SYSTEM TOPOLOGIES AND TRANSFORMERS FOR 1 KV NETWORKS

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ABSTRACT

Using 1 kV as an intermediate voltage level in low voltage (LV) networks can be used to decrease the loop impedance and increase the power capability.

1kV systems are especially suitable when the voltage on existing cable can be raised from 0.4 kV to 1 kV. This is possible for most modern low voltage cables.

This paper describes practical limitation and transformer parameters that can be specified when buying 1 kV transformers. The parameters have been optimized in cooperation with several transformer suppliers.

INTRODUCTION

Many LV cables are designed and manufactured according to standards (e.g. [1]) that states 1 kV as the nominal voltage. This makes it possible to use ordinary LV cables for 1 kV systems.

The three main applications that have been identified for 1 kV systems are:

A: Decreased voltage on short medium voltage (MV) sections with many disturbances. (Decrease number of customers affected.)
B: Increase power capability of LV cables/lines.
C: Mitigate power quality problems.

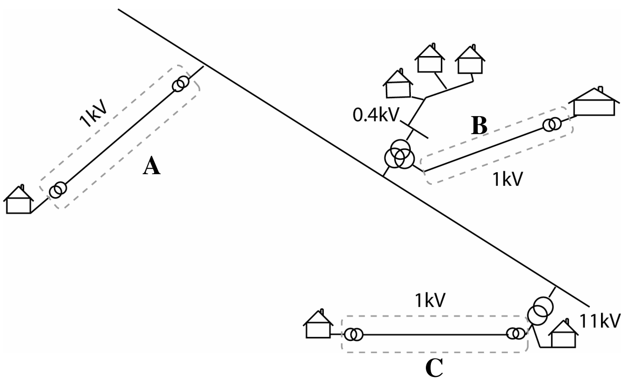

Figure 1. Possible use of 1kV

SYSTEM TOPOLOGIES FOR 1KV NETWORKS

The main difference between ordinary low voltage networks and networks using 1kV is the introduction of new transformers and fuses.

Transformers

In general, transformers for 1kV systems can be arranged in three different ways, as described in figure. 2. The different configurations are described below.

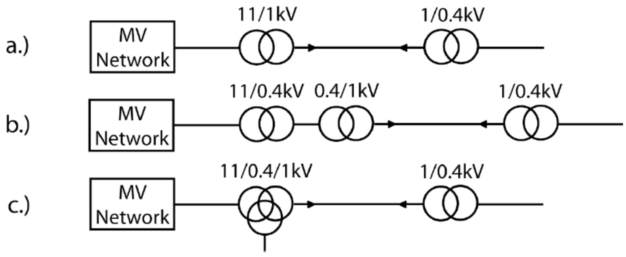

Figure 2. Typical transformer configurations for 1kV

Configuration A can be used to increase the power capacity of a single cable supplying one major load. This configuration requires fuses or relay protection for the 1 kV section.

Configuration B can be used if only a part of a 0.4 kV cable should be used with 1 kV. A typical application is in rural areas where customers nearby the secondary substation are connected to 0.4 kV and there are more remotely customers with long cable in between. The long cable can in this case be used for 1 kV. When transforming from 0.4 kV it is possible to use ordinary fuses at 0.4 kV level before transformation up to 1 kV. This configuration can also use auto transformer for the transformation 0.4/1 kV.

Configuration C uses a three winding transformer for supplying nearby customer directly with 0.4 kV and remotely, or high power customers, via the 1 kV system. This configuration can also use auto transformer for the transformation 0.4/1 kV.

The chosen type of protection for the 1 kV system affects which types of transformers that can be used and the maximum power rating of the transformers.

Fuses and relay protection

The choice between fuses and relay protection is depending on several aspects. Fuses are more robust but require higher fault currents for fault clearance.

Lessons learned from early 1 kV projects are that fuses for 1 kV can be difficult to order and problems can arise with spare fuses. This makes it advantageous to place the fuses before the transformation 0.4/1kV in combination with an auto transformer. The combination of fuses and transformers must ensure fault clearance according national regulations for touch voltages and their maximum duration.

The largest 1kV fuses that have been available for Vattenfall in Sweden have been fuses rated 40 A. This limits the maximum power to 69 kVA per each 1 kV fuse group.

LOOP IMPEDANCE IN LV NETWORKS

The loop impedance (Z_s) is defined as the impedance experienced by a single line to ground (SLG) fault. The loop impedance is mainly made up of the contribution of the feeding distribution transformer and the contribution from the LV lines or cables. The general expression of the loop impedance is [2]:

$$\underline{Z}_s = \underline{Z}_e + \underline{Z}_1 + \underline{Z}_2 \quad (1)$$

Where: $\underline{Z}_s$ Loop impedance
$\underline{Z}_e$ Impedance external to the LV system
$\underline{Z}_1$ Impedance of phase conductor
$\underline{Z}_2$ Impedance of neutal conductor

The impedances external to the LV network ($\underline{Z}_e$) consists of the short circuit impedance of the feeding MV network and the impendance of the feeding distribution transformer ($\underline{Z}_T$) and the zero sequence ($\underline{Z0}$) of the distribution transformers.

The general scheme below [2] is valid for transformers with vector groups Dyn or Yzn as recommended in [3]. Together with the impedance of the LV lines, $\underline{Z}_T$ and $\underline{Z0}$ will have a big impact to the total loop impedance, $\underline{Z}_s$.

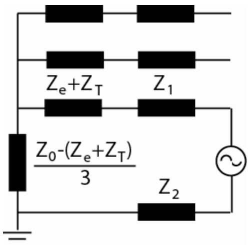

Figure 3. Equivalent scheme, seen from the SLG fault

The transformer's impedance in Ω is given by:

$$Z_T = \frac{u_k \cdot U_n^2}{S_n} = \sqrt{R_T^2 + X_T^2} \quad (2)$$

Where: Z_T Positive sequence impedance (Ω)
u_k Impedance voltage (pu)
U_n Nominal voltage (V)
S_n Nominal apparent power (VA)
R_T Real(Z) (Ω)
X_T Imag(Z) (Ω)

The resistive part of $\underline{Z}_T$ can be expressed as:

$$R_T = P_{kT} \frac{U_n^2}{S_T^2} \quad (3)$$

Where: P_{kT} Transformer load losses (W)
U_n nominal voltage (V)
S_T Apparent power of transformer (VA)

The inductive part of $\underline{Z}_T$ is thereafter obtained:

$$X_T = \sqrt{Z_T^2 - R_T^2} \quad (4)$$

Finally, the zero sequence impedance $\underline{Z0}$=R0+jX0 will be obtained from data sheet or using typical values [2].

OPTIMIZED PARAMETERS FOR 1KV TRANSFORMERS

Optimizing 1kV transformers is a matter of maximizing the total value of the 1kV system. The characteristics of the transformer should match the characteristics of the LV network and provide low additional impedance in positive- and zero sequence. This is mainly obtained by not choosing too small transformers.

Rated power

As a general rule of thumb, Vattenfall Eldistribution is not using 1kV transformers <30 kVA. Small transformers are generally used for mitigation of power quality problems in weak LV networks. In that context, transformers rated <30 kVA will not decrease the loop impedance enough to motivate the investment.

Suitable transformer sizes for transformation 0.4 /1 kV are 30, 50 and 70 kVA. The latter corresponds to 40 A fuse at 1 kV.

If the power would exceed 70kVA, it seems most suitable to use transformation directly from MV.

Positive sequence impedance and load losses

The transformer impedance is dependent on the load losses as seen in (3) and (4). Decreasing the impedance will require decreased load losses which in turn will increase cost for winding material. The values in the table 3 have been optimized for Vattenfall Eldistribution.

Table 3. Optimized transformer parameters (1/0.4 kV)

Vector group:	Rated power, Sn:	Uk:	Load losses, Pk:
ZNzn	30 kVA	2.5 %	560 W
ZNzn	70 kVA	3.0 %	1300 W
YN (auto)	50 kVA	1.5 %	500 W

The impact that different transformers have to the total positive sequence impedance (Z1) is illustrated in figure 4 on the next side. The two networks used for the comparison is one overhead line and one PE-insulated aerial cable (ALUS). The latter is very common in Vattenfall Eldistribution's rural networks.

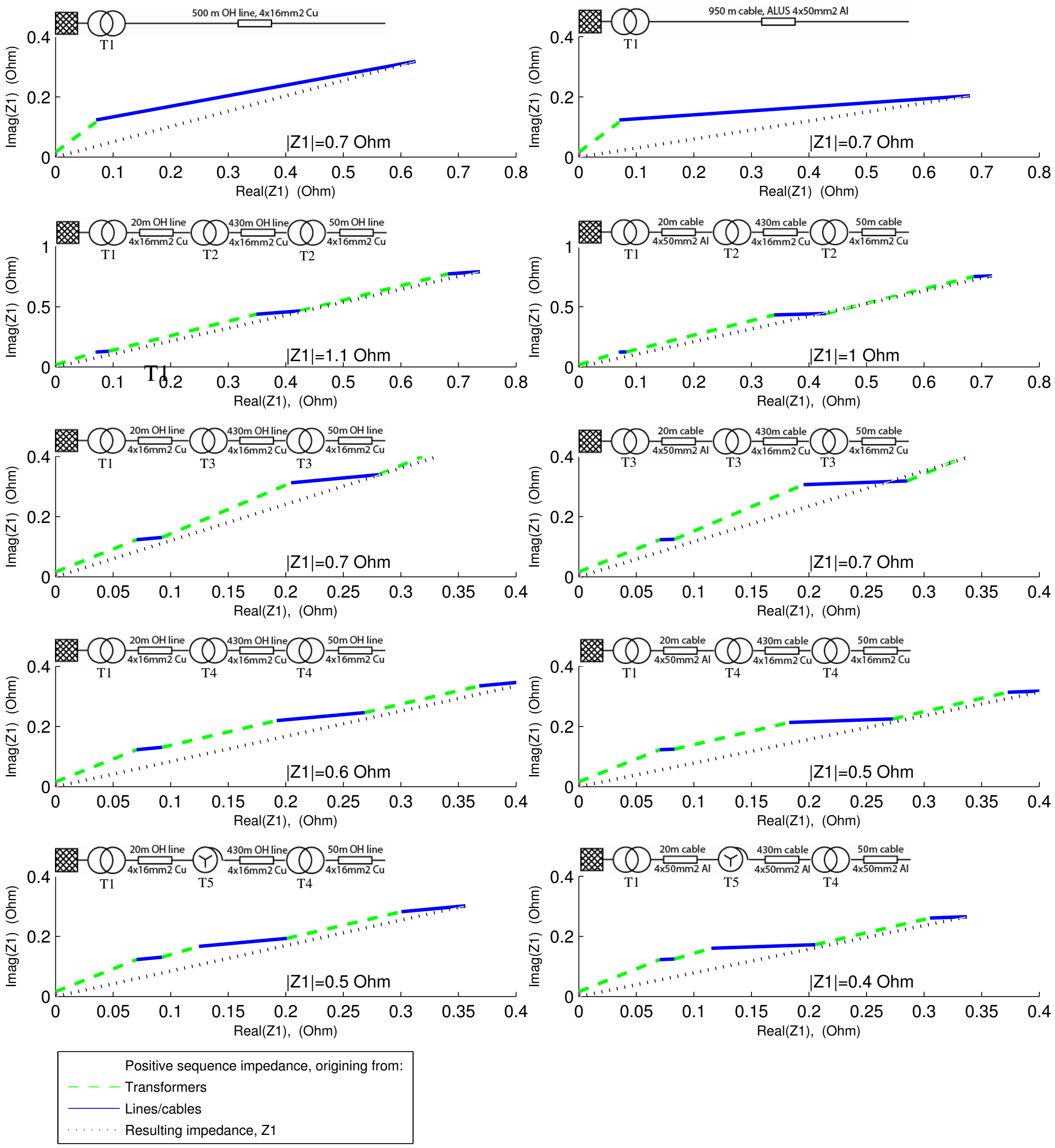

Figure 4. Positive sequence impedance with different transformer configurations

Table 2. Transformer data

T1:	T2:	T3:	T4:	T5:
S_n:50 kVA U_k: 4 % P_{kT}:1100 W	S_n:16 kVA U_k: 4 % P_{kT}: 410 W	S_n:30 kVA U_k: 4 % P_{kT}: 630 W	S_n:30 kVA U_k: 2.5 % P_{kT}: 560 W	S_n:50 kVA U_k: 1.5 % P_{kT}: 500 W
	Non-optimized parameters		Optimized parameters	

Transformer parameters for the "non-optimized" transformers are taken from real transformers sold in Sweden for use in 1kV systems.

As seen in figure 4, the non-optimized transformers have a large contribution to the positive sequence impedance, Z1. The impedance of the 16 kVA transformers actually increases the Z1 compared to the 0.4 kV network.

Zero sequence impedance

Keeping the zero sequence impedance low is a main focus on both 1 kV and 0.4 kV voltage levels. Low zero sequence impedance will keep the loop impedance low on 0.4 kV level and keep the fault clearance time low at 1 kV level.

Transformers connected in zig-zag (Yzn, Dzn, ZNzn) provides very low zero sequence impedances and are therefore a natural choice for 1 kV systems. Transformers connected Yzn might have high zero sequence impedance seen from the Y-side and therefore make them unsuitable for transformation 0.4/1kV.

CONCLUSIONS

This paper has shown how 1 kV can be used as an intermediate voltage level within the low voltage network. This is possible because most modern cables have a rated voltage of 1kV.

Transformers for 1 kV systems must provide low impedance in both positive- and zero sequence. Therefore, small transformers are not suitable for 1 kV systems.

Optimized transformer parameters have been given for transformers rated 30, 50 and 70kVA and their contribution to the total positive sequence impedance have been analyzed and the results have been compared with 1 kV transformers sold in Sweden with non-optimized parameters.

REFERENCES

[1] *SS 4241418 Power cables of rated voltage 0,6/1 kV – Specifications for design and testing*, SEK Svensk Elstandard, 2007, Stockholm, Sweden

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[3] *EN 50464-1, Three-phase oil-immersed distribution transformers 50 Hz, from 50 kVA to 2500 kVA with highest voltage for equipment not exceeding 36 kV – Part 1: General requirements*, CENELEC, 2007, Brussels, Belgium