Working to Perfect the Flow of Energy

PJM Manual XX:

PJM Protection Standards

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Prepared by
System Planning Division
Transmission Planning Department

PJM Manual XX:

PJM Protection Standards

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Approval

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Current Revision

Revision 00 ():

This is a new manual. This manual establishes the minimum design standards and requirements for the protection systems associated with the bulk power facilities within PJM.

Introduction

Welcome to the PJM Manual for Protection Standards of PJM. In this Introduction, you will find the following information:

- What you can expect from the PJM Manuals in general (see "About PJM Manuals").
- What you can expect from this PJM Manual (see "About This Manual").
- How to use this manual (see "Using This Manual").

About PJM Manuals

The PJM Manuals are the instructions, rules, procedures, and guidelines established by PJM for the operation, planning, and accounting requirements of PJM and the PJM Energy Market. The manuals are grouped under the following categories:

- Transmission
- PJM Energy Market
- Generation and Transmission interconnection
- Reserve
- Accounting and Billing
- PJM administrative services

For a complete list of all PJM Manuals, go to www.pjm.com and select "Documents," then select "Manuals" on the left hand side.

About This Manual

The PJM Manual for Protection Standards is the first PJM manual to deal with Protection Systems. This Manual is intended to provide design specification for new protection system installations. This manual can be used as evidence for compliance with NERC Standards:

- PRC-001 - System Protection Coordination
- FAC-001 - Facility Connection Requirements

Intended Audience

The intended audiences for the PJM Manual XX: PJM Protection Standards are:

- PJM Transmission Owners
- PJM Generator Owners
- PJM Interconnection Customers
- PJM Staff

References

The references to other PJM documents that provide background or additional detail directly related to the PJM Manual for PJM Protection Standards are the following:

- PJM Relay Subcommittee Protective Relaying Philosophy and Design Standards (http://www.pjm.com/committees-and-groups/subcommittees/~/media/committees-groups/subcommittees/rs/postings/RS_stnd.ashx)

This manual does not supersede the formal requirements of any of the referenced documents.

Using This Manual

Each section of this manual begins with an overview and the philosophy is reflected in the way material is organized. The following bullet points provide an orientation to the manual's structure.

What You Will Find In This Manual

- A table of contents
- An approval page that lists the required approvals and the revision history
- A section on protection philosophy
- New generator protection requirements
- New unit power, unit auxiliary and start-up station service transformer and lead protection requirements
- New line protection requirements
- New substation transformer protection requirements
- New bus protection requirements
- New capacitor and reactor protection requirements
- New breaker failure protection requirements
- New phase angle regulator protection requirements
- New transmission line reclosing requirements
- Information on design of supervision and alarming of relaying and control circuits
- New underfrequency load shedding requirements
- New special protection system requirements
- Information on the use of dual trip coils, direct transfer trip, dual pilot channels, three-terminal line applications and triggered fault current limiters

Section 1: Applicability

This document establishes the minimum design standards and requirements for the protection systems associated with the bulk power facilities within PJM. The facilities to which these design standards apply are generally comprised of the following:

- all 100 MVA and above generators connected to the BES facilities,
- all 200 kV and above transmission facilities
- all transmission facilities 100 kV to 200 kV critical to the reliability of the BES as defined by PRC-023-1 and determined by PJM System Planning
    - PJM System Planning will also investigate the criticality of equipment (generators, buses, breakers, transformers, capacitors and shunt reactors) associated with the PRC-023-1 determined lines

General principles of applicability include:

A. Compliance with NERC Transmission Planning Standards, TPL-001-1 through TPL-004-0 and the associated Table 1, as may be amended from time to time, is mandatory.

B. Where a protection system does not presently meet the requirements of NERC Transmission Planning Standards, TPL-001-1 through TPL-004-0 and the associated Table 1, action shall be taken by the facility owner to bring the protection system(s) into compliance.

C. Adherence to applicable NERC and Regional reliability standards is mandatory; however, the PJM requirements set forth in this document are in some cases more restrictive than the applicable NERC or Regional reliability standards.

A protection system is defined as those components used collectively to detect defective power system elements or conditions of an abnormal or dangerous nature, to initiate the appropriate control circuit action, and to isolate the appropriate system components. All new protection systems designed after the adoption date of this document shall conform to these design standards. It is recognized that some facilities existing prior to the adoption of these requirements do not conform. It is the responsibility of the facility owners to consider retrofitting those facilities to bring them into compliance as changes or modifications are made to those facilities.

Section 2: Protection Philosophy

For the background and basis of the philosophy behind the requirements set forth in this document, please refer to the PJM Relay Subcommittee Protective Relaying Philosophy and Design Standards, Revision 03, effective Date: June 1, 2003. [http://www.pjm.com/committees-and-groups/subcommittees/~/media/committees-groups/subcommittees/rs/postings/RS_stnd.ashx]

Section 3: Generator Protection

This section outlines the requirements for interconnecting unit-connected[1] generators as defined in this manual Section 1 - Applicability. In addition, the requirements specified in this section are applicable to generators interconnecting to utility transmission systems within PJM with output ratings greater than or equal to 100 MVA.

It is emphasized that the requirements specified in this section must not be construed as an all-inclusive list of requirements for the protection of the generator owner's apparatus.

The following standards and publications were used as a reference for developing the requirements specified in this section.

- ANSI/IEEE C37.101 Guide for Generator Ground Protection
- ANSI/IEEE C37.102 Guide for AC Generator Protection
- ANSI/IEEE C37.106 Guide for Abnormal Frequency Protection for Generating Plants

3.1 Generator Stator Fault Protection

The following sections outline the requirements for phase and ground fault protection for the generator stator winding. As outlined in the requirements listed below, phase and ground protection for 100% of the stator winding is required.

3.1.1 Phase Fault Protection

Two independent current differential schemes are required for phase fault protection. The schemes must each employ individual current sources and independently protected DC control circuits. The backup scheme may, for example, consist of an overall generator and unit transformer differential. Both schemes must function to issue a simultaneous trip of the generator breaker(s), excitation system, and turbine valves.

3.1.2 Ground Fault Protection

Two independent schemes are required for ground fault protection with independent current or voltage sources and independently protected DC control circuits. At least one of the schemes is required to be designed to provide protection for 100% of the stator winding. The relays must be properly coordinated with other protective devices and the generator voltage transformer fuses. Both schemes must function to issue a simultaneous trip of the generator breaker(s), excitation system, and turbine valves.

Units with output ratings under 500 MVA are exempt from the redundancy requirement. Generators grounded through an impedance which is low enough to allow for detection of all ground faults by the differential relays do not require dedicated ground fault protection.

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[1] Unit with a dedicated generator step-up transformer ("GSU"). Cross-compound units are considered unit-connected.

3.2 Generator Rotor Field Protection

Field ground fault protection must be provided to detect ground faults in the generator field winding. Upon detection of a ground fault, tripping of the generator is acceptable, but not required. At a minimum, the protection scheme must initiate an alarm and upon activation of the alarm, the generator should be shut down as quickly as possible.

3.3 Generator Abnormal Operating Conditions

The requirements specified in this section are to provide protection for the generator and interconnected transmission system for abnormal operating (non-fault) conditions that the generator may be exposed to. The reader is referred to the documents cited in the beginning of this section for additional protection schemes that they may choose to include in the generator protection scheme design.

3.3.1 Loss of Excitation (Field)

Independent primary and backup relay schemes are required to detect loss of excitation (or severely reduced excitation) conditions. The schemes must employ independent current and voltage sources and independently protected DC control circuits and must function to trip the generator output breaker(s). The loss of excitation protection must be set to coordinate with (operate prior to encroachment upon) the generator’s steady-state stability limit (SSSL).

A simultaneous trip of the excitation system and turbine valves is recommended but, not required.

Units with output ratings under 500 MVA are exempt from the redundancy requirement for this protection scheme.

3.3.2 Unbalanced Current Protection

A negative-sequence overcurrent relay is required for protection from the effects of sustained unbalanced phase currents. An alarm shall be generated if the generator’s continuous negative-sequence current (I_2) capability is exceeded. For sustained unbalanced currents, the relay must coordinate with the I_2^2 t damage curves as normally supplied by the generator manufacturer and must trip the generator breaker(s). A simultaneous trip of the excitation system and turbine valves is recommended but not required.

3.3.3 Loss of Synchronism

Detailed stability studies are required to be performed by PJM to determine if an out-of-step protection scheme is required for the generator installation. If the results of the study indicate that the apparent impedance locus during an unstable swing is expected to pass through the generator step-up transformer (GSU) or generator impedance, an out-of-step protection scheme is required. This scheme must function to trip the generator breaker(s) within the first slip cycle. A simultaneous trip of the excitation system and turbine valves is recommended but not required.

3.3.4 Overexcitation

Two independent protection schemes are required for protection against the effects of sustained overexcitation. Both schemes shall respond to generator terminal volts/Hz and must be in service whenever field is applied. The schemes must employ independent voltage sources and independently protected DC control circuits. Relays either with inverse-time characteristics or with stepped-time characteristics configured to simulate an inverse-time characteristic are required. An alarm shall be generated if the generator continuous volts/Hz rating is exceeded. For sustained overexcitation the relays must coordinate with volts/Hz damage curves as normally supplied by the generator manufacturer and must trip the generator breaker(s) and the excitation. A simultaneous trip of the turbine valves is recommended but not required.

Note: it is typical to protect both the generator and the GSU with the same volts/Hz protection schemes. In this case, the protection must coordinate with the volts/Hz damage curves for the more restrictive of the two.

Units with output ratings under 500 MVA are exempt from the redundancy requirement for this protection scheme.

3.3.5 Reverse Power (Anti-Motoring)

Anti-motoring protection which initiates an alarm followed by a simultaneous trip of the generator breaker(s), excitation system, and turbine valves is required.

Standard industry practice is to use the reverse power relay as the means for opening the generator breaker(s) following a routine manual or automatic trip of the turbine valves. Typical steam turbine anti-motoring protection consists of a reverse power relay set with a short time delay and supervised by closed turbine valve contacts to initiate a trip. Due to inherent reliability problems with valve position switches, this scheme must be backed up by a reverse power relay (may be the same relay) acting independently of the turbine valve position switches to initiate a trip. The latter scheme must incorporate a time delay as needed to provide security against tripping during transient power swings.

3.3.6 Abnormal Frequencies

Abnormal frequency protection (where applied) must be set to allow generators to remain in operation in accordance with PJM and Regional generator off-frequency operation requirements.

3.3.7 Generator Breaker Failure Protection

Breaker failure protection shall be provided for all relay-initiated generator trips with the exception of anti-motoring. It should be noted that some generator abnormalities that require the generator to be tripped will not result in an overcurrent condition and therefore may not operate current-actuated fault detectors incorporated in the breaker failure scheme. In these cases the current actuated fault detectors must be supplemented with breaker auxiliary switches using “OR” logic.

3.3.8 Excitation System Tripping

Redundant methods for removal of field current (where available) shall be utilized for all protective relay trips. Available methods include the tripping of two field breakers (i.e., main field breaker and the exciter field breaker) or the tripping of a single field breaker with simultaneous activation of the static de-excitation circuit.

Units with output ratings under 500 MVA are exempt from the redundancy requirement.

3.3.9 Generator Open Breaker Flashover Protection

Open breaker flashover protection is required for all gas and/or air circuit breakers used for generator synchronizing.

3.3.10 Protection During Start-up or Shut-down

The generator must be adequately protected if field is applied at less than rated speed during generator start-up or shut-down.

3.3.11 Inadvertent Energization Protection

Protection schemes designed specifically to detect the inadvertent energization of a generator while on turning gear is required for all generator installations. This scheme must function to trip the generator breaker(s).

3.3.12 Synchronizing Equipment

A synchronism checking relay is required to supervise all manual and automatic synchronizing of the generator. If the generator is required for system restoration, the synchronism checking scheme shall be designed to permit a close of the generator breaker into a de-energized grid.

3.3.13 Generator Lead Protection

The generator leads, which consist of the phase conductors from the generator terminals to the unit power transformer and the unit auxiliary transformer, shall be protected by a primary current differential relay scheme. A redundant current differential relay scheme is required if either (1) the generator leads are not installed in bus duct segregated by phase or (2) the generator is not grounded through a high impedance to limit ground faults to levels undetectable by current differential relays. Where redundant schemes are required, independent current sources and independently protected DC control circuits are required. The scheme(s) must function to simultaneously trip the generator breaker(s), excitation system, and turbine valves.

Section 4: Unit Power Transformer and Lead Protection

This section outlines the requirements for the protection of unit power transformers and associated high-side leads where the transformers are (1) rated greater than or equal to 100 MVA, or (2) are connected to utility systems at transmission system voltages above 200 kV, or (3) are connected to facilities as defined in this manual Section 1 - Applicability.

The following standards and publications were used as a reference for developing the requirements specified in this section.

- ANSI/IEEE C37.91 Guide for Protective Relay Applications to Power Transformers

4.1 Transformer Fault Protection

Two independent schemes providing high-speed protection for 100% of the transformer winding are required. Acceptable combinations of protective relay schemes to satisfy this requirement are the following:

- Two independent current differential schemes.
- One current differential scheme and one sudden pressure relay scheme.

The zone of protection for one of the current differential schemes may also include other equipment such as the transformer leads, the generator, and the unit auxiliary transformer and its leads. The schemes must employ independent current sources (where applicable) and independently protected DC control circuits.

4.2 Transformer High-Side Lead Protection

The transformer high-side leads are required to be protected by two independent current differential schemes or equivalent high-speed schemes. The schemes must utilize independent current sources and independently protected DC control circuits.

4.3 Overexcitation Protection

Overexcitation protection for the unit power transformer is required. Generally, this protection is provided by the generator overexcitation protection. Refer to Section 3 for the requirements for this protection.

Section 5: Unit Auxiliary Transformer and Lead Protection

This section outlines the requirements for the protection of unit-connected auxiliary power transformers and associated high and low-side leads where the associated generating units are (1) rated greater than or equal to 100 MVA, or (2) are connected to transmission systems at transmission system voltages above 200kV, or (3) as defined in this manual Section 1 - Applicability.

The following standards and publications were used as a reference for developing the requirements specified in this section.

- ANSI/IEEE C37.91 Guide for Protective Relay Applications to Power Transformers

5.1 Transformer and Low-Side Lead Protection

Two independent protection schemes are required for protection of the transformer and low-side leads. At least one of the schemes must provide high-speed protection for the entire protection zone. Acceptable combinations of schemes for satisfying the redundancy requirement are the following:

- Two current differential schemes
- One current differential scheme and one high-side overcurrent scheme
- One current differential scheme, one sudden pressure relay scheme, and one low-side overcurrent scheme

If the transformer low-side neutral is grounded through an impedance which limits ground fault currents to levels not detectable by current differential relays, then the above must be supplemented with a neutral overcurrent scheme. Backup protection for the neutral overcurrent scheme is not required. Independent current sources and independently protected DC control circuits are required for the schemes listed above.

5.2 Transformer High-Side Lead Protection

The transformer high-side leads must be included in a current differential scheme (i.e., the unit differential scheme). A redundant current differential scheme is required if either (1) the high-side leads are not installed in bus duct segregated by phase or (2) ground faults are not limited to levels undetectable by current differential relays. Where redundant schemes are required, independent current sources and independently protected DC control circuits are required for each of the schemes.

Section 6: Start-up Station Service Transformer and Lead Protection

This section outlines the requirements for the protection of start-up station service transformers and associated high and low-side leads connected to transmission systems at system voltages above 200 kV or as defined in this manual Section 1 - Applicability.

The following standards and publications were used as a reference for developing the requirements specified in this section.

- ANSI/IEEE C37.91 Guide for Protective Relay Applications to Power Transformers

6.1 Transformer and Low-Side Lead Protection

Two independent protection schemes are required for protecting the transformer and low-side leads. At least one of the schemes must provide high-speed protection for the entire protection zone. Acceptable combinations of schemes for satisfying this redundancy requirement are the following:

- Two current differential schemes
- One current differential scheme and one high-side overcurrent scheme
- One current differential scheme, one sudden pressure relay scheme, and one low-side overcurrent scheme

If the transformer low-side neutral is grounded through an impedance which limits ground fault currents to levels not detectable by current differential relays, then the above must be supplemented with a neutral overcurrent scheme. Backup protection for the neutral overcurrent scheme is not required.

Independent current sources and independently protected DC control circuits are required for each of the schemes listed above.

6.2 Transformer High-Side Lead Protection

Two independent current differential or other high-speed relaying schemes are required to protect the transformer high-side leads. Independent current (and voltage, where applicable) sources and independently protected DC control circuits are required for each of the schemes.

Section 7: Line Protection

This section outlines the requirements for the protection of lines at system voltages above 200 kV and as defined in this manual Section 1 - Applicability.

The following standards and publications were used as a reference for developing the requirements specified in this section.

- ANSI/IEEE C37.113 Guide for Protective Relay Applications to Transmission Lines

7.1 General Requirements

Independent primary and backup protection schemes are required for all lines covered by these requirements. The schemes applied must be capable of detecting all types of faults including maximum expected arc resistance that may occur at any location on the protected line.

The primary and backup protection schemes must employ independent current and voltage sources and independently protected DC control circuits. Details on the requirements for the current and voltage sources are provided below.

7.1.1 Current Sources

Independent current transformers (CTs) are required for the primary and backup line protection schemes. For dead tank breakers, both primary and backup relays shall be connected such that breaker faults will be detected by the primary and backup relays of both protection zones adjacent to the breaker. Overlapping zones of protection are required in all cases.

7.1.2 Voltage Sources

Independent voltage sources are required for the primary and backup line protection schemes. The following design options are acceptable:

- Independent voltage transformers (VTs)
- Independent secondary windings of the same VT

7.2 Primary Protection

The primary line protection scheme must provide high-speed simultaneous tripping of all line terminals. The scheme must have sufficient speed so that it will provide the required fault clearing times for system stability as defined in the NERC Transmission Planning Standards, TPL-001 through TPL-004 and the associated Table 1. To meet the speed and coverage requirements as defined above, a high speed communication channel is required for this scheme.

7.3 Back-up Protection

The back-up line protection scheme shall be independent of the primary line protection scheme and must utilize independent current and voltage sources and independently protected DC control circuits. The following requirements apply for the back-up protection:

- Relays from the same manufacturer are acceptable for both the primary and back-up systems. The use of different models is recommended but not required.
- The back-up protection must always include a non-communications-assisted tripping scheme for phase and ground faults.
- Back-up protection must have sufficient speed to provide the clearing times necessary to maintain system stability as defined in the NERC Transmission Planning Standards, TPL-001 through TPL-004 and the associated Table 1, as may be amended from time to time.
- Non-communications-assisted Zone 1 shall be set to operate without additional time delay (other than as required to override transient overreach behavior) and to be insensitive to faults external to the protected line.
- Non-communications-assisted Zone 2 shall be set with sufficient time delay to coordinate with adjacent circuit protection including breaker failure protection. For two-terminal-line applications, sufficient sensitivity is required to provide complete line coverage of the protected line. For three-terminal-line applications, see Appendix E
- The back-up protection may require the inclusion of a communications-assisted tripping system in order to meet clearing time requirements. In such cases, the communication path must be independent of the communication path for the primary relays. Refer to Appendix C for further details on requirements for the communications channels. When redundant communications-assisted protection is required, alarms must be provided sufficient to detect a failure which disables both primary and back-up communications-assisted tripping.

7.4 Restricted Ground Fault Protection

A scheme must be provided to detect ground faults with high fault resistance. The relay(s) selected for this application must be set at 600 primary amperes or less, provided that this setting is greater than the maximum line zero-sequence load unbalance. These relays may serve as the overreaching non-communications-assisted ground tripping function.

7.5 Close-in Multi-Phase Fault Protection (Switch-Onto-Fault Protection)

Protection must be provided to clear zero-voltage faults present when a line is energized with the relay potential source provided by line-side voltage transformers. A scheme designed to specifically provide this protection must be provided if this protection is not inherently provided by the primary and/or back-up line protection schemes. Scheme redundancy is not required.

7.6 Out-of-Step Protection

Out-of-step protection is typically not utilized within the PJM system. The application of out-of-step relays in any transmission application must be reviewed and approved by PJM, with input from the PJM Relay Subcommittee as necessary.

7.7 Single-Phase Tripping

Single-phase tripping is typically not utilized within the PJM system. The application of single-phase tripping must be reviewed and approved by PJM, with input from the PJM Relay Subcommittee as necessary.

Section 8: Substation Transformer Protection

This section outlines the requirements for the protection of substation transformers with high-side voltages of 200 kV and above or as defined in this manual Section 1 - Applicability.

The following standards and publications were used as a reference for developing the requirements specified in this section.

- ANSI/IEEE C37.91 Guide for Protective Relay Applications to Power Transformers
- ANSI/IEEE C37.110 Guide for the Application of Current Transformers Used for Protective Relaying Purposes

8.1 Transformer Protection

8.1.1 Bulk Power Transformers

- Bulk Power Transformers are transformers with low-side voltages greater than 100kV and networked on the low side
- Two independent high-speed protection schemes are required. Acceptable combinations of schemes for satisfying the redundancy requirement are the following:
    - Two independent current differential schemes
    - One current differential scheme and one sudden pressure relay scheme
- Independently protected DC control circuits are required.

8.1.2 All other substation transformers

- Two independent protection schemes, at least one of which must be high-speed, are required. Acceptable combinations of schemes for satisfying the redundancy requirement are the following:
    - Two independent current-based schemes, one of which must be differential
    - One current-based scheme and one sudden pressure relay scheme
- Independently protected DC control circuits are required.

8.1.3 Sudden Pressure Relay Applications

For transformers with a tap changer in a compartment separate from the main tank a sudden pressure relay must be installed in both the main tank and the tap changer compartment or a back-up current scheme must be applied.

8.1.4 Current Differential Zone Considerations

If the transformer current differential zone is extended to include the bus between breakers on the high or low sides of the transformer: the current circuit from each breaker must be connected to separate restraint windings in the differential relay, with the following exception. Two or more current circuits may be paralleled into one restraint winding only if current can flow in no more than one of the paralleled circuits for all faults external to the differential protective zone (i.e., radial feeder breakers with no source of fault current).

8.2 Isolation of a Faulted Transformer Tapped to a Line

This section is concerned with non-bulk-power (e.g., local load) transformers connected to bulk-power lines[2] such that, if there were no dedicated high-side interrupting device, a fault on the secondary bushings would interrupt power flow on the bulk power line. The requirements below apply regardless of whether the connection point is at one of the line terminals, or at a mid-line location.

- Fault-interrupting devices are required on the source (primary) side of the transformer. The interrupting device shall be fully-capable of interrupting faults on the transformer secondary bushings. The protection shall be coordinated such that secondary faults are cleared by the interrupting device and do not result in an interruption to the bulk-power line other than for failures of the interrupting device or of the protection system. Protection and coordination requirements for transformer primary faults shall be determined by, or in discussions with the transmission line owner(s).
- A disconnect switch is typically installed on the source side of the fault-interrupting device. The switch may either be integral to the fault-interrupting device assembly or independent from it. The requirement to install a disconnect switch and any requirements for the operation of the switch shall be determined by, or in discussions with the transmission line owner(s).
- Certain situations may require the transformer protection to initiate tripping of the transmission line terminals. For line restoration or other purposes, the tripping logic frequently utilizes auxiliary switch contacts of the primary disconnect switch. The following application recommendations apply. (Elevation of the recommendations to requirements shall be determined by, or in discussions with the transmission line owner(s).)
    - Auxiliary contacts associated with the disconnect switch operating mechanism (e.g., a motor-operator) should not be used if the mechanism can be de-coupled from the switch. Otherwise, the switch may indicate open when it is in fact closed, likely defeating desired protection functions. A separate auxiliary switch assembly attached to the operating shaft of the switch itself should be used.
    - Due to dependability concerns with auxiliary switches, it is recommended that the transformer primary disconnect switch auxiliary contacts not be used in such a manner that if the auxiliary switch (i.e., 89a) contact were to insulate or otherwise falsely indicate that the disconnect switch is open, the required tripping of local breakers or the direct transfer tripping of remote breakers would be defeated. The use of auxiliary switches in the protection scheme should be limited to local trip seal-in, direct transfer trip termination, etc. For example, assume that a fault occurs within the transformer with a magnitude which exceeds the capability of the interrupter, but cannot easily be detected by the line relays at the terminals. Trip (local and/or remote) logic of the form T =

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[2] Bulk-power lines operated at greater than 300 kV shall not be tapped. Lines operated at less than 300 kV lines may be tapped with the concurrence of the transmission line owner(s).

94+T*89a is permissible. Trip logic of the form T = 94*89a is not recommended. Alternatively, trip logic of the form T = 94*(89a + 50) may be acceptable, where "50" is a current detector set as low as practical and connected to monitor current through the switch.

- Using the above example, if the transformer is connected in such a manner that it can be switched between two bulk-power lines, there may be no alternative than to use auxiliary switch contacts to determine which line to trip. In this case, any redundancy requirements will extend to the auxiliary switches, which should be electrically and mechanically independent.

8.3 Transformer Leads Protection

The transformer high and low side leads must be protected by two independent schemes, both of which must be high-speed unless the leads are included in a line protection zone. The schemes must utilize independent current and/or voltage sources and independently protected DC control circuits. Where the voltage rating of the low-side leads is less than 100 kV, redundancy in the low side lead protection is not required.

Independent "blind-spot" protection systems must be provided if any operating condition, such as an open high-side disconnect switch defeats the transformer lead protection.

Section 9: Bus Protection

This section outlines the requirements for the protection of substation buses rated 200 kV and above or as defined in this manual Section 1 - Applicability.

The following standards and publications were used as a reference for developing the requirements specified in this section.

- ANSI/IEEE C37.97 Guide for Protective Relay Applications to Power System Busses
- ANSI/IEEE C37.110 Guide for the Application of Current Transformers Used for Protective Relaying Purposes

Two independent high-speed protection schemes are required for protecting the bus. They must utilize independent current and/or voltage sources and independently protected DC control circuits.

Section 10: Shunt Reactor Protection

This section outlines the minimum requirements for the protection of shunt reactors rated 200 kV and above or as defined in this manual Section 1 - Applicability.

The following standards and publications were used as a reference for developing the requirements specified in this section.

- ANSI/IEEE C37.109 Guide for the Protection of Shunt Reactors
- ANSI/IEEE C37.110 Guide for the Application of Current Transformers Used for Protective Relaying Purposes

In general, the requirements for the protection of shunt reactors are functionally equivalent to the requirements for the protection of substation transformers. Some requirements do not apply to reactors, for example those relating to multiple windings.

The specific hardware used for reactor protection will generally be different from that used for transformer protection; however, as noted above, the functional requirements are equivalent and are summarized as follows:

- The reactor must be protected by two independent high-speed schemes. The two schemes must utilize independently protected DC control circuits.
- The reactor leads must be protected by two independent schemes, both of which must be high-speed unless the leads are included in a line protection zone. The two schemes must utilize independent current and/or potential sources and independently protected DC control circuits.
- For additional detail and for other requirements (e.g., the use of auxiliary contacts in the protection scheme), see Section 8 on Substation Transformer Protection.

Section 11: Shunt Capacitor Protection

This section outlines the minimum requirements for the protection of shunt capacitors rated 200 kV and above or as defined in this manual Section 1 - Applicability.

The following standards and publications were used as a reference for developing the requirements specified in this section.

- ANSI/IEEE C37.99 Guide for the Protection of Shunt Capacitor Banks
- ANSI/IEEE C37.110 Guide for the Application of Current Transformers Used for Protective Relaying Purposes
- IEEE 1036-Guide for Application of Shunt Power Capacitors

The following schemes must be provided to protect each capacitor bank:

11.1 Primary Leads Protection

The capacitor bank leads must be protected by two independent schemes, both of which must be high-speed unless the leads are included in a line protection zone. The two schemes must utilize independent current and/or potential sources and independently protected DC control circuits.

11.2 Unbalance Detection Scheme

Primary and back-up capacitor bank unbalance detection schemes must be installed. These schemes should be set to trip the capacitor bank for unbalances resulting in greater than 110% of rated voltage across the individual capacitor cans. For externally-fused capacitor banks, the bank must be designed such that a single can failure does not result in greater than 110% of rated voltage across the remaining cans. Independently protected DC control schemes must be used for each of the schemes. Where potential sensing is used in both the primary and back-up schemes, independent voltage sources are required, with the exception of voltage differential schemes which will result in a trip of the capacitor bank upon the loss of the voltage source to the scheme.

11.3 Capacitor Bank Fusing

For externally fused capacitor banks, the fuse size should be chosen to protect the capacitor can from catastrophic can rupture in the event of an internal can fault. In the case of fuseless banks, the protection scheme operating characteristics and bank design must be selected to protect against catastrophic can ruptures.

Section 12: Breaker Failure Protection

This section outlines the minimum requirements for breaker failure protection for fault interrupting devices (including circuit switchers, where applicable) at system voltages above 200 kV or as defined in this manual Section 1 - Applicability.

The following standards and publications were used as a reference for developing the requirements specified in this section.

- ANSI/IEEE Std C37.119 - IEEE Guide for Breaker Failure Protection of Power Circuit Breakers

12.1 Local breaker failure protection requirements

- A dedicated[3] breaker failure scheme shall be used for each fault-interrupting device and shall initiate tripping of all local sources of fault current.
- The breaker failure output tripping relay shall block both manual and automatic closing of all local breakers required to trip until the failed breaker has been electrically isolated.

12.2 Direct transfer trip requirements (See also Appendix B)

- Local breaker failure protection shall initiate direct transfer tripping of associated remote terminals if any of the following conditions exist.
    - Speed is required to assure system stability.
    - Remote back-up protection is unacceptable because of the number of circuits and area affected.
    - The sensitivity of remote relay schemes is inadequate due to connected transformers, connected generators, line-end fault levels, or due to strong infeed from parallel sources.
- Tripping shall be maintained at the remote terminal until the failed breaker has been electrically isolated.
- Automatic reclosing shall be prevented at the remote terminal until the failed breaker has been electrically isolated.

12.3 Breaker failure scheme design requirements

- Failure of a single component shall not disable both the tripping of the breaker and the breaker failure scheme.

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[3] A “dedicated” scheme is defined for purposes of this document as one which utilizes a separate breaker failure timer (or timers) for each breaker as opposed to a scheme which utilizes a breaker failure timer common to all breakers supplied by a bus. A dedicated scheme may utilize elements common to other breakers such as an auxiliary tripping relay which trips all breakers on the affected bus.

- For security against possible false breaker failure scheme operation, the minimum acceptable margin between normal fault clearing and a breaker failure trip decision is 24 msec.
- Current actuated fault detectors are always required. However, when the primary and backup relays detect conditions for which the current actuated fault detectors lack the required sensitivity, breaker auxiliary switches shall also be used.
- Breaker failure scheme designs generally include an optional "re-trip" feature whose purpose is to prevent unnecessary breaker failure operations which could occur for various reasons[4]. The re-trip feature must be implemented unless it has been established that fault-detector settings, scheme logic, or other considerations negate the advantages of the re-trip feature. The re-trip feature must function to re-trip the protected interrupting device upon initiation of the breaker failure scheme.

12.4 Pole Disagreement Tripping

Pole Disagreement Tripping must be installed on all fault interrupting devices capable of individual pole operation. The pole disagreement scheme must incorporate the following features:

- All poles of the device must be opened if the position of one pole fails to agree with the position of either of the other two.
- An alarm specifically for "pole disagreement" must be initiated by the above scheme.
- The disagreement scheme is to trip only the affected device.

12.5 Live tank circuit breakers

Live tank circuit breakers must be provided with high speed flashover protection to detect and isolate a phase-to-ground flashover of the circuit breaker column if the column would be in a blind spot from local protection schemes for such a flashover.

12.6 Current transformer support columns

Current transformer support columns must be provided with high speed flashover protection to detect and isolate a phase-to-ground flashover of the current transformer support column if the CTs would be in a blind spot from local protection schemes for such a flashover.

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[4] Applications of the re-trip feature include (1) activation of a second trip coil in recognition of the possibility that the first trip coil may be defective; (2) the attempt to trip the breaker prior to the expiration of breaker failure timing in the event that breaker failure has been initiated without trip having been initiated. Events of the latter type have occurred due to improper test procedures and due to certain relay failure modes.

Section 13: Phase Angle Regulator Protection

This section outlines the minimum requirements for the protection of phase angle regulating transformers connected at system voltages above 200 kV or as defined in this manual Section 1 - Applicability. The protection of phase angle regulating transformers is a highly specialized subject and the design of the protection scheme should take into consideration such factors as application requirements, transformer manufacturer input, design of surrounding system protection systems, and clearing time requirements

The following standards and publications were used as a reference for developing the requirements specified in this section.

- Protection of Phase Angle Regulating Transformers, an IEEE Power System Relaying Committee Report, October 1999
- IEEE Guide for the Application, Specification, and Testing of Phase-Shifting Transformers, IEEE Standard C57.135

13.1 Detailed Protection Requirements

The detailed protection requirements (especially in regard to the differential protection) are highly specific to the transformer winding connections, for which there are different designs in use. The protection scheme is generally developed through discussions with the transformer manufacturer, protection equipment manufacturers, applicable industry guides and technical papers as appropriate, and through consultations with the interconnecting utility.

The following requirements pertain to the protection of phase angle regulating transformers of all types:

- Individual pressure actuated devices which operate for a change in gas or oil pressure must be provided for each individual winding and LTC compartment. The operation of these protective devices must be wired to trip the unit.
- A protection scheme to detect an out-of-step tap changer position.
- Independent current sources and independently protected DC control circuits

The following are the minimum requirements specific to the current-derived protection of the most common type of phase angle regulating transformer[5] in use within PJM

- A primary current differential scheme which includes the primary series winding and the primary excitation (shunt) winding.
- A secondary current differential scheme which includes the secondary series winding and the secondary excitation (LTC) winding.
- An overcurrent scheme for the neutral connection of the primary excitation (shunt) winding.
- An overcurrent scheme for the neutral connection of the secondary excitation (LTC) winding.

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[5] Wye-grounded exciting winding, delta-connected secondary series winding.

- Some Phase Angle Regulators are equipped with an “Advance-Retard Switch” (ARS) that reconfigures the series transformer delta winding to control the direction of power flow. The secondary differential scheme must be designed to allow for a full transition from the Advance state to the Retard state and vice-versa. During the transition, the CT delta connection OR the CT compensation settings in the secondary differential relay must be modified accordingly without causing the unit to trip. A microprocessor relay capable of multiple setting groups is strongly suggested for the secondary differential protection.

Section 14: Transmission Line Reclosing

This section outlines the requirements for applying automatic reclosing schemes for fault interrupting devices at system voltages above 200 kV or as defined in this manual Section 1 - Applicability.

The following standards and publications were used as a reference for developing the requirements specified in this section.

- ANSI/IEEE Std C37.104 Guide for Automatic Reclosing of Line Circuit Breakers for AC Transmission and Distribution Lines

14.1 Reclosing Requirements

The following requirements must be met when applying automatic reclosing on transmission lines:

- The impact on generator shaft torque of system connected generators due to line reclosing must be considered. An appropriate time delay must be used to maintain the generator shaft torque within acceptable values.
- Reclosing times and sequences must take into account the capability of the fault interrupting device.
- Reclosing for line faults shall not be used on transmission lines consisting entirely of cable. Where combinations of open wire and cable are used, an evaluation should be made to determine if reclosing should be used for faults in the aerial portion of the circuit and blocked for cable faults.
- Automatic reclosing shall be configured to prevent reclosing on a failed transformer or reactor, or on a failed breaker. For such conditions, see the appropriate section for further discussion.
- Automatic reclosing shall not be used where transient voltage analysis studies indicate that reclosing may produce switching surges exceeding equipment design levels.
- Automatic reclosing following out-of-step conditions must be reviewed and approved by PJM, with input from the PJM Relay Subcommittee as necessary.

14.2 High-Speed Reclosing Requirements

For purposes of this document, the following statements in ANSI/IEEE Std C37.104 apply:

> *High-speed autoreclosing: Refers to the autoreclosing of a circuit breaker after a necessary time delay to permit fault arc deionization with due regard to coordination with all relay protective systems. This type of autoreclosing is generally not supervised by voltage magnitude or phase angle.*

The following requirements must be met when applying high-speed automatic reclosing on transmission lines:

- The reclose interval must be selected to allow for proper de-ionization of the fault arc. Based on voltage level, the minimum dead time required to de-ionize the fault can be determined from the following equation:

$$T=10.5 + (kV/34.5) \text{ cycles}$$

where kV is the rated line-line voltage.

Note: the equation above is valid for voltages as high as 230 kV but may be overly-conservative at higher voltages. For example, industry experience indicates that 30 cycle dead time is adequate at 765 kV.

- ~~Stability studies must be performed by PJM before applying high-speed autoreclosing on transmission line circuit breakers.~~ Most applications of HSR do not require study for stability, unless the HSR is on a line electrically close to a line originating at a generating station. If the results from such ~~of the~~ stability studies indicate that reclosing following a specific type of fault or system condition would result in an unacceptable situation, adaptive reclosing as defined in IEEE Standard C37.104 may be used.
- High-speed reclosing must only be initiated by a communications assisted relaying scheme.

Section 15: Supervision and Alarming of Relaying and Control Circuits

This section outlines the requirements for supervision and alarming of relaying and control circuits applied to protect equipment at system voltages above 200 kV or as defined in this manual Section 1 - Applicability.

15.1 Design Standards

The following conditions shall be reported remotely from unattended stations. Some functions can be grouped together when reporting the alarm condition to the remote site based on the availability of alarm points. Facilities shall be provided to indicate the specific trouble at the local site.

- Battery low voltage condition
- Blown fuse on protective relaying DC control circuit
- Loss of AC relaying potential
- Alarm condition of protective relay pilot channels as described in Section 15.2
- Relay trouble alarms where internal alarm features are provided

15.2 Relaying Communication Channel Monitoring and Testing

All relay communication channels must be monitored to detect any channel problems and initiate an alarm. Schemes utilizing a signal that is “On” continuously shall be monitored continuously. Schemes that use a channel which is normally off and transitioned to an on state by the protective scheme must be tested automatically at least once a day, preferably at both reduced and full power levels.

Section 16: Underfrequency Load Shedding

This section outlines the requirements for under-frequency load shedding within PJM.

- Under-frequency load-shedding schemes shall be designed and implemented in accordance with Regional requirements.
- The load-shedding scheme shall be distributed in application as opposed to a centralized design.
- Loads tripped by the load-shedding scheme shall require manual restoration (local or remote) unless otherwise authorized by PJM.
- The under-frequency detection scheme shall be secure for a failure of a potential supply.

Section 17: Special Protection Schemes

This section outlines the requirements for Special Protection Schemes (SPSs) which are occasionally employed in response to an abnormal condition or configuration of the electric system.

17.1 Introduction

A special protection system (SPS) or remedial action scheme is designed to detect abnormal system conditions (e.g., abnormal system configuration) and to automatically take appropriate corrective action to maintain system stability, acceptable system voltages, and acceptable facility loading.

Whereas “normal” protective relaying systems are typically designed to isolate faulted elements, SPS’s may take seemingly unrelated actions such as the tripping of local or remote system elements (including generators), generator runback, and load shedding.

Transmission line out-of-step tripping, trip blocking, and reclose blocking are not considered to be SPS’s, nor are standard generator protection functions such as loss-of-field protection, over-excitation protection, and out-of-step protection.

17.2 Installation Requirements

SPS’s should not be installed as a substitute for good system design or operating practices. Their implementation is generally limited to temporary conditions involving the outage of critical equipment.

The decision to employ an SPS should take into account the complexity of the scheme and the consequences of misoperation as well as its benefits. The use of an SPS, like any protection scheme, entails the risk that it will misoperate. However, the consequences of an SPS misoperation are often more severe than those of fault protection schemes.

When conditions are such that an SPS is no longer required, the SPS shall be retired.

For SPS’s which are needed only under certain conditions, procedures shall be established to ensure that these schemes are disabled when the conditions requiring their use no longer exist.

For SPS’s which are not normally armed, there may be two levels of action. The first stage is designed to recognize a predetermined condition (often system configuration) and “arm” a second stage. The second stage takes concrete action (e.g., tripping of system elements) if certain subsequent events occur. When the SPS is armed, there shall be indication of that fact in a manned facility.

Greater detail is available in “MAAC Special Protection System Criteria” (Document A-3), and ECAR Document 12. However these documents will be superseded by an RFC standard.

Appendix A: Use of Dual Trip Coils

This section outlines the requirements for the use of dual trip coils in circuit breakers.

- Dual trip coils must be applied to meet the dependability requirements mandated by this document to assure that a failed trip coil does not result in the failure of a breaker to operate.
- If the design of the operating mechanism is such that the simultaneous energization of both trip coils with voltages of opposite polarity results in a failure of the mechanism to operate, testing shall be performed to verify proper polarity of the trip coil circuits.
- Undesirable breaker failure operations are possible if the primary trip path is open and tripping is initiated through slower-operating backup relays. Where this is the case, one of the following measures must be taken:
    - Energize both sets of trip coils with both the primary and backup relays or at least with the relaying system which is known to be faster. In such designs, care must be taken to maintain independence of the primary and backup control circuitry.
    - Use high-speed relays to cover the entire zone of protection for both the primary and backup protection.
    - Apply the breaker failure retrip logic to energize the trip coil associated with the slower relays prior to expiration of the breaker failure timer. If identification of the slower relays is difficult, then the retrip logic shall energize both trip coils.
    - Apply “cross-trip” auxiliary relays in the breaker tripping control scheme.

Appendix B: Direct Transfer Trip Requirements

This section outlines the requirements for Direct Transfer Trip (DTT) schemes.

- Audio tone transceivers operating over analog multiplexed systems - the design of the equipment and/or the scheme must be immune from the effects of frequency translation (or “drift”) in the carrier. This requires the transmission of two tones, one configured to shift up in frequency and the other to shift down in frequency.
- Audio tone transceivers operating over digital multiplexed systems – the design of certain older audio tone receivers makes them subject to generating false trip outputs in the presence of the type of noise characteristic of digital systems. The audio tone equipment manufacturer should be consulted in regard to the application of the tone equipment in any environment which may include digital transmission for any portion of the communications path.
- Digital transceivers – it is required that the overall DTT scheme include addressing capability between transmitters and receivers connected through a multiplexing system or through direct fiber where a fiber patch panel is employed.

Appendix C: Dual Pilot Channels for Protective Relaying

This section outlines the requirements for the application of dual pilot channels when required by the standards presented in this document. Dual pilot channels are defined as two separate, independent communications channels which are applied to provide high speed clearing for transmission line faults via both the primary and backup relay schemes. Each scheme must have sufficient speed to provide the clearing times necessary to maintain system stability as defined in the NERC Transmission Planning Standards, TPL-001 through TPL-004 and the associated Table 1.

The following standards and publications were used as a reference for developing the requirements specified in this section.

- IEEE 643 – IEEE Guide for Power Line Carrier Applications
- ANSI/IEEE C37.93 – IEEE Guide for Power System Protective Relay Applications of Audio Tones over Voice Grade Channels
- ANSI/IEEE C37.113 – Guide for Protective Relay Applications to Transmission Lines

1. Channel Independence

- Communications channels utilized for the dual pilot relaying systems must be designed with the same level of independence as the primary and backup protection and control systems.
- The following factors are used to determine the level of independence of communications channels used for dual pilot relaying systems:
    - Physical relationship between the communication facilities and paths used for both channels
    - Physical relationship between the channel path(s) and related power system facilities
    - Probability of a simultaneous failure due to physical proximity
    - Performance of the relay system in the event of a path failure
    - Time required to repair a failed path
    - Capability to repair or maintain one pilot channel while keeping the remaining channel fully functional
- Steady-state loss of both channels
    - Upon loss of both pilot channels, the associated transmission line must be taken out of service, or if possible, tripping delay time reduced to a level at which stability requirements are met and relay coordination is maintained for normal clearing of faults.

2. Applications

The following sections provide specific requirements for different types of communications channels.

2.1 Power Line Carrier

- Dual independent paths can be achieved by using two separate carrier systems, connected to separate phases. Signal attenuation must be reviewed and other system arrangements must be used if signal attenuation will be above acceptable levels.

2.2 Microwave Radio Channels

- Two completely independent microwave systems can rarely be justified from an economic standpoint. However, modern systems are often configured with a high degree of redundancy. To the extent that susceptibility to a common-mode failure is limited to passive equipment generally considered to have an extremely low probability of failure (e.g., a single communications battery or common microwave tower), a single microwave system is acceptable. No single-contingency failure of an active component shall compromise both pilot schemes.
- Complete redundancy in the radio frequency path (i.e., two antennas) and in the electronic RF multiplexing equipment is required. No single path failure is permitted to result in the unavailability of both pilot protection schemes for longer than the switching time from normal to alternate facilities which is normally of the order of milliseconds.

2.3 Leased Telephone Circuits

If dual pilot channels are required, they may not both utilize leased telephone circuits.

2.4 Fiber Optic Systems

- Dual pilot protection systems utilizing fiber optic communications channels must be designed to maintain high speed coverage for the transmission line in the event of a single contingency. In evaluating the level of redundancy, both the fiber path routing and protection scheme types must be considered. The following protection scheme/fiber optic path examples are presented as examples of the analysis which must be performed to determine adequate redundancy:

  a) Two permissive tripping schemes, one fiber optic shield wire – This scheme is unacceptable for dual pilot protection since a break in the shield wire would disable both protection systems and could create a fault on the protected line. In addition, using two fibers in the shield wire may result in the loss of both channels if the shield is damaged and maintenance outages may be difficult to obtain to repair the fibers in a timely manner.

  b) Two permissive tripping schemes, two independent fiber optic shield wires – Although this scheme offers some improvement over that mentioned in (a), outside interference such as an aircraft could cause the loss of both shield wires during a fault. This scheme is acceptable for dual pilot protection, but not recommended.

c) <u>Two unblocking schemes, one fiber optic shield wire</u> – In the case of a broken shield wire, both channels would be disabled if the fault takes longer than 300 msec to develop. In addition as in (a), using two fibers in the shield wire may result in the loss of both channels when the shield is damaged with uncertain repair time. This scheme is unacceptable for dual pilot protection.

d) <u>Two unblocking schemes, two independent fiber optic shield wires</u> – This arrangement is similar to (c), but with the repair problem of (a) alleviated. This scheme is acceptable for dual pilot protection, but not recommended.

e) <u>Underbuilt fiber optic cable</u> – Use of an underbuilt fiber optic cable in conjunction with an over head fiber optic cable, or use of two underbuilt fiber optic cables, is acceptable for dual pilot protection. However, as in (b), outside interference such as an aircraft could cause the loss of both fiber paths during a fault.

f) <u>Simultaneous line fault with loss of dual channels</u>

If at least one of the pilot schemes is a blocking scheme, then independent fiber paths are not required since the loss of the channel will not disable the high speed tripping of the blocking scheme. However, system security implications with the application of a blocking scheme must be considered.

Similarly, if at least one of the pilot schemes is a current differential scheme, which reverts to a sensitive overcurrent element or otherwise provides for high speed tripping for the entire line on loss of channel, then independent fiber paths are not required.

- Fiber Optic Multiplexed Communications

  If the fiber optic channel utilizes multiplexing equipment, the failure of this equipment must be considered when evaluating susceptibility to a single mode failure. A single mode failure must not result in the unavailability of both pilot protection systems for longer than the switching time from normal to alternate facilities which normally occurs within milliseconds of a channel failure.

- Fiber Optic Self-healing Ring Topology

  Fiber optic systems utilizing a self-healing ring topology can be utilized to provide path redundancy. However, the failure of the multiplexing/switching equipment must not result in the unavailability of both pilot protection systems.

Appendix D: Small Generator Protection Requirements

- For generating units less than 100 MVA and connected below 200 kV and not previously addressed in this document, generation developers are referred to the following sources of requirements depending on generator size.
    - Generators < 20 MVA: Refer to PJM Manual 14A, Attachments E and E-1
    - Generators ≥ 20 MVA and <100 MVA: Refer to requirements of the applicable transmission owner.

Appendix E: Acceptable Three Terminal Line Applications

This appendix outlines the categories of three terminal line applications and associated protection requirements which have been deemed acceptable for use within PJM. Three terminal line applications are only permitted at voltages less than 300 kV when the requirements listed below are met. No three terminal line applications are permitted on systems at 300 kV and above.

1.0 Category I – Temporary Installation

This category applies when an acceptable long-term reinforcement was already identified but cannot be installed in time and consequently the reliability of the transmission system may be compromised. Examples include construction delays, unusual combinations of system demand and long term transmission equipment forced outages. The three terminal line configuration must be removed when the planned permanent reinforcement is in place.

The following requirements apply to Category I installations.

1.1 Protection Requirements

- A detailed relay coordination review must be performed which establishes that the planned addition will result in no compromises to coordination. The review shall include consideration of apparent impedances at each terminal, weak sources, fault current nulls or outflows.
- The protection scheme(s) must be designed to provide high-speed (pilot) clearing of faults at all locations on the three terminal line. Designing for sequential clearing of faults is not acceptable.
- Backup protection must be provided and applied such that for faults anywhere on the circuit, each terminal shall be able to detect the fault and initiate tripping without regard to whether the other terminals have opened or are still closed.
- The backup line protection may be pilot (high-speed, communications dependent) or non-pilot (stepped-distance, ground time overcurrent) depending on the specific circumstances and results of fault and stability studies, etc. Each affected Transmission Owner will evaluate the proposed installations on a case-by-case basis. If a backup high-speed pilot scheme is required, the requirements for dual pilot channels outlined in Appendix C of this document must be met.

2.0 Category II – Permanent Installation

2.1 Protection Requirements

- A detailed relay coordination review must be performed which establishes that the planned addition will result in no compromises to coordination. The review shall include consideration of apparent impedances at each terminal, weak sources, fault current nulls or outflows.

- The protection scheme(s) must be designed to provide high-speed (pilot) clearing of faults at all locations on the three terminal line. Designing for sequential clearing of faults is not acceptable.
- Backup relays must be provided and applied such that for faults anywhere on the circuit, each terminal shall be able to detect the fault and initiate tripping without regard to whether the other terminals have opened or are still closed.
- The backup line protection may be pilot (high-speed, communications dependent) or non-pilot (stepped-distance, ground time overcurrent) depending on the specific circumstances and results of fault and stability studies, etc. Each affected Transmission Owner will evaluate the proposed installations on a case-by-case basis. If a backup high-speed pilot scheme is required, the requirements for dual pilot channels outlined in Appendix C of this document must be met.
- For reliability reasons, extending an existing two-terminal directional comparison blocking or unblocking scheme operating over power line carrier to a third terminal is not acceptable for primary or backup line protection.
- In all cases where a pilot scheme is required, digital communications channels between the three terminals must be used. No portions of these channels may be metallic (i.e. telephone cable, coaxial cable, etc) other than between relays and multiplex equipment (where used) within the control house. External audio-tone interfaces are not acceptable. Where multiplexing schemes are use, they must be evaluated with respect to the characteristics of the proposed protection (i.e. susceptibility to mal-operation due to variances in path delay) on a case-by-case basis.

Appendix F: Application of Triggered Fault Current Limiters

This appendix outlines the requirements for the application of triggered fault current limiters (FCL's) when proposed for the mitigation of increased fault current availability at a utility distribution bus resulting from the installation of new equipment or rearrangement of existing equipment at a non-utility station. Note: in the context of this appendix, "utility" refers to the delivery or "wires" company whose equipment is being affected by the addition of the new equipment or rearrangement of existing equipment.

The following standards and publications were used as a reference for developing the requirements specified in this section.

- Limitations of Fault-Current Limiters for Expansion of Electrical Distribution Systems, J.C. Das, IEEE Transactions on Industry Applications, Vol. 33, No. 4, July/August 1997.

The requirements for the application of FCL's are the following.

- All concerned parties must understand the exposure of the FCL to a range of faults on the utility system and to faults within the FCL owner's system which can result in operation of the FCL, and must formally agree that the loss of equipment resulting from the operation of the FCL for those faults is an acceptable consequence.
- The FCL owner must provide detailed calculations demonstrating that the fault current limiter will achieve its intended purpose of protecting the utility equipment from being subjected to current beyond its capability. The calculations must include the anticipated current-versus time waveforms of the total asymmetrical current flowing through the utility equipment for the maximum fault and minimum fault that will operate the FCL. The maximum current shall be the maximum asymmetrical current available based on the calculated X/R ratio, and shall include both the contributions from the system as well as the let-through contribution from the FCL. Detailed waveform analysis may be unnecessary if the calculation method used is sufficiently conservative (i.e. the arithmetic addition of the FCL peak let-through current and the system peak asymmetrical current). The calculations will require modeling of the utility system and FCL owner's system, and must include the transient effects of induction and synchronous motors. Since the FCL will not operate for fault level values below its threshold, the RMS value of the threshold of the FCL shall be added to the short circuit current of the breaker for determination of interrupting duty.
- The utility must supply the FCL owner with sufficient modeling information of the utility system to allow the FCL owner to perform the analysis described in 2.0 above.
- The FCL owner must provide design information showing that the operation of the FCL will not be compromised under low AC voltage conditions at the FCL owner's facility resulting from any fault on the utility system requiring the FCL to operate.
- If changes are made to the FCL owner's electrical system, the FCL owner must re-apply the requirements outlined in 2.0 above and provide documentation of this analysis to the utility for review.

- The FCL owner must provide design information showing that for the single contingency failure of the FCL to perform its intended function, the overall intent of protecting the utility equipment from overduty conditions is still met.
- The FCL owner shall have a written procedure which prohibits bypassing the FCL unless it is demonstrated to the satisfaction of the utility that conditions do not require operation of the FCL.
- Routine testing of FCL trigger levels, firing logic, and firing circuitry must be conducted at least every four years. Documentation of this testing shall be available upon request by the utility. The utility shall be granted physical access to inspect the FCL as deemed necessary by the utility.