

C37.108™

IEEE Guide for the Protection of Network Transformers

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

19 September 2002

Print: SH94988
PDF: SS94988

Recognized as an
American National Standard (ANSI)

IEEE Std C37.108™-2002 (R2007)
(Revision of
IEEE Std C37.108-1989)

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Approved 21 March 2002
Reaffirmed 5 December 2007

IEEE-SA Standards Board

Abstract: Guidelines for the application of network protectors are established. The use of network transformers and protectors with distributed resources is addressed.

Keywords: distribution generation, master relay, network limiter, network protector, network relays, network transformers, spot networks

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Print: ISBN 0-7381-3257-8 SH94988
PDF: ISBN 0-7381-3258-6 SS94988

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Introduction

(This introduction is not part of IEEE Std C37.108-2002, IEEE Guide for the Protection of Network Transformers.)

This guide was prepared by the Network Transformer Protection Working Group of the Substation Protection Subcommittee of the IEEE Power System Relaying Committee. This guide is intended to aid in the effective application of relays and other devices for the protection of power transformers in network transformer vaults. New additions to this guide include clauses on distributed source generation and network distribution Supervisory Control and Data Acquisition (SCADA).

Network distribution systems differ from radial distribution systems due to several factors. These factors include: high-fault currents on the low-voltage side of the transformers, possible frequent operation of network protectors, varying practices of providing dedicated high-voltage transformer protection, confined spaces, backfeed issues, and proximity to dense public populations in city streets and office buildings.

Protection techniques presented in this guide will help minimize the effects and damage caused by network faults. However, proper protection applications are only a supplement to other important issues related to network power equipment. These issues, covered in other appropriate publications, include the following items:

- a) Vault and equipment design, construction, operation, and maintenance should conform with applicable standards and regulations, including company, municipal, state, and country operating rules.
- b) Manufacturers' recommended operating and maintenance procedures should always be utilized.

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IEEE Guide for the Protection of Network Transformers

1. Overview

Network transformer vaults are fire retardant enclosures normally within or adjacent to buildings or underneath streets and alleys. They typically contain two or more power transformers. These transformers are supplied from different subtransmission or distribution lines and are paralleled on their low-voltage side through circuit interrupting devices called *network protectors*. Typically, high-voltage current-interrupting devices have not been applied within the network vault. The low-voltage bus of a network vault may be electrically tied to a number of other vaults to form a network secondary distribution system, which will be called a *low-voltage network grid* in this guide, or each individual vault may stand alone as a *spot network*. A one-transformer vault can be considered a network vault if connected to other such vaults via low-voltage cables.

Low voltage in this guide implies 600 V or less, and high voltage implies 2400 to 34 500 V. Typical low voltages are 208Y/120 V, 480Y/277 V, and 600Y/347 V. A typical high voltage is 12 500 V.

Low-voltage network systems have been used since the 1920s as a method of providing a highly reliable source of electrical power to densely populated commercial areas, such as office buildings. Equipment protection within the network vaults is typically limited. Historically, users have depended upon the physical design of the vault to limit the risks of fault damage for faults within the vault. They have relied upon remote detection and interruption for transformer faults and low-voltage devices, such as transformer fuse links and low-voltage cable limiters, to provide a measure of low-voltage bus fault protection.

This guide is intended to aid those engineers who have reevaluated problems associated with faults within network vaults, particularly for those network vaults located within or near high-rise buildings. It will also identify currently available devices that are being used in network transformer protection schemes. These devices should act to sense the fault and initiate fault interruption locally or remotely, thereby minimizing damage and restoration time. These devices will be described as to their fault detecting capabilities.

Several annexes are included with this guide. Annex A describes network protector response for high-voltage feeder faults. An example utilizing a number of protective schemes is presented in Annex B. Annex C addresses other concepts that are currently being investigated. Annex D provides bibliographic references, such as IEEE[®] Conference papers and IEEE Transaction papers, e.g., Anderson [B1].^{1, 2}

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²The numbers in brackets correspond to those of the bibliography in Annex D.

2. References

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

Accredited Standards Committee C2-2002, National Electrical Safety Code[®] (NESC[®]).³

ANSI C37.16-1997, American National Standard for Switchgear—Low-Voltage Power Circuit Breakers and AC Power Circuit Protectors—Preferred Ratings, Related Requirements, and Application Recommendations.⁴

ANSI C37.42-1996, American National Standard for Switchgear—Distribution Cutouts and Fuse Links—Specifications.

ANSI C37.47-1981 (R1988), American National Standard Specifications for Distribution Fuse Disconnecting Switches, Fuse Supports, and Current-Limiting Fuses.

ANSI C37.50-1989 (R2000), American National Standard for Switchgear—Low Voltage AC Power Circuit Breakers Used in Enclosure—Test Procedures.

ANSI C37.51-1989 (R1995), American National Standard for Switchgear—Metal-Enclosed Low-Voltage AC Power Circuit-Breaker Switchgear Assemblies—Conformance Test Procedures.

ANSI C57.12.40-2000, American National Standard for Network Transformers—Subway and Vault Types (Liquid Immersed)—Requirements.

IEEE Std 80TM-2000, IEEE Guide for Safety in AC Substation Grounding.^{5, 6}

IEEE Std 142TM-1991, IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems, *IEEE Green Book*TM.

IEEE Std 242TM-2001, IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems, *IEEE Buff Book*TM.

IEEE Std C37.2TM-1996, IEEE Standard Electrical Power System Device Function Numbers and Contact Designations.

IEEE Std C37.13TM-1990 (Reaff 1995), IEEE Standard for Low-Voltage AC Power Circuit Breakers Used in Enclosures.

IEEE Std C37.20.1TM-1993 (Reaff 1998), IEEE Standard for Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear.

IEEE Std C37.29TM-1981 (Reaff 1990), IEEE Standard for Low-Voltage AC Power Circuit Protectors Used in Enclosures.

³The NESC is 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/>).

⁴ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

⁵IEEE publications 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/>).

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IEEE Std C37.41™-2000, IEEE Standard Design Tests for High-Voltage Fuses, Distribution Enclosed Single-Pole Air Switches, Fuse Disconnecting Switches, and Accessories.

IEEE Std C37.60™-1981 (Reaff 1992), IEEE Standard Requirements for Overhead, Pad Mounted, Dry Vault, and Submersible Automatic Circuit Reclosers and Fault Interrupters for AC Systems.

IEEE Std C37.91™-2000, IEEE Guide for Protective Relay Applications to Power Transformers.

IEEE Std C57.12.44™-2000, IEEE Standard Requirements for Secondary Network Protectors.

IEEE Std C57.109™-1993, IEEE Guide for Transformers Through-Fault-Current Duration.

NFPA 70-1999, National Electrical Code® (NEC®).⁷

3. Definitions

The following definitions are found in *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition [B9] and may aid in the understanding of this guide.

3.1 network feeder: A feeder that supplies energy to a network.

3.2 network limiter: An enclosed fuse for disconnecting a faulted cable from a low-voltage network distribution system and for protecting the unfaulted portions of that cable against serious thermal damage.

3.3 network master relay: A relay that functions as a protective relay by opening a network protector when power is backfed into the supply system and as a programming relay by closing the protector in conjunction with the network phasing relay when polyphase voltage phasors are within prescribed limits.

3.4 network phase relay: A monitoring relay that has as its function to limit the operation of a network master relay so the network protector may close only when the voltages on the two sides of the protector are in a predetermined phasor relationship.

3.5 network protector (power and distribution transformers): An assembly comprising a circuit breaker and its complete control equipment for automatically disconnecting a transformer from a secondary network in response to predetermined electrical conditions on the primary feeder or transformer, and for connecting a transformer to a secondary network either through manual control or automatic control responsive to predetermined electrical conditions on the feeder and the secondary network.

3.6 network protector fuse: A backup device for the network protector.

3.7 network secondary distribution system: A system of alternating current distribution in which the secondaries of the distribution transformers are connected to a common network for supplying light and power directly to consumers' services.

3.8 network transformer (power and distribution transformers): A transformer designed for use in a vault to feed a variable capacity system of interconnected secondaries.

3.9 network tripping and reclosing equipment: A piece of equipment that automatically connects its associated power transformer to an ac network when conditions are such that the transformer, when connected,

⁷The NEC is published by the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, USA (<http://www.nfpa.org/>). Copies are also 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/>).

will supply power to the network and automatically disconnects the transformer from the network when power flows from the network to the transformer.

3.10 spot network: A small network, usually at one location, consisting of two or more primary feeders, with network units and one or more load service connections.

3.11 spot-network type: A unit substation, which has two step-down transformers, each connected to an incoming high-voltage circuit. The outgoing side of each transformer is connected to a common bus through circuit breakers equipped with relays that are arranged to trip the circuit breaker on reverse power flow to the transformer and to reclose the circuit breaker upon the restoration of the correct voltage, phase angle, and phase sequence at the transformer secondary.

3.12 vault: A structurally solid enclosure above or below ground with access limited to personnel qualified to install, maintain, operate, or inspect the equipment or cable enclosed.

3.13 vault-type transformer (power and distribution transformers): A transformer that is constructed so as to be suitable for occasional submerged operation in water under specified conditions of time and external pressure.

4. General background

The physical and electrical characteristics of network transformer vaults have evolved over time, as have the characteristics of the load that they serve. This clause gives a brief description of this evolution. The application considerations of grid versus spot-network vaults and of 208Y/120 V versus 480Y/277 V secondaries are also discussed.

4.1 Network development

The first low-voltage ac network system is reported to have been installed in Memphis, Tennessee, about 1907. The network transformers were supplied by primary feeders through distribution cutouts and were connected to a solid grid of low-voltage cables that were protected with fuses. In Seattle, Washington, in 1921, improvements were made in the basic system by connecting the secondary terminals of the network transformers to the solid cable grid through network protectors that would trip automatically upon reverse power flow and were reclosed manually. In 1922, the first ac network system in which network protectors were automatically tripped and closed by relays was placed in service in New York, NY by the United Electric Light and Power Company. The cable grid was a three-phase, four-wire system and it operated at a nominal voltage of 208Y/120 V. By 1925, this type of system became an accepted method of supplying combined power and lighting load. Today's 208Y/120 V network grid systems are very similar in configuration and basic operation to the first systems. It is from these systems that the design, operating practices, and overcurrent protection practices evolved for the first 480Y/277 V spot networks installed in this country.

Grid networks served the needs of the commercial areas of many cities until the early 1950s, although it was necessary to develop network protectors of higher continuous current ratings to carry the increasing loads. By then, the loads in some commercial buildings were reaching the level where it was very difficult or uneconomical for the utility to supply the load at 208Y/120 V from either a grid or spot network. These higher loads were due mainly to air conditioning, higher lighting levels, and larger buildings. Furthermore, the wiring costs of the building systems became very high as the loads increased at this voltage level.

Because of economics and equipment availability, higher utilization voltages, either 460Y/265 V or 480Y/277 V, were adopted for service to large commercial buildings. Use of these higher voltages resulted in significant reductions in wiring costs and in the cost of the utility system supplying the building load. Many

utilities decided to serve these loads from 480Y/277 V spot networks. One utility made its first 480Y/277 V installation in 1937, and by 1954 had eighteen 480Y/277 V vaults in service.

Figure 1 illustrates a typical network system. Many present-day network systems are installed without network transformer high-side switches. The primary distribution substation bus may have several bus tie or sectionalizing breakers in order to insure a reliable supply to the network. The bus tie breakers are normally closed, but may be opened when there is an adequate source to each bus section to avoid voltage differences between bus sections. A difference in bus voltage magnitude or angle may unload some feeders and cause network protectors to open.

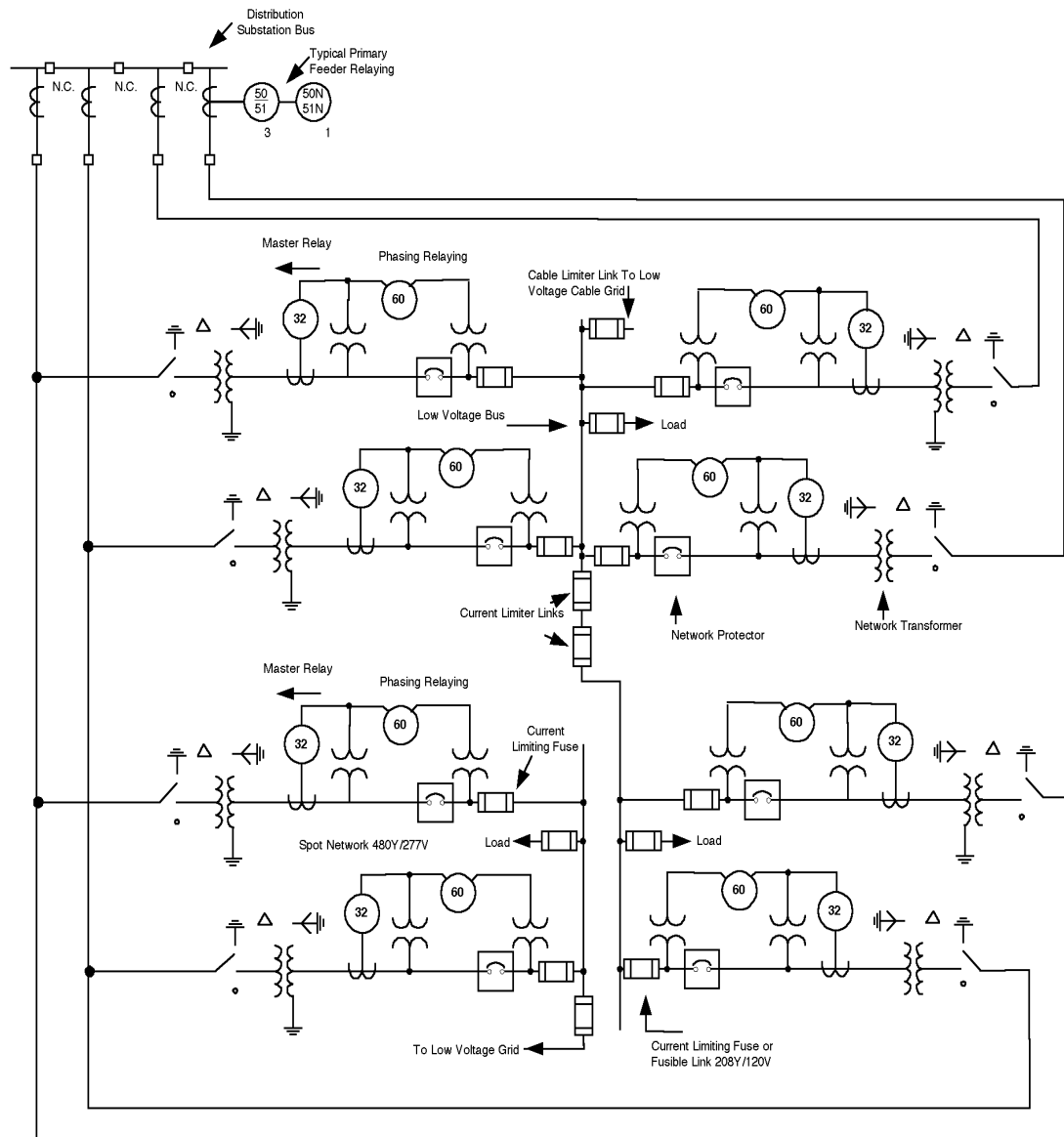


Figure 1—Typical network system