IEEE Guide for the Application of Faulted Circuit Indicators for 200 A, Single-Phase Underground Residential Distribution (URD)

Sponsor

Transmission and Distribution Committee
of the
IEEE Power Engineering Society

Approved 7 December 2000

IEEE-SA Standards Board

Abstract: This application guide provides information on what a basic faulted circuit indicator (FCI) is designed to do, and describes methods for selecting FCIs. The application of FCIs to single-phase, 200 A, underground residential distribution (URD) circuits is described.
Keywords: overcurrent protection, power distribution

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

Print: ISBN 0-7381-2722-1 SH94901
PDF: ISBN 0-7381-2723-X SS94901

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

Use of an IEEE Standard is wholly voluntary. The IEEE disclaims liability for any personal injury, property or other damage, of any nature whatsoever, whether special, indirect, consequential, or compensatory, directly or indirectly resulting from the publication, use of, or reliance upon this, or any other IEEE Standard document.

The IEEE does not warrant or represent the accuracy or content of the material contained herein, and expressly disclaims any express or implied warranty, including any implied warranty of merchantability or fitness for a specific purpose, or that the use of the material contained herein is free from patent infringement. IEEE Standards documents are supplied "**AS IS**."

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. Every IEEE Standard is subjected to review at least every five years for revision or reaffirmation. When a document is more than five years old and has not been reaffirmed, 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 publishing and making this document available, the IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity. Nor is the IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing this, and any other IEEE Standards document, should rely upon the advice of a competent professional in determining the exercise of reasonable care in any given circumstances.

Interpretations: Occasionally questions may arise regarding the meaning of portions of standards as they relate to specific applications. When the need for interpretations is brought to the attention of IEEE, the Institute will initiate action to prepare appropriate responses. Since IEEE Standards represent a consensus of concerned interests, it is important to ensure that any interpretation has also received 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 interpretation requests except in those cases where the matter has previously received formal consideration.

Comments for revision of IEEE Standards are welcome from any interested party, regardless of membership affiliation with IEEE. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Comments on standards and requests for interpretations should be addressed to:

Secretary, IEEE-SA Standards Board
445 Hoes Lane
P.O. Box 1331
Piscataway, NJ 08855-1331
USA

Note: 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 with respect to the existence or validity of any patent rights in connection therewith. The IEEE shall not be responsible for identifying patents for which a license may be required by an IEEE standard or for conducting inquiries into the legal validity or scope of those patents that are brought to its attention.

IEEE is the sole entity that may authorize the use of certification marks, trademarks, or other designations to indicate compliance with the materials set forth herein.

Authorization to photocopy portions of any individual standard for internal or personal use is granted by the Institute of Electrical and Electronics Engineers, Inc., provided that the appropriate fee is paid to Copyright Clearance Center. To arrange for payment of licensing fee, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; (978) 750-8400. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

Introduction

[This introduction is not a part of IEEE Std 1216-2000, IEEE Guide for the Application of Faulted Circuit Indicators for 200 A, Single-Phase Underground Residential Distribution (URD).]

This guide is intended to be a supplement to the training in high-voltage electrical equipment, established safe operating procedures, and the manufacturer's instructions for the application of faulted circuit indicators. Installers and operators of faulted circuit indicators require formal training in the use of high-voltage electrical equipment. It is the users' responsibility to establish safe operating procedures and provide training. The manufacturers are required to provide installation and operating instructions for their products.

This document is the first IEEE guide issued that addresses the application and operation of faulted circuit indicators. This application guide is the product of close collaboration between representatives of both users and manufacturers of faulted circuit indicators.

At the time this guide was completed, the Faulted Circuit Indicators Working Group had the following membership:

Richard H. Arndt, *Chair*

Jose Alvarez
Ernest H. Baker
John F. Banting
Joe F. Buch
James J. Burke
Ray Capra
William R. Daniel
David Donovan
Dan Flick
Cal H. Foster
Massoud Ghaemi
David L. Gilmer
Harry Hayes
Joseph L. Kane
Clayton C. King
Mike O. Klingbeil
Terry Klusmeyer
Tom Kulas
Joe A. Lapoint
Raymond M. Litwin
John J. Mahoney
Vladimir Manlapa
Tom McCarthy
Dale T. Metzinger
Paul E. Orehek
Orville Plum
Tim Qualheim
Robert A. Resuali
Russ Schoentker
Betty Tobin
Brian Trager
Anh Van Le
Daniel J. Ward
Art Westrom

The following members of the balloting committee voted on this standard:

Roy W. Alexander
Richard H. Arndt
Gernot K. Brandt
Kristine K. Buchholz
James J. Burke
Frederick W. Burtelson
Frank A. Denbrock
Paul R. Drum
George Gela
Edward Jankowich
Ralph O. Jones
George G. Karady
Nestor Kolcio
Donald E. Koonce
Gary L. Michel
Daleep C. Mohla
Ronald J. Oedemann
Robert G. Oswald
Carolos O. Peixoto
Robert C. Peters
Radhakrishna V. Rebbapragada
John Rumble
Donald R. Ruthman
Lawrence Salberg
Donald Sandell
Roger A. Schoneman
Mohamed H. Shwehdi
Mark S. Simon
Daniel J. Ward

When the IEEE-SA Standards Board approved this standard on 7 December 2000, it had the following membership:

Also included is the following nonvoting IEEE-SA Standards Board liaison:

Alan Cookson, *NIST Representative*
Donald R. Volzka, *TAB Representative*

Jennifer McClain Longman
IEEE Standards Project Editor

Contents

IEEE Guide for the Application of Faulted Circuit Indicators for 200 A, Single-Phase Underground Residential Distribution (URD)

1. Overview

The vast majority of faulted circuit indicators (FCIs) used by the utility industry are applied to single-phase underground residential distribution (URD) circuits. Faults on these circuits are assumed to be permanent and bolted. This guide will describe the application of FCIs to single-phase, 200 A URD circuits.

1.1 Scope

This application guide provides information on what an FCI is designed to do, and describes methods for selecting FCIs. The application of FCIs to single-phase, 200 A URD circuits is described.

2. References

This guide shall be used in conjunction with the following publication. When the following standard is superseded by an approved revision, the revision shall apply.

ANSI/IEEE Std 495-1986, IEEE Guide for Testing Faulted Circuit Indicators.[1]

3. Definitions

For the purposes of this standard, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards Terms* [B5][2] should be referenced for terms not defined in this clause.

[1]ANSI/IEEE Std 495-1986 has been withdrawn; however, copies are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).

[2]The numbers in brackets correspond to those of the bibliography in Annex A.

3.1 automatic reset faulted circuit indicator (FCI): A type of faulted circuit indicator (FCI) that resets automatically after an operation. Automatic reset control parameters include voltage, current, and time, and combinations of these three.

3.2 bolted fault: A low-impedance path to ground in which the maximum available fault current can flow.

3.3 current reset: A type of automatic reset in a faulted circuit indicator (FCI) design that utilizes current.

3.4 display: The portion of the faulted circuit indicator (FCI) that indicates that the fault current has been sensed.

3.5 fault current: Any current through the sensor equal to or in excess of the trip current of the faulted circuit indicator (FCI).

3.6 faulted circuit indicator (FCI): Devices that are used on primary distribution circuits (typically 5, 15, 25, and 35 kV) and when properly applied, reliably indicate the occurrence of a fault beyond that location. FCIs are used to detect faults on primary underground residential distribution (URD) circuits and are not expected to detect faults on the secondary side of padmounted transformers.

3.7 faulted circuit indicator (FCI) components: FCIs can be visualized as consisting of three basic components. The components are the sensor, the logic circuit, and the display.

3.8 inrush restraint: A faulted circuit indicator (FCI) design feature to minimize false tripping due to current inrush during energization of the circuit.

3.9 logic circuit: A faulted circuit indicator (FCI) internal circuit design for recognizing a fault condition. The section of the FCI that determines if and when a fault condition exists.

3.10 looped circuit: A type of distribution circuit with two or more sources, usually separated by an open switch.

3.11 manual reset faulted circuit indicator (FCI): A type of FCI that requires manual reset by the operator.

3.12 proximity effect: The magnetic induction effect of load or fault current flowing in an adjacent wire, cable, or ground conductor that may cause a faulted circuit indicator (FCI) to malfunction (i.e., false trip, fail to trip, or reset incorrectly).

3.13 radial circuit: A type of distribution circuit fed from a single source.

3.14 remote display: A faulted circuit indicator (FCI) display that is physically separated from the sensor.

3.15 reset: The state of a faulted circuit indicator (FCI) indicating a normal condition.

3.16 reset current: The nominal rms value of current that will cause the indicator of the automatic current reset faulted circuit indicator (FCI) to change from FAULT to NORMAL indication.

3.17 reset time: The time required for the faulted circuit indicator (FCI) to return automatically to NORMAL indication after its reset current or voltage has been established, or for the time reset FCI to reset.

3.18 response time: The time required for the faulted circuit indicator (FCI) sensor to detect its rated value of fault current.

3.19 sensor: The sensing section of a faulted circuit indicator (FCI) designed to detect a fault condition.

3.20 time reset: A type of automatic reset that resets a faulted circuit indicator (FCI) after a specified time.

3.21 trip current: The actual value of current in amperes rms that will cause the faulted circuit indicator (FCI) to indicate FAULT.

3.22 trip level: The threshold current that will cause the faulted circuit indicator (FCI) to operate.

3.23 tripped faulted circuit indicator (FCI): An FCI that has operated to indicate a fault condition.

3.24 voltage reset: A type of automatic reset in a faulted circuit indicator (FCI) design that utilizes voltage.

4. 4. Single-phase 200 A URD circuits

4.1 Introduction

Distribution voltages currently range from 5 kV to 35 kV, with most distribution systems within the 15 kV class. Length of distribution circuits is determined by load and voltage. Typically, distribution circuits are 16 km or less; however, some circuits may reach 32 to 48 km.[3] The longer circuits are typically energized by higher distribution voltages (i.e., 21 to 35 kV). The average short circuit level at the secondary bus of substations is about 10 000 A. Typical feeder distribution circuits are rated for 600 A but rarely exceed 400 A at full load current. A typical 200 A URD lateral full load current does not exceed 50 A even during peak conditions. Figure 1 shows a typical distribution feeder in some detail.

[3] For example, typically, distribution circuits are 10 miles or less; however, some circuits may reach 20 to 30 miles.

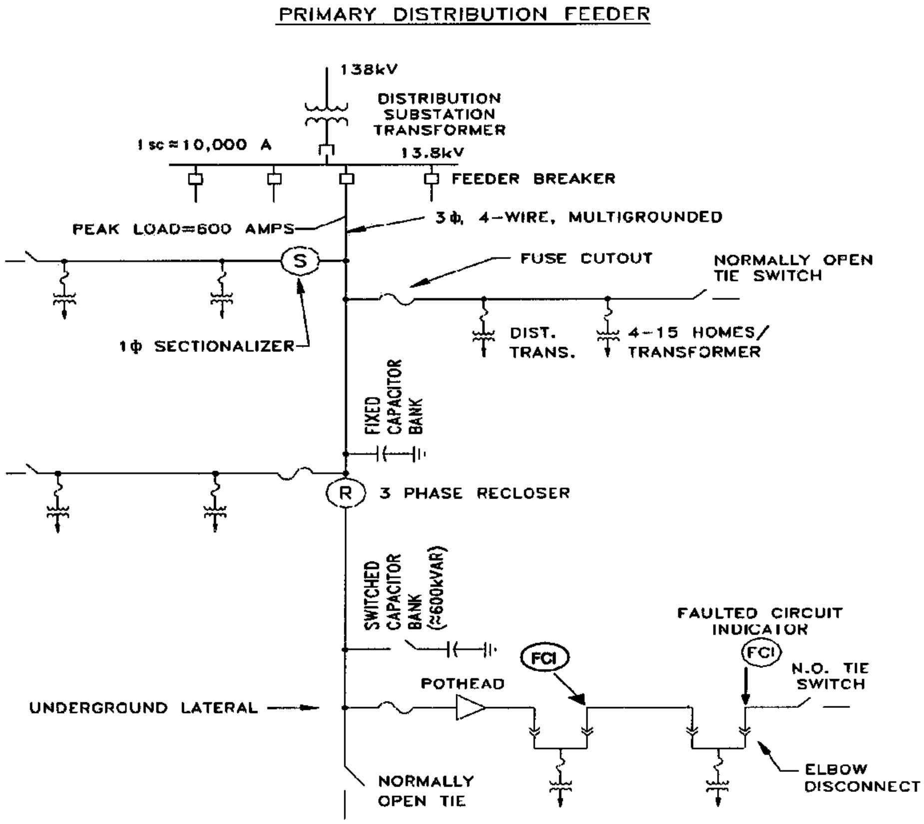

Figure 1—Typical distribution system

4.2 Fault levels

There are two types of faults, low-impedance and high-impedance. A high-impedance fault is considered to be a fault that has a high impedance due to the contact of the conductor to the earth, i.e., impedance is high. By definition, a bolted fault at the end of a feeder is classified as a low-impedance fault. Following is a summary of findings on faults and their effects.

4.2.1 Low-impedance faults

Low impedance faults or bolted faults can be either very high in current magnitude (10 000 A or above) or fairly low, e.g., 300 A at the end of a long feeder. Faults able to be detected by normal protective devices are all low-impedance faults. These faults are such that the calculated value of fault current assuming a “bolted fault” and the actual value are very similar. Most detectable faults, per study data, do indeed show that fault impedance is close to 0 Ω (Burke and Lawrence [B3]). This indicates that the phase conductor makes good contact with ground, either by contacting the concentric neutral, arcing to the neutral, or by establishing a low-impedance path through the earth. An EPRI study indicated that the maximum fault impedance for a detectable fault is 2 Ω or less. Figure 2 indicates that 2 Ω of fault impedance influences the level of fault current depending on the location of the fault. As can be seen, 2 Ω of fault impedance considerably decreases the level of fault current for close in faults but has little effect for faults some distance away. It can be concluded that fault impedance does not significantly affect faulted circuit indicator performance, since low level faults are not greatly altered.

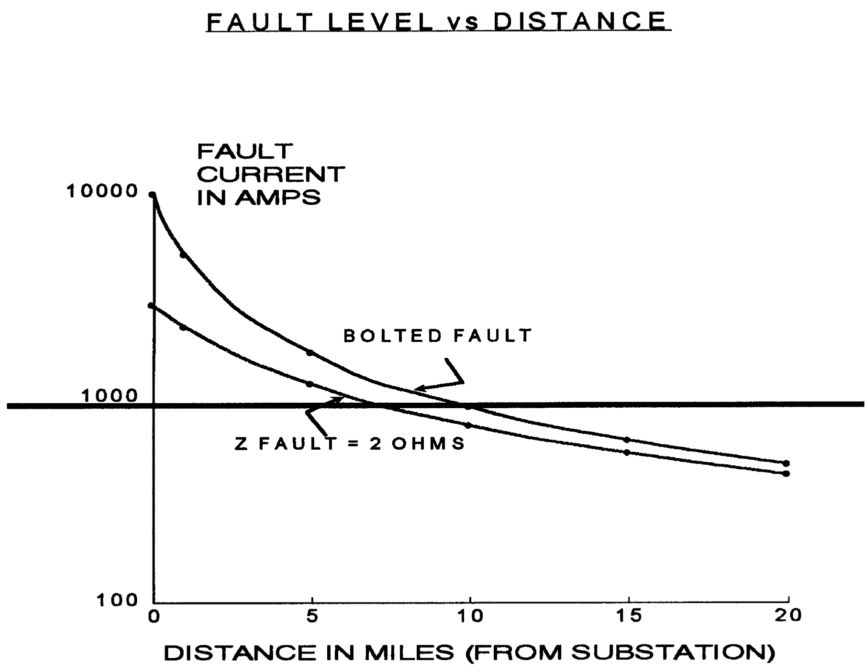

Figure 2—Low impedance faults

4.2.2 High-impedance faults

High-impedance faults are faults that are low in value, generally less than 100 A. This implies that high-impedance faults do not contact the neutral, do not arc to the neutral, or there is not enough voltage to establish a low-impedance earth return. As such, they are not detectable by conventional means and are not to be considered when selecting faulted circuit indicators for typical 200 A URD systems.

4.3 Reclosing and inrush

On most systems where most faults are temporary, reclosing and the resulting inrush currents are a fact of life.

These reclosing sequences produce inrush primarily resulting from the connected transformer kVA. This inrush current is high and can approach the actual fault current level in many instances. Figure 3 shows the relative magnitude of these currents. What keeps most protective devices from operating is that the duration of the inrush is generally short, and as a consequence, may not melt a fuse or operate a time delay relay. It is generally believed that the maximum inrush at the lateral tap level is below the trip value of most FCIs. Also, FCIs located near the end of the lateral see even less inrush.

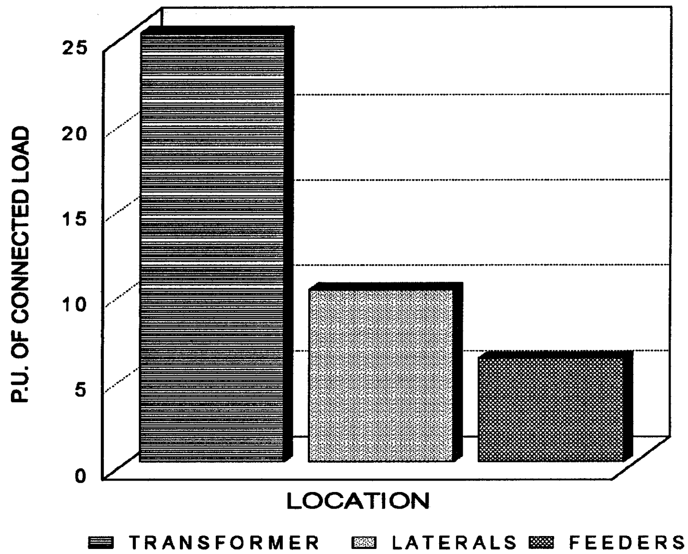

Figure 3—Typical magnitudes of inrush current

4.4 Cold load pickup

Cold load pickup, occurring as the result of a permanent fault and long outage, is often maligned as the cause of many protective device misoperations. Figure 4 illustrates several cold load pickup curves developed by various sources. These curves are normally considered to be comprised of the following three components:

a) Inrush—lasting a few cycles

b) Motor starting—lasting a few seconds

c) Loss of diversity—lasting many minutes

When a lateral fuse misoperates, it is probably the result of the loss of diversity, i.e., the fuse is overloaded. This condition is rare on most laterals. Relay operation during cold load pickup is generally the result of a trip on the instantaneous unit and probably results from high inrush. Likewise, an FCI operation would not appear to be the result of loss of diversity, but rather the high inrush currents. Since inrush occurs during all energization and not just as a result of cold load pickup, it can be concluded that cold load pickup is not a factor in the application of FCIs that have auto-reset.

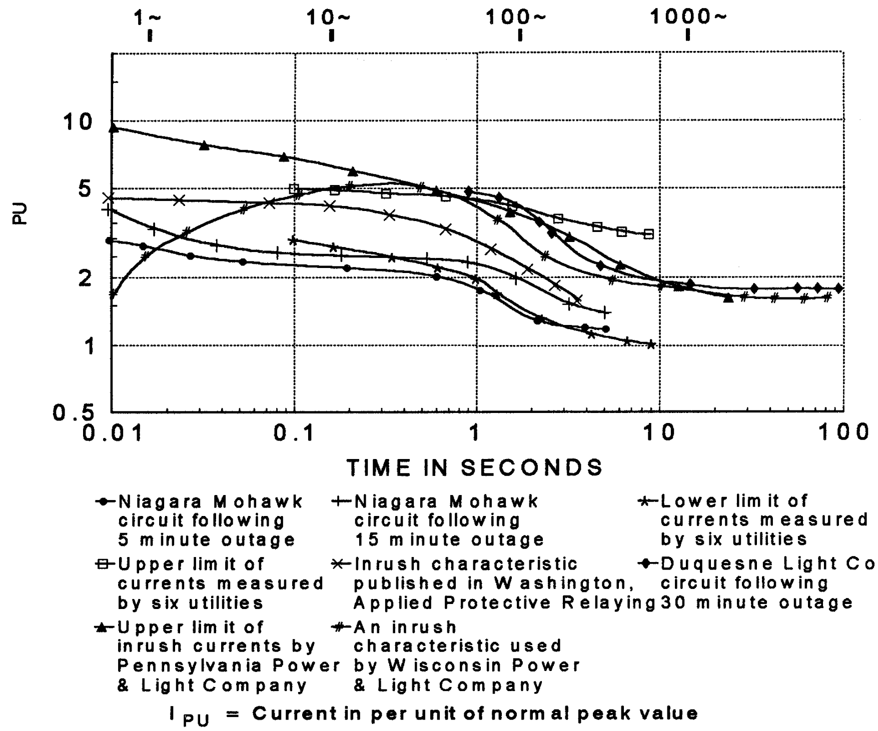

Figure 4—Cold load inrush current characteristics for distribution circuits

5. Application of FCIs

5.1 Manual reset

Manually reset fault indicators must be concerned with such items as cold load pickup, inrush, switching surges, and power follow currents. With the large variety of system conditions that can occur on a distribution system, as well as the large number and type of manually reset FCIs available to the user, it is impossible to generalize application rules. This type of FCI must be coordinated somewhat like a fuse. The problem here is that some of the items it must coordinate with are largely undefined in terms of magnitude or duration, e.g., inrush on laterals. Figure 5 indicates a few system conditions that may (or may not) have to be considered.

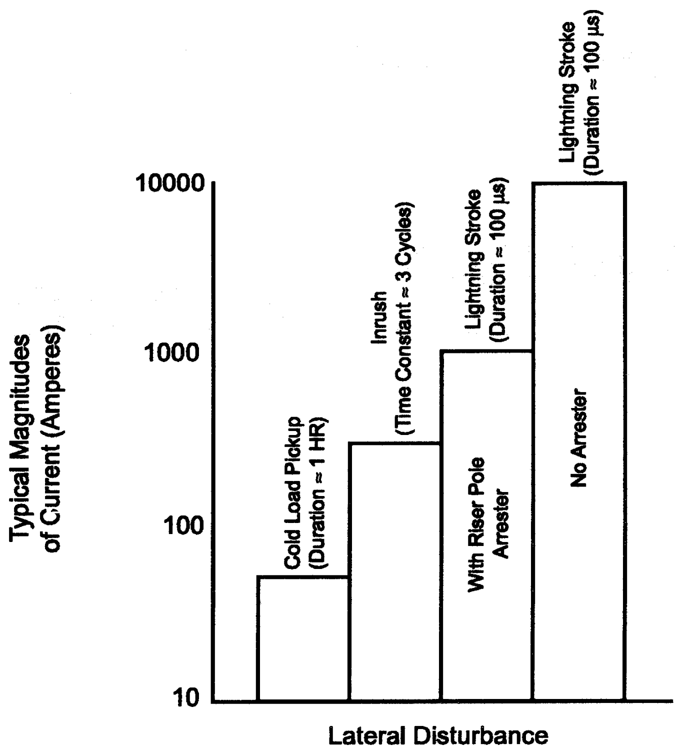

Figure 5—Lateral conditions affecting manually reset FCIs

5.1.1 Inrush restraint

Inrush is generally not considered to be a problem on a single-phase URD. If inrush is a concern (usually because fault levels are very low, requiring FCI with low trip), then precautions must be taken to prevent operation of manually reset FCIs. A variety of inrush restraints are available from manufacturers. Some use special time/current response curves, while others use more sophisticated inrush restraint logic.

Consider that the time/current characteristics of a fuse curve and an inrush curve are similarly shaped with the inrush curve lying to the left of the fuse curve, as shown in Figure 6. If an FCI with only a time/current response curve is applied, that response must lie between the inrush curve and the fuse curve to assure coordination. If it is coordinated, the FCI will not trip on inrush, but will trip before the fuse clears. A manual reset FCI must be coordinated. A case can be argued that if an automatic reset FCI is applied, the unit can trip on inrush every time the circuit is re-energized and then be allowed to reset. However, an FCI should not trip on inrush due to the possibility of an upstream breaker or recloser operating immediately prior to a fault occurrence and tripping some of the FCIs.

There are two reasons why it is difficult to apply FCIs with only time/current response curves, and without inrush restraint logic.

a) While the total clearing time/current curve of the fuse is well known, the time/current curve of the inrush current is not well known and varies with the connected transformer kVA.

b) The time/current response curves of FCIs tend to consist of a series of horizontal and vertical lines not unlike a step function. It is difficult to keep the FCI response between the inrush time/current curve and the fuse total clearing time/current curve.

The FCI should be slower than the system inrush and faster than the fuse curve.

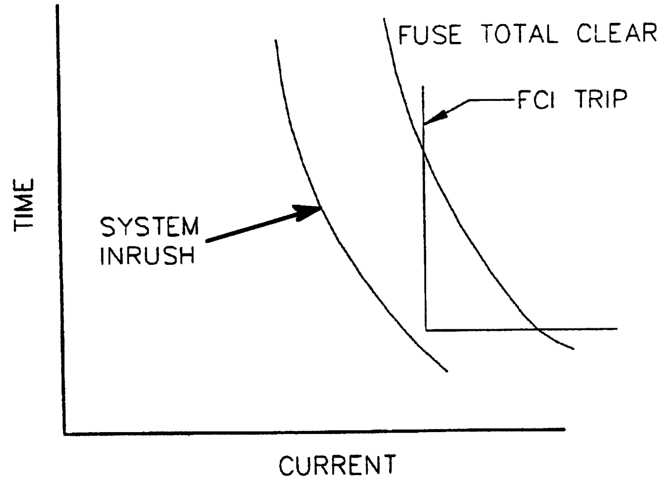

Figure 6—Coordination of manually reset FCIs

5.2 Automatic reset

In general, FCIs are available with a variety of resets. The reset is the method of returning a tripped unit to its untripped state. Automatic reset types include voltage, current, time, and combinations.

5.2.1 Current resetting

When using current resetting FCIs, the minimum load current available for reset must be considered. Referring of Figure 7, the load current through the FCI located in TR 5 is essentially zero. In addition, the load currents through the FCIs located in TR 3 and TR 6 will be very small, especially during light load conditions. These small currents may not be sufficient to reset the FCIs.

One also needs to be aware of changes in the normally open point. For example, moving the normally open point to TR 3 can result in a load current insufficient to reset a current resetting FCI in TR 2.

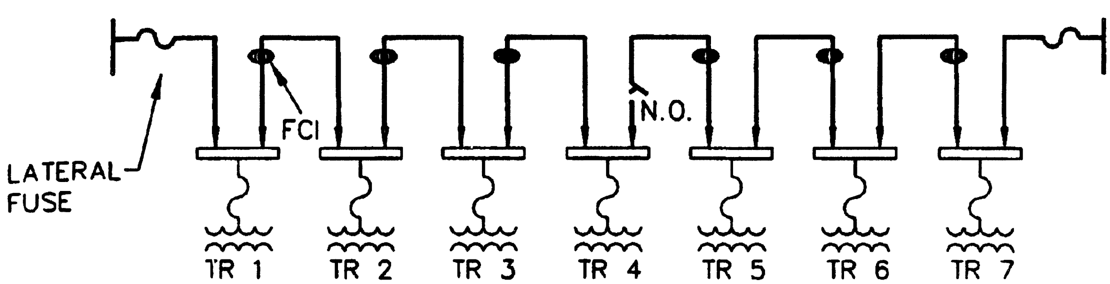

Figure 7—Example of faulted circuit indicator application to single phase, 200 A, URD circuits

5.2.2 Voltage resetting

Voltage resetting fault indicators are not affected by load conditions because they are in no way dependent on the load current. Moving the open point will have no adverse affect on voltage resetting fault indications for the same reason. Either a high voltage reset or a low voltage reset can be used on an underground system. High voltage resetting devices depend on the electrostatic field surrounding a high-voltage cable or a separable connector's capacitive test point for operating power. Thus, an electrostatic reset type requires that the cable be unshielded, and a test point reset type requires a test point type separable connector. Low-voltage resetting devices are designed for use wherever a secondary voltage is available and so do not require a "test point type separable connector."

5.2.3 Time resetting

When choosing the length of time before reset, the time chosen should be long enough to allow operating personnel time to locate and isolate the fault. If some or all of the units reset before this is accomplished, confusing information as to the location of the fault exists. In contrast, choosing an excessively long time can also cause problems if there is a subsequent fault before the units have had a chance to reset. This generally is not a concern. However, the use of inrush restraint needs to be considered. It is typical to have multiple faults occur on a distribution feeder during stormy weather. If the FCIs trip on inrush, and subsequently a fault occurs on the cable before enough time has elapsed to reset the FCI, then misleading information as to the location of the fault can result.

6. Other considerations

6.1 Display

The basic function of an FCI is to detect fault currents and provide evidence that a fault current was detected. When choosing an FCI display, the first decision required is its location.

The display can be located on the primary cable immediately below the termination. This arrangement has the disadvantage of having to open the enclosure or substructure to observe its display.

The display can be mounted such that it is visible without opening the padmount. This design requires a sensor on the cable termination that is connected to the remote display via a cable.

The second decision is the type of display. This can be a mechanical flag, audible alarm, light, fiber, or counter.

6.2 Placement

The typical single-phase, 200 A URD circuit can be radial or looped. The looped circuit typically has an open point. When choosing the placement of FCIs, a trade off between cost and customer reliability needs to be made. FCIs could be placed on both the incoming and outgoing cables of each transformer. This would provide the most knowledge on where the fault is located since information would be available to differentiate between cable faults and faults on the high voltage bus in the transformer. Evidence has shown that, in general, primary cable faults are much more prevalent than high-voltage bus faults in the transformer. Thus, to address the problem of cable faults, FCIs need only be placed on the outgoing cables of each transformer. One could further reduce the number of FCIs installed by locating them at every other transformer or less. However, for each reduction in the number of FCIs, the time to locate and isolate the faulted cable will increase. The customer outage time will also increase. Referring to Figure 7, the transformer at the open point in the loop (TR 4) is a special case. Normally an FCI would not be installed at this location. However, when the open point is permanently relocated to a different transformer, the locations of the FCIs need to be adjusted. This results in the placement of an FCI at TR 4. If the utility operating practice is such that the open point is temporarily moved for an extended period of time, one of the spans of cable connected to TR 4 will not be covered by an FCI. In this case, the utility may wish to consider the installation of a FCI at TR 4.

6.3 Coordination

Be certain that the FCIs' response coordinates with all protective devices to ensure that it will trip under all fault conditions. Be especially concerned about coordination with current-limiting fuses.

6.4 Proximity effect

Some FCI sensors can be influenced by other current-carrying conductors and grounded neutral conductors in close proximity. Follow the manufacturer's directions to prevent misapplications.

7. Recommendations

The typical application of FCIs to 200 A, single-phase URD circuits is summarized as follows:

a) Pick a trip level of less than 50% of the available fault current or 500 A, whichever is less.

b) Ignore inrush, except on very long or heavily load laterals. In cases where inrush is a problem, use inrush restraint.

c) Use a fault impedance of 0 Ω to 2 Ω when calculating fault currents.

d) Ignore "high-impedance" faults since they are undetectable with FCIs.

e) Ignore "cold load pickup" when using automatic resetting FCIs.

f) For current resettable devices, select the device with the lowest reset current available.

g) Use voltage reset or time reset where load currents are low (e.g., 25 kVA transformer on a 34.5 kV system).

h) Coordinate FCIs with inrush current and protective devices.

i) Place the FCIs on outgoing cables.

j) Select a display method that enhances operating practices.

Annex A

(informative)

Bibliography

[B1] Burke, J. J., "Characteristics of Distribution Systems That May Affect Faulted Circuit Indicator," IEEE T&D Conference and Exposition, 1994.

[B2] Burke, J. J., Douglass, D. A., and Lawrence, D. J., "Distribution Fault Current Analysis," Electric Power Research Institute, EPRI-EL-3085, May 1983, p. 340.

[B3] Burke, J. J. and Lawrence, D. J., "Characteristics of Fault Currents on Distribution Systems," *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-103, no. 1. Jan. 1984, pp. 1–6.

[B4] DiDonato, J. P., "Application of Fault Indicators on the Con Edison Electrical Distribution System," EEI T&D Meeting, May 17, 1989.

[B5] IEEE 100, *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition.

[B6] Muench, Jr., F. J., and Wright, G. A., "Fault Indicator Types, Strengths and Applications," *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-103, no. 12, Dec. 1984, pp. 3688–3693.

[B7] Mulkey, D., "Service Experience with Fault Indicators," IEEE T&D Conference and Exposition, 1991.

[B8] Royster, T. E., "Fault Indicator Applications at Virginia Power Company," IEEE/PES T&D Conference and Exposition, 1991.