DESIGN OF AN URBAN 150 KV CABLE CONNECTION WITH REGARDS TO REGULATORY REQUIREMENTS FOR MAGNETIC FIELDS

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ABSTRACT

The design of an urban distribution grid has to fulfil an increasing number of requirements today. When a new distribution line has to be built technical and economical optimisation is getting more and more challenging as environmental compatibility and additional regulatory constraints including the approval process have to be taken into account. In this paper several variants for the connection of two substations by underground cables are investigated with the objective of an economically efficient construction in compliance with the regulations regarding magnetic field emissions.

INTRODUCTION

ewz is a Swiss utility, which operates distribution networks in the city of Zurich and parts of the Grisons. In the city of Zurich ewz operates a 150 kV network with a total length of 160 km; 90 km thereof are underground cables.
In Switzerland strict electromagnetic field limits apply for new installations, which are fixed by the "Ordinance on the protection against non ionising radiation (NISV)" [1]. The limit at the rated power for new installations in locations with sensitive utilisation is 1 µT and for all other accessible locations 100 µT. Locations with sensitive utilisation are locations within buildings, where persons stay regularly over a longer period e.g. schools, offices, homes and also children's playgrounds.
In the 150 kV grid of the city of Zurich a new connection of approx. 3 km between two substations has to be built. Several variants are studied, which all involve underground cables due to a high building density in Zurich.
It is analysed from a technical and economical point of view which variant is optimal for the urban distribution grid taking into account costs, losses and service reliability. Special emphasis is laid on the magnetic field emissions and the associated regulatory requirements including the approval process.

PLANNING TASK

In the new concept for the supply of Zurich from the transmission grid, the maximum capacity of the 220/150 kV transforming station FAL increases from currently 240 MVA to 500 MVA in 2012 (Fig. 1). Consequently the connection between the stations FAL and DRA becomes a bottleneck. The capacity of the existing overhead lines to the terminal tower is still sufficient, whereas the cable connection further on to DRA is not. Therefore a connection is planned between the terminal tower FAL and SEM, which has the additional benefit, that the substation SEM has an additional incoming feeder. As the planned route is in a densely built-up area, the connection has to be built underground.

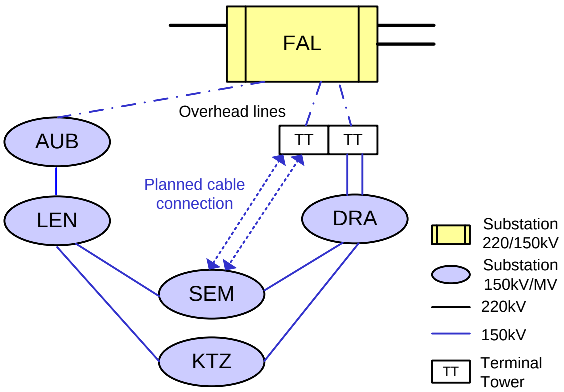

Figure 1 Scheme of substation SEM with adjacent subnet

RENEWAL VARIANTS

The renewal variants (Fig. 2) which are studied in the following are:

Var. 1: One single-core XLPE insulated cable 3x1x1000 mm^2 with ewz standard cable duct.

Var. 2: Two single-core XLPE insulated cables 3x1x400 mm^2 with standard cable duct and standard arrangement.

Var. 3: Two single-core XLPE insulated cables 3x1x400 mm^2 with new cable duct and centrosymmetric arrangement.

Var. 4: Two three-core XLPE insulated cables with integrated electromagnetic shielding 3x630 mm^2 with new cable duct.

The variants with single-core cables (Var. 1, 2 and 3) differ in the number of cables, their arrangement and the respective dimensions of the cable duct. Special permits or additional shielding measures are necessary to a different extend for these variants. In Var. 4 the employment of a three-core cable is evaluated. These three-core cables were originally designed for retrofitting gas-pressure cables in steel pipe. As the project in the city of Zurich is a new construction, a three-core cable with magnetic shielding laid in plastic pipe will be assessed. In Switzerland this type of cable has not yet been employed for this voltage level, but a new connection is under construction in the Netherlands.

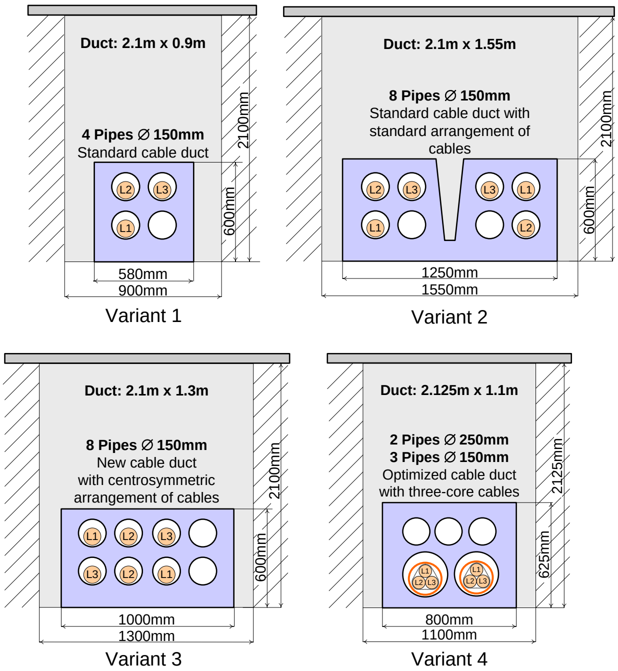

Figure 2 Cable duct structure

ANALYSIS OF THE VARIANTS

Regulatory Requirements

New installations of overhead lines and monophase cables in separate tubes with a nominal voltage above 1000 V have to comply with the magnetic field limits set by the NISV [1] in Switzerland. For multi-conductor cables it is assumed that the immission limits are respected. The Federal Ministry for the Environment has published an enforcement aid to the ordinance for high voltage lines in the status of a pilot project [2], where the execution, the calculations and the measurements are specified. The 100 µT limit is usually not of concern for an underground cable, as the magnetic field of this amplitude will not exceed the surface. The 1 µT limit restricts the long term exposition of the population to magnetic fields in a preventive manner. Therefore it applies only for locations with sensitive utilisation. The investigation perimeter, which is the width of the 1 µT corridor on both sides of the planned route, must be determined and is directly related to the number of locations where the limits are possibly exceeded. Each location must then be individually considered. Firstly the utilisation of each building must be evaluated to determine if it is a location with sensitive utilisation. Then a cross section with height differences (depth of coverage, height to location with sensitive utilisation) must be calculated. If the limits cannot be kept in the given corridor additional technical measures are analysed and in case that the limits are still exceeded an exemption with the authorisation procedure is needed.

An obvious solution would be to move the cables further from the critical locations. The problem is the proximity of the buildings on both sides of the street in the old area of the city and also that the possible locations in the street are limited due to other utilities (i.e. water, gas, sewage water system, etc.).

The following figures (Fig. 3a-d) show the magnetic field curves for the four variants in a two dimensional graph. The outer blue line of the magnetic field curves is the 1 µT line and the inner red line is the 100 µT line.

The 1 µT limit for Var. 1 is dependent mainly on the current and distance between conductors (Fig. 3a). With an investigation perimeter of 8.16 m it will not be possible to withhold the 1 µT limits without additional shielding measures for a large part of the route. This means high additional costs and it still cannot be guaranteed that the 1 µT limit will be kept at all locations. Therefore the possibility remains that an exemption with the authorisation procedure will be needed. The future requirements of this exemption are not known or the possible legal costs and delays due to objections. The magnetic fields along the route remain the highest, which is not our objective.

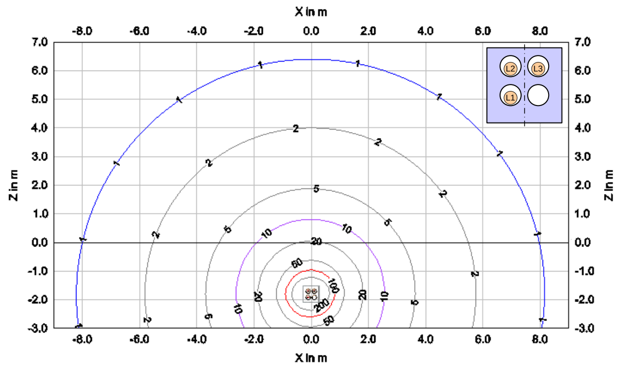

Figure 3a Magnetic field curves for Var. 1:
1 µT line at r = 8.16 m

In Var. 2 and Var. 3 (Fig. 3b, 3c) the current is divided between the two systems. The 1 µT limit is dependent on the vectorial sum of the resulting magnetic fields and therefore the layout of the phases.

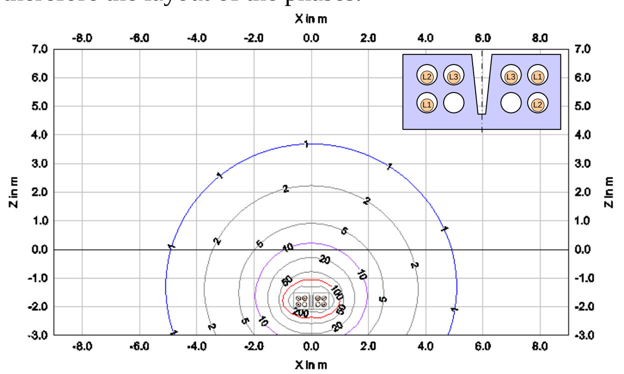

Figure 3b Magnetic field curves for Var. 2:
1 µT line at r = 5.09 m

Var. 3 is an adaption of the normal layout to a centrosymmetric arrangement, also known as the low inductive arrangement for better compensation. Var. 2 will need shielding in multiple locations to withhold the limits and Var. 3 also on individual locations [3].

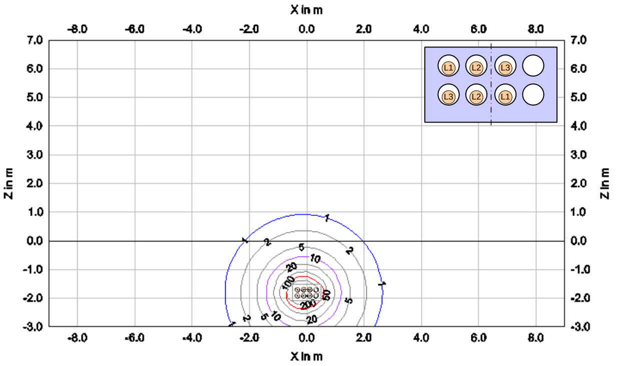

Figure 3c Magnetic field curves for Var. 3:
1 µT line at r = 2.65 m

The regulations for magnetic field emissions apply to overhead lines and single core cables in separate cable ducts. Therefore the authorisation procedure is simplified for Var. 4. The magnetic fields in Var. 4 are reduced due to the distance between conductors for a three-core cable being a lot smaller and the cores are also twisted, which reduces the fields further. The calculations without shielding lead to a 1 µT line at 2.00 m. Additionally the cable in Var. 4 has an integrated magnetic shielding [4], which reduces the investigation parameter to 0.80 m (Fig. 3d).

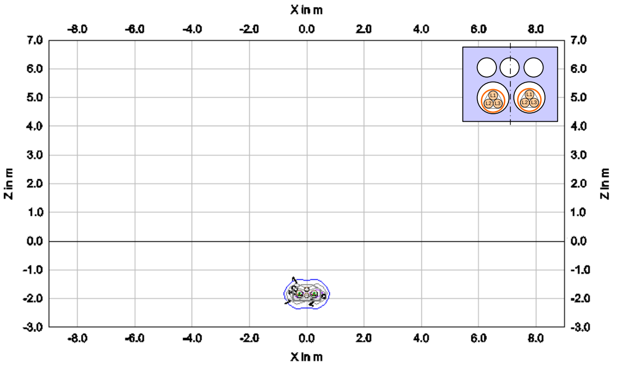

Figure 3d Magnetic field curves for Var. 4:
1 µT line at r = 0.80 m
Approximation with shielding

Supply Quality

The planned cable connection will provide a sufficient capacity to transport power from the transformation station FAL towards the city centre of Zurich. Additionally the supply quality of the station SEM will be improved through the additional third feeder. Calculations have been made in order to assess the supply quality at SEM with an additional feeder for the four variants. At first the new connection FAL-SEM is modelled for the four variants and the corresponding reliability indices are calculated based on statistics [5] and manufacturer data. All variants have a high reliability. It is evident that the variants with two cable connections (Var. 2, 3 and 4) are clearly advantageous in comparison to the single cable connection (Var. 1). As in all variants the same route is used, the average interruption frequency is the same for all four variants; the connection experiences one interruption in 8 years. The mean duration is reduced from 70 hours in Var. 1 to 40 hours in Var. 2-4. Hereafter the improvement for the station SEM through the additional connection is investigated. In order to simplify the analysis the grid is reduced to the stations and lines shown in Fig. 1 which form part of a sub network. Therefore the reliability indices differ significantly from those for the whole grid and should be only used for comparison of the two cases. The reliability analysis is done by modelling the available paths from the 220/150 kV transformation station FAL to the station SEM using a tool based on block diagram technique (Fig. 4).

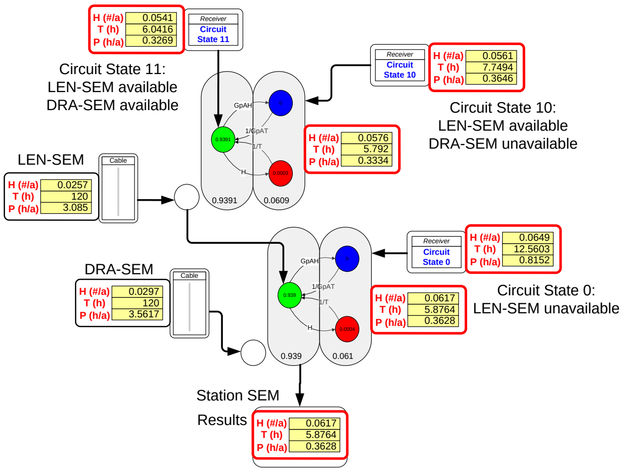

Figure 4 Reliability analysis station SEM (target state)

Within the theoretical sub network under consideration the station SEM experiences one interruption in 18 years with the additional connection FAL-SEM compared to one in 13 years without. The mean duration drops from approximately 10 hours to approximately 6 hours. This means a significant improvement of the reliability for all four variants.

Cost Calculation

For the calculation of the investment costs, the complete construction of the installation was taken into account. Over the life time the losses of the cable connection are evaluated as they influence the economic and ecologic efficiency of a variant. Additionally costs for measures to comply with magnetic field limits are considered.
At first the costs were analysed without additional shielding measures. The following Fig. 5 shows the costs normalised by the total for Var. 1 for the different cost components (additional shielding measures not incorporated). The costs

of the cable duct and the cable itself determine the cost efficiency of the variants; this means that the dimensioning of the cable duct is very important. The cable trenches are less significant in respect to the overall costs. The losses, which are also looked upon from an ecological point of view are 30 % higher for Var. 2 and Var. 3 and 25 % smaller for Var. 4 in comparison to Var. 1.

When additional shielding is not incorporated in the costs Var. 1 with one single-core cable and a small cable duct is the most cost efficient variant. If two systems with single-core cables are used, the cable duct has to be bigger, in Var. 2 the standard cable duct for eight pipes and in Var. 3 an optimised cable duct is calculated. Var. 2 results in additional cost of about 60 % compared to Var. 1, which can be reduced by optimising the duct to 40 % for Var. 3. In Var. 4 two three-core cables are employed, this allows building a cable duct of smaller dimensions and overcompensates the additional costs for the three-core cables in comparison to Var. 2 and Var. 3. The additional costs compared to Var. 1 are 25 % for this solution.

In a second step the route was analysed and costs for additional shielding measures were estimated. These are represented as dashed box on top of the bars in Fig. 5. Overall it can be seen that Var. 4 is on a par with the most cost efficient Var. 1, when additional shielding is taken into account.

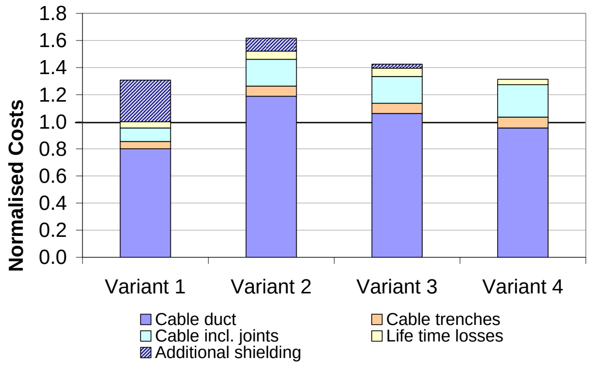

Figure 5 Cost calculation incl. additional shielding

DISCUSSION AND CONCLUSIONS

A crucial point for the construction of distribution lines today is the compliance with the regulations and the duration of the approval process. Compared to other European countries Switzerland has very high requirements regarding preventive measures to protect the population against the long-term exposition to magnetic fields of electric lines [2]. The analysis of four variants for an underground cable connection in the city centre of Zurich shows that seemingly small differences of the construction can lead to significant differences especially when regulatory constraints and the corresponding approval process are concerned. Table 1 summarises the different criteria considered in the analysis of the variants.

	Var. 1	Var. 2	Var. 3	Var. 4
Installation costs for the complete construction	✓	xx	x	✓
Additional shielding cost to comply with limits	xx	x	-	✓✓
Reliability	x	✓	✓	✓
Losses	-	xx	xx	✓
Authorisation procedure	xx	x	x	✓✓

Table 1 Summarising assessment of all criteria

From an exclusively cost-centred standpoint (additional measures to comply with regulations are not taken into account) Var. 1 is favourable. On the other side Var. 1 leads to magnetic fields which would need exemption with the authorisation procedure. Var. 2 and Var. 3 are economically less efficient but with additional shielding measures the magnetic field limits could be observed. With a broader consideration two parallel three-core cables with magnetic shielding (Var. 4) turn out to be an advantageous solution as it fulfils technical requirements as well as regulatory constraints and is an advantageous solution also from an economical point of view. It leads to a significant reduction of the magnetic fields, low losses and a good reliability. Furthermore the approval process is simplified, which is a significant advantage when the time to implement a project is concerned.

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