

IEEE Std C37.95™-2002
(Revision of IEEE Std C37.95-1989)

C37.95™

IEEE Guide for Protective Relaying of Utility-Consumer Interconnections

IEEE Power Engineering Society

Sponsored by the
Power System Relaying Committee



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

17 April 2003

Print: SH95075
PDF: SS95075

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Approved 11 December 2002
Reaffirmed 5 December 2007

IEEE-SA Standards Board

Abstract: Protective relay applications involving electric service to consumers that requires a transformation between the utility's supply voltage and the consumer's utilization voltage are covered in this guide. This guide describes the factors that need to be considered in the design of adequate protection facilities, outlines modern relay practices, and provides several examples of the protection of typical utility-consumer interconnections.

Keywords: backup protection, breaker-failure relaying, bus protection, electric service, non-utility generation, protective relays, transformer protection, utility-consumer interconnection

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

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Print: ISBN 0-7381-3515-1 SH95075
PDF: ISBN 0-7381-3516-X SS95075

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Introduction

(This introduction is not part of IEEE Std C37.95-2002, IEEE Guide for Protective Relaying of Utility-Consumer Interconnections.)

This guide is intended to assist engineers in the application of protective relays at the interface between the utility and consumer systems, where there is transformation between the utility's supply voltage and the consumer's utilization voltage. As a practical matter, this guide applies principally to larger commercial and industrial supply facilities, since it deals primarily with systems above 600 volts. It is a revision of IEEE Std C37.95™-1989, IEEE Guide for the Protective Relaying of Utility-Consumer Interconnections. This guide has been updated to reflect current practices, advances in technology, and the impact of non-utility generation on the utility-consumer interconnection.

Participants

At the time this guide was completed, the Working Group for the Protective Relaying of Utility-Consumer Interconnections had the following membership:

I. O. Hasenwinkle, Chair

F. O. Griffin, Vice Chair

A. N. Darlington
D. J. Finley
C. F. Henville

K. J. Khunkhun
A. P. Napikoski
F. P. Plumptre

D. C. Reckerd
T. L. Seegers
J. E. Stephens

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

John Appleyard
Michael P. Baldwin
Robert W. Beckwith
Kenneth Behrendt
Stuart H. Bouche
John Boyle
Mark Carpenter
Simon R. Chano
Stephen P. Conrad
Albert N. Darlington
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Jonathan D. Gardell
Jeffrey G. Gilbert
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John Kenneth Greene
Stephen. E. Grier
E. A. Guro
Robert W. Haas
Robert E. Hall

Roy E. Hart
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C. A. Petrizzo
Robert D. Pettigrew
Alan C. Pierce
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Roger E. Ray

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Mohindar S. Sachdev
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Tony L. Seegers
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William P. Waudby
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IEEE Guide for Protective Relaying of Utility-Consumer Interconnections

1. Overview

The point at which the equipment used to provide electrical service to a consumer changes ownership is usually referred to as the *interconnection*. However, it is important to remember that the physical laws of nature, which govern the behavior of electric power systems, apply across ownership boundaries. For a well-engineered interconnection, therefore, the electric power system protection should be studied and analyzed critically without regard to ownership.

From the viewpoint of service reliability and service continuity, it is emphasized that the best-conceived and best-implemented protective relaying system is no substitute for an adequately designed power system. Similarly, inadequately applied protective relaying will contribute to unsatisfactory performance of an otherwise well-designed power system. In considering a new installation, or changes to an existing arrangement, it is very important that protective relaying and safety be given careful attention in the early stages of planning.

1.1 Scope

This guide contains information on a number of different protective relaying practices for the utility-consumer interconnection. It is intended to cover applications involving service to a consumer that normally requires a transformation between the utility's supply voltage and the consumer's utilization voltage. Interconnections supplied at the utilization voltage are not covered.

This guide is not intended to supplant specific utility or consumer practices, procedures, requirements, or any contractual agreement between the utility and the consumer. The examples in Clause 7 are used for illustrative purposes only and do not necessarily represent the preferred protection under all conditions.

This guide addresses consumers, with or without generation, that are connected to utility subtransmission or transmission circuits. The specific control schemes associated with generation are not addressed. It is not intended to apply necessarily to consumer generation connected to utility distribution circuits.

1.2 Purpose

The primary purpose of this guide is to help those who are responsible for the application of protective relaying for the electrical interconnection between utility and consumer systems. It is anticipated that representatives of the utility, the consumer, and their consultants who are responsible for the specification, design, and operation of the interconnection will use this guide. Recognizing the diverse audience being

addressed, background information is included in a bibliography to direct the reader to more complete treatment of the material.

2. References

This guide shall be used in conjunction with the following publications. When the following publications are superseded by an approved revision, the revision shall apply.

IEEE Std C37.2TM-1996 (Reaff 2001), IEEE Standard Electrical Power System Device Function Numbers and Contact Designations.^{1,2}

IEEE Std 315TM-1975 (Reaff 1993), IEEE Standard Graphic Symbols for Electrical and Electronics Diagrams.

3. Establishing consumer service requirements and supply methods

3.1 Interconnection

The utility-consumer interconnection provides the path for power flow between supplier (utility) and user (consumer). The interconnection may comprise one or more circuits and is assumed to include voltage transformation. For the purposes of this guide, the interconnection extends from the nearest source-side protective device used for switching on the transformer high-voltage side to the transformer low-side bus and switching devices.

3.2 General design approach

The supply that is selected should satisfy the consumer's load requirements. Available utility supply options in the area as well as the utility's design standards and operation and maintenance practices should also be considered.

3.2.1 Consumer's load requirements

Prior to meeting with utility personnel, the consumer should define the present and future load requirements, including the connected kVA, the average load, and peak demand power requirements (both real and reactive). The effect of interruptions and voltage dips on plant operation, the required dependability and security of the utility's electrical service, and any other needs that may be unique to the operation should be determined. The consumer's engineer should be prepared to discuss these requirements in detail with utility engineers to ensure that there is a clear understanding of the consumer's requirements.

3.2.2 Utility service availability

The utility should describe the supply voltages available in the area and estimate the initial and total costs of the various alternatives. Most utilities establish nominal limits on the load that can be supplied at different voltage levels. The number of utility supply lines available and the performance level of each line should be discussed in detail. In addition, the utility should inform the consumer of any required studies, unusual

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problems, or future plans that may affect the quality or continuity of service. Some utilities publish standard information booklets detailing the requirements for service.

When the consumer has identified critical power requirements, the utility engineer should investigate these requirements and be certain that both parties have a clear understanding of the effect of interruptions and voltage dips. The utility may then be able to suggest a supply system that will meet these requirements, or suggest plant control changes to make the operation more successful.

3.3 Information exchange

Once the supply method is established, a further exchange of information is required so that the station design can be completed and the utility can make the necessary preparations to supply the service. By establishing good communication between the utility and the consumer as early as possible, specific requirements for either a new or modified supply can be identified and included in the initial design before equipment is ordered.

3.3.1 Typical information furnished by utility

- a) Available utility short-circuit current, including values for normal and alternate supply facilities, as well as any anticipated future values (i.e., range of single and three phase-to-ground fault currents, and associated X/R ratios, at the consumer's point of service)
- b) Expected minimum, maximum, and nominal voltage at the consumer's point of service for available voltage levels
- c) Outage history of the supply, including both forced and maintenance outages
- d) Estimated frequency, duration, and magnitude of momentary voltage dips at the consumer's point of service
- e) Operating requirements and restraints
- f) Specific protection requirements to coordinate with the utility system
- g) Specific reclosing practices on both normal and alternate supply facilities
- h) Harmonic content, voltage fluctuation, and current unbalance limits imposed by the utility
- i) Estimates of voltage harmonic distortion and harmonic current injection from other sources on the utility system, if requested by the consumer
- j) Load shedding requirements
- k) Additional information requested by the consumer, such as
 - 1) Supply line construction and routing
 - 2) Supply substation arrangement and location
 - 3) Utility grounding and lightning protection practices
 - 4) Metering arrangements and data

3.3.2 Typical information furnished by consumer

- a) Expected service date (when consumer will be ready for power)
- b) Complete one-line and three-line diagrams of plant distribution system
- c) Preferred supply voltage
- d) Transformer ratings, connections, voltage taps, and impedances
- e) Power factor correction capacitor ratings and connections
- f) Available short-circuit current from the consumer at the point of service based on the procedures outlined in IEEE Std 141TM-1993 [B9]³
- g) Switchgear specifications, including protective relay types and ranges
- h) Motor loads, types, sizes, starting current, contactor data, and frequency of starts
- i) Unusual load characteristics, such as those due to furnaces, thyristors, and other nonlinear loads

³The numbers in brackets correspond to those of the bibliography in Annex A.

- j) Generator and large synchronous motor information, including ratings, impedance data, time constants, and exciter data
- k) Voltage balance requirements
- l) Protection and control schematic drawings, as appropriate
- m) Point of interconnection physical arrangement drawings
- n) Expansion plans, which include projected loads, future substation development, and estimated dates
- o) Station ground grid design
- p) Method used to ground neutrals and ratings of the neutral grounding device
- q) Qualifications of the consumer's maintenance personnel

3.3.3 Future utility system changes

The utility should inform the consumer of any substantial utility system changes. For example, the installation of a large transformer that alters short-circuit currents at the supply point may affect the consumer's power system.

3.4 Specific supply considerations

In determining the final supply method, consideration should be given to the design of the interconnection, the arrangement of the utility's supply system, its protective relaying requirements, and its maintenance requirements and responsibilities.

3.4.1 Division of ownership

Individual operating and maintenance philosophies of the consumer and utility may impact electric system design. Regardless of ownership, however, the protective equipment should be specified and designed to provide a coordinated system. Proper engineering design must not be compromised, but the protection of the utility-consumer interconnection facilities should satisfy the objectives of both parties. In all cases, the protection requirements, equipment specifications, relay settings, fuse ratings, station battery requirements, and testing procedures should be discussed and agreed on by both parties.

3.4.2 Supply line reliability

Line length, construction, fault clearing times, and utility transmission system configuration all affect the supply line reliability. Reliability requirements should be determined based on both long-term and momentary outages.

3.4.2.1 Long-term outages

Long-term outages result from equipment failures that require an extended time to repair or replace. If a utility-consumer interconnection consists of a single line supplied from a single source connected to a single transformer, it is subject to long-term interruptions due to forced or planned outages of the supply source, line, or transformer. To reduce the possibility of long-term outages, a second supply line may be considered. This can, for example, be provided by

- a) Two lines from separate utility sources
- b) Two lines derived by sectionalizing an existing utility tie line

Continuity of service will be further enhanced by the addition of a second transformer. The service to the consumer can be arranged so that it is normally provided by one source with standby supply from the second. This enables restoration of service by automatic or manual switching operations upon the failure of the principal source of supply. Another alternative is parallel operation with two full-capacity lines and transformers. These and other supply configurations are covered in detail in Clause 4.

3.4.2.2 Momentary outages and voltage dips

Momentary outages are generally caused by a trip of the supply line to the customer that is quickly returned to service either by a successful auto-reclosing of the line or by automatically switching to an alternative source. Depending on the customer's process equipment, this interruption may cause a plant shut down even with high-speed restoration.

Voltage dips are caused by faults on the utility system that do not result in an outage to the customer. The fault location, type of fault, system configuration, connections of the service transformer, and the customer load influence the magnitude of these voltage dips.

It should be recognized that there is no electrical utility supply method that completely eliminates the possibility of momentary service interruptions or voltage dips. The primary cause of service complaints is the failure to adequately evaluate the effect of interruptions and voltage dips on the consumer's equipment. Depending on the type of operation, a severe dip can be very costly because it can disrupt an industrial process. It is especially critical that the consumer make a careful evaluation of the voltage requirements of sensitive loads and the electronic systems that provide process control. Curves describing voltage versus time tolerances can be used to determine the maximum allowable delay for outages or dips. The ITI (CBEMA) curve [B13], for example, describes typical supply voltage variations that can be tolerated by most information technology equipment without any interruption in function. In many instances, special means can be used to make the loads tolerant of unavoidable voltage conditions on the power system. In other cases, it may be necessary to install uninterruptible power supplies or other equipment to allow plant facilities to ride through these periods.

3.4.3 Interconnection protection requirements

The complexity of the protection used at an interconnection will vary depending on voltage level, system configuration, the type and amount of consumer load, and specific requirements of either the consumer or utility. In a dual supply system, for example, additional relaying may be required to respond to undesirable power flow from one supply to the other. Special consideration must also be given to consumers with large motors or generators.

3.4.4 Maintenance

In designing the interconnection system and associated protective equipment, it should be recognized that periodic maintenance of all facilities is required. Documentation for the equipment to be tested should provide sufficient information to the test personnel so they have a clear understanding of the intent of each protective system. The design should include test blocks and isolation devices to allow relay calibration using an external source for inputs to the protection and for making in-service measurements of all input quantities to the relay from instrument transformers. Critical relay outputs should be available for measurement. In those instances where communication channels are used in conjunction with protective systems, the design of the communication should be coordinated to assure that

- a) There is agreement on nomenclature for test and isolation facilities so that a request to isolate a facility or to initiate a signal is understood by utility and consumer personnel.
- b) Test switch and isolation devices are provided so appropriate signals can be transmitted and measured on the channel under test.

During periods of maintenance, the reliability of the supply or possibly even the continuity of service may be affected. This work should be coordinated between the utility and the consumer to minimize any adverse impact. If the consumer cannot tolerate the loss of service for periodic maintenance, the installation of an alternative supply is required.

3.4.5 Load considerations

The primary concerns in applying protection for faults on the electrical supply systems are to maintain system integrity and minimize equipment damage. However, the effect of the protective equipment on the load served should also be considered. For example, the operating time of fuses or protective relays and switching devices determines the time to isolate a faulted piece of equipment. As discussed in 3.4.2.2, during a fault, an electric system is subjected to voltage dips on the unfaulted portions of the system. Extended clearing times can aggravate the adverse effect that these dips have on the operation of process controls, ac contactors, motors, computers, and other electronic devices.

Other considerations include the reclosing practices of the utility. Automatic reclosing can provide prompt restoration of service following a temporary fault, or to a portion of the system once a permanently faulted section has been isolated. The consequences of reclosing may be detrimental, however, if the consumer's system includes generators or large motors. It is essential that the implications be understood and that designs be selected to meet the required objectives.

3.4.6 Harmonics

Harmonics can be generated in an electric system by numerous devices. The consumer must be cognizant of the effect of harmonics on the plant equipment and the utility system (see IEEE Std 519™-1992 [B12]). Limits may be imposed on the acceptable level of harmonics, beyond which corrective action should be taken. The effect of capacitors should also be considered. Capacitors do not create harmonics but can cause a change in distribution of harmonic levels throughout the system. This may increase in harmonic voltages on the system that may not necessarily be at the location of the capacitor or the source of harmonics. It may be desirable, as part of the joint utility-consumer checkout of interconnection facilities, to measure and document harmonics present in the bus voltage before and after applying load to the station. The harmonic content of the load current should also be recorded.

3.4.7 Grounding

The utility and the consumer normally construct station ground grids as required by ANSI C2-2002 [B1] and recommended in IEEE Std 80™-2000 [B7]. Where these two grids are located close together, they are generally connected together at a minimum of two points. Where some distance physically separates the stations, connecting the ground grids is neither practical nor necessary. However, consideration should be given to the difference in ground potential that may exist during faults and its affect on any low-voltage circuits connecting equipment located in the utility station to equipment in the customer facility (such as instrument transformer secondary circuits, dc control circuits, station service circuits, communication circuits, or load management control circuits). If the consumer and utility grounds are not interconnected, these low-voltage circuits need to be properly treated to avoid possible equipment damage and personnel hazards due to the transferred potential. For additional information, see IEEE Std 80-2000 [B7].

The method of system neutral grounding employed by the consumer may differ from that used by the utility. Some consumers prefer to employ resistance grounding. Neutral grounding should be discussed, and an agreement should be reached on the practice to be followed and on important concerns such as ground relay settings and surge arrester ratings.

3.4.8 Ferroresonance

Ferroresonance can occur when capacitance is excited in series with nonlinear inductance and is a phenomenon that can produce severe overvoltages on the system. Normally, ferroresonance is not present but may occur as a result of a switching operation. For example, ferroresonance can occur when a single-phase switch is opened on a length of cable or transmission line that is terminated by a lightly loaded transformer. Ferroresonance can also occur when a weak source is isolated together with a lightly loaded feeder containing power factor correction capacitors. Ferroresonance cannot always be avoided, but steps can be taken to reduce the

probability of its occurrence, such as locating switches and fuses close to transformers, use of Y-grounded transformer connections, three-phase switching, and using high-speed voltage and frequency sensors to isolate consumer generation. For further discussion of ferroresonance, see IEEE Std C57.105™-1978 [B6].

3.4.9 Voltage considerations

The utility electric supply voltage may be regulated or unregulated. In general, service from a distribution system will be a regulated supply, whereas service from a transmission or subtransmission system will be unregulated. Consumer substations served by unregulated systems may require compensation for the variations in supply voltage and for voltage drop caused by load changes. The method of compensation can be by load-tap changing transformers or by switched capacitors.

Flicker is defined as the rapid change in voltage produced by arc furnaces, welders, and other pulsating irregular loads. In these cases, there is concern for both the magnitude of the voltage change and the frequency of occurrence. Limits of operation are normally specified by the utility for flicker-producing loads, and these may require the installation of facilities designed to limit the voltage variation.

3.4.10 Phase balance considerations

Power is normally supplied and consumed in a balanced set of three phases. When the balance is upset, either on the supply or on the consumption side, the resulting asymmetry can cause problems. Utilities and consumers should consider the effect of unbalances on their systems, especially under weak source conditions.

Balance can be upset from the supply side by operation of single-phase interrupting devices, such as power fuses or automatic-circuit reclosers. More infrequently, unbalance can result from the misoperation of a device that normally operates in a three-phase mode. For instance, one pole of a three-phase circuit breaker may fail to open or close at the same time as the other two. Consumers should consider the effect of unbalanced supply and ensure that their equipment and processes are properly protected in the presence of such unbalance. Motors and generators are commonly protected by the application of single-phasing protection or negative phase sequence protection. Overvoltage protection may also be required if there is a possibility that ferroresonant conditions may arise as the result of the unbalanced supply.

Balance can also be upset from the consumer's side. The most common cause is unbalanced load. Unbalanced load may be the natural characteristic of some types of load such as electric railway systems, or it may also result from the operation of single-phase protective devices. If the amount of unbalanced load is significant, it can result in unbalanced voltages on the utility supply system, which may cause problems for other customers, or for sensitive protection on that system. Negative sequence polarized directional relays, for example, may respond to negative phase sequence voltages as low as a few percent of the nominal system voltage.

3.4.11 Transformer connection

Transformers are commonly connected in a delta-wye configuration when the interconnection with the utility occurs at transmission or subtransmission voltages. The high-voltage delta winding will minimize third harmonic voltages and, with the secondary neutral grounded, will circulate and trap zero-sequence current for faults on the low side. This isolates the utility ground relays from ground faults on the customer side. This is important because it allows the utility to maintain sensitivity and speed in clearing high-voltage ground faults. The wye connection on the low side provides the consumer with a location for a good ground. The delta winding helps to balance the phases on the wye side, which makes it more tolerant of unbalanced load. As discussed in 6.1, however, transformers with delta-connected, high-voltage windings can introduce system problems where there are synchronous motor loads or generators connected to the low-voltage side.

Consumer transformer connections that are a source of ground fault current on the utility's system (e.g., with the high-voltage connected grounded-wye and the low-voltage delta) are, in many instances, unacceptable. For example, when this type of transformer is tapped to a utility transmission line, it decreases the ground fault current contribution from the utility and makes it more difficult to detect ground faults on all portions of the line. If it is necessary to use these transformers, such as when the consumer has generation, it may also be necessary to employ high-voltage breakers to ensure proper protection of the transmission lines.

4. Typical utility-consumer interconnection configurations

In the typical service arrangements that follow, such aspects as dependability, security, and ease of maintenance range from minimal to optimal. The consumer load requirements will strongly influence the degree to which each of these aspects is considered. Protective relaying systems for certain selected examples are described in detail in Clause 7 of this guide. Note that this is only a limited selection used to illustrate the principles discussed in this guide and that numerous other service arrangements are in general use.

4.1 Single supply-single transformer

This is a common form of utility-consumer interconnection. It consists of a single transformer connected to a single source. The consumer will generally have multiple feeders connected to the low-voltage side of the transformer. Supply from this configuration is subject to interruption upon loss of the supply source, line, or transformer.

Figure 1 is a basic single supply-single transformer interconnection. The high-side fuse provides protection for transformer primary and secondary side faults, as well as backup protection for low-side feeder circuits. Protective relays on the supply source breaker will protect for line faults and provide limited backup protection for the high-side fuse. A consumer power outage will be necessary if maintenance is required on any of the system components other than the consumer feeder devices.