SERVING POWER QUALITY NEEDS – OPERATIONAL OPTIMIZATION AND CUSTOMER ORIENTATION IN INDUSTRIAL DISTRIBUTION NETWORKS

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ABSTRACT

From the point of view of an industrial network operator serving power quality needs means to find a balance between an adequate reliability of supply and an economically justifiable cost structure of the service. In this paper typical supply structures at chemical sites are presented and analysed concerning relevant power quality aspects.

INTRODUCTION

Adequate power quality in the definition of reliability of supply and voltage quality is a crucial location factor for a chemical site. On the one hand complex production processes have highest demands on reliability of electricity supply because of process economy and security for environment and human beings. On the other hand total necessity of global competitiveness of a chemical site forces economically justifiable solutions of supply. Maximum fulfilment in both challenges is unsolvable.

In the role of an industrial network operator it is necessary to find a compromise between these two aspects: quality and economy. Focused on the demands of the customers the network has to be developed and operated. The challenge is to find the optimal solution for multiple customers in one network: perfect power quality tailored for one customer could be too expensive for his neighbour! Furthermore electrical network structures are historically grown and have long live cycles, development of chemical production structure in the global competition is very fast. Therefore electrical network solutions have to be very flexible concerning changing of customer structure.

In the following some decision guidance in engineering and operation optimization questions in the context of power quality is discussed.

INDUSTRIAL NETWORK OF BAYER INDUSTRY SERVICE

Bayer Industry Services GmbH & Co. OHG (BIS) is the infrastructure company at the three German Bayer chemical sites Leverkusen, Krefeld-Uerdingen and Dormagen. In this function BIS is power plant and network operator at these sites.

The electrical feeding of the sites is realized with redundant connection to the European transmission grid 220 kV and alternatively to the local 110 kV distribution grid. Transporting the electricity to the load centres via meshed operated 25/30 kV networks it is transformed to the subordinated 5/6/10 kV networks and finally to the end distribution level at 0.5/0.4 kV direct at the process (Figure 1).

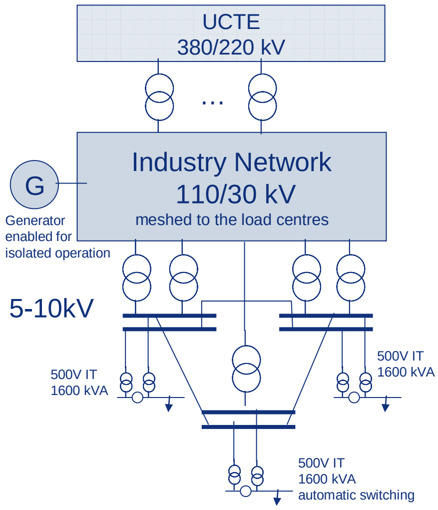

Figure 1: Typical network structure at a chemical site

Special customer demands call for special supply solutions. A strong backbone of the electrical network is an absolute must to be able to serve high reliability for each load point. Therefore redundant network structures down to the process are essential. The possibility of isolated operation of the network (site co-generation) completes the supply solution. High load density and meshed network structures bring problems with short-circuit strength for equipment. Favourable for reliability of supply meshed networks on the other hand increase the electrical interaction of costumers in questions of voltage quality (dips, harmonics).

Redundant supply lines down to the process (open-circuit control) are typical for a chemical site. Disturbances in the network like short-circuits can often be switched of without interruption of supply, but the consequences of voltage dips could influence a vast part of the network.

Specially designed for premium reliability demands separate reserve networks are operated autonomously from the normal supply, but are permanently live. In network parts without reserve feeding stand-by generating sets are used for special reliability demands. Sensitive loads like control systems are protected by UPS in times of short term voltage drops.

APPLIED DETERMINATION METHODS

Reliability of Supply

Reliability of supply is significantly determined by occurrence and impact of planned and unplanned interruptions as well as characteristics of the restoration processes. The adequate description and evaluation requires a determination of probabilistic reliability indices. The indices used in this study are internationally approved and commonly used [1,2]:

- Customer Interruption Index (CI-index): Indication of how many times in a year energy is not supplied to a customer (also referred to SAIFI)
- Customer Minutes Lost Index (CML-index): Cumulative yearly duration of interruptions per customer (also referred to SAIDI)

The analysis of reliability of supply for individual network customers needs probabilistic reliability analysis methods developed for the investigation of electrical distribution networks. Investigations made in this study are based on [3,4].

Significant information for the realization of reliability analysis comprises reliability parameters defined for each system component. These parameters can be derived from component-based reliability and availability statistics. Parameters used in this study are based on the so-called German "VDEW-Statistik" [5] and individual statistics for industrial distribution networks.

Voltage Dips

In general the sensitivity of devices concerning short-time voltage dips is given by edge of minimal residual voltage U_{Rest} subject to the duration of voltage dip (Figure 2) [6]. In addition the kind of device connection (1- or more-phase) and the type of electrical fault have influence.

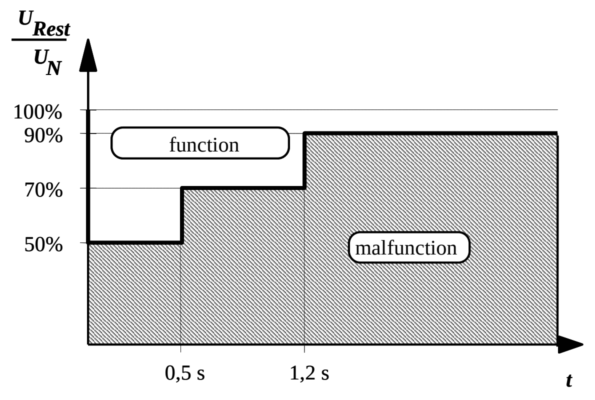

Figure 2: Exemplary model for the description of devices sensitivity regarding short-time voltage dips

Analysis of customer devices, which are supply by BIS, has shown that the adjustable-speed drives represent the most sensitive 3-phase devices. Figure 3 shows a typical tolerance curve for such a drive at symmetrical fault [7].

If the voltage on the driver-connection decreases due to lower voltage on the dc link entry, a reduction of the rotational speed is caused. As a result a voltage dip on only 80 % of nominal voltage U_N drops the rotation speed at about 6 %, when tripping duration of the protection equipment is 300 ms. The sensitivity as regards limits is dependent on the need for a constant rotational speed for industrial processes, which are supported by this drive.

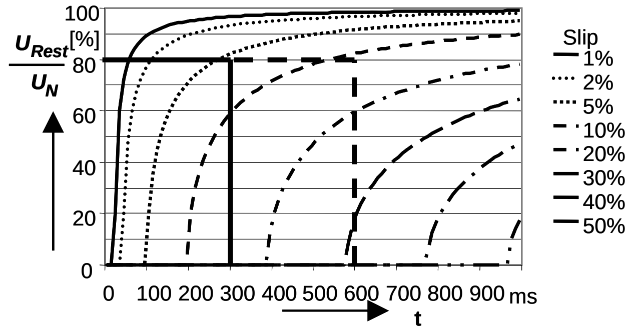

Figure 3: Tolerance curve for adjustable-speed drive

For the calculation of voltage dips the following methodology is applied:

- Starting point is the calculation of all possible short-circuits on cables, transformers and bus bars, which represents the largest part of all short-circuits in the networks, as well as of the residual voltages at customer nodes. The fault frequency was adopted from [5].
- As the sensitivity range of the connected customer devices are not known in detail (s. Figure 3), the magnitude of voltage dip on the customer node is evaluated for different residual voltage values (90% and lower).
- The sum of the frequency of fault components, which has led to undershooting the residual voltage limit, will be called the frequency of critical voltage dips $H_{U,crit}$.
- If a short-circuit on a component leads to supply interruptions for a customer, this event will be not noted to $H_{U,crit}$, because it will be recorded in probabilistic reliability analysis.

RESULTS

Reliability of Supply

Status Quo

Reliability investigations made in this study reveal a significant impact of network structures and different operation strategies on reliability of supply. Figure 4 shows the resulting CI-index for a typical MV- and LV-customer – each supplied by the same MV-substation – within the distribution system at each of the locations anonymously named by A, B and C. The MV-customers have no access to a reserve network structure. For this reason, reliability indices determined for MV-customers represent reliability of supply only based on the standard network.

Figure 4 reveals the CI-index of system B being 90% higher compared to system A. The difference is in first place caused by a higher number of switchgear components especially within the MV-substations of system B that again can be traced back to other planning standards in the past and a differing supply task. Due to the same reasons the network structure of system C offers a lower redundancy. Especially within the MV-grid a couple of outages of system components cause short customer interruptions that have to be restored by switching measures.

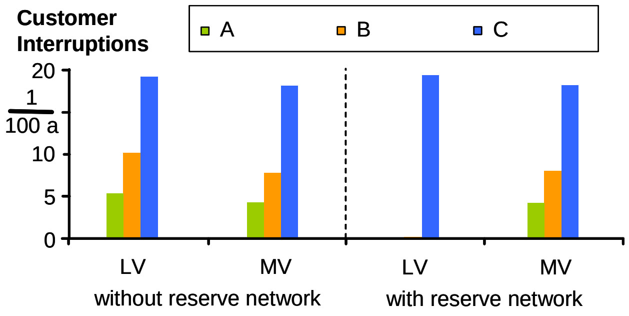

Figure 4: CI-index

For LV-customers without access to a reserve network the CI-index is based on the supplying MV-switchgear. As also outages of LV-components are responsible for an interruption of a LV-customer, their CI-index is 10% to 30% higher compared to the supplying MV-switchgear.

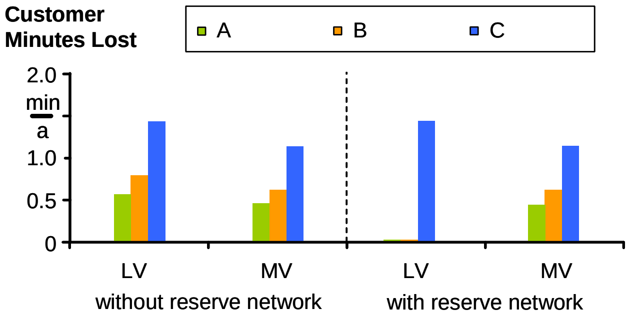

Figure 5: **C**ML-index

Figure 5 shows the CML-index based on the same investigation scenarios as mentioned before. Results concerning the CML-index reveal similar correlations as already discussed for the CI-index. A large number of switching devices provide a remote-controlled operation. Thus, a large number of customer interruptions can be restored by remote-controlled switching operations within a few minutes. Only few interruptions cause long restoration times of several hours or even days. For this reason, the average duration of a customer interruption is quite similar to the average switching time and only varying from 5 to 12 minutes depending on the considered network and customer. Obviously, the CML-index is much more affected by the CI-index than by the average restoration times.
The resulting reliability parameters are characteristic for industrial supply scenarios. Within a further investigation these parameters have been compared to characteristic reliability parameters for public distribution systems. An anonymous statistic evaluation based on a large number of public distribution networks in Germany (annually performed by VDN e.V. Berlin [6]) provides reliability of supply indices for MV-customers in those networks. The average CI-index is about 4 customer interruptions within 10 years, which is significantly higher than in the analyzed industrial networks. The same applies to the average CML-index of public distribution systems in Germany of about 20 minutes per year. This is in first place caused by different structures and equipment of industrial networks. They often reveal much more redundant network structures than public distribution systems. Furthermore, within industrial networks numerous switching devices are remote-controlled, whereas in public distribution systems, especially on medium and low voltage, only few devices have this technique. Reliability indices determined in this study are expected values and thus just a prediction of the system behaviour in future. The system behaviour in the past has been analyzed by a BIS-based evaluation of customer interruptions and availability during the last 11 years. Due to this evaluation a MV-customer suffers about 12 interruptions in 100 years and an average CML-index of about 2 minutes per year. These parameters correspond well to results from the reliability investigations made in this study.

Customer Specific Reliability

The industrial distribution systems A and B offer an additional and independent reserve network structure for immediate restoration of numerous LV-customers by automatic switching operations. The reliability analysis (Figures 4 and 5) shows almost no remaining outages for LV-customers paying for access to these redundant networks. In this case, only few and unlikely combinations of component outages lead to customer interruptions. The outage of one or even two system components does in most cases not cause a customer interruption.

Voltage Dips

The absolute level of critical voltage dips determined for a residual voltage of 90 % U_N, representing a very sensitive customer device, is between 0.32 1/a in location A and 1.19 1/a in B. However, lowering the sensitivity of the devices, these frequencies almost stay the same. Due to the small electrical distances in the network those faults, who occur in upstream system levels, often lead to either big voltage dips of the nominal voltage or marginal drastic dips. Compared to the frequency of supply interruption, the frequency of critical voltage dips can exceed by an order of magnitude. Table 1 shows the critical dip frequencies for close and open bus coupling at the 25/30-kV-stations of the networks. Of course all locations show an increase of the frequency of critical voltage dips in case of closed bus coupling due to the lower electrical distances at that switching mode. This effect is strongest in location C up to 50 % and least of all in B. The latter is on account of a higher meshed network on 25/30-kV-level in location B compared to C (see also explanation of figure 4).

Table 1: Frequency of critical dips $H_{U,crit}$ (MV customer)

location	bus coupling open	bus coupling close
A	0.32	0.45
B	1.09	1.19
C	0.51	1.05

Operational Optimization

The operation of the couplings in the substation at 25- or 30-kV-level has always been subject to investigations at BIS. Open couplings lead to lower frequency of critical voltage dips, while closed couplings, partly with use of reactors to reduce short circuit power, tend to result in lower frequency of supply interruptions.

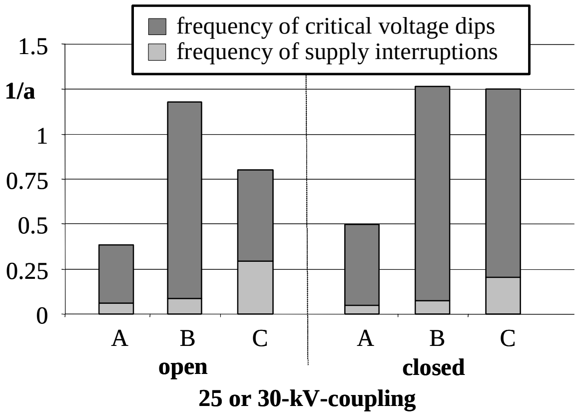

Figure 6: Total frequency of critical events for different switching mode of substation couplings (MV customer)

Figure 6 shows the total frequency of those events depending on the network operation. The influence on CML is quite proportional to CI, because in case of interruptions all switching possibilities in the network will be utilized. The results confirm today's normal switching mode (A: closed; B and C open). In network C a closed operation would cause a lot of additional voltage dips. This is the reason for the open coupling operation in agreement with the customers. In network B a closed operation would only slightly decrease the frequency of supply interruptions that already shows low values. Even if at site A the total frequency of critical events could be reduced by open coupling operation, the frequency of critical voltage dips remains quite low, while the negative impact on reliability of supply has to be attached more value, because all devices, not only those with high sensitivity as regards voltage dips, are affected.

SUMMARY

In this paper the results of the determination of power quality as regards the actually most discussed attributes reliability of supply and voltage dips of the industrial networks of BIS are presented. Due to the favourable supply task of high load and customer density at chemical industry sites a higher level of reliability of supply can be served compared to the average of public distribution networks. This is also achieved by more meshed network structures, especially on the cost-intensive MV and LV-level. Nevertheless, this can be achieved at competitive conditions.

Moreover, specific customer needs for even higher reliability of supply can be met by additional reserve networks parallel to the "normal" network, because distances are quite short and the demand for that kind of service is high for chemical industry due to safety and economical reasons. Of course dimensioning of that network is smaller that the total peak power demand. From the network operators point of view this is a suitable solution to cope with the conflict between long lifetimes and investment costs of network components on the one hand and the high dynamic of customer characteristics and structure on the other hand. Furthermore, cost allocation based on quality served becomes possible.

Especially in industrial networks with small electrical distances high frequencies of critical voltage dips are promoted. Therefore, particularly in industrial networks with a high number of sensitive devices, this topic has to be dealt with. Indeed the possible countermeasures in the network are limited, especially if the oppositional interdependency with reliability of supply is kept in mind. This paper shows based on the example of switching mode that determination of both supply quality aspects enables objective optimisation.

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