PPL EU REQUIREMENTS FOR TRANSMISSION CONNECTED FACILITIES TO BE OWNED AND OPERATED BY PPL EU

Attachment 3
Relay and Control Facilities

Location Codes	S	0	6	0												Sorts				

Rev	Date	Sponsor	Reviewer	SUBSTATION ENGINEERING INSTRUCTION PPL ELECTRIC UTILITIES CORPORATION
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Record of All Issued Revisions

Revision	Page(s)	Section(s)	Description	Issue Date
0	All	All	Initial Issue	9/19/2014
1	All	All	Major overhaul of updated protection philosophy	8/31/2017

Distribution:

1. RC 0880 – T&S Standards
2. RC 0883 – Substation Engineering
3. RC 0601 – T&S Asset Management
4. RC 0878 – T&S System Engineering
5. RC 0905 – Relay Engineering

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1. Statement of Philosophy

The broad objectives in applying protection schemes on our system are to:

- Permit transient, dynamic and steady state stability to be maintained within the capability of facilities.
- Prevent or minimize equipment damage.
- Minimize outage time.
- Minimize outage area.
- Minimize voltage disturbance.
- Allow the free flow of normal and emergency power without imposing load limitations within the constraints of the Planning and Operating Principles & Practices or within the primary equipment capabilities.

2. General Practices

The accomplishment of the aforementioned objectives requires that protection criteria be coordinated with the design criteria of the PPL Electric Utility (PPL) system. It is essential that careful analysis be made of the system's planned design intent when determining protection requirements. It must be recognized that, at times, due to economic considerations, protective equipment may impose operating restrictions on the system. Likewise, during abnormal system conditions and during system emergencies, some risk must be accepted to allow for system operation. Considerable effort should be expended in analyzing the degree and impact of the risks involved in order to determine if they are acceptable.

Relaying shall be provided such that it produces minimal interference with system operation as outlined in the Operating Principles & Practices. In general, relay settings shall be applied such that coordination and selectivity shall exist and specified minimum faults detected under normal operating conditions.

3. Bulk Power System

The Bulk Power system includes 500 kV and 230 kV transmission lines, 500 kV and 230 kV switchyards, and 500-230 kV substations. This system requires the highest standards of protection, since the impact of faults can be most severe. The relay protection to be used incorporates the most up-to-date industry

practices, meets the accepted system requirements for reliability, sensitivity, selectivity, and stability and satisfies the minimum criteria established by the PJM Relay Subcommittee. Features of this protection incorporate:

- Separate primary and backup relays, including physical separation. The primary and backup relays for each zone of protection operate independent of one another while providing redundant protection to ensure reliability in the case that either the primary or backup relay is out of service or has failed. In addition, controls for each circuit breaker are provided with a dedicated relay.

- Separate multi-ratio current transformers to obtain maximum physical isolation.

- Each line and bus is equipped with a set of three Coupling Capacitor Voltage Transformers (CCVT) – one per phase – with triple secondary windings with the proper accuracy rating.

    - One secondary winding connected to supply potential for primary relays.
    - One secondary winding connected to supply potential for backup relays.
    - If required, one secondary winding connected to supply potential for interconnection meters.

- Separate DC tripping circuits, individually fused, and circuit breakers with dual trip coils. Failure of any fuse of the DC control should not affect more than one protection scheme.

Circuit Breaker Failure Protection

- Circuit Breaker failure protection is provided for the event that a breaker fails to operate or interrupt. Local breaker failure relaying senses such a failure and initiates tripping of adjacent breakers including remote breakers where necessary to remove the fault.

- This protection will trip and lock out the adjacent circuit breakers, initiate direct transfer trip signals to the remote breakers where necessary and stop the appropriate blocking signals/key the appropriate permissive transmitters. Overall clearing time will be approximately 12 to 17½ cycles depending on the timer circuitry.

- At generating stations, machine instability may result even if 12 cycle clearing of high magnitude faults were used. Where a stability problem exists for multiphase faults only, which is usually the case, a high speed breaker failure scheme is employed in addition to the standard breaker failure scheme to differentiate between multiphase faults and single phase-to-ground faults.

Circuit Breaker Flashover - Ground Protection

- Where current transformers are located on only one side of the breaker, circuit breaker flashover - ground protection is included in the relay scheme to partially compensate for loss in protection. The protection required is related to the construction of the particular circuit breaker and current transformer modules. Bushing type ground current transformers are provided with each such circuit breaker module, with secondaries of each phase paralleled and connected to (three) separate instantaneous overcurrent relays.

- The tripping circuits are arranged to clear equipment on both sides of the circuit breaker, to stop the appropriate blocking signals/key the appropriate permissive transmitters and to initiate direct transfer tripping to the remote terminals where necessary. This scheme provides sensitive, high speed protection for most types of ground faults involving the breaker insulation.

Current Transformer Column Ground Protection

- CT columns are protected from ground faults by an instantaneous three phase overcurrent relay supplied by current transformers specifically provided for this purpose located around the bottom of the CT columns.

- A separate master trip relay is provided for CT column ground fault protection to trip and block closing of the adjacent 500 kV breakers and the remote line terminals, as necessary, for isolation of the faulted CT columns.

3.1. Transmission Lines 500kV

The transmission circuits, being the backbone of the bulk power system, warrant the best protection available. The protective line relaying must be capable of high speed clearing of all faults, as well as having a high degree of dependability and security. This basically requires the application of a pilot relay scheme for high speed primary protection supplemented by an independent backup relaying system. Where it is essential that faults be effectively cleared in high speed 100 percent of the time (typically done on the 500kV system), dual pilot relaying systems with additional backup protection are installed.

In addition to the above protective relaying, adequate provisions must be made to clear a solid three phase fault at or very near a station when energizing a line. If the relays incorporate memory action and receive their potential from the bus source, no further provision is required. When line potential is supplied to the relays, however, an additional protective scheme must be provided - only one protective scheme is required rather than both primary and backup due to the rarity of the occurrence. The additional protection furnished for this condition consists of three instantaneous overcurrent relays set above line inrush currents, but with sufficient sensitivity (35% margin) to detect close-in faults with the

system altered by any single contingency. The trip circuit of these relays is such that they are only permitted to cause tripping when the line is being energized by the associated breaker. After energization, or breaker closing, the relay trip circuits are disabled from the breaker trip in 15 to 18 cycles.

A faulted transmission line is isolated by the tripping of all breakers in its corresponding zone of protection.

3.1.1. Relay Setting Criteria

All 500 kV transmission lines can be classified into three categories:

- Lines requiring dual-pilot protective relaying schemes.
- Lines not affected by directional distance relay limitations.
- Lines adversely affected by directional distance relay limitations.

The reach of the protective relaying must take into consideration the following:

- Must be capable of sensing specified minimum fault conditions, with the system normal and with it altered by any single contingency, without imposing limitations on circuit or equipment capabilities.
- Must assure against unnecessary line tripping on power swings for those conditions for which the system is stable. The corresponding setting must not limit the maximum load carrying capability of the line.
- Must enclose arc resistance values with the required margin at both the near and remote line terminals, with the system normal and with it altered by any single contingency.
- Must be capable of clearing not only sustained arcing faults, but restricted ground faults. Therefore, whenever directional distance type relaying is employed for ground protection of transmission lines, an additional relay directionally responsive to ground current must be applied. The relay should be set at 600 primary amperes or less. Where the primary or backup relaying employs other types of relays directionally responsive to ground current, they must also be set to allow detection of faults of the same restriction, under the same system conditions.

3.1.2. Reclosing

The application of automatic reclosing to the 500 kV transmission system includes reclosing sequences which are compatible with the operating restrictions imposed by transient overvoltage conditions. In addition, automatic reclosing provides the fastest and safest means of re-establishing a 500 kV line, thus minimizing equipment outages and effects of underlying systems.

The choice as to high speed reclosing (measured in cycles) or slow speed reclosing (measured in seconds) depends upon the particular circumstances of the network, each case requiring separate investigation. In some cases, system stability may be adversely affected by slow speed reclosing; in others, high speed reclosing on lines terminating at generating stations may be a hazard to the generators.

In general, the reclosing scheme consists of a single shot reclosing, in approximately 45 cycles (3/4 of a second), of the 500kV circuit breakers at the initiating line terminals. However, reclosing of the line terminals in the vicinity of generating stations may be delayed 10 seconds because of concerns with high speed reclosing and the mechanical stresses that it can introduce on generator shafts.

The automatic reclosing scheme for the initiating line terminal incorporates the following design features:

- Automatic reclosing will be allowed for all line relay operations only if the pilot relays are in service and voltage relays verify there is voltage on the bus side of the breaker being closed; however, automatic reclosing will take place even though tripping was caused by a time delay backup relay. For those lines with two pilot relay schemes, automatic reclosing will be allowed for all line relay operations if either one or both pilot relay schemes are in service.

- The reclosing scheme will test the line once if the conditions identified in the bullet above are met; if the reclosing is unsuccessful, no further automatic tests are attempted and the initiating terminal breaker must be reclosed by supervisory or manual control.

- Automatic reclosing will not be allowed for failure of an associated breaker to operate or interrupt, including a faulted circuit breaker. The initiating terminal will be prevented from reclosing automatically by the direct transfer trip signals that are transmitted for remote clearing of a failed breaker. Automatic reclosing will take place however, if the direct transfer trip is inoperative and a failed breaker at the remote end of the line is cleared by action of the "stop blocking signal/key permissive transmitter" scheme. Also, reclosing will be permitted if the remote circuit breaker is equipped with automatic disconnects to isolate the breaker.

- Where transient overvoltage criteria must be satisfied, breaker interlocks will be provided to guarantee that the minimum source exists behind the initiating terminal.

The automatic reclosing scheme for the follower (remote) line terminal incorporates the following design features:

- Automatic reclosing will be allowed for all line relay operations only if the pilot relays are in service; however, automatic reclosing will take place even though tripping was caused by a time delay backup relay. For those lines with two pilot relay schemes, automatic reclosing will be allowed for all line relay operations if either one or both pilot relay schemes are in service.

- Voltage relays and the synchrocheck relay will verify that there is voltage on the bus side and on the line side of the breaker being closed and that an in-synchronism condition exists.

- The reclosing scheme will attempt to close the breaker once; if the reclosure is unsuccessful, the follower terminal breaker must be reclosed by supervisory or manual control. However, if the initiating terminal reclosure attempt was unsuccessful, the reclosing scheme at the follower terminal will remain active until the initiating terminal is closed successfully or until the reclosing scheme is manually defeated at the follower terminal.

- Automatic reclosing will not be allowed for failure of an associated breaker to operate or interrupt, including a faulted circuit breaker. However, reclosing will be permitted if the circuit breaker is isolated by automatic disconnects.

3.2. Transmission Lines 230kV

A faulted 230 kV line is isolated by the tripping of all breakers in its corresponding zone of protection.

3.2.1. Relay Setting Criteria

The specific line protection selected for a 230 kV transmission line, as with a 500 kV line, will depend on the ability to set the reach to meet the required setting criteria.

3.2.2. Instantaneous Phase

Zone 1 - Directional Distance

- Set at least 10% short of nearest remote bus, without consideration given to in-feed in cases of multi-terminal lines. Additional margin is applied when utilizing older type relays where transient overreach is not limited by design.

- Setting should be able to detect close-in line faults with a minimum of 125% of the maximum arc resistance at the near terminal, with the system normal and with it altered by any single contingency.

- The corresponding setting must not limit line's maximum load ability per PPL guidelines.

Pilot Trip - Directional Distance

- Set for complete coverage of the line with a minimum setting of 125% of the impedance of the protected line, preferably providing for a minimum overreach of five ohms. On multi-terminal lines, the minimum setting should be 125% of the highest apparent impedance to the farthest remote bus under maximum in-feed conditions, preferably providing for a minimum overreach of five ohms. Coverage should include a minimum of 125% of the maximum arc resistance with the system normal and with it altered by any single contingency. Arc resistance values should be enclosed at both the near and remote line terminals.

- The corresponding setting must not limit line's maximum load ability per PPL guidelines.

Pilot Blocking (Where Required) - Directional Distance

- Setting must not allow Pilot Trip relay operation for an external fault - setting must reach farther than the Pilot Trip setting(s) at the remote terminal(s). A margin of 25% must be maintained for faults which will cause the Pilot Trip relay(s) at the remote terminal(s) to operate.

- A minimum forward offset setting of 0.5 secondary ohms is applied to prevent possible Pilot Trip relay mis-operation for nearby, zero-voltage external faults.

3.2.3. Time Phase

Zone 2 - Directional Distance

- Set for complete coverage of the line with a minimum setting of 125% of the impedance of the protected line, preferably providing for a minimum overreach of five ohms. On multi-terminal lines, the minimum setting should be 125% of the highest apparent impedance to the farthest remote bus under maximum in-feed conditions, preferably providing for a minimum overreach of five ohms.

- Setting should be able to detect line-end faults with a minimum of 125% of the maximum arc resistance at the remote terminal(s), with the system normal and with it altered by any single contingency.

- The corresponding setting must not limit line's maximum load ability per PPL guidelines.

- Setting should not reach farther than the Zone 1 Directional Distance settings on the external terminals, with the system normal. A safety margin of 10% overreach of the Zone 2 directional distance relay and 10% pullback of the Zone 1 directional distance relay should be applied.

- Timer set to allow sufficient time, with 12 cycles margin, for clearing of external faults through circuit breaker failure protection initiated by Instantaneous Phase relays.

3.2.4. Instantaneous Ground

Directional Instantaneous Overcurrent

- Set for 115% of the maximum external fault with the system normal and with it altered by any single contingency.

Pilot Trip - Directional Instantaneous Overcurrent

- Set to detect line end faults having up to 100 ohms restriction, with the system normal. Where Pilot Start is required, the Pilot Trip setting should not be lower than 125% of the Pilot Start setting at the remote end of the line. On multi-terminal lines, the setting should not be lower than 125% of the sum of the Pilot Start settings at the remote ends of the line.

Pilot Blocking (Where Required) - Instantaneous Overcurrent

- Setting must not allow Pilot Trip relay operation for an external fault - setting must be more sensitive than the Pilot Trip setting(s) at the remote terminal(s). The Pilot Start setting should not be higher than 80% of the Pilot Trip setting at the remote end of the line. On multi-terminal lines, the setting at the local terminal should not be higher than 80% of the lowest remote terminal pilot trip setting divided by the total number of remote terminals.

Fault Current Reversal (Where Required) – Overcurrent

- Setting must not allow Pilot Trip relay operation for an external fault - setting must be more sensitive than the Pilot Trip overcurrent setting at the remote terminal. The setting should not be higher than 80% of the Pilot Trip setting at the remote end of the line.

Harmonic Restraint (Where Required) - Overcurrent

- Harmonic Restraint Unit - setting should not be higher than 80% of the Pilot Trip overcurrent setting.

- Instantaneous Unit - setting must be above the maximum expected transformer inrush current.

3.2.5. Time Ground

Directional Time Overcurrent

- Set to pick up at 600 amperes or less to detect restricted ground faults.

- Time delay must allow sufficient time, with 12 cycles margin, for clearing of external faults through circuit breaker failure protection initiated by Instantaneous Ground Relays, with the system normal.

- Time delay must allow sufficient time, with 12 cycles margin, for clearing of external faults through Instantaneous Ground Relays, with the system altered by any single contingency.

- Time delay must allow sufficient time, with 12 cycles margin, for clearing all external faults through Time Ground Relays, with the system normal or with it altered by any single contingency.

3.2.6. Reclosing

In all cases, delayed-two shot automatic reclosing will be designed for the 230 kV transmission system to allow a preselected terminal to close on a dead line or a live line in synchronism. The other terminal or terminals will only close on a live line in synchronism. This type of reclosing, on the initial reclosure, is capable of restoring a line to service following a transient fault within a few seconds.

The standard reclosing schedule applied to 230 kV line terminals is as follows:

- 1st shot reclosing – 90 cycles (1.5 seconds)

- 2nd shot reclosing – 900 cycles (15 seconds)

Initiating Line Terminal:

- Delayed reclosing will be allowed for all line relay operations as indicated above, except for line terminals in the vicinity of generating stations, in which reclosing may be delayed 10 seconds if studies reveal a generator shaft damage concern.

- With the exception of rarely used high speed reclosing, voltage relays will verify that there is voltage on the bus side of the breaker being closed.

- Automatic reclosing will not be allowed for failure of an associated breaker to operate or interrupt, including a faulted circuit breaker, unless the failed breaker is isolated from the 230 kV line. The initiating terminal will be blocked from reclosing automatically by the direct transfer trip signals that are transmitted for clearing of a remote failed breaker. Automatic reclosing will take place, however, if the direct transfer trip is inoperative and a failed breaker at the remote end of the line is cleared by action of the "stop blocking signal/key permissive transmitter" scheme.

- Automatic reclosing will not be allowed for remote transformer faults, if cleared by direct transfer trip, until after the faulted transformer is isolated from the 230 kV line. Automatic reclosing will take place, however, if the direct transfer trip is inoperative and transformer faults at the remote end of the line are cleared by action of the automatic ground switch or "stop blocking signal/key permissive transmitter" scheme.

Follower (Remote) Line Terminal:

- Delayed reclosing will be allowed for all line relay operations within one to five seconds on the initial reclosure.

- With the exception of high speed reclosing, voltage relays and the synchrocheck relay will verify that there is voltage on the bus side and on the line side of the breaker being closed and that an in-synchronism condition exists.

- If the initiating terminal reclosed successfully, the reclosing scheme will attempt to close the breaker once; if the reclosure is unsuccessful, one more delayed reclosure can follow. However, if the initiating terminal reclosure attempt was unsuccessful, the follower terminal will be activated until the initiating terminal is closed successfully or until it is manually defeated at the follower terminal.

- Automatic reclosing will not be allowed for failure of an associated breaker to operate or interrupt, including a faulted circuit breaker, unless the failed breaker is isolated from the 230 kV line. The follower terminal will be blocked from reclosing automatically by the direct transfer trip signals that are transmitted for clearing of a remote failed breaker. Automatic reclosing will take place, however, if the direct transfer trip is inoperative and a failed breaker at the remote end of the line is cleared by action of the "stop blocking signal/key permissive transmitter" scheme.

- Automatic reclosing will not be allowed for remote transformer faults, if cleared by direct transfer trip, until after the faulted transformer is isolated from the 230 kV line. Automatic reclosing will take place, however, if the direct transfer trip is inoperative and transformer faults at the remote end of the line are cleared by action of the automatic ground switch or "stop blocking signal/key permissive transmitter" scheme.

3.3. Switchyards 500kV – Buses

Bus relaying is applied to all buses except where bus sections are relayed as part of the associated transmission lines or transformers. This protection generally consists of two independent sets of current differential relays, each set adjusted for maximum sensitivity according to manufacturers' recommendations. The faulted bus is isolated by the tripping of all breakers on the bus.

No automatic bus testing is employed on 500 kV buses following a bus differential operation; bus tests will be permitted by supervisory or manual control.

3.4. Switchyards 230kV – Buses

At non-generating station switchyards where bus testing is employed, the bus will be tested once following a bus differential operation. If successful, all remaining breakers will close restoring the station to normal; if unsuccessful, all breakers will be blocked from further automatic operations. Further bus tests will only be by supervisory or manual control. There is a preferred breaker to test the bus, and if this source is unavailable an alternate breaker will be automatically selected to test the bus.

3.5. 500-230kV Substations

Primary protection for all 500-230 kV transformers consists of harmonic restraint differential relays. A similar set of harmonic restraint differential relays and sudden pressure relays provide backup protection. The sudden pressure relays provide sensitive detection for faults within the transformer tanks.

A time overcurrent relay in the tertiary provides protection against excessive circulating current in the tertiary winding. To prevent imposing an operating limitation to the system, the tertiary relay must not operate during over-excitation, the relay must be insensitive to third harmonic current over-excitation and its setting coordinated with over-excitation limits on the transformer.

All transformers are protected against overvoltage during possible short time over excitation. Voltage relays monitoring tertiary or 230 kV voltage are installed to alarm and/or isolate the transformer at fixed voltage steps and time which relate to the overvoltage excitation limits for the transformers. These relays are set to:

- Alarm at 110% overvoltage, at an approximate 10 second time delay to override transients. The alarm will be received locally and at the Transmission Control Center.

- Isolate the transformer at 130% overvoltage, with an approximate 5 minute time delay.

In addition, all transformers are provided with an Electronic Temperature Monitor (ETM). The ETM uses microprocessor-based technology and advanced thermal modeling to monitor winding hot spot and top oil temperatures within liquid-cooled transformers.

- Hot Spot Thermal Relay – A relay contact from the ETM is used for the high winding temperature alarm, which operates at 115℃. A second contact is interlocked with loss of all coolers to provide another alarm at 120℃.

- Top Oil Indicator - A relay contact from the ETM is used to energize an auxiliary relay, which provides the following functions:

    - Top oil temperature alarm at 105℃
    - A second alarm set at 105℃ interlocked with the loss of all coolers.

3.6. Shunt Capacitors

Shunt capacitors are provided on the transmission system to provide reactive capacity and are generally connected to station buses.

The protection scheme compares phase and ground current flows to detect bank unbalance (bank configured as a double wye with unfused capacitor cans). This detection method will prevent stressing the individual capacitor cans with voltage in excess of 110% of rated can voltage.

4. Regional Delivery System 500-138kV, 230-138kV and 230-69kV

The Regional Delivery System includes all facilities necessary to supply and operate the 69 kV and 138 kV portions of the PPL system. The 69 kV System extends from the high side of the 230/69 kV transformers to the high side of the 69-12.47 kV transformers and includes 69 kV lines and switches, generation connected to the 69 kV system, and delivery to 69 kV customers. The 138 kV system extends from the high side of the 500-138 kV and 230-138 kV transformers to the high side of the 138-69 kV and 138-12.47 kV transformers and includes all 138 kV lines and switches, generation connected to the 138 kV system, and delivery to 138 kV customers.

4.1. Transformer Protection

Since the function of these transformers is critical to the dependable operation of our system and represents a sizable amount of capital investment, the application of a high level of protection is required. This protection will generally consist of the following:

- Primary and backup Percentage Differential Harmonic Restraint Relays – Set as sensitive as possible within the following constraints:
    - Thermal rating of the relay is not exceeded with the transformer loaded to its maximum two hour winter emergency rating.
    - Instantaneous unit does not operate on maximum transformer magnetization inrush current.
    - Maximum mismatch current for all possible transformer tap settings does not cause relay operation.
- Sudden Pressure Relaying – Preset by Manufacturer.
- Thermal Overload Monitoring
    - Hot Spot Thermal Relay – A relay contact from the ETM is used for the high winding temperature alarm, which operates at 115℃. A second contact is interlocked with loss of all coolers to provide another alarm at 120℃.
    - Top Oil Indicator - A relay contact from the ETM is used to energize an auxiliary relay which provides the following functions:
        - Top oil temperature alarm at 105℃.
        - A second alarm set at 105℃ interlocked with the loss of all coolers.
- Breaker Failure Protection – The function of this protection is to prevent transformer damage for the failure of the transformer hide side or low side circuit breaker to operate or interrupt. Guidelines that are followed in setting the breaker failure relays are asfollows:
    - Breaker Failure Fault Detectors - Phase - Setting should be capable of detecting all unrestricted phase faults, with 135% margin, in the area for which operation of these relays is required to initiate breaker failure operation. A maximum setting of approximately 5.0 secondary amperes is generally applied.

- Breaker Failure Fault Detectors - Ground - Setting should be capable of detecting all unrestricted ground faults, with 135% margin, in the area for which operation of these relays is required to initiate breaker failure protection. A maximum setting of approximately 1.0 secondary ampere is generally applied.
- Breaker Failure Timer - Set at 15 cycles for breakers having normal operating times of 5 cycles.

- Backup Protection for overloads due to 69 kV and 138 kV faults – The design of this protection will vary depending on the design of the station. Generally it will consist of time overcurrent and definite time overcurrent phase and ground relays applied on a 69 kV or 138 kV bus section basis. Guidelines for applying settings to the above relays are as follows:
  - Summation Time Overcurrent Phase:
    - Pickup setting should be at least 125% of the bus section's maximum load responsibility.
    - Time delay must be set to select with other protective devices on the system, with a minimum margin of 12 cycles with the system normal and with the system altered by any single contingency.
  - Summation Definite Time Overcurrent Phase:
    - Pickup setting should be at least 125% of the bus section's maximum load responsibility.
    - Setting must prevent operation of this relay for faults which will be cleared by action of time delay relays with the system normal and with the system altered by any single contingency. Setting should be 110% of the maximum current flow through this relay for faults that are not cleared by instantaneous relays. This maximum current flow is determined by increasing the instantaneous relay setting by a factor of 10% to provide sufficient safety margin.
    - Timer shall be set to allow sufficient time, with 12 cycle’s margin, for instantaneous clearing of external faults.
  - Summation Time Overcurrent Ground:
    - Pickup setting should be approximately 125% of the maximum current flowing through this relay for faults restricted to the pickup settings on the Time Overcurrent Ground relays on the 69 kV or 138 kV line terminals being backed up.

- Time delay should be set to select with other protective devices on the system with the system normal and with the system altered by any single contingency, with a minimum margin of 12 cycles.

- Summation Definite Time Overcurrent Ground:

  - Setting must prevent operation of this relay for faults which will be cleared by action of time delay relays with the system normal and with the system altered by any single contingency. Setting should be 110% of the maximum current flow through this relay for faults that are not cleared by instantaneous relays. This maximum current flow is determined by increasing the instantaneous relay setting by a factor of 10% to provide sufficient safety margin.

  - Timer shall be set to allow sufficient time, with 12 cycles margin, for instantaneous clearing of external faults.

- Tertiary circulating current relay and over excitation relay for 500-138 kV transformers only.

Isolation of the 230-138 kV or 230-69 kV transformers from the 230 kV side is provided by a circuit breaker.

4.2. 69kV and 138kV Bus Protection

Since bus faults will generally result in high magnitudes of fault current, it is imperative that these faults be cleared as rapidly as possible. This protection generally consists of utilizing current type differential relays. Operation of the bus protective relays will initiate tripping of all circuit breakers required to isolate the faulted bus.

As a practice, the bus differential relays are set as sensitive as possible within the following constraints:

- Thermal rating of relay is not exceeded under maximum load flow or fault conditions.

- Relay must not operate for external faults, load current, or inrush current. To accomplish the above practice, the differential relays are usually set at maximum sensitivity based on the manufacturer's recommendation.

4.3. Station Service Transformer Protection

Station service transformers are often supplied directly from the main transformer tertiary winding. Protection for these transformers consists of current limiting fuses installed at beginning of the leads from the tertiary to the station service transformer.

4.4. Line Protection

Since the impact of 69 kV or 138 kV line faults is not as potentially widespread as those on the Bulk Power System, high speed clearing for all line faults is not considered essential. Therefore, a pilot relaying scheme is provided only when unusual circumstances dictate.

Automatic reclosing is used on all 69 kV and 138 kV regional delivery lines, excluding those consisting entirely of underground cables. Lines within the existing Regional Delivery System can be classified into three categories as follows:

- Lines which are normally operated as tie lines as part of the network.
- Lines which are normally operated radial, but which have sectionalizing facilities available to be made part of the network.
- Lines normally operated radial with no sectionalizing facilities available to be made part of the network.

In order to maximize economic operation of our system, protective equipment should not limit the ability of the above lines to supply load and to provide area protection. Relaying shall be installed, therefore, to provide maximum flexibility in utilizing these lines to their full operational design intent. To accomplish this goal, line relaying shall be provided as follows:

- Instantaneous Phase (Zone 1) - Directional Distance or Instantaneous Overcurrent (Directional if required) Relays.
- Time Phase (Zone 2) - Directional Distance Relays with characteristic suitable to carry the line's maximum load rating and to protect the line with the system normal and with the normal system altered by any single contingency. Time delay is obtained by utilization of a suitable timer or a torque-controlled time overcurrent relay with an inverse time- current characteristic.
- Instantaneous Ground - Directional instantaneous overcurrent relay.
- Definite Time Ground (if needed) - Directional instantaneous overcurrent relay. Time delay is obtained by utilizing a suitable timer.
- Time Ground - Directional time overcurrent relay with a very inverse time-current characteristic.

In cases when pilot relaying is required, similar guidelines to those used for 230 kV lines may be applied. The current transformer ratios on the 69 kV and 138 kV terminals shall be such that the line's load carrying capability will not be limited by the thermal capability of the current transformers or the equipment they supply. Detailed relay requirements and settings are based, therefore, on the following guidelines:

- With sectionalizing normal, line coverage shall exist with the system normal and with the normal system altered by any single contingency.
- With sectionalizing normal, coordination and selectivity shall exist (except in preselected and specific instances) with all other protective devices on the system, with the system normal and with the system altered by any single contingency.
- With sectionalizing abnormal, adequate line coverage, relay coordination and selectivity shall be feasible with the normal system altered by any single contingency. To accomplish this, temporary relay settings may be required but their need minimized whenever possible.
- Selectivity with primary protective devices at 69-12.47 kV and 138-12.47 kV distribution substations and customer fuses is not an absolute requirement. Selectivity with the 12.47 kV protective devices, however, is a requirement.

Guidelines that are followed in determining actual settings in order to obtain line coverage and relay coordination are as follows:

4.4.1. Instantaneous Phase

Directional Distance

- Set at least 10% short of nearest remote bus. Some additional margin is applied when utilizing older type distance relays.
- Setting should not limit the line's maximum load carrying capability based on the criteria outlined in Appendix II.

Instantaneous Overcurrent (Directional if required)

- Pickup setting should be 115% of the maximum current flow through this relay for external faults based on the system normal or altered by any single contingency.

4.4.2. Time Phase

Directional Distance

- Set for complete coverage of the line with a minimum setting of 125% of the maximum apparent impedance of the protected line. Preferably the setting should provide for a minimum overreach of 5 ohms beyond the maximum apparent line impedance at the line angle. Coverage should include a minimum of 125% of the maximum arc resistance expected for phase faults at any location on the protected line.

- Setting must not limit the line's maximum load carrying capability.
- Setting should not allow relay operation for external faults not detected by Instantaneous Relays with the system normal or with it altered by any single contingency. A safety margin of 10% overreach of the time phase distance relay and a 10% increase to the setting of the instantaneous relay (decrease if a distance relay) should be applied.
- Timer of controlled Time Overcurrent Relay - Setting must allow sufficient time with a minimum of 12 cycles margin, for instantaneous clearing of external faults.

4.4.3. Instantaneous Ground

Directional Instantaneous Overcurrent

- Pickup setting should be 115% of the maximum current flow through this relay for external faults based on the system normal or altered by any single contingency.

4.4.4. Definite Time Ground

Directional Instantaneous Overcurrent

- Pickup setting should be 110% of the maximum current flow through this relay for external faults not detected by instantaneous relays with the system normal or with it altered by any single contingency. The instantaneous relays' setting should be increased by a factor of 10% to provide sufficient safety margin.
- Timer shall be set to allow sufficient time, with 12 cycles margin, for instantaneous clearing of external faults.

4.4.5. Time Ground

Directional Time Overcurrent

- Pickup setting should be set at a minimum of approximately 120 primary amperes. A higher setting is permissible based on the specific coordination and coverage requirements. It is desirable to be capable of detecting ground faults with up to 100 ohms of fault restriction.
- Time delay shall be set to select with all other ground relays on the system with 12 cycles margin with the system normal and with the system altered by any single contingency.

4.5. Reclosing

Delayed, three shot, automatic reclosing is applied on all terminals of overhead lines. The standard reclosing schedule applied to 69 kV and 138 kV line terminals is as follows:

- 1st shot reclosing – 90 cycles (1.5 seconds)
- 2nd shot reclosing – 900 cycles (15 seconds)
- 3rd shot reclosing – 900 cycles (15 seconds)

One terminal of a network line shall be designated as the "initiating" terminal with the "Follower" terminal(s) having facilities to close on a live or dead line. (Each terminal may be provided with facilities to close on a live or dead line). The "Follower" terminal(s) will close on voltage check unless it is in the proximity of a generator and the possibility exists that the generator may become isolated from the system. In these cases a synchrocheck relay is applied. In some instances a different reclosing schedule may be needed due to customer or system requirements.

4.6. Generation – NUG/IPP

Refer to other PPL EU documents regarding interconnection of Independent Power Producers.