

IEEE Guide for Fault-Locating Techniques on Shielded Power Cable Systems

IEEE Power and Energy Society

Developed by the
Insulated Conductors Committee



IEEE
3 Park Avenue
New York, NY 10016-5997
USA

IEEE Std 1234™-2019
(Revision of
IEEE Std 1234-2007)

IEEE Guide for Fault-Locating Techniques on Shielded Power Cable Systems

Developed by the

Insulated Conductors Committee
of the
IEEE Power and Energy Society

Approved 21 March 2019

IEEE-SA Standards Board

This is a Redline Document produced by Techstreet, a business of Clarivate Analytics

This document is intended to provide users with an indication of changes from one edition to the next. It includes a full-text version of the new document, plus an indication of changes from the previous version.

Redlines are designed to save time and improve efficiencies by using the latest software technology to find and highlight document changes. More professionals are using valuable new technologies like redlines, to help improve outcomes in a fastpaced global business world.

Because it may not be technically possible to capture all changes accurately, it is recommended that users consult previous editions as appropriate. In all cases, only the current base version of this publication is to be considered the official document.

Redline Processing Notes:

1. ~~Red Text~~ - Red strikethrough text denotes deletions.
2. Blue Text - Blue underlined text denotes modifications and additions.

Abstract: Test and measurements, which are performed on shielded power cables to identify the location of a fault, are described. Whenever possible, the limitations of a particular test and measurement to locate a fault are provided and recommendations are made regarding specialized fault-locating techniques. A fault characterization chart is included as an aid to select a fault-locating technique.

Keywords: arc reflection, cable fault locating, cable testing, grounding, IEEE 1234, safety, sectionalizing, thumping, time domain reflectometry, (TDR)

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

Copyright © 2019 by The Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 28 June 2019. Printed in the United States of America.

IEEE is a registered trademark in the U.S. Patent & Trademark Office, owned by The Institute of Electrical and Electronics Engineers, Incorporated.

PDF: ISBN 978-1-5044-5691-3 STD23630
Print: ISBN 978-1-5044-5692-0 STDPD23630

IEEE prohibits discrimination, harassment, and bullying.
For more information, visit <http://www.ieee.org/web/aboutus/whatis/policies/p9-26.html>.

Important Notices and Disclaimers Concerning IEEE Standards Documents

IEEE documents are made available for use subject to important notices and legal disclaimers. These notices and disclaimers, or a reference to this page, appear in all standards and may be found under the heading “Important Notices and Disclaimers Concerning IEEE Standards Documents.” They can also be obtained on request from IEEE or viewed at <http://standards.ieee.org/ipr/disclaimers.html>.

Notice and Disclaimer of Liability Concerning the Use of IEEE Standards Documents

IEEE Standards documents (standards, recommended practices, and guides), both full-use and trial-use, are developed within IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (“IEEE-SA”) Standards Board. IEEE (“the Institute”) develops its standards through a consensus development process, approved by the American National Standards Institute (“ANSI”), which brings together volunteers representing varied viewpoints and interests to achieve the final product. Volunteers are not necessarily members of the Institute and participate without compensation from IEEE. While IEEE administers the process and establishes rules to promote fairness in the consensus development process, IEEE does not independently evaluate, test, or verify the accuracy of any of the information or the soundness of any judgments contained in its standards.

IEEE does not warrant or represent the accuracy or content of the material contained in its standards, and expressly disclaims all warranties (express, implied and statutory) not included in this or any other document relating to the standard, including, but not limited to, the warranties of: merchantability; fitness for a particular purpose; non-infringement; and quality, accuracy, effectiveness, currency, or completeness of material. In addition, IEEE disclaims any and all conditions relating to: results; and workmanlike effort. IEEE standards documents are supplied “AS IS” and “WITH ALL FAULTS.”

Use of an IEEE standard is wholly voluntary. The existence of an IEEE standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard.

In publishing and making its standards available, IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity nor is IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing any IEEE Standards document, should rely upon his or her own independent judgment in the exercise of reasonable care in any given circumstances or, as appropriate, seek the advice of a competent professional in determining the appropriateness of a given IEEE standard.

IN NO EVENT SHALL IEEE BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO: PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE PUBLICATION, USE OF, OR RELIANCE UPON ANY STANDARD, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE AND REGARDLESS OF WHETHER SUCH DAMAGE WAS FORESEEABLE.

Translations

The IEEE consensus development process involves the review of documents in English only. In the event that an IEEE standard is translated, only the English version published by IEEE should be considered the approved IEEE standard.

Official statements

A statement, written or oral, that is not processed in accordance with the IEEE-SA Standards Board Operations Manual shall not be considered or inferred to be the official position of IEEE or any of its committees and shall not be considered to be, or be relied upon as, a formal position of IEEE. At lectures, symposia, seminars, or educational courses, an individual presenting information on IEEE standards shall make it clear that his or her views should be considered the personal views of that individual rather than the formal position of IEEE.

Comments on standards

Comments for revision of IEEE Standards documents are welcome from any interested party, regardless of membership affiliation with IEEE. However, IEEE does not provide consulting information or advice pertaining to IEEE Standards documents. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Since IEEE standards represent a consensus of concerned interests, it is important that any responses to comments and questions also receive the concurrence of a balance of interests. For this reason, IEEE and the members of its societies and Standards Coordinating Committees are not able to provide an instant response to comments or questions except in those cases where the matter has previously been addressed. For the same reason, IEEE does not respond to interpretation requests. Any person who would like to participate in revisions to an IEEE standard is welcome to join the relevant IEEE working group.

Comments on standards should be submitted to the following address:

Secretary, IEEE-SA Standards Board
445 Hoes Lane
Piscataway, NJ 08854 USA

Laws and regulations

Users of IEEE Standards documents should consult all applicable laws and regulations. Compliance with the provisions of any IEEE Standards document does not imply compliance to any applicable regulatory requirements. Implementers of the standard are responsible for observing or referring to the applicable regulatory requirements. IEEE does not, by the publication of its standards, intend to urge action that is not in compliance with applicable laws, and these documents may not be construed as doing so.

Copyrights

IEEE draft and approved standards are copyrighted by IEEE under U.S. and international copyright laws. They are made available by IEEE and are adopted for a wide variety of both public and private uses. These include both use, by reference, in laws and regulations, and use in private self-regulation, standardization, and the promotion of engineering practices and methods. By making these documents available for use and adoption by public authorities and private users, IEEE does not waive any rights in copyright to the documents.

Photocopies

Subject to payment of the appropriate fee, IEEE will grant users a limited, non-exclusive license to photocopy portions of any individual standard for company or organizational internal use or individual, non-commercial use only. To arrange for payment of licensing fees, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; +1 978 750 8400. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

Updating of IEEE Standards documents

Users of IEEE Standards documents should be aware that these documents may be superseded at any time by the issuance of new editions or may be amended from time to time through the issuance of amendments, corrigenda, or errata. An official IEEE document at any point in time consists of the current edition of the document together with any amendments, corrigenda, or errata then in effect.

Every IEEE standard is subjected to review at least every ten years. When a document is more than ten years old and has not undergone a revision process, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE standard.

In order to determine whether a given document is the current edition and whether it has been amended through the issuance of amendments, corrigenda, or errata, visit the IEEE-SA Website at <http://ieeexplore.ieee.org/> or contact IEEE at the address listed previously. For more information about the IEEE-SA or IEEE's standards development process, visit the IEEE-SA Website at <http://standards.ieee.org>.

Errata

Errata, if any, for all IEEE standards can be accessed on the IEEE-SA Website at the following URL: <http://standards.ieee.org/findstds/errata/index.html>. Users are encouraged to check this URL for errata periodically.

Patents

Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken by the IEEE with respect to the existence or validity of any patent rights in connection therewith. If a patent holder or patent applicant has filed a statement of assurance via an Accepted Letter of Assurance, then the statement is listed on the IEEE-SA Website at <http://standards.ieee.org/about/sasb/patcom/patents.html>. Letters of Assurance may indicate whether the Submitter is willing or unwilling to grant licenses under patent rights without compensation or under reasonable rates, with reasonable terms and conditions that are demonstrably free of any unfair discrimination to applicants desiring to obtain such licenses.

Essential Patent Claims may exist for which a Letter of Assurance has not been received. The IEEE is not responsible for identifying Essential Patent Claims for which a license may be required, for conducting inquiries into the legal validity or scope of Patents Claims, or determining whether any licensing terms or conditions provided in connection with submission of a Letter of Assurance, if any, or in any licensing agreements are reasonable or non-discriminatory. Users of this standard are expressly advised that determination of the validity of any patent rights, and the risk of infringement of such rights, is entirely their own responsibility. Further information may be obtained from the IEEE Standards Association.

Participants

At the time this IEEE guide was completed, the F12 Working Group had the following membership:

Rachel I. Mosier, *Chair*
Martin J. von Herrmann, *Vice Chair*

Kraig E. Bader	Robert W. Hobson	Johannes Rickmann
Ettore Bartolucci	William E. Larzelere	Aron Sexton
Manfred J. Bawart	Arie Makovoz	Jason Souchak
Dominique A. Bolliger	Henning H. Oetjen	Peter L. Tirinzoni
Craig G. Goodwin	Bruce D. Olson	Nijam Robert Uddin
	Frank Petzold	

The following members of the individual balloting committee voted on this guide. Balloters may have voted for approval, disapproval, or abstention.

John Ainscough	Craig G. Goodwin	Bruce D. Olson
Ali Al Awazi	Todd Goyette	Howard Penrose
Saleman Alibhay	Steven Graham	Branimir Petosic
Kraig E. Bader	Randall Groves	Benjamin Quak
Thomas Barnes	Jeffrey Helzer	Lakshman Raut
Ettore Bartolucci	Lauri Hiivala	Johannes Rickmann
Earle Bascom III	Werner Hoelzl	Charles Rogers
Martin Baur	John Kay	Ryandi Ryandi
Manfred J. Bawart	Peter Kelly	Bartien Sayogo
Dominique A. Bolliger	Yuri Khersonsky	Michael Smalley
Kenneth Bow	Boris Kogan	Jerry Smith
Jeffrey Britton	Jim Kulchisky	Gary Smullin
Chris Brooks	Mikhail Lagoda	Kris Sommerstad
Demetrio Bucaneg Jr.	Chung-Yiu Lam	Gary Stodter
William Byrd	William E. Larzelere	Peter L. Tirinzoni
Thomas Campbell	Michael Lauxman	Nijam Robert Uddin
John Cancelosi	Gerald Liskom	John Vergis
Robert Christman	Arturo Maldonado	Martin J. von Herrmann
David Crotty	James Michalec	Wayne Walters
Frank Di Guglielmo	Jerry Murphy	Kenneth White
Gary Donner	Arthur Neubauer	Jian Yu
	Michael Newman	

When the IEEE-SA Standards Board approved this guide on 21 March 2019, it had the following membership:

Gary Hoffman, *Chair*
Ted Burse, *Vice Chair*
Jean-Philippe Faure, *Past Chair*
Konstantinos Karachalios, *Secretary*

Masayuki Ariyoshi
Stephen D. Dukes
J. Travis Griffith
Guido Hiertz
Christel Hunter
Thomas Koshy
Joseph L. Koepfinger*
Thomas Koshy

John D. Kulick
David J. Law
Joseph Levy
Howard Li
Xiaohui Liu
Kevin Lu
Daleep Mohla
Andrew Myles

Annette D. Reilly
Dorothy Stanley
Sha Wei
Phil Wennblom
Philip Winston
Howard Wolfman
Feng Wu
Jingyi Zhou

*Member Emeritus

Introduction

This introduction is not part of IEEE Std 1234-2019, IEEE Guide for Fault-Locating Techniques on Shielded Power Cable Systems.

Many fault locators are experienced in locating short and open circuits on shielded power cables. Proper locating of high resistance or intermittent cable faults, which are the majority of the faults on cables with extruded dielectric insulation, is considered tedious, inconsistent, and time consuming. Therefore, reclosing, re-fusing, burning, and thumping at unnecessarily high voltage and energy levels, in order to generate an open or short circuit, are frequently used without consideration of cable and equipment properties. The danger of activating dormant faults, generating new faults, or damaging utility and customer equipment by improper locating methods is not always recognized.

By establishing cable fault-locating guidelines and training programs which incorporate recommended cable fault-locating measurements and techniques, cable owners can realize substantial savings in labor, cable and equipment replacement, and avoid unnecessary losses from customer outages.

Contents

1. Overview.....	13
1.1 General.....	13
1.2 Scope.....	13
1.3 Purpose.....	13
2. Normative references	13
3. Definitions, acronyms, and abbreviations	14
3.1 Definitions.....	14
3.2 Acronyms and abbreviations	16
4. Cable system faults and fault locating	16
4.1 Cable system faults.....	16
4.2 Fault-locating overview.....	17
5. Safety	19
5.1 Safety practices.....	19
5.2 Precautions for ac cable systems.....	20
5.3 Grounding	20
6. Cable system fault locating	21
6.1 Non-network system.....	22
6.2 Network system.....	25
7. Cable system fault-locating techniques	29
7.1 General	29
7.2 Terminal methods	30
7.3 Tracing/locating/pinpointing methods.....	52
Annex A (informative) Bibliography.....	55
Annex B (informative) Cable system fault location in underground residential distribution.....	57
Annex C (informative) Fault location in network feeders	59
Annex D (informative) Fault location on cable systems with metallic shield corrosion	61
Annex E (informative) Recommended minimum of fault-locating tools	62

List of Figures

Figure 1—Models of insulation/shunt cable faults (left) and open-circuit/series cable faults (right)	16
Figure 2—Cable fault location flow chart	19
Figure 3—Single system ground at test site.....	21
Figure 4—Non-network and network system fault-locating considerations	22
Figure 5—Non-network system fault locating	23
Figure 6—Network system fault locating.....	26
Figure 7—TDR schematic diagram.....	32
Figure 8—TDR basic signatures	32
Figure 9—TDR typical display	33
Figure 10—Available energy associated with configurations of the thumper internal capacitors.....	35
Figure 11—Surge impulse duration curves versus fault ignition curve	36
Figure 12—Typical TDR comparison, illustrates fault before and after fault conditioning.....	37
Figure 13—Surge arc reflection, schematic diagram.....	37
Figure 14—Typical surge arc reflection diagram	38
Figure 15—Impulse current method, schematic diagram.....	39
Figure 16—Typical impulse current method measuring diagram.....	40
Figure 17—Impulse current differential method, schematic diagram	41
Figure 18—Typical impulse current differential method	41
Figure 19—Decay method, schematic diagram.....	42
Figure 20—Typical decay method, measuring diagram	42
Figure 21—Differential decay method, schematic diagram	43
Figure 22—Circuit diagram for Murray bridge method	44
Figure 23—Murray bridge method connection diagram for conductor-to-ground fault locating	46
Figure 24—Circuit diagram for Glaser bridge method.....	47
Figure 25—Glaser bridge method connection diagram for conductor-to-ground fault locating.....	47
Figure 26—Murray bridge method connection diagram for jacket fault locating.....	48
Figure 27—Glaser bridge method connection diagram for jacket fault locating	48
Figure 28—Alternate Glaser bridge method connection diagram for jacket fault locating	49
Figure 29—Connection of four-point voltage-drop measurement for conductor-to-shield faults in ac systems.....	49

Figure 30—Connection of three-point voltage drop measurement for dc systems	50
Figure 31—Voltage-drop method connection diagram for jacket fault locating.....	51
Figure 32—Connection of four-point voltage-drop measurement for jacket fault pre-location using a parallel shield as an auxiliary conductor.....	51
Figure 33—Jacket fault pinpointing on a cable with two jacket faults.....	53
Figure 34—Coincidence method.....	54
Figure B.1—Example of a TDR display of a faulted URD power cable loop section.....	57
Figure C.1—TDR signature of a feeder circuit.....	59
Figure C.2—TDR signature of a fault flashover in a network feeder circuit.....	60
Figure D.1—Signature of a cable system with transformers, splice, and metallic shield corrosion.....	61

List of Tables

Table 1—Cable fault categories based on their electrical characteristics	17
Table 2—Preferred pre-locating techniques	17
Table 3—Pre-locating methods for various fault resistance values	28
Table 4—Fault diagnosis from insulation resistance measurements (cable end open-circuited)	31
Table 5—Fault diagnosis from conductor and metallic shield resistance continuity measurements (cable end short-circuited)	32

IEEE Guide for Fault-Locating Techniques on Shielded Power Cable Systems

1. Overview

1.1 General

This ~~document~~ ~~guide~~ has been developed as a guide for cable fault locating ~~techniques~~ on shielded power cable systems. It is intended to emphasize those fault-locating techniques ~~which~~ ~~that~~ maintain cable integrity, reduce customer outage time, and consider customer equipment sensitivity ~~and~~ ~~safety~~. This guide applies to all ~~voltage levels of~~ insulated, shielded power cable systems.

1.2 Scope

During the lifecycle of shielded cable systems, failures may occur. In most situations, the system operator locates the failure in order to effect repairs and return the system to operation. Cable fault-locating methods should be chosen to maximize the effectiveness of the fault-locating procedure while minimizing any additional damage to the insulation of the cable system.

~~The introduction of cables with extruded dielectric insulation and of modern splicing technology has imposed new conditions and restrictions on cable fault locating. The use of excessive high voltages and energies during ac, dc, and surge testing of service-aged power cable systems with extruded dielectric insulation may overstress insulation, creating defects that become faults after the cables are returned to service.~~

This guide is intended to be applied to ~~all~~ ~~medium~~ voltage classes of insulated, shielded power cable systems ~~distribution cables. Medium voltage distribution systems generally operate at system voltages above 1 kV and up to 34.5 kV nominal.~~

~~The end user of the cable circuit should evaluate the necessity for verifying the integrity of extruded dielectric insulated cables, and, if they are in critical service, proceed to perform the high-voltage/energies testing. If not detected during dielectric tests, defects in dielectric materials may result in cable failures during the transient voltage surge episodes while in service.~~

1.3 Purpose

This guide is intended to provide [troubleshooting](#) ~~trouble-shooting~~ and testing personnel with [guidance](#) ~~information~~ to [safely and](#) quickly [localize](#) ~~identify~~ a faulted cable section ~~and/or~~ locate a cable [system](#) fault with minimum risk of further damaging serviceable cables, [accessories](#) ~~terminations~~, and equipment.

2. Normative references

The following referenced documents are indispensable for the application of this document [\(i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained\)](#). ~~For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.~~

[IEEE Std 400™, IEEE Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems Rated 5 kV and Above.](#)^{1,2}

IEEE Std 510™ ~~1983~~, IEEE Recommended Practices for Safety in High-Voltage and High-Power Testing ~~(Reaff 1992)~~.^{1,2,3}

^{1 2}The IEEE standards or products referred to in Clause [2](#) are trademarks [owned by](#) ~~of~~ The Institute of Electrical and Electronics Engineers, [Incorporated](#) ~~Inc.~~

^{2 1}IEEE publications are available from The Institute of Electrical and Electronics Engineers ~~, 445 Hoes Lane, Piscataway, NJ 08854, USA~~ (<http://standards.ieee.org/>).

³~~IEEE Std 510-1983 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792 2181 (<http://global.ihs.com/>).~~

[IEEE Std 1216™, IEEE Guide for the Application of Faulted Circuit Indicators for 200 A, Single-Phase Underground Residential Distribution \(URD\).](#)

[IEEE Std 1727™, IEEE Guide for Working Procedures on Underground Transmission Circuits with Induced Voltage.](#)

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this [document](#) ~~guide~~, the following terms and definitions apply. The ~~Authoritative Dictionary of IEEE Standards~~ [Dictionary Online](#) ~~Seventh Edition [B9]~~⁴, should be [consulted](#) ~~referenced~~ for terms not defined in this clause.³

aerial installation type: An assembly of insulated conductors installed on a pole or similar overhead structure; it may be self-supporting or installed on a supporting messenger cable.

bolted fault: A [short-circuit](#) cable fault having a resistance value of less than 5 Ω.

branch circuits: A cable system in which independent cables branch out radially from a common source of supply. ~~(See also: radial feed.)~~

breakdown: A disruptive discharge through insulation.

[burner or burn set:](#) [The test equipment used to convert a high-resistance or intermittent cable fault to a low-resistance fault.](#)

[burning:](#) [The process of conditioning a faulted cable by reducing the fault resistance.](#)

cable tray installation type: [Cables routed through cable tray systems consisting](#) ~~A structure~~ of ladders, troughs, channels, solid bottom, and other similar [structures](#) ~~devices through which cables systems may be routed.~~

³[IEEE Standards Dictionary Online](#) is available at: <http://dictionary.ieee.org>.

⁴~~The numbers in brackets correspond to those of the bibliography in Annex A.~~

characteristic impedance: The driving impedance of the forward-traveling transverse electromagnetic wave of. ~~In cable fault locating, an incident wave on a cable (time domain reflectometer [TDR], thumper, etc.) is reflected back to the source positively, negatively, or not at all by discontinuities and inhomogenities in the cable where impedance values differ from the characteristic cable impedance, respectively.~~

~~3.1.7 concentric neutral shield (metallic shield type): Wires helically applied over the semi-conducting insulation shield to carry charging, fault, and neutral currents.~~

conduit installation type: ~~A structure containing one or more ducts.~~ NOTE—Conduit may be designated as metallic or nonmetallic, such as galvanized steel or iron pipe conduit, tile conduit, polyvinyl chloride (PVC) or polyethylene (PE) conduit, fiberglass conduit, etc.

direct-buried installation type: Cable that is laid in a trench ~~or pre-cast trough~~ and covered with sand, specially prepared backfill material, and/or excavated material. Cables can be or, cable plowed directly into ~~the~~ earth or installed using into the earth with guided boring techniques. Precast troughs can be installed just below the surface and cables can be installed within the trough either by laying or pulling. The troughs are later covered with either solid or ventilated covers.

duct bank installation type: A group of conduits held in a fixed regular configuration. The backfill may contain reinforcing to protect against damage by outside physical loads.

~~3.1.10 direct distribution: A primary feeder or cable that supplies energy directly to a consumer.~~

~~3.1.11 drain wires shield (metallic shield type): Wires helically applied over the semi-conducting insulation shield to carry charging currents only.~~

extruded dielectrics: Cables with polymeric insulation, such as ~~Insulation like~~ polyethylene (PE), cross-linked polyethylene (XLPE), tree-retardant cross-linked polyethylene (TRXLPE), ethylene propylene rubber (EPR), etc.

flashover: A disruptive discharge through air around or over the surface of a solid or liquid insulation, between parts of at different potential or polarity, produced by the application of voltage wherein the breakdown path becomes sufficiently ionized to maintain an electric arc.

hipot: [An abbreviation for high potential in the context of test equipment.](#)

intermittent fault: [An infrequent, non-constant fault that often appears voltage dependent.](#)

~~3.1.14 installation types: See: aerial installation type, cable tray installation type, conduit installation type, direct buried installation type, and submarine installation type.~~

laminated dielectrics: [Insulating tapes consisting of paper or a combination of paper and a polymer, such as polypropylene, impregnated with an insulating saturant.](#) ~~Insulation like paper used in PILC cable design.~~

~~3.1.16 LC (longitudinally corrugated) shield (metallic shield type): A longitudinally applied, corrugated shield of copper or aluminum. LC shields are typically designed to carry both charging and fault currents, and sometimes neutral currents.~~

~~3.1.17 lead sheath shield (metallic shield type): An extruded layer of lead that serves as a metallic shield and also as a hermetic moisture barrier.~~

loop feed: A number of tie feeders in series, forming a closed circuit.

~~3.1.19 metal tape shield (metallic shield type): A tape helically applied over the semi-conducting insulation shield. Tape shields are typically designed to carry charging currents and limited fault currents.~~

network feeder: A primary feeder that supplies energy to a secondary network.

network [system distribution](#): *See: network feeder.*

[non-network system:](#) [A primary feeder or cable which supplies energy directly to a consumer.](#)

pinpoint: [Locating](#) ~~To locate exactly~~ the [exact](#) fault [location](#) ~~site~~ for excavation and repair.

pre-locate: Locating the general area of a fault as a distance from cable start, end, splice, transformer, change in cable type, etc. Identifying a faulted section of cable between two transformers, junction boxes, manholes, etc.

propagation velocity: The velocity at which an [electromagnetic](#) ~~electric~~ signal travels through a cable. Propagation velocity is usually expressed in feet, yards, or meters per microsecond or as a percentage of the speed of light. The value of the propagation velocity [for any particular cable](#) depends on the (relative) dielectric constant of the insulation material used, ~~the characteristic of the semicon shields, and the cable construction~~; it is assumed [to be](#) constant for ~~all~~ practical purposes.

radial feed: A cable system in which independent feeders branch out radially from a common source of supply.

reflection coefficient: A measure of how much of an incident wave is reflected back to the source.

[shield \(metallic type\): A nonmagnetic metallic layer applied over the outer nonmetallic semiconducting layer of an insulated cable. Syn: sheath \(metallic type\).](#)

~~3.1.27 shield (metallic shield types): See: concentric neutral shield (metallic shield type), drain wires shield (metallic shield type), LC shield (metallic shield type), metal tape shield (metallic shield type), and lead sheath shield (metallic shield type).~~

shielded cable: A cable in which each insulated conductor or conductors is/are enclosed in a conducting envelope(s).

shield interrupt: An insulated break installed in a cable [metallic](#) shield so as to interrupt the flow of induced current in the metallic shield. [They are typically made at splice locations and used when special bonding \(i.e., cross-bonding or single-point bonding\) is applied to the circuit. Syn: shield break.](#)

submarine installation type: A cable designed [and installed](#) for service under water.

[surge: A capacitive discharge. Syn: thump.](#)

[thumper](#): In North America, the common term for a capacitive discharge device. See 7.2.5.

3.2 Acronyms and abbreviations

~~EPR~~: ethylene propylene rubber [cable insulation](#)

~~PE~~ [polyethylene cable insulation](#)

~~HV~~: ~~high voltage~~

~~LC~~: ~~longitudinally corrugated~~

~~PILC~~: ~~paper insulated lead covered — a cable design.~~

~~TDR~~: time domain reflectometer/[reflectometry](#), frequently referred to as *cable radar* in the power industry.

~~TRXLPE~~ [tree-retardant cross-linked polyethylene cable insulation](#)

~~PE~~, XLPE ~~polyethylene~~, cross-linked polyethylene, cable insulation

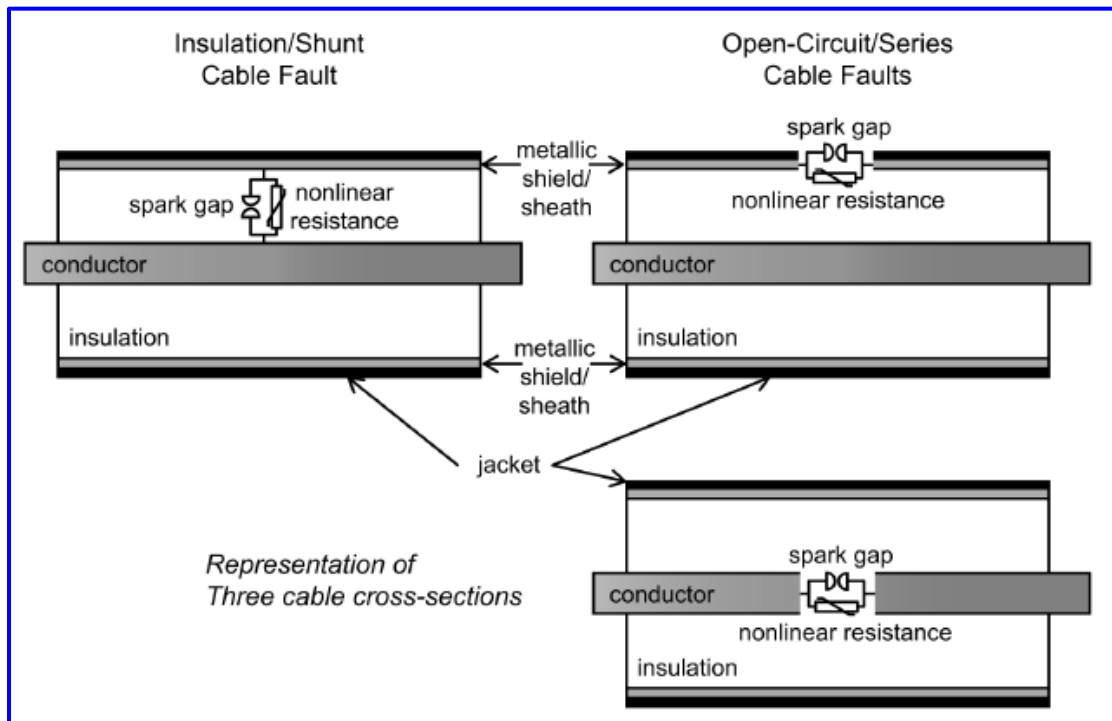
~~URD~~: ~~underground residential distribution~~

[4. Cable system faults and fault locating](#)

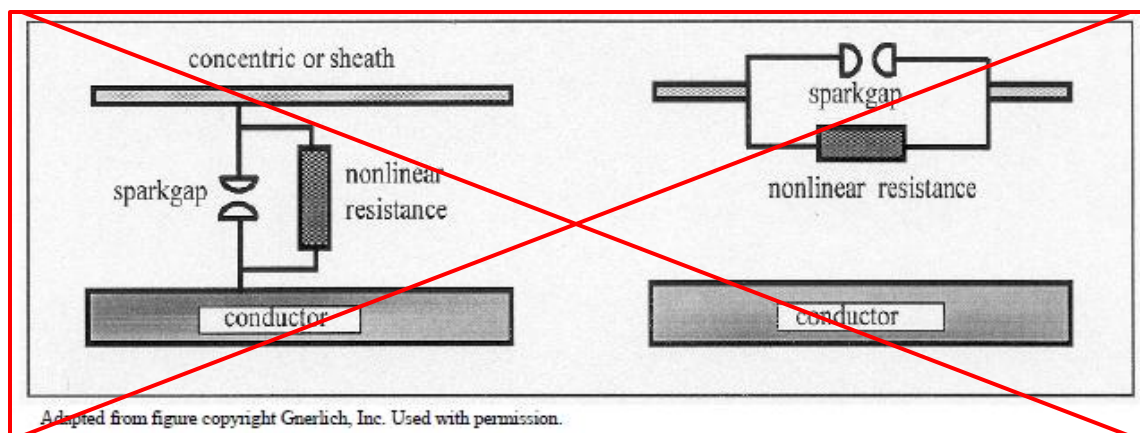
4.1 Cable system faults

A fault can be described as a spark gap in parallel with a nonlinear resistance. The spark gap-nonlinear resistance equivalent circuit can be thought of in [parallel \(shunt\)](#) or in series with a cable section, (see Figure 1 ~~3~~). Actual faults may be a combination of [parallel \(shunt\)](#) and series faults.

~~Adapted from figure copyright Gnerlich, Inc. Used with permission.~~



(New)



(Deleted)

Figure 1—Models of insulation/shunt cable faults (left) and open-circuit/series cable faults (right)

Cable faults may be categorized as series ([open circuit](#), [nonlinear](#), [current-dependent](#)) or [insulation](#)/~~or shunt~~, (~~short or open circuit~~, [nonlinear voltage](#)), phase-to-ground or phase-to-phase, ~~and nonlinear voltage dependent or nonlinear current dependent~~. Table 1 2 lists possible fault types based on their electrical characteristics.

Table 1—Cable fault categories based on their electrical characteristics

Insulation or shunt faults To detect an insulation or shunt fault, an insulation resistance test is performed. The cable end remains open-circuited.	Open-circuit or series faults To detect an open-circuit (conductor) or series fault, a continuity test is performed. The cable end remains short-circuited.
Short circuit — Mechanical damage has forced center conductor and metallic shield into contact. — A low resistance, $R < 100 \Omega$, carbon-metal bridge exists between conductor and metallic shield. Nonlinear (voltage-dependent) — Most faults on cables with extruded dielectric insulation fall into this category; at low voltage, $V < 500 \text{ V}$, cable exhibits characteristics of an unfaulted cable; at a voltage, $V > 500 \text{ V}$, the cable fault flashes over or the cable fault exhibits the characteristics of a nonlinear voltage dependent resistance. — In submerged cable faults, the shunt resistance changes with applied voltage. Flashing, intermittent fault — Cable will often hold a dc voltage greater than the peak phase-to-ground voltage. — Mechanical damage, open termination, or separated splice. — Through reclosing, conductor is blown apart and the conductor end is electrically isolated from the far end conductor. — A non-carbonized hole in the insulation permits a high resistance or insulating path between conductor and metallic shield.	Open circuit — Mechanical damage. Metallic sheath or conductor is severed; separated splice. — Electrical damage. Cable, joints, or terminations are blown apart. Note: This kind of cable system damage is often caused when sectionalizing via reclosing or re-fusing is practiced. Nonlinear (current-dependent) — Metallic shield corrosion — Deteriorating splice or termination — Burnt conductor — Water-soaked blown-out fault

(New)

Shunt faults To detect a shunt fault, an insulation resistance test is performed. The cable end remains open-circuited.	Series faults To detect a series fault, a continuity test is performed. The cable end remains short-circuited.
Short circuit a) Mechanical damage has forced center conductor and concentric into contact. b) Burnt cable insulation; a low resistance, $R < 5 \Omega$, carbon-metal bridge exists between conductor and concentric. c) Evaporated insulation permits a low-resistance path between conductor and concentric. Nonlinear (voltage dependent) a) Most faults on cables with extruded dielectric insulation fall into this category; at low voltage, $V < 500$ volts, cable exhibits characteristics of an unfaulted cable; at a voltage, $V > 500$ volts, the cable fault flashes over, or the cable fault exhibits the characteristics of a nonlinear voltage-dependent resistance. b) In submerged cable faults, the shunt resistance changes with applied voltage. Open circuit Cable will often hold a dc voltage greater than the conductor-to-ground voltage. a) Mechanical damage, open termination, or separated splice. b) Through re-closing, conductor is blown apart and the conductor end is electrically sealed off.	Open circuit a) Mechanical damage. Concentric, sheath or conductor is severed; separated splice. b) Electrical damage. Cable, joints, or terminations are blown apart. NOTE—This kind of cable system damage is often caused when sectionalizing via re-closing or re-fusing is practiced. Nonlinear (current dependent) a) Concentric neutral corrosion b) Deteriorating splice or termination c) Burnt conductor d) Water-soaked blown-out fault

(Deleted)

4.2 Fault-locating overview ~~preferences chart~~

The intent of the following guidance is To reduce high-voltage ~~(the HV)~~ stress on service-aged cables, diagnose faults, and select the ~~should be diagnosed.~~ Fault-locating techniques which offer the most efficient fault-location process and allow use of ~~that enable fault locating at~~ the lowest possible voltage in the shortest amount of time ~~should be selected.~~ Table 2 3 lists preferred pre-locating techniques for the most common types of cable faults. Reclosing or re-fusing and applying the system power are not acceptable fault-locating methods.

Table 2—Preferred pre-locating techniques

	Bolted fault, short-circuit faults, low-resistance faults	Open conductors, metallic shield/sheath corrosion	Water-soaked faults, high-resistance faults	HV flashover faults, high-resistance faults	Jacket	Very high-voltage flashover faults, intermittent faults
Conventional time domain reflectometers (TDRs)	X	X				
Comparison and difference TDRs	X	X				
Surge arc reflection method			X	X		
Impulse current method			X	X		

(New)

Table 2—Preferred pre-locating techniques (*continued*)

	Bolted fault, short-circuit faults, low-resistance faults	Open conductors, metallic shield/sheath corrosion	Water-soaked faults, high-resistance faults	HV flashover faults, high-resistance faults	Jacket	Very high-voltage flashover faults, intermittent faults
Burn arc reflection method			X	X		
Decay method voltage coupled				X		X
Bridge methods	X		X		X	

(New)

	Bolted fault, short circuit faults	Open conductors, concentric neutral corrosion	Oil- or water-soaked faults	HV flashover faults, high-resistance faults	Conductor-to-ground faults	Very high HV flashover faults, intermittent faults
Conventional TDRs						
Comparison and difference TDRs						
Surge arc reflection method						
Surge pulse reflection method						
Burn arc reflection method						
Decay method voltage coupled						
Bridge methods						

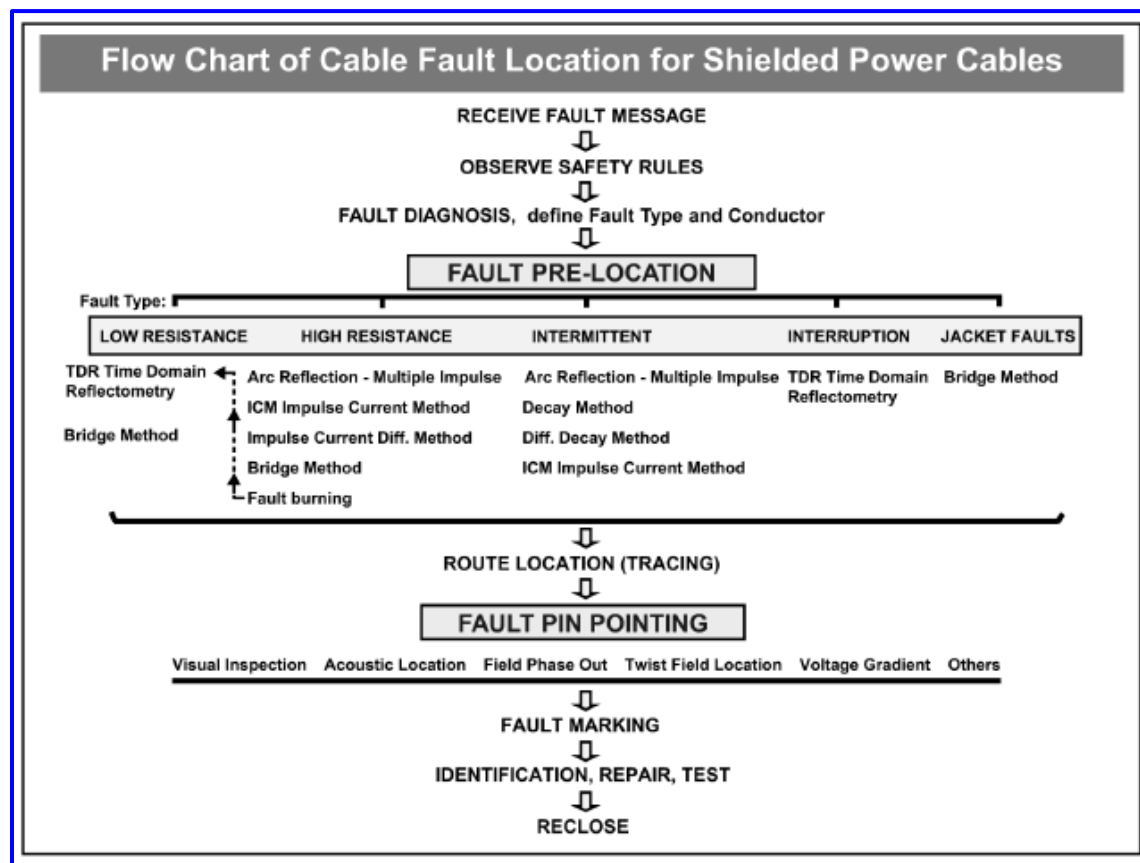
(Deleted)

When fault characteristics are conducive to using a simple TDR, faults can be quickly and easily identified and located. However, many faults are high resistance, limiting the use of a simple TDR approach. In these cases, methods may be used to lower fault resistance so that other methods can be used, such as TDR, arc reflection, and bridge methods permit fault locating with the highest benefit /cost ratio. However, fault locating with TDR and bridge techniques is not possible for all cable installations. Powerful thumpers and ac or dc burnsets inject fault currents into the defective cable system. AC, DC, or pulse (surge) tracing instruments are used to follow the fault current signal to the fault.

Fault conditioning is a euphemism for burning the cable fault ~~for hours or days~~ into a low-resistance state. This method can be, ~~is often required when using current tracing techniques.~~ ~~Current tracing methods are quite~~ destructive to adjacent cables in close proximity to the faulted section and may result in cable system fires near ~~in the vicinity of~~ the fault.

When fault-burning techniques are used, the fault is typically burned to the point that identification of any possible cause of the fault, other than installation damage, is not possible.

The following flow chart (Figure 2) steps through cable fault-location procedures on shielded power cables.



(New)

Figure 2—Cable fault location flow chart

5. Safety⁵

5.1 Safety practices

When testing [a cable system](#), personnel safety and service reliability of the electrical systems are of [ultimate](#) ~~utmost~~ importance. All cable and equipment tests [shall](#) ~~must~~ be performed on isolated and de-energized systems, except where otherwise specifically required and authorized. The safety practices [shall](#) ~~must~~ include, but ~~are not~~ [be](#) limited to, the following requirements:

- a) Applicable user safety operating procedures
- b) IEEE Std 510TM, [IEEE Recommended Practices for Safety in High-Voltage and High-Power Testing⁴](#) ~~1983~~
- c) Applicable state and local safety operating procedures
- d) Protection of utility and customer property

While testing, one or more cable ends will be remote from the testing site, therefore:

- Cable ends [shall](#) ~~must~~ be cleared and guarded.
- [Communications shall be maintained with personnel at the remote end at all times.](#)
- Cables [shall](#) ~~must~~ be de-energized and grounded before testing is begun.
- [Any cables and/or conductors not under test shall be solidly grounded during testing.](#)

At the conclusion of high-voltage (~~HV~~) testing, attention should be given to ~~the following~~:

- Special techniques required for discharging cables and cable systems [to dissipate any stored energy that may be present in the cable.](#)

⁴[Information on references can be found in Clause 2.](#)

⁵~~Some of the material appearing in this document is adapted with permission from Cnerlich, Inc. training courses. [B5], [B6]~~

- Grounding requirements for cables to assure that adequate time is given to completely discharge the trapped charges that can exist in a cable due to ~~eliminate the aftereffects of the cables' dielectric absorption, and capacitance characteristics~~

4.2 Responsibility

~~Training requirements for cable fault locating and trouble shooting personnel will vary with cable type, installation, system, environment, and the equipment and instruments used. Operations and cable fault locating departments should establish initial and continuing education training programs to qualify their cable fault locating and trouble shooting personnel.~~

~~The minimum qualification for the responsible, on-site cable fault locator or trouble shooter should include, but is not limited to the following:~~

- ~~– Initial training in the use of cable fault locating instruments and devices with thorough understanding of their advantages and limitations~~
- ~~– Familiarity with all applicable user, state, and local safety operating procedures~~
- ~~– Knowledge of cable and equipment specifications and the ability to select cable fault locating techniques, instruments, and devices that minimize the risk of damaging cable, joints, terminations, and equipment~~

5.2 Precautions for ac cable systems

Many cable fault locators and troubleshooters use ~~a~~ high-voltage dc ~~test (see IEEE Std 400™ [B11]⁶)~~ as part of their standard fault-locating procedure. It is known ~~In the late seventies, it became apparent~~ that dc testing may generate additional ~~exacerbate~~ cable defects in service-aged ac cables with extruded dielectric insulation, in particular, XLPE ~~lacking tree-retardant properties. Such cables may ultimately fail sooner than they would have if dc testing had not been performed.~~ Therefore, dc proof testing of service-aged cables with extruded dielectric insulation ~~lacking tree-retardant properties~~ is not recommended. This precaution does not apply to dc cable systems or paper-insulated cables.

⁶~~The numbers in brackets preceded by the letter B correspond to those of the bibliography in Annex A.~~

Failure to completely discharge a cable after it has been charged with voltage may result in failure upon re-energization. Due to trapped charges, which have a long discharge time constant, the residual dc voltage may cause a failure upon re-energization. See the IEEE Std 400™ omnibus.

Some utility or industrial standards do not yet take into account the potentially damaging effects of dc testing on extruded cables used in ac systems. If dc ~~proof~~-testing ~~of service-aged cables~~ should become necessary ~~for a justifiable reason~~, the cable manufacturer should be consulted for the maximum dc test value. This restriction does not apply to cables with laminated, oil-impregnated-~~paper-type insulation maintenance test value. For example, testing of cables by qualified cable fault-locating and trouble-shooting personnel, in critical service areas such as hospitals, continuous-process industries, and cold storage units, still provides the advantage of identifying deteriorated cables prior to their failure, and enabling repairs/replacement to be done, under planned conditions, without sudden interruption of service.~~

There is a key difference between what is considered a dc cable test and an applied dc voltage during fault locating. As stated, it is not recommended to dc test an extruded cable. Typically when fault locating, a dc voltage is applied when using the thumper method to determine the breakdown voltage of the fault. This information is then used to determine the proper thump voltage level to use. This process of setting the thump voltage takes just a few seconds, as opposed to dc cable testing which is typically a minimum of 15 minutes in duration. Reducing the thump voltage and the number of times a cable is thumped can also be achieved by one of the arc reflection methods discussed in Clause 7.

DC voltage sources are also used as part of some fault-locating techniques including the bridge methods, current tracing methods, metallic shield/sheath, and jacket (oversheath) fault locating. Again, these methods typically apply a dc voltage less than the peak of the ac operating voltage for a short time duration.

Connected equipment and the cable terminal voltage ratings should be considered before applying a dc test voltage. Special consideration should be given if there are gas-insulated cable terminations.

When testing a faulted cable, be cautious of induced voltage from parallel transmission circuits. Please refer to IEEE Std 1727™.

5.3 Grounding

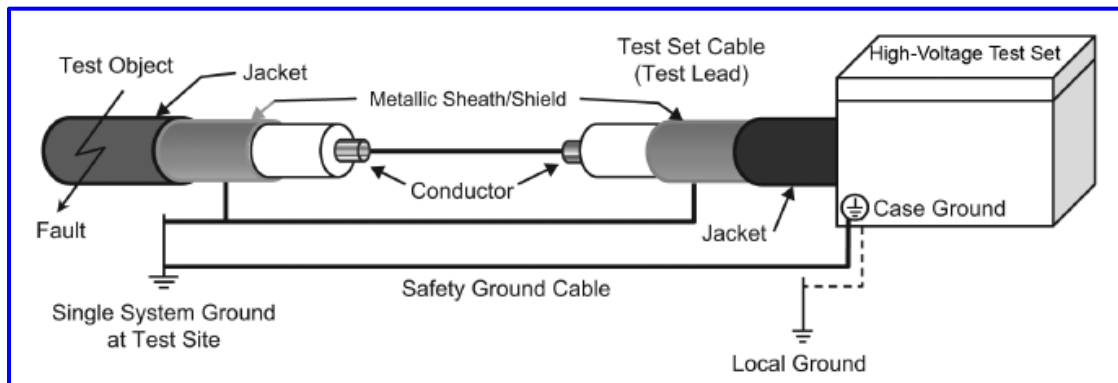
WARNING

Cables can only be considered de-energized and grounded when ~~the~~ conductor and metallic ~~the concentric~~ shield are connected to ~~the~~ system ground at the test site, and, if possible, at the far end of the cable. In general, depending on the system configuration, all phases shall be grounded, including the tested phase (both before and after testing).

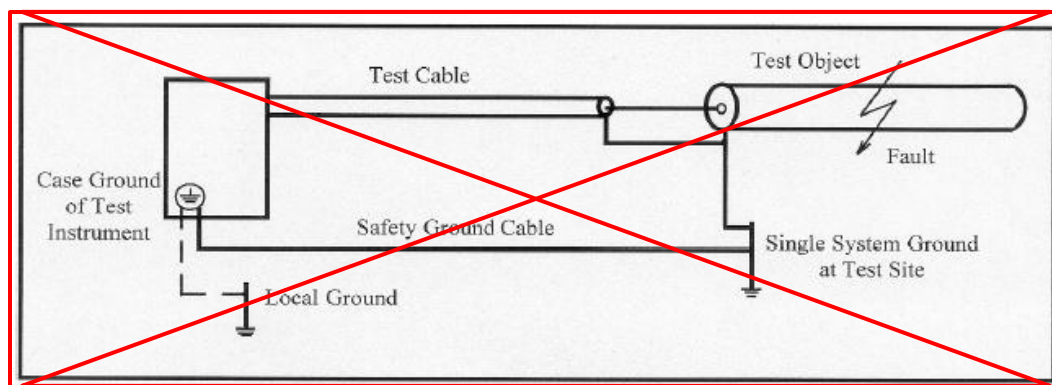
When fault locating on a defective cable, installation, or system, a **single system ground at the test site** is recommended, (see Figure 3 4). The metallic shield(s) ~~or concentric conductor~~ of the faulted cable or cable being tested shall be ~~is~~ connected to system ground with a mechanically sound connection. High current magnitudes with fast rise times can flow during cable fault locating. Short and solid connections are required to reduce the creation of voltage potential differences between grounding points and the test set. If the metallic shield ~~this~~ connection is missing, deteriorated, or has been removed, it shall ~~must~~ be replaced at this time. **A safety ground cable shall must connect the instrument case with system ground.** All ground connections should be as short as possible. If the test instrument produces high voltages ~~is an HV device~~, the safety ground cable shall ~~should~~ be at least a braided or stranded #2 AWG copper cable. Only after the safety ground cable is in place shall ~~should~~ the test cables ~~cable~~ be connected to the phase conductor and the metallic shield. The phase ~~center~~ conductor ~~and concentric shield; the center conductor~~ to-ground connection for the cable to be tested may now ~~can then~~ be removed.

Should a local ground be advisable or required for the test equipment, the case ground of the test instrument shall ~~must~~ remain connected to ~~the~~ system ground in order to maintain an acceptable single ground potential.

All ground connections shall ~~must~~ be screw-type connections that ~~which~~ cannot accidentally be disconnected.



(New)



(Deleted)

Copyright Gnerlich, Inc. Used with permission.

Figure 3— Single system ground at test site