SUMMARY
The liberalisation process of the electricity market leads to an increased cost pressure on power system operators. This will also have negative effects on the quality of supply. However, a high quality of supply is requested also in liberalised markets. In this context, the detailed knowledge of e.g. supply reliability in the power system is an important basis for different technical and economic decisions. Correspondingly, the importance of a comprehensive outage statistic and its efficient usage is growing.

This paper describes the new requirements of an Austrian distribution system operator, and the appropriate extension and implementation of the outage statistic and the related software tools in the company. Especially, the registration of outages in medium voltage systems considering individual stations affected by supply interruptions and failure affected equipment is described. Of course, the MV outage registration increases the effort for the statistic, but the overview of and the insight into the power system performance improve significantly.

INTRODUCTION

General

Since 1\textsuperscript{st} October 2001, the Austrian electricity market is fully liberalised [1]. Of course, the power supply networks still form a so-called natural monopoly, but customers and politics put an ever increasing cost pressure on network operators. The Austrian regulating authority, the Elektrizitäts-Control-GmbH [2], wants the network operators to decrease the costs, but to maintain the power quality on the current high level. As customers become more aware of issues relating to their power supply, they still request a high quality of supply, also – or even particularly – in the liberalised environment.

However, the measures taken to reduce capital as well as operating costs in the network in general will have negative effects on the quality of supply [3]. So, the delicate question to find the acceptable balance between cost efficiency on the one side and appropriate power quality on the other side is a major task for the network operators. This question becomes even more complicated, if the fact is considered that different customers usually have different requirements towards power quality. Moreover, in several liberalised electricity markets, the regulation implements direct economic consequences for the network operators depending on the system’s power quality performance, e.g. in the UK [4] or in Norway [5].

In this context, the detailed knowledge of e.g. supply reliability in the power system is an important basis for many different technical and economic decisions. Correspondingly, new requirements for outage statistics are emerging, and the importance of an efficient usage of outage statistics is growing [6, 7]. From the point of view of Vorarlberger Kraftwerke AG (VKW), a customer specific registration of supply interruptions, the registration of failure affected network components, and the ability to calculate the DISQUAL indices from the recorded data are the most important aspects relating to the outage statistic. As there is no systematic allocation of individual customers to nodes in the low voltage network, and as the MV distribution network has the predominant influence on the supply reliability of customers, the customer specific registration actually is achieved by the registration of the individual MV stations affected by supply interruptions.

DISQUAL indices

In order to define indices describing the availability of supply in a unique way and to be able to compare corresponding statistics, UNIPEDE formed a group of experts that elaborated an appropriate report [8]. These indices are known as the so-called DISQUAL indices. Three different indices are considered:

- Average frequency of supply interruptions per year and per customer,
- Average interruption duration per year and per customer (also designated as non-availability),
- Average interruption duration per customer supply interruption.

These indices can be calculated according to three different methods that are defined in the report, depending on the data available – using either the number of interrupted customers, the number of interrupted transformer stations or the rated power of interrupted transformer stations.
The DISQUAL indices are system indices of individual network operators and give average values of all supply interruptions for all customers of the system in the period under consideration. Indices for individual stations or indices of other network operators can be compared to these system indices, if it is ensured that identical definitions and identical methods for their calculation were used. As special circumstances relating to separate network operators, e.g. extraordinary geographical or climatic conditions, might have significant influence on the supply reliability and the availability indices, the report explicitly requires that the DISQUAL indices should always be accompanied by short key information on the system under consideration.

VDN statistic of incidents

The VDN statistic of incidents (VDN: Verband der Netzbetreiber e.V. beim VDEW – association of network operators in Germany) – formerly known as VDEW statistic of incidents (VDEW: Verband der Elektrizitätswirtschaft – association of electricity economy in Germany) – since many years provides a yearly summary and analysis of the outage performance of the German public power supply networks [9]. The recording of outage events in large parts of the German public networks over many years according to a well-defined scheme [10] has built a large database that serves as an important basis for several different statistical analyses. Since an extension of the recording scheme 1994, in networks with a nominal voltage of 110 kV and above also detailed data on the sequence of outages, including information on supply interruptions, is included. For MV networks, a corresponding extension is being prepared and will probably be introduced in 2004. Also here, the ability to derive the DISQUAL indices for distribution networks will be a main part of the next revision of the recording scheme.

REGISTRATION OF OUTAGES IN A DISTRIBUTION NETWORK

Software tool INTERASS

The systematic registration, maintenance and analysis of outage data requires appropriate software tools. In order to be able to derive trustworthy results from the recorded events, data should be recorded over several years in a coherent scheme. Thus, even for small network operators, the usage of IT tools is a prerequisite for efficient handling. The software tool INTERASS, which is used by many network operators, especially in the distribution level, was developed for this purpose. It relates closely to the registration scheme defined in the German VDN statistic of incidents. One important feature is that each data set is checked for conformity and plausibility according to the registration scheme.

Apart from tables with the data for the occurrence and the sequence of outage events, which are part of the standard analysis and report of the VDN statistic of incidents, individual component specific analyses are also implemented. A component database is integrated to supply the required equipment information. The specific analyses include detailed data on the failure performance of individual components, or the determination of component reliability indices which are the basis for probabilistic reliability analyses of the system. These examples demonstrate that in total there are significantly more application possibilities than compiling the standard VDN statistic of incidents report. Further, as INTERASS is based on the standard office tool MS Access, it is comparatively easy to implement individual analyses, or to extend the scope of data to be recorded according to the individual requirements of different network operators.

Extension for station specific registration of supply interruptions

The existing scope of recorded outage data at VKW met the changing requirements in the liberalised market only partially. Especially, a detailed determination of the supply reliability of individual customers should be realised, as well as the detailed description of the sequence of outage events in order to be able to derive component reliability data for probabilistic reliability calculations [11]. Of course, the recording and processing of the required data must be supported by efficient software tools, so that flexible analyses e.g. for individual MV stations over a chosen time period can be performed easily.

In order to meet these new requirements, the software tool INTERASS already used at VKW was extended according to the specific needs. The main topics addressed are:

- The data describing the sequence of MV outage events is extended to include the end of the outage event, which is an important input for probabilistic reliability analyses.
- Also, an automatic allocation of individual network components to the separate outage events is implemented, which allows a regional and component specific analysis of outages. Thus, the failure performance of the system can be checked for geographical and component related peaks. This information is important for the prioritisation of maintenance and re-investments.
- Using data from the network information system, supply interruptions are recorded with a list of all affected stations. The interrupted power is also included, so that together with the duration of the interruption, also the energy not supplied can be determined. Thus, all DISQUAL indices can be calculated.
With these extensions, the course of outage events and supply interruptions can be recorded in detail. Figure 1 shows an example network, for which a line outage with the sequence given in Table 1 is supposed. With the new schema, it is possible to reconstruct the complete sequence of individual outage events, as given in Figure 1 and Table 1, using the recorded data and general information on the network.

**APPLICATIONS OF THE EXTENDED OUTAGE STATISTIC**

**General analysis of the outage statistic**

At VKW, all outages since 1989 are recorded, each with a list of the individual stations affected by supply interruptions, as the case may be, in the INTERASS database. One main purpose of the database is the yearly analysis summarised in the yearly outage report of VKW. This report can be compared with the yearly VDN- or VEÖ-reports (VEÖ: Verband der Elektrizitätsunternehmen Österreichs – association of Austrian electricity companies).

Additionally, the database can be analysed for any other aspect that might be of interest for the network operator. As the following list of further applications will demonstrate, it can be used to derive valuable information for both technical and economical decisions. Together with geographical data, it is e.g. possible to compile a comprehensive regional overview of supply reliability. Figure 3 presents the mean non-availability of the MV stations in a part of VKW’s system.

Apart from calculating indices for individual stations, of course also the system-specific DISQUAL indices can be determined. Figure 2 shows the yearly non-availability for the years 1990 to 1999, as well as the average value in this 10-year-period. The influence of the storms Daria (1990) and Lothar (1999) on the supply reliability in this area can be clearly recognised. Because of the significant differences between the yearly values, which are caused mainly by influences beyond the responsibility of the network operator, such as severe weather, only indices calculated over a longer period can be used as a basis for responding to customer calls.

**TABLE 1 – Sequence of a line outage event in the example network**

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:00 h</td>
<td>Short circuit on line STAT B – STAT C</td>
<td>Circuit breaker tripping</td>
</tr>
<tr>
<td></td>
<td>Supply interruption at STAT A, STAT B, and</td>
<td>Supply interruption at STAT C</td>
</tr>
<tr>
<td>11:00 h</td>
<td>Disconnection of failure</td>
<td>Re-supply of STAT A and STAT B</td>
</tr>
<tr>
<td></td>
<td>affected line section</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reconnection of circuit breaker</td>
<td></td>
</tr>
<tr>
<td>11:00 h</td>
<td>Begin of repair works</td>
<td></td>
</tr>
<tr>
<td>12:00 h</td>
<td>Begin of emergency generator set operation at STAT C</td>
<td>Re-supply of STAT C</td>
</tr>
<tr>
<td>17:00 h</td>
<td>Line STAT B – STAT C ready</td>
<td>End of down-state</td>
</tr>
<tr>
<td>19:00 h</td>
<td>Reconnection of line STAT B – STAT C</td>
<td>End of outage duration of line STAT B – STAT C</td>
</tr>
<tr>
<td></td>
<td>Shutdown of emergency generator set</td>
<td>End of outage event</td>
</tr>
</tbody>
</table>

**Outage data registration process**

Figure 2 presents the outage registration process as it is implemented at VKW. All data is stored in the central database, which is accessible via the company network. Outage data is recorded in a decentralised way, where after an outage has occurred the responsible operation centre or the main control centre, respectively, enter the basic data relating to the actual event.

The communication between the different units involved in the outage data registration process is done via email. After a new outage event is recorded, a short preliminary outage report is generated automatically and distributed via email to predefined recipients. This report includes information on the extent of the outage, outage location and cause of outage, and it is e.g. used as a basis for responding to customer calls. The information of all relevant business units – already using this preliminary data immediately after an outage occurrence – and the strict integration into the business processes is an important aspect for the achievement of additional benefits from the extended outage statistic.
time period really give a trustworthy description of the supply reliability in a system.

**Network planning / maintenance planning.** The advantages and disadvantages of different network structures can be quantified in their supply reliability performance. The effectiveness of special measures, like e.g. bird-protection of overhead lines, or building in-house transformer stations instead of outdoor installations, can be determined. Large industrial customers can be connected to the most reliable network feeder in case of new connections or re-construction of network areas, thus improving their power quality. Also, the knowledge of weak points in the network can be used as an additional input to the maintenance planning.

**Replacement of protection devices.** Analysis of the past outage performance can be used to determine the effectiveness of protection devices. At VKW, several protection devices reaching the end of their expected lifetime were not replaced by new devices, if this analysis together with a consideration of the network topology proved that this device was neither indispensable for the selective protection of the network, and that it had rarely operated in the past. Also requests for additional protection devices can be determined in an objective way.

**Regulatory issues.** As price and quality of supply are the most important aspects addressed by regulators, it is crucial for network operators to have detailed data available in both fields. It is obvious that a comprehensive outage statistic, allowing a complete description of the system’s power quality performance, is of great help in discussions with the regulator. Especially, it is a sound basis for the factual and realistic discussion of power quality standards and appropriate tariffs. This is of peculiar importance in the field of supply reliability, as there exist no defined national or international technical standards which could be used for defining or even measuring supply reliability. Also for the assessment of economic effects of power quality, an outage statistic is required.

Besides, also the Austrian regulator E-Control is collecting data on the power quality performance of the network operators. The corresponding law is the so-called “Statistikverordnung” [12], which became effective on 1st January 2002 after only very short discussions. The scope of the data to be delivered significantly increased to what was common practice before this statute. For VKW, its long experience with their outage statistic proved to be a great advantage, as most of the required data is easily available.

**EXAMPLE FOR INVESTMENT PRIORITISATION**

The extended usage of a comprehensive outage statistic is demonstrated in this example from VKW about the prioritisation of investments. Two operation centres requested the replacement of certain critical overhead line sections by cables in their distribution network. In both cases, villages in the mountains with three MV stations in village A and two
MV stations in village B are fed via a long single overhead line without any alternative network feeders.

Both villages claimed that during storms or in winter with heavy snow on trees nearby the overhead lines, their supply reliability was impaired by “frequent” outages. However, neither village could provide a detailed record of the historical supply reliability. Because the investments for any of these two projects was quite significant, a closer investigation was performed. All outages with supply interruptions in the last 10 years were analysed for both villages. The significant influence of atmospheric effects on the supply reliability was confirmed in both cases, as well as the importance of the overhead lines under consideration. Table 2 lists the relevant events for village B as an example.

In Figure 5, the frequency of supply interruptions is shown for both villages. The yearly VKW DISQUAL indices are also included for comparison, as well as the corresponding 10 year average value.

It can be seen that both villages indeed suffer supply interruptions significantly more frequently than on average in the VKW network. So, the request for investments aiming to improve the supply reliability are justified.

In the comparison of the frequency of supply interruptions, village A has mostly higher values than village B. However, the frequency of supply interruptions does not consider the extent of supply interruptions. Second, the non-availability is analysed for both villages. Also, all stations in the VKW network are sorted by their non-availability and ranked into four groups – the average value for each quarter of all VKW stations is also presented in the following Figure 6 for comparison.

FIGURE 5 — Frequency of supply interruptions in the two villages A and B in the years 1990 – 1999 and corresponding VKW DISQUAL indices

This figure again shows that both villages indeed face a supply reliability significantly worse than the average, and well in the field of the worst quarter of all VKW stations. But with the non-availability, the values for village B are much higher because the repairs for the feeding overhead line take more time than with village A. So, the overhead line feeding village B was the first to be replaced by a cable because of the magnitude of the supply interruptions, despite the fact that village A is affected by supply interruptions more often.

CONCLUSION

Contrary to the widespread trend to reduce the effort for the registration of outages in electric power systems, VKW has decided to extend its outage recording scheme and to use information derived from the collected data in many different applications. The recording of outages and supply interruptions in the new extended schema requires more effort, but it also provides a higher benefit for the network operator. The ability to perform both customer specific and component specific analyses greatly increases the insight into the performance of the system and provides valuable information to support decisions in a liberalised market. Additionally, as the extended scheme is still compatible with the standard scheme of the VDN statistic of incidents, a comparison with the average performance described in the public statistics of VDN or VEÖ is available. In general, the information provided by the extended outage statistic is of vital importance to achieve an economic network structure that will still provide an appropriate power quality.

FIGURE 6 – Frequency of supply interruptions in the two villages A and B in the years 1990 – 1999 and corresponding VKW DISQUAL indices

The VKW outage statistic is based on the recording scheme of the VDN statistic of incidents. The extensions to meet VKW’s additional requirements in the liberalised market include the recording of the failure affected components and of all individual stations affected by supply interruptions for...
each outage event. Also, the process of recording outage data as well as the way how information on outages is distributed and used within the company was reorganised. The new statistic serves VKW as:

- an powerful information tool for answering customer requests, e.g. offering customers the possibility to get a detailed list of supply interruptions affecting their feeding MV station in the last 10 years,
- a database for the determination of the supply reliability of the network, of separate customer groups, and of individual customers,
- a supporting tool for the evaluation and prioritisation of investments,
- the basis for many further analyses that can be used for several other purposes, e.g. the determination of component reliability data for probabilistic reliability calculations, for assessing the effectiveness of protection devices etc.

The recent decision of the Austrian regulator – already demanding the submission of indices for the supply reliability performance – to focus on the energy not supplied as the main reliability index confirms VKW’s decision to maintain a detailed outage statistic and to develop its efficient application in network planning.

From its experience up to now, VKW is convinced that the additional effort for the extended outage statistic pays off. With the database growing over the years, it is even expected that in future more new application possibilities will be developed, and that the outage statistic will continue to evolve into an strategic source of information.

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