Protection Design - Standard

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1. Introduction

1.1 Purpose

This standard specifies the requirements for the design of Protection Systems.

1.1.1 Requirements for Protection Systems

- To enhance safety to the public and staff who are working on Powerlink assets through the fast clearance of high voltage faults,
- To protect high voltage electrical plant by initiating its fast disconnection from the transmission system, when it has failed or is at risk of damage,
- To ensure only the failed plant or plant at risk will be disconnected from the system,
- To ensure the power system does not become unstable as a result of faults that are credible contingency events,
- To ensure inter-regional or intra-regional power transfers are not unduly constrained,
- To ensure consequential equipment damage is minimised,
- To ensure the continued reliable operation of the transmission system following an operation of plant protection,
- To ensure the continued stable operation of the power system following a major system disturbance,
- To provide backup protection in the event a circuit breaker fails to trip under fault conditions,
- To maximise the availability of transmission plant during maintenance or failures of protection systems,
- To maximise the availability of protection systems,
- To ensure compliance with relevant Acts, Regulations, Rules and Standards.

1.1.2 Requirements for Protection Ancillary Functions

- To provide appropriate information for fault management and maintenance,
- To enable secure remote access to information for plant monitoring and fault management,
- To provide effective self-diagnostic function for protection systems.

1.2 Scope

This document describes the policies for faults considered credible contingency events in the National Electricity Rules (NER) Clauses S5.1.2.1 (a) to (d).

This document describes the standards for the design of: -

- Transmission Line Protection
- Hybrid Transmission Line Protection
- Transformer Protection
- Busbar Protection
- Reactor Protection
- Capacitor Protection
- SVC / STATCOM Protection
- Circuit Breaker Fail Protection
- Protection Signalling
- Protection Ancillary Functions

1.3 References

Unless otherwise specified, the latest edition of the referenced document (including any amendments) applies.

Document code	Document title
NER	National Electricity Rules
IEC 60255	IEC Standard – Measuring relays and protection equipment
IEC 60834	IEC Standard – Teleprotection Equipment of Power Systems

1.4 Defined terms

Terms	Definition
AC	Alternating Current
CB	Circuit Breaker
CT	Current Transformer
DC	Direct Current
DEF	Direction Earth Fault
HV	High Voltage
IEC	International Electrotechnical Commission
kV	KiloVolts
LV	Low Voltage
NER	National Electricity Rules
NPS	Negative phase sequence or unbalance protection
OC & EF	Overcurrent and earth fault
OH	OverHead (transmission line)
POR	Permissive Over-Reach
PRD	Pressure relief device or Qualitrol (transformer mechanical protection device)
PUR	Permissive Under-Reach
REF	Restricted earth fault scheme (transformer protection)
SCADA	Supervisory Control And Data Acquisition
STATCOM	Static Synchronous Compensator
SVC	Static Var Compensator
TPAR	Three Pole Auto-Reclose
VT	Voltage Transformer
WAMPAC	Wide Area Monitoring, Protection and Control

2. Standard

The main function of the protection relay is the timely and accurate operation of the protection system. The operation of the system will not be jeopardised by ancillary functions.

The protection systems used by Powerlink will be designed to ensure system security consistent with NER requirements. The protection systems used at a connection point between Powerlink and another transmission network user will additionally be co-ordinated by Powerlink to ensure protection scheme compatibility.

Due to technological and economical limits, the below mentioned philosophy MAY be compromised, but only after a sufficient risk analysis is carried out. However, safety to the public and workforce is NEVER to be compromised.

2.1 Protection Basic Philosophy

The basic design philosophy for a protection scheme is as follows:

- Each protection system should:
  - Employ Reliability Centred Design Principles,
  - Be as simple as possible,
  - Be designed to meet the reliability objectives of the system,
  - Be designed to meet the security objectives of the system,
  - Be designed with the philosophy that reliability should take precedence over security if a conflict should arise.
- The protection systems are duplicated (or primary and back-up systems are provided) for each item of plant such that:
  - Each system will be capable of detecting and clearing solid or bolted faults on the primary plant,
  - Each system should be capable of detecting and clearing high resistance / low level faults on the primary plant,
  - The primary plant can safely remain in service during protection or communication system maintenance, or failure of any one item of protection equipment occurs,
  - Protection relays in the duplicated systems should preferably be sourced from different manufacturers. It may be acceptable where this cannot be achieved, to have the equipment which will use dissimilar algorithms to minimise the possibility of common mode failure,
  - Note that it is acceptable to use the same electromechanical protection relays for duplicated high impedance differential schemes. This is due to scheme simplicity and low failure rate of these type of relays,
  - Each system will be assigned to an independent DC battery supply and independent protection circuits. No galvanic connection that affects the protection functions will exist between duplicated protection systems.
- The protection scheme's communication systems will be arranged so that any common mode failure will allow operation of at least one protection system.
- With some duplicated protection systems, it is acceptable and expected that one scheme will be more sensitive to certain fault types compared to the complementary scheme.

2.2 Performance Goals

2.2.1 Fault Clearance Times

The fault clearance times of protection schemes <u>must</u> ensure:

- Legislative requirements are complied with, in particular those that are designed to reduce the danger to the public and workforce,
- Faults clearance times comply with section S5.1.9 of the NER.

The fault clearance times of protection systems should ensure, within technological and economic limits:

- Compliance with Table 1 - Maximum Fault Clearance Times (NER Table S5.1a.2) for all types of faults for new installations and upgrades or alterations to existing systems,
- Damage at the fault point is minimised,
- There is no damage to healthy plant due to the passage of fault current.

Maximum Fault Clearance Times (milliseconds)			
System Voltage (kV)	**Faulted End**	**Remote End**	**Breaker Fail**
≥400kV	80	100	175
≥250kV to < 400kV	100	120	250
>100kV to < 250kV	120	220	430
≤ 100kV	As necessary to prevent plant damage and meet stability requirements		

Table 1 - Maximum Fault Clearance Times (NER Table S5.1a.2)

2.2.2 Availability

The protection relay manufacturer will provide the mean time between failures and the mean time to repair as well as the calculation method used to determine each statistic during the relay evaluation phase. These statistics along with purchase and repair records kept by the Procurement staff will be used to determine relay performance of different product families and manufacturers.

Connecting the relay watchdog contact and internal relay alarms to the control system is used to monitor protection relay health and availability.

Each individual protection system will be capable of being isolated without affecting other protection systems or substation operation.

The relays undergo regular maintenance. The maintenance procedure is determined by a reliability centred maintenance analysis workshop. For further details refer to the Secondary System Maintenance Standard.

2.2.3 Accuracy

The accuracy of protection components will be commensurate with achieving the selectivity of operation and required clearing times. The accuracy requirements will be outlined in the specification.

2.3 Standard

2.3.1 General

In accordance with these requirements, protection design should be based on Powerlink's policies, Substation Design Specifications and the NER.

The design will:

- Provide a safe operating environment for staff working in the substation and provide facilities to minimise maintenance,
- Overlap the protection zones and eliminate 'dead zones or blind spots',
- Perform its intended function and prevent the inadvertent operation of protection systems,
- Maximise the load transfer capability of the plant or line through the judicious selection of scheme, relay characteristic or setting as appropriate,
- Ensure an uncleared fault in an adjoining zone will be cleared with appropriate grading of operation.

The design, layout, selection and installation of equipment and circuits, will minimise the coupling to primary circuits, the environment, and interference generating devices, so as to enable protection equipment complying with IEC 60255 to be incorporated.

For duplicated independent protection systems, the systems will be called 'X' and 'Y' respectively.

Unless otherwise stated, all relevant protection schemes will be capable of independently achieving the requirements of 2.2 Performance Goals.

2.3.2 Protection Systems above 400kV

Additional requirements for protection of systems above 400 kV include:

- The preferred protection scheme for transmission line protection will be a single travelling wave protection scheme in addition to duplicated line differential protection.
- High impedance protection should be used instead of a restricted earth fault scheme where 3 x single phase transformers are installed.
- The current check facility within CB fail schemes must reset within 20mS, even in the presence of CT saturation and CT residual DC subsidence current,
- Primary protection trip outputs which are required to be NOT latched will be maintained for the minimum specified CB tripping time.

2.3.3 Transmission Line Protection

Transmission lines will be protected by two independent protection schemes. The trip outputs will not latch.

Transmission line protection will initiate autoreclose for line differential, zone 1 or fast zone 2 operation due to line discrimination. Refer to the Auto Reclosing Scheme documents for further details.

For two ended lines, duplicate line differential schemes are acceptable when the relays at each end of the line are compatible and there are diverse communication paths. Line differential and an accelerated distance scheme is also acceptable for two ended lines. For multi ended lines, duplicate line differential is the preferred method of line protection.

Modern relays have the capability of both differential and distance protection. Backup basic distance should be set on line differential relays in the event of a loss communications between relays.

At least one (X or Y no requirement for both) protection scheme for lines will operate for high resistance earth faults. Line differential relays provide the required high resistance earth fault protection. Otherwise, a distance relay directional earth fault (DEF) scheme should be implemented. The DEF scheme should only be implemented on two ended feeders where Powerlink owns the feeder and both local and remote protection relays.

2.3.4 Hybrid Transmission Line Protection

Transmission lines that include underground cable sections (hybrid feeders) or those comprised only of underground cable will be protected by two independent protection schemes. Trip outputs will not latch.

In the case of hybrid feeders, transmission line protection may initiate autoreclose, but only for faults occurring on the overhead feeder sections. Refer to the Auto Reclosing Scheme documents.

In the case of short transmission lines (<5km overhead), or where the cable section becomes significant (such that the OH feeder impedances, especially zero sequence, no longer dominate), duplicate current differential protection should be implemented.

2.3.5 Stub Protection

Stubs will be protected by two independent protection schemes.

2.3.6 Transformer Protection

HV power transformers and any associated earthing transformers will be protected by two independent protection systems. The preferred protection scheme for the power transformer is duplicate bias differential.

A single buchholz system each for main and switch tank, over temperature and pressure relief devices (PRD) will be spread across the two systems so as to give effective redundancy. A single restricted earth fault (REF) scheme should be implemented per star connected galvanic winding (i.e. single REF scheme for autotransformers and two REF schemes for star-star transformers). The primary protection, buchholz, PRD and REF trip outputs will trip HV & LV CBs and latch.

Transformers without a local HV or LV circuit breaker require duplicate protection signalling to trip the remote end. This signalling will be incorporated within the relevant line protection.

A single thermal (e.g. I^2t) overload protection system should be installed on each transformer where the protection relay has the capability. Only the LV CB will be tripped. The thermal overload trip output will not latch.

Winding and Oil temperature protection systems should be installed on each transformer, spread across the two systems so as to give effective redundancy. Only the LV CB will be tripped. The temperature trip outputs will not latch. The Network Operator is to ensure the transformer is not overheated by curtailing load as necessary. This protection is a backup system.

Overcurrent and earth fault schemes should be implemented on a case by case basis as required. Details of these schemes are outlined in the design standards.

Additional guidelines for renewable transformers are provided in the Renewable Energy Transformer Protection Guideline.

2.3.7 Busbar Protection

HV busbars will be protected by two independent protection systems. The preferred protection scheme for busbars is duplicate differential protection. Further details regarding high impedance and low impedance differential schemes are outlined in the relevant design standards. Trip outputs will latch.

Bus sections and bus section CBs should have suitable location of CTs to eliminate ‘blind spots’. Where ‘blind spots’ do exist, protection to clear ‘blind spot’ faults will be provided. These systems should be duplicated where not backed-up by another protection and must be duplicated at 275kV and above.

As allowed by Rules Clause S5.1.9 L (1), the CB fail protection scheme may be used to clear a ‘blind spot’ fault. The scheme will send an intertrip to the remote end. The intertrip will trip the remote end CB and initiate CB fail at the remote end.

2.3.8 Reactor Protection

A buchholz relay and pressure relief device will be provided for oil cooled reactors. These mechanical protections will be spread across the two systems so as to give effective redundancy.

Oil and winding temperature protections will also be provided. These will not latch.

In addition to the above, shunt reactors connected to transmission lines will be protected by a single differential protection system. The backup protection function will be provided by the line protection system. Shunt reactors connected directly to the bus will have duplicated differential protection schemes.

Tertiary connected shunt reactors will be protected by two independent protection systems.

The trip outputs will latch for primary protection, buchholz, and pressure relief device (where fitted).

To minimise damage to 3 phase reactors (as opposed to 3 x 1 phase units), under failure of a CB pole to close or open, a single unbalance protection facility should also be provided, to trip all poles of the reactor CB (e.g. NPS protection). This is especially important for 3 limb units. CB fail should also be then initiated. Unbalance trip outputs will not latch.

2.3.9 Capacitor Protection

The capacitor banks will be protected by duplicate protection systems. Trip outputs will not latch. At voltage levels greater than 250kV, duplicate ‘out of balance’ protection systems will be required and at voltage levels less than 250kV, a single ‘out of balance’ protection system will be required. Two stages for each balance protection will be implemented. Stage one will issue an alarm and stage two will issue a trip.

Overvoltage protection should be fitted to capacitor banks to reduce the risk of plant damage due to high system voltage levels. The requirement here is separate to the emergency voltage regulation system requirements.

A single negative phase sequence overcurrent (e.g. NPS protection) protection will be provided for capacitor banks to reduce the risk of plant damage due to circuit breaker pole discrepancy. CB fail should also be then initiated. Unbalance trip outputs will not latch.

2.3.10 SVC / STATCOM Protection

The following high voltage equipment will be protected by independent protection systems in accordance with their relevant Sections of this Policy:

- HV Line (substation to SVC / STATCOM)
- Transformers
- Reactors
- Capacitors and Filters (trip and alarms required)
- Busbars

The SVC / STATCOM will include components such as thyristors, IGBT, IGCT, valves, DC capacitors and cooling pumps / fans. The protection system for this equipment will be supplied by the manufacturers. The protection system must ensure:

- High availability
- High reliability
- Low failure rate
- High mean time between failure
- Resilience under specified system conditions

The supplier will provide detailed reports to demonstrate compliance to these requirements.

2.3.11 Circuit Breaker Fail Protection

All HV circuit breakers will be protected by two independent CB fail protection systems. It is acceptable for older circuit breakers at voltages less than 250kV to have a single CB fail protection where the existing equipment does not allow for a duplicated CB fail protection system (i.e. either of the two relays does not have a suitable CB fail function). Trip signals will not latch.

As CB fail protection scheme trips all of the associated bus circuit breakers and remote circuit breaker(s), the security of operation will be ensured so that only genuine events cause operation. In particular, the absence of AC current will be the criteria determining the open status of the CB poles. However, installations where fault current may fall below the CB fail current check setting, will also include CB auxiliary switch status as a CB fail initiating criteria, with particular cases including:

- Transformer buchholz protection
- SVC protection

CB fail schemes should comply with NER clearance times for all scenarios. Where this is not possible the following measures should be taken in conjunction with design risk assessment:

i) Ensure that at least one of the duplicated CB fail schemes does not exceed the maximum CB fail fault clearance times for all scenarios.
ii) Ensure compliance with the minimum access standard for fault clearances of a breaker fail protection system for all scenarios (i.e. fault is cleared in time that would not damage any part of the power system other than the faulted element while fault current is flowing or being interrupted).
iii) Review network analysis and requirements with Network Planning to consider network risk and cost-benefit for options during scoping and estimate for project design options
iv) Comply with performance standards for connections set by Business Development and Planning
v) Review primary fault current ratings and impact with Substation Strategies and Primary Design
vi) Review safety compliance, such as with earth grid, safe step and touch potential for associated substation and transmission line assets with Substation Strategies and Primary Design
vii) Signalling scheme baud rates are increased to the maximum allowed by the relevant design standards.
viii) The CB fail scenarios that are not expected or do not meet the times are documented in a Register with options considered and communicated to the Senior Engineer, Planning Engineer and the Asset Manager.

2.3.12 System Protection

For the System Protection standard details (e.g. overvoltage, undervoltage, underfrequency, WAMPAC) refer to the Secondary System Design Standard.

2.4 Protection Signalling

Protection signalling will be employed on all transmission line protection schemes as required.

The communication systems are to be arranged so that a common mode failure or maintenance of a communication system will allow for code compliant operation of at least one protection system.

Only Powerlink owned telecommunication paths, or paths where Powerlink has an operational usage agreement, shall be used to carry protection signalling. Communication systems should not employ automatic route switching for line differential protection.

The preference is to use the protection relays' built-in proprietary communication protocol rather than discrete protection signalling units. The built-in proprietary protocol will be deemed suitable during the initial relay evaluation period. The scheme must be able to exchange eight bits of status information and be compliant with IEC 60834-1.

2.4.1 Protection signalling for CB fail

CB fail direct intertrip signals will be exchanged over the protection signalling path for remote backup purposes. For modern relays, a single DIT signal will trip the remote end CB and also initiate the remote CB fail protection thus catering for any blind spot or dead zone faults. Legacy schemes may also have an additional separate signal for tripping the remote end CB and NOT initiating remote end CB fail protection. As the DIT is issuing a trip directly and not being checked by the receiving relay, it is preferred that this signal must be received two consecutive times before issuing a trip output.

2.4.2 Protection signalling for accelerated distance schemes

Permissive overreach schemes will be the preferred accelerated distance scheme for transmission line applications. Permissive Underreach schemes and Blocking schemes can also be used. No consecutive checking of received signals is required for accelerated distance scheme signals.

2.4.3 Protection Signalling for directional earth fault schemes

Where duplicate distance schemes are implemented and as noted in the transmission line section above, distance relays will require DEF schemes to operate for high resistance earth faults.

Permissive overreach DEF scheme is the preferred design. A separate DEF signal is required.

The implementation of blocking DEF schemes is NOT to be used due to the complexity of the blocking intertrip signals and additional single pole open signalling requirements.

No consecutive checking of received signals is required for directional earth fault schemes.

2.5 Protection Ancillary Functions

2.5.1 SCADA Interface

Appropriate alarms, indications, statuses and controls will be provided as stated in, SCADA Requirements for Operational Purposes Standard.

Remote changing of setting groups via the SCADA interface will be allowed for transmission line protection applications. The protection permit and configuration management procedures will be adhered to.

2.5.2 Disturbance/ event recording facilities

Appropriate disturbance/event recording facilities will be provided as stated in 'Data Requirements for Use in Fault Management and Condition Monitoring'. The impedance fault location function should be configured on all line protection relays as required. The internal relay event recorder should be fully configured. All of the required analogue and digital signals should be mapped to the relay's internal disturbance recorder to allow for in depth event analysis.

2.5.3 Time Synchronisation

The relay should be connected to the substation clock. The internal event list, internal disturbance records and interface to the SCADA system should have a ±1ms resolution.

2.5.4 Remote Interrogation facilities

Appropriate remote interrogation facilities matching the available communication medium will be provided to access substation disturbance/event information.

Remote access security for protection relays will adhere to the Powerlink cybersecurity policies and guidelines.

Where remote interrogation facilities are not available, latching trip indications will be provided on the front screen of the protection relay.

Passwords are to be changed from manufacturers' default passwords and stored in the configuration management system.

Remote setting changes will be allowed for in future applications. The configuration management procedures will be adhered to.

2.5.5 Self-diagnostic facilities

Equipment used in protection systems will provide and communicate comprehensive self-diagnostic functionality of system operation, calibration, stability, analogue circuit health (CT, VT) as well as details on other critical functions. The implementation of supervision functions will be detailed in the relevant design standards.

Communication of the self-diagnosis should be monitored through the watchdog contact as well as serial or ethernet links to the SCADA system and remote interrogation facilities.

2.5.6 Intra substation communication

It is preferred the protection device communicates to the SCADA interface device by a protocol specified by an International Standard or Association.

2.5.7 Security of Protection Relay Input circuits

The protection relay's input circuits will be designed to provide secure operation under normal and abnormal substation conditions. Some examples include high noise events and earth on battery events.