MODELLING AND LIVE MEASUREMENTS OF STEP AND TOUCH VOLTAGES AT LV CUSTOMERS IN DEVELOPING GRIDS, CAUSED BY MV FAULTS

F.T.J. van ERP
Nuon Tecno – The Netherlands
Frans.van.Erp@nuon.com

M.J.M. van RIET
Nuon Tecno – The Netherlands
Maarten.van.Riet@nuon.com

J.F.G. RASING
Nuon Tecno – The Netherlands
Jos.Rasing@nuon.com

F. PROVOOST
Eindhoven TU/e – The Netherlands
F. Provoost@tue.nl

A.P.J. van DEURSEN
Eindhoven TU/e – The Netherlands
A.P.J.v.Deursen@tue.nl

ABSTRACT

Earth faults in the medium voltage (MV) grid cause touch and step voltages in the low voltage (LV) grid. If a MV and LV grid share their earthing systems at the MV-LV transformer, one may question the safety with respect to LV customers in case of a phase-to-earth fault in the MV grid.

In 2005 models and actual measurements in an operating grid were preformed to determine the current distribution and touch voltages in a global earthing system. The results showed that a phase-to-earth fault leads to low touch voltages in urban global earthed areas. Furthermore it has been demonstrated that the highest touch voltage appeared during a short circuit at the end of a cable.

New developed grids start with a single: MV cable, MV/LV transformer and LV cable from the substation. Therefore this assembly does not benefit from a global earthing system, leading to higher touch and step voltages. To identify the magnitude of these voltages calculations and measurements have been preformed. The result of this study is that Continuon (grid operator of Nuon) sees no more objections to apply TN grounding in their network.

INTRODUCTION

Two important changes are implemented in the medium and low voltage grids served by the Dutch company NUON. First, NUON offers its low voltage customers a TN earthing system (ES). This TN systems gradually replaces the TT system, which had to be installed and maintained by the customers. Secondly, the MV grid is equipped with an effective neutral earthing, to replace the former isolated neutral system. Previous experiments showed that for rural and urban areas the safety could easily be guaranteed by measures at the MV-LV transformer [1].

New developed meshed grids that are radial operated start with a single XLPE MV cable, MV/LV transformer and LV cable from the substation. Therefore this assembly does not yet benefit from a global earthing system; leading to higher touch and step voltages. To identify the magnitude of these voltages, calculations and measurements were preformed. This has been done by modelling the currents and 'source voltage for touching' (SVFT) of one RMU. Also the effect of more ring main units (RMU) in a radial network (RN) was investigated by measurement.

MODEL SETUP

Calculations were carried out to determine whether touch and step voltages stay at a safe level in case of an assembly of a single: XLPE MV cable, MV/LV transformer, earth electrode at MV/LV transformer and LV cable. During experiments a current source (CS) applied at the substation eathing transformer (ET) and a current measurement (CM) is applied at the fault location (FL). To simulate the fault, ET2 is applied at the FL. We investigated the reduction of the SVFT by an extra earth electrode (R_{EXTRA}) at 50m and 100m upstream the MV/LV transformer.

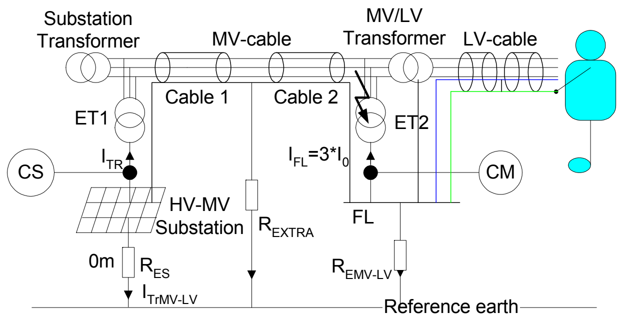

Figure 1: Grid assembly with extra electrode at 50 or 100m

The low voltage cable is neglected in both cases giving the worst values. Two types of the MV cable were investigated one with a 70mm^2 copper screen and the other with a 50mm^2 copper screen. Even more, the effect of low (9Ωm) and high (100Ωm) earth resistance is taken into account.

The resistance of the earthing electrodes at the MV-LV transformer (R_{EMV-LV}) is assumed to be between 0.2 and 2Ω, and the resistance to earth of the mesh earth electrode at the substation (R_{ES}) is 0.2Ω. Both ETs had a reactance of 7Ω. The length of cable1 is varied from 50m to 15km.

PARAMETER VALIDATION

The cable is modelled as a steady-state phasor admittance based on a standard model of a pipe-type cable in EMTP/ATP at 50 and 60 Hz for both screen diameter cases.

If the 60 Hz zero sequence parameters comply with the 60 Hz experiment one may assume that the 50 Hz calculated parameters are valid. The validity of the MV cable 50 Hz model is verified in two ways:
1. The one phase – screen impedance is validated using the impedance results of a Finite Element Method Model at 50 Hz;
2. The 60 Hz zero sequence parameters are checked with the 60Hz zero sequence experiment of a single MV cable running from a effective earthed substation bay to a grounding transformer.

A second 60 Hz experiment was done in three subparts to evaluate the current distribution in a radial network with more RMUs. The radial network should simulate a growing meshed network that is radial operated (MNRO) in its premature phase: it grows from a single ring main unit to some and several RMUs in a radial network and finally to a meshed network. Experiments regarding MNRO can be found in [1].

EXPERIMENT SETUP

To evaluate the calculated zero sequence impedance of a cable with 50 or 70 mm^2 screen, 433 meter cable of 70mm^2 and 50 mm^2 screen are connected in turn to a bay while the other is diconnected. The cable is connected at the end to a earthing transformer (ET). At 50m and 100m before the end of the cable, earthing electrodes can be connected to the cable screen. All applied electrodes are 9m in length with a resistance of 1Ω; see figure 2. At the substation a current source (CS) injects a 60Hz current in the starpoint of an earthing transformer. The injected current and the electrode voltages are measured (CM) at the earthing transformer ET2.

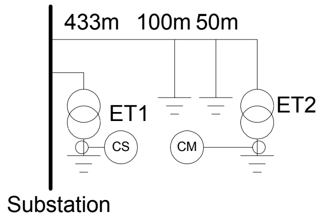

Figure 2: Grid layout zero sequence validation

To verify a developing grid the following measurement setups were made in the earlier used meshed MV and LV grid of [1]:
1. one RMU;
2. five RMUs;
3. nine RMUs.

The earthing screens of the existing MV grids are disconnected at specific points to construct a radial MV network. The LV grid and its screens are not disconnected. The three setups are depicted in figure 3, 4 and 5. The earth electrode at MV/LV transformer is disconnected in the setup of one RMU to validate the influence.

In case of the several RMU's in a radial network, the influence of extra earth electrodes is investigated at 50 and 100m upstream last RMU, see figure 5.

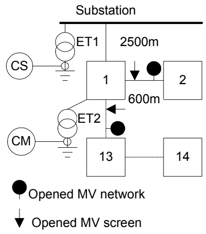

Figure 3: One RMU

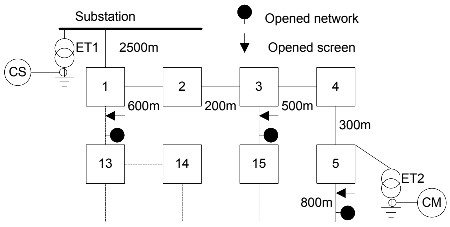

Figure 4: Five RMUs

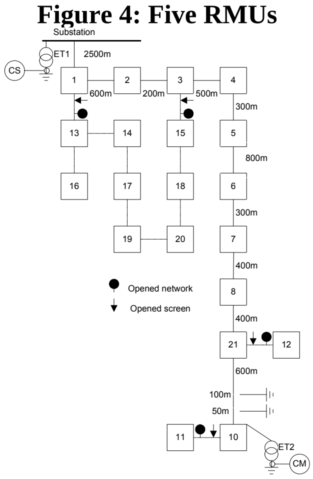

Figure 5: Nine RMUs

PARAMETER VALIDATION 50HZ

To verify the 50 Hz one-phase – screen impedance the following results were calculated:

	Z (Ω)	Z (Ω)	|Z| (Ω)	|Z| (Ω)	R (Ω)	Error |Z| (%)
XLPE AL240	analytic	FEMM	analytic	FEMM	analytic	(F-a)/a
70mm^2	0.383 + j0.0889	0.371 + j0.082	0.393	0.380	98%*Z	3.4
50mm^2	0.486 + j0.0899	0.470 + j0.086	0.494	0.478	98%*Z	3.4

Tabel 1 Validation one phase – screen impedance

The 50Hz phase - screen impedance is mainly resistive and can be calculated with an error of less than 4%.

MEASUREMENT METHOD

The measurements were performed in cooperation between Nuon Tecno and Eindhoven University of Technology (TU/e) . The fault was imitated by injecting a 60 Hz zero sequence current in the 50 Hz grid. This current was supplied by a 60 Hz motor generator, synchronized to the measuring equipment via GPS to within one degree of phase per day. The current was injected at the star point of ET1 at the substation. At the "fault location" a second ET was placed which provided a return path for the current in a same way as in a real fault.

EXPERIMENTAL RESULTS

Table 2 shows the results for the case of a single cable with a 70mm^2 earth screen. The experiments resulted in the shown SVFT per injected 3*zero sequence current at the fault location. The measurement and calculations shows that the model error is maximum 5% and that an extra electrode lowers the SVFT.

Electrode	Calculated (V/A)	Measured (V/A)	Error (%)
-	0.0815	0.0774	5.1
50 extra	0.0662	0.0658	0.7
100 extra	0.0693	0.0677	2.4
50-100 extra	0.0584	0.0581	0.6

Tabel 2: Results zero sequence 70mm^2

Table 3 shows the results for the SVFT case of a single cable with a 50mm^2 earth screen.

Electrode	Calculated (V/A)	Measured (V/A)	Error (%)
-	0.1107	0.1133	2.3
50 extra	0.0890	0.0950	6.8
100 extra	0.0935	0.0982	5.1
50-100 extra	0.0783	0.0842	7.6

Tabel 3: Results zero sequence 50mm^2

The measurement and calculations show that the zero sequence model error is maximally 8% for the thinner sheet. The extra electrode lowers the voltage. The thinner sheet gives a higher SVFT. From the results shown in table 2 and 3 it can be concluded that the zero sequence model can be accepted for further calculations.

# RMUs	RMU	Calculated (V/A)	Measured (V/A)	M/C (%)
1	1 –No electrode	-	0.0106	-
	1- With electrode	0.2470	0.0103	4.2
5	5	0.1405	0.0826	59
	4	0.0996	0.0433	43
	1	0.0273	0.0124	46
9	10	0.3070	0.0928	30
	4	0.1529	0.0042	3
	1	0.0802	0.0122	15
9 + electrode at 50m	10	0.1638	0.0659	40
	4	0.0673	0.0040	6
	1	0.0227	0.0122	54
9 + electrode at100m	10	0.1663	0.0713	43

Tabel 4: Results measurements at RMUs

Table 4 shows the results for the earlier described grid lay outs. The measured values are significantly lower than the calculated values. This is ascribed to non modeled earth connections in the LV grid as M/C is very low. This also explains the small influence of the extra earth electrodes in the case of one RMU. Given the results of 5 and 9 RMUs one concludes that the extra electrodes lower the voltage.
There is little influence on the measured values with and without earth electrode given one RMU. This is ascribed to non modeled earth connections in the LV grid as M/C is very low.

EXTRA EXPERIMENT

The measured current at the fault location ET2 (Fig. 4) was larger than the injected current at starpoint of the substation ET1. A resonance phenomenon was suspected. As a test we measured the zero sequence admittance at the substation as function of frequency. A 50 W audio amplifier was connected to a small C-core transformer. The earthing lead of the substation ET encircled the core twice. The zero-sequence admittance was determined by the ratio of the injected current and voltage, both measured with the aid of a lock-in amplifier. Two different circuits were employed, a) injection with only one ET L1 in the grid (o in Fig. 8), and b) injection while the second earthing transformer L2 was switched in parallel (x in Fig. 8). The two circuit diagrams are shown as insets. Curve fitting to the measured admittance gave the results summarized in Table 9. The zero-sequence selfinductance of the ET agreed well with manufacturer's data, L_1 = 7.74 mH. The resonance frequency f_a provided the total cable capacitance C_c, and f_b provided a value for L_2. The series and parallel resistance are caused by the transformer losses and skineffect on the conductors. One observes that $Rp = Rs*Q2/\sqrt{2}$ holds quite accurately, the factor of $1/\sqrt{2}$ stemming from the increase in series resonance in case b).

Reliable measurements could be performed with the small 50 W audio amplifier as current source, because of the sensitivity and selectivity of the measuring equipment. A broader range of frequencies, or frequencies closer to 50 Hz were also possible.

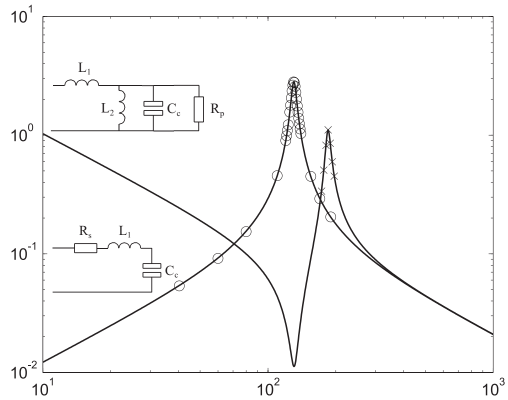

Figure 6: Measured zero sequence admittance with a single earthing transformer (o), and with two earthing transformers (x). The solid lines are a fit to the data. The insets show the schematic diagrams.

L_1 (mH)	C_1 (μF)	R_s (Ω)	f_a (Hz)	L_2 (mH)	R_p (Ω)	f_b (Hz)
7.74	193	0.35	130	7.68	89	185

Table 5. Circuit parameters derived from the fit to the data.

SIMULATION

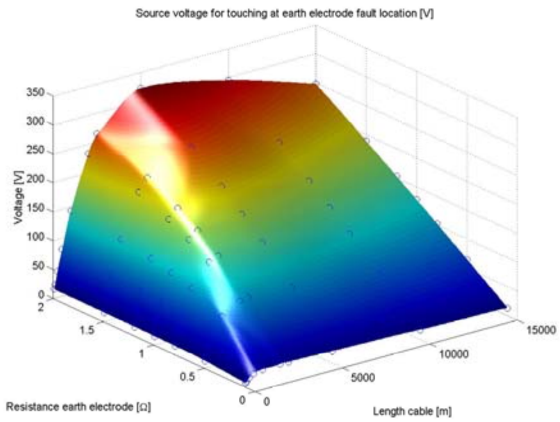

Figure 7: Al240/70mm2,100Ωm soil resistivity

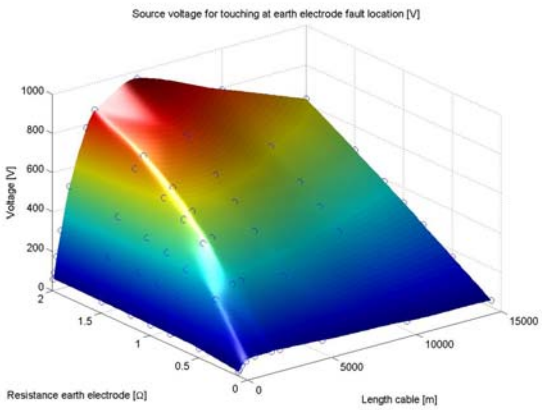

Figure 8: Al240/70mm2, 9Ωm soil resistivity

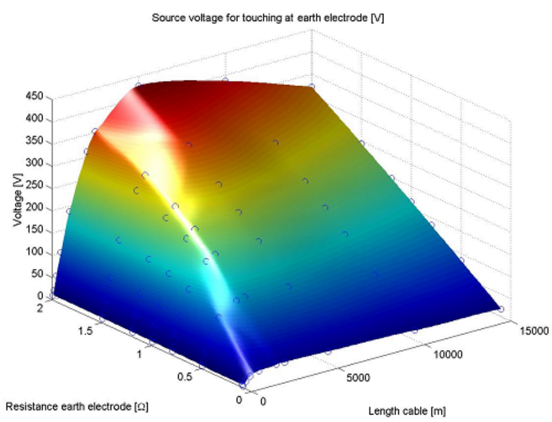

Figure 9: Al240/50mm2, 100Ωm soil resistivity

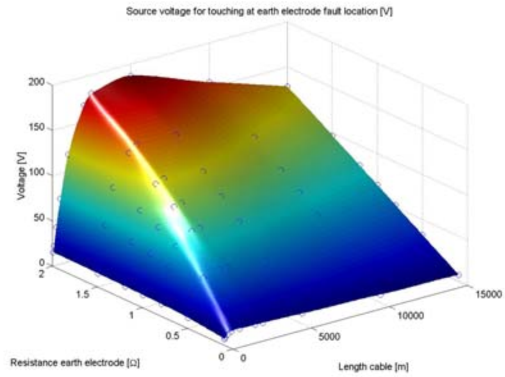

Figure 10: Al240/70mm2,100Ωm soil resistivity extra electrode at 50m

After the validation the model is used to calculate the SVFT. Reslust are shown in figure 7up to and including 10.

The simulations show that the maximum voltage is achieved in the first 5 km from the substation.

One electrode 2Ω		Two electrodes 2Ω	
70mm^2 100Ωm	70mm^2 9Ωm	70mm^2 100Ωm	70mm^2 9Ωm
350 V	980 V	200 V	600 V
50mm^2 100Ωm	50mm^2 9Ωm	50mm^2 100Ωm	50mm^2 9Ωm
450 V	1180 V	250 V	700 V

Tabel 6: Maxima at 2Ω earth electrode resistance

A lower soil resistivity leads to higher SVFT at equal earth electrode resistance as seen in table 6. A low earth resistance of the electrode is easier to obtain in a low soil resistivity situation, a practical 9m electrode in a 9Ωm soil results in a 1Ω resistance. Thinner screen leads to higher SVFT at equal earth electrode resistance. Extra earth electrodes at 50m lower the SVFT with about 40%.

Given the reduction by an extra earthing electrode and short time settings of protection equipment, the grid operator Continuon sees no objections to apply TN grounding in their network.

REFERENCES

[1] F.T.J. van Erp, J.F.G. Rasing, M.J.M. van Riet, F. Provoost, A.P.J. van Deursen, P.L.J. Hesen, “MODELLING AND LIVE MEASUREMENTS OF STEP AND TOUCH VOLTAGES AT LV CUSTOMERS IN URBAN AREAS CAUSED BY MV FAULTS”, *18 th International Conference on Electricity Distribution*, Session “: Power Quality and EMC, CIRED Turin ’05, 6-9 June 2005, paper 198