Eskom	Standard	Technology

Title: **CONTINUITY MEASUREMENT OF SUBSTATION EARTH GRID SYSTEMS**

Unique Identifier:	**240-84854974**
Alternative Reference Number:	**41-642**
Area of Applicability:	**Engineering**
Documentation Type:	**Standard**
Revision:	**1**
Total Pages:	**17**
Next Review Date:	**February 2022**
Disclosure Classification:	**Controlled Disclosure**

Compiled by	Approved by	Authorized by
Theunus Marais	**Colin Smith**	**Phineas Tlhatlhetji**
Chief Engineer – Substation Engineering	**Manager – Design Base Maintenance**	**Senior Manager – Substation Engineering**
Date: 6/02/2017	Date: 07 FEB 2017	Date: 21/02/2017

Supported by SCOT/SC

Archie Jaykaran

Chairperson – Power Delivery Plant Maintenance SC

Date: 17 Feb 17

PCM Reference: **Execute Work**

SCOT Study Committee Number/Name: **Maintenance & Operating**

Content

Page

1. Introduction 4
2. Supporting clauses 4
   2.1 Scope 4
      2.1.1 Purpose 4
      2.1.2 Applicability 4
   2.2 Normative/informative references 4
      2.2.1 Normative 4
      2.2.2 Informative 4
   2.3 Definitions 5
      2.3.1 General 5
      2.3.2 Disclosure classification 5
   2.4 Abbreviations 5
   2.5 Roles and responsibilities 6
   2.6 Process for monitoring 6
   2.7 Related/supporting documents 6
3. Conducting earth continuity measurements 6
   3.1 Acceptable measured value 6
   3.2 Measurement frequency 7
      3.2.1 New/additional plant installation 7
      3.2.2 Post fault conditions 7
      3.2.3 Known problem areas 7
      3.2.4 Planned continuity testing 7
   3.3 Safety considerations while doing the tests 7
      3.3.1 General considerations 7
      3.3.2 Adverse weather conditions 8
      3.3.3 Reducing the effects of induced voltages in test leads 8
      3.3.4 Reducing the effects of damage to test equipment 8
   3.4 Factors affecting the accuracy of results 8
   3.5 Equipment and accessories 9
      3.5.1 Test instrument 9
      3.5.2 Current leads 9
      3.5.3 Potential leads 9
      3.5.4 Clamping devices 9
   3.6 Test method 10
      3.6.1 Measuring method description 10
      3.6.2 Reference points 11
      3.6.3 Fences 11
      3.6.4 Overhead line terminal towers 11
   3.7 Recording of results 12
   3.8 Analysing, allowable variances and trending 12
   3.9 Recommendations 12
   3.10 Safe keeping of records 12
4. Authorization 13
5. Revisions 13

6. Development team 13

7. Acknowledgements 13

Annex A – Example of Recording Format for Continuity Measurement of Substation Earthing Systems 14

Figures

Figure 1: Typical leads and clamping devices (red for current, black for voltage) 10

Figure 2: Four point measuring method connection 11

Figure 3: Recording of resistance value 12

1. Introduction

This standard defines the requirements for the testing of the earth continuity of Distribution and Transmission substation earth grids.

Testing the continuity of a substation earth grid is important to establish the integrity of a new or existing grid and is a necessity to detect any open circuit or isolated structures/equipment that should be connected to the earth grid. Furthermore, continuity tests are essential to ascertain the degradation of earthing conductive material, primarily copper, by way of mechanical failure or corrosion activity

This standard serves as a formal method of testing from which any deviation will cause inconsistency in test results.

2. Supporting clauses

2.1 Scope

This standard details the methodology to be followed when testing earth continuity in distribution and transmission substations. Substation earth grid continuity testing is important to establish the integrity of new or existing earth grids and is a necessity to detect any open circuit or isolated structures/equipment that should be connected to the earth grid.

2.1.1 Purpose

The purpose of this document is to provide employees and contractors with a methodology to follow in carrying out substation earth grid continuity measurements in order to determine if all structures within the substation are connected to the earth grid.

2.1.2 Applicability

This document shall apply throughout Eskom Holdings Limited Divisions. This standard is intended for those involved in the commissioning and maintenance of Distribution and Transmission substations.

2.2 Normative/informative references

Parties using this document shall apply the most recent edition of the documents listed in the following paragraphs.

2.2.1 Normative

[1] 240-44175132, Eskom Personal Protective Equipment (PPE)

[2] 240-76624513, Standard for the Calibration of Test Instruments Used by Field Staff

[3] BS 7430:2011+A1:2015, Code of practice for protective earthing of electrical installations

[4] NRS 000-1, NRS Definitions

[5] OHS Act No. 85, Occupational health and safety act and regulations.

2.2.2 Informative

[6] DPC 34-227, Pre-Task Planning and Feedback Process

[7] IEEE Std 81, IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Grounding System

[8] IEEE Std 81.2, IEEE Guide for Measurement of Impedance and Safety Characteristics of Large, Extended or Interconnected Grounding Systems

[9] ISO 9001, Quality Management Systems

2.3 Definitions

2.3.1 General

Definition	Description
Bonding/shunt conductor	A conductor designed and constructed to ensure a touch potential free working area by introducing a temporary jumper.
Earth	Conducting mass of the earth whose electrical potential at any point is conventionally taken as zero.
Earth conductor	Conductor of low impedance which provides an electrical connection between a given point in equipment (an installation or system) and an earth electrode.
Earth connection	Terminal or clamp at earth potential, to which all the equipment earth wires are connected and to which an earth electrode is connected externally.
Earth electrode	Part, or group of parts, of the earth termination system which provides direct electrical contact with, and disperses fault and lightning current to the general mass of earth. Conductor or group of conductors in intimate contact with and providing an electrical connection to the earth.
Earth grid/mat	An earth electrode consisting of a large rectangular arrangement of conductors buried in trenches and divided by longitudinal and transverse conductors into a number of smaller rectangles. (Also refer to the definition of earth electrode above.)
Earthed/earthing	The electrical connection between an apparatus and the general mass of earth in such a way that it will ensure a safe discharge of electrical energy.
Earthing system	A system intended to provide at all times, by means of one or more earth electrodes in a specific area, a low impedance path for the immediate discharge of electrical energy, without danger, into the general mass of the earth.
HV yard	Enclosure that contains exposed overhead medium voltage, high-voltage; extra-high voltage or ultra-high voltage components.
Order of magnitude	A level in a system used for measuring something in which each level is ten times larger than the one before.
Prohibited area	An enclosed area in which live conductors or live parts of electrical apparatus working at high-voltage are accessible, but situated in such a position that inadvertent human contact therewith is not possible from ground/floor level.

2.3.2 Disclosure classification

Controlled disclosure: controlled disclosure to external parties (either enforced by law, or discretionary).

2.4 Abbreviations

Abbreviation	Description
Dx	Distribution
HV	High voltage
I	Current, measured in amp (A)
NEC	Neutral earthing compensator

Abbreviation	Description
NECRT	Neutral earthing compensator with series resistor and auxiliary windings
NER	Neutral earthing resistor
PPE	Personal Protective Equipment
R	Resistance, measured in ohm (Ω)
s/s	Substation
SCOT	Steering Committee of Technologies
Tx	Transmission
V	Voltage, measured in volt (V)

2.5 Roles and responsibilities

The designated person or his/her delegate shall ensure that this standard is implemented and adhered to. The authorized/responsible person is responsible for the safe execution of all work and activities as set out in this document.

2.6 Process for monitoring

All work shall be done in accordance with the following documents:

1) 240-45920887, Process Control Manual (PCM) for Manage Maintenance Base.
2) DPC_34-04, Procedure for Management Of Technical Documents For SCOT.
3) 32-1397, Process Control Manual (PCM) for Execute Work (Wires)
4) 240-41836800, Process Control Manual (PCM) for Establish Maintenance Objectives, Standards and Procedures (Wires)

2.7 Related/supporting documents

This document supersedes the following documents:

- DMN34-878, Substation Earthmat Testing (applicable sections).
- TPC41-865, Earth Resistivity Measurement of Transmission Lines and Substations Procedure (applicable sections).
- TST41-642, Continuity Measurement of Transmission substation Earthmat System.

3. Conducting earth continuity measurements

3.1 Acceptable measured value

The MAXIMUM ALLOWABLE resistance value is 10 milli-ohms for any distance up to but not exceeding a maximum distance of 45m for all structures/equipment in the substation yard including substation prohibited area (HV yard) fencing, but excluding remote perimeter fences and remote line terminal towers.

It is important to note that the measured results for all structures/connections in the same bay/yard/substation should be of similar order of magnitude, and within the maximum values listed.

- Line terminal towers: For any distance longer than the 45m stipulated above, the maximum allowable resistance value is 0.3 milli-ohms per meter of earthing distance measured.

- Bonded remote perimeter fences: For any distance longer than the 45m stipulated above, the maximum allowable resistance value is 0.5 milli-ohms per meter of earthing distance measured. Note that in most cases perimeter fences are not bonded to the earth grid.

3.2 Measurement frequency

The frequency of carrying out substation earth grid continuity tests is subject to environmental and operational conditions. In an attempt to accommodate these variables the following recommendations are based on periodic and conditional intervals which should address normal to extreme conditions. This is only a guideline and the frequency should be changed as required per substation.

3.2.1 New/additional plant installation

After the installation of new or additional plant and equipment that need to be bonded to the earth grid, continuity tests shall be carried out. This also applies to when existing plant has been removed and reinstalled or refurbishment has taken place. Only the affected bay/area of the new or replacement plant has to be tested for continuity to the existing earth grid.

This is also applicable when earth tails or sections of the earth grid have been replaced after theft incidents. On completion of the replacement work continuity to all structures in the affected bays shall be tested.

3.2.2 Post fault conditions

After the occurrence of an incident resulting in a severe earth fault (either single phase-to-earth or multiple phases-to-earth), the affected part of the earth grid system shall be measured for earth grid continuity. The term severe fault shall refer to any substation fault that has exceeded 80% of the substation fault level as well as exceeding a fault clearing time of 300 milliseconds, or a bus-strip or bus zone trip has occurred.

3.2.3 Known problem areas

In areas containing harsh chemical corrosive substances, in severe environmental conditions or in the presence of accelerated electrolytic reaction, measurements shall be carried out more frequently and based on time intervals that reveal excessive variations in resistance.

3.2.4 Planned continuity testing

In the absence of the conditions described in paragraphs 3.2.1, 3.2.2 and 3.2.3 above, at least 20% of the entire substation shall be measured for earth continuity yearly, ensuring that the whole station earth grid is tested at least once over a five year period. The intention of this is to ensure that some form of earth continuity test is done at least once per year in each substation to ensure structure/equipment bonding is intact.

3.3 Safety considerations while doing the tests

The main considerations while carrying out continuity testing are that all operators are to comply with the ESKOM Operating Regulations for High Voltage Systems (ORHVS) and wear appropriate PPE.

3.3.1 General considerations

The following are precautions but not limited to the list intended as reminders of potential hazards and risks associated with the task and it also serve as a guide in conducting tests safely:

a) The test method described in this document requires connections between two points of the same grid. Extended test leads and power systems are exposed to atmospheric disturbances, line-to-ground faults, and ground potential rise; to minimise risks when tests are not in progress disconnect and isolate externally routed test leads from the grid; treat them as being energised.

b) Field testing of power system earthing exposes participating personnel to possible faults on the system under test, transferred potentials from remote grounds, and inadvertent line energization. Although the probability of occurrence of one of these events is low, always enhance personnel safety by:

- Making certain that all test participants understand their roles, discuss test procedures, hazardous conditions, and the responsibilities of each person in advance. Also, inform all personnel present in the substation about the nature of the test.
- Use appropriate PPE as applicable (insulated gloves, safety boots, hard hats, etc.).
- Work on clean dry crusher stones, or on insulating blankets or clean floor surfaces.
- Avoiding bare hand contact with the equipment and exposed test leads.

c) It is essential that only one person co-ordinates all operations, maintains control of connections made to externally routed circuits, and authorises all test energization.

3.3.2 Adverse weather conditions

Prior to earth grid testing the weather conditions on site must be confirmed. It must also be realised that during high humid conditions the static activity will be higher than in dry conditions.

Do not schedule testing during periods of lightning activity over the test area including out-of service lines. If lightning appears in the test vicinity, stop testing and isolate all externally routed test conductors from the grid.

3.3.3 Reducing the effects of induced voltages in test leads

Voltages are transferred from one circuit to another by means of mutual capacitance and inductance between two circuits. The distance of overhead conductors and the current carrying capacities of such conductors influence the magnitude of voltage induced. These induced voltage effects can be reduced by taking special note of how test leads are to be carried in the HV yard and the earthing of test equipment. Test leads should be preferable coiled up in small diameters as to reduce the exposed area to induce voltages. Where test leads are repositioned it is advisable, where possible, not to “drag” test leads across the HV yard parallel to the overhead conductors. In this position the test leads have greater exposure to induced voltages. Further precaution against induced surges may be applied by wearing high voltage insulating gloves.

3.3.4 Reducing the effects of damage to test equipment

Modern electronic test equipment is more sensitive to induced voltages via test leads. To reduce and possibly eliminate these effects the metal casing of the test equipment (if applicable) must be earthed to the closest earth grid point and via the shortest route.

3.4 Factors affecting the accuracy of results

Note that certain micro-ohm meters will not switch on if the unit is not properly earthed, it is therefore important to read the instruction/operating manual of the unit to be used carefully before attempting any tests.

Ensure good quality connections between the leads and the equipment/structure and reference point at all times.

Leads must be in a good condition as damaged insulation on leads will cause incorrect readings.

3.5 Equipment and accessories

The following minimum equipment is needed:

3.5.1 Test instrument

A robust four terminal micro-ohm meter capable of injecting sufficient current into the test circuit should be used to ensure acceptable test measurements and reliable results.

- Minimum injection current shall not be less than 10 Amps, although instruments capable of injecting up to 100 Amps are advisable for testing.
- The test instrument must have a valid calibration certificate, refer to [1].

3.5.2 Current leads

Current injection leads shall be sized in relation to the instrument it will be used with (refer to Figure 1):

- 1 x 5m long insulated stranded copper cable (current injection, connection to reference point),
- 1 x 50m long insulated stranded copper cable (current injection, connection to equipment/structure under test),
- Minimum conductor size16mm^2.

3.5.3 Potential leads

Since the potential leads do not carry any current the type of wire used is not important from a measurement point of view. However, these leads should be adequately insulated and mechanically sufficiently strong to support their own weight if long leads are being used. Refer to Figure 1.

- 1 x 5m long insulated stranded copper cable (potential measurement, connection to reference point),
- 1 x 50m long insulated stranded copper cable (potential measurement, connection to equipment/structure under test).
- A minimum conductor size of 2.5mm^2 is proposed.

3.5.4 Clamping devices

Ensure that the correct connections are fitted to the leads for connection to the test instrument.

Various options can be considered to connect the leads to the equipment/structures. Whatever clamping devices are used it must be assured that there is sufficient pressure and contact to ensure a proper connection to reduce contact resistance to a minimum. Refer to Figure 1.

- Chrome vanadium vice-grip clamps are acceptable, but it is advised that insulated heavy duty clamps or welding clamps are used for the current connections.
- Smaller clamps can be used for the potential lead connections as indicated in Figure 1.

Figure 1: Typical leads and clamping devices (red for current, black for voltage)

3.6 Test method

The 4 point measuring method is ideally suited for low resistance measurements as it employs two “current terminals” for current injection and two “potential terminals” for voltage measurement. Therefore the current leads do not form part of the circuit of which the resistance is to be measured.

3.6.1 Measuring method description

The 4 point measuring method as shown in Figure 2 shall be used, consisting out of:

- Two “current connections” for current injection, indicated as C1 and C2,
- Two “potential connections” for voltage measurement, indicated as P1 and P2.
- Important: Current injection connections are to be placed on the outside of the circuit with the voltage measurement connections on the inside of the circuit.

The minimum measuring points within the substation are from the transformer star point to all surge arresters, voltage transformers, earth switches, NEC/R/Ts and portable earthing points. Thereafter, the continuity to other equipment should be measured.

The process below must be followed when preparing for and taking the actual measurements

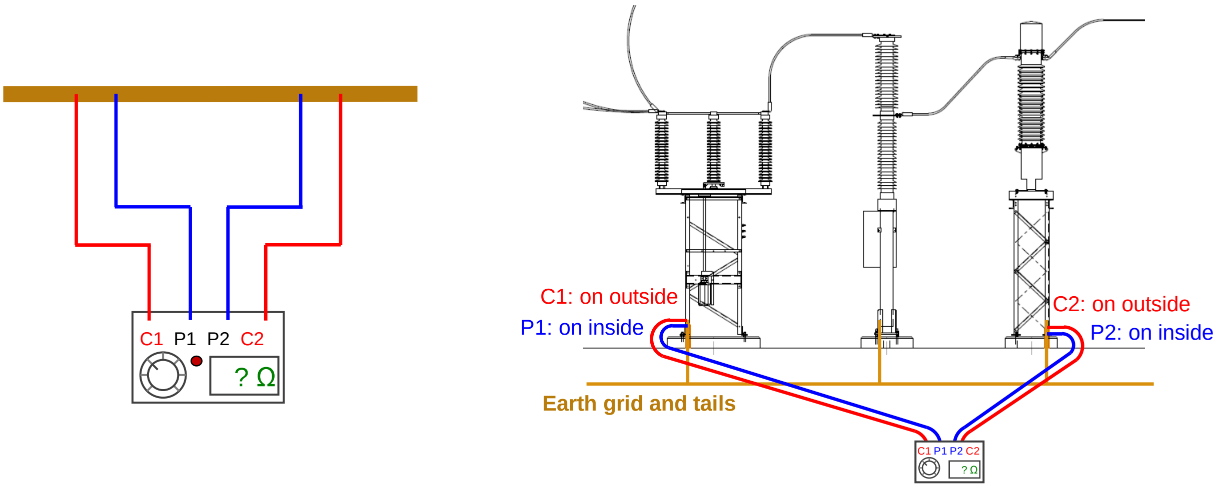
1) Carefully assess the area where the measurements will be done and do a risk assessment.
2) Identify the first reference point, and mark it on the applicable drawing.
3) Connect the short leads to the reference point and then the test instrument. :
    - Ensure that the test instrument is properly earthed (if required).
    - Ensure that the current connection (C1) is connected the outside of the measurement circuit at the equipment/structure in relation to the potential connection (P1), refer to Figure 2.
    - Ensure proper connections to the reference point as well as to the test instrument.
4) Connect the long leads to the equipment/structure to be measured, as well as the test instrument.
    - Ensure that the current connection (C2) is on the outside of the measurement circuit at the equipment/structure in relation to the potential connection (P2), refer to Figure 2.
    - Ensure proper connections to the equipment/structure as well as to the test instrument.

5) Take the measurement and capture the result. Consider the magnitude of the measured value, if it is more than the required maximum:

- Check all connections to ensure proper contact is made,
- Repeat the test to verify the previous result.

6) Move the current (C2) and potential (P2) leads to the next piece of equipment/structure and repeat steps 4 and 5.

7) When the test leads run out of reach, identify the next reference point and repeat steps 3 to 6 until all equipment/structures have been tested.



(a) Basic connection (b) Connection to structures

Figure 2: Four point measuring method connection

3.6.2 Reference points

A transformer neutral/star point shall be chosen as the first reference point as the transformer will be the primary source and return path of any fault current. As the measurements progress further away from this point and the test leads run out of reach, any structure already measured with an acceptably low resistance to the first reference point may be used as a second reference point and so on.

It is important to note that fences or fence post should not be used as reference points measurements.

3.6.3 Fences

Substation prohibited area (HV yard) fencing must also be measured for continuity between the various reference points and the earth connecting points of the fence. These fences should be connected to the earthmat at least every 20 meters.

Not all perimeter security fences are connected to the earth grid, but must also be tested as verification.

3.6.4 Overhead line terminal towers

Overhead lines with shield wires form an integral part of the substation earthing system and as such all terminal towers of these lines should be bonded to the earth grid and must therefore also be tested for continuity.

3.7 Recording of results

A copy of the substation earth grid layout, key plan/general arrangements as well as the bay layout drawings (as applicable/available) should be obtained. On these the reference points with their respective reference zones must be demarcated.

On the drawing (whichever is available) at each piece of equipment/structure the test values measured must be recorded. Refer to Figure 3 for an example of this.

On completion of the tests the test date must be recorded on the drawings as well as the responsible person's name and signature.

The drawing shall serve as a record of the measurements and complements the final measurement report. Refer to Annex A for an example of what should be captured in the final measurement report.

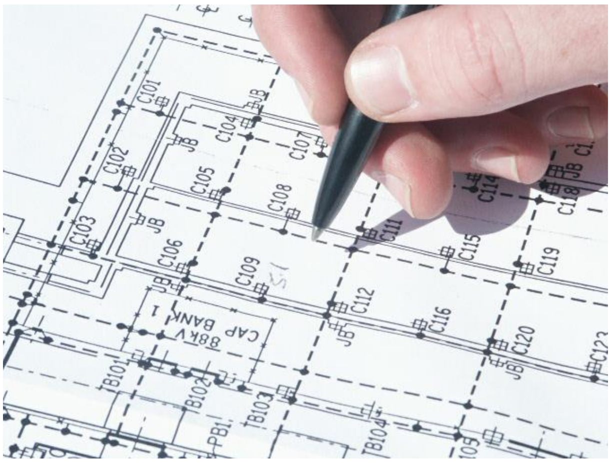


Figure 3: Recording of resistance value

3.8 Analysing, allowable variances and trending

While carrying out measurements it is important to compare measured values to values of a similar sub-network. An example would be the values between three foundation earth tails within the same bay. If one value differs from the others by an order of magnitude, this may be an indication of an inadequate connection. Due to parallel connections and distance from reference points there are no absolute measurement values.

Test results should be compared against previous results and the trend analysed. Where results show a significant increase in resistance between tests, the most recent test should be repeated to check for inaccurate measurement. If the large variance in test results persists, there is the probability that an earth grid defect is present and it should be investigated further.

3.9 Recommendations

Recommendations must form an integral part of all substation earth grid continuity test reports. These recommendations must be specific with action items, areas of responsibilities and accountabilities. During audits these recommendations must be checked to confirm that action has been taken.

3.10 Safe keeping of records

All records relating to substation earth grid continuity tests must be maintained, secured, and made available for either planned or unplanned inspections.

4. Authorization

This document has been seen and accepted by:

Name and surname	Designation
Prince Moyo	GM, Power Delivery Engineering
Archie Jaykaran	Power Delivery Plant Maintenance SC Chairperson
Bheki Ntshangase	Plant Equipment SC Chairperson
Colin Smith	Design Base Maintenance Manager
Phineas Tlhatlhetji	Substations SC Chairperson
David Ntombela	Consultant, PDE DBO

5. Revisions

Date	Rev	Compiler	Remarks
Feb 2017	1	TJ Marais	New document based on TST41-642 with applicable sections from the following documents consolidated herein: DMN34-878 and TPC41-865

6. Development team

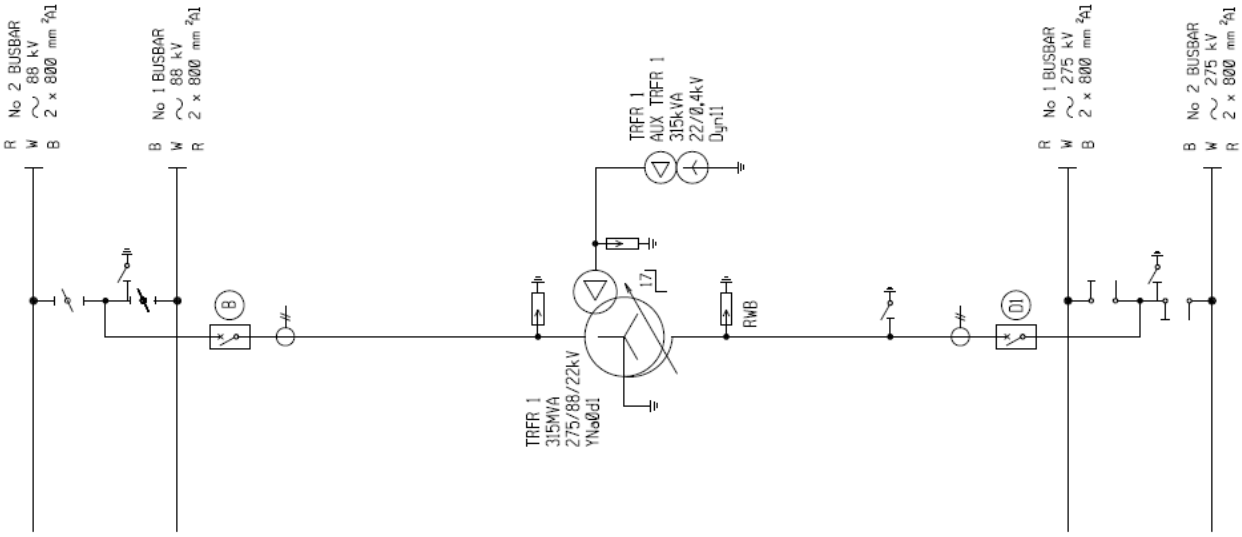
As listed in the documents being replaces by this (TST41-642 and DMN34-878, TPC41-865).

7. Acknowledgements

Everybody that took the time to comment on this document.

Annex A – Example of Recording Format for Continuity Measurement of Substation Earthing Systems

The results table in this example is only for 275kV and 88kV transformer 1 indicated below. Similar tables must be generated for all bays in the substation to be tested.



REPORT:	**CONTINUITY MEASUREMENT OF SUBSTATION EARTHING SYSTEMS**		
Substation	**Test Date**	**Drawing Numbers**	**Test Instrument Serial Number**
Test Person	**Revision Date**		**Test Instrument Calibration Number**
Comments and Recommendations:			
Corrective Action:			
Responsible Person:			

Note: Substation Drawings form an integral part of the test records

Bay:	**Trfr 1**	**Reference point:**			
Voltage:	**275kV**	**RØ**	**WØ**	**BØ**	**Comments**
Equipment	**Busbar 1 Isolator**				
	Busbar 2 Isolator				
	Circuit Breaker				
	CT				
	Earth Switch				
	Surge Arrestor				
	Other:				

Bay:	**Trfr 1**	**Reference point:**		
Voltage:	**275kV**	**Number**	**Result**	**Comments**
	Columns	**C113**		
	Columns	**C114**		
	Columns	**C115**		
	Columns	**C116**		
	Columns	**C117**		
	Columns	**C118**		
	Columns	**C119**		
	Columns	**C120**		
	Columns	**C121**		
	Columns	**C148**		
	Columns	**C149**		
	JB	**103**		
	JB	**105**		
	JB	**301**		
	JB	**106A**		
	Other:			

Bay:	**Trfr 1**	**Reference point:**			
Voltage:	**88kV**	**RØ**	**WØ**	**BØ**	**Comments**
Equipment	**Busbar 1 Isolator**				
	Busbar 2 Isolator				
	Circuit Breaker				
	CT				
	Aux Trfr				
	Surge Arrestor				
	Other:				

Bay:	**Trfr 1 Aux**	**Reference point:**			
Voltage:	**22kV**	**RØ**	**WØ**	**BØ**	**Comments**
Equipment	**Surge Arrestor**				
	Aux Trfr				
	Other:				

Bay:	**Trfr 1**	**Reference point:**		
Voltage:	**88kV**	**Number**	**Result**	**Comments**
	Columns	**C1**		
	Columns	**C2**		
	Columns	**C3**		
	Columns	**C4**		
	Columns	**C5**		
	Columns	**C6**		
	Columns	**C7**		
	Columns	**C8**		
	Columns	**C9**		

Bay:	**Trfr 1**	**Reference point:**		
Voltage:	**88kV**	**Number**	**Result**	**Comments**
	Columns	**C10**		
	Columns	**C11**		
	JB	**1**		
	JB	**2**		
	JB	**3**		
	Floodlight	**FLT3**		
	Fire barrier	**FB1**		
	Fire barrier	**FB2**		
	Fire barrier	**FB3**		
	Fence	**88kV: Corner Post**		
	Fence	**“West to East” Post 5**		
	Fence	**“North to South” Post 5**		
	Fence	**“North to South” Post 10**		
	Fence	**“North to South” Post 15**		
	Fence	**Gate Post 1**		
	Fence	**Gate Post 2**		
	Other:			