Part of Energy Queensland

Substation Standard

Standard for Interlocking

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Abstract: This standard document contains requirements around interlocking for the operation and or access to primary plant.

Keywords: Interlocking, Switchgear, Switchboard

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1 Overview

1.1 Purpose

The purpose of this standard is to provide guidance on the application of interlocking within substations for both indoor and outdoor switchgear. As new technologies are implemented in substations the cost of interlocking schemes can be reduced while providing improved protection. This standard will influence the procurement of future plant to ensure that the plant is capable of the requirements in this document. New switchgear shall have the required contacts, auxiliary relays and blocking magnets or mechanical interlocks needed to achieve the requirements of this document.

1.2 Scope

Interlocking makes the operation of a switching device dependent upon the position or operation of one or more other pieces of equipment. Interlocking is to be used on HV plant to prevent incorrect operation that may result in harm to the operator or damage plant.

This standard will cover the following areas:

- Interlocking for access to HV plant
- Interlocking to control the operation of HV plant

This standard does not cover protection interlocks. Where tools are required to access HV plant interlocking is not required.

The interlocking requirements presented in this standard are defined for both bay and switchgear type. When purchasing new switchgear, it shall meet the requirements for the switchgear type and where technology allows, and it is cost beneficial the additional bay requirements shall also be met.

2 References

2.1 Legislation, regulations, rules, and codes

(National Electricity Rules, 2023) (AEMC)

(Queensland Electricity Act, 1994) (Queensland Government)

(Queensland Electricity Regulation, 2006) (Queensland Government)

(Queensland Electrical Safety Act, 2002) (Queensland Government)

(Queensland Electrical Safety Regulation, 2013) (Queensland Government)

(Queensland Work Health and Safety Act, 2011) (Queensland Government)

(Queensland Work Health and Safety Regulation, 2011) (Queensland Government)

2.2 Ergon Energy controlled documents

Operate the Network Enterprise Process - P53 - 2909674

https://ecmprd.erp.energyqonline.com.au/otcs/cs.exe/app/nodes/2909674

Health and Safety Policy - P009 - 692225

https://ecmprd.erp.energyqonline.com.au/otcs/cs.exe/app/nodes/692225

Network Risk Framework – 2877290

https://ecmprd.erp.energyqonline.com.au/otcs/cs.exe/app/nodes/2877290

2.3 Ergon Energy other documents

Standard ZSS Template - 11kV Feeder Bottom Panel - EESS-10307

Standard ZSS Template - 11kV Feeder Top Panel - EESS-10306

Standard ZSS Template - SCADA RTU 1 Panel +1A2.3 - EESS-10321

Standard ZSS Template - SCADA RTU 2 Panel +1A12.3 - EESS-10322

Standard ZSS Template - SCADA RTU 3 Panel +1B3.3 - EESS-10323

Standard ZSS Template - SCADA RTU 4 Panel +1B5.3 - EESS-10324

Standard ZSS Template - SCADA RTU 5 Panel +1B9.3 - EESS-10325

Technical Specification for Capacitor Banks - EESS-10731-01-0A

Protection Relay Testing for Commissioning SWP - SP0518

Power Capacitor Bank Applications and Shunt Capacitor Bank Design Guide - SS-1-4.3

2.4 Other sources

(AS 2067, 2016), Substations and high voltage installations exceeding 1 kV a.c.

(AS 61508.1, 2011), Functional safety of electrical/electronic/programmable electronic safety-related systems - General requirements

(AS 61508.2, 2011), Functional safety of electrical/electronic/programmable electronic safety-related systems - Requirements for electrical/electronic/programmable electronic safety-related systems

(AS 61508.3, 2011), Functional safety of electrical/electronic/programmable electronic safety-related systems - Software requirements

(AS 61508.4, 2011), Functional safety of electrical/electronic/programmable electronic safety-related systems - Definitions and abbreviations

(AS 61508.5, 2011), Functional safety of electrical/electronic/programmable electronic safety-related systems - Examples of methods for the determination of safety integrity levels

(AS 61508.6, 2011), Functional safety of electrical/electronic/programmable electronic safety-related systems - Guidelines on the application of IEC 61508-2 and IEC 61508-3

(AS 61508.7, 2011), Functional safety of electrical/electronic/programmable electronic safety-related systems - Overview of techniques and measures

(AS 62271.200, 2005), High- voltage switchgear and controlgear

(IEC 61243-1, 2009), Live working - Voltage detectors - Part 1: Capacitive type to be used for voltages exceeding 1 kV a.c.

(IEC 61243-2, 2002), Live working - Voltage detectors - Part 2: Resistive type to be used for voltages of 1 kV to 36 kV a.c.

(IEC 61243-5, 1997), Live working - Voltage detectors - Part 5: Voltage detecting systems (VDS)

(IEC 61850), Communication networks and systems for power utility automation (All parts)

(IEC 62271-206, 2011), High-voltage switchgear and controlgear - Part 206: Voltage presence indicating systems for rated voltages above 1 kV and up to and including 52 kV

3 Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this standard, the following definitions apply.

Bay	A functional unit for feeder connection, transformer connection, bus section connection and capacitor bank connection
De-energised	Not connected to any source of electrical energy but not necessarily Isolated. De-Energised does not mean Isolated or discharged, or both. (P53)
Earth Position	Position of a removable part or state of a disconnector in which the closing of a mechanical devices causes a main circuit to be short-circuited and earthed. (AS 62271.200, 2005)
Isolated	Disconnected from all possible sources of energy by means that prevent unintentional energisation of the Electrical Apparatus and that are assessed as a suitable step in the process of making safe for access purposes. (P53)
Normal arrangement	The system arrangement which the network is normally operated it.
Nonwithdrawable Switchgear	Switchgear where a disconnector or isolator is used to provide physical break between the bus and circuit breaker. (AS 62271.200, 2005)
NOMAD	Mobile transformer with associated protection and control equipment
Shall	mandatory
Should	advisory
Service Position	Position of a removable part in which it is fully connected for its intended function. (AS 62271.200, 2005)
Switchgear	General term covering switching devices
T Style Substation	A substation that uses transportable building for the control buildings and constructed to the Ergon Energy T style standards
Test position	Position of a withdrawable part in which an isolating distance or segregation is established in the main circuit and in which the auxiliary circuits are connected. (AS 62271.200, 2005)
Withdrawable Switchgear	Switchgear where the circuit breaker can be physically disconnected from the circuit and removed from the switchboard. (AS 62271.200, 2005)

3.2 Acronyms and abbreviations

The following acronyms and abbreviations appear in this standard.

CB	Circuit Breaker
CBF	Circuit Breaker Fail
CT	Current Transformer
DC	Direct Current
DNOB	Do Not Operate Board
EDMS	Electronic Document Management System
ES	Earth Switch
GIS	Gas Insulated Switchgear
GOOSE	Generic Object Orientated Substation Event
HMI	Human Machine Interface
IED	Intelligent Electronic Device such as protection relays, metering devices, programmable logic controllers
I/O	Input or Output
MCB	Miniature Circuit Breaker
MMS	Manufacturing Message Specification
N/O	Normally Closed
SCADA	Supervisory Control and Data Acquisition
SEF	Sensitive Earth Fault
VDS	Voltage Detection System (IEC 61243-5, 1997)
VPI	Voltage Presence Indicator (IEC 62271-206, 2011)
VT	Voltage Transformer
ZSS 32	Zone Substation Standard with 32MVA Transformers

4 Interlocking principles

A well-designed interlocking system will allow an operator to place the system into any valid operational state and allow safe access to plant while preventing unsafe operation and access to plant not appropriately isolated. Switching sheets and operating procedures which are designed to prevent unsafe operations and access are an administration control whereas interlocking is an engineering control. Engineering controls are higher on the hierarchy of controls than administrative controls and as such interlocking should be implemented where possible to reduce the risk to staff and plant.

Interlocks shall be designed and installed to prevent access to energised or unearthed plant, the applications of earths to energised plant and the making of an electrical connection between live and earthed plant. Devices shall be prevented from operating above their rating; for example a disconnector shall be prevented from breaking load current.

4.1 Substation interlocking

Substation interlocking can be split into; bay level and station level. Bay level interlocks are associated with devices in a single bay such as circuit breaker, isolator and earth switch interaction in a feeder bay. Station level interlocks function between bays. Station level interlocks send either a block or an allow signal to the bay interlock schemes such as sending an allow to close to all circuit breakers on a bus when the bus section earth switch is open.

Interlocking between substations is considered for bay types with a connection to another substation as discussed in section 5.2. Bays include:

- Sub-transmission feeder bay
- Transformer ended feeder bay
- Generator bay
- Dedicated customer

4.2 Implementation

It is expected that the substation interlocking schemes will evolve as new technology is installed. It is not expected that the interlocking schemes of existing substations will be upgraded to meet this standard unless coinciding with switchgear replacement or secondary systems upgrades that facilitate the use of electronic interlocking.

Where switchgear is installed that enables the use of the interlocks, the requirements for the switchgear type as defined in section 5.4 shall be implemented. Bay specific interlocking requirements that interface with other items of plant should be implemented as the technology is available and the cost of implementation is not disproportionate to benefits. It is not expected that electrical interlocks will be installed on existing outdoor air insulated switchgear (AIS) gear to meet bay interlock requirements. Where the required statuses of air insulated switchgear are available these can be used in the interlocking schemes of other devices.

4.3 Fail safe design principles

The Standards Australia for Substations and high voltage installations exceeding 1 kV a.c. (AS 2067, 2016) requires that all electrical interlocks shall fail safely for the loss of the power supply. All new interlocks shall be designed to this requirement.

The Australian Standards for functional safety of electrical safety-related systems (AS 61508.1, 2011) requires a hazard and risk assessment to be completed and safety integrity levels to be applied. The manufacturers who currently supply IEDs to Ergon Energy do not produce devices that conform to the Australian Standards for functional safety of electrical safety-related systems (AS 61508.1, 2011), (AS 61508.2, 2011) and (AS 61508.3, 2011).

The mechanical interlocks implemented to prevent access to energised high voltage plant are not required to be designed to the Australian Standards for functional safety of electrical safety-related systems (AS 61508.1, 2011). The interlocks to control the operation of plant provide protection to both personnel and the plant. If the interlock scheme fails, the procedures in the operate the network process (P53), an administrative control, will continue to direct the safe operation of the plant. If this control also fails, the plant shall be designed to contain any arcing caused and safely vent any hot gases away from personnel.

Interlocking schemes shall be designed to be fail safe. All possible failures shall be considered including DC supply, intelligent electronic device (IED), blocking magnet failure, communications and any other equipment or system failures associated with the interlocking scheme. During the design stage the fail-safe state shall be determined. Some schemes may be designed to allow an operation in the failed state and other schemes may be required to block an operation in the failed state. Each element shall be considered individually and as part of the complete scheme.

5 Interlocking requirements

5.1 Common interlocking requirements

All interlocking schemes shall be fail-safe irrespective of the switchgear or bay type; section 5.6 details fail safe design.

5.1.1 Common bay interlocking requirements

The following shall be achieved for all bay types irrespective of the switchgear:

- Tripping by attempting isolation shall be prevented. For example a circuit breaker shall not be tripped if an attempt is made to operate the disconnector while the circuit breaker is closed.
- Where earths are applied through a circuit breaker, it shall not be possible to open it electrically whilst it is being used to apply the earth. It shall also be possible to padlock a circuit breaker to prevent the removal of an earth by mechanical means. Where an earth switch can be applied remotely, electrical interlocks shall be designed to prevent the operation of the circuit breaker except for the purpose of removing the earth.
- Disconnectors and earth switches shall be able to be locked with a padlock in either the open or closed position.
- Earths shall be able to be removed for testing and commission purposes.
- An isolated circuit breaker shall be operable for testing purposes; section 5.4.1 defines isolated for the different switchgear types.
- Where switchgear has specific cable compartments, access to these shall be prevented unless the circuit is isolated and earthed.
- Where plant is required to be proven de-energised a voltage detection system shall be used; section 5.5 has further details.
- Where operations are performed manually blocking magnets are not required to be installed. As a minimum, mechanical interlocks shall be used with associated plant and equipment.

5.1.2 Common station interlocking requirements

- A circuit breaker cannot be closed while either its corresponding circuit earth or a bus earth is applied.

5.2 Bay specific requirements

There are specific interlocking requirements for standard bay types. This section discusses the interlocking requirements for each of the bay types.

5.2.1 Distribution feeder bays

A typical distribution feeder bay is shown in Figure 1. The circuit breaker close blocking required for a distribution feeder bay is as described in section 5.1.1 Common bay interlocking requirements.

Each circuit earth shall be interlocked with its associated circuit breaker so that the circuit earth cannot be applied until the circuit breaker is open and isolated as defined by the switchgear type. Conversely, it shall not be possible to modify the circuit isolation whilst the circuit earth is applied. The circuit shall be proved de-energised before the circuit earth can be applied.

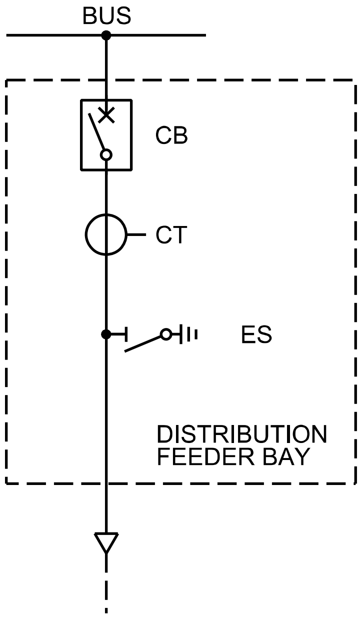


Figure 1: Typical distribution feeder

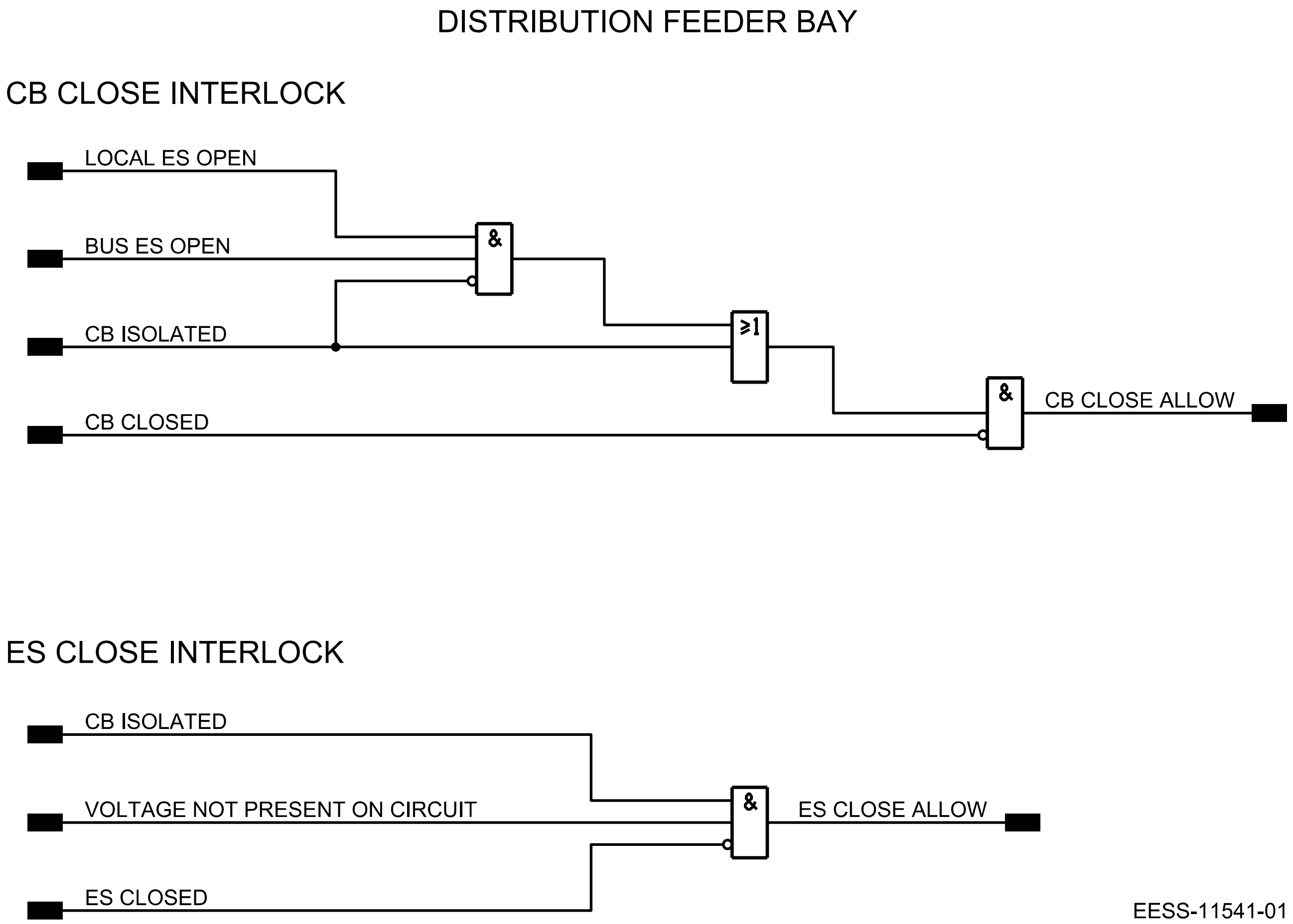


Figure 2: Distribution feeder interlocking logic

5.2.2 Bus section

The bus section circuit breaker shall be interlocked with the bus earth switches on the two buses that it connects. The circuit breaker shall be prevented from closing if any of these earth switches are closed.

Busbar earth switches shall be interlocked such that the busbar earth(s) cannot be applied unless all potential sources of in-feed to the bus (including all outgoing feeders on the bus) have been opened and isolated. The bus bar shall be proved de-energised before the earth can be applied. Conversely, it shall not be possible to modify any point of isolation from the busbars whilst busbar earths are applied.

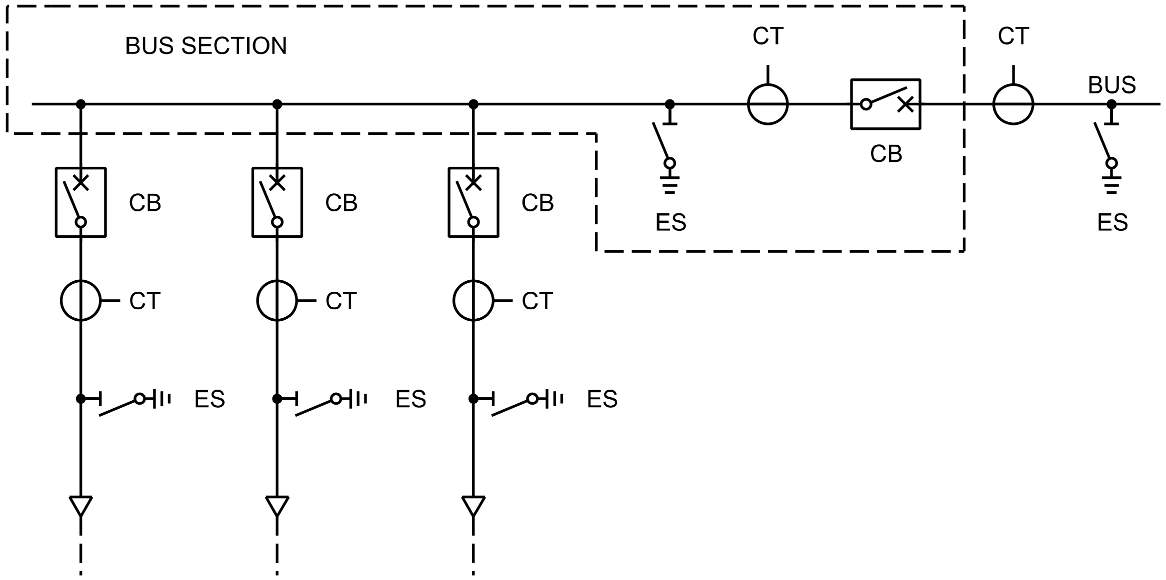


Figure 3: Typical bus section

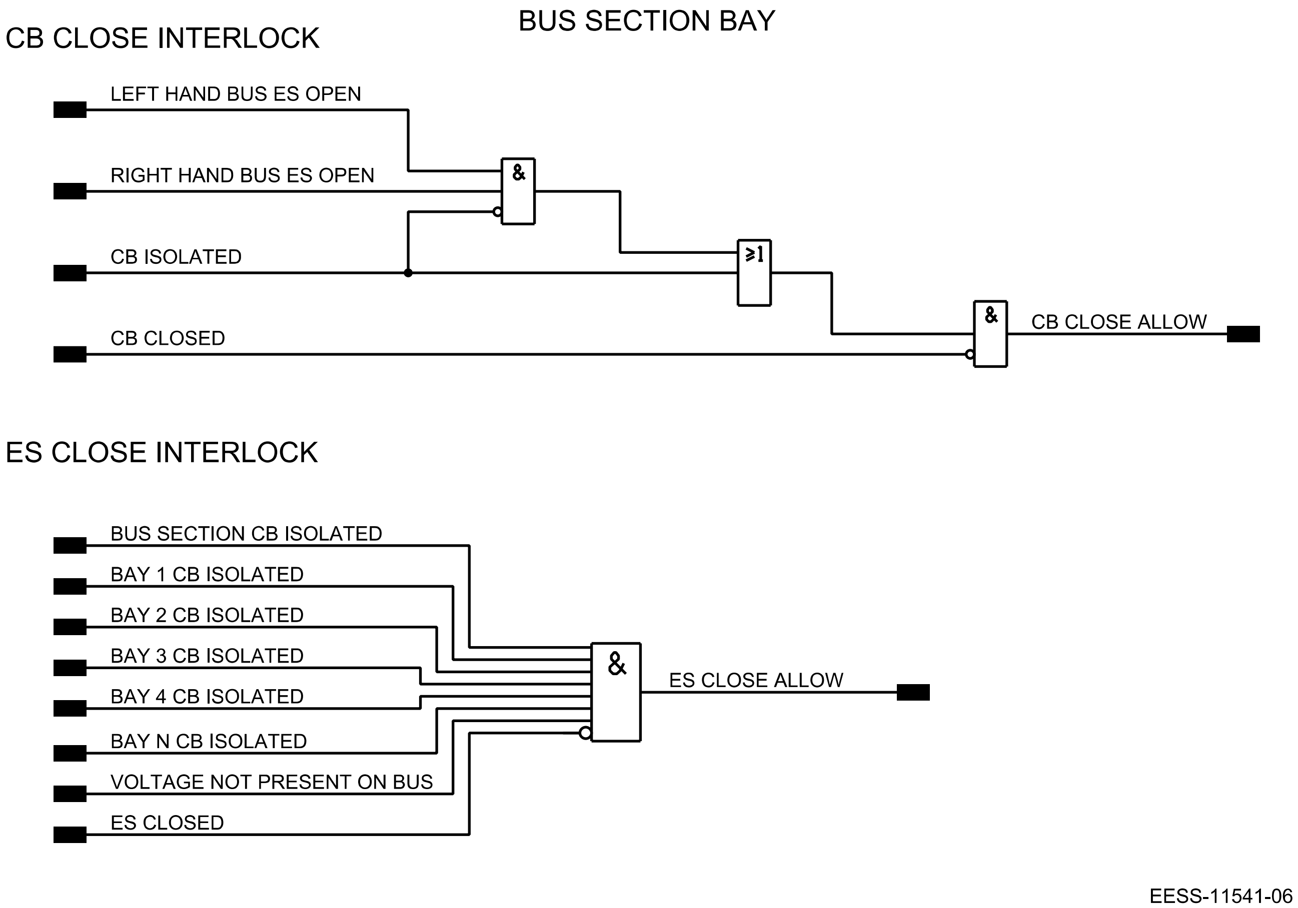


Figure 4: Bus section interlocking logic

5.2.3 Sub-transmission feeder bays

Many protection schemes installed on the sub-transmission and transmission network use a communications path between the substations. Feeders that have a communication path to all ends and no operational network connections to other feeders, the remote end isolation and earthing status shall be included in the interlocking schemes. Each end will send two signals an isolated and an earthed signal, which will be used in the interlocking logic. By sending a generic isolated signal instead of specific details (e.g. circuit breaker withdrawn or disconnector open) the switchgear type at the remote end is not required. With this approach the remote end determines if it is correctly isolated e.g. circuit breaker racked out, line isolator open, etc. The remote isolated signal is required before the earth can be applied, at the local end. The remote earthed signal is required to block removal of the isolation, at the local end. For a communications failure, the status of the remote end is not required to operate local plant.

Feeders with normally open switches to other feeders shall only be interlocked to the remote end if the statuses of all switches are available and included in the interlock scheme to ensure that the isolation and earthing required matches the system configuration at the time.

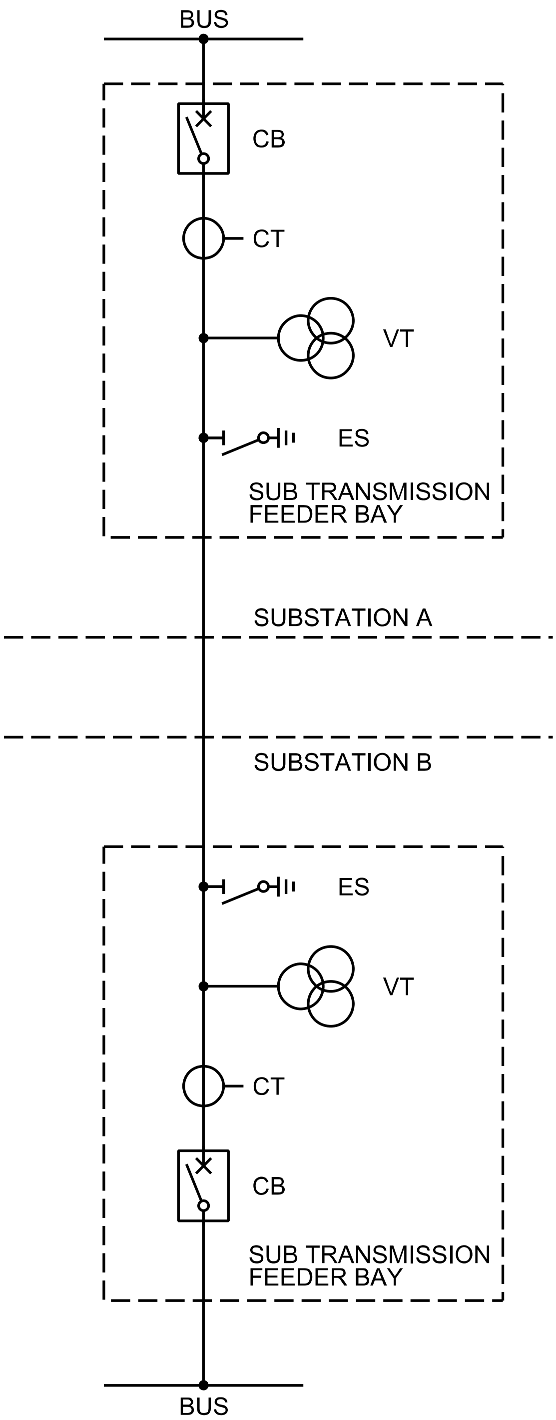


Figure 5: Typical sub-transmission feeder

The earth interlocks shall not be carried through HV switching devices. Only the line side earth switch is to be used. An example is a feeder with a tee off to a transformer is shown in Figure 6. The LV earth switch is downstream of the HV isolation point and shall not be used in the sub-transmission feeder interlocking scheme.

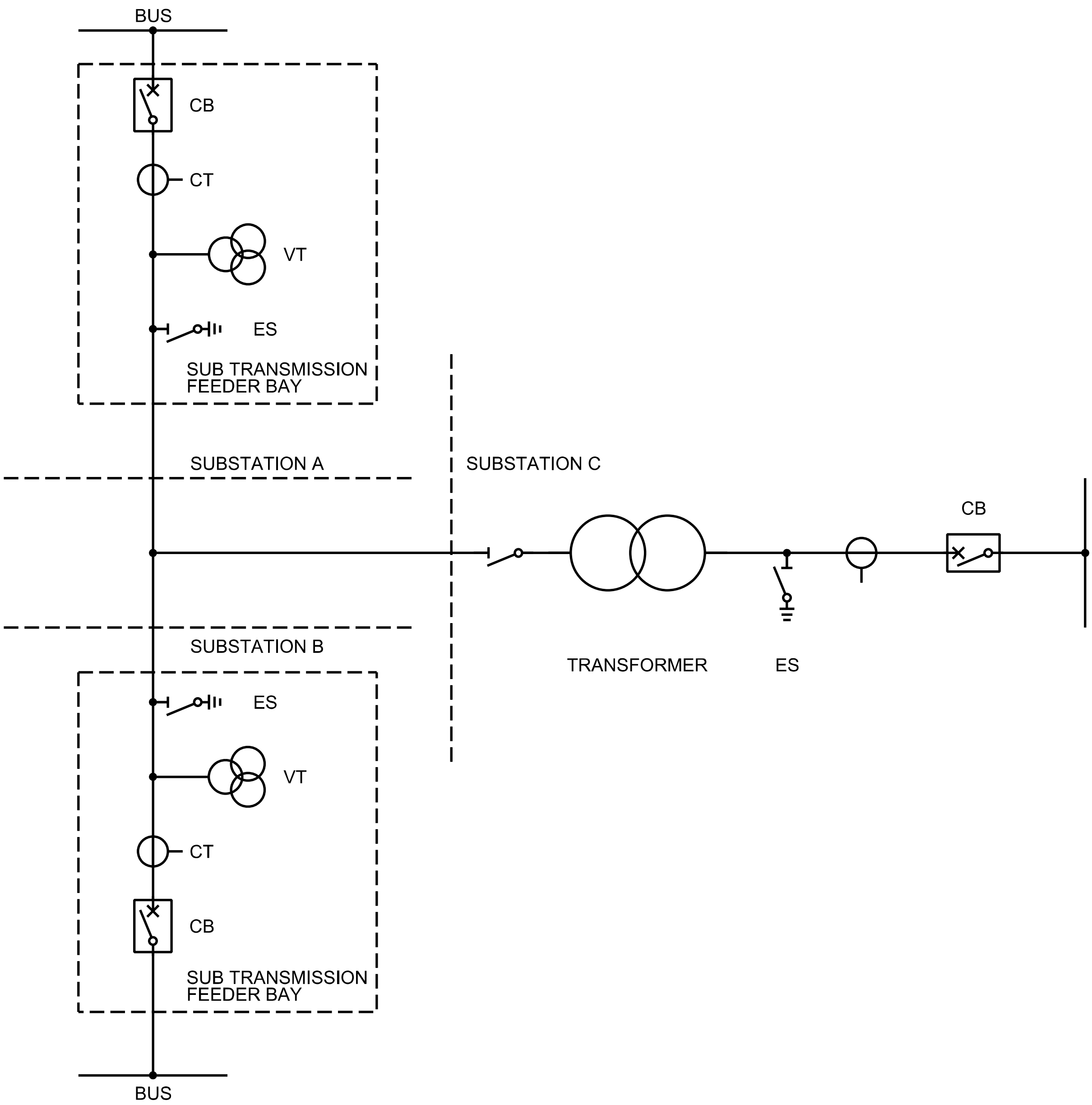


Figure 6: Sample sub-transmission feeder with tee off

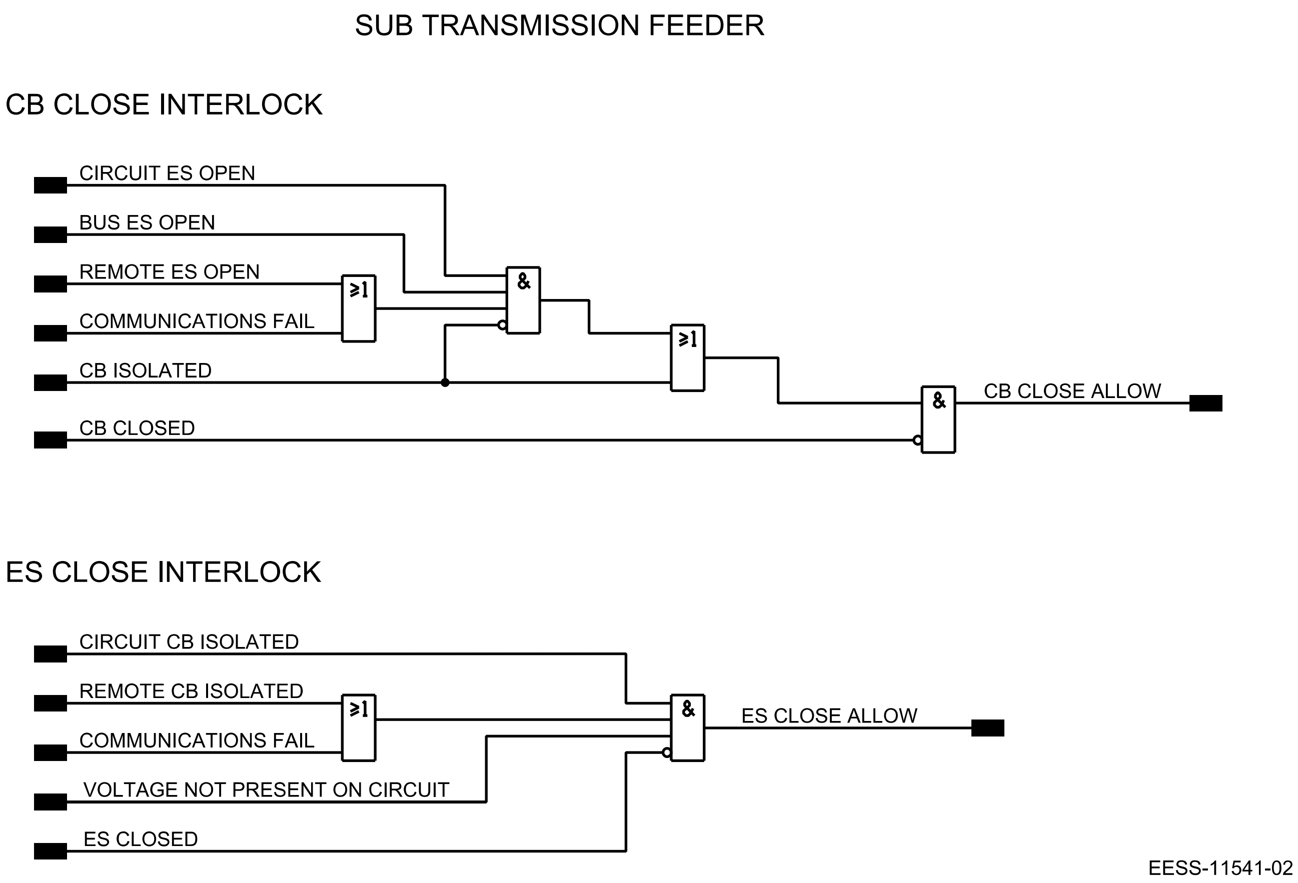


Figure 7: Sub-transmission interlocking logic

5.2.4 Transformers bays

It is acceptable to prove de-energised from another winding on a transformer, provided that it is not possible to isolate the measurement device used to prove de-energised. Where it is possible to use electrical interlocks, the interlock schemes shall consider the position of the isolation and earthing on the other winding/s of the transformer.

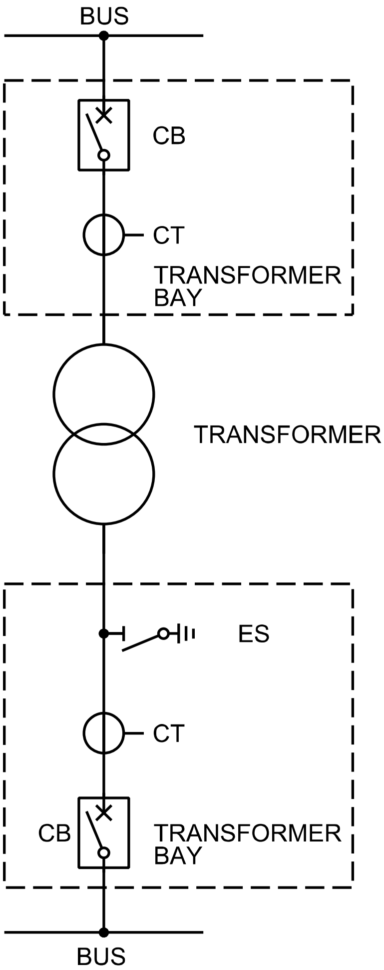


Figure 8: Typical transformer bay

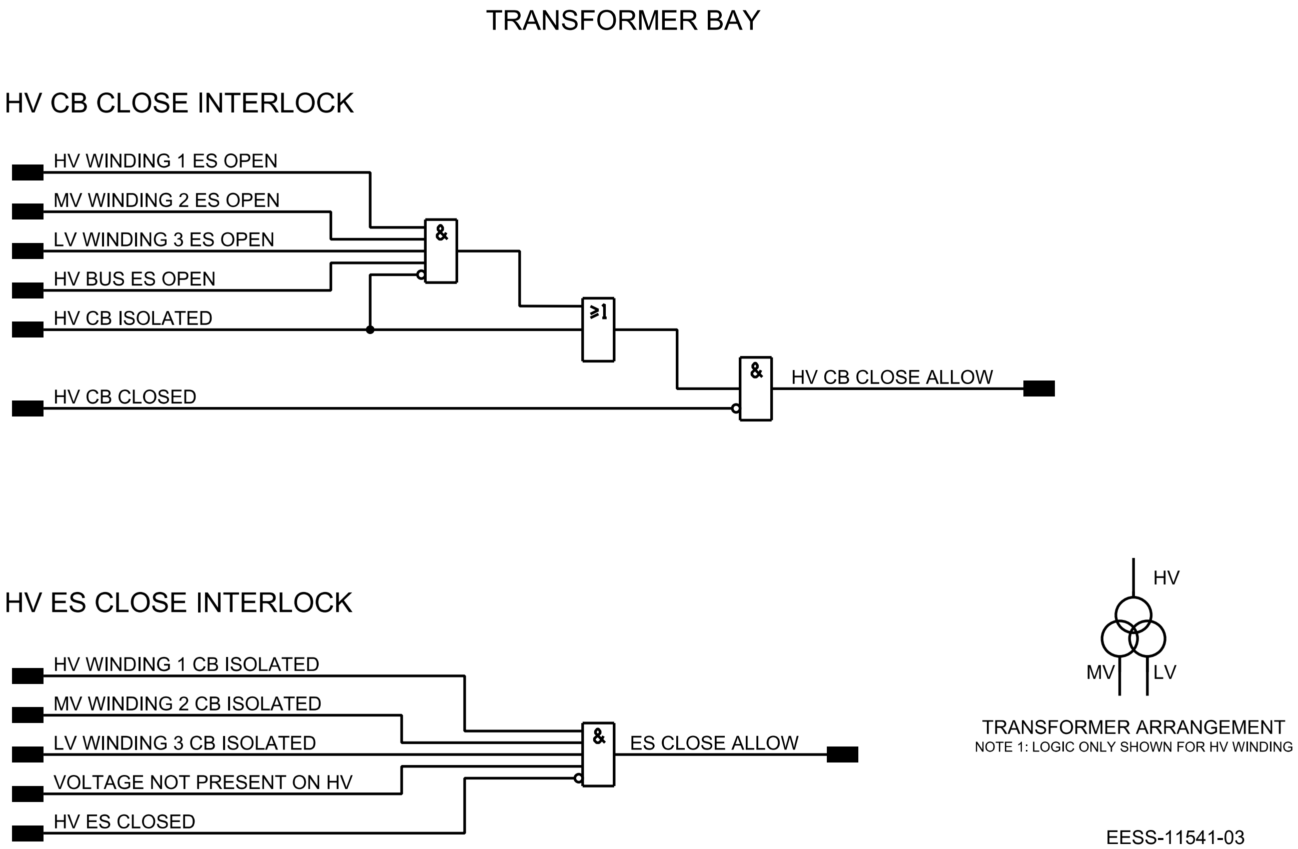


Figure 9: Transformer interlocking logic

5.2.5 Transformer ended feeder bays

Where electrical interlocking is available at the feeder (source) end, the isolation and earthing at the transformer end shall be included in the feeder interlocking logic at the source substation. The closest isolation point to the feeder circuit breaker should be used. Where outdoor HV isolation is used, the status of the isolation and earthing shall be included in the interlocking logic at the source. Where no HV isolation is installed, the LV isolation and earthing shall be used in the interlocking scheme for the remote bay.

The interlocking on the LV side of the transformer shall follow the requirements of a transformer bay. Where the isolation and earthing status of the HV winding is used in the LV winding interlocking scheme the plant closest to the transformer will be used for interlocking purposes.

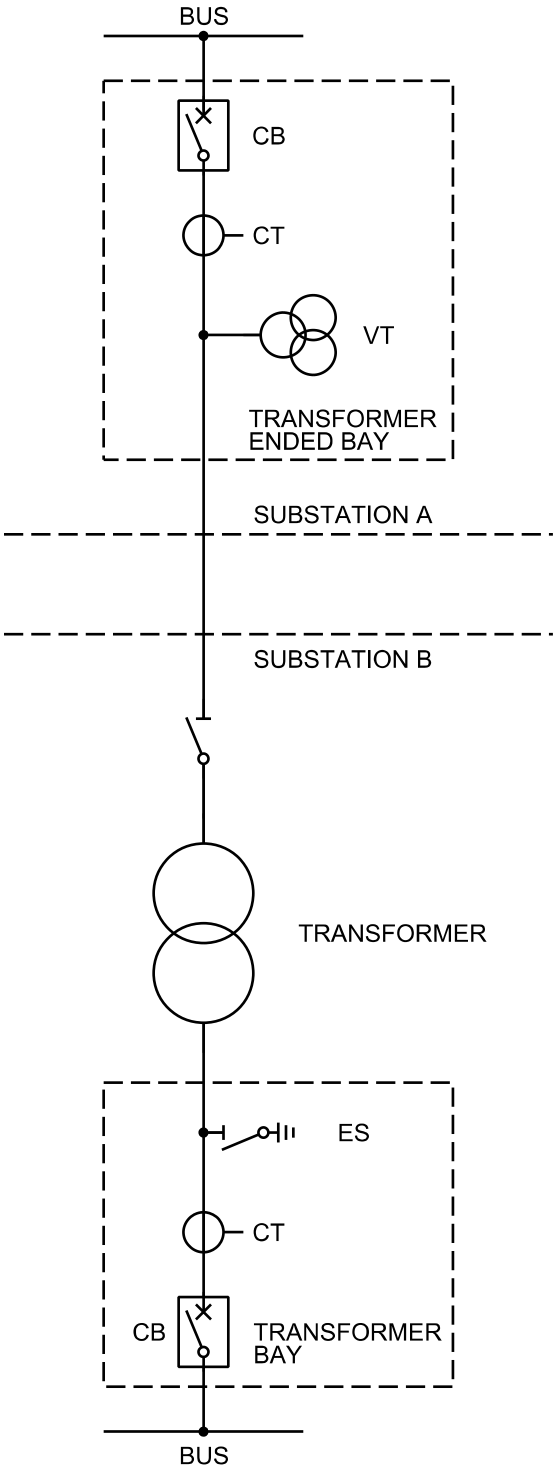
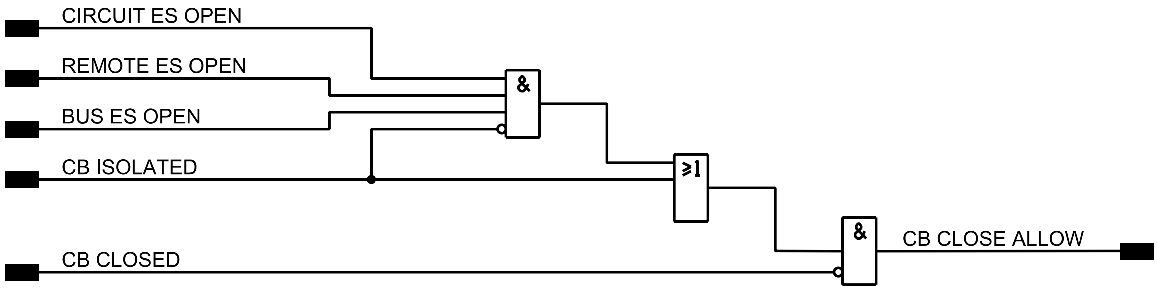


Figure 10: Typical transformer ended feeder bay

TRANSFORMER ENDED FEEDER

CB CLOSE INTERLOCK



ES CLOSE INTERLOCK

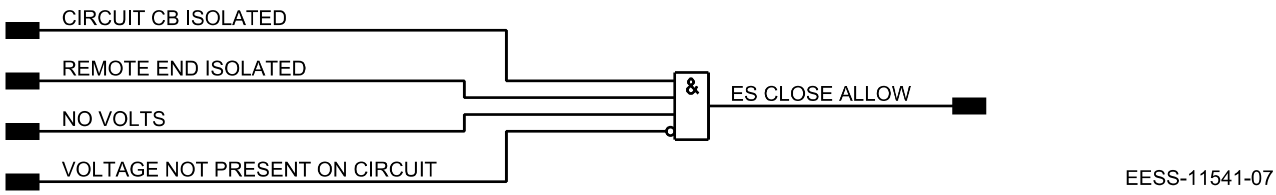


Figure 11: Transformer ended feeder interlocking logic

5.2.6 Capacitor bank bays

Capacitor bank bays shall have the same interlocking requirements as a distribution feeder bay with some additional requirements. It shall not be possible to close the circuit breaker until the capacitor has discharged. It shall not be possible to close the circuit breaker if physical access to the capacitor is possible. Where a capacitor bank is installed in a dedicated room the door status shall be included in the circuit breaker close logic.

It shall not be possible to gain access to cubicle or kiosk style capacitor banks unless they are isolated and discharged through the earth switch.

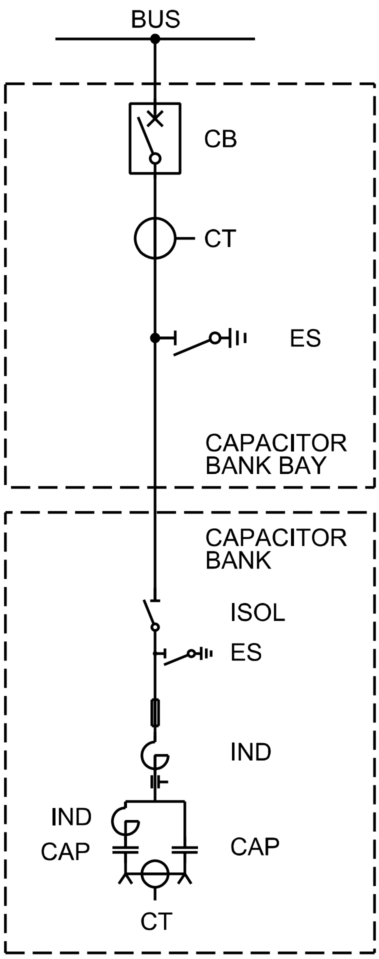


Figure 12: Typical capacitor bank bay

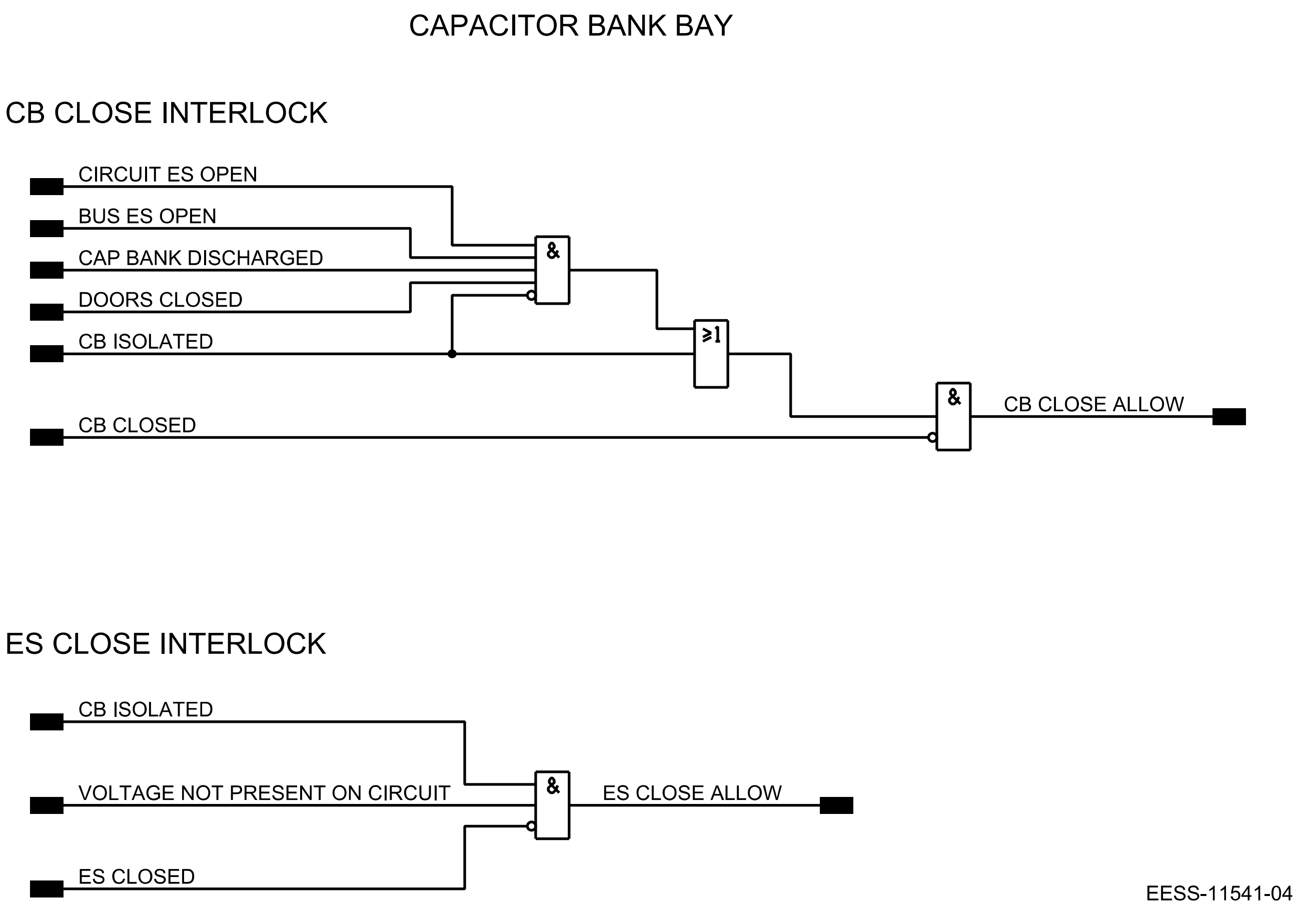


Figure 13: Capacitor bank interlocking logic

5.2.7 Generator bays

Bays connected directly to generation or substations with generation have, the same requirements as sub-transmission bays with the addition of a line de-energised check in the circuit breaker closing logic. New generator connections require the generator owner to synchronise and complete any required synchronism checks on their own plant. As such only a de-energised check is required before closing on new generator connections. Where a synchronisation check is performed across Ergon Energy's circuit breaker in these cases a synchronisation check is required before closing.

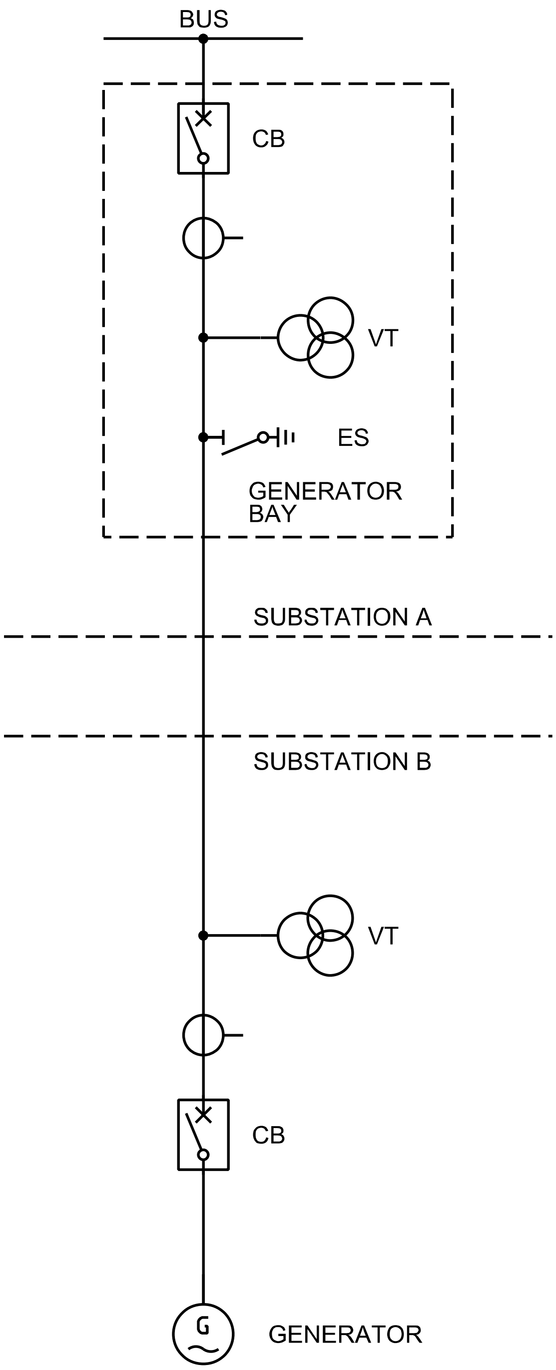


Figure 14: Typical generator bay

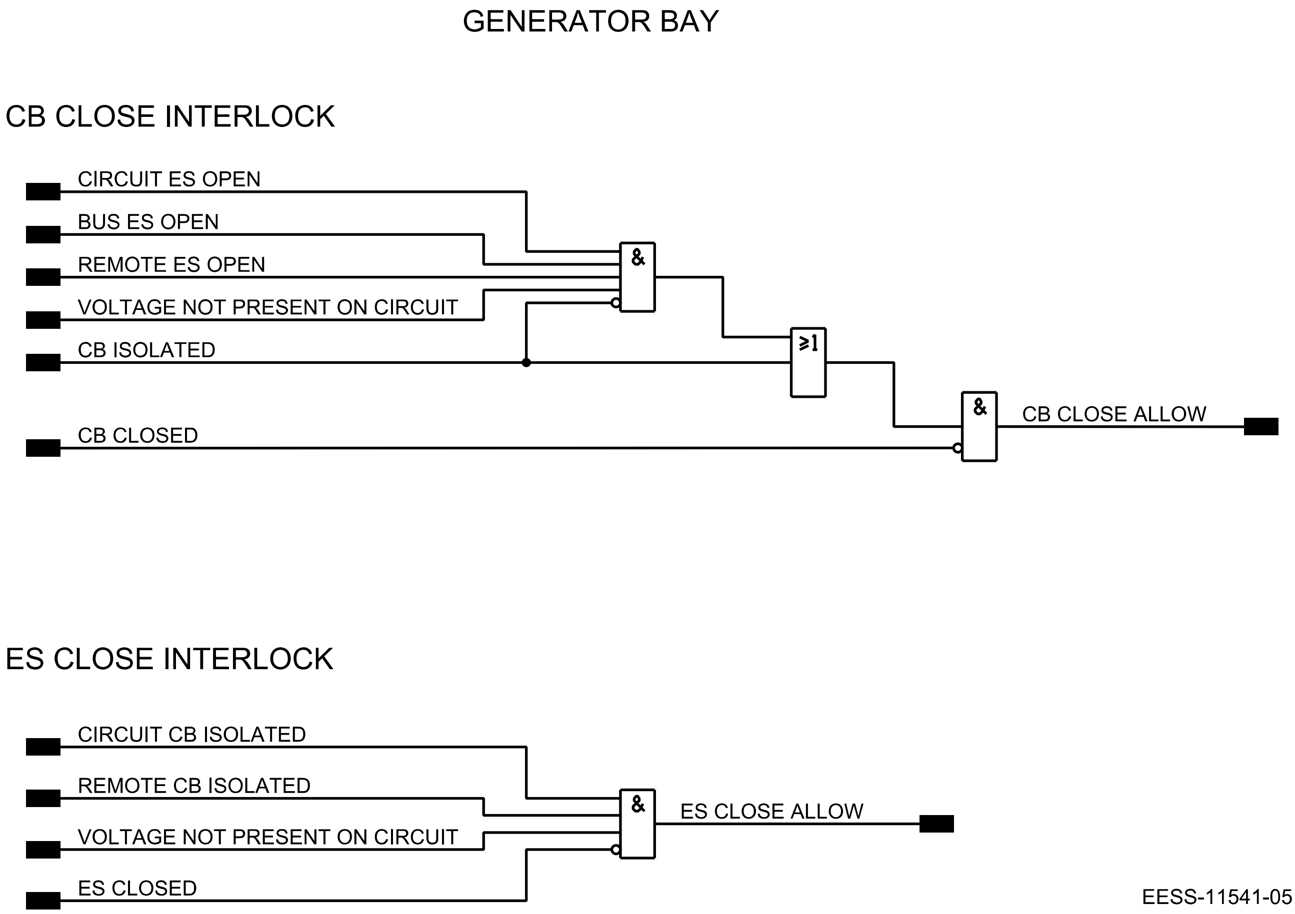


Figure 15: Generator bay interlocking

5.2.8 Dedicated customer bays

The interlocking between Ergon Energy substations and customer installations will depend on the connection and the plant installed. Where there is a direct connection from an Ergon Energy feeder bay to the customer's bay, interlocking schemes shall be the same as the sub-transmission bays. Where a switching device or devices such as a ring main unit (RMU) are installed between the customer and Ergon Energy's feeder bays no interlocks shall be passed between the bays unless the state of the switches is included in the interlock scheme.

Figure 16 (a) shows an example of a direct connection to the customer in this case interlocking between Ergon Energy and customer shall be implemented. Figure 16(b) shows a switching device installed between the two bays. In this case interlocking between the bays shall only be implemented if the statuses of the switch devices are included in the interlocking scheme.

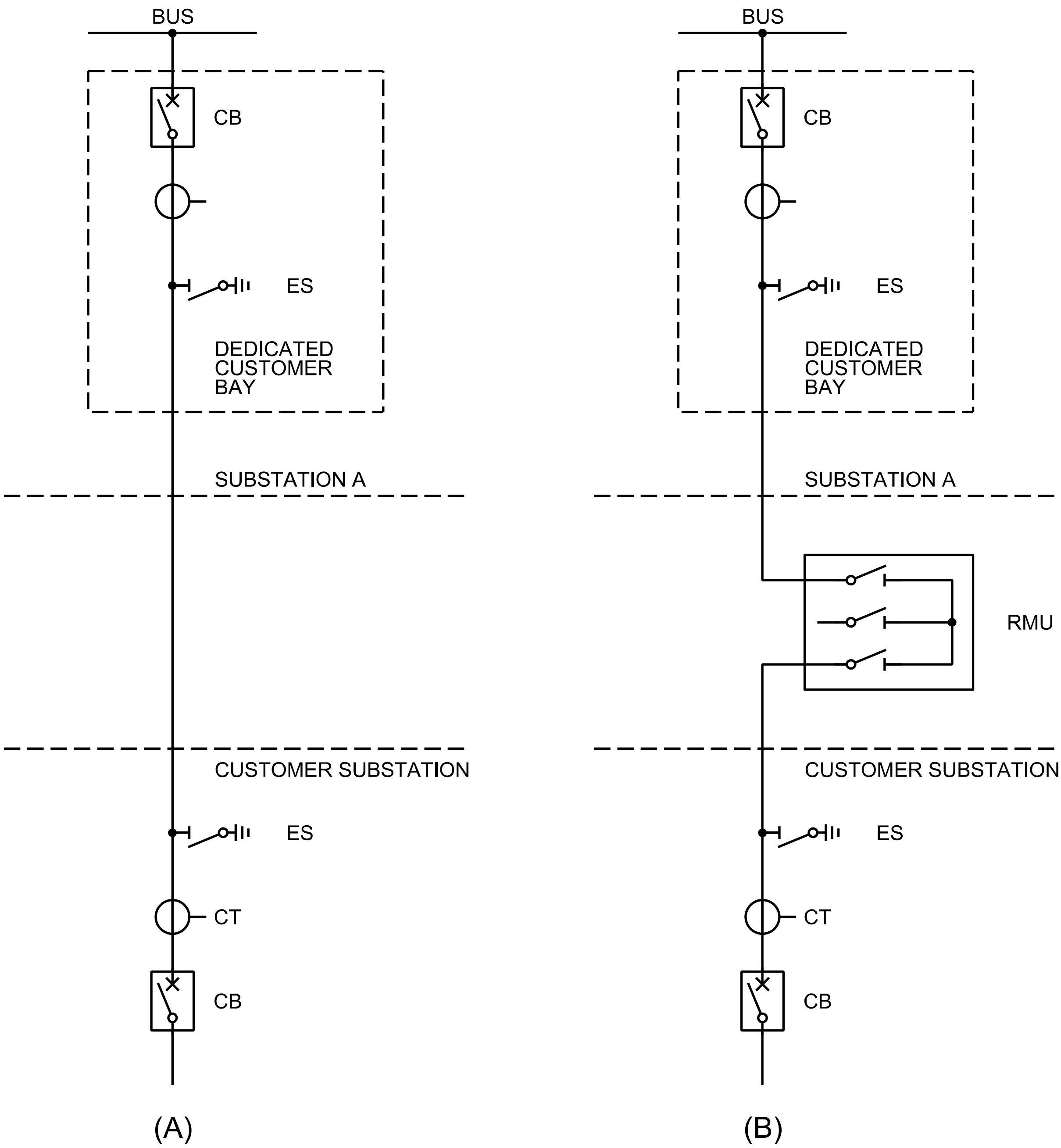


Figure 16: Typical dedicated customer connections

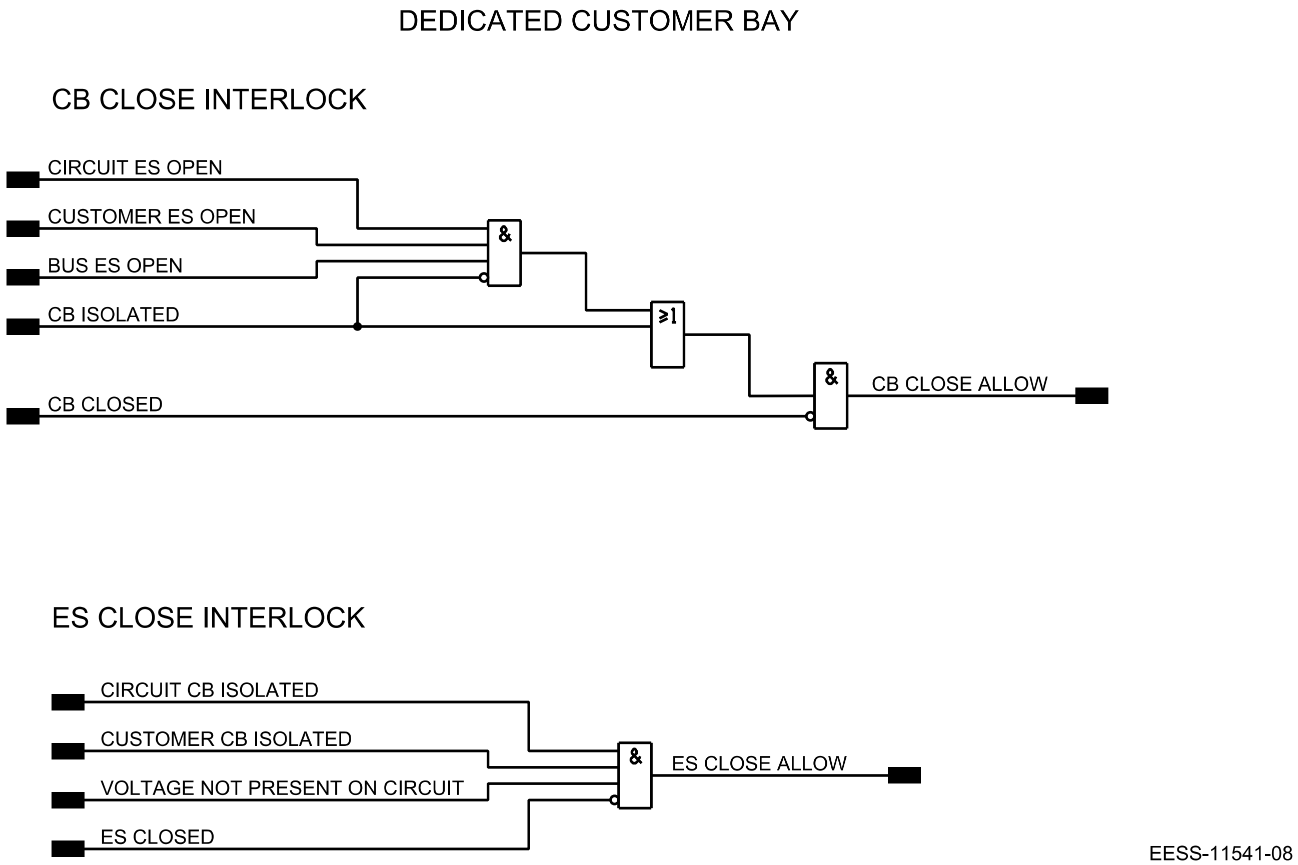


Figure 17: Dedicated customer bay interlocking logic

5.3 Station level interlocks

Station level interlocks operate between bays and are defined in the bay requirements. Station level interlocks include the isolation and earthing on another winding of a transformer, bus earth switches in feeder bay schemes and bay isolations in bus schemes.

Where generators are installed station level interlocking should be configured to ensure that an islanded network is not produced and that the islanded network cannot be reconnected to the remainder of the network without a synchronism check.

5.4 Specific requirements based on switchgear type

Ergon Energy currently uses following main types of switchgear withdrawable switchgear, nonwithdrawable switchgear, gas insulated switchgear and outdoor air insulated. This section details interlocking requirements specific to the different switchgear types.

5.4.1 Isolated definitions

Isolated as defined by the switching and access definitions (P53H05R03) means that a the plant is disconnected from all possible sources of energy by means to prevent unintentional energisation of the Electrical Apparatus and that are assessed as a suitable step in the process of making safe for access purposes.

The isolated definitions by switchgear type are:

- For withdrawable switchgear a circuit breaker is considered isolated when the circuit breaker has been removed from the service position and placed in the test position.

- For nonwithdrawable switchgear, a circuit is considered isolated when the bus disconnector is opened.
- For gas insulated switchgear, a circuit breaker is considered isolated when both the bus and line side isolators are open.
- Figure 18 shows the requirements which define circuit isolated for each switchgear type.

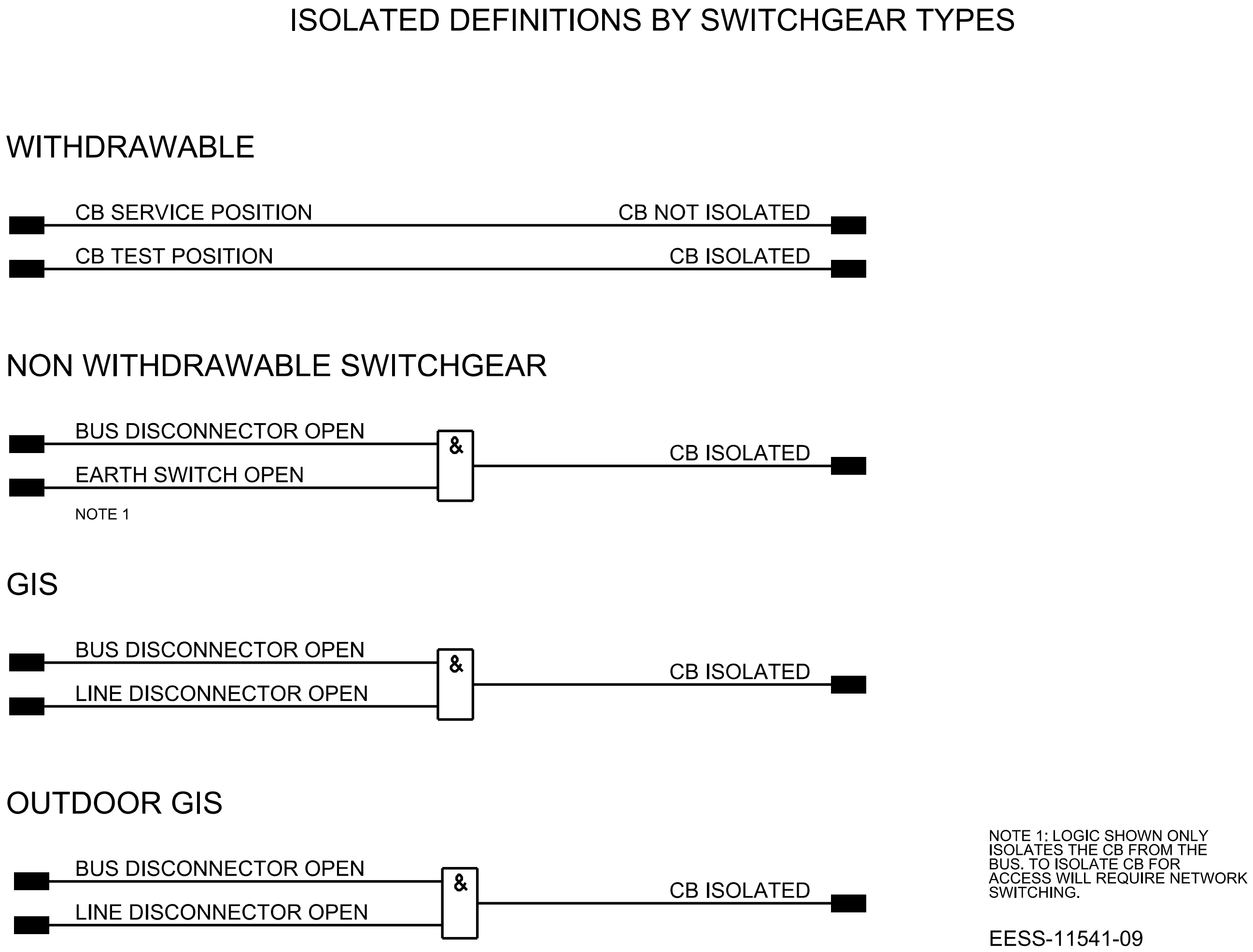


Figure 18: Isolated definitions by switchgear type

5.4.2 Withdrawable switchgear

There are various arrangements for withdrawable switchgear. Figure 19 shows a typical arrangement of the withdrawable metal enclosed switchgear. Unless otherwise stated this section is based on this.

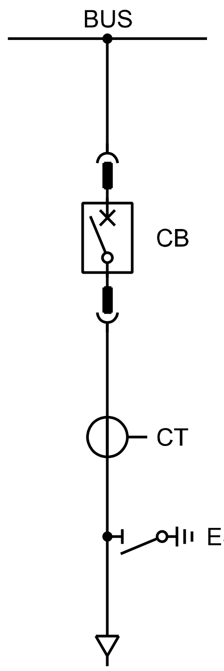


Figure 19: Typical withdrawable bay

The following shall be achieved for withdrawable type switchgear:

- A closed-circuit breaker shall be prevented from being withdrawn from or inserted into the service position.
- It shall not be possible for a circuit breaker truck to be transitioned between the service, test and earthed positions with its front access door open.
- It shall not be possible to operate a circuit breaker in the service position with its front access door open.
- It shall not be possible to remove the circuit breaker truck secondary wiring plug connections when it is racked into the service position.
- Where earthing through a circuit breaker it shall not be possible to electrically trip the circuit breaker. In addition, it shall not be possible to return the circuit breaker to the service position without restoring the operation of the electrical tripping circuit. Refer to annex A.2 for requirements on remote earthing applications.
- Where a withdrawable VT is installed, it shall be considered a source of supply and included in the earth switch interlock, requiring the VT to be placed into the test position before the bus earth switch can be closed.
- Placing a circuit breaker into the test position shall remove any interlocks preventing its operation.

While a circuit is considered isolated when it is in test position, the switchboards typically used by Ergon Energy do not have an electrical interlock to prevent the placement of the circuit breaker into the service position. For the bus earth switch interlocks, the circuit breaker shall be in the test position to apply the earth but once the earth is applied it is possible to place the circuit breaker into the service position. It is not possible to close the circuit breaker while in the service position and the bus earth is closed.

The bus earth switch interlocks were originally designed to check that all circuit breakers are open by the switchboard manufacturers. With this design, it is not possible to modify the isolation while the earth switch is closed. Changing the interlock to require all circuit breakers to be in the test position was requested by Ergon Energy. A blocking device is required to prevent the placement of circuit breaker into the service position, when the bus earth switch is applied.

Where motor driven racking of circuit breaker trucks is used the motor shall be prevented from operating while a bus earth is closed. A blocking device is required to prevent an operator from manual racking the circuit breaker truck into the service position.

For withdrawable switchgear which uses the circuit breaker to earth circuits or bus sections by placing the circuit breaker into the earth position, the circuit breaker shall be prevented from closing unless the interlock requirements for the earth position are met.

5.4.3 Nonwithdrawable switchgear

Figure 1Figure 20 shows a typical nonwithdrawable metal enclosed switchgear bay. For this arrangement the earth is be applied by closing the circuit breaker

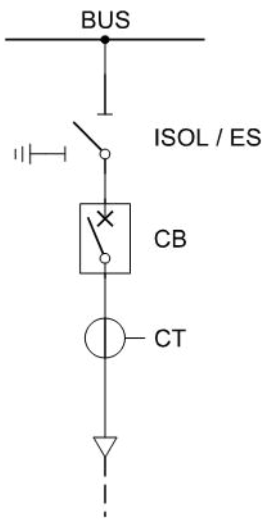


Figure 20: Typical nonwithdrawable bay

The following shall be achieved for nonwithdrawable switchgear:

- Disconnectors cannot be operated while the associated circuit breaker is closed.
- A circuit breaker shall be prevented from tripping for the attempted operation of the disconnector.
- Access to the main circuit of the circuit breaker, unless it has been isolated, shall be prevented.
- Where earthing through a circuit breaker it shall not be possible to electrically trip the circuit breaker. In addition, it shall not be possible to return the circuit breaker to the service without restoring the operation of the electrical tripping circuit. Refer to Annex A. for requirements on remote earthing applications.

5.4.4 Gas insulated switchgear (GIS)

Figure 21 shows a typical gas insulated switchgear bay.

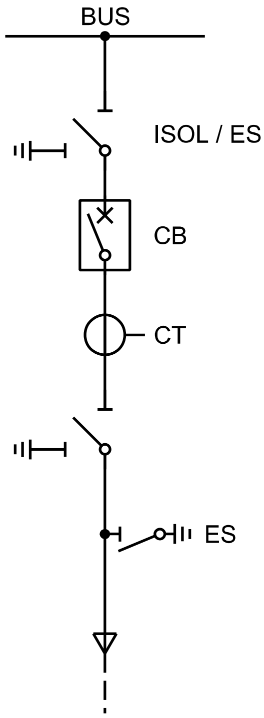


Figure 21: Typical GIS bay

The following shall be achieved for GIS switchgear:

- Access to the main circuit of the circuit breaker, unless it has been fully isolated, shall be prevented.
- Disconnectors cannot be operated while the associated circuit breaker is closed.
- Where a circuit breaker can be earthed independently from the bus and circuit earths through its own bus and line side earths, the earths shall be interlocked with both the bus and line side isolators.

Figure 22 shows the logic for the interlocks between the HV plant with a gas insulated switchgear bay.

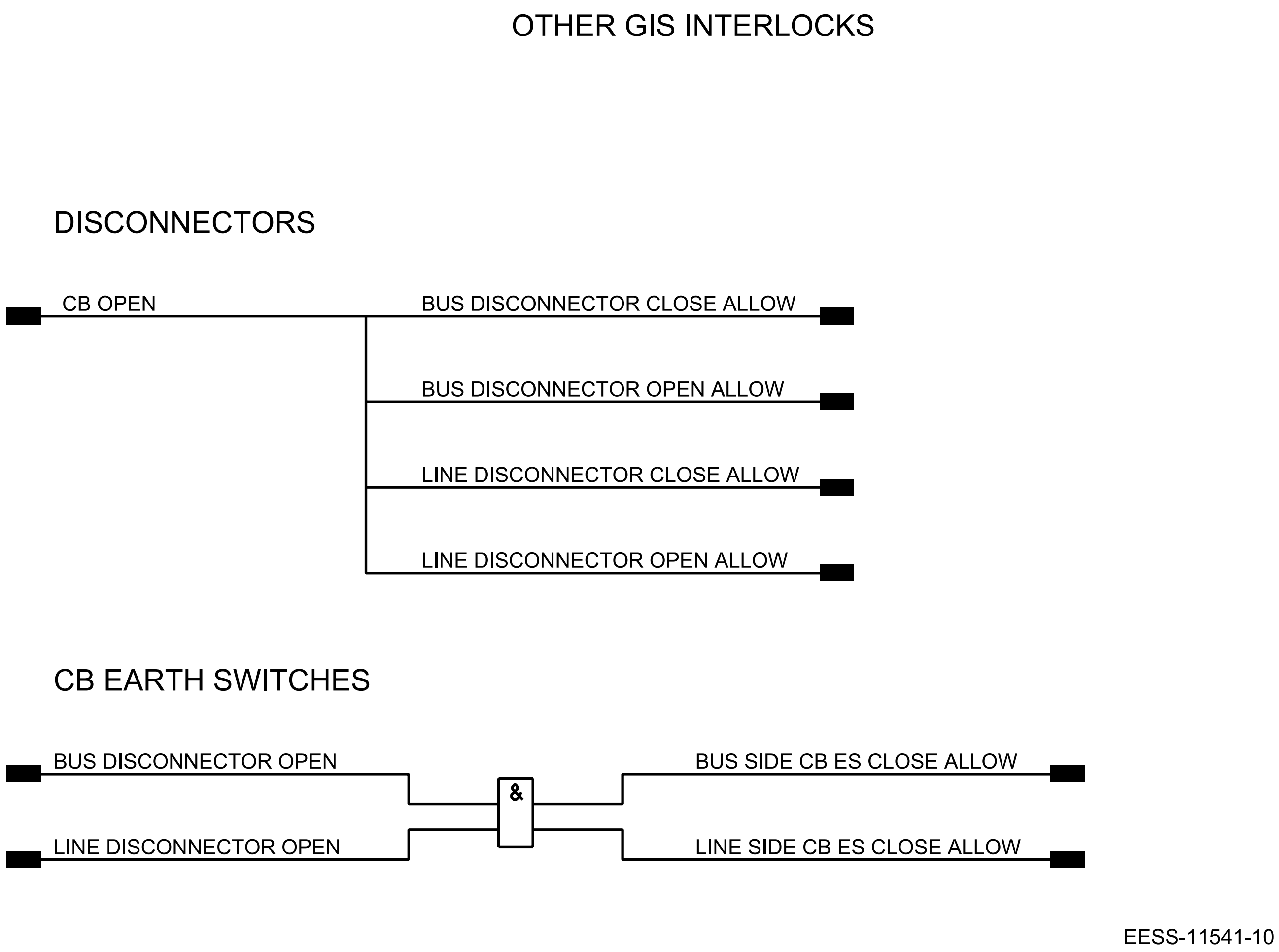


Figure 22: Additional GIS interlock logic

5.4.5 Outdoor air insulated switchgear (AIS)

- For outdoor equipment, isolators and earth switches shall be mechanically interlocked. Indication of the status of the isolators and earth switches should be for use in other interlocking schemes. Motor driven switching devices shall have electrical interlocks that achieve the requirements of the bay the device is installed in.

5.5 Functional interlocks

5.5.1 Gas lockout

Pressurised sulphur hexafluoride (SF6) is used in gas insulated switchgear and high voltage circuit breakers because of its insulating properties. When the pressure is reduced the insulating effectiveness of the gas is reduced, to prevent failures of the insulation during low pressure the device must be locked out.

Before the pressure has reduced to a level where lockout is required the device shall alarm to the control room. Two methods of lockout for sulphur hexafluoride low gas pressure are available with in circuit breakers. One prevents all operation of the device (lockout), the second trips the device and then prevent any further operations (trip and lockout). Ergon Energy’s preferred option to lockout on low gas. If a protection operation is required, the circuit breaker will not operate and relies on circuit breaker fail protection to operate and isolate the fault.

SF6 GAS LOCKOUT

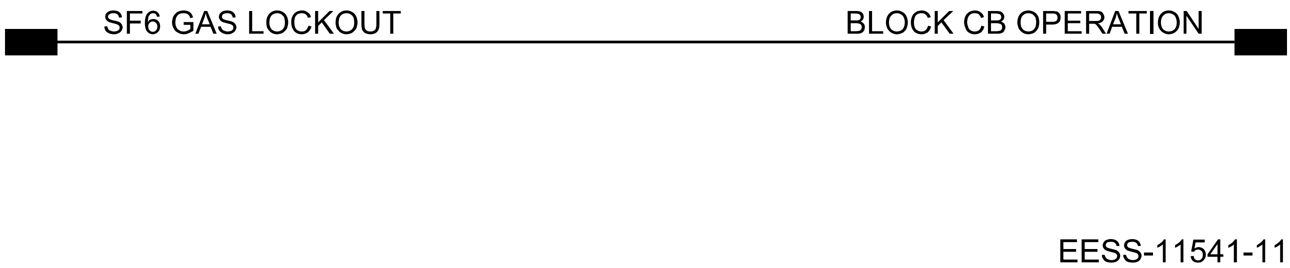


Figure 23: SF6 gas lockout logic

5.5.2 Blocking CB fail for earthed bay

It is possible that current may flow between earths where they are applied at different locations (circulating currents). Circulating currents are not a power system fault and do not need to be cleared by protection. If the protection current transformers are on the circuit side of the earth switch, the current will be seen by the protection relays may be of a magnitude large enough to cause a pickup and operation. Sensitive earth fault (SEF) protection may operate in cases where no sensitive earth fault check scheme is used by the sensitive earth fault protection. If the circuit breaker is under access, it may be already open or part of the earthing circuit and disabled so that it cannot be operated electronically, a protection trip will not remove the circulating currents. The protection relay may operate a circuit breaker fail trip and clear the bus. Clearing bus will result in the loss of supply to all customers connected to the bus.

It is recommended that circuit breaker fail trips are prevented from operating while the bay earth switch is closed only for bays where the current transformers are located downstream of the earth switch. The scheme shall be designed so the bay cannot be returned to service with the circuit breaker fail protection disabled. Protection trips shall not be prevented, this ensures that the bay will always have protection enabled. The interlock which prevents electrical operations of the circuit breaker while it is used for earthing prevents a protection operation from removing the earth. The interlock shall be designed as a circuit breaker fail protection block so that in the failed arrangement circuit breaker protection will be enabled. It is expected that the source of this interlock will be the same as the circuit earthed signal which may already be required by the substation station interlock relay. However, if both the circuit earthed and circuit breaker fail block signals are required, they shall be published separately. By using separate signals, the bay controller shall be configured to only send a circuit breaker fail block if the switch gear configuration is such that it requires a block to be sent.

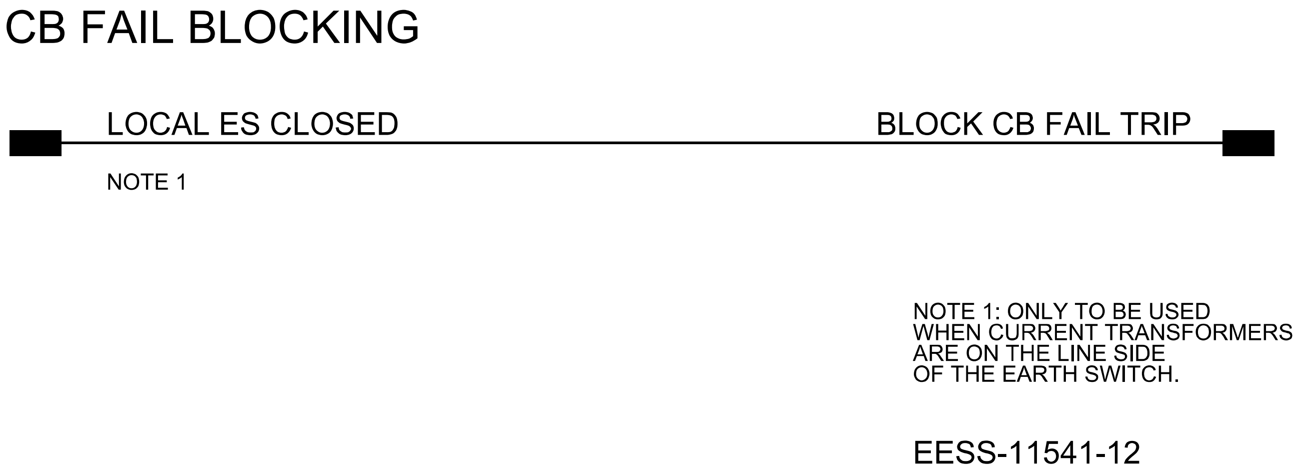


Figure 24: Earth switch CB fail blocking logic

5.5.3 Circuit breaker close blocking

A circuit breaker close could be blocked by any of the following functions: bus earth, discharge timer, circuit de-energised check, synchronism check or access to live HV parts. Circuit breaker closing blocking depends on the bay type; individual bay requirements are detailed in section 6.2. Circuit breaker close blocking logic diagrams are also shown for each bay type.

5.6 Voltage detection

Voltage detection devices are installed on all circuits and bus sections for all switchgear types except for outdoor air insulated switchgear.

The IEC High-voltage switchgear and controlgear - Part 206: Voltage presence indicating systems for rated voltages above 1 kV and up to and including 52 kV (IEC 62271-206, 2011) states that voltage presence indication systems are not sufficient to be used for switching purposes and identifies IEC Live working - Voltage detectors - Part 1: Capacitive type to be used for voltages exceeding 1 kV a.c. (IEC 61243-1, 2009), IEC Live working - Voltage detectors - Part 2: Resistive type to be used for voltages of 1 kV to 36 kV a.c. (IEC 61243-2, 2002) and IEC Live working - Voltage detectors - Part 5: Voltage detecting systems (VDS) (IEC 61243-5, 1997) are to be followed for devices used for switching.

Where voltage detection systems are used to check for de-energised, it is required that the detection system the IEC Live working - Voltage detectors - Part 5: Voltage detecting systems (VDS) (IEC 61243-5, 1997) for voltages less than 52kV. Ergon uses these devices in the interlocking circuits to check buses are de-energised however it is unclear what standard the devices are manufactured to. This standard requires that all voltage presence indicators will be used to prove that the system is de-energised. As such, all new voltage presence indicators shall be voltage detection systems conforming to the IEC Live working - Voltage detectors - Part 5: Voltage detecting systems (VDS) (IEC 61243-5, 1997).

5.7 Voltage transformer selection

Typically voltage selection relays have been used to ensure that voltage input is available to protection relays. Where a voltage measurement is used for protection functions logic must implemented to ensure that the selected voltage transformer is measuring electrically the same point, i.e. all isolators and circuit breakers between the normal voltage transformer and the secondary voltage transformer are closed.

The order of preference for voltage selection is:

1. at the protection location
2. bus voltage transformer
3. adjacent feeder voltage transformer on the same bus section
4. voltage transformer on a different bus section (bus or line voltage transformer)

Some relays supporting IEC 61850 are able to subscribe to two sampled values streams for the same measurement input. Where possible, this feature should be used for voltage transformer inputs with requirements detailed above.

5.8 Bypassing interlock schemes

Instances where bypassing the interlocking scheme may be required include testing, changes to the network configuration (not from switching) or a plant or secondary systems failure. If a voltage detection system fails, it prevents the cable compartment door from opening as the earth switch will be unable to be applied. To replace the failed capacitor coupling of voltage detection system this interlock would need to be bypassed to allow access. Interlocking schemes shall be designed to allow for the repair of failed equipment in the scheme.

Interlocks shall only be bypassed to make repairs or to accommodate an abnormal network arrangement arising from the temporary installation of new plant. Where interlocking has been designed by the manufacturer it shall be bypassed as per the manufacturer' instructions.

5.8.1 Bypassing Methods

Currently it is possible to bypass or defeat an interlocking scheme by shorting contacts via the terminal strip. Bypassing interlocks implemented with IEC 61850, introduces additional complications, which need to be considered, as many of the signals in the interlocking scheme are digital.

An option for bypassing interlocks is to have an override switch. If an override switch is used, the switch shall be controlled by switching procedures and would have to be an item on the switching sheet. To further control this, a key switch requiring the switching key, could be used. This option requires additional hardware with the number and location of the switches depending on the design. From a safety point of view, a key per scheme would be safer as this would ensure that only a specific scheme is bypassed. Other options include bypass keys for the bay, voltage or substation level, digital overrides on the human machine interface (HMI).

For testing purposes, a test set compatible with IEC 61850 could be used to change the state of GOOSE messages on the network and allow an interlock to be bypassed. This method could be acceptable for testing and commissioning purposes as test staff and the test set would already be required on site. If this method is adopted, difficulties could arise when implementing it for failed plant. Normal procedure is for the substation operations staff to switch out the failed piece of plant and make repairs/replace. Before test staff complete the required testing and return the plant to service. The substations operations group does not have the skills and test equipment required to change the state of GOOSE messages. For this procedure to work either more test resources are required, or the substations operations staff shall be upskilled.

Using a test set to change the state of GOOSE messages has additional risks involved. Firstly changing the state of a message can change the SCADA associated indications depending on the configuration and other plant subscribed to that message. Procedures also need to be in place to ensure that the correct message is changed as the rest of the substation could be in operation and live. Changing the messages could bypass the interlocks on another bay, lead to a trip of a healthy in-service circuit and even a circuit breaker fail trip that clears an entire bus section.

Many of the signals will be hardwired as I/O to an IED which will then convert the signal to a GOOSE message to be shared across the network. As these terminals are low voltage there is no requirement to have access interlocked. All IEDs shall be installed in low voltage, compartments which can be accessed to ensure access to the terminals on an IED is always possible. In this case, it is possible to short out a contact enabling an interlock.

With current interlocking practises, a hardwired signal used in an interlock scheme is not used for anything else. An additional contact from the device or via a follower relay is used for any other purposes. In substation utilising IEC 61850 a status will only be hardwired once and used for multiple functions. In this case it is preferable to bypass the interlock by shorting the output contact of the IED that controls the electrical interlock. This way other functions are not affected by the bypassing of the interlock. It is possible that not all signals in an interlocking scheme will be hardwired. For example if a voltage check is conducted using a voltage transformer and an IED there will be no hardwired signal that can be shorted. By shorting the output contact of the interlock, these signal types can be bypassed.

It is recommended that during the design phase, all failure modes of each interlocking scheme are considered. The effect of the failures and whether high voltage access is required for repairs shall also be considered. All effort should be made at the design stage to design the scheme such that for a failure, any high voltage access required to make repairs can be safely achieved. Where it is not possible to design the interlock schemes to allow for the identified failure modes the method of bypassing the scheme shall be detailed.

It is recommended that the state of Goose messages is not changed by, either with a test set or by forcing inputs in IEDs. The simultaneous defeating of the substation interlocking schemes is not acceptable. If required, it is recommended that bypass control points are installed on the HMI instead of key switches.

5.8.2 Change in Network Configuration

The interlocking schemes shall be designed to consider all possible switching arrangements that can be made using the hardware on the high voltage network. Abnormal network arrangements created by the installation of temporary plant will require changes to the interlocking scheme. Updating the interlocking logic can be done as part of the installation of the temporary plant. In this case, an interlock override switch is not required.

However for a NOMAD installation where a dedicated NOMAD bay is not installed at the substation it is expected that changes to interlocking schemes will be required. Typically, the NOMAD will be connected to a failed transformer bay or a feeder bay; these bays will likely consider remote isolation and earthing indications in the interlocking scheme requiring a change in the interlock scheme before the NOMAD can be installed. While the required personnel to make any changes will be onsite as part of the NOMAD installation, the new logic has to be created and tested. When the NOMAD is required for a plant failure and shall be installed in the shortest possible time, creating and installing new logic is not practical as part of the NOMAD installation. The interlock scheme shall be designed to allow for the NOMAD installation.

It is suggested that a control point be installed on the human machine interface to bypass the remote end interlocks for each bay to allow for the NOMAD installation. The use of this bypass would need to be controlled by switching procedures.

5.8.3 Failure of plant

This section looks at different failures and determines if the failure will create an access issue to repair. Table 1 lists these failures and includes alternate methods to gain access

Table 1: Plant failures and work arounds

Device	**Failure Mode**	**Access Issues**	**Operational Alternative**
Bay Controller	Failure of the complete device or individual input or relay	Nil	As the device is located in the LV compartment it can be replaced without any switching and requires no bypassing
Circuit Breaker Status	Failure of either the normally open or normally closed status	Nil: the status of the circuit breaker is not required to open the circuit breaker.	Nil- if there is a problem with the status of the circuit breaker, closing the circuit breaker will be blocked
Earth Switch Status	Failure of either the normally open or normally closed status	Closing the earth switch requires the earth switch to be open. If there is an issue with the status contacts, the earth switch will need to closed to allow access to repair the damaged auxiliary switches.	As both the normally open and normally closed statuses will be available to the IED, a discrepancy check can be completed. As discussed in 5.1.1 the earth switch will be allowed to close for a discrepancy.
Earth Switch Mechanism	Mechanism failure resulting in it being unable to close the earth switch	Mechanical interlock will prevent opening of the cable door.	This is an existing issue and tool access is required to make repairs.
Voltage detector system	Failure of the coupling capacitor	Unable to close earth switch for access to cable compartment to make repairs	Short earth switch close allow signal on the back of the bay controller. Some voltage detector system models can output device health. This shall be used to allow the earth switch to be closed if all other interlocking requirements are met (e.g. bay isolated).
Voltage detector system	Failure of indicator	Unable to close the earth switch.	Nil – as the indicator is located in the LV compartment, HV access is not required to repair or replace the device.
Communications path to remote end			

6 Interlocking architecture

6.1 Interlocking intelligent electronic devices

Statuses such as a bus earth position are used in multiple interlocking schemes and are currently hardwired to each scheme from follower relays. There are benefits in using IEDs to do the interlocking including reducing the amount of wiring required and removing the need for follower relays. Another benefit of using an IED for interlocking is that changes can be made to the interlocking schemes by configuration instead of rewiring.

Bay level interlocking can be implemented in an IED associated with each bay. In the existing substation architecture, the only bay level IED is the protection relay. Standard feeder protection relays have a limited number of digital inputs and outputs (I/O) and most are used for protection related functions. It is not recommended to use protection relays for bay level interlocking because protection relay testing procedures require the entire relay function tested for any changes. The implementation of an interlocking scheme and any future changes to the scheme will require the testing of all the protection functions. Conversely, protection changes or maintenance will require retesting of all the interlocking functions. Protection relays are installed on the control panels and not within the switchgear meaning wiring is required between the relays and switchgear to allow or block operation of the interlocking schemes used to control the primary plant.

An alternative option is to use a dedicated substation interlocking IED to control all the electrical interlocks for the substation. With this option, any changes to the interlocking scheme will only require a setting change in one device. This option could be implemented as a transition to substations that utilise IEC 61850. A device with enough hardwired digital inputs and outputs is required to the achieve this. Most of the inputs required by the interlocking schemes are already hard wired to the remote terminal units in the substation for indication to SCADA. If these signals are wired to the interlocking IED instead, the IED could provide interlocking and SCADA functions. Some additional wiring will be required as outputs to control each electrical interlock. Once IEC 61850 is implemented, it is expected that the interlocking IED would have no hardwired digital inputs and outputs and be dedicated for station interlocking only.

Many of the inputs required for an interlocking scheme are already available in the remote terminal units, remote terminal unit are only used for control and indication not protection functions. While interlocking could be considered a control scheme in that it is controlling the operation of plant, it is also a protection scheme as it is providing operator safety and protection against plant damage.

As with the dedicated interlocking IED, outputs are required for each interlocking scheme. The remote terminal units installed in a ZSS 32 substation have space for additional digital output cards however there is limited space to install the terminal blocks to connect to the digital outputs. A new panel design would be required to provide space for the required terminal blocks.

6.1.1 IED fail safe requirements

The in addition to the requirements of section 5.3 the following requirements apply where interlock is control through an IED.

All equipment status inputs into IEDs used for interlocking schemes shall directly represent the required state used by the interlocking scheme. For withdrawable switchgear where it is possible to place the circuit breaker in a position other than the service condition, it is not acceptable to invert the status of another position indication for interlocking purposes. A scheme requiring a circuit breaker to be in the test position shall not invert the service position contact to flag that the circuit breaker is in the test position.

Switching devices that have both normally open and normally closed contacts shall use both contacts and perform a discrepancy check. Whether a device is allowed to operate for a discrepancy will depend on the interlocking scheme and the safety requirements. If a discrepancy occurs access for repairs should be possible, provided all other requirements of the interlock scheme are met.

Where only one contact can be used the contact must be selected to ensure a fail-safe design is achieved. To determine whether a normally open or normally closed contact from a device is to be used in an interlock scheme, the scheme type and the effect of the status shall be known. Table 2 shows how an IED will interrupt normally open and normally closed contacts for a wiring failure.

Table 2: Plant state for contact types

Plant State	Contact Type	Signal at IED	Signal at IED (failed wiring)	IED Value (failed wiring)
Open	Normally Open	Low	Low	Open
Open	Normally Closed	High	Low	Closed
Closed	Normally Open	High	Low	Open
Closed	Normally Closed	Low	Low	Closed

6.2 IEC 61850 interlocking

In a substation utilising IEC 61850 it is expected that a device will be required at each circuit breaker to convert the circuit breaker and bay digital inputs and outputs to generic object-oriented substation event (GOOSE) messages. For this document, this will be referred to as a bay controller.

Protection relays could be used for interlocking however, as mentioned in section 6.1 it is not recommended to do the interlocking functions in protection relays.

Instead, it is recommended that the bay controller is used to provide the bay level interlocks. Completing bay level interlocks in a bay controller has the following advantages:

- For the failure of a bay controller, only the interlocks for the associated bay are affected. The loss of a bay controller will also mean the loss of all control and protection trips to the bay. Circuit breaker fail trips will still trip circuit breakers in the other bays to clear the fault. As there is only one bay controller, the failure of a bay controller should be considered the same as the failure of the circuit breaker. The way to operate the circuit breaker when a bay control is out of service is through the push buttons on the front of the circuit breaker which bypass the interlocks. If the bay controller has failed, a fault will be cleared by the circuit breaker fail protection. It is possible to accelerate the circuit breaker fail protection for the loss of communications with the bay controller or a device health fail from the bay controller to reduce protection clearing times during this scenario.
- As all the bay level inputs to the interlock schemes are hardwired to the bay controller, there will be less communications traffic on the ethernet network as less signals will be passed between using IEDs. While most of the signals are required for indication to the SCADA system, these signals will be transmitted as manufacturing message specification (MMS) from the bay controller and only signals required by other using IEDs will be included in GOOSE messages. In an existing substation, this would be the circuit breaker 52a contact to the protection relays and the signals required for station level interlocking (circuit breaker isolated and in some cases the earth switch status)

The issue with this arrangement is that any change to bay level interlocks will require a setting change in multiple intelligent electronic devices that will then have to be completely retested.

The station level interlocking, completed by a station interlocking IEDs will interface with all the bay controllers and any other IEDs required in the interlocking scheme. During the design of the substation architecture a risk assessment will be completed to determine the level of redundancy required for interlocking.

6.2.1 IEC 61850 signal flow

As discussed above, the expected architecture for a substation utilising IEC 61850 is to have a bay controller for each bay and a station interlocking IEDs for all station level interlocks. It is expected that some signals will be required to be passed to protection relays including circuit breaker fail blocks, circuit breaker isolated and circuit earthed to be communicated to remote ends or customers. These signals can be either passed directly from the bay controller to the protection relays or to the station interlocking IEDs which will then transmit them to the protection relays. Signal flow will be discussed further in the IEC 61850 strategy document and during the design stage.

The preferred option is for the bay controller to only interface with the station interlocking IEDs which will process and broadcast the signals required by other IEDs with the protection relays subscribed to the interlocking IED.

6.3 Key interlocking

Key interlocking systems are used in some older switchboards installed in Ergon Energy's substations and are still offered by some manufacturers. It is expected that more switching devices will be motor driven and can be remotely controlled (the latest gas insulated switchgear purchased has this functionality). If key interlocking systems are used, they will require someone on site to operate the keys or may be bypassed with the remote control of devices.

Keys are also another point of failure that is added to the system. Damage due to age, incorrect use, stiff mechanisms and loss of the keys are all issues with the of use keys interlocking systems. New interlocking systems shall only use key interlocks to control access to plant or interfaces with customers.

7 Record keeping

Mechanical interlocks shall be shown on the operating single line diagrams which are stored in the electronic document management system (EDMS). Notes should be made of the presence of electrical interlocks on the operating single line diagrams with all conditions required to operate the device listed. One method to achieve this is to use an interlock table. An example interlock table is shown in Figure 25. The logic behind electrical interlocks shall be recorded as a logic diagram, which will be stored in a system which can be access as required. Bay specific interlocking diagrams are required for all bays. This ensures that each scheme is correctly recorded and includes signals from other bays or substations.

11KV SWITCHBOARD ELECTRICAL INTERLOCKS	
CB CLOSING BLOCK	
CIRCUIT	BLOCKING SIGNAL
FB22Q00 TO FB26Q00	DC CONTROL SUPPLY FAILURE OR 11KV BUS 2 ES FB21Q05 CLOSED
BUS EARTH SWITCH ACCESS FLAP BLOCKING	
FB21Q05	DC CONTROL SUPPLY FAILURE OR LIVE LINE INDICATION OR FEEDER CB IN SERVICE POSITION OR BUS VT IN SERVICE POSITION

Figure 25: Example interlocking table

Annex A

Informative

Discussion points

A.1 Voltage transformer as a source of supply

Before applying an earth, HV plant shall be proven de-energised. Current practises either use a fixed voltage presence indicator or a portable high voltage tester. Where earths can be electrically interlocked or remotely controlled, the dead check needs to be completed by a permanent device with an input into the interlock logic scheme. For metal enclosed switchboards and gas insulated switchgear voltage presence indicators are installed that can be used for this function. Section 5.6 defines the requirements of the voltage detector systems to be used for this function. In outdoor situations the only permanent measuring device is a voltage transformer. Switching procedures require the voltage transformer to be isolated before earths can be applied. This is not currently an issue as the earths are either portable earthing devices or fixed devices with mechanical interlocks requiring onsite application by personnel.

If electrically operated earth switches are installed in substations; it may be beneficial to use the voltage transformer to check for dead. The location of the voltage transformer in the existing arrangement of a feeder bay will not measure the line voltage when the line has been isolated for earthing. Consideration to the type and location of voltage detection devices will be required for the implantation of outdoor air insulated motor driven earth switches.

Current practise is to consider all voltage transformers as a source of supply and isolate before earthing. Withdrawable VTs are racked out and nonwithdrawable or outdoor VTs have the LV connections isolated and a do not operate board (DNOB) placed. A measuring circuit, such as protection relay, is not a source of supply; it only becomes a source of supply when a test set is used to inject the circuit.

As the IEC 61850 is implemented, voltage measurements will no longer be hard wired and will become digital. Relay testing will be done digitally without the need to secondary inject the relay. However, in the cases where merging units are used at the instrument transformers, these units will require some testing possibly including primary injections to confirm accuracy of the device. If this is the case, this should only be done while the HV earth is applied. This means that if the secondary isolation is not completed correctly and the VT becomes a source of the supply, the test set will overload and be unable to back energise the HV.

Where the substation AC supply is provided by high burden or power voltage transformers these shall be considered a source of supply. This will ensure that low voltage generators connected to the low voltage AC board cannot back energise the high voltage plant under access.

Where voltage transformers are considered a source of supply and a miniature circuit breaker (MCB) is used on the low voltage side instead of fuses an auxiliary contact from the miniature circuit breaker should be used in the interlocking scheme as an isolation point.

A.2 Remote earthing through circuit breakers

Some switchgear types apply earths through the circuit breakers. There is the requirement that all electronic operations of the circuit breaker are prevented while the circuit breaker is used for earthing. To remotely apply and remove earths, it shall be possible to operate the circuit breaker remotely which requires electric operations of the circuit breaker to be functional. To achieve this, it is proposed to have an additional set of control points in SCADA and on the HMI. These control points will open and close the circuit breaker only while the earth switch is closed. All protection and other control operations will be prevented from operating the circuit breaker while the earth switch is applied.

In situations where a circuit is earthed through a circuit breaker, the feeder current transformers will be downstream of the earth switch and the requirements of section 5.4.5 apply. Protection trips are not blocked however all electrical trips are isolated as part of as part of the switching procedures. While the earth is applied, protection trips shall be blocked to ensure that the earth is not removed except when required by the switching sheet. The scheme shall be designed so that protection trips are restored before the circuit breaker is returned to service.

Annex B

Informative

Interlocking examples

B.1 NOMAD

The NOMAD has various interlocks to prevent the operation of high voltage plant including circuit breakers, disconnectors and earth switches. This section outlines the interlocks installed on the NOMAD and the method by which they are achieved.

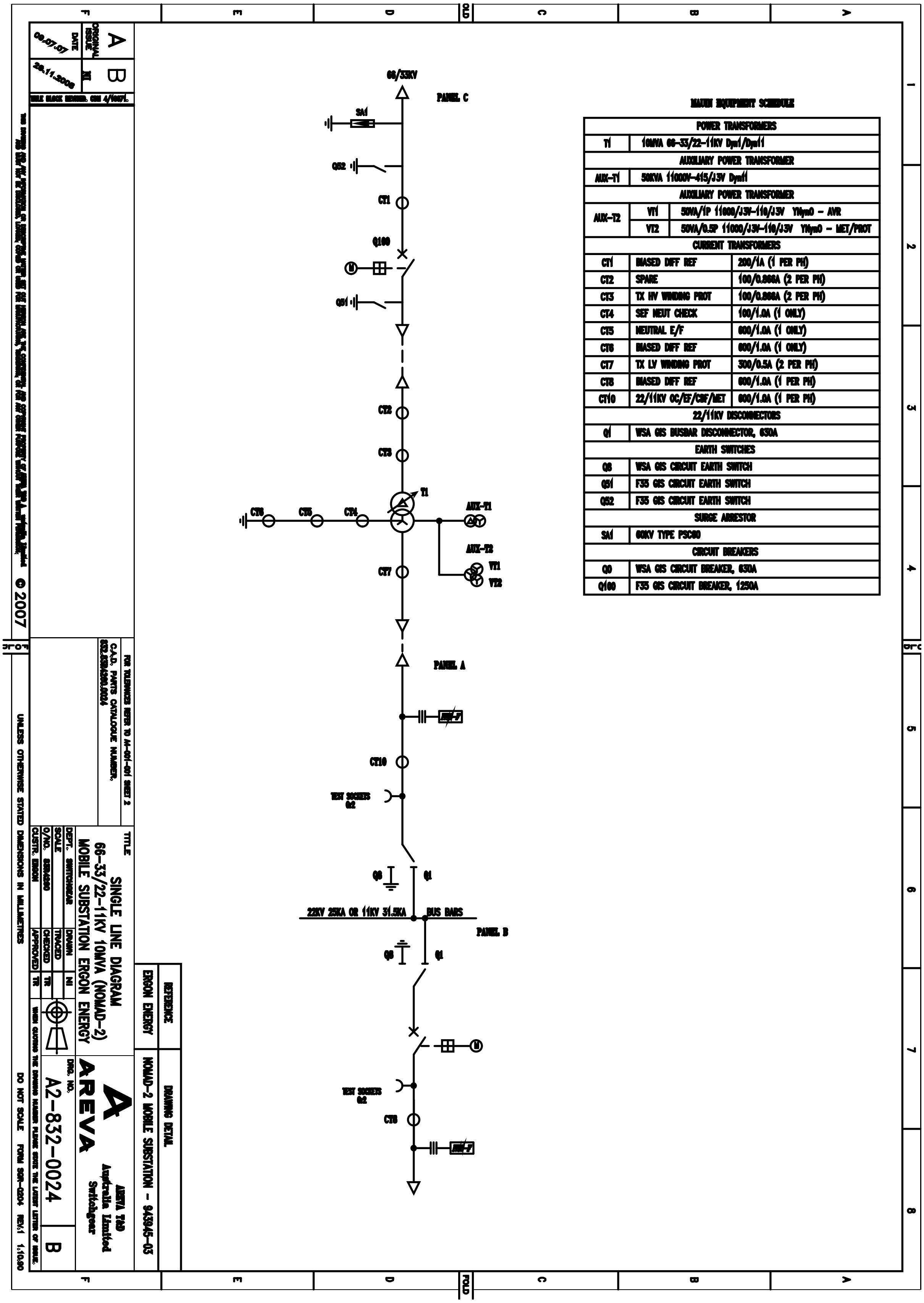


Figure 26: Nomad single line diagram

B1.1 66/33 kV plant

On the high voltage (66/33 kV) side of the NOMAD, the bay level interlocks functions are processed by the bay controller (Areva C434). The station level interlocks are hardwired electrical interlocks. To operate either of the earth switches (Q51 and Q52), the customer permission (key interlock) needs to be active and the Q100 circuit breaker shall be open. The bay level interlocks which allow the circuit breaker to close are the gas lockout, which needs to be reset, and both earth switches open or closed. To open the circuit breaker the gas lockout must be reset. The station level interlocks only apply to closing the circuit breaker and are hard wired in series with the close coil. The station level interlocks to close the circuit breaker are both the 22/11 kV earth switches (2A Q8 and 2B Q8) which shall be opened.

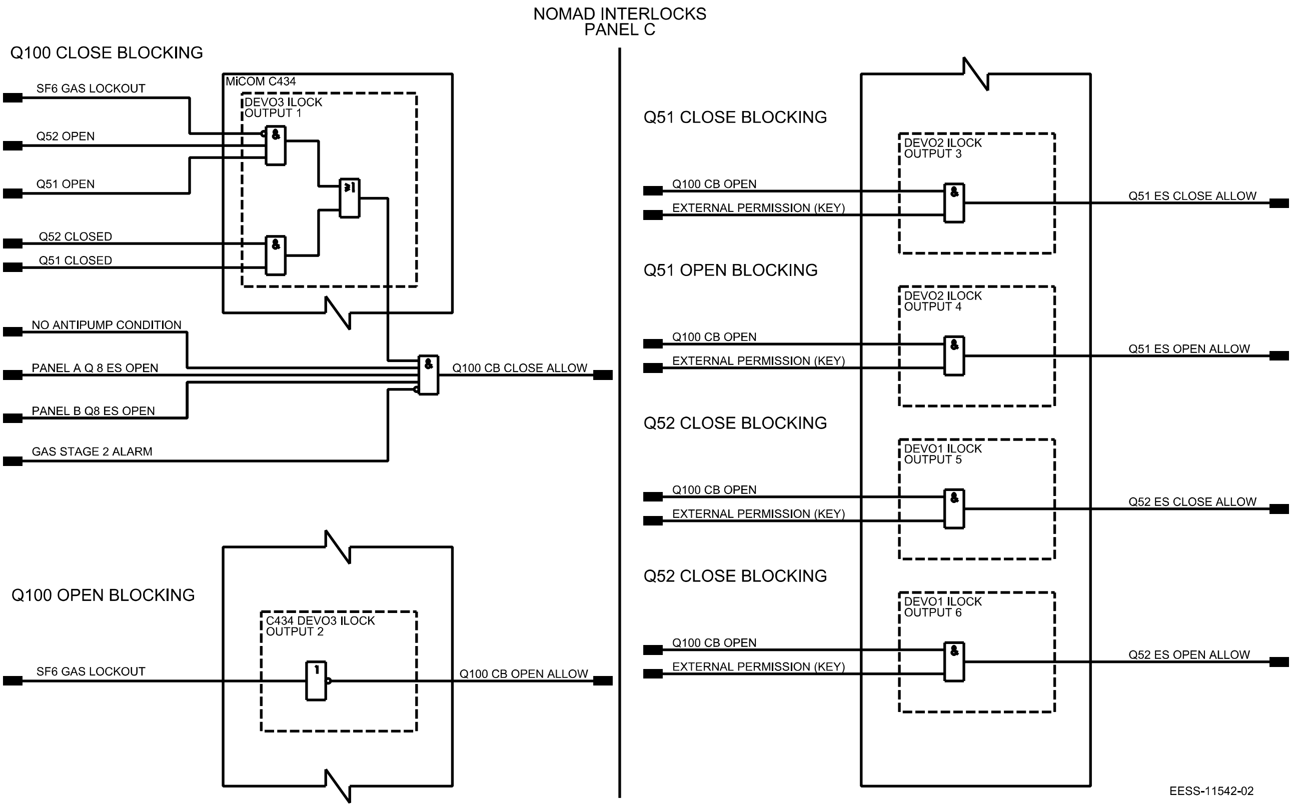


Figure 27: Nomad HV interlocking logic

B1.2 22/11 kV

All electrical interlocks on the 22/11 kV switchgear are hardwired. There are two switchgear panels; 2A and 2B. Panel 2A has a disconnector and earth switch and panel 2B has a circuit breaker, disconnector and earth switch.

Operation of both panel 2A and 2B disconnectors requires both circuit breakers to be open. Operation of the panel 2A earth switch requires both circuit breakers open.

Operation of the panel 2B earth switch requires the Q100 circuit breaker to be open and both the LV circuit breaker Q0 and disconnector Q1 to be open or the earth switch Q8 to be closed. To close the Q0 circuit breaker requires the spring to be charged and the circuit breaker to be open.

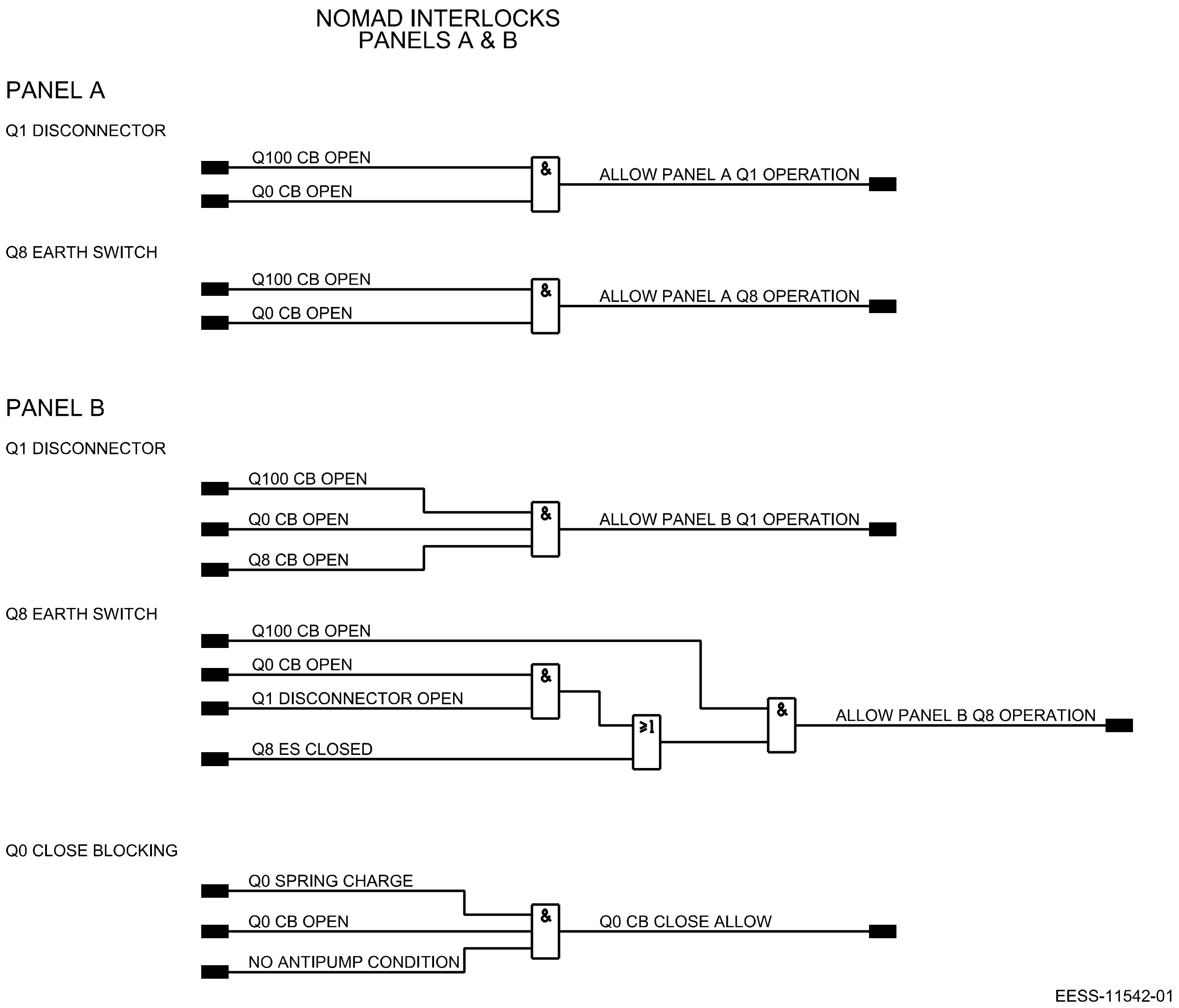


Figure 28: Nomad HV interlocking logic

B1.3 Operational issues with the scheme

With the current interlock scheme it is not possible to close the Q100 circuit breaker unless both Q8 earth switches are opened. Consequently it is not possible to earth the LV NOMAD cable while the NOMAD is energised.

The panel 2B Q1 disconnector requires the Q100 circuit breaker to be open to allow operation. This requires the NOMAD to be de-energised before the disconnector can be operated. To ensure that the disconnector does not break load while allowing the NOMAD to remain energised, the interlock logic could instead require the Q0 circuit breaker and the panel 2A Q1 disconnector to be open instead of the Q100 circuit breaker.

Annex C

Informative

T-Style substations

The T-style substation design philosophy includes a two-bus medium voltage switchboard that can be staged with either bus built first. To be consistent with this, the interlocking scheme must allow for the staging. The interlocking requirements are based on the interlocking used in the existing zone substation standards.

To ensure required interlocks are maintained when two T-style substation buildings and switchboards are interfaced, equipment status signals must be transferred between the buildings. A standard design has been produced to reduce the number of signals and ensure that the scheme can be achieved with the auxiliary contacts available on the current switchboards.

The main difference between this arrangement and a standard two section switchboard is that when two bus sections are connected together, one of the buses will have two bus earth switches. Both bus earth switches need to be considered in the interlocking schemes.

C.1 Bus earthing

Before a bus earth switch can be applied the following shall be true:

- all withdrawable devices on the bus are withdrawn,
- the bus is de-energised
- the bus earth switch open.

The test position indication of the bus tie circuit breaker is required to confirm that it has been withdrawn. There are currently no spare test position contacts in the combination panel, however there is a test position contact reserved for indication to SCADA. This contact is not used in Ergon Energy designs and the published zone substation template drawings do not connect anything to this contact. Instead of installing a follower relay for the test position, this unused reserved contact will be used for the interlocking logic.

To share the test position indication of all devices on the bus with both bus earth switches, an auxiliary follower relay will be used. As all the inputs into the relay are normally open and normally open contacts will be used for the outputs, there will be no change to the fail-safe state of the interlock scheme.

A voltage presence indicator is used for the bus de-energised check. The earth switch in the riser panel has an associated live line indicator which is already included in the interlocking scheme. The earth switch in the combination panel also has an associated live line indicator which is used in the interlocking scheme when the bus tie panel is used as a feeder. To minimise wiring between the two buildings, when the switchboards are connected, the bus de-energised check for each earth switch will be completed by the live line indicator in the same panel as the earth switch.

C.2 Circuit breaker close blocking

To prevent a circuit breaker from being closed onto an earthed bus, the status of the bus earth switch is required by the circuit breaker close blocking logic of each circuit breaker on the bus. To achieve this, the current design of the iPower 11kV switchboards is to use an earth switch normally open auxiliary contact and an auxiliary relay (bus earth switch auxiliary relay) with normally closed output contacts. The issue with this is that for a loss of DC supply to the relay it will be possible to close a circuit breaker onto an earthed bus provided all the other conditions are achieved. The scheme is therefore does not fail safe for the loss of the power supply and doesn't meet the Standards Australia for Substations and high voltage installations exceeding 1 kV a.c. (AS 2067, 2016). As the DC control supply for each panel is separately fused, it is possible to have no control supply to the riser panel and the bus earth switch auxiliary relay, but still have a control supply to other breakers on the bus section.

In the T-style substations each bus section will be in a separate building which will have its own DC supply. In this case there is the additional risk of loss of DC supply to the building without the bus tie circuit breaker which will allow the bus tie circuit breaker close onto an earthed bus. This is an additional risk as other cases only have one DC system, and the loss of the system will prevent all circuit breakers from being closed. For the bus with two earth switches, if either of the earth switches are closed, the circuit breakers on that bus shall be prevented from closing.

For each panel on the bus there is a dedicated contact from the bus earth switch auxiliary relay which is used in the close blocking logic. To reduce the additional wiring required, the earth switch from the tie panel which becomes the second bus earth switch will be wired into the existing auxiliary relay so that if either bus earth switch is closed, the circuit breakers will be blocked from closing.

To make the scheme fail safe it is possible to use a normally closed earth switch auxiliary contact with an auxiliary relay which has normally open output contacts. The earth switches installed in the iPower 11kV switchboards have only two normally closed contacts which are currently used for earth switch close blocking and indication to SCADA.

To maintain the existing functionality and ensure fail safe operation for the loss of DC supply, an additional auxiliary relay is required with normally open contacts. The contact currently used in the earth switch close blocking interlock scheme will be used as the input into this new auxiliary relay which requires a minimum of two normally open outputs. The first contact will be used in the earth switch close blocking scheme. The second contact will be an input into the bus earth switch auxiliary relay (-K058). The bus earth switch auxiliary relay (-K058) is required to have a minimum of six normally open outputs.

The new auxiliary relay is also required, in the combination bus tie / feeder panel. The first output of the auxiliary relay will be the same as for the riser panel (earth switch close blocking). The second output depends on use of the panel as a distribution feeder, close blocking of its own circuit breaker and for a bus tie and close blocking of all circuit breakers on the bus section using the bus earth switch auxiliary relay (-K058) in the riser panel.

C.3 Solution

To complete the interlocking schemes, four equipment status signals are required between the two-control building/switchboards. All required inter-switchboard signals are to be wired to the interface cubicle. The wiring between the two switchboards is between the riser panel and tie panel which are connected together. Each panel sends and receives two signals. Panels not connected together shall have bridging as per the Table 3 to ensure that the interlock scheme is maintained. All bridges are to be made in the building interface cubicle. A new auxiliary relay is required to indicate that all devices in the bus are in the test position (bus isolated relay); this relay will be located in the riser panel.

Table 3: Requirements by panel type

Panel Type	Send	Not connected state
Combination Feeder	Circuit breaker test position	Bridge to all devices in test position
	Earth switch status (N/O)	Bridge to bus earth switch status
Bus Riser	All devices in test position	Short
	Bus earth switch applied	Open

If the required bridges and shorts are not installed, the interlock schemes will prevent the operation of the interlocked device. This ensures that the switchboard cannot be placed in an unsafe operating arrangement.

C.4 Example

For this example, FB16 is connected to FB21 as shown in Figure 29. Table 4 shows the connections to be made between the two buses and the required bridging for the panels not connected. Circuitry drawings from the T-style substations standard are shown in Figure 30 and Figure 31.

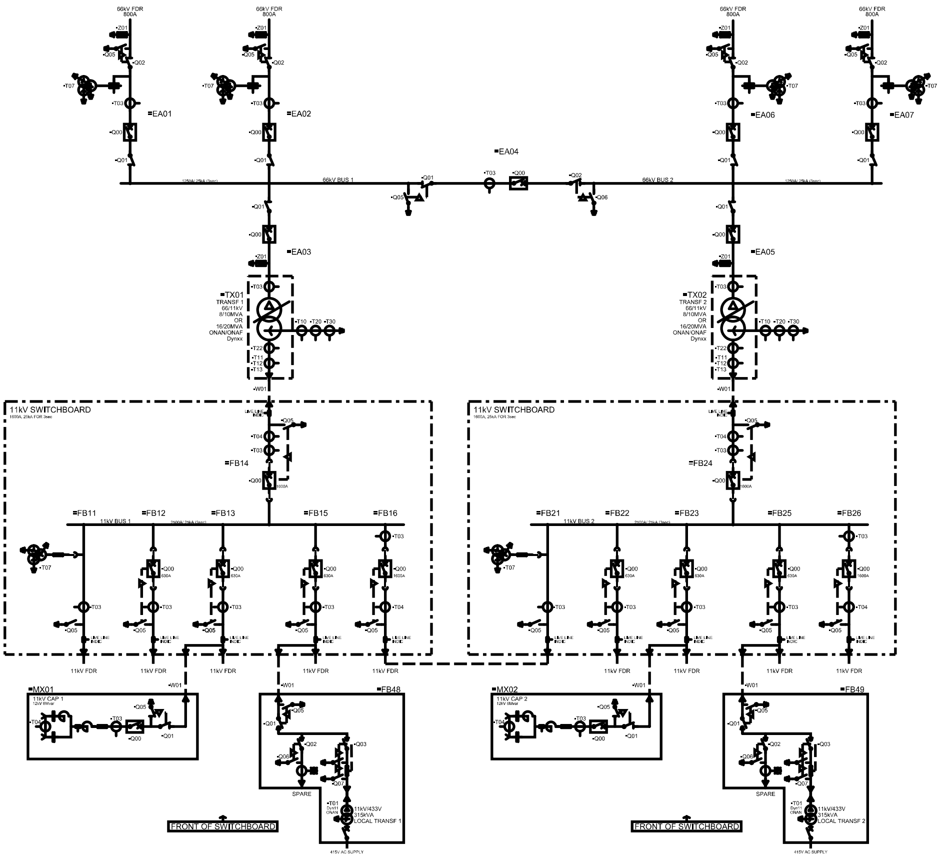


Figure 29: Single of T-subs for example

Table 4: Example requirements

Panel	Signal	Destination Action
FB16	=FB16-Q00 test position	FB21: connect to Bus 2 isolated relay
FB16	=FB16-Q05 status	FB21: connect to bus 2 earth switch auxiliary relay
FB21	Bus 2 isolated	FB16: connect to earth switch close blocking
FB21	Bus 2 earth applied	FB16: connect to circuit breaker close blocking
FB26	=FB26-Q00 test position	FB26: bridge to earth switch close blocking
FB26	=FB26-Q05 status	FB26: bridge to circuit breaker close blocking
FB11	Bus 1 isolated	FB11: short inputs in to bus 1 isolated relay
FB11	Bus 1 earth applied	FB11 leave open

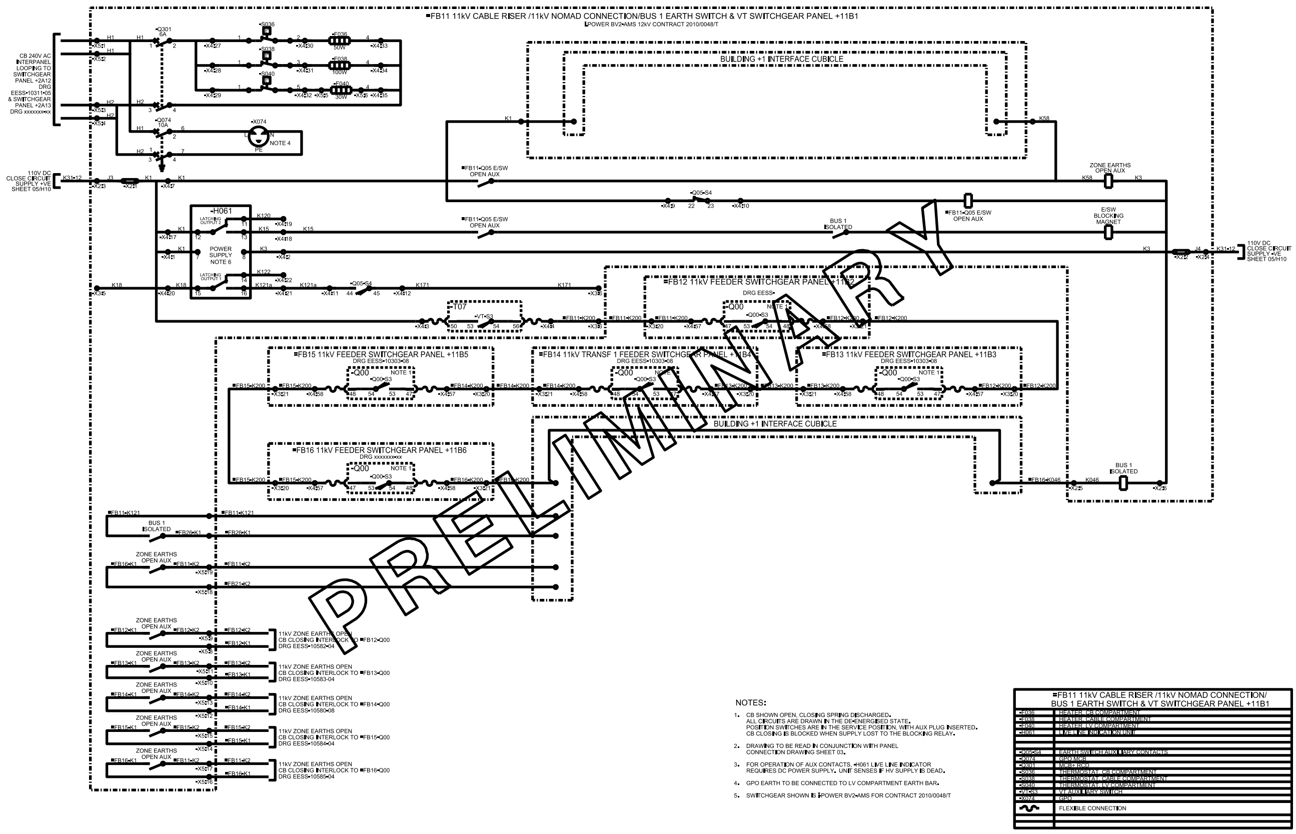


Figure 30: Bus riser panel DC schematic

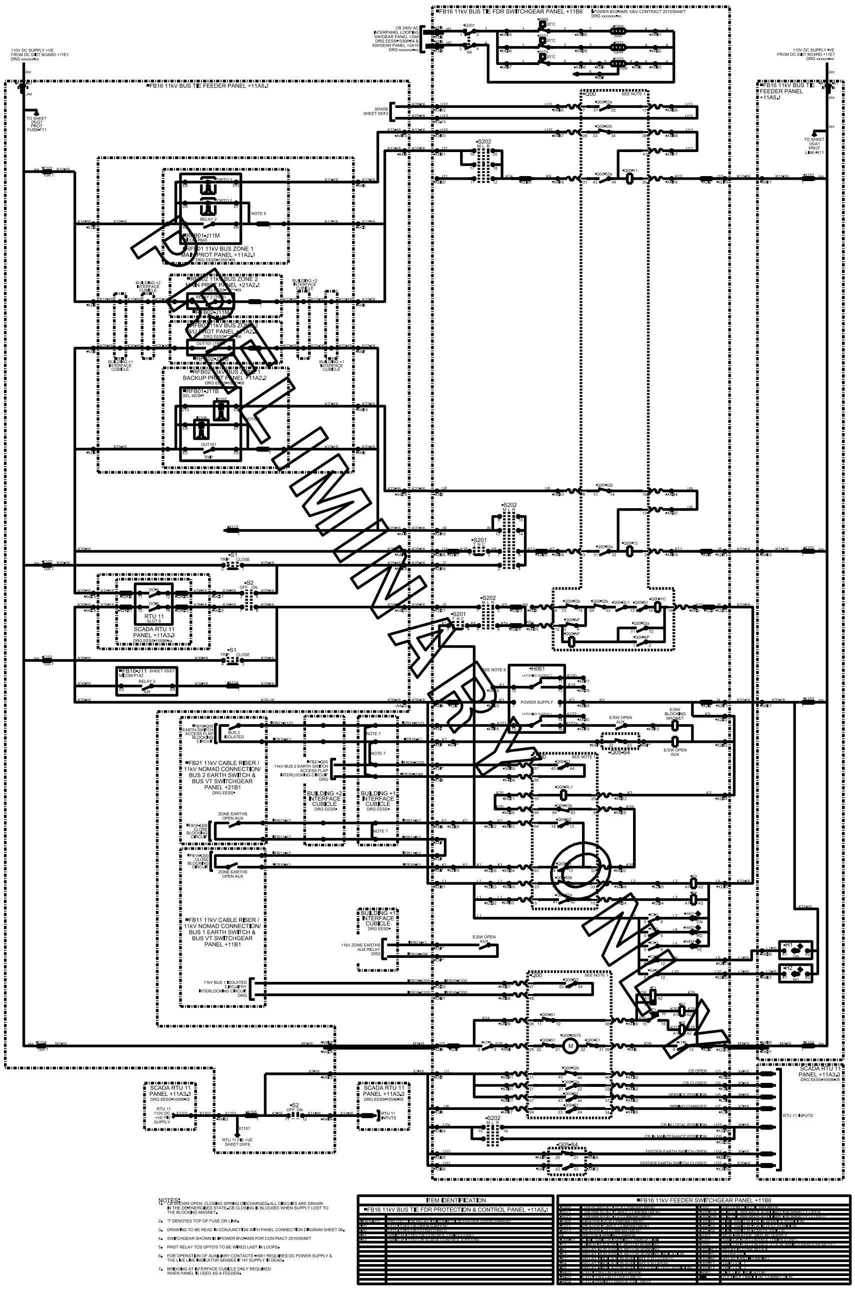


Figure 31: Bus tie / feeder panel DC schematic

Annex D

Informative

Sample switchgear

D.1 Sample withdrawable switchgear

Figure 32: Sample withdrawable switchgear

D.2 Sample nonwithdrawable switchgear

Figure 33: Sample nonwithdrawable switchgear

D.3 Gas insulated switchgear

Figure 34: Sample gas insulated switchgear

D.4 Sample air insulated switchgear

Figure 35: Sample air insulated switchgear

Annex E

Revision History

Revision date	Version number	Author	Description of change/revision
29/08/17	1	A.Gabriel	Initial issue
June 2023	2	A.Gabriel	Update format for ECM audit