Electricity Distribution

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Company Directive

STANDARD TECHNIQUE: TP21OD/0

Earthing System Measurements - Part D
Terminal Tower Bonding

Summary

This Standard Technique defines the requirements for carrying out terminal tower bonding measurements on earthing systems which are to be owned or adopted by National Grid Electricity Distribution.

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Implementation Date: **March 2025**

Approved by

Craig Sharp
Engineering Policy Manager

Date: **5th March 2025**

Target Staff Group	**Network Services Teams, Engineering Trainers & ICPs**
Impact of Change	**GREEN - The change has no immediate impact on working practices or has been aligned to current working practices – Communication via a monthly update of changed policy. Team Manager discretion on how the changes are communicated to the team.**
Planned Assurance checks	**Policy Assurance Specialists shall confirm whether the requirements have been complied with during their sample checking of completed jobs**

IMPLEMENTATION PLAN

Introduction

This Standard Technique defines the requirements for verifying bonding between Terminal Towers and Substations which are to be owned or adopted by National Grid Electricity Distribution.

Main Changes

This document is a new ST, however, it replaces parts of TP21O.

Impact of Changes

This Standard Technique is relevant to staff, Contractors and Independent Connection Providers involved with the design / assessment of earthing systems.

Implementation Actions

Managers should notify relevant staff that this Standard Technique has been published.

There are no retrospective actions.

Implementation Timetable

The document can be implemented once being read and understood and can be utilised from issue.

REVISION HISTORY

Document Revision & Review Table		
Date	**Comments**	**Author**
March 2025	• New document issued.	Mark Kneebone

Contents

1.0 INTRODUCTION

This Standard Technique defines the requirements for carrying terminal tower bonding tests for earthing systems which are to be owned or adopted by National Grid Electricity Distribution.

The bonding between the terminal tower and substation earthing systems must be sufficient to elininate any hazardous voltages between the two installations.

2.0 DEFINITIONS

For the purpose of this document the following definitions are employed:

TERM	DEFINITION
Earth Electrode	A conductor or group of conductors in direct contact with the soil and providing an electrical connection to earth.
Earthing Conductor	A protective conductor which connects plant and equipment to an earth electrode.
Earthing System	The complete interconnected assembly of earthing conductors and earth electrodes (including cables with un-insulated sheaths).
Earth Impedance	The impedance between the earthing system and remote reference earth.
Earth Potential	The difference in potential which may exist between a point on the ground and remote reference earth.
Transfer Voltage	The potential transferred by a long metallic object which is connected to earth at one or more points and which bridges locations that are at different potentials with respect to the general mass of earth. As such, the object may transmit the potential rise of an earthing system into an area with low or no potential rise, or transmit reference earth into an area of potential rise, resulting in a potential difference occurring between the object and its surroundings.
Reference Earth	Part of the Earth, the electric potential of which is conventionally taken as zero.
Terminal Tower	The last tower of a circuit that connections to a substation

3.0 REFERENCES

This document makes reference to, or should be read in conjunction with, the documents listed below. The issue and date of the documents listed below shall be those applicable at the date of issue of this document, unless stated otherwise.

3.1 British Standards

NUMBER	TITLE
BS EN 50552	Earthing of power installations exceeding 1 kV a.c.
BS EN 50341-1	Overhead electrical lines exceeding 45kV – Part 1: General requirements – Common specifications

3.2 Energy Networks Association

NUMBER	TITLE
ENA TS 41-24	Guidelines for the design, installation, testing and maintenance of main earthing systems in substations

4.0 REQUIREMENTS

4.1 Method

Terminal towers with ineffective bonding can pose a shock hazard due to induction from the overhead line.

Before any bonding measurements can be made it must first be established that effective bonding is in place and that there is minimal potential difference between the terminal tower and substation.

After checking for effective bonding a resistance measurement can be made using a four-terminal portable micro-ohmmeter.

The procedure is therefore broken into three stages:

1. Establish that effective bonding is in place.
    - a visual inspection to identify the presence of bonding
    - a measurement of the current flowing in the tower legs in order to confirm that effective bonding is in place – a low current flow provides an indication of high impedance bonding whilst an unequal current indicates bonding.
2. Test for hazardous potential differences between measurement points
    - a voltage measurement between the tower and substation using a high voltage probe to ensure that the potential difference does not exceed 1kV (the rating of the voltmeter without the high voltage probe)
    - a voltage measurement between the tower and substation using a volt meter to ensure that the potential difference does not exceed 25V.
3. Bonding measurement
    - A resistance measurement between the tower and substation using a four-terminal micro-ohmmeter.

4.1.1 Establish that effective bonding is in place.

Complete a visual inspection to identify the presence of bonding.

The presence of effective bonding can be inferred by measuring the leakage current flowing in the legs of the tower. It is likely that the bonding will be directly connected to either the closest two legs (Figure 1) or the electrode system of the tower (Figure 2). In both cases there will be a difference in the proportion of leakage current flowing in each tower legs due to the asymmetrical connection of the bonding to the substation.

Figure 1: Bonding between tower legs and substation

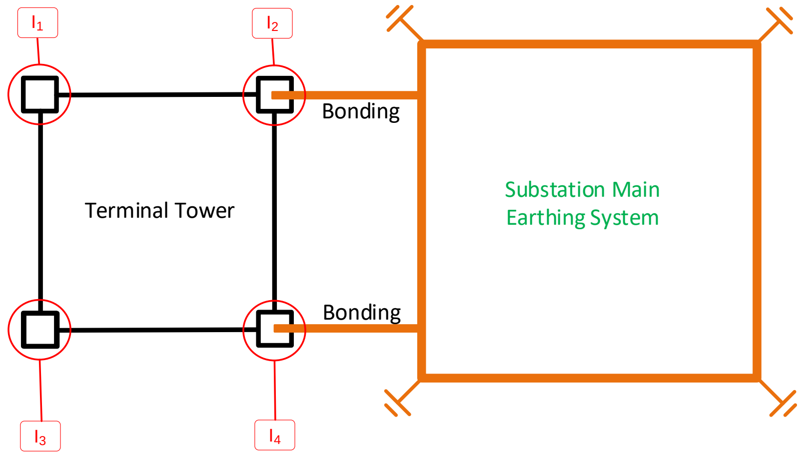
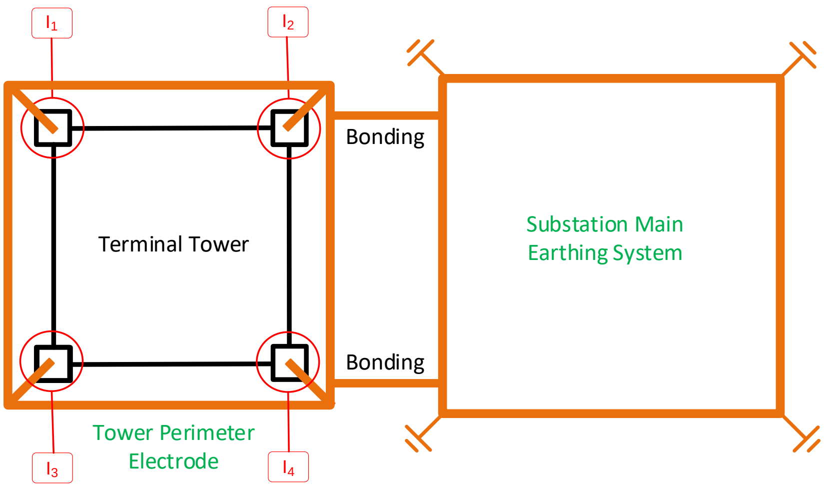
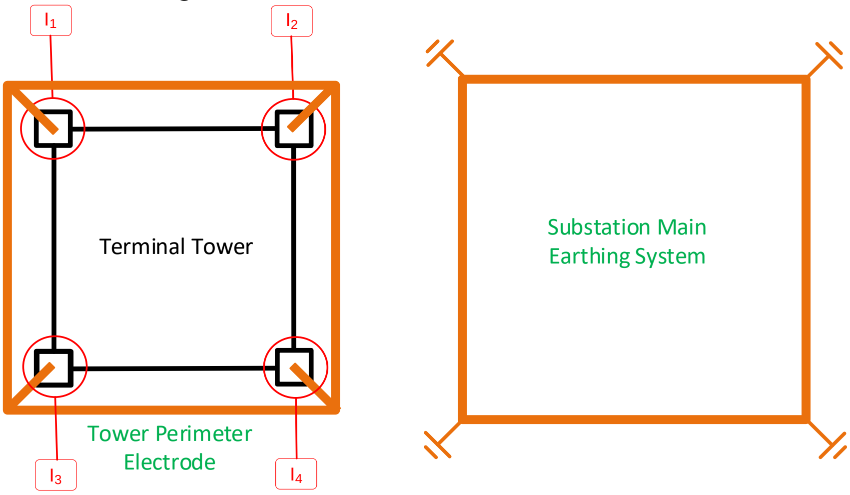


Figure 2: Bonding between tower electrode system and substation



In the absence of any bonding to the substation the current flow in each leg is likely to be equal and low (Figure 3).

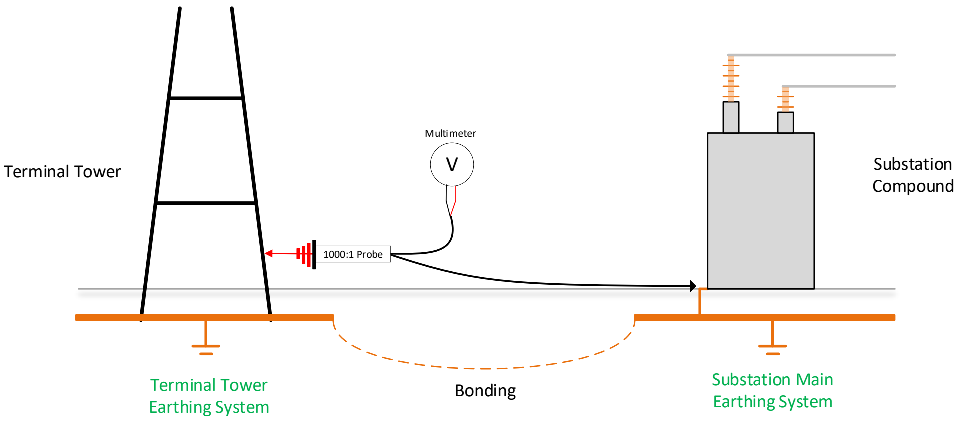
Figure 3: Tower and substation not bonded



4.1.2 Test for hazardous potential differences between measurement points

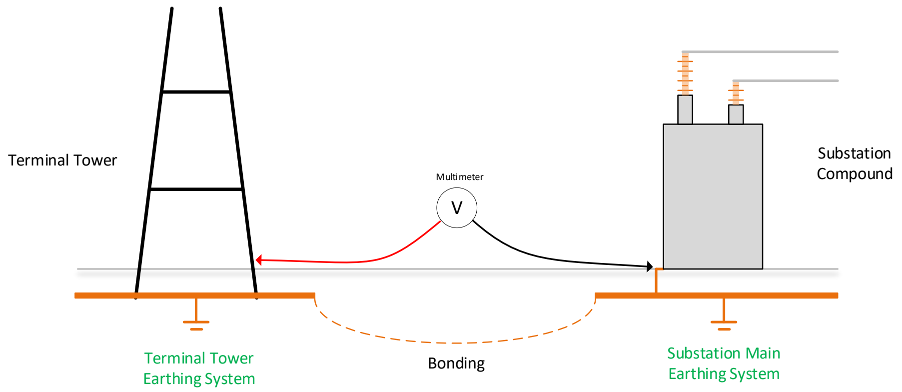
Check voltage is below 1000V using a 1000:1 voltage probe rated to at least 8kV (Figure **4**).

Figure 4: Voltage measurement with 1000:1 probe and multimeter



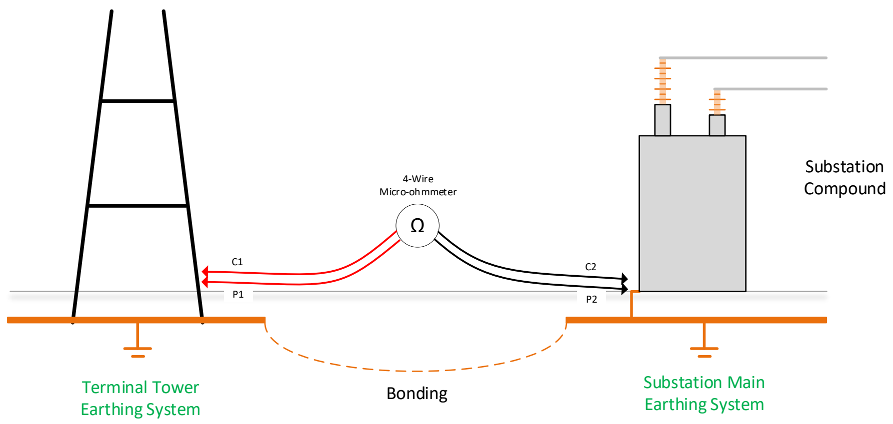
Once it has been established that the voltage difference is below 1kV a more precise measurement using a 1kV multimeter can be made. Check that the voltage difference is below 25V (Figure 5).

Figure 5: Voltage measurement with multimeter



4.1.3 Bonding measurement

Figure 6: 4-Wire resistance measurement



Using a four-terminal portable micro-ohmmeter measure the resistance between the tower and substation (Figure 6). Note that any current flowing in the bonding will affect the resistance measurement, it may be necessary to repeat the measurement by reversing the test lead connection and taking an average of the two readings. Many instruments, including the DLRO10 incorporate an auto function to automatically make both measurements in a single test.

4.2 Restrictions

Care must be taken to ensure that the path of test current cannot operate system protection. Resistance measurements shall not be performed across any CT.

4.3 Interpretation Of Results

The expected resistance between two effectively bonded points in an earthing system should be low. It is determined by:

- Series resistance of the bonding conductor(s)
- Series/parallel resistance of earth electrode
- Series/parallel resistance of joints/connections

It will largely depend on the length of conductor/electrode involved and its cross-sectional area. Using the resistance per meter for the appropriate conductor below an anticipated bonding resistance can be calculated. An addition of 50μΩ for each joint should be included in the calculation. **Error! Reference source not found.** below gives example values.

Table 1: Conductor Resistance per meter at 20°C

Conductor	Resistance per meter without joints (μΩ)
50mm x 6mm copper tape	57
50mm x 4mm copper tape	86
50mm x 3mm copper tape	115
25mm x 4mm copper tape	172
25mm x 3mm copper tape	229
120mm^2 stranded copper	143
70mm^2 stranded copper	254
35mm^2 stranded copper	509

Worked example:

A tower is bonded to the substation main earthing system using two separate bonds comprising of 20m of 70mm HDC with two joints in each bonding conductor.

Individual bond resistance = (20m x 254μΩ) + (2 joints x 50μΩ)

= 5,180μΩ or 5.18mΩ

Combined bonding resistance = 2.59mΩ

Consequently, bonding measurements should be in the high micro-ohms or low milliohms range rather than ohms.

If the measured value is less than 20mΩ then this implies adequate bonding, a measured value above this threshold will require further investigation.

4.4 Sources Of Measurement Error

Paint, scale or oxide coatings on conductors may affect the accuracy of the resistance measurement. Conductors shall be abraded to expose clean surfaces for connections.

Micro-ohmmeters are designed for a specific lead resistance. If higher resistance leads are used the injected current may be reduced and may cause signal-noise problems that may reduce the accuracy and/or repeatability of the resistance measurement.

5.0 METHOD STATEMENT

5.1 Equipment

The following test equipment is required in order to perform electrode separation measurements:

- Four-terminal portable micro-ohmmeter (e.g. Megger DLRO10)
- Insulated test leads rated for 8000V AC RMS – minimum size 1.5mm^2
- Suitable high voltage multimeter probe (e.g. Tenma High Voltage Probe - Model No. 72-3040)
- Digital multimeter rated for CAT III 1000V
- Flexible AC current probe (e.g. 48” LEMflex Model No. RR3030) & BNC connector adaptor
- Suitable test clamps/clips
- Paint scraper, emery cloth and wire brush
- Portable earth mat
- 50m non-conductive tape measure
- Suitable protective coating for post-test application to bared tower metal – see ST:SP2B

5.2 Safety Precautions

Note that if an overhead line tower with earth wire is not connected into a substation a hazardous voltage can exist between the tower and substation. This is due to induction by phase current and so is a continuous hazard presenting a higher risk of serious injury when conducting a bonding test.

When performing the measurement methodology defined in section 5.3, the following precautions shall be taken:

- Comply with applicable safety rules
- Conduct Site Specific Risk Assessment and communicate risks to people at risk in accordance with ST: HS20A.
- All testing under immediate control of one person.
- Communication between earth tester operator and personnel who move 'remote' trailing leads.
- Personnel wear Class 1 rubber gloves and the additional protection of insulating safety footwear.
- No testing if lightning likely (e.g. lightning risk warning Category 1).
- CONTROL notified and no work if relevant fault switching planned/under way (e.g. either on substation under test or, where cable is present, ANY point on the network fed from the source primary substation AND INCLUDING any primary substation run in parallel).
- If relevant lightning or fault switching occurs while testing, the testing must cease immediately.
- Ensure condition of test equipment is satisfactory prior to use.

5.3 **Method**

1	INFORM	CONTROL before commencing work. Confirm risk of lightning not Category 1 and that no fault switching will be performed. Ensure earth conductor to test has visible connection to earth and check visually that system insulators associated with earthed structure where earth connection will be made are undamaged. If in doubt then prove the earthed structure DEAD using procedure in ST:OS4B.
2	INSPECT	tower legs for earth connections at/near ground level. If any connections are missing or disconnected instigate the procedure for the loss of substation earthing equipment set out in ST:OS2G. Record findings on Terminal Tower Bonding Test Record.
3	MEASURE	and record the current flowing in each tower leg at its base using the flexible current probe. If it is not possible to close the probe around a leg because of the cross-bracings then measure the current in the leg and each associated bracing and summate these readings.
4	DETERMINE	whether the current in each tower leg is equal and low; if this is the case and no visible earth connections are present then STOP TEST and report findings (NB terminal-tower not effectively bonded to substation).
5	IDENTIFY	which tower leg(s) has/have higher current. Proceed with the following for these 'higher current' tower legs.
6	CONNECT	two 8kV insulated test leads to the substation earthing system. Ensure clamps/clips make good contact with clean metal. Run the leads safely along the ground, through fencing as necessary, to the terminal-tower under test.
7	CLEAN	a 'higher current' tower leg back to metal and attach two test clamps/clips without leads attached.
8	PLACE	earth mat immediately adjacent to this tower leg and attach to tower metal.
9	STAND	on the earth mat (NB both legs).
10	CONNECT	the high voltage probe to the multimeter.
11	CONNECT	one of the 8kV insulated test leads from the substation to the high voltage probe.
12	MEASURE	the voltage on the tower relative to the substation and record. Disconnect.

13	DETERMINE	whether the voltage is in excess of 1kV. NB Probe ratio is 1000:1 so a measurement in excess of 1V on the multimeter indicates an actual voltage in excess of 1000V. If the actual voltage is above 1kV then STOP TEST, report findings and DO NOT PROCEED to items 14-22 (NB terminal-tower not effectively bonded to substation).
14	CONNECT	one of the insulated test leads from the substation to one of the multimeter voltage terminals. Connect the other multimeter voltage terminal to the remaining tower clamp/clip with a short insulated test lead.
15	MEASURE	the voltage on the tower relative to the substation and record. Disconnect.
16	DETERMINE	whether the voltage is in excess of 25V. If the actual voltage is above 25V then STOP TEST, report findings and DO NOT PROCEED to items 17-22.
17	PLACE	micro-ohmmeter and earth tester on earth mat.
18	CONNECT	C1 and P1 micro-ohmmeter terminals to the tower clamps/clips and C2 and P2 terminals to the substation.
19	MEASURE	resistance of tower leg-substation connection and record. Disconnect
20	REPEAT	from item 7 for each ‘higher current’ tower leg.
21	MEASURE	and record the distance between terminal-tower and substation compound fence if tower outside the substation fence.
22	DISCONNECT	the temporary test leads and clamps/clips above
23	APPLY	paint to the metal cleaned in item 7 to prevent corrosion but only if the metal is rust-free. If metal rusty then report this so that a rust stabilizer can be applied.

5.4 Test Results

The following spreadsheet shall be employed for recording the results of Termina Tower Bonding.

<u>TP21OD Test Results</u>

The measured value of equipment connection along with its reference should be recorded in the construction/project file.

Figure 7: Example test results sheet

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TERMINAL TOWER BONDING MEASUREMENTS (TP21OD)

Tower Number:	
Substation Name:	

Date:	
Person Undertaking Measurement:	

Test Equipment			
Type	Make	Model	Serial No.
Flexible Current Clamp			
HV Probe			
Multi-meter			
Micro-ohmmeter			

Tower Leg Current Measurements				
Tower Leg	1	2	3	4
Current (mA)				
Highest (tick)				

Tower Leg-Substation Voltage Measurements				
Tower Leg	1	2	3	4
HV Probe (V)				
Multi-meter (V)				

Tower Leg-Substation Bonding Measurements				
Tower Leg	1	2	3	4
Micro-ohmmeter (Ω)				

Tower to Substation Distance Measurement	
Distance (m)	

Plan Sketch

APPENDIX A

SUPERSEDED DOCUMENTATION

None.

APPENDIX B

RECORD OF COMMENT DURING CONSULTATION

ST: TP21OD/0

APPENDIX C

ANCILLARY DOCUMENTATION

POL: TP21 - Fixed Earthing Systems

APPENDIX D

KEY WORDS

Earth; Earthing; Measurement; Test; Bonding; Equipment Connections; Terminal Tower