TRANSFORMERS

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1.0 SCOPE

This data sheet provides electrical protection recommendations for the prevention of losses in power and distribution transformers. It also provides fire protection recommendations for power, distribution, arc furnace and induction furnace transformers. Loss experience and test information is provided as support for these recommendations.

1.1 Changes

January 2007. The reference goal of the recommendation 2.3.1.1.2.2.2 was clarified.

1.2 Superseded Information

This data sheet supersedes the January 1997 edition with revisions of September 1998.

2.0 LOSS PREVENTION RECOMMENDATIONS

Conventional power and distribution transformers are reliable devices having low electrical failure rates. If the transformer is FM Approved (see Appendix A for definition), or equivalent, which involves the use of a less flammable insulating liquid and electrical and mechanical protection, and is not a network, arc furnace, induction furnace or generator step-up transformer, the failure frequency is considered low enough to be acceptable without fire protection. For other transformer types, there are the potentials for either an internal or an external electrical fault which results in overpressure of the transformer. If increase in pressure is rapid the pressure relief device may not be adequate to prevent tank failure of the transformer. Tank failure may release substantial quantities of insulating liquid. If fire occurs, the resulting property damage depends on the amount and type of liquid and whether buildings or other equipment are exposed.

2.1 Electrical Protection

2.1.1 Electrical

2.1.1.1 Each transformer, depending on its criticality, and whether it presents a fire exposure, should have a protection system as determined by an accurate engineering study. This protection system should be functionally equivalent to the protection illustrated in Figures 1a through 1e. Table 1 summarizes the various devices available for the electrical protection of transformers.

Table 1. Electrical Protection

Device Number	*Device Name*	*Device Description*
FUSE	Expulsion-type.	Provides protection for both internal and external faults. Current limiting type. Provides internal fault protection and limitation of fault current levels.
24	Volts per Hertz relay.	A relay that functions when the ratio of voltage to frequency exceeds a preset value. Used on unit connected transformers.
26	Thermal device.	A device that functions when the transformer liquid temperature exceeds a predetermined value. (Other than the transformer winding temperature as covered by device 49)
49	Thermal relay.	A relay that functions when the transformer winding temperature or other load carrying element exceeds a predetermined value.
50G[1]	Zero sequence instantaneous ground overcurrent relay.	A relay that functions instantaneously when the ground fault current exceeds a predetermined value. Use when time coordination is not required. Device 50G is connected to a toroidal CT. Device 50G provides ground fault protection for the transformer wye winding and through faults.
50GD[2]	Zero sequence instantaneous ground overcurrent relay.	A relay that functions instantaneously when the ground fault current exceeds a predetermined value. Device 50GD is connected to a toroidal CT on the delta winding conductors. Device 50GD provides ground fault protection for the transformer delta winding and the transformer leads between the winding and the toroidal CT.
50N[1]	Instantaneous ground overcurrent relay.	A relay that functions instantaneously when the ground fault current exceeds a predetermined value. The relay is connected in the transformer neutral. Device 50N provides ground fault protection for the transformer wye winding and through faults. The relay is set for either high magnitude ground faults for use with 51N, or sensitively to be used alone when time coordination is not required.

Device Number	*Device Name*	*Device Description*
50ND[2]	Instantaneous ground overcurrent relay.	A relay that functions instantaneously when the ground fault current exceeds a predetermined value. The relay is residually connected in the CT secondary on the delta winding conductors. Device 50ND provides high magnitude ground fault protection for the transformer delta winding and the transformer leads between the winding and the CT.
50NY[1]	Instantaneous ground overcurrent relay.	A relay that functions instantaneously when the ground fault current exceeds a predetermined value. The relay is residually connected in the CT secondary on the wye winding conductors. Device 50NY provides ground fault protection for primary wye windings, back fed secondary windings and through faults occurring downstream of the secondary wye winding. It is set for either high magnitude ground faults for use with 51NY, or sensitively to be used alone when time coordination is not required.
50TF	Instantaneous phase overcurrent relay.	A relay that functions instantaneously on an excessive value of current. Provides protection for transformer internal faults.
51N[1]	AC time ground overcurrent relay.	A relay that functions when the ground fault current exceeds a predetermined value for a given time. The current and operating time are inversely proportional. The relay is connected in the transformer neutral. Device 51N provides ground fault protection for the transformer wye winding and through faults occurring downstream of the secondary wye winding.
51ND[2]	AC time ground overcurrent relay.	A relay that functions when the ground fault current exceeds a predetermined value for a given time. The current and operating time are inversely proportional. The relay is residually connected in the CT secondary. Device 51ND provides ground fault protection for the transformer delta winding and the transformer leads between the winding and the CT.
51NY[1]	AC time ground overcurrent relay.	A relay that functions when the ground fault current exceeds a predetermined value for a given time. The current and operating time are inversely proportional. The relay is residually connected in the CT secondary. Device 51NY provides ground fault protection for primary wye windings, back fed secondary wye windings, and through faults occurring downstream of the secondary wye winding.
51TF	AC time overcurrent relay.	A relay that functions when the ac input current exceeds a predetermined value. The input current and operating time are inversely proportional. Provides transformer through fault and backup protection.
51TL	AC time overcurrent relay.	A relay that functions when the ac input current exceeds a predetermined value. The input current and operating time are inversely proportional. Provides transformer overload protection.
63	Pressure switch or relay.	A switch or relay which operates on given values, or on a given rate of change of pressure.
67N[3]	AC directional neutral overcurrent relay.	A relay that functions on a desired value of ground fault current in a predetermined direction. Provides ground fault protection of the transformer wye winding for only internal faults.
71	Liquid level gauge.	Measures the level of insulating liquid in the transformer tank.
87T	Transformer differential relay.	A relay that functions on a percentage difference of the primary and secondary side currents. Provides fault protection for the transformer for only internal faults.
87TN[3]	Transformer ground differential relay.	A relay that functions on a predetermined difference between neutral and phase residual currents for a transformer ground fault. Provides ground fault protection of the transformer wye winding for only internal faults.

Notes:
1. Devices 50G, 50N/51N, and 50NY/51NY are alternatives.
2. Device 50GD is an alternative to 50ND/51ND.
3. Device 67N is an alternative to 87TN.

2.1.1.2 Provide ground fault protection on both sides of the transformer at each voltage level in a facility. Each voltage level has its own unique system ground and, therefore, must have its own ground fault protection system with appropriate tripping and/or alarm. Provide system ground fault protection in accordance with the recommendations in Data Sheet 5-10, *Protective Grounding for Electric Power Systems and Equipment*. Depending upon the type of system grounding, these devices should trip the upstream (high side) breaker if provided or alarm at a constantly attended location (e.g., Fig. 1a). The alarm should be treated as a fire event and responded to appropriately. An alarm response procedure should be developed and posted. The Plant

Emergency Organization should include both fire and electrical personnel capable of de-energizing the equipment. If de-energization can not be accomplished in a timely manner, then a high side breaker must be installed and tripped (e.g., Fig. 1b).

2.1.1.3 An arc monitoring system ABB Arc Guard System or FM Approved equivalent should be provided to detect arcing faults in transformer vaults with exposed energized components. This additional protection should be provided where the ground fault relay cannot be set low enough to detect ground fault current due to neutral imbalance current flow. These devices, in conjunction with the ground fault protection in Section 2.1.1.2, should trip the upstream (high side) breaker if provided or alarm at a constantly attended location. The alarm should be treated as a fire event and responded to appropriately. An alarm response procedure should be developed and posted. The Plant Emergency Organization should include both fire and electrical personnel capable of de-energizing the equipment. If de-energization cannot be accomplished in a timely manner, then a high side breaker must be installed and tripped (e.g., Fig. 1b).

Figure 1a is for all transformers rated 1000 to 10000 kVA with primary fuses. The table in Figure 1a shows the recommended protective devices for dry-type transformers, and 1000- to 5000-kVA and 5000- to 10000-kVA liquid insulated transformers. The table also shows the action (I—Indication, A—Alarm, or T—Trip) of the protective device for the three categories of transformers. Figure 1a also applies to transformers rated less than 1000 kVA when the transformer creates a fire exposure. Alternative protective devices are shown in Figure 1e.

Figure 1b is for all transformers rated 1000 to 10000 kVA with primary circuit breakers. The table in Figure 1b provides the same information as described for Figure 1a. Figure 1b also applies to transformers rated less than 1000 kVA when the transformer creates a fire exposure. Alternative protective devices are shown in Figure 1e.

Figure 1c is for transformers rated 10,000 kVA and above. Alternative protective devices are shown in Figure 1e.

Figure 1d is a typical relay diagram for a dual supply and dual transformer configuration (secondary selective system).

Figure 1e shows all of the protective devices described. Other schemes are available that provide equivalent protection and reliability. The protection for ungrounded and high resistance grounded systems is not covered by Figures 1a through 1e. Appropriate ground fault protection should be provided.

2.1.2 Operation and Maintenance

2.1.2.1 Transformers should be installed, operated and maintained in accordance with manufacturers' recommendations.

2.1.2.2 When a transformer is delivered empty of liquid, the manufacturer's instructions must be strictly followed in regard to drying and liquid-filling procedures.

Device No.	*Description*	*Dry*	*Liquid (MVA)*	
			1–5	*5–10*
26	Liquid thermal device		I	I
49	Winding thermal device	I		I
51N[1]	Time delay overcurrent relay. (Ground fault protection of transformer wye winding and through faults.)	T	T	T
51TL	Time delay overcurrent relay. (Transformer overload protection)	T	T	T
63	Sudden pressure relay			T
71	Liquid Level Device		I	I

Notes:
A—Alarm, I—Indication, T—Trip
1. Devices 50G, 50N/51N, 50NY/51NY, 67N and 87TN are alternatives. (See Fig 1E.)

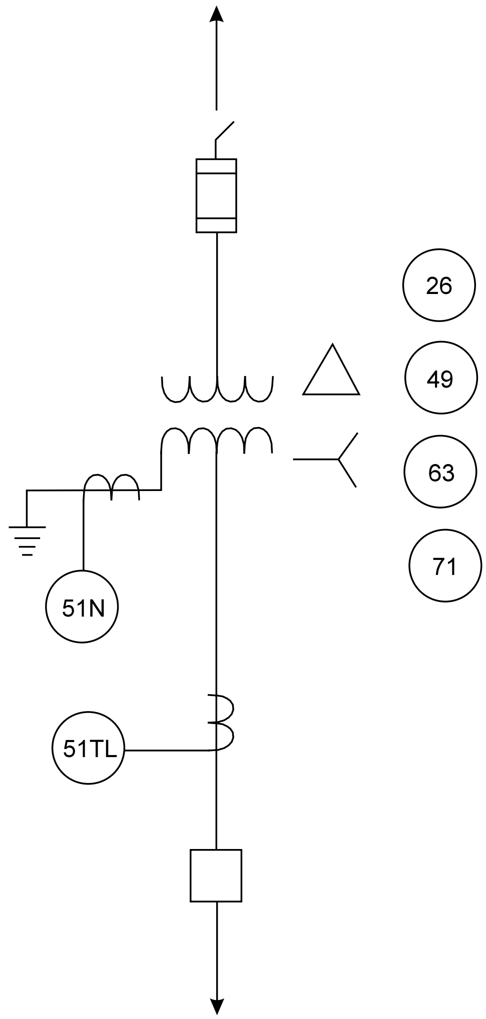


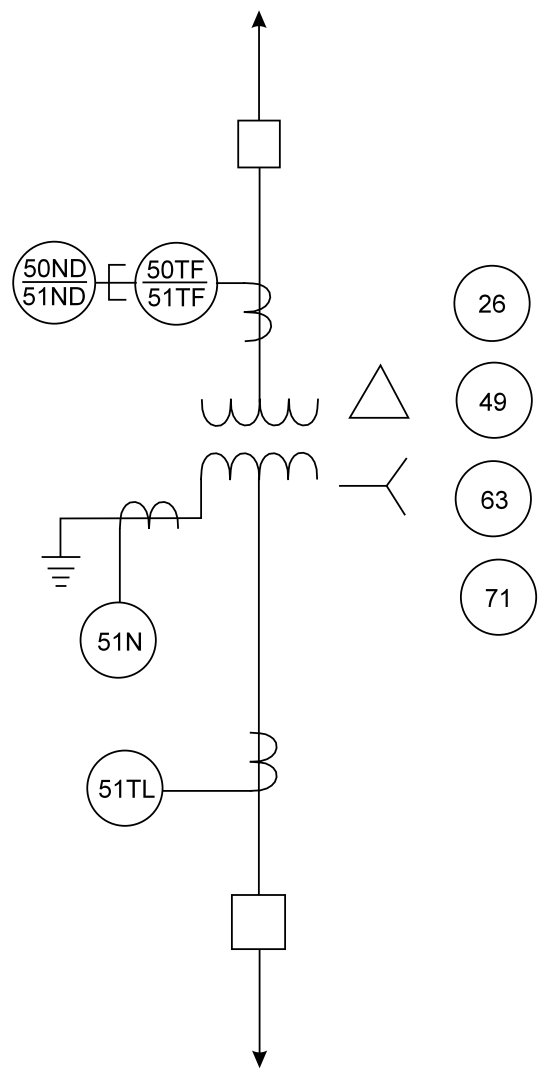
Fig. 1A. Electrical protection one-line. Primary fuse.
1000- to 10000-kVA transformers.
Less than 1000 kVA when transformer creates fire exposure.

2.1.2.3 Before commissioning, transformers should be inspected and tested in accordance with manufacturers' instructions. Dielectric characteristics of the insulation media (winding insulation, insulating liquid, bushings, tap changer oil) should be measured and recorded to establish bench marks for future reference. Refer to Data Sheet 5-20, *Electrical Testing*. The transformer should be energized if it is to be stored for a lengthy period.

2.1.2.4 Immediately after commissioning and periodically for several days, the transformer should be inspected thoroughly for indications of overheating, oil leaks, vibration or malfunction. Proper operation and calibration of each monitoring and protective device should be verified. Dissolved-gas-in-oil analysis should be performed within 18 to 24 hours after energization, one month later, and six months later to determine if the transformer is having a gassing problem.

2.1.2.5 The operation of each transformer should be monitored on a fixed schedule. Overheating caused by continuous overloading, overexcitation, etc. should be corrected immediately. If a temporary overloading becomes necessary because of outages of other units, switching operations or other reasons, the latest revisions of ANSI/IEEE Standards C57.91 and C57.92 should be followed.

Device No.	*Description*	*Dry*	*Liquid (MVA)*	
			1–5	*5–10*
26	Liquid thermal device.		I	I
49	Winding thermal device.	I		I
50ND[2]	Instantaneous ground overcurrent relay. (High magnitude ground fault protection of transformer delta winding and leads.)	T	T	T
50TF	Instantaneous overcurrent relay. (High magnitude transformer internal phase fault protection.)	T	T	T
51N[1]	Time delay overcurrent relay. (Ground fault protection of transformer wye winding and through faults.)	T	T	T
51ND[2]	Time delay ground overcurrent relay. (Ground fault protection of transformer delta winding and leads.)	T	T	T
51TF	Time delay overcurrent relay. (Phase through fault protection.)	T	T	T
51TL	Time delay overcurrent relay. (Transformer overload protection)	T	T	T
63	Sudden pressure relay			T
71	Liquid level device		I	I



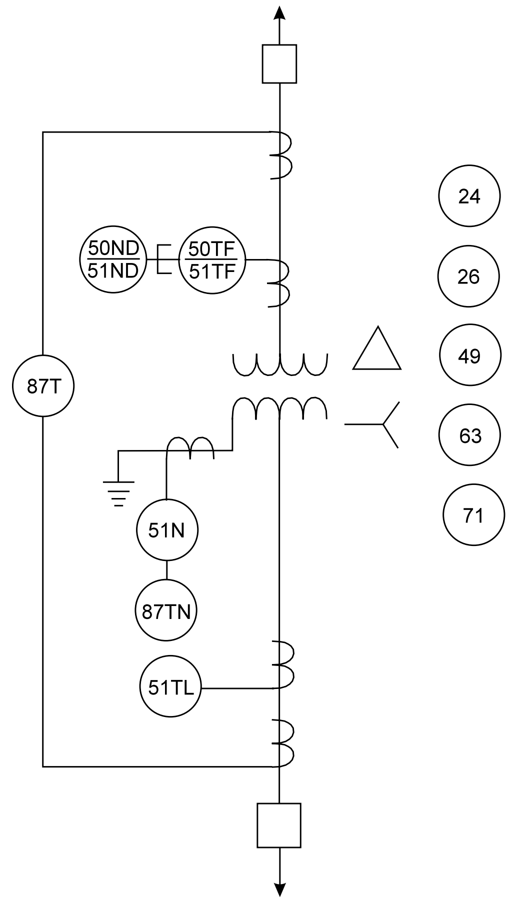
Notes:
A—Alarm, I—Indication, T—Trip
1. Devices 50G, 50N/51N, 50NY/51NY, 67N and 87TN are alternatives. (See Fig 1E.)
2. Device 50GD is an alternative to 50ND/51ND. (See Fig 1E.)

Fig. 1B. Electrical protection one-line. Primary breaker. 1000- to 10000-kVA transformers outdoors. Less than 1000 kVA when transformer creates fire exposure.

2.1.2.6 Perform electrical testing on all transformers whose failure would cause serious property damage and/or production interruption. Testing should be performed in accordance with manufacturers' instructions in conjunction with Data Sheet 5-20, *Electrical Testing*.

2.1.2.7 All component parts (both in air and under liquid) associated with the automatic operation of the transformer's load tap changer should receive periodic preventive maintenance. Tests should be performed

Device No.	Description	Action
24	Volts/hertz relay (For unit connected transformers only)	T
26	Liquid thermal device	A
49	Winding thermal device	A
50ND[2]	Instantaneous ground overcurrent relay. (High magnitude ground fault protection of transformer delta winding and leads.)	T
50TF	Instantaneous overcurrent relay. (High magnitude transformer internal phase fault protection)	T
51N[1]	Time delay overcurrent relay. (Ground fault protection of transformer wye winding and through faults.)	T
51ND[2]	Time delay ground overcurrent relay. (Ground fault protection of transformer delta winding and leads.)	T
51TF	Time delay overcurrent relay. (Phase through fault protection.)	T
51TL	Time delay overcurrent relay. (Transformer overload protection)	T
63	Sudden pressure relay	T
71	Liquid Level Device	I
87T	Transformer differential relay (Fault protection for transformer internal faults)	T
87TN[3]	Transformer ground differential relay (Ground fault protection of transformer wye winding internal faults)	T



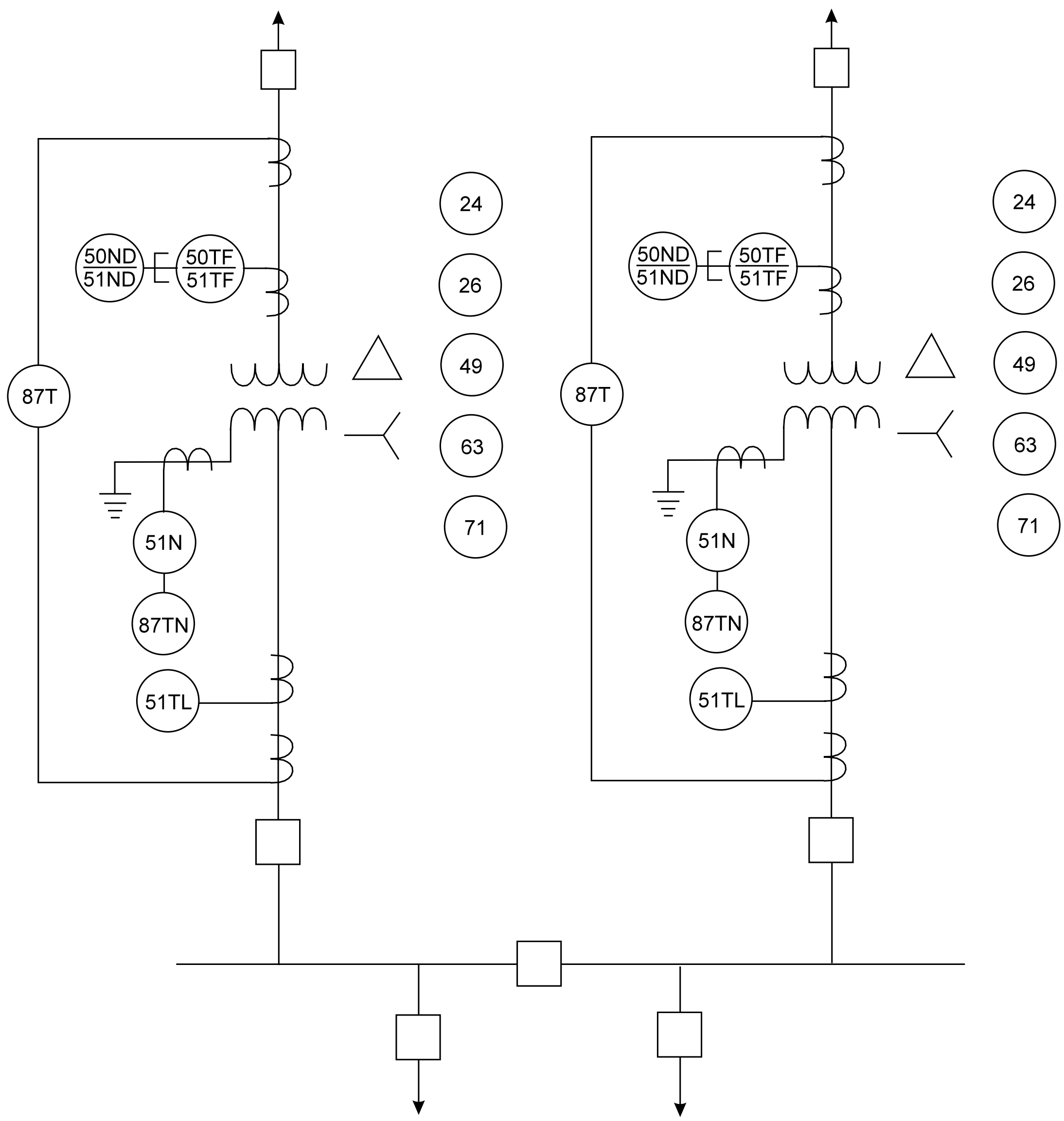
Notes:
A—Alarm, I—Indication, T—Trip
1. Devices 50G, 50N/51N, and 50NY/51NY are alternatives. (See Fig 1E.)
2. Device 50GD is an alternative to 50ND/51ND. (See Fig 1E.)
3. Device 67N is an alternative to 87TN. (See Fig 1E.)

Fig. 1C. Electrical protection one-line. 10000-kVA and larger transformers.

on the mineral oil in the load tap-changer compartment. Low oil level in the tap changer compartment should be investigated. Periodic preventive maintenance on load-tap changers should be performed in accordance with the tap changer manufacturer's instructions, operating experience and recommended practice. The oil-filled load-tap changer compartment should be provided with a mechanical over-pressure relief device. Replacement parts for the load-tap changer should be readily available. The no-load tap changer operating mechanism should be locked to prevent inadvertent operation.

2.1.2.8 Condenser-type bushings should be tested for an increase in power factor and capacitance with time. The bushings should be tested in accordance with manufacturers' instructions and Data Sheet 5-20, *Electrical Testing,* for high power factors and capacitance values. If test results exceed manufacturers' limits for power factor and/or capacitance, they should be removed from service.

2.1.2.9 Test and maintain monitoring and electrical protective devices (fuses, circuit breakers and relays) in accordance with Data Sheet 5-19, *Switchgear and Circuit Breakers,* and Data Sheet 5-20, *Electrical Testing*.



Note:
Electrical protection shown for 10-MVA and larger transformers. Protection should be chosen per Fig. 1A, 1B, or 1C depending upon transformer size.

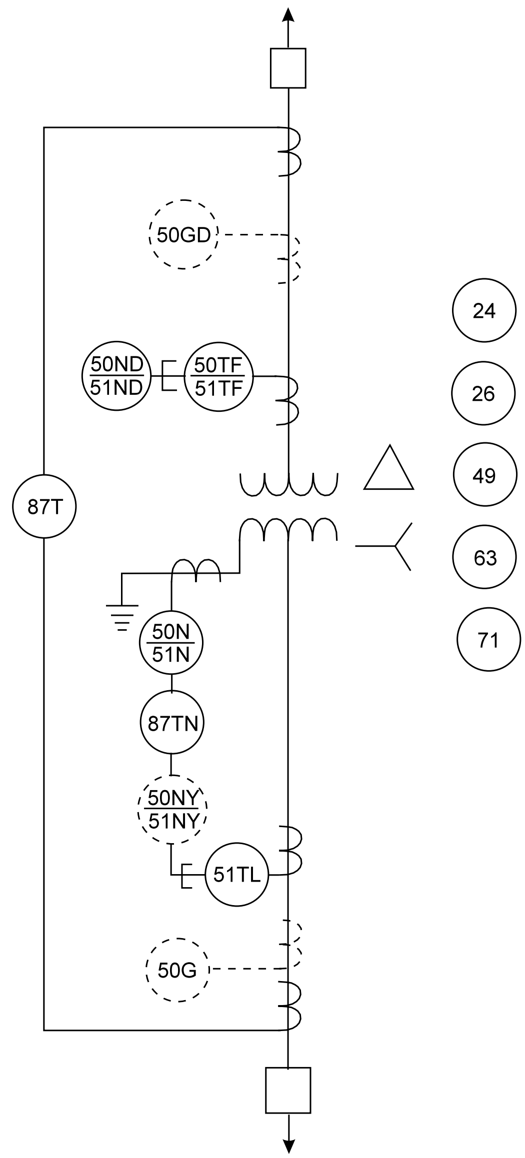
Fig. 1D. Electrical protection one-line. Secondary selective system.

All the components of the protection systems should be inspected and maintained according to their manufacturer's instructions and the recommendations of the transformer supplier.

2.1.2.10 The cause of protective relay operation should be determined before action is taken to reclose the transformer onto the electrical system. Many failures after reclosure following relay operation have been reported. Unsuccessful reclosure leads to further damage and destruction of the evidence of the cause of the relay operation.

2.1.2.11 Provide transient overvoltage (''surge'') protection in accordance with Data Sheet 5-11, *Lightning and Surge Protection for Electrical Systems*.

Device No.	Description
24	Volts/hertz relay (For unit connected transformers only)
26	Liquid thermal device
49	Winding thermal device
50G[1]	Zero sequence instantaneous ground overcurrent relay. (Ground fault protection of wye winding and through faults)
50GD[2]	Zero sequence instantaneous ground overcurrent relay. (Ground fault protection of transformer delta winding.)
50N	Instantaneous ground overcurrent relay. (High magnitude ground fault protection of wye winding and through faults.)
50ND	Instantaneous ground overcurrent relay. (High magnitude ground fault protection of transformer delta winding and leads.)
50NY	Instantaneous ground overcurrent relay. (High magnitude ground fault protection of wye winding and through faults.)
50TF	Instantaneous overcurrent relay. (High magnitude transformer internal phase fault protection)
51N	Time delay overcurrent relay. (Ground fault protection of transformer wye winding and through faults.)
51ND	Time delay ground overcurrent relay. (Ground fault protection of transformer delta winding and leads.)
51NY	Time delay overcurrent relay. (Ground fault protection of transformer wye winding and through faults.)
51TF	Time delay overcurrent relay. (Phase through fault protection.)
51TL	Time delay overcurrent relay. (Transformer overload protection)
63	Sudden pressure relay
67N[3]	AC Directional neutral overcurrent relay. (Ground fault protection of transformer wye winding internal faults)
71	Liquid Level Device
87T	Transformer differential relay (Fault protection for transformer internal faults)
87TN	Transformer ground differential relay (Ground fault protection of transformer wye winding internal faults)



Notes:
1. Devices 50G, 50N/51N, 50NY/51NY are alternatives.
2. Device 50GD is an alternative to 50ND/51ND.
3. Device 67N is an alternative to 87TN.

Fig. 1E. Electrical protection one-line. Protection alternatives.

2.1.2.12 A sound and consistent maintenance program should be established. This program should follow the specific instructions of the manufacturer of the transformer, experience and guidelines of this data sheet. The importance, criticality, physical environment and operating conditions of the transformer should be considered to establish an effective schedule.

2.2 Indoor Transformers

The following protection recommendations are based on whether the transformer is FM Approved or equivalent, the type of insulating liquid, the type of transformer and the electrical protection provided. Network transformers are considered separately from other types of transformers. A network transformer can be energized from either primary or secondary winding. The failure rates for network transformers are higher than for other types because the secondary electrical protection is not adequate.

2.2.1 Construction and Location

2.2.1.1 General

2.2.1.1.1 Indoor transformers should be located a minimum of 3 ft (0.9 m) from building walls.

2.2.1.1.2 Containment systems should be provided for liquid insulated transformers. Where transformers are located in main plant areas, curbing should be provided. Where located in a room, the room should be capable of containing the volume of liquid in the largest transformer.

2.2.1.1.3 Where nonthermal damage could occur to the occupancy liquid insulated transformers should be relocated to a room not exposing the occupancy or the room should be provided with a designed mechanical ventilation system. Power for the ventilation system should be supplied from an emergency power supply. The room construction should have a fire resistance rating specified in the following applicable sections. If a fire resistance rating is not specified, the room should be of noncombustible construction.

2.2.1.1.4 Provide ionization type smoke detection/alarms in electrical rooms to sound at a constantly attended location regardless of any automatic sprinkler protection or heat detection that may exist. Response should include notification of personnel capable of de-energizing the electrical equipment. The presence or absence of smoke detectors does not change the need for sprinklers. Smoke detection spacing should be accordance with Data Sheet 5-48, *Automatic Fire Detection*.

2.2.1.1.5 Develop a prefire plan for fire and electrical response. Electrical personnel should be capable of responding at the same time as fire fighting personnel and be able to de-energize equipment so there will be no delay in fire fighting activities. An upstream (high side) breaker located outside the electrical room accessible during emergencies may be needed to accomplish this.

2.2.1.2 Liquid Insulated Network Transformers

2.2.1.2.1 Transformers should preferably be FM Approved or equivalent (see Section 3.1.1.2, *FM Approved and Equivalent Transformers.)*

2.2.1.2.2 Transformers should be located within a room of fire resistant construction and/or protection. The fire resistance of the construction depends on the quality of insulating fluid in the largest transformer. Transformer rooms should be located on the outside wall were possible:

a) A fire resistance rating of 3 hours; or

b) A fire resistance rating of 1 hour, and provided with automatic sprinkler protection or an FM Approved gaseous agent suppression system, or a water mist system FM Approved for machinery spaces. If automatic sprinklers are used, a discharge density of 0.30 gpm/ft^2 (15 mm/min) should be provided over the area of the room.

2.2.1.2.3 Transformer rooms should be located on an outside wall where possible.

2.2.1.3 Liquid Insulated Transformers (Except Network)

2.2.1.3.1 Less Flammable Liquid Insulated Transformers

2.2.1.3.1.1 Transformers should be FM Approved or equivalent (see Section 3.1.1.2) or the following should be done:

- Location within a room with a fire resistance rating of one hour; or
- Automatic sprinklers should be provided over the transformer and for 20 ft (6.1 m) beyond. The design discharge density should be 0.20 gpm/ft^2 (10 mm/min).

2.2.1.3.2 Oil Insulated Transformers

Transformers should be located within a room of fire resistant construction. The fire resistance of the construction depends on the quantity of insulating liquid in the largest transformer. Transformer rooms should be located on an outside wall of the building where possible.

2.2.1.3.2.1. For 100 gal (0.38 m^3) or less, the fire resistance rating of the room should be one hour.

2.2.1.3.2.2 For more than 100 gal (0.38 m^3), one of the following methods should be used:

a) Location within a room with a fire resistance rating of 3 hours.

b) Location within a room of one-hour fire resistance and provided with automatic sprinkler protection or an FM Approved gaseous agent suppression system, or a water mist system FM Approved for machinery spaces. If automatic sprinklers are used, a discharge density of 0.30 gpm/ft^2 (15 mm/min) should be provided over the area of the room.

2.2.1.3.2.3 For multiple transformers in the same room, the room should be of 3-hour fire rated construction and one of the following protection methods should be used:

a) Subdivide the room so that transformers are in separate fire areas using construction with a 3-hour fire resistance rating.

b) Provide automatic sprinkler protection, an FM Approved gaseous agent suppression system, or a water mist system FM Approved for machinery spaces. If automatic sprinklers are used, a discharge density of 0.30 gpm/ft^2 (15 mm/min) should be provided over the room area (see Fig. 2).

2.2.1.3.3 Dry-Type Transformers

2.2.1.3.3.1 If dry-type transformers are located outside an electrical room they should be separated from combustible material by distance or barriers to prevent ignition of the combustible material or exposure to the transformer.

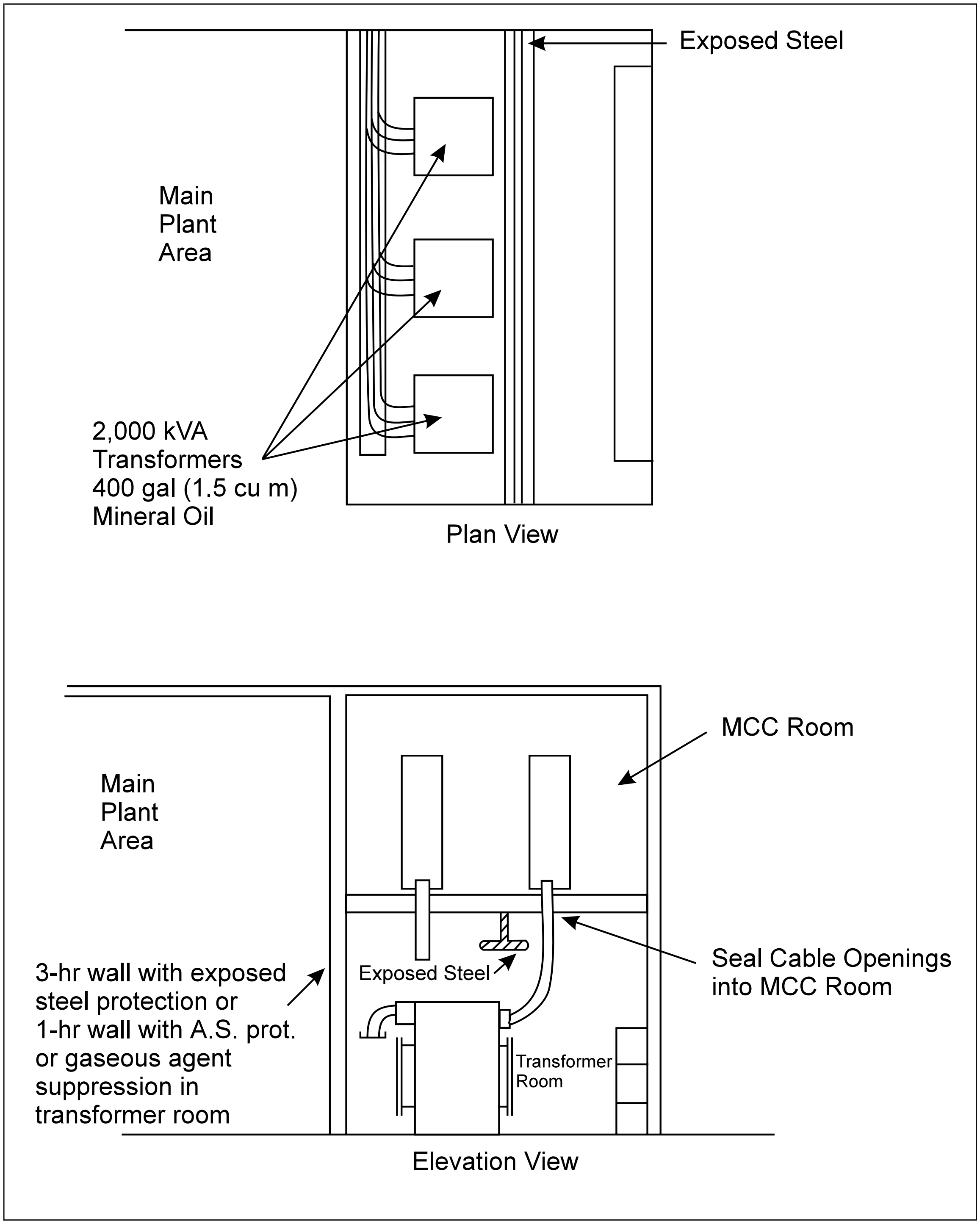


Fig. 2. Plan and elevation view of transformer room and MCC room containing three mineral oil insulated transformers.

The separation distance should be 5 ft (1.5 m) horizontally and 10 ft (3.0 m) vertically; or

A barrier of noncombustible construction should be provided.

2.2.1.3.3.2 Air-cooled transformers should be located in a pressurized room where exposed to dusty or corrosive atmospheres. Cooling air for the transformer should be filtered and free of corrosive contaminants.

2.3 Outdoor Transformers

The following protection recommendations are based on whether the transformer is FM Approved or equivalent, and the volume and type of insulating liquid used. Outdoor transformers may be located on or adjacent to buildings as often happens with generating station transformers and distribution transformers at manufacturing plants. They may also be located in remote areas such as substations.

2.3.1 Construction and Location

2.3.1.1 Exposure Protection

Buildings or equipment exposed by transformers should be protected by separation, a fire barrier or a water spray system on the transformers.

2.3.1.1.1 Separation Distance

2.3.1.1.1.1 The separation distance between buildings and transformers should be as indicated in Table 2a. Horizontal distance is measured from the transformer if an FM Approved less flammable fluid is used. Horizontal distance is also measured from the transformer where unapproved fluids or mineral oil filled transformers less than 500 gal (1.9 m^3) are used and the ground slopes away from the transformer. If the transformer contains an unapproved fluid or mineral oil of 500 gal (1.9 m^3) or more the distance is measured from the dike (see Fig. 3).

2.3.1.1.1.2 The separation distance between other equipment (including adjacent transformers) should be as indicated in Table 2b.

Table 2a. Separation Distance Between Outdoor Liquid Insulated Transformers and Buildings

Liquid	*FM Approved Transformer or Equivalent*	*Liquid Volume, gal (m^3)*	*Horizontal Distance (1)*			*Vertical Distance ft (m)*
			Two Hour Fire Resistant Construction, ft (m)	*Non-combustible Construction, ft (m)*	*Combustible Construction, ft (m)*	
Less Flammable (FM Approved Fluid)	Yes	N/A	3 (0.9)			5 (1.5)
	No	≤10,000 (38) >10,000 (38)	5 (1.5) 15 (4.6)		25 (7.6) 50 (15.2)	25 (7.6) 50 (15.2)
Mineral Oil or (unapproved fluid)	N/A	<500 (1.9) 500-5,000(1.9-19) >5,000 (19)	5 (1.5) 15 (4.6) 25 (7.6)	15 (4.6) 25 (7.6) 50 (15.2)	25 (7.6) 50 (15.2) 100 (30.5)	25 (7.6) 50 (15.2) 100 (30.5)

(1) All transformer components must be accessible for inspection and maintenance.

Table 2b. Outdoor Fluid Insulated Transformers Equipment Separation Distance (1)

Liquid	*FM Approved Transformer or Equivalent*	*Fluid Volume, gal (m^3)*	*Distance, ft (m)*
Less Flammable (FM Approved Fluid)	Yes	N/A	3 (0.9)
	No	≤10,000 (38) >10,000 (38)	5 (1.5) 25 (7.6)
Mineral Oil or (unapproved fluid)	N/A	<500 (1.9) 500-5,000 (1.9-19) >5,000 (19)	5 (1.5) 25 (7.6) 50 (15.2)

(1) All transformer components must be accessible for inspection and maintenance.

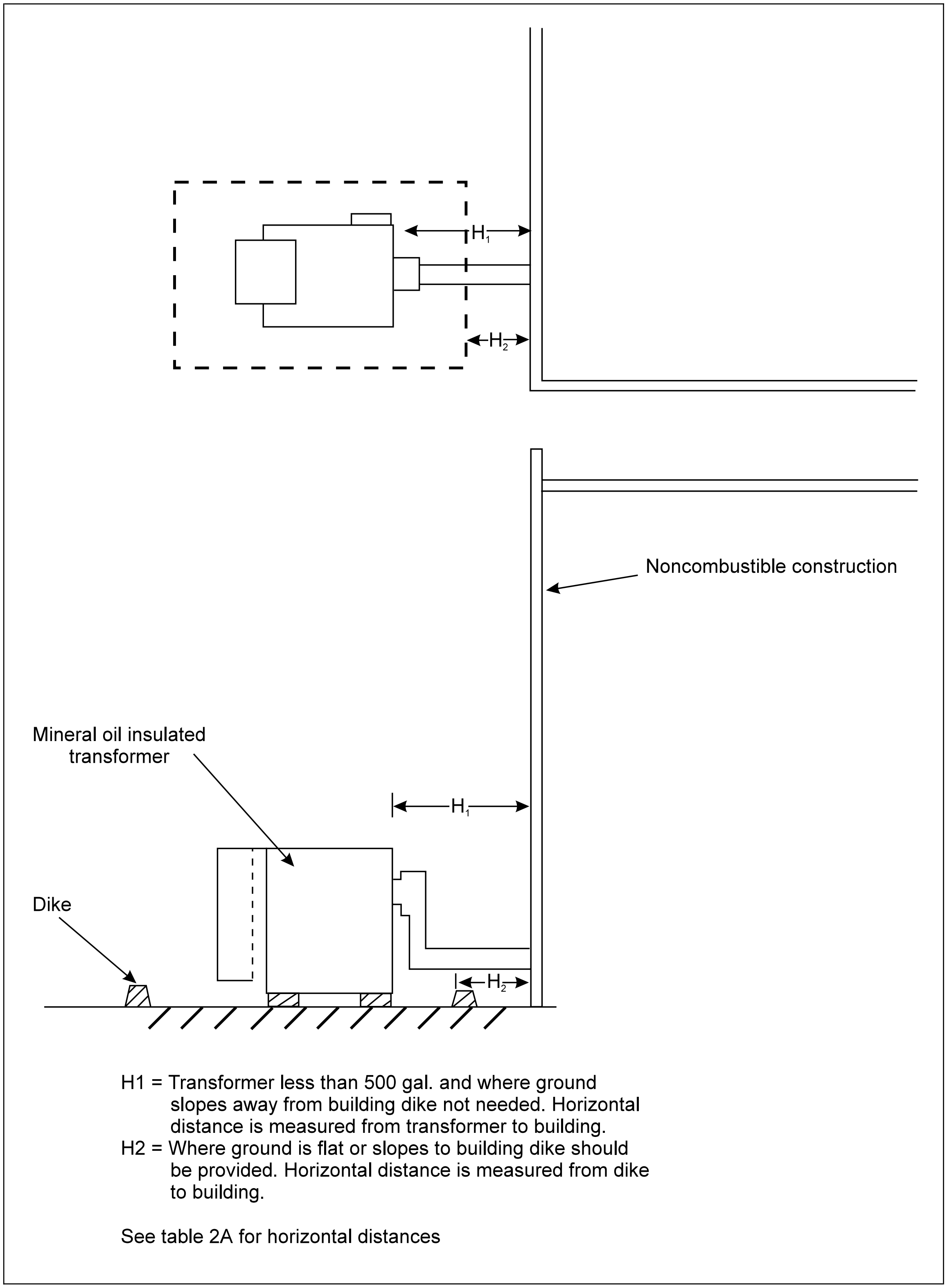


Fig. 3. Separation between liquid insulated transformer and building.

2.3.1.1.2 Fire Barriers

2.3.1.1.2.1 Buildings

2.3.1.1.2.1.1 Where building walls are used for protection, the exposed wall should extend the horizontal and vertical distances from the dike or transformer specified in Table 2a.

2.3.1.1.2.1.2 Roofs exposed by mineral oil insulated transformers should be Class A rated for the exposed area. The exposed area is considered to be the following:

a) 15 ft (4.6 m) from a transformer containing 1,000 to 5,000 gal (3.8 to 19 m^3) of mineral oil where roofs are less than 25 ft (7.76 m) high.

b) 25 ft (7.6 m) from a transformer containing in excess of 5,000 gal (19 m^3), where roofs are less than 50 ft high.

2.3.1.1.2.2 Equipment

2.3.1.1.2.2.1 For equipment protection, barriers should extend 1 ft (0.3 m) vertically and 2 ft (0.6 m) horizontally beyond transformer components that could be pressurized as the result of an electrical fault. This would typically include bushings, pressure relief vents, radiators, tap changer enclosures, etc.

2.3.1.1.2.2.2 Provide barriers of concrete block or reinforced concrete construction adequate for two-hour fire resistance. Fire barriers constructed of other materials may be used provided: (1) all components are capable of withstanding a two-hour fire exposure by an ASTM E-119 test from either side with no flame penetration to the unexposed side, and (2) barriers are capable of withstanding not less than 25% of full design wind loads at maximum fire-exposed material temperatures. Use design wind speeds (3-second gust) per DS 1-28, *Design Wind Loads*, or similar, acting concurrently with the worst-case fire exposure.

2.3.1.2 Containment

2.3.1.2.1 General

2.3.1.2.1.1 Provide a containment system for transformers where:

a) a release of mineral oil would expose buildings.

b) more than 500 gal (1.9 m^3) of mineral oil could be released.

c) more than 1320 gal (5 m^3) of FM Approved less flammable fluid could be released.

d) more than 2,640 gal (10 m^3) of biodegradable FM Approved less flammable fluid could be released. For this purpose: 1) the fluid must be certified as a biodegradable fluid by the government environmental protection agency, 2) a release of the fluid must not expose navigable waterways (see Appendix A for definition) and 3) the transformer must be properly labeled.

2.3.1.2.1.2 The containment system should be large enough for the volume of oil in the largest transformer and the water from a 10-min discharge of the water spray system if provided. If there are three or more transformers, it should be assumed that the fire will occur in the middle transformer and the water spray systems on adjacent transformers will operate.

2.3.1.2.1.3 The containment system should consist of a pit or a diked area and a drainage system for removal of rainwater. The pit should be protected as described in 2.3.1.2.2 and 3 if the transformer is mineral oil insulated. It may be unprotected if the transformer contains an FM Approved less flammable fluid.

2.3.1.2.1.4 The pit or diked area should be sized to contain the contents of the largest transformer. The area of the pit should extend as follows:

a) For transformers containing 1,000 gal (3.8 m^3) or less, the area of the pit should extend 3 ft (0.9 m) beyond oil containing components where curbing is provided and 5 ft (1.5 m) beyond oil containing components where curbing is not provided.

b) For transformers containing more than 1,000 gal (3.8 m^3), the area of the pit should extend 5 ft (1.5 m) beyond oil containing components where curbing is provided and 8 ft (2.4 m) beyond oil containing components where curbing is not provided.

2.3.1.2.2 Rock-Filled Pits

2.3.1.2.2.1 Where rock-filled pits are used, the rock should be loosened and turned as necessary to prevent filling of void spaces by dirt, dust or silt. The frequency is dependent on area of the country and location near manufacturing facilities which generate dust or flyash.

2.3.1.2.3 Open Pits

2.3.1.2.3.1 Where an open pit is used, one of the following forms of protection should be provided:

a) Automatic sprinkler or water spray protection should be provided for the pit area designed to a discharge density of 0.30 gal/min ft^2 (15 mm/min) over the area of the pit; or

b) A 12-in (30 cm) thick layer of rock located on steel grating should be provided at the top of the pit. The rock used should be 1.5 in. (3.8 cm) washed and uniformly sized rock, (Size No 5, ASTM D448 *Standard Classification for Sizes of Aggregate for Road and Bridge Construction*). (See Fig. 4.)

2.3.1.3 Roof-Mounted Transformer Installations

2.3.1.3.1 Containment systems should be provided for roof-mounted transformers.

a) For transformers with 500 gal (1.9 m^3) or less insulating liquid, the containment system may be a welded steel pan or curbed concrete mat with capacity large enough to handle the liquid in the largest transformer.

b) For mineral oil insulated transformers with more than 500 gal (1.9 m^3) liquid capacity, containment should be rock-filled or of the open pit design with protection as recommended in Section 2.3.1.2.2 and 2.3.1.2.3. For FM Approved less flammable fluid insulated transformers an open containment may be used.

c) Class A roof construction should be used for the horizontal distance from the transformer specified for noncombustible construction in Table 2a.

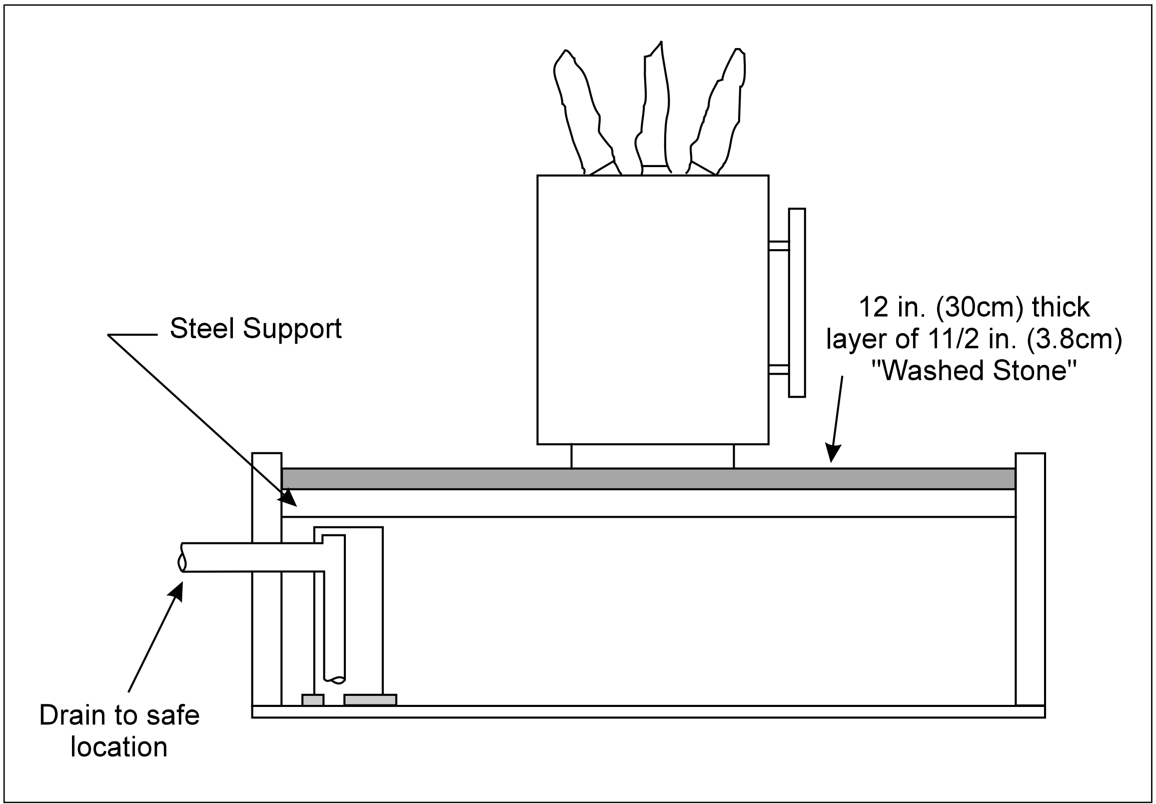


Fig. 4. Open-pit containment system.

2.3.1.3.2 The containment system should be drained to a safe location acceptable to the authority having jurisdiction.

2.3.1.3.3 Adjacent buildings and other equipment should be protected in accordance with Section 2.3.1.1.

2.3.2 Protection

2.3.2.1 Water Spray Exposure Protection

2.3.2.1.1 Buildings

2.3.2.1.1.1 If water spray or automatic sprinkler protection is used for building protection, a discharge density of 0.20 gpm/ft^2 (8 mm/min) should be used over the exposed surface.

2.3.2.1.1.2 The water supply should be adequate for 2 hours and should include a hose stream demand of 500 gpm (1900 l/min).

2.3.2.1.2 Equipment

2.3.2.1.2.1 For multiple transformer installations the water spray system should be designed based on simultaneous operation of the water spray systems for the adjacent transformers.

2.3.2.1.2.2 The water spray system should be designed to provide a density of 0.25 gal/min ft^2 (10 mm/min) over transformer surfaces, except areas under the transformer in accordance with Data Sheet 4-1N, *Water Spray Fixed Systems*.

2.3.2.1.2.3 Where the ground around the transformer is nonabsorbing, water spray should be provided at a density of 0.15 gal/min ft^2 (6 mm/min) for the diked area or for a distance of 10 ft (3 m) from the transformer in all directions.

2.3.2.1.2.4 Components of the water spray system, such as piping, spray nozzles, etc. should be a minimum of 18 in. (45.7 cm) from the transformer.

2.3.2.1.2.5 Piping should not pass over the top of the transformer or be exposed by tank relief vents.

2.3.2.1.2.6 Water spray nozzles should not be directed at bushings.

2.3.2.1.2.7 The water supply should be adequate for 1 hour and include a hose stream demand of 250 gpm (950 l/min).

2.3.2.2 Hydrant Protection

2.3.2.2.1 Provide hydrant protection where transformers present an exposure to buildings and equipment. Nozzles FM Approved by FM Approvals for use on electrical equipment are preferred. Nozzles that produce a spray angle of 30 to 90 degrees without passing through a solid stream are acceptable. If solid hose streams are used with equipment up to 138 kV, the minimum approach distance should be 20 ft (6.1 m) for 1-½ in. nozzles and 30 ft (9.1 m) for 2-½ in. (6.4 cm) nozzles. Tests have not been conducted on equipment with voltages above 138 kV and solid hose streams should not be used until this equipment is de-energized.

2.4 Transformer Production Test Areas

2.4.1 Protection

2.4.1.1 Automatic sprinkler protection should be installed at ceiling level throughout the test area. The discharge density should be a minimum of 0.20 gpm/ft^2 (8 mm/min) for the following: a) 3,000 ft^2 (278.7 m^2) for wet pipe systems with 286°F (141°C) rated heads; b) 4,000 ft^2 (371.6 m^2) for wet systems with 165°F (74°C) heads; c) 5,000 ft^2 (464.5 m^2) for dry systems with 286°F (141°C) heads; d) 6,000 ft^2 (557.4 m^2) for dry systems with 165°F (74°C) heads.

2.4.1.2 At least 6 in. (15 cm) high curbs should be provided around the test area with the curbed area drained to a safe location acceptable to the authority having jurisdiction.

2.4.1.3 A standpipe with 1-½ in. (40 mm) hose connections should be provided such that all areas can be reached with at least one hose stream.

2.5 Transformers Insulated with Liquids Containing Polychlorinated Biphenyls (PCBs)

2.5.1 Operation and Maintenance

2.5.1.1 General

2.5.1.1.1 Transformers which have been flushed and refilled with a replacement liquid should be tested at 3 to 5 year intervals in accordance with Data Sheet 5-20, *Electrical Testing,* to verify that PCB concentrations are below 50 ppm.

2.5.1.1.2 PCB-filled and PCB-contaminated transformers containing more than 50 ppm PCBs should be replaced.

2.5.1.2 Operation, Maintenance, and Fire Protection

Pending replacement of PCB-filled and PCB-contaminated transformers, the following should be done:

2.5.1.2.1 An emergency response plan to handle a PCB spill should be developed. The plan should be in writing and should include:

- Availability of an emergency power supply

Telephone numbers for salvage and emergency, critical plant personnel, a PCB disposal firm, and the local FM Global office.

Telephone numbers of appropriate authorities. In the United States this includes the National Spill Response Center, and the nearest EPA Office.

2.5.1.2.2 A visual inspection should be performed for transformers in use or stored for reuse on a *monthly* frequency if the transformer is accessible without shutdown of the transformer, and *annually* where the transformer cannot be inspected without shutdown.

2.5.1.2.3 Damaged or leaking areas should be repaired.

2.5.1.2.4 Floor drains exposed to a PCB spill should be sealed except drains to an oil containment system.

2.5.1.3 PCB-Insulated Transformer Replacement

2.5.1.3.1 Drain PCB-contaminated liquid from transformers containing more than 100 gal (0.38 m^3) before movement.

2.5.1.3.2 Drums containing liquid PCB should be packed within a larger outer drum with absorbent material between the two drums.

2.5.1.3.3 A pre-emergency plan should be developed before moving PCB-filled equipment or containers to minimize exposure to plant areas. The plan should include verification that spill containment equipment such as plastic sheeting, oil absorbent materials and empty drums are available.

2.5.1.3.4 Drums containing PCBs should be removed from main plant areas and disposed of as soon as possible. If drums are stored on-site, they should be stored in detached low value buildings. The following precautions should be taken:

- The drums should be stored in a room of noncombustible construction with noncombustible occupancy.
- Floor areas should be provided with a minimum 6 in. (15.2 cm) high curb. The volume of the curbed area should be capable of containing either twice the volume of the largest container or 25% of the volume of the PCB containers in the room, whichever is larger.
- There should be no drains within the curbed area.
- Floor and curbing surface area should be constructed of impervious materials, such as concrete.

2.5.2 Construction and Location

2.5.2.1 Where transformers are in open plant areas the following should be done:

- Provide a curbed area around each transformer or bank of transformers sufficient to contain liquid from the largest transformer. Isolate PCB-contaminated transformers from hazardous processes or areas of combustible storage by means of one of the following:

a) A one-hour fire rated barrier

b) A minimum 15 ft (5 m) separation distance free of combustibles.

2.5.2.2 Where transformers are within rooms or vaults the following should be done:

- Seal wall penetrations
- Exhaust air directly to the outside
- Keep the room free of combustibles

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Discussion

3.1.1 FM Approved and Equivalent Transformers

Approval is intended for liquid-filled transformers rated at 5 to 10,000 kVA. If a transformer is FM Approved, fire frequency is considered reduced sufficiently such that fire protection considerations are not necessary. The FM Approval program considers the transformer as a system that includes evaluation of the fire properties of the liquid, the ability of the tank and transformer components to withstand the pressure generated by a low level electrical fault, and the ability of electrical protection to clear a fault before tank rupture. The conditions of Approval are as follows:

1. Tank design strength to prevent tank rupture under low energy fault conditions.

2. A pressure relief device to relieve pressure if a low current fault occurs until the fault can be cleared by electrical protection described in Item 3 below.

3. Electrical protection to clear sustained low current faults. This protection could be in the form of a ground fault relay and sudden pressure relay, or other devices of equivalent reliability.

4. Electrical protection to clear high current faults. This protection is based on the kVA rating of the transformer and is intended to electrically isolate the transformer rapidly enough to prevent pressure increase to greater than half the tank burst pressure.

5. FM Approved transformer fluids have a fire point of 572°F (300°C) or more.

For FM Approved network transformers, secondary side electrical protection is needed in addition to the above. This protection could be in the form of ground fault detection or other technology of demonstrated equivalence. This device should trip the high-side disconnect devices of the transformer experiencing the fault and other paralleled transformers in the network.

An equivalent transformer is one with a UL listing per NEC Section 450-23 and electrical protection to clear sustained low current faults. A UL listed transformer per NEC Section 450-23 will include the protection features described above except for Item 3. If electrical protection to clear sustained low current faults is provided, the transformer should be equivalent to an FM Approved transformer.

3.1.2 Transformer Electrical Protection

The purpose for providing transformer electrical protection is to:

a) Separate the transformer from the remainder of the system to allow the system to continue to operate.

b) Limit damage to the transformer.

c) Limit damage to the rest of the system.

d) Minimize the possibility of fire.

e) Minimize hazards to personnel.

The cost of transformer repairs and the associated downtime may be expensive. High speed sensitive transformer protection can reduce transformer and system damage and therefore repair costs. There is no single way to protect transformers. Various protection alternatives need to be investigated to determine the best and most cost effective scheme considering protective device speed, sensitivity and selectivity. Backup protection should also be considered since failure of a single protective device or breaker could cause even more extensive damage to the transformer. The selected protection should minimize:

a) Cost of repairing or replacing transformer damage.

b) Cost of lost production.

c) Cost of repairing/replacing adjacent equipment/property.

d) Adverse effects on the balance of system.

There are several devices available that can be used to detect faults in the transformer and guard against the associated hazards.

3.1.2.1 Mechanical Detection of Faults

There are several devices that are used to detect liquid level and tank pressure.

3.1.2.1.1 Liquid Level Gauge, Device 71[1]

The liquid level gauge measures the level of the insulating liquid within the transformer tank. The gauge is calibrated against a predetermined liquid level at 25°C (77°F). A low liquid level could indicate a loss of liquid. Low liquid level can result in overheating, insulation failure or flashover. The liquid level gauge should be provided with alarm contacts. The alarm should sound to an attended location prior to the liquid level lowering to the point where the transformer is endangered.

3.1.2.1.2 Pressure-vacuum Gauge

The pressure-vacuum gauge indicates the difference between the transformer internal pressure and atmospheric. The transformer tank internal gas pressure is related to the thermal expansion of the transformer liquid and varies with the temperature. The temperature of the liquid is a function of the ambient temperature and transformer loading. The pressure-vacuum gauge should be tested for proper operation if its indication remains constant for a long period under various temperature and loading conditions. The pressure-vacuum gauge should be set to alarm before a tank rupture or deformation can occur. It is always better to have a positive pressure (3-5 psi) to prevent possible moisture and other contaminants from entering the tank.

3.1.2.1.3 Pressure Relief Device

This device should be provided on all liquid-filled transformers to prevent overpressurization and tank rupture. When the transformer tank's internal pressure exceeds the pressure relief device set pressure, the device opens, allowing the gas and/or liquid to be released. On large transformers the device should be provided with an alarm contact and initiate an alarm at an attended location. The pressure relief device is self resetting and self sealing. The pressure relief device should be tested to ensure proper operation. The device is normally mounted on top of the transformer tank and is provided with a visual operation indicator.

The operation indicator must be manually reset after the pressure relief device operates.

3.1.2.1.4 Gas Accumulation and Sudden Pressure

There are two basic mechanical methods for detecting transformer faults: gas accumulation and oil or gas pressure increase. Gas accumulation results from decomposition of insulation or oil. Sudden pressure increases are caused by internal and through-faults. The sudden pressure from the through-fault is caused by the electromagnetic forces moving the core/core assembly. The sudden pressure from internal faults is caused by the electromagnetic forces and oil vaporization from the arc energy. For internal faults these relays are more sensitive than relays using electrical quantities.

3.1.2.1.4.1 Gas Detector Relay, Device 63

The gas detector relay is applicable only on transformers having conservator-type liquid preservation/sealing systems. It detects gas evolution from arcs and overheating. The relay alarms when 200 cc of gas has accumulated in its chamber. A gas sample should then be removed for analysis.

3.1.2.1.4.2 Sudden Gas Pressure Relay, Device 63

The sudden gas pressure relay is applicable to gas-cushioned oil-immersed transformers. The relay is mounted in the region of the gas space. The relay can detect low or high energy arcs. The inert gas above the insulating liquid transmits the pressure wave to the relay. For high energy arcs the relay operates on

[1] *Device numbers are listed in Table 1.*

a gas pressure rate-of-rise. The speed of the relay is directly proportional to the pressure rate-of-rise. High energy internal faults produce a large quantity of gas with a resultant high pressure rate-of-rise. The high pressure rate of rise results in fast relay operation (50-100 ms). Low energy arcs produce a smaller pressure rate of rise. The lower rate-of-rise results in slower relay operating times (500-1000 ms).

The most recent design of this relay uses two chambers, two control bellows, and a single sensing bellow. All three bellows have a common interconnecting silicone passage. Dissimilar expansion rates of the two control bellows initiates relay operation.

The relay should be mounted in accordance with the transformer manufacturer's instructions. An auxiliary relay (63X) should be provided to seal in the sudden pressure relay contacts and to prevent false operations. With the above precautions taken into consideration, the reliability of the modern sudden pressure relay is very good. The relay should be connected to trip the transformer high and low side circuit breakers.

3.1.2.1.4.3 Sudden Oil Pressure Relay, Device 63

This relay is applicable to all oil-immersed transformers and is mounted on the tank below the minimum liquid level. It detects internal faults generating rapid rises in oil pressure. The rapid rise in oil pressure is transmitted to the silicone liquid in the relay by way of the transformer oil and the relay closes its contacts. The most recent design of this relay is similar to that described for the sudden gas pressure relay. The same installation precautions as for the sudden gas pressure relay need to be considered. The relay should be connected to trip.

3.1.2.1.4.4 Gas Accumulator Relay (Buchholz Relay), Device 63

The gas accumulator relay is applicable only to transformers with conservator tanks without gas space in the main tank. It is a combination of a gas detector relay and a sudden oil pressure relay. The relay is installed in the pipe running from the main tank to the conservator tank. It can detect gas volume generated in its gas detector mode or high velocity oil flow (large faults) in the sudden oil pressure mode. The gas detector portion of the relay is normally used to alarm and the sudden pressure part is used to trip.

Note: Not all these devices can be used in a given type of transformer, although generically they appear to be compatible. This is due to physical construction of a given transformer, oil pump location, cover construction, and liquid preservation system. The transformer manufacturer should be consulted for the applicability of a specific gas and/or sudden pressure relay and for its mounting location on the specific transformer.

3.1.2.2 Thermal Detection of Abnormalities

Overheating shortens the life of transformer insulation. Insulation deterioration is directly proportional to the duration and magnitude of overtemperature. Severe overtemperature may result in rapid or immediate insulation failure. Transformer overheating may be caused by:

1. High ambient temperature (greater than 30°C [86°F])

2. Failure of cooling system

3. Overloading

4. Through-faults not cleared within transformer's through-fault capability characteristic time.

5. Abnormal system conditions (high voltage, low frequency, overexcitation, volts/hertz, nonlinear loads, phase unbalance.)

Continuous monitoring of transformer temperature and protection against overtemperature is imperative and is attained by the following methods.

3.1.2.2.1 Hot-spot Temperature, Device 49.

The hot-spot temperature gauge indicates the hottest-spot temperature of the transformer. The location of the hottest spot of the transformer is monitored by simulation methods, and appropriate warnings or trips are triggered when necessary. Hot-spot temperature can be simulated by thermal relays and replica relays. The thermal relay is responsive to both top-oil temperature and to the direct heating effect of load current. A current transformer (CT) supplies current proportional to winding current to the thermometer bulb heating coil mounted in the top oil. The thermometer bulb measures the oil temperature with the heat effect of loading and therefore tracks the temperature which the hot spot of the winding attains during operation.

The replica relay, based on the Wheatstone Bridge principle, measures the resistance of resistance temperature detectors (RTD) immersed in the oil. Current transformers supply current, proportional to winding current, to a heating coil mounted beside the RTD. The heating coil heats the oil around the RTD, simulating a hot spot. The RTD's resistance varies with this oil temperature. The RTD forms the balance leg of the bridge circuit in the relay. The relay is therefore responsive to the transformer hot spot temperature. Temperatures from several locations within the transformer can be monitored with this scheme.

3.1.2.2.2 Top-oil Temperature, Device 26

The liquid temperature indicator measures the insulating liquid temperature above the core/coil assembly. The temperature indicator is reflective of the transformer loading only to the extent that loading affects the liquid temperature rise above ambient. The top-oil temperature changes very slowly to changes in load because the liquid thermal time constant is much greater than the winding time constant. During periods of rapid load increases or decreases, the liquid temperature reading may lag behind the actual temperature of the conductors.

3.1.2.2.3 Fuses or Overcurrent Relays, Device 51

These devices, under certain conditions, may provide some degree of thermal protection. These devices are mainly used to provide short circuit protection. Description of these devices for both thermal and fault protection can be found in Section 3.1.2, Transformer Electrical Protection.

3.1.2.2.4 Overexcitation Protection, Device 24

Overexcitation protection for transformers is needed for direct-connected unit generator step-up transformers. The protection prevents overheating the transformer and unlaminated metal parts, with resultant thermal damage to adjacent insulation from excessive excitation current. Overexcitation relays (volts/Hz) provide warnings and/or trip functions mainly for directly-connected generator transformers subjected to wide ranges of frequency during the acceleration and deceleration of turbine-generator sets. The volts per hertz ratio should be less than 1.1 times the ratio of transformer rated voltage to rated frequency.

Overexcitation occurs when the ratio of volts/hertz exceeds 110% at the transformer's primary terminal. For a generator step-up transformer this would be the low voltage side. Overexcitation can occur during startup and shutdown of the generator, especially if the machine's voltage regulator is in a manual mode. This protection may be provided as part of the excitation control of the generator or by a separate Volts per Hertz Relay, Device 24.

Separate overexcitation protection of unit connected generator step-up transformer is required if the protection is not built into the generator excitation system. A separate volts per hertz should be provided if the overexcitation protection supplied by the generator manufacturer is bypassed when the voltage regulator is in manual mode and this is the normal method used to start and stop the machine. The transformer manufacturer should be contacted for proper coordination with either device and the transformer overexcitation limits.

3.1.2.3 Electrical Detection of Overloads and Faults

Overloads and faults can be electrically detected by fuses and protective relays. To provide proper protection, these devices must be able to distinguish between an acceptable overload within the transformer's capability and internal faults. The protective device must also be able to detect harmful overloads and through-faults that are not cleared by downstream protection. The electrical protection system must be able to detect all types of faults (three-phase, phase-to-phase, and phase-to-ground faults). Generally, several different devices are needed for the various fault conditions/types and overload conditions. Transformer overload protection should be applied on the load side of the transformer. Separate transformer protection for phase and ground faults should be provided. Transformers that are connected delta-wye require two ground fault schemes, one for the delta winding and one for the wye winding.

3.1.2.3.1 Coordination of Protective Devices

The selection of appropriate fuses and/or protective relays should be the result of an engineering study that has considered the coordination of all other protective devices and the electrical characteristics of the system to be protected.

The primary-phase protective device must be set above the transformer magnetizing inrush current and normal overload. This requirement reduces the degree of protection provided for the transformer. The protective devices at transformer loads should be selected to prevent loading of the transformers beyond the transformer short time overload capability. The transformer manufacturer can be consulted to determine the overload capability of specific transformers. The time-current characteristic of the transformer primary protective devices should coordinate with other overcurrent devices on both the primary and secondary-side of the transformer.

The primary protective device should protect the transformer against damage from thermal and mechanical stresses resulting from a transformer secondary-side fault. The primary protective device time-current curve should coordinate and be less than the transformer through-fault withstand capability curve. (See ANSI Standard C57.109, Transformer Through-Fault Current Duration Guide.) This characteristic takes into consideration that the transformer damage is cumulative. The degree of transformer protection provided by the primary device for the minimum value for different types of secondary-side faults (three-phase, phase-to-phase, phase-to-ground) should be determined. The device should be selected so that it will operate fast enough to prevent transformer winding damage for minimum values of fault currents.

Electrical quantities (kV, kA, kVA, kW, kVAR, and Z) are usually expressed in per unit or percent of a reference or base value. Percent is 100 times per unit quantity. The per unit value of any quantity is the ratio of that quantity to its base value. A 2500 kVA, 13.8 kV/480 V, 5.75% delta-wye transformer base values are 2500 kVA, 13.8 kV primary voltage, 105 A primary current, 0.480 kV secondary voltage, and 3000 A secondary current. The nameplate impedance is given in percent. Its per unit value is 0.0575 pu.

For a delta-wye transformer a secondary line-to-ground fault results in primary currents on two phases of 0.58 per unit or 58% of the secondary fault current referred to the primary-side. If a 20-kA secondary-side line-to-ground fault occurred on phase ''A'', the primary current seen by phases ''A'' and ''C'' would be 0.58 (0.480 kV/13.8 kV) 20 kA = 0.4 kA or 400 A. A secondary phase-to-phase fault on this transformer connection results in primary currents of 1.0 per unit on one phase and 0.5 per unit on the other two phases.

For a delta-delta transformer a secondary phase-to-phase fault results in primary currents on two phases of 0.87 per unit of the secondary current. Table 3 shows the effects of the delta-wye phase shifts for various faults.

3.1.2.3.2 Fuse Protection

This method is mainly used for transformers rated less than 5000 kVA. Fuses are a simple and inexpensive means of providing overload and fault protection of transformers. The main disadvantage of using fuses is that the operation of a single fuse 1) may cause single phasing and 2) may not de-energize a fault on a three-phase system. Single phasing on a three-phase system occurs when one phase does not carry any current and the other two phases do carry current. Both conditions expose other components of the distribution system to failure. The resulting single phase service may endanger polyphase motors and other loads. Fuses should be applied in combination with load-interrupter switches to trip all three phases.

Primary-side fuses are often used for protection against source-side and internal faults. They may not be effective for load-side faults when fuses are applied on the source-side only. They are not effective in detecting secondary-side arcing ground faults. Also primary-side fuses larger than 125% of transformer rated current may not provide adequate overload protection.

Fuse selection should be based on the following factors:

1. Ampere rating. The primary fuse should have an ampere rating that provides a continuous current capability greater than the maximum expected load. This requirement may reduce the degree of protection provided by the transformer.

Table 3. Effects of Delta-Wye Phase Shifts

Fault Type	Primary Line Current	Primary Winding		Secondary Winding		Secondary Line Current
		Type	Current	Type	Current	
3-Phase	1.0	Δ	0.58	Δ	0.58	1.0
3-Phase	1.0	Δ	0.58	Y	1.0	1.0
Line-Line	A 0.87	Δ	AB 0.58	Δ	AB –0.58	A 0.87
	B –0.87		BC 0.29		BC 0.29	B –0.87
	C 0		CA 0.29		CA 0.29	C 0
Line-Line	A 1.0	Δ	AB 0.5	Y	A 0.87	A 0.87
	B –0.5		BC 0		B –0.87	B –0.87
	C–0.5		CA –0.5		C 0	C 0
Line-Neutral	A 0.58	Δ	AB 0	Y	A 1.0	A 1.0
	B 0		BC 0		B 0	B 0
	C –0.58		CA –0.58		C 0	C 0
					N 1.0	N 1.0

2. Withstand inrush currents. The actual time-current profile for both transformer cold and hot load pickup of the distribution system should be determined. Cold load pickup is the combined magnetizing and load inrush currents associated with re-energizing a transformer after an extended outage. Hot load pickup is the combined magnetizing and load inrush currents associated with re-energizing a transformer after a momentary service interruption. The fuse characteristic must be greater than the sum of both transformer magnetizing and cold load inrush and transformer magnetizing and hot load inrush currents of the distribution system.

3. Interrupting rating. The fuses' interrupting capability must be greater than the available system fault current at the point of application.

4. Transformer through-fault withstand. The primary-side fuse total clearing time-current curve should coordinate and be less than the transformer through-fault withstand capability curve. The total clearing time curve of the primary-side fuse should cross the transformer through-fault capability curve at a low level of current. The lower the intersection of the two curves, the greater the degree of protection provided by the primary-side fuse.

5. Coordinate with other protective devices. The time-current characteristic of the transformer primary-side fuse should coordinate with other overcurrent devices on both the primary and secondary side of the transformer.

A power fuse is defined per ANSI/IEEE C37.100-1981 as: ''A fuse consisting of an assembly of a fuse support and a fuse unit or fuse holder which may not include the refill unit or fuse link.'' There are two basic types of power fuses: 1) expulsion type and 2) current limiting type.

The expulsion-type fuse is a vented fuse that extinguishes the arc via the deionization action of the gases. The gases are liberated from the lining of the interrupter chamber of the fuse. The gases are produced by the arc heat when the fusible element melts.

Expulsion-type fuses have several benefits.

1. They can be sized to provide overload protection and accommodate expected load levels.

2. They can withstand the transformer current inrush due to magnetizing and load current even when fuse is sized close to the transformer full load rating.

3. They are sensitive to both primary-side and secondary-side phase faults

4. They can coordinate with the transformer through-fault capability curve, thus providing protection against damaging overcurrents.

A current-limiting fuse is a fuse, that when melted by a current within its specified current limiting range, abruptly introduces a high arc voltage impedance to reduce the current magnitude and duration. The current-limiting fuse melts in less than one-half of a cycle and therefore can interrupt the current before it reaches its maximum value.

The benefits of a current-limiting fuse are that it limits the available fault current in its current limiting range and therefore reduces thermal and magnetic stresses on system components; and it can achieve very high interrupting ratings. The major disadvantages are: 1) it generates transient overvoltages when it functions; and a fuse with ampere ratings higher than transformer full load ratings is required since the fusible element may break due to thermal fatigue from inrush currents and loading.

3.1.2.3.3 Overcurrent Relay Protection

Overcurrent protection is used to prevent damage to transformers from overloads and from through-faults. Overcurrent relays are also normally used for protection of transformers rated below 5 MVA for internal faults and as backup protection to differential relays for larger transformers.

3.1.2.3.3.1 Time phase overcurrent relays, Device 51

Time phase overcurrent relays must be set so that they do not falsely operate on normal overload and transformer inrush current, but do protect the transformer for external faults. One way of meeting all these constraints would be to use both primary and secondary-side overcurrent relays. Through-fault and backup protection would be provided by the transformer primary-side overcurrent relay, device 51TF. The relay must be set to coordinate with both upstream and downstream protective devices, the transformer inrush characteristic and the through-fault capability curves. Inrush current is typically 8 to 12 times rated current for 0.1 seconds. Refer to Section 3.1.2.3.1, Coordination of Protective Devices, for a discussion on transformer through-fault withstand capability and per unit fault magnitudes for various transformer winding connections. Since relays normally trip all three phases of circuit breakers, single phasing will not occur, as it can with fuse protection.

Overload protection would be provided by the secondary-side overcurrent relay, device 51TL. The relay should be coordinated with both the transformer short-time overload capability and the transformer through-fault capability curves. Overload protection is typically set at 115% of the maximum acceptable overload.

3.1.2.3.3.2 Instantaneous Phase Overcurrent Relays, Device 50TF

Instantaneous phase overcurrent relays, device 50TF, provide fast tripping for severe transformer internal faults. Extensive damage to the transformer could result if only time phase overcurrent relays are used for internal fault protection. The instantaneous relay is placed on the transformer primary side and set so that it will not respond to the maximum asymmetrical through-fault on the secondary side. The setting must be above the transformer inrush current to prevent nuisance tripping.

3.1.2.3.4 Differential Protection, Device 87T

Differential protection, device 87T, is typically used on transformers 10 MVA and above. The current actuating the differential relay is the net difference between input and output currents of the transformer properly transformed to the relay via current transformers. The current transformers may be located on the transformers’ primary and secondary bushings (e.g., bushing CTs) or they may be located remotely on circuit breakers to give a larger ‘‘zone of protection’’. The most common type of differential relay is the percentage differential relay with harmonic restraint. This relay incorporates both percentage differential restraint and harmonic restraint.

The percentage differential restraint ensures accurate discrimination between internal and external faults at high fault currents. This prevents undesired tripping of the relay due to mismatch of relay currents, and/or relay taps for transformer through-faults. Relay currents may be mismatched due to CT ratio imbalances, CT saturation, CT wire length and transformer turns ratio due to tap changer operation. The amount of restraint is stated as percentage of the differential or net current to the relay. The relays are usually provided with several percent slope taps (15-40%). Variable percentage slope can also be provided which provides high sensitivity at low current magnitudes with an increase in percentage ratio at higher currents.

The harmonic restraint feature enables the relay to distinguish between transformer magnetizing inrush and an internal fault by the difference in waveform. As a minimum, second harmonic currents that are always present during transformer magnetizing are used to restrain the relay during energization of the transformer.

The CTs used for differential protection of wye-delta transformers must be connected in delta on the transformer wye winding, and wye on the delta winding. This is done to compensate for the 30˚ phase angle shift introduced by the wye-delta bank, and to eliminate zero sequence currents caused by external faults on the wye side of the transformer from operating the relay.

Phase-to-ground faults on either the wye- or delta-connected windings for solidly grounded systems will cause two of the three phases of the differential relays to operate. If either side of the transformer is connected to a low resistance grounded system, then the differential relay operation will be marginal for ground faults on the low resistance side, and alternative ground fault protection should be used. If either side of the transformer is high resistance or ungrounded, then the differential relay will not operate for ground faults on that side of the transformer.

3.1.2.3.5 Ground Fault Protection

Transformer ground fault protection can be provided by either differential relays or by overcurrent relays on solidly grounded systems. Dedicated ground fault protection schemes should be provided for transformers on resistance and ungrounded systems.

The following ground fault protection schemes can be used on either solidly grounded systems or on low resistance grounded transformers. Scheme selection depends upon the required sensitivity, coordination and physical restraints.

3.1.2.3.5.1 AC Time Ground Overcurrent Relays, Devices 51N & 51NY

An AC time ground overcurrent relay functions when the ground fault current exceeds a predetermined value for a given time. The current and operating time are inversely proportional. They should be used when time coordination with other system ground fault protection is required. If time coordination is not required, then an instantaneous ground overcurrent relay can be used. Ground fault relays can be set more sensitive than phase fault relays since they do not see phase currents. The time ground overcurrent relays can be located either in the transformer neutral or residually connected in the CT secondary (CT neutral) for the phase overcurrent relays.

Device 51N is located in the transformer wye winding neutral. Device 51N can be set more sensitively than residually connected ground fault relays since they do not see load current unbalance and CT dissymmetry unbalance. This device provides ground fault protection for wye windings and ground faults occurring downstream of secondary wye windings (through faults) for the following systems:

1. Three-phase, three-wire systems with the transformer neutral grounded.

2. Three-phase, four-wire, single-point grounded systems with the ground fault relay CT located between the neutral conductor and the system ground. (**Note:** Device 51N would have to be set greater than the load current unbalance if the CTs were located between the neutral conductor and the transformer neutral.)

Device 51N may not be effective if the electrical system neutral is grounded at more than one point for the following reasons:

1. The unbalanced load current may divide between the system neutral conductor and the ground conductor, which will require device 51N to be set less sensitively.

2. Not all of the downstream ground fault current will return to the transformer neutral, which will require a more sensitive setting.

Device 51NY is residually connected in the neutral of the phase CTs on the wye winding side of the transformer. Device 51NY must be set greater than the maximum load current unbalance and CT dissymmetry unbalance. It provides ground fault protection for primary wye windings, back fed secondary wye windings and ground faults occurring downstream of secondary wye windings (through faults).

3.1.2.3.5.2 Instantaneous Ground Overcurrent Relays, Devices 50N & 50NY

An instantaneous ground overcurrent relay functions instantaneously when the ground fault current exceeds a predetermined value. If time coordination for ground faults is not required, then an instantaneous ground overcurrent relay can be used alone. If a high current pickup for severe ground faults is wanted, then an instantaneous ground overcurrent relay can be used in conjunction with AC time ground overcurrent relays (51N, 51NY). The relay is located either in the transformer neutral or residually connected in the CT secondary.

Device 50N is located in the transformer wye winding neutral. When used with device 51N, it is normally set to pick up only for severe ground faults. The pickup setting must be greater than downstream protective devices to prevent nuisance tripping. When used alone and coordination is not required, its pickup is set very sensitive. Other sensitivities and limitations for both high and low set device 50Ns are basically the same as stated for device 51N (AC time ground overcurrent relay).

Device 50NY is residually connected in the neutral of the phase CTs on the wye winding side of the transformer. When used with device 51NY it is normally set to pickup only for severe ground faults. The pickup setting must be greater than downstream protective devices to prevent nuisance tripping. When used alone and coordination is not required, its pickup is set very sensitively. Other sensitivities and limitations for both high and low set device 50NYs are basically the same as stated for device 51NY.

3.1.2.3.5.3 Zero Sequence Overcurrent Relays, Device 50G

Zero sequence instantaneous ground overcurrent relays can also be used. This method uses a toroidal or window CT. Either the transformer neutral conductor and/or the main conductors pass through the window CT. The instantaneous relay must be matched to the window CT to obtain the required sensitivity for a given application. This scheme is only applicable to low voltage and medium voltage systems where all of the conductors can be fitted through the window CT. For three-phase, four-wire systems, the three-phase conductors and the neutral conductor are passed through the window CT. Load unbalance will therefore not produce any output current in the window CT secondary, and device 50G can be made very sensitive. Other sensitivities and limitations for device 50G are basically the same as stated for the AC time ground overcurrent relays.

3.1.2.3.5.4 Dedicated Ground Fault Protection for Transformer Grounded Wye Winding, Devices 67N & 87TN

Both directional ground relays (67N) and ground differential relays (87TN) can detect ground faults in the transformer wye-connected windings. Both protection schemes can discriminate between transformer internal faults and faults external to the transformer protected zone. Both schemes will operate for an internal ground fault in the wye winding, irrespective of the wye winding adjacent breaker position. (Source must be available from delta side when wye side breaker is open.) These schemes will operate properly for internal transformer ground faults when an external zero sequence current source exists (external system ground) but will not operate for external ground faults.

3.1.2.3.5.5 Dedicated Ground Fault Protection for Transformer Delta Winding, Devices 50GD & 51ND

The transformer delta winding and the phase conductors between the CTs and the delta winding can be protected by a time ground overcurrent relay, Device 51ND, when the system is either solidly or low resistance grounded (an external source of zero sequence current is available). The relay is residually connected in the CT secondary. If the CTs are located on adjacent breakers, then the transformer delta winding, cable, bus and associated bushings are all provided with sensitive ground fault protection.

Zero sequence instantaneous ground overcurrent relays, Device 50GD, can also be used in similar applications. All three of the transformer phase conductors are passed through the window CT. This scheme is basically the same as described for protection on the transformer wye winding and has the same physical limitations.

3.1.2.3.5.6 Transformer Ground Fault Protection for High Resistance Grounded System, Device 59N

Time overvoltage relays, Device 59N, connected across the neutral resistance either directly or on the secondary of a neutral voltage transformer should be used.

3.1.2.3.5.7 Fire Detection Systems for Ground Faults in Network Vaults

The heat and smoke generated by an arcing ground fault can be sensed by a fire detection system. This is an acceptable alternative to secondary-side electrical protection. A heat detector should be located within the network protector for each transformer, and a smoke or heat detection system should be located in the transformer room in accordance with the recommendations contained in 5-48, *Automatic Fire Detection*. Actuation of one heat detector or two smoke detectors should be arranged to trip the appropriate primary and secondary breakers.

3.1.2.3.6 Network Protectors

The network protector is normally flange mounted directly on the network transformer low voltage terminals. The network protector contains the following components: low voltage air circuit breaker (ACB), controls for the ACB, and network relays. Network protectors trip for faults occurring on the primary side of the network transformer and/or when a power reversal occurs with power flowing from the secondary side of the network transformer to the primary side.

The watt-var network master relay has superior operating characteristics over the standard watt network master relay. If a primary-side line-to-ground fault occurs and a single primary fuse operates without tripping the feeder breaker, the unfaulted phases may still supply power to the network. Under these conditions the net three-phase power flow in the network protector is not in the reverse direction and the standard watt master relay will not operate. The reactive flow (vars) in the network protector will be in the reverse direction. The watt-var master relay properly connected to see this reverse reactive flow will operate for this condition.

3.2 Barriers

Concrete masonry block or reinforced concrete walls are preferred separation for transformers.

Other construction may be considered acceptable provided an exposure fire equivalent to an ASTM E-119 test has been conducted with no flame penetration to the unexposed side of the barrier. Barriers should be capable of withstanding 25% of full design wind loads at maximum fire-exposed material temperatures. Exposed steel must be protected by two-hour fire rated material. Surface temperatures higher than allowed by the ASTM E-119 test, on the unexposed side, are not expected to result in significant damage to the exposed transformer.

3.3 Loss History

Nearly 50% of the dollar loss for transformers reported to FM Global occurs in the utility industry. Another 10% occurs for transformers in the chemical industry, 7% in pulp and paper and 6% at commercial locations.

A study of modern transformer breakdown records shows that between 40% and 60% of the transformer failures are traced to windings. Statistics of FM Global Loss and Operational Analysis Department statistics show that 60% of transformer failures involve the windings. IEEE statistics from IEEE Std. 493-1990, *Design of Reliable Industrial and Commercial Power Systems,* report that 53% of the failures involve windings. Doble Engineering surveys reports that for the last five years, 44% of the failures involve windings (Table 4).

According to the Doble Engineering's transformer winding location failure analysis survey, 36% of the failures occur in the high voltage winding and 41% occur in the low voltage winding (Table 5). Turn-to-turn faults represent 30% of the winding failures, phase-to-ground is 16%, and phase winding-to-winding is 14% (Table 6). The cause of the failures is not always clearly identified because all evidence is often eliminated by the very nature of the breakdown.

Table 4. Transformer Failure Analysis 1989–1993[1]

Components	*Total No.*	*Total %*
Bushings	84	6
Coil Blocking	102	7
Core & Clamping Assembly	84	6
De-Energized Tap Changer Assembly	43	3
Insulating Liquid	82	6
Lead & Lead Support Structure	70	5
Load Tap Changer Assembly	237	17
Tank, Gasket, Cooling Equip. & Access.	55	4
Winding	658	47
Not Identified	87	6
Total	1389	

[1]Transformer Failure Analysis statistics from Doble Engineering Company, Watertown, MA

Table 5. Transformer Winding Location Failure Analysis 1989–1993[1]

Location of Winding Failure	*Total No.*	*Total %*
Common (LV on Autotransformer)	20	3
Series (HV on Autotransformer)	20	3
High Voltage	273	36
Low Voltage	314	41
Regulating or Tap	56	7
Tertiary	39	5
Not Indicated	47	6

[1]Transformer Failure Analysis statistics from Doble Engineering Company, Watertown, MA

Table 6. Transformer Winding Insulation Failure Analysis 1989–1993[1]

Winding Insulation	*Total No.*	*Total %*
Winding to Ground	189	16
Winding to Winding	129	14
Phase to Phase	42	5
Turn-to-Turn	263	29
Winding Distortion or Movement	103	11
Not Identified	189	16

[1]Transformer Failure Analysis statistics from Doble Engineering Company, Watertown, MA

4.0 REFERENCES

4.1 FM Global

Data Sheet 4-1N, *Fixed Water Spray Systems for Fire Protection.*
Data Sheet 5-10, *Protective Grounding for Electric Power Systems and Equipment.*
Data Sheet 5-11, *Lightning and Surge Protection for Electrical Systems.*
Data Sheet 5-19, *Switchgear and Circuit Breakers*.
Data Sheet 5-20, *Electrical Testing.*
Data Sheet 5-48, *Automatic Fire Detection*.

4.2 Other

NFPA 70, *National Electric Code (NEC),* 1996

NFPA 850, *Electric Generating Plants,* 1996

ANSI/IEEE Std 979-1984

Code of Federal Regulations: Part 761-Polychlorinated Biphenlys (PCBs)

ANSI/IEEE C37.100-1981

ANSI/IEEE C57.109-1985

ANSI/IEEE Std.493-1990, *Design of Reliable Industrial and Commercial Power Systems*.

ANSI/IEEE Std. C57.91

ANSI/IEEE Std. C57.92

ASTM D448, *Standard Classification for Sizes of Aggregate for Road and Bridge Construction*.

European Standard EN 50195, *Code of Practice for the Safe Use of Fully Enclosed Askarel-Filled Electrical Equipment*.

APPENDIX A GLOSSARY OF TERMS

Equivalent transformer: A transformer equivalent to an FM Approved transformer. An example is a UL transformer listed per Section 450-23 and provided with electrical protection to clear a sustained low-current fault.

FM Approved: references to "FM Approved" in this data sheet means the product or service has satisfied the criteria for Approval by FM Approvals. Refer to the *Approval Guide* for a complete listing of products and services that are FM FM Approved.

FM Approved transformer: A less flammable liquid filled transformer rated at 5 to 10,000 kVA. The transformer includes electrical protection to clear high current as well as sustained low current faults. A pressure relief device and tank discharge strength prevent tank rupture under a low-level electrical fault.

Higher secondary voltages: secondary voltages equal to or greater than 480 volts, including 480/277 volt systems.

Less Flammable Liquid Insulated transformer: A transformer insulated with an FM Approved less flammable liquid with a fire point of not less than 572°F (300°C). The transformer is not FM Approved.

Lower secondary voltage: transformers with secondary voltages below 480 volts.

Navigable waterway: Navigable waterway is defined by 40 CFR Part 112 as:

a) All waters that are currently used, were used in the past, or may be susceptible to use in interstate or foreign commerce, including all waters subject to the ebb and flow of the tide.

b) All interstate waters, including interstate wetlands, mudflats, and sandflats.

c) All other waters such as intrastate lakes, rivers, streams (including intermittent streams), wetlands, mudflats, sandflats, sloughs, prairie potholes, wet meadows, playa lakes, or natural ponds, the use, degradation, or destruction of which could affect interstate or foreign commerce including any waters that could be used for recreational purposes, or from which fish or shellfish could be taken and sold in interstate or foreign commerce; or that are used or could be used for industrial purposes by industries in interstate commerce.

Network transformer: these transformers are located in vaults in buildings or adjacent to buildings. The vaults contain two or more power transformers. These transformers are supplied from different transmission 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 used in 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, called a low-voltage network grid.

Primary winding: the winding into which energy normally flows. The primary winding can be energized from the secondary winding under abnormal conditions.

Radial transformer: a transformer that can only be energized from the primary winding.

Secondary winding: the winding from which energy flows during normal operation.

In or near commercial buildings: within the interior of, on the roof of, attached to the exterior wall of, in the parking area serving, or within 30 meters of a non-industrial non-substation building. Commercial buildings are typically accessible to both members of the general public and employees, and include: 1) Public assembly properties, 2) educational properties, 3) institutional properties, 4) residential properties, 5) stores, 6) office buildings, and 7) transportation centers (e.g., airport terminal buildings, subway stations, bus stations, or train stations).

APPENDIX B DOCUMENT REVISION HISTORY

January 2007. The reference goal of the recommendation 2.3.1.1.2.2.2 was classified.

May 2006. New definitions were added to Appendix A, Glossary of Terms.

May 2005. Editorial changes were done to the recommendation 2.3.1.2.1.1.

January 2005. The following changes were done for this revision:

1. Section 2.2 Indoor Transformers, recommendations 2.2.1.2.2 & 2.2.1.3.2.2. A protection alternate to CO-2 of an FM Approved gaseous agent protection system or a water mist system FM Approved for machinery spaces is recommended. Also, where automatic sprinkler protection is used, the density has been increased to 0.3 gpm/ft^2 (15 mm/min) from 0.2 gpm/ft^2 (10 mm/min).

2. Section 2.3 Outdoor Transformer, recommendation 2.3.1.2.3 for open pit containment system. Where automatic sprinkler protection is used, the sprinkler density has been increased to 0.3 gpm/ft^2 (15 mm/min) from 0.15 gpm/ft^2 (6 mm/min). Where a flame arrestor is used to increase the amount of time before burning oil enters the pit Size No 5 rather than Size No 2 ASTM D448 Standard Classification for Sizes of Aggregate for Road and Bridge Construction should be used. Size No 5 is closer to the 1.5 in (3.8 cm) washed and uniformly sized rock tested at the FM Global Research Campus.

3. Section 3.1.1, Approved and Equivalent Transformer. A transformer equivalent to an FM Approved transformer is defined as a transformer with a UL listing per NEC Section 450-23 with electrical protection to clear sustained low current faults. The reference to NEC 450-23 was left out of the previous edition. Transformers complying with NEC 450-23 include four of the five safeguards requested for an FM Approved transformer. Low current fault protection is the remaining safeguard.

May 2003. The following changes were done for this revision:

1. Tables 2a and 2b Separation Distances. The change allows medium sized transformers containing FM Approved less flammable fluids to be located as close to buildings and to other transformers as small transformers were in the previous standard. This provided there is adequate space for inspection and maintenance. Medium sized transformers may contain up to 10,000 gal (37.9 m^3) of fluid.

2. Section 2.3.1.2 Containment. The change increases the quantity of FM Approved less flammable fluid in a transformer before a containment system is recommended. It increases the size of the transformer to 1320 gal (5 m^3) for transformers containing all FM Approved less flammable fluids. It further increases the size to 2640 gal (10 m^3) if the fluid is certified as biodegradable and if a release does not expose navigable waterways. A definition is included for navigable waterways. The fluid would have to be certified as biodegradable by the responsible governmental authority.

In the United States, there are two certified fluids: Envirotemp FR3 made by Cooper Power Systems and BIOTEMP made by ABB. The existing standard did not differentiate between containment needed for mineral oil and that needed for various types of FM Approved less flammable fluids.

3. Minor editorial changes were made to Section 2.3.1.2.1.4.

January 2001. The recommendation for the smoke detection for electrical rooms was revised to provide consistency within 5-series data sheets.

September 2000. This revision of the document was reorganized to provide a consistent format.

The following major changes have been made:

a) Addition of emergency power supply recommendation for mechanical ventilation (Section 2.2.1.1.3).

b) Change requirement for smoke detection to fire detection (Section 2.2.1.1.4).

c) Add recommendation for location of rooms containing network transformers to outside wall where possible (Section 2.2.1.2).

d) Addition of fire protection recommendations for multiple indoor oil insulated transformers (Section 2.2.1.3.2).

e) Open pits without protection acceptable containment for FM Approved less flammable fluid insulated transformer (Section 2.3.1.2.1.2 and 2.3.1.3.1).

December 1998. Editorial changes were made.

APPENDIX C SUPPLEMENTARY INFORMATION

C.1 Other Standards

There are three standards that cover transformers as follows:

C.1.1 NFPA 70, National Electric Code

Fire protection for transformers is covered under Article 450 of the *National Electric Code (NEC)*. This includes dry-type, less-flammable liquid-insulated, and oil-insulated transformers installed both indoors and outdoors.

The major difference between this data sheet and the NEC is the treatment of PCB-filled or PCB-contaminated transformers. This data sheet recommends that these transformers be replaced if the loss exposure warrants. NEC and OSHA regulations allow the use of existing PCB-filled or PCB-contaminated transformers provided they have been equipped with enhanced electrical protection.

C.1.1.1 Indoor Transformers

Dry-Type transformers

(450-21b) Over 112.5 kVA. Install in room of fire resistive construction.

Exception 1. Transformers with 175°F (80°C) rise and higher separated from combustible material by a fire resistant heat-insulating barrier or by a minimum distance of 6 ft (1.8 m) horizontally and 12 ft (3 m) vertically.

Exception 2. Transformers with a 175°F (80°C) rise or higher rating and completely enclosed except for ventilation openings.

Over 35,000 volts. Install in vault (3 hour fire resistance rating for walls and roof).

(450-23) Less Flammable Liquid Insulated Transformers

Up to 35,000 volts. Can install in Type I and II buildings provided: a) no combustible storage; b) a liquid containment area is provided; and c) fire point of the liquid exceeds 570°F (300°C).

Over 35,000 volts. Install within a vault.

Use of these transformers is allowed when they are attached to, adjacent to, or on the roof of Type I or II buildings. They may be used in other types of buildings provided fire barriers, space separation and requirements for the listing of the liquid are followed.

Type I building structural components are noncombustible or limited combustible and, except for exterior nonload bearing walls, they have a fire resistance rating. Type II building structural components are noncombustible or of limited combustible construction and may not have a fire resistance rating.

(450-24) Nonflammable Liquid Insulated Transformers

Up to 35,000 volts. Shall be provided with a liquid confinement area and a pressure relief vent.

Over 35,000 volts. Shall be installed in a vault.

(450-25) Askarel Insulated Transformers

Over 35,000 volts. Shall be installed in a vault. Also see OSHA regulations.

Oil Insulated Transformers

(450-26) Indoors. Shall be installed in a vault. The following exceptions apply:

1. If total capacity does not exceed 112.5 kVA, the vault can be constructed of 4-in. (102 mm) thick reinforced concrete.

2. If voltage does not exceed 600 and total transformer capacity does not exceed 10 kVA, the transformer may be installed in a combustible building; or if transformer capacity does exceed 75 kVA, the transformer may be installed in a building of fire resistant construction.

3. Oil-insulated transformers can be used in a detached building if the building does not present a fire exposure to other buildings or property and if it is used only for electric service and is accessible only to qualified persons.

C.1.1.2 Outdoor Transformers

Combustible material, combustible buildings, door and window openings shall be safeguarded from fires in oil-insulated transformers. Methods of achieving this are space separation, fire resistant barriers, automatic water spray and enclosures to confine oil from a ruptured transformer.

C.1.2 NFPA 850

NFPA 850, *Fire Protection for Fossil Fueled Steam Electric Generating Plants,* contains recommended practices for both indoor and outdoor transformers.

There is no conflict with NFPA 850.

This data sheet gives separate distances between transformer and buildings based on the quantity of fluid in the transformer and the type of construction of the building. NFPA 850 assumes that the building construction will be noncombustible (typically insulated metal on steel frame) and gives spacing based on the volume of fluid in the transformer. The separation distances given in this data sheet are the same as those given in NFPA 850 for this type of construction.

This data sheet allows separation, barriers or water spray protection to be used to protect transformers. NFPA 850 recommends that oil-filled main, station service and startup transformers be protected by water spray or foam water systems.

C.1.2.1 Indoor Transformers

Where oil-filled transformers of greater than 100 gal (380 dm^3) oil capacity are installed, they should be separated from adjacent areas by fire barriers of 3 hr fire resistance rating. Where an automatic fire suppression system is provided, the fire barrier rating may be reduced to one hour.

C.1.2.2 Outdoor Transformers

Where transformers are in excess of 500 gal (1.9 m^3) oil capacity, a 2-hr-rated fire barrier or space separation is needed to protect adjacent structures including other transformers. The space separation is dependent on the quantity of oil in the transformer. Twenty-five feet (7.6 m) is needed for 500 to 5,000 gal (1.9 to 19 m^3); 50 ft (15.2 m) is needed where quantities are in excess of 5,000 gal (19 m^3). Where a fire wall is not provided, the edge of the oil spill (dike) must be a minimum of 5 ft (1.5 m) from the exposed structure.

In addition, oil-filled main, station service, and startup transformers should be protected by water spray or foam-water systems.

C.1.3 IEEE Std 979-1984

Fire protection guidance for indoor and outdoor substations is covered in the ANSI/IEEE Std 979-1984.

There is a difference with regard to separation distances. This data sheet recommends a 25 ft (7.6 m) separation between mineral oil insulated transformers containing from 500 to 5,000 gal (1.9 to 19 m^3) and 50 ft (15.2 m) separation between transformers continuing in excess of 5,000 gal (19 m^3) of mineral oil. Water spray or a 2-hour rated fire barrier are given as alternatives.

IEEE 979 recommends 30-ft separation between transformers with more than a 333-kVA rating (approximately 100-150 gal [0.38-0.57 m^3]). An automatic extinguishing system or a 1-hour fire barrier are given as alternatives.

C.1.3.1 Indoor Transformers

The use of oil-filled equipment inside a building is discouraged. If oil-filled transformers are used, a transformer room or vault with a fire rating sufficient to withstand the largest credible fire is recommended. Installation of fixed fire extinguishing systems and containment is also recommended.

C.1.3.2 Outdoor Transformers

Spacing of transformers from buildings depends on the quantity of oil contained within the transformer. Transformers containing 2000 gal (7.6 m^3) or more of oil should be a minimum of 20 ft (6.1 m) from an exposed building regardless of protection provided. It is recommended that a minimum separation distance of 50 ft (15.2 m) from buildings be used unless the building has walls equivalent to or are protected by a 2-hour fire barrier. The separation distance for transformers containing smaller amounts of oil ranges from 10 ft (3 m) for 75 kVA or less, to 20 ft (6.1 m) for transformers from 76 to 333 kVA, and 30 ft (9.1 m) for more than 333 kVA. Oil containment systems are also recommended in the form of yardstone, diked areas and pits.

A separation distance between large transformers of 30 ft (9.1 m) of clear space or a one hour fire barrier is recommended.

Also automatic extinguishing systems should be considered for all liquid-cooled transformers except those that are adequately separated or that contain less than 500 gal (1.9 m^3) of combustible transformer liquid.

C.1.4 Code of Federal Regulations: Part 761—Polychlorinated Biphenyls (PCBs)

The following regulations and list of definitions are excerpts from the *Code of Federal Regulations:* Part 761—*Polychlorinated Biphenyls (PCBs) Manufacturing, Processing, Distribution in Commerce, and Use Prohibition.* Subpart B—*Manufacturing, Processing, Distribution In Commerce, and Use of PCBs and PCB Items.* § 761.30 *Authorizations*.

‘‘Use in and servicing of transformers (other than railroad transformers). PCBs at any concentration may be used in transformers and may be used for purposes of servicing including rebuilding these transformers for the remainder of their useful lives, subject to the following conditions:

1. Use conditions.

a) The use and storage for re-use of PCB transformers that pose an exposure risk to food or feed is prohibited.

b) The use of network PCB transformers in or near commercial buildings is prohibited except for:

i) All network PCB transformers with secondary voltages below 480 volts in or near commercial buildings not located in sidewalk vaults that have not been removed from service must be equipped with electrical protection to avoid transformer ruptures caused by high current faults, or must be removed from service.

ii) Current-limiting fuses or other equivalent technology must be used to detect sustained high current faults and provide for the complete de-energization of the transformer within tenths of a second before transformer rupture occurs. The installation, setting, and maintenance of current-limiting fuses or other equivalent technology to avoid PCB transformer ruptures from sustained high current faults must be completed in accordance with good engineering practices.

c) The installation of PCB transformers, which have been placed into storage for re-use or which have been removed from another location, in or near commercial buildings is prohibited.

d) All radial PCB transformers with secondary voltages below 480 volts in use in or near commercial buildings must be equipped with electrical protection to avoid transformer ruptures caused by high current faults.

i) Current-limiting fuses or other equivalent technology must be used to detect sustained high current faults and provide for the complete de-energization of the transformer or complete de-energization of the faulted phase of the transformer within several hundredths of a second. The installation, setting, and maintenance of current-limiting fuses or other equivalent technology to avoid PCB transformer ruptures from sustained high current faults must be completed in accordance with good engineering practices.

e) All radial PCB transformers with secondary voltages equal to or greater than 480 volts, including 480/277 volt systems in use in or near commercial buildings that have not been removed from service must be equipped with electrical protection to avoid transformer ruptures caused by:

i) High current faults.

Current-limiting fuses or other equivalent technology must be used to detect sustained high current faults and provide for the complete de-enerigzation of the transformer within several hundredths of a second before tank rupture occurs. The installation, setting, and maintenance of current-limiting fuses or other equivalent technology to avoid PCB transformer ruptures from sustained high current faults must be completed in accordance with good engineering practices.

ii) Sustained low current faults. Be equipped with protection to avoid transformer ruptures caused by sustained low current faults.

iii) Pressure and temperature sensors (or other equivalent technology which has been demonstrated to be effective in early detection of sustained low current faults) must be used.

iv) Disconnect equipment must be provided to insure complete de-energization of the transformer in the event of a sensed abnormal condition caused by a sustained low current fault. The disconnect equipment must be configured to operate automatically within 30 seconds to one minute of the receipt of a signal indicating an abnormal condition. The disconnect equipment can also be configured to allow for manual de-energization from a manned on-site control center within one minute of the receipt of a signal indicating an abnormal condition. If automatic operation is selected and a circuit breaker is utilized for disconnection, it must also have the capability to be manually opened if necessary.

v) The enhanced electrical protective system required for the detection of sustained low current faults and the de-energization of transformers must be properly installed, maintained, and set sensitive enough to detect sustained low current faults and allow for rapid de-energization prior to PCB transformer rupture (either violent or non-violent rupture) and release of PCBs.''

C.2 Trade Names for Askarels

Trade Names for Insulating Liquids having PCBs as a major constituent.

The following is a list of some typical trade names for insulating liquids having PCBs as a major constituent.

This list is included in the Annex A of the European Standard EN 50195 ''Code of practice for the safe use of fully enclosed askarel-filled electrical equipment''. This European Standard was prepared by the Technical Committee CENELEC TC 14, Power transformers, and was approved by CENELEC as EN 50195 on 1996-07-02.

The generic term ''askarels'' is used in this Standard for transformers and capacitors insulating/cooling liquids having PCBs as a major constituent.

CENELEC is the European Committee for electrotechnical Standardization. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving the European Standards the status of a national standard without any alteration. National and Local Authority (if any) take priority.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Denmark, Finland, France, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

Table 7. Some Typical Trade Names for Askarels

Trade Name	*Manufacturer*	*Country of Origin*
Asbestol	American Corporation	USA
Aceclor	ACEC	Belgium
Apirolio	Caffaro	Italy
Aroclor	Monsanto	USA
Bakola 131	Monsanto	USA
Clorinol	Sprague Electric	USA
Clophen	Bayer	Germany
Diaclor	Sangamo Electric	USA
Dycanol	Cornell Dubille	USA
Elemex	McGraw Edison	USA
Eucarel	Electrical Utilities	USA
Hyvol	Aerovox	USA
Inerteen	Westinghouse	USA
Kanechlor	Kanegafuchi	Japan
No-flamol	Wagner Electric	USA
Pyralene	Prodelec	France
Pyranol	General Electric	USA
Pyroclor	Monsanto	Great Britain
Saf-T-Kuhl	Kuhlmann Electric	USA
Soviol/Sovol/Solvol	Soviol/Sovol	Soviet Union
Ugilect		

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