

IEEE Guide for the Protection of Network Transformers

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Foreword

(This Foreword is not a part of ANSI/IEEE C37.108-1989, 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.

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IEEE Guide for the Protection of Network Transformers

1. Introduction

1.1 Scope

Network transformer vaults are fire retardant enclosures within buildings or adjacent to them that 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 and 480Y/277 V. A typical high voltage is 12 500 V.

Low-voltage network systems have been used since the 1920's 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 the risks associated with faults within network vaults, particularly for those network vaults located within or near highrise 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. An example utilizing a number of protective schemes is presented in Appendix B.

1.2 References

The following publications shall be used in conjunction with this guide:

- [1] ANSI C2-1990, National Electrical Safety Code.¹
- [2] ANSI C37.47-1981, American National Standard Specifications for Distribution Fuse Disconnecting Switches, Fuse Supports, and Current-Limiting Fuses.
- [3] ANSI/IEEE C37.2-1987, IEEE Standard Electrical Power System Device Function Numbers.²
- [4] ANSI/IEEE C37.29-1981 (R 1985), IEEE Standard for Low-Voltage AC Power Circuit Protectors Used in Enclosures.
- [5] ANSI/IEEE C37.41-1988, IEEE Standard Design Tests for High-Voltage Fuses, Distribution Enclosed Single-Pole Air Switches, Fuse Disconnecting Switches, and Accessories.
- [6] ANSI C37.42-1981, American National Standard Specifications for Distributed Cutouts and Fuse Links,
- [7] ANSI/IEEE C37.60-1981 (R 1986), IEEE Standard Requirements for Overhead, Pad-Mounted Dry-Vault and Submersible Automatic Circuit Reclosers and Fault Interrupters for AC Systems.
- [8] ANSI/IEEE C37.91-1985, IEEE Guide for Protective Relay Applications to Power Transformers.
- [9] ANSI/IEEE C57.109-1985, IEEE Guide for Transformer Through-Fault Current Duration.
- [10] ANSI/IEEE Std 80-1986, IEEE Guide for Safety in AC Substation Grounding.
- [11] ANSI/IEEE Std 142-1982, IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems.
- [12] Dunki-Jacobs, J. R. The Effects of Arcing Ground Faults on Low-Voltage System Design. *IEEE Transactions on Industry Applications*, vol. IA-8, no. 3, May/June 1972.
- [13] Glenn, D. J. *A New Fault-Interrupting Device for Improved Medium-Voltage System and Equipment Protection*. IEEE/IAS Pulp and Paper Conference, Paper 440-T52, Toronto, Ontario, Canada, June 1984.
- [14] Griffin, T. R., Byrd, G. L., and Whitter, D. A. *Fault Tests on 480Y/277 V Spot Networks*, IEEE/PES Conference, Paper 66-485, New Orleans, July 1966.
- [15] National Electrical Code, 1987.
- [16] Roop, D. W. and Vidonic, N. G. Arcing Fault Protection on VEPCO's 480Y/277 V Secondary Spot Networks. *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-102, no. 2, Feb. 1983, pp. 364–372.
- [17] Sonnemann, W. K., *et al.* Compensator Distance Relaying—Part I, II, and III. *AIEE Transactions on Power Apparatus and Systems*, vol. 77, 1958, pp. 372–402.

2. 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 section gives a brief description of this evolution. The application

¹ANSI publications are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

²ANSI/IEEE publications are available from the Service Center, Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08854-1331.

considerations of grid versus spot network vaults and of 208Y/120 V versus 480Y/277 V secondaries are also discussed.

2.1 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 City 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 over current 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 work protectors of higher continuous current net-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.

2.2 Application Considerations of Adding Protection to Spot Network Vaults versus Grid Network Vaults

As noted earlier, the first network vault installations were operated primarily at 208Y/120 V and were connected to other vaults on the low-voltage side. These vaults were generally located below grade and external from buildings, for example, underneath sidewalks in business districts. Historical evidence indicates that 208Y/120 V faults in these vaults are generally self-clearing. That is, faults have been contained within the vault enclosure and the locations of the vaults are sufficiently isolated from buildings to allow for the fault to continue until enough conductive material melts thereby extinguishing the fault-generated arc without damaging the buildings.

As the loading in newly constructed high-rise buildings increased, the 208Y/120 V vaults were installed inside them and dedicated to serving the load of the building. Due to the economics of scale, the building vaults had enough capacity to supply the building load with at least a single contingency outage margin. Ties between vaults were no longer needed or practical and the era of the spot vault was born. Eventually, 480Y/277 V spot vaults replaced the 208Y/120 V spots. Also, during this transition period, some small 480Y/277 V grid network systems were installed.

These changes prompted consideration by some utilities to provide additional network vault protection. Frequently, the damage caused by arcing 480 V faults has caused lengthy power outages to buildings, more so than at 208 V. Since many of these vaults are inside buildings, a higher incidence of damage caused by smoke has occurred.

The principles of protection included in this guide apply equally to spot network vaults or grid network vaults and at any low-voltage level. The need to consider additional protection and the associated high-voltage interrupting devices should be evaluated on the basis of risk assessment and cost.

3. Operation of a Network Transformer Vault Under Fault Conditions

A network system can be separated into three parts when considering operation under fault conditions: (1) the high-voltage primary supply circuits; (2) the network equipment, which consists of the network transformer, its associated primary side switch (disconnect and grounding), the low-voltage network protector, and the low-voltage bus; (3) secondary voltage supply to the consumer and interconnecting cables to other transformer vaults, if any.

3.1 Primary Feeder Faults

Referring to Fig 1, a short circuit on a high-voltage primary feeder circuit is cleared by tripping the primary feeder breaker at the distribution substation and opening the network protectors of the transformers connected to the faulted feeder. Primary feeder breaker tripping is usually controlled by nondirectional time and instantaneous overcurrent relays sensing both phase and ground (residual) currents (devices 50/51 and 50N/51N). The network master relay (device 32) will trip its protector if the net three-phase power (watt) flow is in the reverse direction, i.e., from the low-voltage bus back to the high-voltage feeder. If the feeder fault is single, phase-to-ground and the network transformer is delta connected or wye ungrounded on the high side, opening the feeder breaker will limit fault current flow to a value allowed by the primary system capacitance. If shunt reactors are connected to the primary feeders, they will also influence the amount of current in the fault path. Then the sensitively set network master relay operates by sensing the reverse flow of real power caused by transformer magnetizing and feeder load. Some network transformer primaries are connected wye grounded and will permit fault current to flow until its protector opens via the network master relay. Some types of feeders, for example those with fused sections supplying the network unit, require that a watt-var network master relay be applied. See Appendix A for a description of the operation of the network protector relays.

The feeder breaker and network protector may operate sequentially since the network master relay may not operate until the feeder breaker is open. Thus, clearing time is equal to the sum of the feeder relay time, feeder breaker time, network master relay time, protector opening time, and the arc interrupting time. Total clearing time is usually 0.5 s or less for faults on the primary feeder excluding the case of a single, ground fault where the total clearing time can be higher due to the limited fault current flow phase-to-after the feeder breaker opens. Clearing feeder faults in this fashion does not result in an outage to the load served by the network.

If the distribution voltage feeder circuit breaker fails to clear the fault, conventional breaker failure relaying or other forms of backup relaying, such as power transformer overcurrent relays, should isolate the fault. If the network protector fails to clear the fault, then the transformer low-voltage current-limiting fuses or low-voltage fuse links are relied upon to melt due to the presence of line fault or line load current feeding back through the network transformer.

Low-voltage current-limiting fuses are silver and sand devices that are designed primarily to quickly interrupt high magnitude fault currents. The melted products are contained within a tubular enclosure where they harden into a glass-like insulating substance called a fulgurite. Fusible links are copper or alloy devices designed to carry high levels of transformer load current. They melt in the presence of transformer overcurrent and can be sized to coordinate with the transformer through-fault thermal limit curve. Figure 1 shows the location of these devices in series with the network protector.