Fault Voltages in LV networks during 1-phase MV shortcircuit

On our way to a total earthing concept

J.B.M. van Waes
Eindhoven University of Technology

J.F.G. Cobben
NUON

F. Provoost
NUON

M. van Riet
NUON

A.P.J. van Deursen
Eindhoven University of Technology

P.C.T. van der Laan
Eindhoven University of Technology

SUMMARY

This paper describes the consequences of a fault in a medium voltage network on the grounding systems at LV-side. Cenelec report HD 384.4.442 S1:1997 describes requirements to obtain safety for personnel and equipment connected to a low voltage network, in case of such a fault.

We caused a single phase to ground fault at the end of a floating 10 kV system. The current distribution in the MV network was measured; the fault current was 125 A. We also measured currents and the relevant voltages in the LV network. Both a TT and a (quasi) TN grounding system in the houses were installed; the lead shielded telecom cable was also included in the TN approach. Current and voltage data are compared with calculations.

The NUON-TUE project aims at a general grounding concept in which we treat different faults and various interference sources e.g. lightning and switching events together.

1. INTRODUCTION

A general grounding concept for buildings and houses should simultaneously consider different disturbance sources such as faults in medium and low voltage grids or lightning currents and the protection of both human beings and electronic equipment. All cables, which enter a building, are involved. A disturbing current will be shared by the cables and by the grounding electrodes or other conductors connected to earth when present.

The relevant voltages to protect humans are the step and touch voltages, or still better, the current through the human body for realistic values for the resistance of the body and footwear. There is agreement on the permissible values for the step and touch voltages. The Dutch requirements are derived from the document IEC479-1; the relevant graph is reproduced in Fig. 1.

The protection of IT equipment or consumer electronics requires low voltages across the input terminals. The currents through the cabling attached to the equipment should be limited to avoid overheating and coupling of interference.

The consequences of faults in the low voltage grid were studied earlier [1,2] by models and by measurements. The transfer of faults in the medium voltage grid towards low voltage networks is studied amongst others by [3,4]. The Canadian measurements dealt with open-air three-phase 25 kV lines, with telephone and CATV cables mounted on the same poles.

The Dutch situation is quite different: nearly all cables are burried. The medium voltage cables are equipped with a lead shield in reasonably good contact with the soil, or with an outer PE insulation jacket. Grounding is provided at the MV to LV transformer stations (typically 2-5Ω) to which the MV cable shields are connected. Both TT and TN systems are applied at the LV side, even in regions served by one distribution company. The adjacent cables for telecom and TV are of similar types; the grounding of those systems is often separated.

In a TT system each customer has an individual grounding arrangement. Faults in LV and MV systems may cause touch voltages on the neutral, which is usually not accessible to the customer. At the transformer station a large voltage may occur between e.g. metal doors and the surrounding earth. A TN-system links the various grounding conductors at the transformer and at all customers. This ensures a distributed grounding and reduces the probability of a customer not having a safe grounding. Also better lightning safety may be assured at lower overall costs. Faults in MV and LV grids may now cause important step and touch voltages.

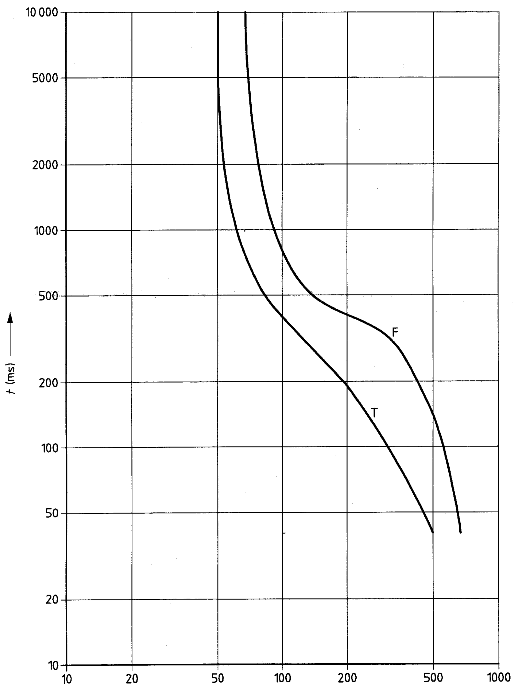

Fig.1. Permissible Fault and Touch voltages (IEC479-1)

2. RELEVANT PARAMETERS

General considerations

In the experiment we determine currents and voltages. The current through a cable or another metallic conductor depends on the position, but is clearly well defined for each position. The voltage between two points depends on the position of both points and on the current distribution. In addition, the measured voltage may depend on the path followed by the voltage measuring leads. This is due to a magnetic flux variation $-\partial\Phi/\partial t$ through the loop formed by the leads and the object to which the leads are connected. A large $|\partial\Phi/\partial t|$ occurs in strong magnetic fields, when large areas are enclosed, or when the frequency is high. We call these ambiguous voltages "far voltages". We use the term "near voltage" when local $|\partial\Phi/\partial t|$'s are small, for instance for voltages between input terminals of equipment. In the experiment most measured values were near voltages, for example those measured between two nearby conductors. We also determined the voltages between a conductor and a grounding pin in the soil over the shortest path to a point at distance of about 1 m, 10 m or more. All voltages were determined with a high impedance instrument. Naturally, the current through the body of a person spanning the 1 m distance is also determined by the contact impedances of the person to the touched conductor and to ground (Fig. 2).

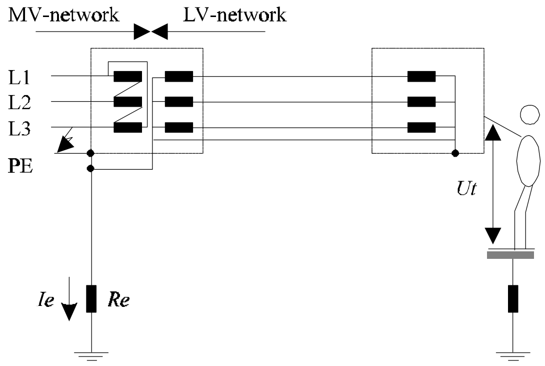

Fig.2. Touch voltages caused by a fault in a MV network.

Details on the network parameters.

The NUON 10 kV network floats with respect to ground. The fault current at a one phase to ground short circuit is determined by the cables installed, in particular by the total cable capacitance and the layout of the network. In the NUON 10 kV network, the maximum short circuit current during a one phase to ground short circuit is 450A. This current may last up to 8 hours, since this type of fault does not influence normal service. Larger fault currents are switched off within 0.1 sec.

The touch voltages are related to:

- the part I_E of the fault current I_f that flows through the local ground,
- the resistance R_E of the grounding arrangement of the transformer sub-station, including lead shields of incoming cables and the grounding arrangements at the customers.

3. EXPERIMENT

The measurements were carried out on a selected site at the end of a single branch, a 3.4 km long 10 kV cable. Figure 3 presents an overview. The directions of the cables are sketched and their lengths are indicated. The 10 kV cable comes from a 10 kV-230/400 V transformer station "Hennekamp" (H), 2.2 km west of our site "de Mossel" (M). A similar transformer at M feeds a house (W2), a small restaurant (PH) and a waste water pump (P).

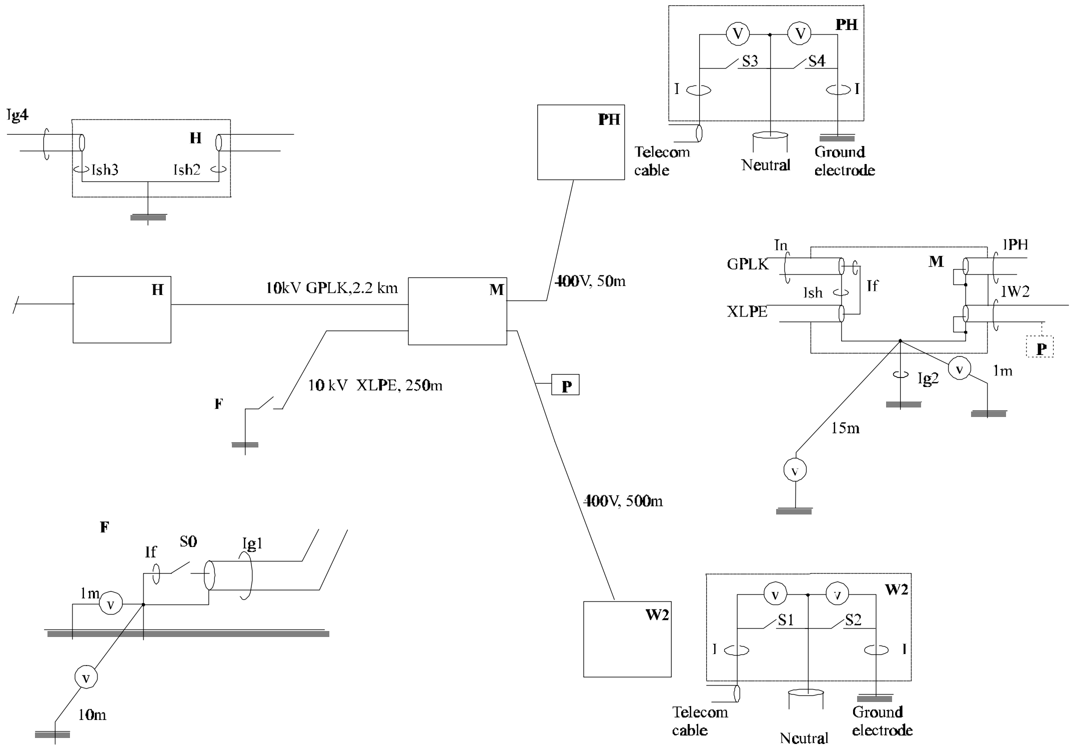

Fig. 3. Overview of the test site
H, M :Transformer station 10 kV/400V
F: Location ground fault
P: Waterpump
PH, W2: LV-users

The site is quite isolated in a nature reserve area, with only a few buildings and constructions nearby. The soil consists of sand with high resistivity, which may cause large voltages. This was one of the reasons to select this site. In addition, in this isolated region we had a reasonably complete overview of the cables, including telecommunication, and conductors such as metal water tubes buried in the soil.

In the tests we deliberately caused a 10 kV one phase to ground fault at the end of the XLPE cable which extends from M over a length of 250m. This cable was laid there for this experiment only. The fault current I_f was about 125 A. The fault current returned through the cable shields and through the local grounding system.

The LV neutral (N) and the shields of the LV cables connected to the site were grounded only near the transformer at M. Individual grounding electrodes were installed at both consumers in a TT configuration. A telecommunication cable also entered PH and W2; this cable had its own ground, most probably via the lead shield. Pump P is well grounded by the water piping and an installed electrode; the neutral is also grounded at P.

The fault is initiated by closure of a 10 kV switch S0 at F; S0 was opened again after 20 seconds. The open ellipses around cables at H, M and F in Fig. 3 indicate that the net current was determined, in EMC terminology: the common mode current through the cable. Various sensors were used, air-core Rogowski coils in a differentiating/integrating measuring setup [5] and inductive current clamps with iron core. HP digital scopes and a Dranetz transient analyser recorded the data up to 3 seconds around the fault begin. The overall measuring accuracy is about 3 percent.

In addition, we measured the near voltages between the three different 'grounds' at the consumer premises. Out of the many measurements we selected three different configurations for presentation:

1) The original TT system in both PH and W2.
2) N and local grounding electrode interconnected in both PH and W2. In Fig. 3 this corresponds to closure of S2 and S4.
3) An additional connection between the telecommunication ground and local electrode in PH and W2, corresponding in Fig. 3 to the closure of S1 and S3.

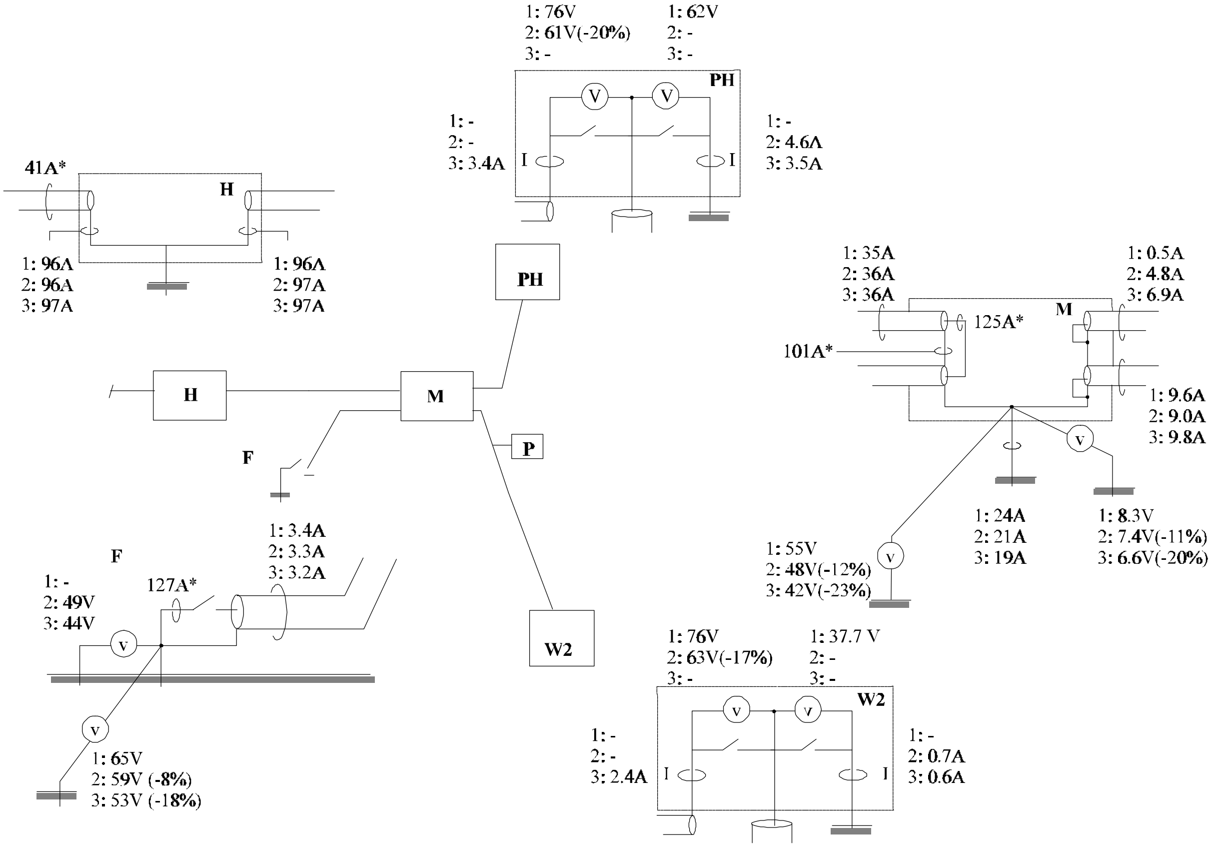

Fig. 4. Measurement results
1: Original situation: TT system on LV-side
2: Neutral and local ground connected on LV-side (S2&S4 closed)
3: Neutral, local ground and telecom ground connected (S1-S4 closed)
*= In all configuration the same current was measured

In configuration 1, the voltages measured between N and local ground are relevant for the TN system. In configuration 2 and 3, we also measured the current through the extra connections made. Interesting voltages were those between the ground at M and F and a short grounding rod at 1 m and at about 15 m (M) or 10 m (F) distance; see Fig. 3.

4. MEASUREMENT RESULTS

Figure 4 summarises the results; effective values are given. The fault current I_f does not vary over the three configurations; a single value is displayed. This is also the case for the current I_{sh} through the shield of the 10 kV cable arriving at M. Only one phase was connected in the XLPE cable; the currents I_f at M and at F are equal within the experimental accuracy.

The other currents and the voltages are given in small tables for the three configurations; a dash means no value obtained or obtainable. The vectorial sum of the currents is zero at all locations where we could check this. To within the accuracy of the measurements no current is missing.

Naturally, the current I_{g2} through the grounding electrode at M and the currents at PH and W2 change when extra ground connections are made at PH and W2. The major part of the 9 A current I_{W2} at M flows into the soil at P; I_{W2} does not appreciably vary over the three configurations. All these currents have a phase angle of about -135 degrees w.r.t. the fault current I_f; see Fig. 5 for configuration 2. This phase angle is in accordance with the values for the shield current Ish at M.

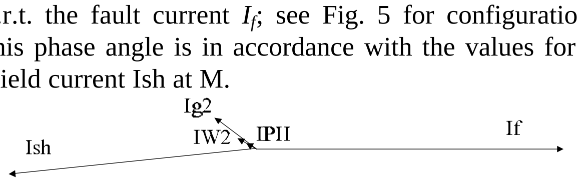

Figure 5
Measured currents at ground node "M" (configuration 2)

The grounding electrode at H appears to carry no appreciable current. The current through the cable shield there is 5 A smaller than at M. The cable between H and

M contributes about 2 A to I_f. The remaining 3 A leaves the lead shield via the contact with the soil.

The voltages at M and F approximately scale with the current I_{g2} through the grounding electrode at M. Large voltages are observed between the different grounds in the cables at PH and W2, up to 76 V. No grounding pins were placed there to carry out more voltage measurements.

5. CALCULATIONS AND MODELLING

For future calculations on the current distribution in MV networks, an EMTP/ATP model was developed. In this model the cable sections are represented by mutually coupled 4x4 pi models, containing the self and mutual resistance, inductance and capacitance of the three phases and the shields. The model was compared for two and three phase short circuits with other programs that only used positive sequence parameters. Those parameters were obtained from cable manufacturers.

The results were very much alike, showing positive and negative sequence parameters of the cable modelling was good. First calculations on single phase faults showed that the fault current could be calculated very accurately. The fault current in the considered network was calculated at 130A. The relevant cable capacitance’s proved to be correct.

No current was measured through the ground rod at H, which is not in accordance with the model. The lead shield of the GPLK cable has a good contact with the soil. This effect and grounding systems at LV side are not taken into account in the model yet.

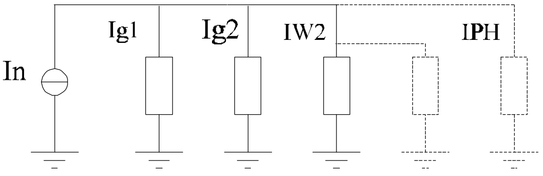

Fig. 6. Schematic representation of the local connections to earth for configuration 1 and configuration 2 (dashed)

From the measurements it can be seen that the total current going into the earth (I_n) at M is almost independent of the ground connections in the houses. In the following text it will be considered constant. We take the voltage between telecom ground and neutral as a reference value (Vref.). In the original situation we measured 76 volts. The local ground currents (I_{g1}, I_{g2}, I_{W2} and I_{PH}) are in phase.

Since the distances are relatively short, resistances mainly determine the current distribution. When no connections in the houses are made, the current I_n splits into three paths.

1) the grounding at F (I_{g1}=3A, R≈ 25Ω)
2) the grounding of the transformer station (I_{g2}=24A, R≈ 3Ω)
3) the grounding at the pump (I_{W2}=9A, R≈8Ω)

The grounding impedances at the two houses were measured to be 11Ω and 50Ω. In configuration2 these ground rods were connected to the neutral (Fig. 6).

Connecting the grounding impedances of the transformer station, pump, and the two houses in parallel results in a decrease of the equivalent local ground resistance. It has no influence on the current distribution in the MV network.

In this simple model the mutual (resistive) coupling between the nearby ground rods and phase shifts between the various currents are neglected.

Table 1: Measured and calculated current distribution configuration 2

Vref.		Ig1		Ig2		IW2		IPH	
Calc	Meas	Calc	Meas	Calc	Meas	Calc	Meas	Calc	Meas
60.2	61/63V	2.7	3.3	19.0	21.0	8.8	9.0	5.5	4.8

6. CONCLUDING REMARKS

Faults in MV networks may cause high step and touch voltages. At the considered site a TN grounding system would require only a minor additional grounding to reduce step and touch voltages below acceptable values. Most sites are in more densely populated areas, with many connections to the soil distributed over a large area. Lower voltages are then to be expected, even in grids with higher fault current. Experiments to this end are planned for the near future. Wherever the TN grounding system was installed, no incidents have been reported up to now.

Metal conductors and lead shields of cables influence the current distribution. This effectively reduces the touch voltages. However modern XLPE cables are isolated from the soil.

The current distribution strongly depends on variations of parameters for grounding resistance and cable shield impedance. A good representation of all cables (including their contact with the soil) and other conductors in the neighbourhood of the faulted place is therefore necessary for accurate modelling.

REFERENCES

[1] Provoost F, “A New Softwaretool for Economical Optimisation of Low Voltage Networks,” 12th International Conference on Electricity Distribution, Birmingham, 1993, paper 6.27, 4p.

[2] J.F.G. Cobben ,"Advantages of earthing according to the TN-system", NUON Duiven.

[3] Y.Rajotte, R. Bergeron, A. Chalifoux, ”Measurement of Touch Voltages on 25-kV Underground Distribution Systems,” 10th International Conference of Electricity Distribution, Brighton, 1989, pp238-242.

[4] Rajotte, J. Fortin, G. Raymond, ”Impedance of Multigrounded Neutrals on Rural Distribution Systems,” IEEE Transactions on Power Delivery, Vol. 10, No 3, July 1995 pp.1453-1459.

[5] E.J.M. van Heesch, A.P.J. van Deursen, M.A. van Houten, G.A.P. Jacobs, W.F.J. Kersten, P.C.T. van der Laan. Field Tests and Response of the D/I High Voltage Measuring System. 6th Int. Symp. On High Voltage Engineering, New Orleans, 1989, paper 42.23, 4p.

NUON TB
P.O. Box 50
6920 AB
Duiven, The Netherlands
Fax: +31 268 5200

Eindhoven University of Technology
P.O. Box 513
5600 MB
Eindhoven, The Netherlands
Fax: +31 40 245 0735