WESTERN POWER DISTRIBUTION

Serving the Midlands, South West and Wales

Company Directive

STANDARD TECHNIQUE: TP21AE

Earthing Design Fundamentals
Part E
Earth Fault Clearance Times

Summary

This Standard Technique defines the earth fault clearance times to be utilized when designing earthing systems which are to be owned or adopted by Western Power Distribution.

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Implementation Date: **December 2020**

Approved By:

Carl Ketley-Lowe
Engineering Policy Manager

Date: **9th December 2020**

Target Staff Group	**Network Services Teams & ICPs**
Impact of Change	**AMBER - The changes have an impact of current working practices that are not safety critical – Communication at next team meeting or as part of a retraining programme**
Planned Assurance checks	**None**

IMPLEMENTATION PLAN

Introduction

This Standard Technique defines the earth fault clearance times to be utilized when designing earthing systems which are to be owned or adopted by Western Power Distribution.

Main Changes

This document is a new ST.

Impact of Changes

This Standard Technique is relevant to employees, 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

This ST shall be implemented with immediate effect.

REVISION HISTORY

Document Revision & Review Table		
Date	**Comments**	**Author**
December 2020	• Initial issue	Graham Brewster

Contents

1.0 INTRODUCTION

This Standard Technique defines the earth fault clearance times to be utilized when designing earthing systems which are to be owned or adopted by Western Power Distribution.

2.0 DEFINITIONS

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

TERM	DEFINITION
ASC	Arc suppression coil. A tuned reactance used to limit earth fault current in the event of a phase-earth fault.
Earth Fault	A fault causing current to flow in one or more earth-return paths. Typically, a single phase to earth fault, but this term may also be used to describe two-phase and three-phase faults involving earth.
Normal Protection	Protection set to clear a fault under normal (usual) circumstances.
Backup Protection	Protection set to operate following failure or slow operation of normal protection.
Short Time Rating	The specified period of time for which a defined value of current must be safely carried.
IDMT	Inverse Definite Minimum Time. A protection characteristic where the operating time is purposely delayed and the period of delay is inversely proportional to the magnitude of the current. IDMT characteristics include standard inverse (SI), extremely inverse (EI) and very inverse (VI).
TM	Time Multiplier. Used in conjunction with the IDMT protection characteristic to adapt the period of delay.
DT	Definite Time. A protection characteristic where the operating time is purposely delayed and the period of delay remains the same regardless of the magnitude of the operating current.
INST	Instantaneous. A protection characteristic where the operating time is not purposely delayed.
Primary Network	An electrical system supplied by one or more sources of voltage at 132kV, 66kV or 33kV.
Secondary Network	An electrical system supplied by one or more sources of voltage at 11kV or 6.6kV.

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.

3.2 Energy Networks Association

NUMBER	TITLE
TS 41-24	Guidelines for the design, installation, testing and maintenance of main earthing systems in substations
EREC S34	A guide for assessing the rise of earth potential at electrical installations

4.0 REQUIREMENTS

4.1 Fault Clearance Times For Conductor Sizing (Thermal Effects)

The earthing system must remain intact for all foreseeable fault conditions. Earth conductor sizing shall allow for an extended fault clearance time, as a consequence of failure of the normal protection, without damage to the earthing system.

From an earth conductor sizing perspective, a three-second fault clearance time shall be employed rather than back-up protection clearance times.

4.2 Fault Clearance Times For Electrode Surface Area Sizing (Thermal Effects)

The soil surrounding an earth electrode is of a much higher resistivity than the electrode conductor material and thus the passage of current through the soil will develop a relatively higher temperature rise. This may cause drying of the surrounding soil, thus further increasing its resistivity, or even the production of steam, which can force a separation between the electrode conductor and the soil.

The surface area of an earthing electrode must be sufficiently large to prevent the soil drying out as fault current flows from the electrode into the soil. From an electrode surface area sizing perspective, a three-second fault clearance time shall be employed rather than anticipated protection clearance times.

Further details on electrode surface area requirements can be found in Standard Technique TP21A-J.

4.3 Fault Clearance Times For Assessing Safety Limits For Touch & Step Voltages

Normal operating times of protection relays and circuit breakers shall be used for safety voltage [1] calculations, rather than worst-case (back-up) protection clearance times.

The overall earth fault clearance time is the period between fault arc inception and fault current interruption at the fault feeding circuit breakers and can be assessed by taking into account the following:

- Power system fault detecting relay response time plus any additional user-settable time delay
- Trip relay operating time (where relevant)
- Intertripping end-to-end time (where relevant)
- Circuit breaker operating time
- A margin which allows for relays and circuit breakers operating at the slow end of their operating tolerance, and for future limited fine-tuning of relay operating times

Faults on incoming/outgoing circuit terminals and also on busbars and transformers within the installation site shall be examined to determine the worst fault location.

Where an installation site is associated with the Primary Network and is able to be supplied from an alternative source, the fault current and clearance time for both the normal and alternative feeding shall be examined in order to determine the worst case scenario [2].

5.0 ASSESSMENT OF NORMAL EARTH FAULT CLEARANCE TIMES

5.1 Circuit Breaker Operating Times

The following circuit breaker operating time shall be assumed when assessing earth fault clearance times:

- Oil Circuit Breakers: 120ms
- Vacuum Circuit Breakers: 70ms
- SF_6 Circuit Breakers: 70ms
- Air Blast Circuit Breakers: 70ms

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[1] Touch and step potentials are sometimes collectively referred to as safety voltages since they relate directly to the safety of persons.

[2] It may be that one of the feeding arrangements has a reduced fault current but an increased clearance time. The worst case scenario is the one which results in the most onerous (i.e. lowest) safety voltages.

5.2 **Protection Operating Times**

5.2.1 Trip Relay Operating Times

Trip relay operating time shall be assumed to be 15ms.

5.2.2 Overcurrent Protection Operating Times

The following methodology shall be employed when assessing overcurrent, earth fault, directional overcurrent & directional earth fault protection operating times.

5.2.2.1 IDMT Protection

Inverse definite minimum time (IDMT) protection relay operating time depends upon the ratio of fault current (I_F) to the relay current setting (I_S), the time-current characteristic, and Time Multiplier (TM) setting. Time-current characteristics include standard inverse (SI), extremely inverse (EI) or very inverse (VI). A standard inverse characteristic is most commonly used.

The relay operating time can be ascertained from Table 1 below.

Table 1: IDMT protection relay operating times

I_F / I_S	SI	EI	VI
2	10.03 x TM	26.67 x TM	13.50 x TM
3	6.30 x TM	10.00 x TM	6.75 x TM
4	4.98 x TM	5.33 x TM	4.50 x TM
5	4.28 x TM	3.33 x TM	3.38 x TM
6	3.84 x TM	2.29 x TM	2.70 x TM
7	3.53 x TM	1.67 x TM	2.25 x TM
8	3.30 x TM	1.27 x TM	1.93 x TM
9	3.12 x TM	1.00 x TM	1.69 x TM
10	2.97 x TM	0.81 x TM	1.50 x TM
11	2.85 x TM	0.67 x TM	1.35 x TM
12	2.75 x TM	0.56 x TM	1.23 x TM
13	2.66 x TM	0.48 x TM	1.13 x TM
14	2.58 x TM	0.41 x TM	1.04 x TM
15	2.52 x TM	0.36 x TM	0.96 x TM
16	2.46 x TM	0.31 x TM	0.90 x TM
17	2.40 x TM	0.28 x TM	0.84 x TM
18	2.35 x TM	0.25 x TM	0.79 x TM
19	2.31 x TM	0.22 x TM	0.75 x TM
20	2.27 x TM	0.20 x TM	0.71 x TM

The current setting (I_S) is usually expressed in terms of relay current and consequently has to be adjusted by the CT ratio in order to derive the equivalent setting in primary current terms.[3]

Where the relay current setting is in secondary amps, the equivalent primary current is calculated by multiplying the relay setting by the CT ratio. For example, if the CT ratio is 400/5 and relay setting is 1A then the equivalent primary current is:

$$Equivalent\ Primary\ Current = Relay\ Setting \times CT\ Ratio = 1A \times \frac{400}{5} = 80A$$

Where the relay current setting is in percent, the equivalent primary current is calculated by multiplying the relay setting by the CT primary current rating and dividing by 100. For example, if the CT ratio is 400/5 and relay setting is 20% then the equivalent primary current is:

$$Equivalent\ Primary\ Current = Relay\ Setting \times CT\ Primary\ Rating = \frac{20}{100} \times 400A = 80A$$

Where the relay current setting is in per unit, the equivalent primary current is calculated by multiplying the relay setting by the CT primary current rating. For example, if the CT ratio is 400/5 and relay setting is 0.2pu then the equivalent primary current is:

$$Equivalent\ Primary\ Current = Relay\ Setting \times CT\ Primary\ Rating = 0.2 \times 400A = 80A$$

5.2.2.2 INST Protection

Instantaneous earth fault protection operating time shall be assumed to be 15ms.

Where INST earth fault protection is employed on overhead circuits with auto-reclose and is blocked from operating at some point during the auto-reclose sequence, the fault clearance time shall be based upon the operating time of the IDMT earth fault protection.

5.2.2.3 DT Protection

Definite-time earth fault protection operating time shall be assumed to be 15ms plus the user-settable time delay.

Where DT earth fault protection is employed on overhead circuits with auto-reclose and is blocked from operating at some point during the auto-reclose sequence, the fault clearance time shall be based upon the operating time of the IDMT earth fault protection.

5.2.3 Feeder Pilot Wire / Current Differential (Unit) Protection

Feeder pilot wire / current differential protection (aka unit protection) operating time depends on the relay technology.

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[3] Note that some modern relays may express the settings in terms of primary current and in these instances no adjustment is necessary

Electro-mechanical pilot wire protection operating time shall be assumed to be 80ms.

Numerical (digital) current differential protection relay operating time shall be assumed to be 30ms.

5.2.4 Feeder Distance Protection

Feeder distance protection relay operating time is the sum of the response time of the relay (which is inextricably linked to the relay technology) and the user-settable time delay for the zone in question.

Where electro-mechanical or analogue electronic relays are employed, the relay response time shall be assumed to be 80ms.

Where numerical (digital) relays are employed, the relay response time shall be assumed to be 30ms.

The following user-settable time delays are typically employed on distance protection schemes:

- Zone 1: no additional time delay
- Zone 2: 500ms time delay
- Zone 3: 1000ms time delay

5.2.5 Intertripping

Intertripping operating time depends on the response times of the intertrip relays at each end of the pilot, the end-to-end signal propagation time, and the intertripping topology i.e. whether the intertrip goes directly to the end substation or is cascaded via intermediate substations by virtue of it being a cascaded or triangulated arrangement.

Where intertripping is via metallic pilots (e.g. GCM05, DBM4 scheme etc), the sum of the relay response times and the signal propagation time shall be assumed to be 80ms.

Where intertripping is via optical pilots or via a telecommunications network, the sum of the relay response times and the signal propagation time shall be assumed to be 40ms, except where ‘Telecode 80’ relays[4] are employed, in which case 80ms shall apply.

5.2.6 Busbar Protection

Busbar protection operating time depends on whether a current differential (aka unit protection) scheme is employed, or whether the busbar is protected by IDMT earth fault protection on incomers and bus sections /couplers.

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[4] Voice frequency intertripping relays installed in the 1980s and early 1990s.

Where current differential protection is employed, the relay response time shall be assumed to be 30ms.

Where the busbar is protected by IDMT earth fault protection, the relay response time shall be determined in accordance with Section 5.2.2.1 above.

5.2.7 Operating Margin

The allowance shown in Table 2 shall be added to the normal earth fault clearance time in order to allow for relays and circuit breakers operating at the slow end of their operating tolerance, and for future limited fine-tuning of relay operating times (i.e. re-grading):

Table 2: Operating margin for various protection types

Fault clearance by IDMT / DT / INST overcurrent type protection	400ms
Fault clearance by other protection types with a normal earth fault clearance time of <200ms	The time needed to realise an overall operating time of 200ms
Fault clearance by other protection types with a normal earth fault clearance time of >200ms	100ms

5.3 **Worked Examples**

5.3.1 Normal Protection Tripping By IDMT Protection

A new ground-mounted distribution substation is to be installed in order to connect a new customer. The earth fault current at the installation site is 1200A. At the source substation oil circuit breakers are employed, the CT ratio is 600/5, the relay earth fault current setting is 30%, the relay earth fault time multiplier setting is 0.25, and a standard inverse IDMT characteristic is employed.

Therefore:

$$I_F = 1200A$$

$$I_S = \frac{30}{100} \times 600A = 180A$$

$$\frac{I_F}{I_S} = \frac{1200A}{180A} = 6.67$$

Round the I_F / I_S value <u>down</u> to 6.

From Table 1 above it is apparent that a relay with a standard inverse characteristic will have a response time = 3.84 x TM. Consequently with a time multiplier setting of 0.25 the relay response time is = 3.84 x 0.25 = 0.96 seconds.

Therefore the earth fault clearance time shall be taken to be 1.5 seconds by taking into account the following:

- Relay operating time = 960ms
- Circuit breaker operating time = 120ms (Oil CB)
- Margin for operating tolerance / future re-grading = 400ms

5.3.2 Normal Protection Tripping By Pilot Wire / Current Differential Protection

A new industrial load cannot be accommodated on ring main type switchgear and so two dedicated 11kV feeder circuits have been provided direct from a Primary substation, which terminate on an 11kV indoor switchboard comprising of two incomers, a bus section and two metering circuit breakers to the customer. The bus section circuit breaker runs normally closed. All circuit breakers are the vacuum type, and the protection on the feeder to the primary is Solkor pilot wire protection.

The earth fault clearance time shall be taken to be 0.2 seconds by taking into account the following:

- Relay operating time = 80ms
- Trip relay operating time = 15ms
- Circuit breaker operating time = 70ms (vacuum CB)
- Margin for operating tolerance / future re-grading = 35ms (i.e. 200ms – 165ms)

Note that faults on the switchboard itself (i.e. busbar faults) are likely to be cleared by IDMT protection rather than by a dedicated busbar protection scheme. It is likely that busbar earth faults will be the worst case fault scenario.

5.3.3 Normal Protection Tripping By Feeder Distance Protection

A new substation is to be teed of an existing 132kV overhead line. The source substation is equipped with circuit breakers are SF_6 type, and the feeder protection is numerical distance protection. Earth faults at the installation site will be seen in Zone 2, and the zone 2 time delay is 500ms.

The earth fault clearance time shall be taken to be 0.8 seconds by taking into account the following:

- Relay response time = 30ms (numerical distance)
- Zone 2 time delay = 500ms
- Trip relay operating time = 15ms
- Circuit breaker operating time = 70ms (SF_6 CB)
- Margin for operating tolerance / future re-grading = 100ms

APPENDIX A

SUPERSEDED DOCUMENTATION

This is a new document and no document is supersedes by its issue.

APPENDIX B

RECORD OF COMMENT DURING CONSULTATION

ST: TP21AE - Comments

APPENDIX C

ASSOCIATED DOCUMENTATION

POL: TP21	Fixed Earthing Systems

APPENDIX D

KEY WORDS

Earthing, Earth, Fault, Current, Protection, Clearance, Time