The paper describes measures to enhance the supply reliability of medium voltage distribution power systems. The measures are evaluated by quantitative reliability analyses and compared to the original status without the measures. The results are described in detail. The necessity of a qualified interpretation of the results is given. Examples are given for a real existing medium voltage system. The measures are concentrated to enhance the supply reliability of seven selected industrial customers of special importance. Further examples are presented for the analysis of the supply reliability of an industrial customer distribution system connected to the public distribution system.

INTRODUCTION

Especially for industrial customers the quality of supply is the main interesting characteristic of electrical energy besides the price. The supply reliability as one part of the supply quality is of special importance, due to increasing requirements resulting from production processes, getting more and more complex and sensitive against supply interruptions. Reliability analyses tools are an adequate measure to handle a centre part of these quality requirements. They allow the determination of quantitative results for the quality of supply of customers or complete power systems. Reliability analyses tools are of grown importance since some years and currently they are an important supplement to classical power system analyses tools like power flow or short circuit calculation [1-3].

For two power systems different measures are evaluated by quantitative reliability indices. The first part of the paper describes examples for the grid connection of industrial customers to a medium voltage distribution system. The second part of the paper deals with an industrial customer distribution system connected to the public distribution system.

Figure 1: Frequency of supply interruptions depending on the line length of the protection area

Values for different protection areas
Linear approximation
The figure shows a straight rising of the interruption frequency with increasing line length of the protection area. With a change of the switching status of the normal operational state, the protection areas can be changed. Based on resulting reduced line length of protection areas, reliability indices can move to lower values.

So the supply reliability can be influenced by change of the switching state, which includes measures that are easy to realize. The following measures are investigated:
- Change of the location of the sectionalizing point of open operated cable loops (see Figure 2a).
- On switching of multiple feeding lines (see Figure 2b)

Additional measures are possible like rearranging the busbar connection, but are not described here.

a) 

b) 

Figure 2: Principle of simple topological measures (part of investigated system, connection of industrial customers A, B), original state and variant

a) Change of the location of the sectionalizing point of open operated cable loops
b) Closing of multiple feeding lines

Figure 3 shows the reliability of the industrial customers in terms of the calculated interruption frequency for the system in original state and after the performance of the described measures (variant).

The results show for the example system and the industrial customers K1 to K7 the potential of the measures in terms of reliability indices. The supply reliability can be enhanced significantly for the considered customers by the realization of the simple switching measures. The frequency of supply interruption can be reduced down to 55% of the original values (see Figure 3).

The results for other reliability indices, where the interruption frequency is a multiplicative component, like the unavailability (defined in min/a) changes in the same manner as the interruption frequency itself.

Acc. to [1], a break down of the reliability indices acc. to their affected components is very useful to understand the origin of the indices and the main influencing equipment. Figure 4 shows the interruption frequency for industrial customer K7 acc. to affected components. The main impact on reliability indices is especially given by three busbars (BB1-BB3), one transformer (T1) and several lines (L1-L5). The figure shows, that for the original state several lines (L1-L4) have a big impact on the interruption frequency while they have nearly no impact due to the executed measures for the variant. The reason is, that the lines L1-L4 are in the same protection area as customer K7 for the original state, while they are shifted to an other protection area for the variant.

It has to be mentioned, that other customers may achieve a supply reliability for the variant, which is worse than the original state. Furthermore the change of system
disconnection points can lead to higher system losses. In the considered case, the overall evaluation of the measures led to the decision of the system operator, to realise them due to the importance of the regarded industrial customers within the whole power system.

**INDUSTRIAL CUSTOMER DISTRIBUTION SYSTEM**

The investigated customer system is a medium voltage system, which is fed by four independent cable connections of the public distribution system to two injecting points. The customer system consists of five substations with an overall load of 10 MW. The loads are connected to the LV busbars. Parallel operation of MV/LV-transformers is used. The substations are connected in closed operated cable loops. The cables are protected by differential protection devices. The customer is associated with the chemical industry and is therefore very sensitive against supply interruptions.

The supply reliability of the different loads of the system is of special importance, due to the fact that supply interruptions lead to very high costs because of ruined products as a consequence of the interruption. The costs rise extremely, if supply interruptions last longer than a duration of e.g. 60 minutes. Therefore first the occurrence of supply interruptions should have a low probability. If supply interruptions occur though, they should be cleared in a short time, e.g. by the execution of switching actions.

To limit the duration of supply interruptions, two different approaches are investigated for the given system:

- Implementation of remote controlled switch gear in the medium voltage system
- Bus sectionalizing of the medium voltage busbars

**Remote controlled switch gear**

The implementation of remote controlled switch gear influences the duration of supply interruptions due to shorter durations for clearing outages. The measure of course does not influence the occurrence of supply interruption. Therefore the interruption frequency is equal for the interruption frequency for the original state and the variant with remote controlled switch gear (see Figure 5).

Implementing the remote control for the switch gear, the unavailability of the loads decreases due to the lower execution duration of switching actions, in comparison to the original state where the switching actions are performed manually. The changes are relative low. This is true, because the main part of the unavailability is given by outages, which cause long lasting supply interruptions like outages due to multiple earth faults or outages of single busbars, where supply interruptions can not be cleared by switching actions. Therefore the implementation of remote controlled switch gear does not deliver major reliability benefits. Nevertheless the remote control leads to a simplification and a speed-up of normal operational tasks.

**Busbar sections**

The distribution system contains several substations that are equipped with single busbars without bus sectionalizing. Figure 6 shows the principle of the bus sectionalizing. In case of busbar failures, the supply of the LV-system can be partly realised if the bus-coupler is opened.

![Figure 5: Interruption frequency and unavailability, variant: remote controlled switch gear](image5.png)

![Figure 6: Single bus bar (original state) and bus sectionalizing (variant)](image6.png)
Figure 7 shows the results of the investigations for the original state and for the sectionalizing of different single busbars (Variants Ia, Ib) or all busbars (Variant Ic) of the system. Busbar 2 (feeding L2a and L2b) is already in the original state equipped with sectionalized busses. The results show, that the interruption frequency is a little higher for the variants for these loads, which are fed by the sectionalized busbars. This effect is caused by the outage of the bus bar sectionalizing itself for the variants (the number of switchgear panel rises). This change of the interruption frequency is low compared to the effect of the bus sectionalizing on the unavailability.

The unavailability of the loads, that are equipped with sectionalized busses decreases by 50 % and more, compared to the single busbar-connection. The reliability standard of the considered system is very high. Therefore the outage of the bus bar has a main effect on the reliability indices. In case of the outage of a single busbar, the connected loads suffer supply interruptions, which last as long, as the outage duration of the busbar lasts (e.g. duration for repair or replacement). If the busbar is sectionalized, the supply interruption can be cleared by sectionalizing the affected busbar section and re-supply the loads via the busbar section that is not affected by the outage. The supply interruption can be cleared in a short time by the execution of switching actions. Depending on the transformer size and the installed load, the supplied transformers can take over LV-loads by closing the LV-buscoupler.

CONCLUSIONS

The described investigations show, that the quantitative reliability calculation is an adequate method to evaluate the supply reliability of customers and loads. Especially the possibility to compare indices for different variants makes this method a worthwhile addition to the conventional planning methods. The contribution describes the application of the method for two real existing distribution systems. Special focus is laid on the consideration of the supply reliability of industrial customers. The first case considers the connection of industrial customers to the public medium voltage distribution system. The investigations show, that the supply reliability can be enhanced significantly for the considered customers by the realization of simple measures. The second part of the investigations deals with measures within a medium voltage distribution system of an industrial customer. Even if the reliability level is very high of the given original system, further big improvements can be regarded by the execution of further investment measures like the bus sectionalizing.

REFERENCES