

GLOBAL EARTHING SYSTEM CHARACTERISATION OF AN ACTUAL UK DISTRIBUTION NETWORK

Dr Paul JONES, Dr Mark DAVIES, Dr Robert WELLER, Stephen LILLEY
 RINA - UK
 paul.jones@rina.org

Stephen TUCKER
 UK Power Networks - UK
 stephen.tucker@ukpowernetworks.co.uk

ABSTRACT

Defining a distribution network as a global earthing system (GES) can simplify the design requirements when adding new substations to a network. Examples often cited include cable networks in dense-urban or city-centre locations, and large industrial areas. A far greater proportion of a network may supply small towns and villages, and these are often discounted as GES due to reduced geographical coverage or lower substation density. Two small networks, fed from a common source substation, have been examined in detail to see if any GES characteristics may be observed. Comprehensive CDEGS models, validated through field-testing, are compared with results from the simplified design tool developed by UK Power Networks.

INTRODUCTION

UK Power Networks, the electricity distribution network operator for London and South East England, developed a simplified design tool [1] for evaluating the earthing and safety requirements for new substations being added to their distribution network. A range of standardised earthing designs are included within the tool allowing the most cost-effective solution to be selected based upon the network topology, construction, and soil resistivity. Further refinements are ongoing, but a significant improvement allowed for network contribution to be more accurately defined based upon the concept of effective area [2]. This is currently directed towards dense-urban or rural networks, but it may be beneficial to introduce a third classification - for more compact networks such as those serving small towns and villages.

As a starting point, two adjacent networks were identified, fed from a common Primary 66kV/11kV substation. The first network services a large village (0.4km²) and contains a mixture of XLPE and older paper-insulated lead-sheath underground cables. The second network covers a similar area but is a relatively modern research park and is almost entirely constructed from insulated sheathed cables (with buried grading electrodes installed along HV routes). Both networks are sufficiently remote from the source substation that they may be considered as independent earthing systems.

Comprehensive computer models have been constructed using CDEGS [3], incorporating the local earthing systems installed at each substation, both the HV and LV (when known) cables networks, and representations of the earthed building steel-work associated with the research park.

Field-testing was undertaken at the Primary substation and nine of the associated distribution substations. Soil

resistivity surveys, earth impedance measurements and worst-case touch potentials where determined, and the results are in good agreement with the values predicted through simulation.

This work is part of a wider research project being carried out by UK Power Networks to investigate global earthing systems via the Ofgem Network Innovation Allowance scheme.

NETWORK MODEL

The overall network model is shown in Figure 1, where red, blue, and green-lines denote HV cables, LV cables, and bare earth electrode respectively. Detail views are provided in Figure 2 and Figure 3.



Figure 1. Overall Network Model

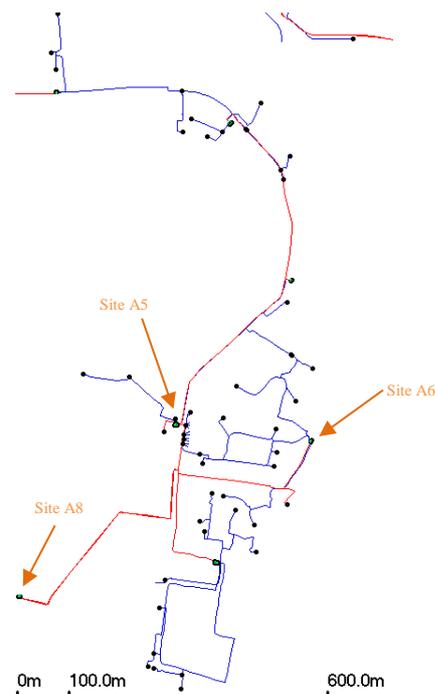


Figure 2. Detail view of Village Network

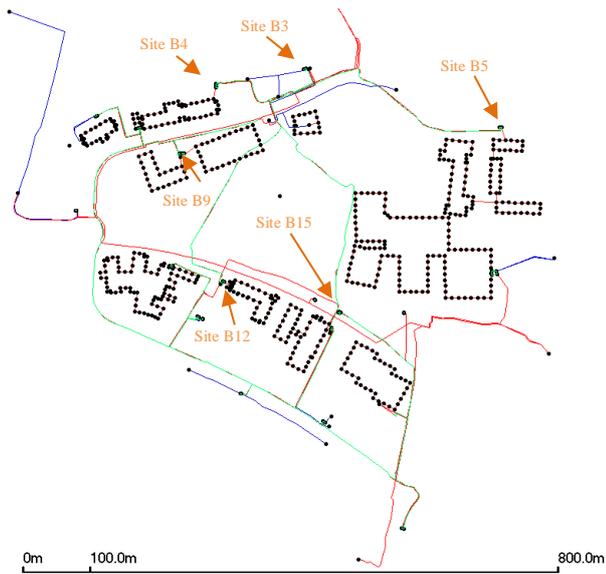


Figure 3. Detail view of Research Park Network

The village network contains eight substations and due to their age, and lack of records, it has been necessary to make approximate representations of their local earthing provision, apart from Site A8 which is relatively new. The twenty-two substations associated with the research park are based upon a 3m x 3m buried copper loop supplemented with 2 x 2.44m rod electrodes. An example of which is shown in Figure 4.

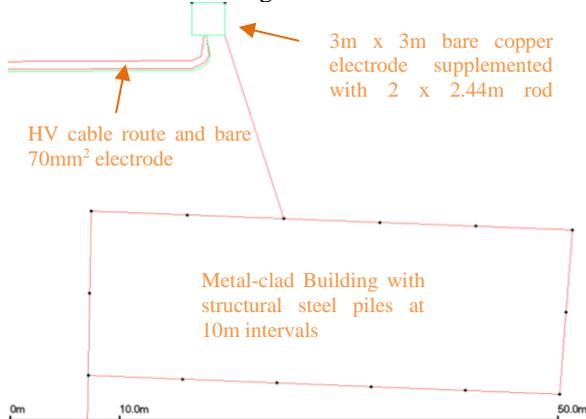


Figure 4. Example distribution substation earthing

Note that the two adjacent systems are interconnected via cable screens at an intermediate substation, although operated as radial networks on the HV system. The interface is approximately mid-way between both systems.

SITE-TESTING AND MODEL VALIDATION

Soil Resistivity

The two-layer soil model provided in Table 1 was derived from the apparent resistivity curves shown in Figure 5.

Measurements, based upon the Wenner technique [4], were taken at seven locations in the vicinity of the two networks and the Primary substation.

Table 1. Soil Model

Layer	Soil Resistivity (ohm-m)	Thickness(m)
1	132.0	3.7
2	56.0	Infinite

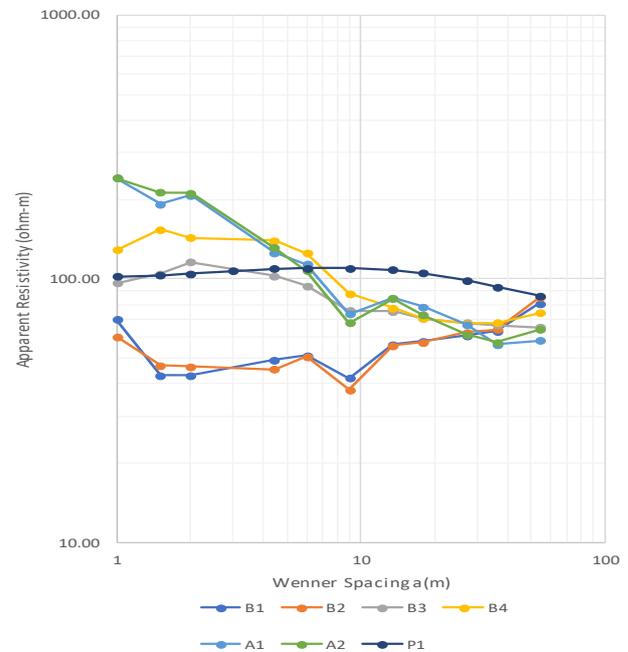


Figure 5. Apparent Resistivity Curves

The resulting soil model is considered representative.

Earthing System Impedances

The earthing system impedance looking into the overall network at each of the nine selected distribution sites was measured using the Fall of Potential technique [5]. An AC current injection system [6] was used to perform the measurements, with current electrode spacings ranging from 200m to 400m and a constant test-lead separation of 5m. The mutual coupling correction technique proposed by White et al [7] was applied to the raw-data, and a sample apparent earth impedance magnitude curve is provided in Figure 6.

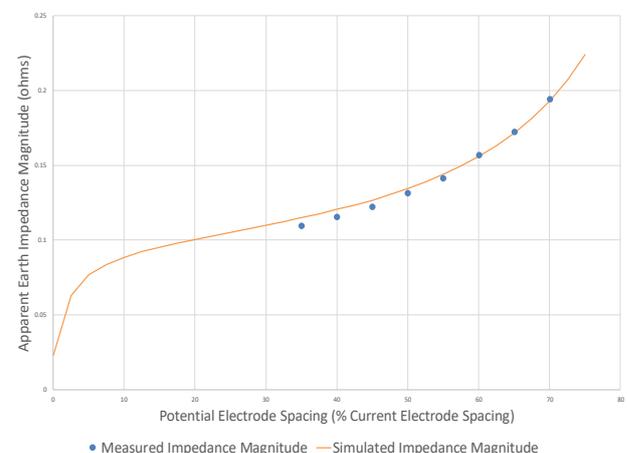


Figure 6. Apparent Earth Impedance Magnitude, Site B12

The test routes and return electrodes were included in the computer model, and simulated apparent impedance curves were produced for each substation. The simulated apparent impedance magnitude curve for Site B12 is included in Figure 6 (orange line) and is in good agreement field-test data.

The earthing system impedance values are summarised in Table 2 (column 2). The RMS error between the measured and simulated magnitude is also included (column 3).

Table 2. Predicted Impedance and RMS Error

Site Name	Calculated Earth Impedance (ohms)	R.M.S. Error
Site A8 (1)	0.295 ∠ 45.5°	0.012
Site A6 (2)	0.170 ∠ 29.6°	0.012
Site A5 (3)	0.144 ∠ 24.8°	0.022
Site B3 (4)	0.210 ∠ 42.8°	0.041
Site B4 (5)	0.171 ∠ 36.5°	0.032
Site B5 (6)	0.207 ∠ 35.3°	0.007
Site B9 (7)	0.150 ∠ 31.2°	0.019
Site B12 (8)	0.145 ∠ 33.7°	0.003
Site B15 (9)	0.130 ∠ 22.1°	0.008

Substations B3, B5, and A8 are located on the periphery of their respective earthing systems, and have correspondingly higher earth impedance values.

Touch Potential Measurements

Worst-case touch potentials were measured in the immediate vicinity of each substation, with reference to the local earthing system and the artificial return electrode used during the impedance measurements. Figure 7 provides calculated values for Site B12, and the measured and simulated values are compared in Table 3. Note that the red-mesh in Figure 7 denotes the 1m x 1m reference grid used to define the measurement locations, with positions 1 and 4 lying 1m outside the substation enclosure. The injected current was approximately 1A @ 45Hz.

Table 3. Comparison between Simulated and Measured Touch Potentials at Substation B12

Simulated (mV)	Measured (mV)						
1	2	3	4	5	6	7	8
33.5	40.1	34	38.1	39.3	43.8	45.9	44.7
47.8	47.4	48.1	44.9	50.4	45.9	53.7	47.4
56.8	46.5	56.5	46.3	57.5	47.4	59.5	47.1
61.6	50.0	61.8	50.1	62.4	47.4	63.4	49.3
65.1	55.5	65.1	49.5	65.6	48.8	66.3	42.6

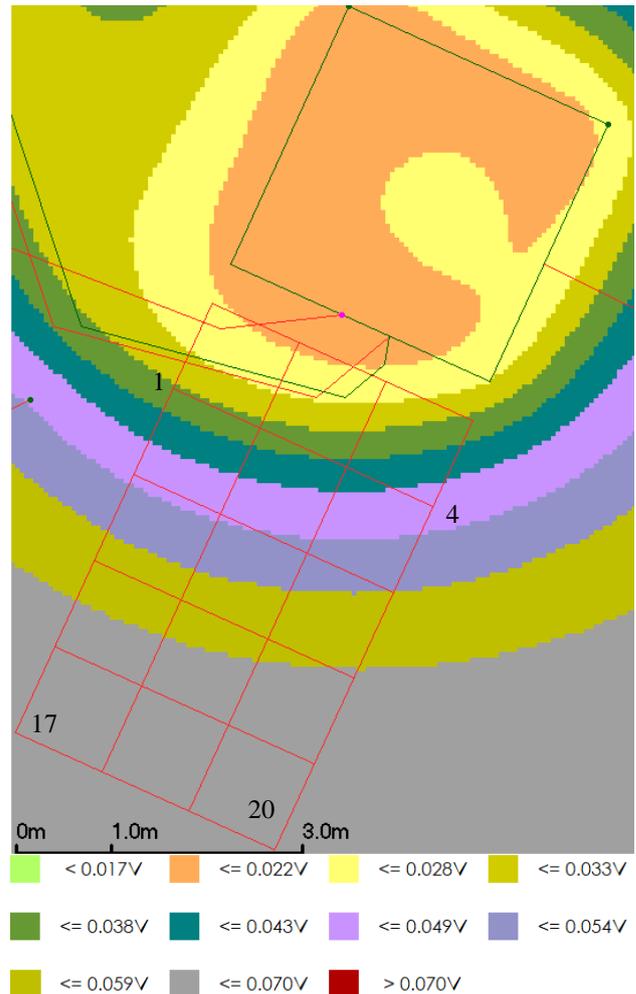


Figure 7. Worst-case Touch Potentials, Site B12

With reference to Table 3, measured values are generally lower than those predicted from the simulation. The exact entry point of the HV and LV cables is unknown so the model is only considered an approximation in this aspect.

NETWORK CLASSIFICATION

BS EN 50522 [9] defines a Global Earthing System as an ‘equivalent earthing system created by the interconnection of local earthing systems that ensures, by the proximity of the earthing systems, that there are no dangerous touch voltages’.

The Ellipse Method [8] has been suggested as an empirical method for classifying and approximating the extent of a global earthing system, as no guidance is provided in the current UK standards.

The method has been applied to the network associated with the Research Park, and this produced the red boundary line shown in Figure 8, encapsulating almost the entire local system.

The technique could not be applied to the Village network because of insufficient substation density – the method

requires that 10 substations should be encompassed by the initial ellipsoid search area. The blue line shown in Figure 8 (target ellipse) only contains five substations. It is suspected that the PILC cable interconnecting the four central substations would more than compensate for the reduced substation density however.



Figure 8. Ellipse Method for GES Boundary identification

Further work is required before the method will gain widespread acceptance, in particular, the justification for the dimensions of the geometric shapes used and whether these are applicable/suitable for all network configurations.

DETAILED HV FAULT STUDIES

The CDEGS HIFREQ module enables concentric and 3-core cables to be modelled explicitly, allowing earth return currents (I_{GR}) to be calculated without recourse to screening factors. Three distribution sites from each network were chosen for further study, and the predicted earth potential rise (EPR) and I_{GR} values are provided in Table 4. Calculations were also carried out using the UK Power Networks design tool, for various network configurations, and these results are also provided in Table 4 for comparison.

Table 4. Comparison between HIFREQ and UK Power Networks Tool for various network configurations

Site	Tool Legacy	Tool Urban PILC	HIFREQ
Site A5 $I_F=605A$	$I_{GR}=100\%$ EPR=89V	L=500m EPR=79V	$I_{GR}=100\%$ EPR=63V
Site A6 $I_F=698A$	$I_{GR}=100\%$ EPR=114V	L=500m EPR=91V	$I_{GR}=100\%$ EPR=94V
Site A8 $I_F=641A$	$I_{GR}=100\%$ EPR=206V	L=200m EPR=161V	$I_{GR}=100\%$ EPR=77V
Site B3 $I_F=1517A$	$I_{GR}=11.4\%$ EPR=47V	L=200m EPR=44V	$I_{GR}=13.0\%$ EPR=49V
Site B5 $I_F=1497A$	$I_{GR}=11.4\%$ EPR=44V	L=200m EPR=43V	$I_{GR}=12.9\%$ EPR=40V
Site B12 $I_F=1467A$	$I_{GR}=11.4\%$ EPR=29V	L=200m EPR=22V	$I_{GR}=11.3\%$ EPR=33V

Note that Legacy values (column 2) refer to calculations based upon the measured overall earthing system

impedance values, entered directly. Urban PILC values (column 3) refer to estimated impedance values determined directly from the tool using the effective area approach. Lengths of 500m have been applied to central sites, and 200m to sites located at the perimeter of the associated network.

With reference to Table 4, the calculated EPR values are generally conservative or marginally lower with respect to the HIFREQ results, when using the Legacy impedance values. The Urban PILC results are broadly similar, but are dependent upon the particular value of cable length selected to represent the wider network. Site A8 shows the biggest discrepancy and this substation least resembles the GES construct, being loosely bound to the parent network located 380m to the east. Also, there is generally good agreement between the tool and the HIFREQ simulations with regards to overall earth return current. Network A contains sections of overhead line (hence $I_{GR}=100\%$ of I_F), but Network B is exclusively cable-fed.

A surface potential plot is provided for the Site B12 fault in Figure 9, expressed a percentage of maximum EPR. It is debateable as to whether the network has created a quasi-equipotential surface, but clearly, surface potentials are elevated throughout the majority of the Research Park and are generally greater than 10%. There is negligible impact on the adjacent village due to the high series impedance between the systems, and that the only connections from the Park to the wider network are via insulated cable.

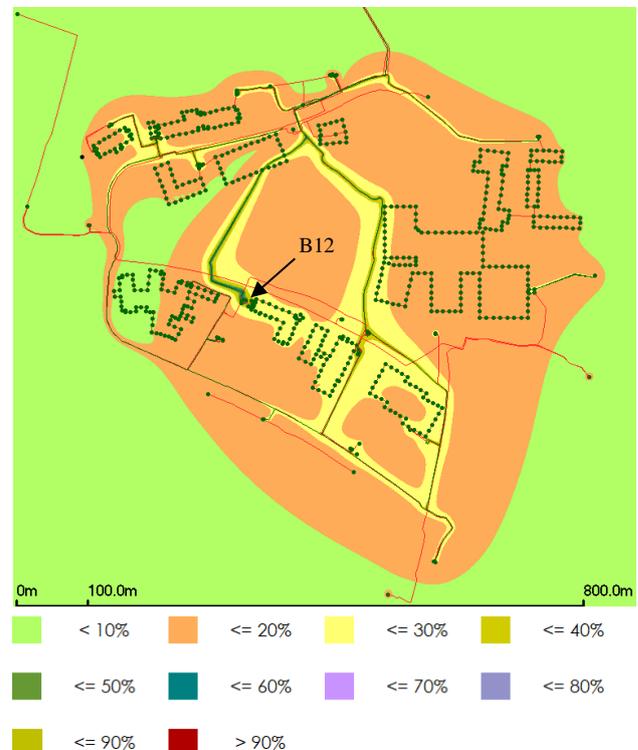


Figure 9. Surface Potentials (%EPR), Site B12 Fault

The corresponding surface potential plot for a fault at Site A6 is provided in Figure 10. Although the overall earth impedance is broadly similar to Site B12, the surface

potential disturbance covers a greater area when compared to the Research Park fault. A large proportion of the network is PILC, and the OHL connection to the Primary forces all of the current to return via the soil. Minimum surface potentials impacting upon the village are generally greater than 20% of EPR, and the shape of the network produced a more uniform distribution.

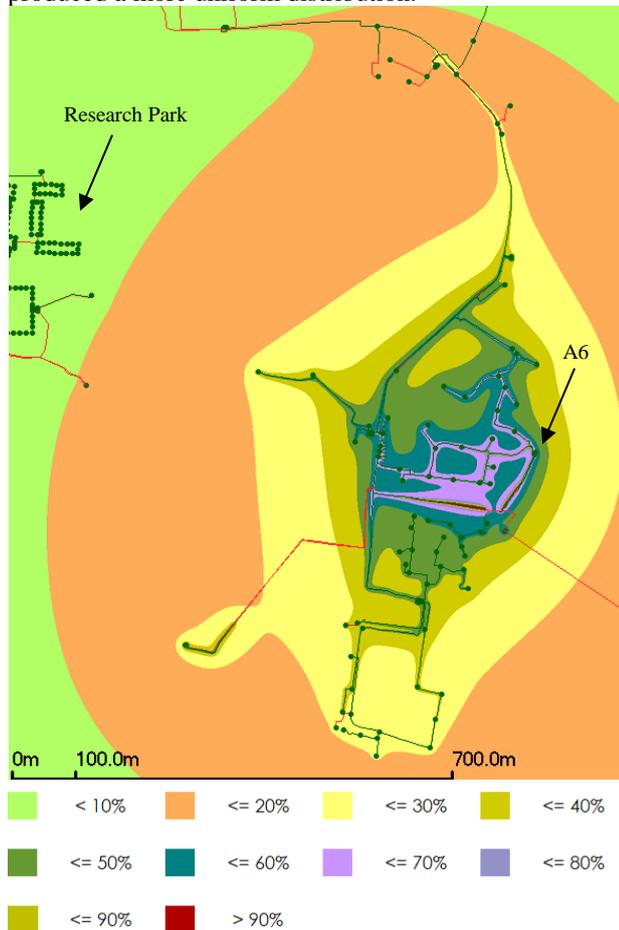


Figure 10. Surface Potentials (%EPR), Site A6 Fault

CONCLUSIONS

Whilst it is possible to produce a detailed computer simulation of the earthing performance of an overall network, considerable effort is required to construct and validate the model. This is not a practical solution when a large number of networks are to be assessed.

UK Power Networks have developed a software tool, allowing site-specific calculations to be performed for each new distribution substation added to the network. The process is cost-effective. Soil resistivity data, fault levels, and network construction details are utilised.

The comprehensive models clearly show that for relatively small networks, the wider network can dominate the overall earthing performance of an individual substation, especially where lead-sheathed cables or radial electrodes are employed. Therefore it is sensible to consider the network as a single entity if a cost-effective design is to be

produced.

The surface potential plots from the detailed simulations indicate that any system will have an effective area, beyond which there will be little or no effect. The extent of which is governed by soil resistivity, electrode density, and connectivity. The two adjacent networks in this study are acting as separate entities rather than an amalgamated system as they are only loosely bound at their extremities.

Although techniques such as the Ellipse Method may be used to classify GES, insufficient substation density may limit its use for small networks and the contribution of underground cables with electrode effect cannot be ignored.

Further work is underway to better understand the implications of effective area, and to further refine the design tool.

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