ELECTROMAGNETIC FIELD MITIGATION TECHNIQUES APPLIED TO MV/LV SUBSTATIONS

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ABSTRACT

Due to the increased attention to low frequency magnetic fields and their possible effects on human health, the "installation limit value" of 1µT was applied in Switzerland. To withhold this strict value, various mitigation possibilities to the equipment and shielding of the components or of the room were analysed, with the aid of diverse calculations and laboratory measurements. The knowledge obtained was implemented in existing MV/LV substations.

This paper presents the practical experience gained during the last few years in a real distribution network with a comparison of the various mitigation techniques.

INTRODUCTION

Beside the internationally recognized "exposure limit value" of 100µT, a stricter "installation limit value" (ILV) of 1µT was introduced in Switzerland, which places a precautionary ceiling on the emission from a single installation. The ILV must be observed in "locations of sensitive use", where individuals spend prolonged periods (e.g. kindergarten, schools, offices, homes), at the rated power of the installation. The compliance of this value will cause considerable investment cost for electrical utilities in Switzerland and eventually in other European countries, while the trend is towards stricter limit values.

The paper reports the measures taken by the Zurich power supplier "Elektrizitätswerk der Stadt Zürich" (ewz) in existing MV/LV substations to reduce the magnetic field in adjacent "locations of sensitive use".

MITIGATION TECHNIQUES

In existing substations the disposition of the electrical equipment is fixed and can only be changed with the complete rebuilding which is only economical with older substations (by earlier rebuilding the remaining amortisation value of a substation should be added to the mitigation costs [1]). Under the restriction of a fixed disposition, diverse calculations were made concerning the economical mitigation possibilities to the equipment. Various shielding arrangements were tested by "ewz" for the individual components or for surface shielding in our specially constructed laboratory [2, 3]. The knowledge obtained was implemented in existing MV/LV substations.

So far 42 substations have been renovated to reduce the magnetic fields (not counting the total rebuilt stations). Table 1 shows the measures taken divided into the three groups: rebuilding; shielding; shielding and rebuilding. For each a number of different mitigation techniques were applied. The mitigation process was usually initiated in stages, to validate the individual mitigation methods and as a basis to evaluate the next stage and so avoid excessive costs.

Several stations are noted as not fulfilling the ILV. These are either in an intermediate stage and awaiting further mitigation or the aim was only to reduce the field (e.g. in an older substation until rebuilding or while the adjacent location is not officially rated as being "sensitive use").

Whether the ILV is fulfilled depends not only upon the mitigation measure, but also upon the distance and orientation to the "locations of sensitive use" and to the rated power of the station. For example a substation with room height below 3m and a rated power of 2x1000kVA requires a combination of rebuilding and shielding with high permeable material to withhold the ILV directly above, whereas a lower rated power and a greater distance to the "locations of sensitive use" greatly reduces the required level of rebuilding and allows the use of more economical shielding material.

	Number of stations	Rebuilding				Shielding			ILV fulfilled	
		LV Cables	LV Distribution	MV/LV Transformer	reduction of rated power	LV Distribution	MV/LV Transformer	TS in- or outside	yes	no
Rebuilding 15 35.7%	5	■							1	4
	1				■				1	
	2	■		■					1	1
	1	■		■	■					1
	6	■	■	■	■				4	2
Shielding 7 16.7%	1					■				1
	1						■			1
	5							■		5
Shielding and Rebuilding 20 47.6%	1	■				■			1	
	2			■		■				2
	1	■		■		■			1	
	1		■	■		■			1	
	1	■	■	■		■			1	
	2	■	■	■	■	■			2	
	3	■					■		1	2
	1	■		■			■			1
	1	■	■	■	■		■			1
	1	■			■	■	■		1	
	3	■						■	2	1
Total 42 100%	1	■		■				■		1
	1	■					■	■	1	
		■		■			■	■	1	

TABLE 1: Mitigation techniques used in existing MV/LV substations.

MITIGATION THROUGH REBUILDING

Here we consider some of the different mitigation techniques applied to the group "Rebuilding".

LV Cables

The LV cables in older stations are a major magnetic field source. These where typically laid in cable duct mounted just below the ceiling or routed to the side but with distance between the phase conductors.
With a point symmetrical phase layout as shown in Figure 1 a substantial reduction can be achieved. The rerouting of the cables from the ceiling to under the floor also increases the distance to the "sensitive locations".

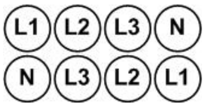

Figure 1: Arrangement of LV cables with optimised phase layout.

In the substation in Figure 2 a reduction from 95µT to 28µT was attained with the rerouting and optimising of the cables. These values were measured 20cm above floor in the room over the substation. The 95µT was over the cables and the new maximum 28µT now being over the LV distribution board (not under the "sensitive location").

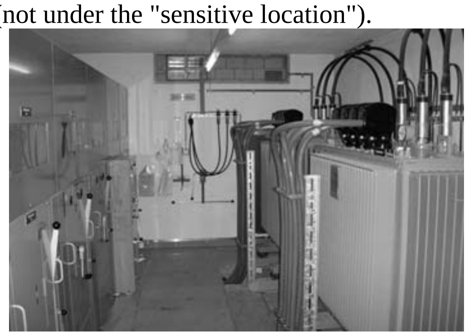

Figure 2: MV/LV substation with optimised LV cables.

The phase optimisation of the cables usually required their replacement. The LV distribution board could also require an adaptation with feeders from below, which also greatly reduces the fields from the distribution board through a better compensation between input and output currents.

LV Distribution Board

The better current distribution in the LV distribution board offers a potential to reduce the magnetic fields. In existing substations the transformer feeders are on either end and the full (rated power) currents flow in the bus bars. It was seen from calculations that the extent of the magnetic field on the left hand feeder is greater (Fig. 3).
The possible rebuilding for the standard LV distribution board with feeders from below was calculated and the optimum was the rebuilding only of the left side, with the circuit breaker in the middle (Fig. 4).
By an additional reduction of rated power, the circuit breakers can be replaced with 1000A fused disconnectors, located centrally on both sides (Fig. 5). This offers a better compensation and also reduces the effective bus bar length.

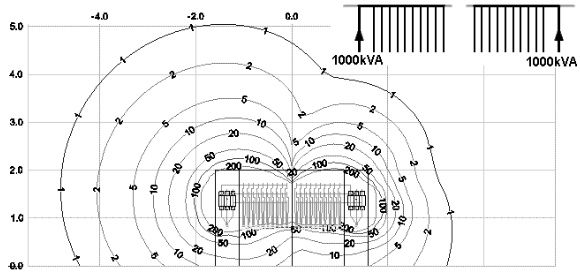

Figure 3: Standard LV distribution board (2x1000kVA) with circuit breaker feeder.

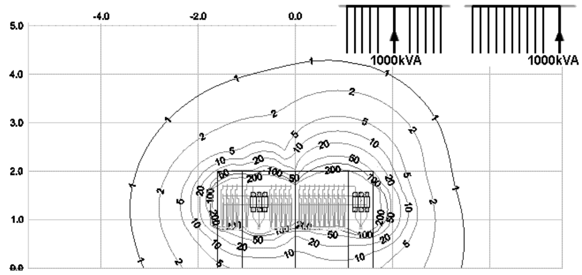

Figure 4: Rebuilt LV distribution board (2x1000kVA) with circuit breaker feeder.

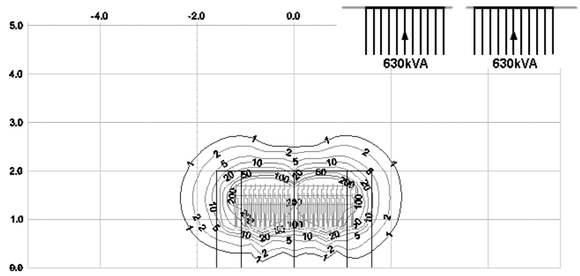

Figure 5: Rebuilt LV distribution board (2x630kVA) with fused disconnector feeder.

In Figure 6, the magnetic fields from a station under a kindergarten were mitigated. With the rebuilding of the LV distribution board (the empty circuit breaker panel can be seen), LV cables and the replacement of the two 1000kVA transformers with reduced emission 630kVA transformers and a "partial shielding" of the LV distribution board (later implemented) a reduction from 6.6µT to 0.95µT in the kindergarten was attained.

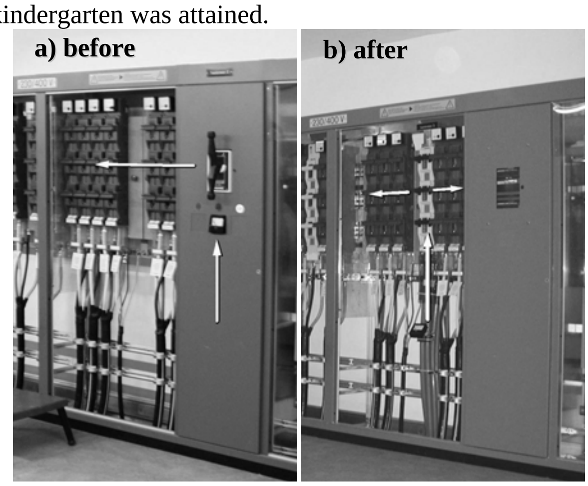

Figure 6: Rebuilding of a LV distribution board (2x630kVA) with fused disconnector.

MV/LV Transformer

The main rebuilding measure for a transformer was the replacement with a "reduced emission" transformer. Various manufacturers now offer these in one of the two variations: either with the four LV connections on the side (Fig. 7b) or with eight LV connections on the top in an optimised configuration (similar to the arrangement of LV cables with optimised phase layout). The lowering of the transformer into the oil sump also came into consideration where the limits were not quite met.
In the substation in Figure 7, a reduction in the children's play area above the substation from 11.5µT to 1.6µT was attained through the replacement with a "reduced emission" transformer and the rerouting and optimising of the cables and LV distribution. The 1µT is not observed due to external fields.

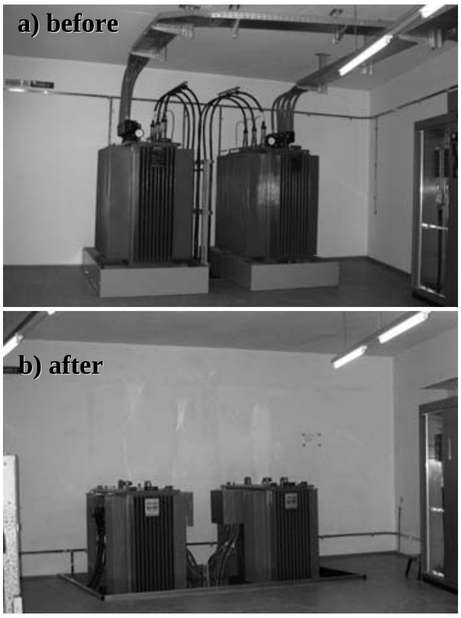

Figure 7: Rebuilding of the transformers.

Reduction of rated power

While the ILV must be observed at the rated power of the installation, a reduction of the rated power is useful in a substation that is not heavily used. This is usually carried out through the replacement of the transformer. Then usually, the rebuilding of the LV distribution board with fused disconnector is also implemented.
The reduction of the rated power can also be obtained through the settings of the protection devices (without rebuilding). This measure however, does not reduce the magnetic fields under the normal operational conditions.

MITIGATION THROUGH SHIELDING

Next we consider different mitigation techniques applied for each subgroup "Shielding".

LV Cables

Shielding of the LV cables was tested in our laboratory but has not been implemented in substations because the reduction due to the phase optimisation and increased distances were sufficient.

LV Distribution Board

One type of shielding of a LV distribution board is a "partial shielding", applied above and behind the distribution board (Fig. 8a). The reduction of the field directly above is only minimal, but is better for a room offset above and behind the distribution board.
An alternative is the "full shielding" of the distribution board (Fig. 8b). This has a greater effect, but is not liked by the workers in the stations, due to the reduced access.

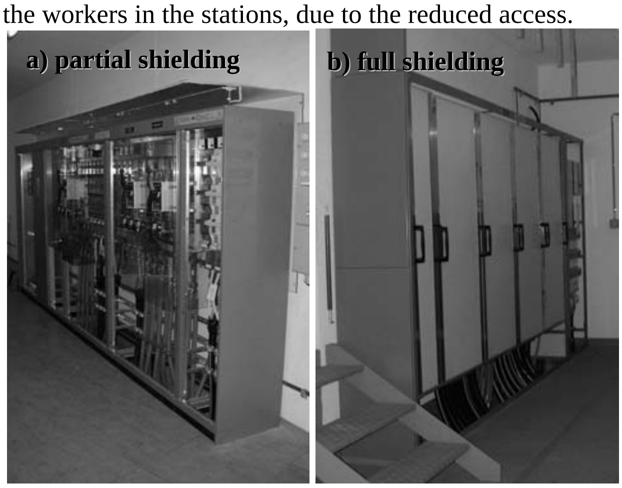

Figure 8: LV distribution board with partial and full shielding.

MV/LV Transformer

There are a few commercial transformer shielding products on the market. The "Transformer-Box" (Fig. 9a) encloses the transformer, but has gaps for access and cooling. The "Transformer Hood" (Fig. 9b) is actually a combination of two hoods which can be also used separately [1, 4]. The inner hood shields the cables until they reach the optimised phase layout. The outer hood shields the transformer and is shown in the raised position for easier access. The main shielding effect is for rooms above.

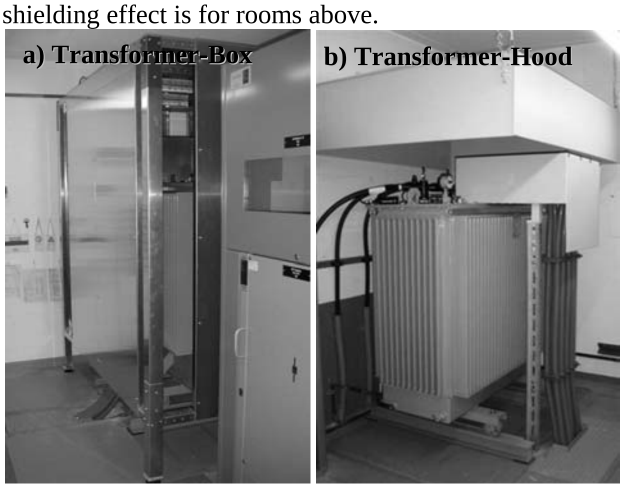

Figure 9: Transformer shielding with a) Transformer-Box and b) Transformer-Hood.

Other possibilities also exist, e.g. an aluminium panel above the transformer.
The complete enclosure of the transformer is not desirable due to access (acceptability of the workers) and cooling.

MV Switchgear

The MV switchgear is usually not a major source of magnetic fields, but mitigation can be necessary when the "locations of sensitive use" is close and the fields from the other equipment are mitigated. There are a few stations that have not yet fulfilled the ILV due to the MV switchgear.
We have calculated a shielding that has a large enough effect but with only the necessary surface area, although this is still awaiting practical verification.

Surface shielding

Large scale surface shielding of a LV/MV substation is a relatively expensive measure. It is usually also necessary to partially shield the walls when this is possible, e.g. openings for doors, windows or ventilation.
A problem is the increased magnetic field at the edge of the shielding, if still in the vicinity of the sensitive location.

COMMENTS

Substations categories (e.g. age, rated power) can be defined, but to determine for each the best mitigation technique is only possible to a limited extent.
The choice of mitigation technique is largely determined by the distance and the orientation to the "locations of sensitive use". The room height determines the extent of the mitigation und the orientation determines whether the whole substation requires mitigation or if only a partial mitigation is required. The aim of the mitigation can be only a reduction of the magnetic field (e.g. in an older substations until it will be rebuilt, or when the surroundings are not rated as a "location of sensitive use").
A large magnetic field reduction in MV/LV substations with relatively high fields, e.g. from approximately 30µT to 3µT, can be achieved with moderate effort and expense. The reduction from 3µT to 1µT, at the rated power, is in contrast difficult and costly. The interaction of the fields of the electrical equipment for the complete substation must be considered by the choice of mitigation technique.
The evaluation of the effectiveness of each mitigation technique is possible, although the actual mitigation effect for a complete substation will be lower than that for the individual component. This estimation must therefore contain a factor for the field interaction for the magnetic field from the substation as a complete unit and as a "worst case" approach. It is therefore suitable only for the initial mitigation or as an approximation.
External fields are not regarded for the fulfilment of the ILV, as they don't belong to the installation and the power supplier has no jurisdiction. The question here however is whether the mitigation of the substation to 1µT makes sense in such cases, e.g. when a neighbouring private distribution board causes a field of 2.6µT in a children's play area above a substation under normal operating conditions.
For new or completely rebuilt substations, the ILV can be kept with minimal additional costs. In existing substations (fixed disposition) the complexity and expense of the mitigation is drastically increased. Mitigation costs are approximately in the range of 10 to 50% of the total rebuilding costs, depending on the level of mitigation. This raises the question as to whether reduced expectations for existing MV/LV substations should be considered until rebuilding, as is the case in the Swiss legislation by other applications.
The appraisal at a defined operating condition is necessary. However should it be at the rated power or at another defined maximum operating condition?
Various new methods are still being analysed. For example a new LV distribution board has been designed and tested by ewz with a factor 8 to 10 magnetic field reduction, but there is still not enough demand on the international market for the commercial production.

CONCLUSION

For a large initial reduction of the magnetic fields, the choice of the mitigation technique is not critical, when the main sources are reduced. This is sufficient in some cases, but for a further reduction to 1µT each solution has to be individually analysed. A comprehensive engineering "know how" and the aid of suitable calculation programs is required. An assessment of the costs is also essential.
The mitigation of magnetic fields due to the possible effects on human health is warranted, however other power suppliers should consider several questions when it comes to the definition of limit values. Is the effort and expense justified for an existing station, or could the limit value be reduced until the stations renewal? Should the limit value still apply where larger external fields exist? At which operating condition is the evaluation necessary?

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