an integrated operation process of Electricity-, Gas- and Water-grids and therefore provides a useful tool to support strategic decisions of multi utility grid operators.

REFERENCES

[1] C. Friedrich, M. Guarisco, M. Laumanns, M. Zdrallek, 2009, "A model to optimise the organisation of grid operation", Proceedings of the 20th International Conference on Electricity Distribution (CIRED 2009).

[2] C. Friedrich, M. Guarisco, S. Kueppers, A. Schweer, 2007, "Grid operation in the contrary regulation challenge of cost reduction an supply quality", Proceedings of the 19th International Conference on Electricity Distribution (CIRED 2007).

[3] M. Guarisco, C. Friedrich, M. Laumanns, M. Zdrallek, 2009, "A grid operation model: resource demand for an adequate quality of supply", Proceedings of the 16th Power Systems Computation Conference (PSCC).