TRANSFER POTENTIALS FROM MV TO LV INSTALLATIONS DURING AN EARTH FAULT

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ABSTRACT

There is an ongoing debate about the circumstances where LV earthing systems should be connected to or isolated from adjacent MV earthing systems. The main concern with an isolated system is how to maintain this over the lifetime of the installation. Evidence from real networks suggests that there is a low incidence of LV system damage on isolated systems even when the separation distance in the ground has been prejudiced. Measurements and calculations on a test network with a distributed LV electrode system have shown that the actual transfer potential onto it is much lower than traditional calculations suggest. A more sophisticated calculation method is needed that accounts for the area enclosed by the LV electrode system, the size of the electrodes within it and their separation distances from the MV electrode.

INTRODUCTION

When an earth fault takes place at a medium voltage (MV) installation, the current that flows to ground via the electrode system creates a voltage rise, termed the Earth Potential Rise (EPR) [1]. Protective measures are designed and installed to control potential differences within the installation and adjacent to it. There is a debate about how to deal with the low voltage (LV) system. This has its own earthing and electrode system and contains the interface with the end customer and sometimes the public.

The two generally accepted methods are to bond the MV and LV earthing systems or to segregate them by introducing a physical separation in the soil.

Figure 1 is a simplified illustration of the two methods that does not account for the effect of the remote LV electrode system. The key decision is to ensure that the voltage safety limits in the LV system are met [1].

The preferred method in urban areas where there is significant density of electrode present is to bond the systems. This should have the advantage of providing a low overall earth resistance. As can be seen from Figure 1 however, the full EPR or at least a significant proportion of it is transferred to the LV system. The critical factor is the overall EPR. If it is low, interconnection is almost always the ideal solution. If the overall EPR, even with the systems bonded, is high then they would normally be separated. For this arrangement, as shown in Figure 1, the factors that influence the voltage transferred to the LV system are the physical separation distance and the MV EPR. The third most important factor is the structure of the ground the electrode systems are situated in.

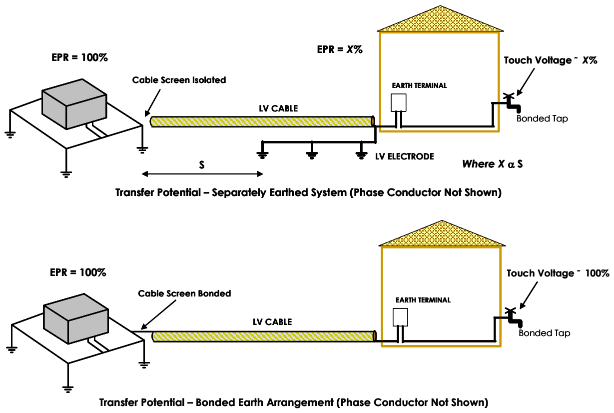
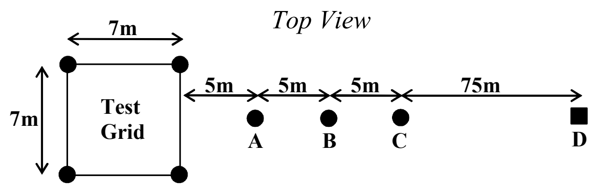


Figure 1: Bonded or segregated methods of earthing and the transfer potential

PRESENT METHODS OF CALCULATING TRANSFER POTENTIALS

The example to be used for calculation and initial measurements is that shown in Figure 2. The MV electrode is a horizontal rectangle of bare copper conductor, with vertical rods fitted at each corner. This is typical of the arrangement that would be found at a small distribution substation or transmission tower. The LV electrodes are vertical rods. In a real TNC-S network of the type used in the UK, these may be at LV cable joints, customer intake positions and the end of LV circuits. The LV cable cores, including the neutral/earth conductor, are enclosed in plastic insulation so only the rods are in electrical contact with the soil.



- Test Grid consists of a 7m square of buried copper conductor with earth rods connected at each corner of between 1.2 and 4.8m length.
- Electrodes A, B and C are 0.5m driven earth rods.
- Point D is the connection point to a ‘real’ LV earthing system whose dimensions are not known but has a measured earth resistance of 4.38 Ohms.

Figure 2: Test arrangement

Formulae are available from standards to enable the potential (V_S) at a point in the soil a distance x from the centre of the MV electrode to be calculated. Equation {1} below is from EA ER S.34, Table 3 [2] where ρ is the soil resistivity (Ωm), *I* is current (A) and R_g is grid resistance (Ω).

{1} $$V_S = \frac{\rho I}{2\pi r}\arcsin\frac{r}{x}$$

Where, $$r = \frac{\rho}{4R_g}$$

Equation {1} has been applied to the arrangement shown in Figure 2, to calculate the potential at LV electrodes A to D. The results are expressed as a percentage of the EPR on the 'Test Grid', as follows:

A:	35.6%
B:	21.8%
C:	15.8%
D:	3.1%

Traditionally a design engineer would calculate the EPR on the MV electrode and then use the formula to determine how far away the first LV electrode must be situated for it to be at or below a certain voltage threshold. This is typically 430V or 650V within Europe and 300V in North America. The underlying assumption has been that the potential picked up from the soil by the first rod is transferred into the LV network neutral/earth conductor.

More complete calculations can also be made using computer software [3] that accounts for the electrode shape and soil characteristics. This has been used for subsequent calculations as the simple approach (Equation 1) overestimates the transfer potential. Voltage contours are produced that illustrate the potentials around the installation (see Figure 3). The contour lines are not completely symmetrical because the rods at the grid corners are of different lengths.

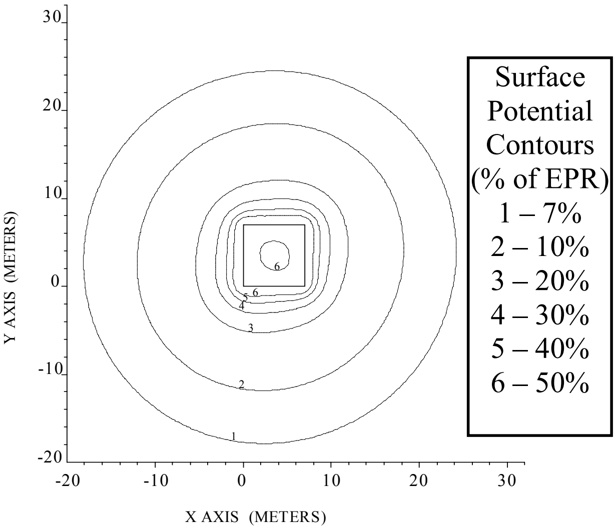


Figure 3: Surface potentials around 'test grid'

WHAT ARE THE PRACTICAL CONCERNS AND EXPERIENCE ?

For segregated systems, the main issue is how to maintain the physical separation into the future. An 'exclusion zone' is needed around the MV electrode in which no LV electrodes are permitted. The zone radius can range from a minimum of 3m up to 20m or more. As the network develops over time, it is inevitable that LV earthed structures (such as a metal street lighting column or a new house) will eventually appear within the exclusion zone. Experience suggests that damage can be caused, mainly to telecommunication equipment or cables, when an excessive potential is transferred into the LV network via the soil or by an incorrectly fitted MV/LV earth connection (e.g. via cable glands).

Statistical investigation in the UK has revealed that there are many situations where the MV/LV separation distance has been compromised on segregated systems, yet the number of damage incidents remains quite low. This was considered to warrant further investigation, in particular to see if the separation distances could be safely reduced.

For interconnected systems, part of the MV fault current and the EPR will be transferred into the LV network. The main concern is to ensure that conditions remain safe within the LV network and that voltage or thermal constraints are not exceeded. Again there is evidence of damage caused to telecommunication equipment fitted on the LV system co-incident with a fault on the MV system. A most interesting study in Canada [4] revealed that the touch voltage on the LV system near a power installation can be as high as 50% of the MV EPR on an interconnected system. Within the MV installation an electrode system is required and typically restricts touch voltages to just 5% to 20% of the EPR. In this situation, the connected LV system is only safe if the MV EPR is very low or if additional protective measures are used.

INVESTIGATION INTO MORE REPRESENTATIVE EARTHING SYSTEMS

In the UK, the most common earthing arrangement on the LV network is TNC-S, where the neutral and earth conductors are combined in the distributors network. More importantly, to protect against the adverse effect of a broken neutral, this conductor has electrodes fitted at a number of geographically dispersed positions.

It is now appropriate to return to Figure 2. The copper rods at positions A, B and C would all be connected to the LV neutral conductor and hence to one another. So what will the actual voltage rise be on the LV neutral/earth? Will there be any significant current flow due to this in the neutral or any mutual interaction with the potential contours established by the MV electrode due to the presence of these connected LV electrodes?

For the first investigation, the grid was energized and the surface potential measured along a 30m traverse in the direction A to C. The transfer potential was measured on Electrodes A, B and C and also on combinations A-B, B-C and A-B-C, connected together with a low impedance lead. Calculations using CDEGS MALZ [3] were carried out (used to account for the three-layer soil structure and test rod characteristics). The measurements were carried out using a derivative of the traditional fall of potential measurement technique.
The measured and calculated results for the surface potential over the 30m traverse are shown in Figure 4.

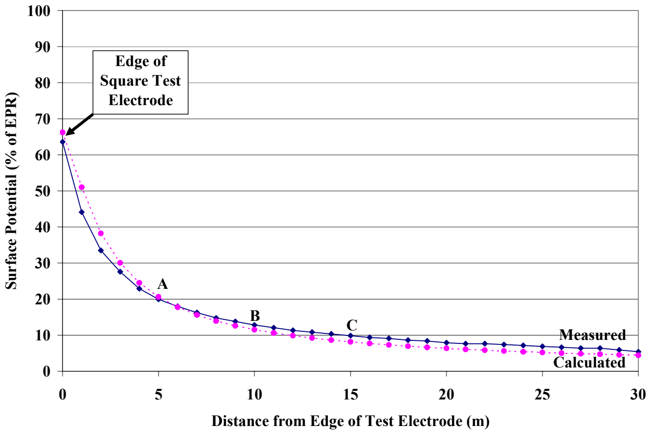


Figure 4: Calculated and measured surface potential profile in the direction A to C.

As can be seen, there is excellent correlation between the measured and calculated values. The surface potential at the locations of Electrodes A, B and C is transferred to each electrode when isolated. The values are shown in Table 1, together with the measured values for the connected rod combinations. Also shown are the corresponding results for similar arrangements simulated in CDEGS MALZ [3].

LV Electrode Arrangement	Measured Transfer Potential (% of EPR)	Calculated Transfer Potential (% of EPR)
A	20.0%	20.6%
B	12.8%	11.5%
C	10.1%	8.1%
A & B	16.7%	16.1%
B & C	11.6%	9.8%
A & B & C	14.8%	13.4%

Table 1: Measured and calculated transfer potentials from 'test grid' to different LV earth rod arrangements.

From Table 1, it can be seen that the calculations support the measurement result outcomes.
As would be expected, the potential on the connected electrodes becomes about the average of the potential on each of them before they were bonded

The investigation needed to be taken a stage forward, mainly because the LV electrode arrangements examined were simple. In particular there were only three short rods that would have minimal impact upon the MV potential contours. Each rod was of similar length and had a measured resistance of about 200Ω.

The next stage is to introduce a large, low resistance electrode into the LV earthing system. In real networks, it is usual to have one or two large electrodes to achieve the required overall resistance value. In Figure 2, electrode D is a large LV earthing system with a resistance about fifty times lower than that of one of the rods.

LV Electrode Arrangement	Measured Transfer Potential (% of EPR)	Calculated Transfer Potential (% of EPR)
A	20.0%	20.6%
B	12.8%	11.5%
C	10.1%	8.1%
D	1.2%	1.5%
A & B & C & D	2.5%	2.3%

Table 2: Measured and calculated transfer potentials from 'test grid' to different LV electrode arrangements.

The outcome from the simple network (see Table 1), on reflection is a fairly obvious finding - although so obvious as to be overlooked in the past! The results in Table 2, after adding the dominant Electrode D, are a little more surprising, as the transfer potential is now much lower than the average and has been 'skewed' down by the dominant electrode. The measurement results are again supported by calculations.
The results may have significant implications for LV electrode systems. If we assume that calculations using the previous method required a 5m separation, then the transfer potential in this example onto Electrode A, should result in a transfer potential of 20% of the EPR. In the various studies where the electrodes have been connected together, the transfer potential ranges from 16.7% down to 2.5%, depending upon the location and size of the electrodes connected. In other words, the potential on the LV neutral is between 3.3% and 17.5% lower than anticipated.
This effect, if occurring in a real system, can explain the lack of damage to telecommunication equipment mentioned earlier. If this was supplied from the LV network, its neutral conductor would rise to the potential shown in Tables 1 or 2, whilst its earth would be at a much lower potential (due to this being connected to a remote, true earth). The equipment internal stress voltage (i.e. between the neutral and earth) would be much lower than anticipated and probably not cause an insulation breakdown.

Most LV installations within the UK have a modestly sized horizontal or vertical electrode installed at the start of the network and would have more rods/electrodes distributed over a larger area than that of the test example.

The findings so far are most enlightening and investigations are to continue to include more complex examples and a representative sample of real MV/LV networks. A number of suitable sites have been identified and measurements/calculations are planned for February and March 2007.

Once the additional investigations are complete and the results analysed, it will be necessary to derive a new set of design rules that can account for these effects and hopefully simplify the installation process. This will impact upon separation distances necessary between different systems, steel framed buildings or domestic properties near large substations and other situations.

We hope that some of the results and design rules are available for presentation at CIRED 2007.

ACKNOWLEDGMENTS

Suhaib Kamarudin for his contribution to the on-site testing whilst working in the UK.
Andrew Bower (EA Technology Ltd) for his advice and guidance during the early stages of the project whilst at the Energy Networks Association.
The Energy Networks Association and their member companies for their financial support of the project and desire to make the findings known.

REFERENCES

[1] IEC61936- 1, Section 10, Power installations exceeding 1kV a.c. – Part 1, Common Rules, 17th October 2002
[2] Electricity Association Engineering Recommendation S.34:1986, A Guide for Assessing the Rise of Earth Potential at Substation Sites.
[3] Current Distribution, Electromagnetic Interference and Grounding Analysis Software (CDEGS), Safe Engineering Services, Canada, 1996.
[4] Yves Rajotte, Jean De Steve, Jaues Fortin, Richard Lehoux, Georges Simard, June 2005, Earth Potential Rise Influence Near HV Substations in Rural areas, CIRED (Turin) 2005.