Many substations in European distribution systems have reached the end of their technical lifetime. This leads to high operation and maintenance cost and at the same time to reduced reliability. Replacement investments are inevitable. At the same time today’s energy distribution market is characterised by increasing competition and reduced profit margins. One of the musts for efficient electrical networks therefore is the application of up-to-date planning procedures and tools, which allow to strategically localise the network assets and guarantee that the investments made into the network generate maximum benefit during the technical life-time of the equipment. For this task, more and more probabilistic methods for reliability calculation are used, e.g. ABB’s network calculation software CALPOS®. These probabilistic methods provide statements about the interruptions to be expected for each customer in the considered network, taking into account the outage behaviour of the electrical equipment observed in the past.

It was the objective of the presented study, to find the economic and technical optimal solution for the MV-busbar-arrangement of an existing main HV/MV transformer substation to be refurbished by a German distribution utility. Furthermore measures for a basic restructuring of the MV-network had to be defined.

The simplified configuration of the existing MV-busbar-arrangement is shown in figure 1. The 20-kV-switchgear to be replaced is designed with a double-busbar-arrangement (DBB), each of them equipped with a longitudinal bus-tie. It is redundant fed from the 110-kV-network via two transformers.

The network architecture is typical for a historical grown network. Besides the infeeding transformer substation, there are several switching stations in the network. S1 and UW3, being satellite stations, are also designed with a DBB.

Busbar arrangements for the HV/MV transformer S/S, considered to be sensible besides the existing DBB-arrangement, are a single-busbar-arrangement (SBB) and a ring-busbar-arrangement (RBB). S1 and UW3 are scheduled to be erased in a future network concept. The existing 5-kV-network (Pub5) shall be turned to 20 kV. A new network architecture has been designed, which does not include these stations anymore. It had to be proven if the supply reliability level of this future concept is comparable to the initial status of the network, especially with regard to the alternative busbar arrangements SBB and RBB. The designed variant for the SBB case is shown in figure 2.

The results for the Restructured Status of the network show considerable changes of the supply reliability. But these are caused by the proposed measures for restructuring of the network and not by the different busbar arrangements in UW1, i.e. in the considered network the SBB arrangement provides the customers practically the same reliability level than a DBB arrangement. Though the provided supply reliability is only one out of many aspects leading to a decision for a future design of a main HV/MV transformer substation, the results the presented reliability study show clearly, that a high quality of supply together cost reduction are not controversy.

Finally, for the planning task to be solved in the presented study, the application of the quantitative, probabilistic reliability assessment has been proven valuable.
ABSTRACT

In a main HV/MV substation of a German distribution utility it's refurbishment is forthcoming. It was the objective of the presented study, to find the economic and technical optimal solution for the medium-voltage (MV) busbar-arrangement from a functional point of view. In addition to the existing configuration (double-busbar-arrangement) simplified alternatives (single-busbar- and ring-busbar-arrangement) were designed and studied by means of probabilistic reliability calculation. The results show clearly, that the simplified configurations are almost equal with regard to the provided supply reliability and also under operational aspects they cause no essential restriction. Consequently the higher investment cost of a double-busbar-arrangement can not be justified.

MOTIVATION OF THE STUDY

Many substations in European distribution systems have reached the end of their technical lifetime. This leads to high operation and maintenance cost and at the same time to reduced reliability. Replacement investments are inevitable. At the same time today's energy distribution market is characterised by increasing competition and reduced profit margins. But as the customers still and more than ever expect a reliable supply with sufficiently high power quality, the market drive is actually not towards low prices but towards optimised efficiency. One of the musts for efficient electrical networks therefore is the application of up-to-date planning procedures and tools, which allow to strategically localise the network assets and guarantee that the investments made into the network generate maximum benefit during the technical life-time of the equipment Carvalho et al (1).

Traditional planning criteria, e.g. the (n-1) criterion allow only qualitative statements and are not suitable for differentiated comparisons of several solutions. For this reason, more and more probabilistic methods for reliability calculation are used. They provide statements about the interruptions to be expected for each customer in the considered network, taking into account the outage behaviour of the electrical equipment. The expected number of interruptions together with their expected duration are quantified by reliability indices, e.g. the interruption frequency or the interruption probability Backes et al (2).

PLANNING TASK

In a main HV/MV substation of a German distribution utility it's refurbishment is forthcoming. The simplified configuration of the existing MV-busbar-arrangement is shown in figure 1. The 20-kV-switchgear to be replaced is designed with a double-busbar-arrangement (DBB), each of them equipped with a longitudinal bus-tie. It is redundant fed from the 110-kV-network via two transformers. The connected MV-network supplies one sensitive industrial firm (Ind1) and several residential areas via loops and strands, partly being operated normally open (Pub1, Pub2B) and partly being operated normally closed (Pub2A, Pub3, Pub4). Furthermore substation UW3 supplies a 5-kV-network (Pub5).

The network architecture is typical for a historical grown network. Besides the infeeding transformer substation, there are several switching stations in the network. S1 and UW3 being satellite station are also designed with a DBB.

It was the objective of the presented study, to find the economic and technical optimal solution for the MV-busbar-arrangement satisfying at the same time the functional requirements of today and in the future.
In addition to these measures for a basic restructuring of the network should be defined. Especially S1 and UW3 are scheduled to be erased in a future network concept.

**STUDIED CASES**

**Initial Status of the Network**

Busbar arrangements, considered to be sensible besides the existing DBB-arrangement, are a single-busbar-arrangement (SBB) and a ring-busbar-arrangement (RBB). The network architecture for the initial status of the network are shown in figures 2 and 3.

![Fig 2: Initial status of the network, case SBB](image)

In the DBB (fig 1) case each feeder can be connected with two busbar-sections. Maintenance of one busbar-section does not lead to an unavailability of the feeders and even in case of a busbar-outage switching over to another busbar section is possible. By way of contrast in case of a SBB- or RBB-arrangement each feeder is assigned to exactly one busbar section.

As a consequence, it must be possible to supply each customer by means of switching from at least two busbar sections. Otherwise the (n-1)-criterion would not be fulfilled anymore.

In the SBB case (fig 2) this can be ensured easily. Even the meshed feeding of the industrial firm Ind1 is still possible (via S1). Only the loops/strands feeding the residential areas Pub1, Pub3 and Pub4 are now operated normally open, what leads to slightly higher losses.

With regard to the supply reliability this means no difference. In both cases, normally open operation and normally closed operation, the whole loop/strand will trip. An additional benefit of the unmeshed operation is the possibility to simplify the network protection system.

One substantial difference compared to the DBB case is, that an outage of one busbar-section leads inevitably to an outage of the connected transformer for the same duration. Due to the existing transformer redundancy, this means no problem. An alternative would be to spread the transformer feeder to each of the busbar sections.

![Fig 3: Initial status of the network, case RBB](image)

This possibility was taken into account for the design of the RBB case. Besides the reduced number of feeders per busbar-section, which would be affected by a busbar-outage, the RBB-arrangement provides one substantial benefit. It provides almost the same flexibility than the DBB-arrangement, e.g. feeding the residential areas Pub1, Pub3 and Pub4 via normally closed loops/strands.

**Restructured Status of the Network**

In the near future also the satellite stations UW3 and S1 will have reached the end of their technical lifetime. Furthermore the existing 5-kV-network will be turned to 20 kV.

A new network architecture has been designed, which does not include these stations anymore. It has to be proved if the supply reliability level of this future concept is comparable to the initial status of the network, especially with regard to the alternative busbar arrangements SBB and RBB. The designed variants for the SBB case and the RBB case are shown in figures 4 and 5.

![Fig 4: Restructured status of the network, case SBB (additional lines dotted)](image)

In the near future also the satellite stations UW3 and S1 will have reached the end of their technical lifetime. Furthermore the existing 5-kV-network will be turned to 20 kV.
Both network architectures are quite similar. The supply of the industrial firm is now unmeshed. Instead of the satellite station $S1$ there is now a simple switching station which is fed unmeshed in normal operation. In case of an outage affecting the residential area $Pub2$ it is possible to close one of the normally open switches to re-supply the interrupted customers. All remaining customers are supplied via open loops.

Differences between the SBB case and the RBB case exist with regard to the possible operating modes. While in case of the SBB arrangement each half of a loop is supplied by a different transformer, this is not necessary in the RBB case.

The DBB case is not shown for the restructured status of the network. The connections are equivalent to the SBB case, while the feeders can be flexible assigned to the busbar-sections.

RESULTS

Figure 6 shows the interruption frequency of selected customers for each case (SBB, RBB, DBB) and each status (Initial Status, Restructured Status) of the network, calculated with ABB’s network calculation software CALPOS®. Only first order contingencies were considered as these already lead to supply interruptions. Consideration of second order contingencies change the results only slightly and result in a small offset to the results shown. This finding was confirmed in many other distribution network studies e.g. in Hofmann and Backes (3) and can be stated as a general rule.

In the Initial Status of the network, the expected number of supply interruptions for the different customers was calculated to values between 0.4/yr (once every 2.5 years) and 0.15/yr (once every 7 years). Due to the chosen connection of the feeders supplying the satellite station $UW1$ in each of the cases, the interruption frequency is almost independent from the chosen busbar arrangement.

Looking at the results for the Restructured Status of the network, considerable changes can be recognised. But these are caused by the proposed measures for restructuing of the network ant not by the busbar arrangement in $UW1$. This is shown for selected customers of the residential area $Pub2$ which have to expect a higher as well as a reduced number of supply interruptions due to the changes in the network architecture. But still these values are within typical ranges for distribution networks, so that additional measures for improvements appear not necessary.

Special attention should be drawn to the industrial customer $Ind1$. Comparing the cases SBB and RBB (once every 12 years) with the DBB case (once every 50 years), for the Initial Status of the network, the calculated values for the expected interruption frequency are increased by 5. The increase is caused by the radial operated redundant feeding. But if required by the customer the supply reliability can be improved by local measures, e.g. a high speed transfer system. A high speed transfer system detects the outage of the feeding and switches over to the reserve feeding within milliseconds.

Figure 7 shows the expected cumulated energy not served differentiated by the contribution of the equipment.

<table>
<thead>
<tr>
<th>Equipment Type</th>
<th>Expected Energy Not Served [MWh/yr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transformer HV/MV</td>
<td>2.5</td>
</tr>
<tr>
<td>Transformer MV/MV</td>
<td>4.0</td>
</tr>
<tr>
<td>Cable</td>
<td>5.0</td>
</tr>
<tr>
<td>Busbar</td>
<td>6.0</td>
</tr>
</tbody>
</table>

Figure 7 shows the expected cumulated energy not served differentiated by the contribution of transformers, cables and busbars to the supply interruptions. As
usual for radial operated distribution networks designed according to the (n-1)-criterion, the contribution of cable outages to supply interruptions is dominating. Transformer and busbar outages are in comparison to cable outages seldom and are only of secondary importance for the supply reliability experienced by the customers.

SUMMARY AND OUTLOOK

For the presented study, to find the economic and technical optimal solution for the MV-busbar-arrangement for a main HV/MV transformer substation of a German distribution utility, the quantitative, probabilistic reliability assessment has been proven valuable. In the considered network the SBB arrangement provides the customers practically the same reliability level than a DBB arrangement. Though the provided supply reliability is only one out of many aspects leading to a decision for a future design of a main HV/MV transformer substation, the results of a reliability study allow a much more differentiated cost-benefit-analysis. The discussions between network-planning, network-operation and merchants becomes more objective. Decisions for investments become more transparent.

The presented results as well as the results of comparable studies, e.g. Hofmann and Backes (3), show clearly, that a high quality of supply together cost reduction are not controversy.

REFERENCES

1. Carvalho A, Christiansen U, Osterholt A, 2000, "Das OSCAR-Projekt von ABB – Der Weg in die richtige Richtung?" Elektrizitätswirtschaft, 6, 70-78