Substation Layout

Design Standard

DOCUMENT HIERARCHY

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RESPONSIBILITIES

Western Power's Engineering & Design Function is responsible for this document

CONTACT

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Contents

Revision Details[1]

Version	Date	EDM Version	Summary of change
0	7/16	0.38	Draft Issue
1	7/19	1	First Issue
2	September 2022	2	Includes updates covering items 6-16 of Register – Engineering Design Instruction, Construction Technical Specification Information & Drawing Issues Register.
2A	September 2023	3	Includes updates covering items 21-24 of Register – Engineering Design Instruction, Construction Technical Specification Information & Drawing Issues Register.
2	January 2024	5	Standards Online Update

1 See Western Power Internal Document

1 Introduction

The layout of a substation yard is extremely important. A good layout ensures that the substation will be able to be constructed, maintained, and expanded over its 40 to 50 year lifetime to meet initial and future requirements of the network. The layout of the substation also has a considerable impact on the overall cost and an optimised layout ensures that the overall whole of life cost is minimised.

This Engineering Design Instruction will guide designers on what to consider while developing an initial layout of a substation or an addition to a substation.

1.1 Purpose and scope

This Engineering Design Instruction will cover the layout of primary equipment in the yard. It does not cover panel or control cable layouts which is covered in Engineering Design Instruction – Substation Secondary Systems Design. The Engineering Design Instruction covers greenfield and brownfield applications for zone and terminal substations. It covers all current approved layout types and provides guidance on extending existing arrangements.

This document references standard layouts and information about how these were derived.

This Engineering Design Instruction also provides some information on layout optimisation and how to apply the principles to develop optimised initial and ultimate layouts.

1.2 Acronyms

Acronym	Definition

1.3 Definitions

Term	Definition
Engineering Design Instruction (EDI)	Describes in detail a particular type of design. This is the "how" to implement a design with clear boundaries defined.
Network Standard (NS)	A Controlled Technical Document that describes in detail "what" needs to be done in regard to a particular network asset or area of the network. It is typically a mid-level document that may contain 10-30 pages including diagrams and operating parameters. Once approved compliance for all new work is mandatory (allowing for a phase in period), While enforcing retrospective compliance for existing assets is determined on a case by – case basis.
SFAIRP	So far as is reasonably practicable
CB	Circuit breaker
C.O.M	Construction, Operation and Maintenance
CT	Current transformer
DES	Disconnector with earth switch

DIS	Disconnector
HMR	Hazard Management Register
HV	High voltage. 66 kV and greater
MV	Medium voltage. Low voltage to 66kV
LV	Low voltage. Up to and including 1000 V
RRST	Rapid Response Standby Transformer
Standard Design	A substation design which follows the criteria listed in Section 7.1
VT	Voltage transformer

1.4 References

References which support implementation of this document

Table 1.1 References

Reference No.	Title

2 Supporting Documentation[2]

3 Compliance[3]

This Engineering Design Instruction complies with all higher-level Western Power technical documents and relevant Australian Standards.

This Engineering Design Instruction should encompass all requirements of the relevant Australian Standards which are current at the time of issue. These relevant Australian Standards are listed in Table 3.2 below. A period will be set when the standard needs to be reviewed. If significant changes occur on an Australian Standard which affects safety, then an out of cycle review can be completed.

Table 3.1: Relevant Documentation

Document Title
Network Standard – Fire Protection, Oil Containment and Noise

[2] See Western Power Internal Document
[3] See Western Power Internal Document

Document Title
Network Standard – Transmission and Distribution Line Easements and Restriction Zones
Engineering Design Instruction – Busbars and Conductors
Engineering Design Instruction – Safety and Maintenance Clearances
Engineering Design Instruction – Substation Secondary Systems Design
Engineering Design Instruction – Labelling and Numbering
Engineering Design Instruction – Earthworks, Roads and Drainage
Engineering Design Instruction – Oil Containment and Fire Protection
Engineering Design Instruction – HV Cables and Terminations
Engineering Design Instruction – Transmission Substation Fences and Gates
Engineering Design Instruction – Substation Lighting Design
Engineering Design Instruction – Substation Building Design
Checklist – Substation Design
Register – Substation Design Drawings – EXTERNAL Version
Network Standard – Fire Protection, Oil Containment and Noise
Network Standard – Transmission and Distribution Line Easements and Restriction Zones

Table 3.2: Australian Standards

Standard Number	Standard Title
AS/NZS 3000	Electrical installations. (The Wiring Rules)
AS/NZS 4836	Safe working on or near low-voltage electrical installation and equipment.
AS 2067	Substations and high voltage installations exceeding 1kV a.c.
ENA NENS 03	National Guidelines For Safe Access To Electrical And Mechanical Apparatus.

Standard Number	Standard Title
ENA NENS 04	National Guidelines For Safe Approach Distances To Electrical And Mechanical Apparatus.
AS/NZS 7000	Overhead line design – Part 1: Detailed procedures

4 Functional Requirements

This Engineering Design Instruction is intended to be used by Substation Engineering staff and by companies completing outsourced design work for Western Power, as it outlines the Western Power requirements pertaining to the layout of transmission substations.

5 Safety in Design

5.1 Hazard Management Register (HMR) [4]

Any identified hazards shall be documented in the Hazard Management Register (HMR) and shall be eliminated, or have risks reduced to SFAIRP. The HMR and relevant design drawings shall undertake a construction, operation, and maintenance (C.O.M) review at relevant stages of the project.

5.2 Design Layout

When designing substation layouts, an important consideration must be the end user. The Safety in Design process ensures that the safety of all personnel is a major aspect of the design by ensuring that potential hazards are identified and eliminated or minimised so far as is reasonably practicable (SFAIRP).

The substation designer may start identifying hazards by considering safe access and clearances. Prompt points could be considered such as:

- Does the layout make logical sense and is it easy to follow for personnel unfamiliar to the site?
- How will equipment be accessed during construction, operation, maintenance and decommissioning?
- Are there adequate clearances to the ground or adjacent live equipment?
- Is there an access path for all machinery and vehicles?
- Have clearances and access routes been considered if work is to be carried out on adjacent circuits using Elevating Work Platforms.
- Can work near existing live equipment be minimised or adequate provision made for segregation such as barriers?
- Are platforms required to allow safe access?
- Will the construction of future stages of development be able to be done safely While the remainder of the substation is energised?

[4] See Western Power Internal Document

Additional safety and health risks to be considered are detailed throughout this Engineering Design Instruction.

6 Overview of the Main Design Elements

There are many variables to consider when designing the layout of a substation. Some of these considerations are discussed in detail in this Engineering Design Instruction, others are mentioned because they must be considered but refer to other Engineering Design Instructions for more detail.

The following elements should be considered when starting a new layout or augmenting an existing substation layout. See the relevant chapter for more information:

- Safety in Design – Section 5
- Ultimate layout – Section 7.1
- Initial layout – Section 7.2
- Sequence of development – Section 7.4
- Layout Optimisation – Section 7.5
- Standards – Section 8.1
- Environmental and social impact– Section 11

6.1 Additional Design Considerations

In addition to the main design elements, the following must be considered:

- Adequate access to maintain plant
- Approval from OAP pertaining access to plant for maintenance purposes where standard design has not been followed
- Council approval of switchroom location (proximity boundaries)
- Ease of distribution feeder exit cables as per Distribution Design requirement may require approval from Distribution Design for Distribution MV cable exit routes.

7 Site Layout

7.1 Ultimate Layout

The future expansion of the substation must be considered when preparing a site utilisation. Substations invariably develop in stages which means facilities and equipment are constantly extended over time. Site utilisation designs need to consider how progression up to the ultimate development can be accommodated in a logical, sustainable, and cost effective way.

A new substation must be designed for the ultimate layout. Grid Transformation will specify the required ultimate single line diagram for the substation. This shall be used by the designer to ensure that the substation can develop in stages over its lifetime to the ultimate configuration.

7.2 Initial Layout

The electrical arrangement of a substation needs to be developed before the physical layout can be determined. This arrangement takes the form of a schematic single line diagram that shows the ultimate electrical arrangement of all circuits and primary and secondary busbars. If applicable, staging from the initial to ultimate development can be useful to designers.

The initial layout will depend on the ultimate layout and the expected sequence of development. For zone substations, generally the whole ultimate substation area is developed as part of the new substation installation, but foundations and plant are only installed for the initial development. For terminal yards, only a small part of the ultimate yard area will be developed, to reduce the initial earthworks, fencing, earthing and site surfacing cost.

7.3 Site Utilisation

Substations are developed in stages over a number of years. Following the initial installation, additional equipment, including transformers, switchboards, line circuits, capacitor banks and feeder cables, are installed periodically until the substation reaches the ultimate development described in the ultimate single line diagram. Sometimes the ultimate plan changes but it is essential that the initial site utilisation shows how the ultimate development proposed at that time can be accommodated on the site.

A stage development should be planned to ensure that the site is developed in a sustainable way. Issues to consider while designing include:

1. Space allowed for future stages must not be obstructed by equipment that is not part of the planned development.
2. Future transmission line termination poles and line entries must not be obstructed.
3. Electrical clearances within the substation and to external equipment must not be compromised.
4. Separation distances required for EMF compliance must not be compromised.
5. Access to the substation is maintained during all stages of development.
6. Access for safe installation of new equipment and maintenance of the whole installation is available at all stages of development.

An effective method of recording each issue is to prepare a site utilisation drawing or set of drawings. To provide a complete picture of the substation and its development over time, the site utilisation drawing should show the following details:

1. Site location – including surrounding streets and the location of the initial transmission lines for short sections from the substation
2. Single line diagram of the initial, intermediate, and ultimate developments
3. Three phase electrical arrangement of the initial, intermediate, and ultimate developments within the fence line.

7.4 Sequence of Development

7.4.1 Zone Substation

The initial development of a substation will be provided by Grid Transformation. The order of transformer installation shall depend on the network requirements as well as the substation layout, operational and maintenance requirements. The orientation of the line circuits shall, wherever possible, align with the direction of incoming lines to avoid additional cost associated with deviating the line entries.

7.4.2 Terminal Yard

The development in a terminal yard is generally done in small portions as line and transformer circuits are required. The middle section of the yard should be developed first, to allow flexibility for new lines to connect into the yard without crossing existing lines or requiring significant deviations. Some degree of planning can be done to work out future line positioning, however since the life of the substation is 50 years, the layout should be flexible to cater for future planning as provided by Grid Transformation and future expansion not currently foreseen.

7.5 Layout Optimisation[5]

The primary layout of a substation is an important aspects to consider when designing a substation. Ensuring that suitable decisions are made at the planning stage of the project can deliver substantial savings and avoid major delays to the project.

While the Substation Designer must ensure that standard designs are followed as far as possible, in some situations such as space restricted sites, careful consideration of alternate layouts should be carried out.

Often, the best opportunity to make financial savings on a substation project is at the land purchase stage. It is not advisable to base the decision on which block to purchase for a substation site purely on the purchase price. There are many other variables to consider which can have a huge financial impact on a project – i.e., the cost to include community requirements, or costs to remove rock or treat acid sulphate soils. Only when considering all the variables of a substation site, one of which is the land cost, can one make a considered and well evaluated decision.

7.5.1 Optimisation Variables

There are many variables to consider during an optimisation exercise. The variables can be categorised into two main areas, technical and social/environmental, see Table 7.1 below.

Table 7.1: Technical and Social / Environmental Variables for a Substation Layout

Technical	Social / Environmental
Constructability	Visual Aspect
Maintainability	Noise

[5] See Western Power Internal Document

Technical	Social / Environmental
Operability	Future Land Use
Site Topography	Road Access
Access and Egress	
Line Entry Positioning	
Location of Major Load	
Road Slope and RRST Access	
Soil Condition	
Cable Layout	
Circuit Arrangement	

The causal relationships between the variables can then be derived, see Figure 7.1. From here the high value thread can be determined which illustrates where the highest value will be gained by optimisation.

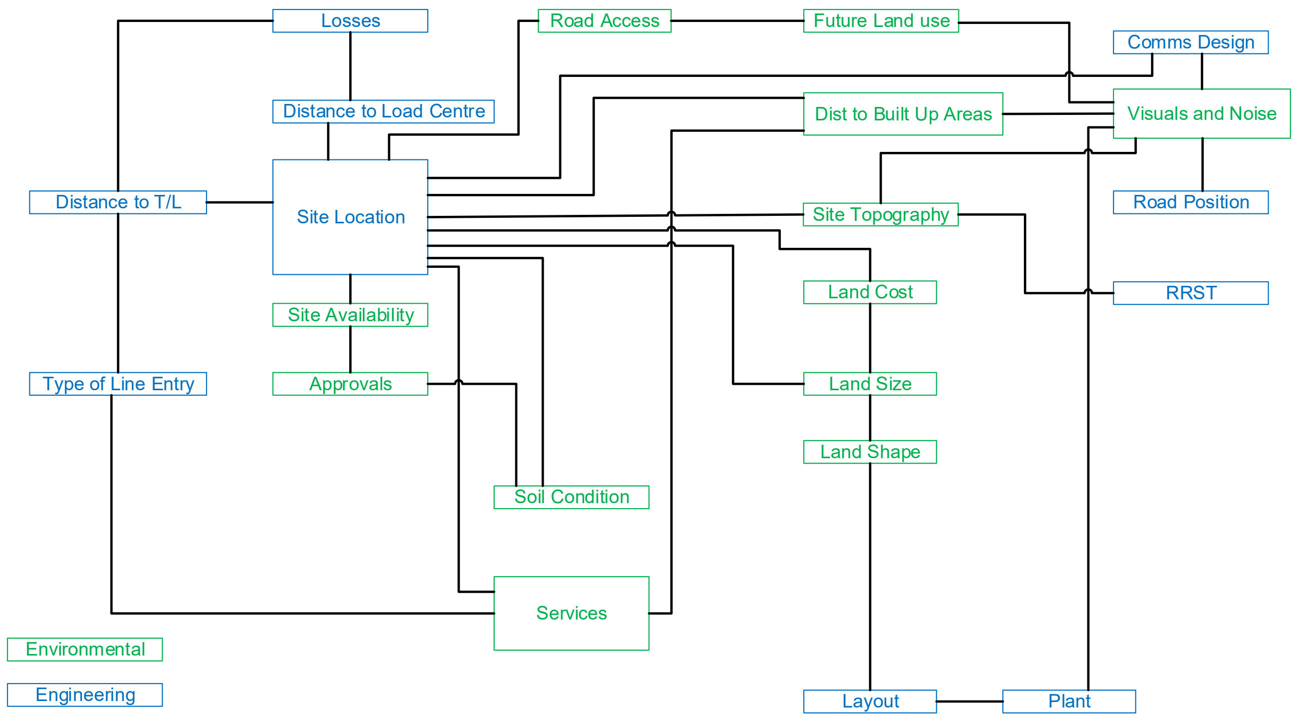


Figure 7.1: Casual Relationship Between Substation Site Location Variables

7.5.2 Orientation of Primary Busbar

A substation layout is primarily dictated by the location of the primary busbar and circuits.

The major requirement in locating the primary busbar is to recognise the approach direction of the incoming transmission lines. These will determine the location of the entries and therefore the line circuits, which will in turn determine the orientation and location of the primary busbar.

Australian Standard AS2067 and Engineering Design Instruction – Safety and Maintenance Clearances provide most of the requirements regarding clearances and other matters relevant to busbar design and substation layouts.

Some matters to be considered when designing the primary busbar circuits are:

- Excessive slope across the site – the preference is for the site to be level along the busbar and with a maximum slope of 2.5% through the circuits.
- Electrical clearances for safe working, impulse withstand and pollution performance.
- Busbar and circuit spacing together with support positions to achieve the required mechanical performance under fault current conditions.
- The ability to install, maintain and operate any item of equipment such that safe working clearances are maintained to adjacent live equipment.
- Space for test and maintenance equipment and working space for the people using it.
- Segregation between equipment items so that a failure or fire on one item does not affect an adjacent item.

Once the primary busbar and circuits have been orientated and positioned on the site, the location of all other equipment and facilities can be determined.

7.6 Brownfield Sites

It may not be possible to meet all the site layout requirements for extension of brownfield sites. In this case the proposed layout should be developed in consultation with input from Grid Transformation, Operational Asset Performance, Construction, Maintenance and Operations teams.

8 Layout Type[6]

There are several different layout types used for Western Power substations, the most common being single bus for zone substations. Terminal yard configurations are generally breaker and a half arrangement but mesh and double bus layouts are also used.

The circuit arrangement will be decided by the Grid Transformation Function during the scoping and estimating phases of the project.

[6] See Western Power Internal Document

8.1 Standards

Western Power's policy is to standardise the design of substations as much as possible. On this basis, a site utilisation study should maintain an awareness of the benefits of standardisation and attempt to keep layouts as close as possible to recognised standard arrangements.

The merit in developing a network of substations which are as standardised as possible includes:

- Assistance in streamlining the estimating and business case approvals process because of their well-recognised modular costs.
- The use of repeatable standard design packages that enhance efficiencies in the design process.
- Designs whose impact on the community and environment can be readily assessed and assist in streamlining the approvals process.
- Standardised operations and maintenance methods, procedures, training, and equipment which minimises whole of life costs, optimises substation availability and minimises the risk of accidents due to unfamiliar layouts and arrangements.
- Built-in flexibility to react confidently to faults because common spares are more readily available and replacement methodologies are well recognised, all of which contribute to minimising downtime and safety risks.

8.2 Zone Substations

For Zone substations the approved standard layout is a single outdoor HV bus and a single MV bus within multiple switchboards, with bus section cables connecting the boards. For some high reliability areas, zone substations use dual-secondary transformers in which case multiple double busbar MV switchboards are used.

Many old yards have an outdoor MV bus and it is not recommended to extend this bus for any more than one or two extra circuits.

8.2.1 Greenfield Zone Substations[7]

The standard layout for new greenfield sites shows four lines and three transformers in a single HV bus arrangement, and three separate switchboards in a single bus arrangement for the MV side. See Section 7.4.1 for the sequence of development of the site.

[7] See Western Power Internal Document

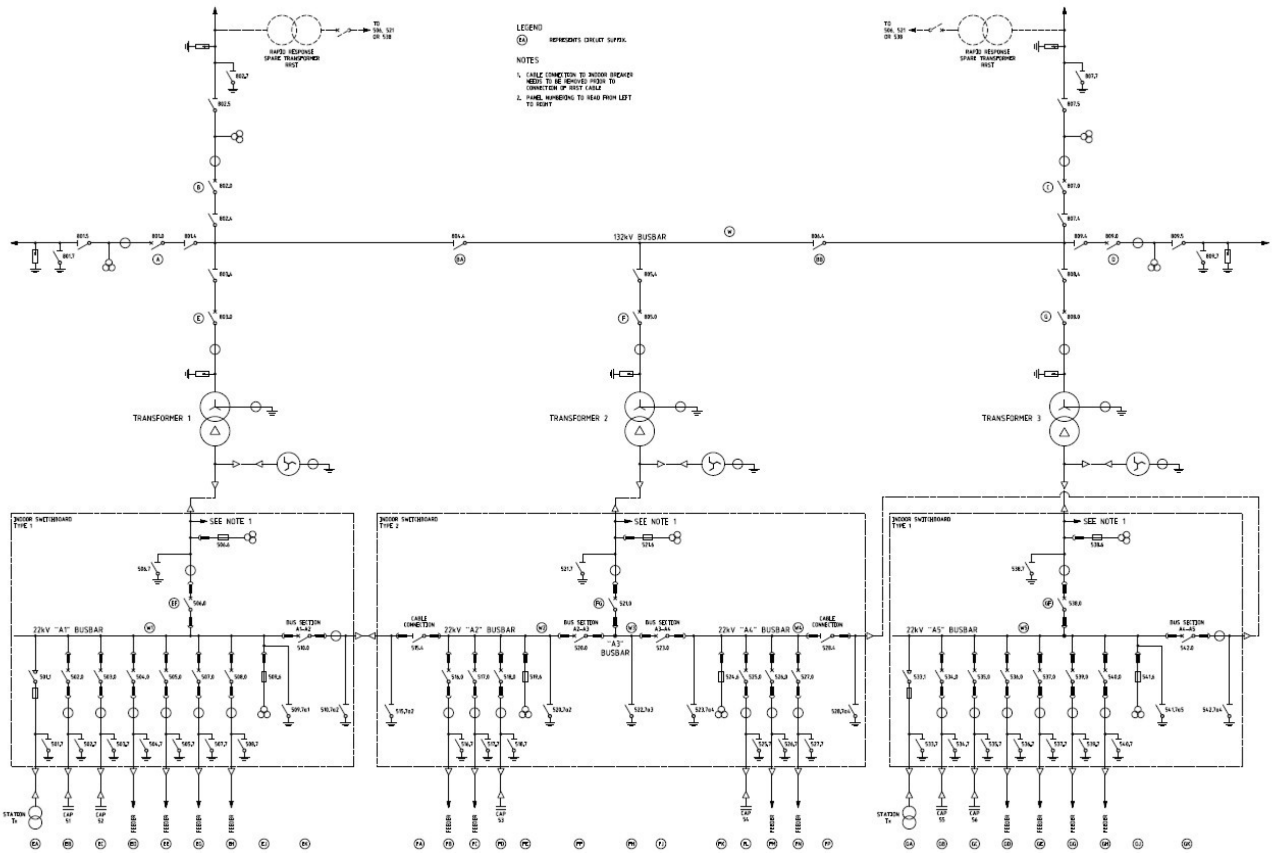


Figure 8.1: Standard Zone Substation Single Line Diagram.

8.3 Terminal Yards

The most common layout used for terminal yards is breaker and a half layout and this is the current standard layout. It allows flexibility of development and a high level of reliability. It is generally developed and populated initially as a mesh arrangement.

8.3.1 Breaker and a Half Layout[8]

This layout incorporates three circuit breakers in a bay for the connection of two line circuits. So, in effect it has 1.5 circuit breakers per line, hence the name. Most new terminal yards are built in breaker and a half configuration as it offers high reliability and good flexibility for expansion. When a substation site is likely to have more than 4 circuits in its maximum development, it should be laid out as a breaker and a half yard.

[8] See Western Power Internal Document

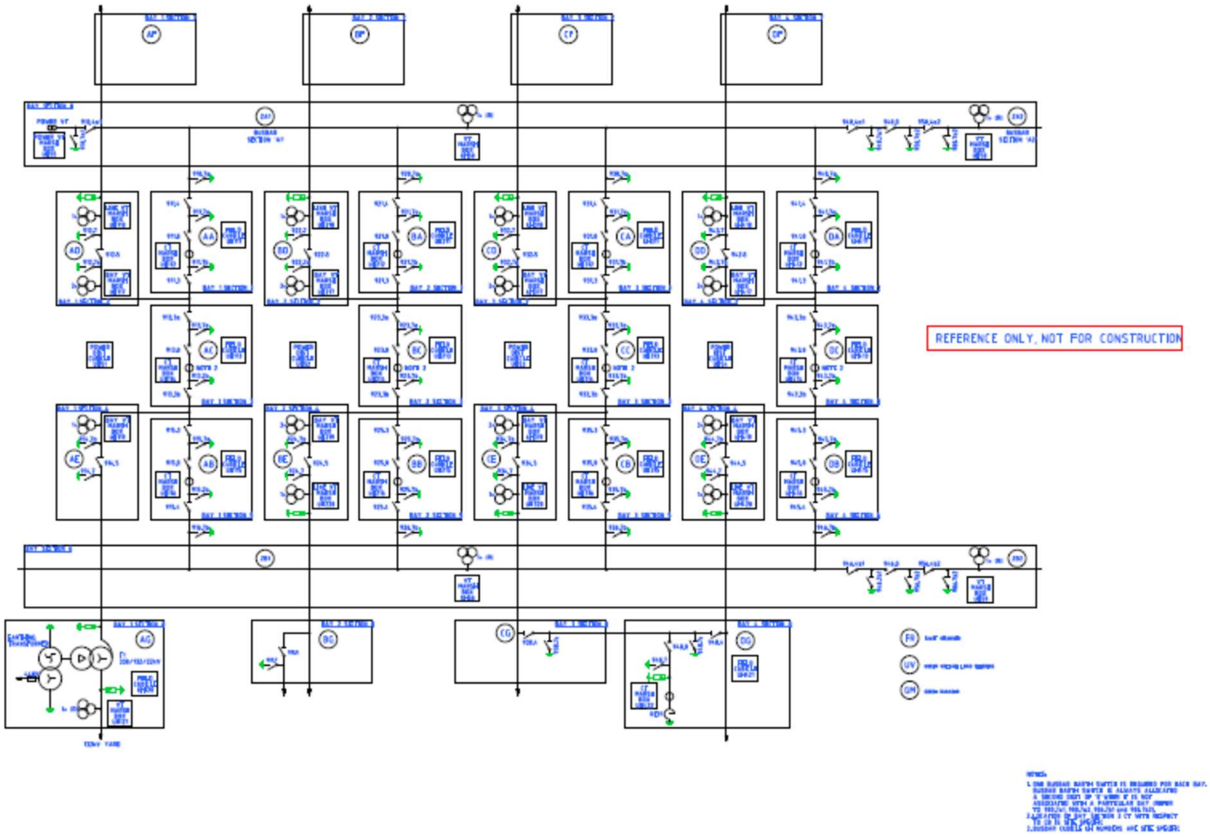


Figure 8.2: Standard Terminal Switchyard.

8.3.2 Mesh Layout[9]

Mesh layout is occasionally used for terminal yards because it is more compact than a breaker and a half yard. Mesh yards are generally used where very low, or no growth is expected. A mesh layout is difficult to expand a mesh layout to accommodate more than 4 circuits. An example of where a mesh layout would be used is at the connection of a major load or generator to the Western Power network.

8.3.3 Double Busbar Layout[10]

A double bus arrangement was used in the past for terminal yards. It consists of two parallel busbars, with each circuit having the provision to be connected to either busbar via a disconnector. Double busbar layouts are very easily expandable however they do not offer the reliability of breaker and a half or mesh yards. If a circuit breaker fails it will disconnect the circuit with no backup supply options.

[9] See Western Power Internal Document
[10] See Western Power Internal Document

8.3.4 Single Busbar Layout[11]

Single busbar arrangements are not generally used. Refer to Network Standard – Transmission Network Configuration and Rating for approved circuit arrangements.

9 Civil and Structural Considerations

9.1 Topography

A survey of the site is required to identify existing topography and features. The survey should include:

- The immediate site for the substation
- A minimum of 20m into adjacent properties, where possible, to allow an understanding of the interface with surrounding properties. Permission from site and adjacent landowners will need to be sought prior to surveying.
- For more information on detailed Civil / Structural considerations refer to:
- Engineering Design Instruction – Earthworks, Roads and Drainage.
- Engineering Design Instruction – Substation Building Design.

9.2 Access

9.2.1 Site Access

There must be access from at least one street for heavy equipment, in particular transformer transporters, loaders, and cranes as well as the RRST where applicable. This requires that:

1. The street be of adequate width for the transformer transporter to turn into the substation roadway, and to reverse out (or vice versa)
2. The turning circle required is not obstructed by street furniture or kerbs
3. The street and entrance be reasonably level so there is no tilting of the transporter
4. The street entrance be capable of bearing the transformer transport weight

The transformer loading and unloading location should be off-street, reasonably level and provide space for the equipment necessary for offloading/loading without interfering with any other facilities within the substation. Substation access is preferred to be via a side street to prevent traffic issues for vehicles accessing the site.

Access to the substation for firefighting is necessary and must be kept clear and preferably available from at least two independent streets, or directions. Access to the main gate is usually via the main access road to a substation. The Fire and Emergency Services should be contacted for advice on access for firefighting if there is any chance the site utilisation may be affected. See Engineering Design Instruction – Oil Containment and Fire Protection for more information.

[11] See Western Power Internal Document

9.2.2 Building Access

The relay room should be positioned near the main substation entry gate, as it should be the first port of call for visitors and saves personnel having to walk across the site (particularly important at night or in emergency situations).

In general, access to substation buildings should be by at least two independent doors on different sides (ends) of the building to ensure there is safe egress in the event of an emergency. These access ways should be segregated from live or hazardous areas and should be arranged such that they cannot be obstructed by materials or plant at any time.

To assist in the movement of heavy equipment and test gear into buildings, it is important that vehicles be able to get close to the relevant doorways. To facilitate this, appropriately located parking areas are required.

9.2.3 Equipment Access

The layout of a switchyard must provide for vehicle and crane access to all parts of the yard for installation, maintenance or replacement of every piece of equipment, with sufficient clearances for adjacent circuits to remain energised. Items to be considered include access and manoeuvrability of anticipated vehicles including consideration of turning circles.

Parking during construction, operations and maintenance needs to be considered in the site utilisation. For more information, refer to Engineering Design Instruction – Earthworks Roads and Drainage.

9.2.4 Internal Roads

The purpose of the internal substation road is to allow for the delivery of the transformers and other equipment and provide for the high traffic area within the substation. The width of the substation internal road is 6m. All roads within greenfield substations and any new roads installed in brownfield substations must be unrestricted, meaning that all clearances must be met for vehicles located anywhere on the hardstand road area. For more information on the clearances required for roadways, see Engineering Design Instruction – Safety and Maintenance Clearances.

9.3 Building Location

9.3.1 Zone Substation Relay Room

The relay room should be positioned near the main substation entry gate, as it should be the first port of call for visitors to the site. Other factors which affect the location of the relay room are as follows:

- Provision of convenient access to operational staff.
- Minimise the distance between the relay room and switchrooms so that cable lengths are minimised.
- Relay room exit doors should not face towards the transformers.

- Fire clearance from transformers.

9.3.2 Zone Substation Switch Room

The main points to be considered in the location of the switchrooms are listed below:

- The geographical location of the load. The switchrooms shall be positioned to minimise the cable route length of the feeder cables.
- The cable routes exiting the substation. The switchroom locations shall consider the space required for the ultimate number of feeder cables exiting the substation.
- The positioning of the transformers. The length of the cables between the transformer and respective switchboard shall be minimised.
- The positioning of the other switchrooms. The length of the bus coupler cables shall be minimised.
- When space is available, switch rooms shall be positioned within boundary fences and not form part of the boundary.
- Derating of circuits. The transformer and feeder cables shall be positioned to minimise any de-rating issues due to the close proximity between circuits.
- Avoid or plan for areas that may be excavated during the life of the substation.
- Access doors shall be positioned alongside access roads to allow for equipment to be taken into the switch room without crossing uneven ground.
- The landing area outside the delivery door shall be large enough to accommodate the largest piece of equipment to be located in the switchroom.

9.3.3 Terminal Yard Relay Room[12]

The Terminal Yard relay room should be positioned such that secondary cable lengths are minimised. Typically, the terminal relay room is positioned symmetrically in between two sets or two pairs of bays. Volt drop between the bay equipment and the relevant relay room must be considered in the room positioning.

9.4 Room Layout

9.4.1 General Layout Requirements

The layout of panels is covered in the Engineering Design Instruction – Substation Secondary Systems Design. The room layout must meet all requirements of AS2067 and AS/NZS AS3000.
The following requirements must be considered when designing the building and its layout:

- The layout of the room shall consider the requirements of initial installation, commissioning, maintenance and general use.
- Evacuation routes shall be at least 600mm wide, even when equipment parts have been removed or cubicle doors are open.
- Minimum of 1000mm from panels where the front can be removed.

[12] See Western Power Internal Document

- To allow for ease of escape in an emergency, equipment doors must close in the direction of egress, where possible.
- Two exits must always be provided, if possible at opposite ends of the building so there is a safe escape route available at all times.
- Clear and safe access for personnel shall be provided at all times.
- Layout of the substation shall allow easy and unimpeded access to all emergency exits.

For more information refer to Engineering Design Instruction – Substation Building Design.

9.4.2 Zone S/S Relay Room

The relay room shall be sized for the ultimate arrangement, and shall at minimum account for the secondary requirements of the standard 3 transformer 4 line zone substation. The following points must be considered when laying out the relay room:

- The protection cubicles should be laid out in a logical manner. The Protection 1 and Protection 2 cubicles should be separated from each other. The cubicles should be laid out in ascending circuit order, with space left for future circuits.
- Our current standard is to install valve regulated batteries in battery combined units (BCU) in the main relay room. Ventilation of the main relay room meeting the requirements of AS2676.2:2020 is required when batteries are installed within the main relay room. Preference is to locate BCUs:
  - Along an external wall
  - At a location to minimise cable lengths.

9.4.3 Zone Substation Switch Room

- Arc ducts must:
  - Be positioned to face the transformer side when applied to standard arrangements. In non-standard layouts arc vents should not face the public and not interfere with the standard numbering convention of switchboards.
  - Angled upwards so that damage to property and injury to personnel during an arc vent event is prevented.
  - Not have equipment installed in front of or in the vicinity to the arc duct vent.
  - Must not have exit doors adjacent to the arc duct vents.
  - Arc duct events must not affect escape routes
  - Be segregated to enable switchgear and busbar maintenance to occur without full switchboard shutdown.
- Access to the cable basement shall be from the outside of the building for all new installations.
- Space in front of and behind the switchboard shall comply with the requirements of AS2067 and AS3000 and be adequate to facilitate access when all cubicle doors are open, and the circuit breakers are extracted.

9.4.4 Doors

Doors to the substation buildings must meet the following requirements:

- Doors must open outwards to allow easy escape.
- Doors shall be positioned such they do not create a hazard when opened and cannot be inadvertently blocked from the outside.
- Panic bars must be installed on all outward facing doors in all substation buildings.
- Outward facing doors shall be a minimum of 1980mm high and 750mm wide.
- A double door for delivering the switchboard into the switchroom is required.
- Internal doors shall not be fitted with locks.
- Exit doors must not face towards the transformer. If this is not possible a Safety in Design assessment must be undertaken to ensure that safe exit routes are provided.

9.4.5 Terminal Yard Relay Room

All the points in Section 9.4.2 apply as well as the following additional requirements:

- For rooms where computer type flooring is used, the 600mm wide panels should align with the 600 x 600mm floor panels. This can be shown on the relay room layout drawing.
- The AC changeover board shall be installed as close to the incoming AC supply cables as possible to limit the length of supply cabling.

9.5 Security

Substations are inherently hazardous sites, containing valuable assets that are crucial to the safe and reliable supply of electricity to the community. To manage the hazards presented by these sites, and to ensure a safe and reliable supply, these assets and the public must be protected by preventing unauthorised access to Substations. This is achieved by installing intruder resistant fences and, where appropriate, employing active security measures. Refer to Engineering Design Instruction – Transmission Substation Fences and Gates.

9.6 Waste and Stormwater

9.6.1 Stormwater

The water flow on site must be studied and designed for in the layout of the substation. Some sites have been designed with a gentle slope across the site, however this can cause difficulties for the design and construction in the placement of foundations and the busbar level. A flat site is preferable wherever possible. For more information, refer to Engineering Design Instruction – Earthworks Roads and Drainage.

For more information on amenities, including toilet, potable water and sewerage requirements, refer to Engineering Design Instruction – Substation Building Design.

9.6.2 Waste

Sewerage must also be considered in the site services design, and a connection will be made whenever possible. The sewerage and water services must be considered in the layout of the substation to ensure the services do not clash with any of the substation equipment.

10 Electrical Considerations

10.1 Phasing

The phasing arrangement for a site is dictated by the transformer layout as shown on Western Power templates. Switch yards with no transformers therefore have no reference to dictate the phasing arrangement. If the incoming line is considered the power source and the customer/load is considered equivalent to the transformer, the transformer layout templates can be used to dictate the phasing arrangement.

Exchanging the red and blue phase in a switch yard can be considered under extraordinary circumstance. It must:

- Be consistent across the site
- Approved by Substation Design's Principal Electrical Design Engineer
- Entered into the non-standard design register

10.2 Circuit Layout[13]

Arrangement of the circuits connecting onto the busbar should be determined by Grid Transformation in consultation with Operations. Generally, the connection point of each transmission line is driven by the physical location of the incoming line. However, there may be site specific requirements, especially where bus section breakers are installed.

For breaker and a half terminal yards, in general, the supply points should supply onto the A bus and the loads should connect onto the B bus. It is best for major loads and major generation to connect into opposite ends of the same bay, so that a busbar outage still permits bulk power transfer through the bay.

The standard phase spacings used in Western Power substations are outlined in Table 10.1 below. For all voltage levels, these standard spacings are considerably larger than the minimum phase to phase clearance requirements. These phase spacings have been influenced over time by plant items, particularly disconnectors. The phase spacing on the lower voltages have been increased to reduce the potential for flashovers as a result of birds or animals bridging across two or more phases.

[13] See Western Power Internal Document

Table 10.1: Phase to Phase Standard Spacing

Voltage Level	Standard Phase Spacing
6.6kV	750mm
11kV	750mm
22kV	750mm (note 1)
33kV	900mm
66kV	1800mm
132kV	2400mm
220kV	3500mm (note 2)
330kV	5800mm (note 3)

Notes:

(1) Clearance should be increased to 900mm to reduce chance of outages due to birds or vermin on circuits that require high reliability. This is supported in AS2067 Section 2.5.1

(2) Typically, 220kV Greenfield sites are built at 330kV. Therefore, 330kV spacings are to be followed. The busbar phase centres for existing 220kV installations are 3500mm.

(3) The main busbar centres (without disconnectors) for 330kV are 4500mm.

Circuit layouts may also change depending on the rating of each circuit, due to the different selections of conductors, busbars and fittings.

10.3 Power Cable Layout

All cables shall be installed in accordance with AS/NZS 3000 and AS 2067. Cable routing in the substation should be practical and provide the shortest possible runs to minimise voltage drop and reduce the amount of cable required in the limited space.

The substation designer must also specify proposed feeder cable routes within the substation boundary in consultation with the Distribution Group. Joints shall comply with requirements of Engineering Design Instruction – Substation HV Power Cables and Terminations.

For more information, refer to Engineering Design Instruction – Substation HV Power Cables and Terminations.

10.4 Aerial Versus Cable Entry

10.4.1 Overhead Entries

Overhead line entry conductors and earth wires usually terminate on gantries that straddle the respective line circuit. They are large structures that can influence clearances to adjacent equipment and facilities such as access roads and even separation between circuits.

Intermediate poles are occasionally required to support the conductors between the line termination poles and the gantries. However these poles are not preferred within the substation boundary fence and need to be justified because they can impact access within the yard.

10.4.2 Cable Entries

There will be situations where the line entries are cabled into a substation. In these cases the cable to overhead transition occurs on a special structure located at the front of the line circuit which in effect increases the length of the circuit. As such it can ultimately influence the location of the circuit and possibly the busbar.

The routes of the cables also need to be considered in the site utilisation to recognise any influence they may have on other facilities such as other cabling and future extensions.

10.5 Space Requirements

10.5.1 Zone Substation

The preferred site dimensions are 111 x 115m which allows for cable entry and a 10m buffer zone. The site requirements may be reduced if necessary but only after an ultimate layout has been developed and agreed on by all stakeholders.

The preferred 10m buffer zone outside the substation fence serves multiple purposes.

- Provides an area in which distribution feeder exit cables can run.
- Allows for the installation of a fence grading wire installed on Western Power owned land.
- Increases clearances from substation equipment to neighbouring buildings for fire separation.
- Provides an area which can be used for landscaping to shield the substation visual impact.

10.5.2 Terminal Substation[14]

The land size required for a terminal varies greatly depending on the number of 330kV and 132kV circuits required. Where the size is not known, a general figure of 500m x 600m can be used.

11 Environmental and Social Impacts

Community awareness of the impacts of public infrastructure such as transmission substations is very high in modern society. Environmental and social issues also have a large impact on the substation site and often also have an impact on how the substation is laid out and what materials are used.

The site utilisation process provides a major opportunity to minimise these impacts and manage perceptions using astute design. The threats to a substation's acceptance within a community are discussed below together with some of the actions that can be taken at the site utilisation phase to minimise the impacts.

[14] See Western Power Internal Document

11.1 Visual Impact

The largest impact on the community is in most cases the visual impact.

Depending on the sensitivity of the surrounding community, different levels of mitigation can be used. In some locations, such as industrial and rural areas, there may be no need for any mitigation work for the standard AIS design. However, substations in sensitive locations may require extensive works to bring them to a level acceptable to the community.

It should be remembered that when a substation is being developed, the level of community sensitivity is determined by the Safety, Environment, Quality and Training (SEQT) Function. SEQT is responsible for negotiating with the community for approvals for substation projects and will work in conjunction with design management, substations, lines and distribution designers to achieve the required outcomes.

There is a range of strategies that can be used to reduce the visual impact as follows in Sections 11.1.1 to 11.1.3.

11.1.1 Landscaping

The 10m buffer zone around a zone substation provides an area for landscaping. The design of the landscaping is the responsibility of the SEQT function and should be done in conjunction with the substation designer to avoid clashes with feeder cables and fence grading wires.

In some cases, the SEQT function may enlist the services of a landscape designer to assess how the substation visual impact can be reduced beyond the screening effect provided by planted vegetation. Many of these options can affect the site utilisation so the designer needs to be aware of them before finalising the substation layout.

11.1.2 Fence/Wall Designs

The standard security fence design uses weld mesh panels. However, in sensitive areas, solid fence designs may be required. These include tilt panel concrete and brick.

In some cases the obvious location of a wall may not be the best from a visual point of view. The location may need to be determined by a landscape architect under direction of the SEQT function and must be considered in the early design stage as it can impact the site utilisation.

11.1.3 Location of Equipment and Facilities

The location of equipment within the yard can influence the visual impact. The following is an example of what may be considered:

- Locate large items of equipment as remote from sensitive boundaries as possible – for instance, transformers can be located nearer to low sensitivity boundaries. This may also assist in noise mitigation.

11.2 Safety/Health Risks

Substations can present real and perceived safety and health risks to the community and other utilities with some of the possible mitigation strategies influencing the site utilisation.

11.2.1 Noise

There are legislated limits to the noise that can be emitted from substations. The main source of noise is from transformers and if necessary, noise enclosures should be installed, or noise can be managed at the site boundary using solid walls. Enclosures will also provide fire isolation between transformers and to surrounding equipment.

Potential enclosure designs need to be recognised in a site utilisation design because of their footprint dimensions and electrical clearance requirements to adjacent equipment.

The SEQT group is responsible for determining the acceptable noise levels from substations. SEQT must be involved in the assessment of specific substations and consulted for advice on the degree of mitigation required.

11.2.2 EMFs

11.2.2.1 Limits

Western Power's policy for exposure to power-frequency electromagnetic fields (EMFs) is based on prudent avoidance via appropriate designs.

Generally, this means distances between live equipment and the public should be such that the maximum levels suggested by the relevant authorities will be met or be better. The National Health and Medical Research Council and the Australian Radiation Protection and Nuclear Safety Authority are both involved in setting limits.

11.2.2.2 Management

The buffer zone around a substation provides inherent additional protection to the substation designs that should already incorporate appropriate separation distances.

Inside the substation, the location of the primary busbars in relation to neighbouring properties needs to be carefully considered in the site utilisation for electrical safety clearances as well as EMF strengths. Busbars should be kept as far away as possible from neighbouring boundaries. If there is reason to suggest that the levels in Section 11.2.2.1 may not be met, a study must be undertaken to show compliance.

11.2.3 Other utilities services

Western Power has a responsibility to recognise the impact a substation development may have on other utilities' services including metallic pipelines such as gas and water and communication cables.

By considering these in the site utilisation study, any impacts that need to be managed for immediate and future consideration will be recognised. Such issues include the effects of EPR on metallic services, egress to the streets for distribution feeder cables and in some cases line entry cables.

11.2.4 Fire protection

11.2.4.1 Internal sources

Relevant building codes provide guidance on the prevention of damage from potential fire sources to neighbouring properties. These requirements can have a considerable impact on the site utilisation, particularly for compact sites that cannot meet fire separation compliance distances.

In these cases, risk mitigating designs will need to be considered in the site utilisation if there are impacts on aspects such as access within the yard, electrical clearances and fence designs.

11.2.4.2 External sources

A substation site may be in a location whereby the risk of bush fires is high. In these circumstances the site utilisation may need to take the risks into account. This may drive requirements such as the space around the security fence for a fire break, the location of strategic equipment away from risk areas and special fence designs.

A similar design approach may be necessary if a substation is near a man-made fire risk installation such as certain industrial areas.

A fire risk assessment shall be undertaken for new substation developments. Refer to Engineering Design Instruction – Oil Containment and Fire Protection.

12 Plant and Equipment Considerations

There are several items that should be considered when connecting each item of plant to the network. These requirements ensure that each item of plant functions as expected in a safe manner and can be maintained over its life. Considerations for each item of plant are outlined below.

12.1 Palm strength on all equipment

When a circuit is subjected to a short circuit, current flow will cause the conductors in adjacent phases to either attract or repel each other. This movement of the conductors causes a dynamic force on the electrical equipment palms. The further apart the primary plant elements are (within the same phase), the more the conductors can move, and the higher the resultant force on the palm. Therefore, before confirming the location of the primary plant, the designer must check that under maximum fault conditions the resultant force on the palms is within the design rating of the plant. This rating should be stated on the plant layout drawing. For more information on short circuit forces see Engineering Design Instruction – Busbars and Conductors.

12.2 Power Transformer

The power transformers for the site shall be located alongside the main substation access road, each within a separate bunded area. Their location shall be such that the HV bushings shall line up with the corresponding HV circuit. The bund size and depth shall allow for the oil volume plus a contingency for firefighting water and the bund wall positioning shall allow for the crest locus distance. Refer to Engineering Design Instruction – Oil Containment and Fire Protection for more information.

Power transformers should be numbered from left to right while viewing the transformer from the LV side. If a transformer is required to be installed to the left of T1, the numbering should clearly indicate that it is out of series. See Engineering Design Instruction – Labelling and Numbering for more information.

To maintain the smallest area for the transformer bay footprint for zone substations and to decrease the number of footings and structures the following has been incorporated in the power transformer layout design:

- The power transformer disconnector is connected to the main 132 kV busbar.
- The power transformer CT structure is located on the bund and the height increased for smoother connections to the surge arrestor and transformer bushing.
- The surge arrestor is located sometimes on the power transformer tank.

12.3 Circuit Breaker

The circuit breaker shall be positioned such that the mechanism box can be easily accessed by maintenance or operational staff. Other considerations are the positioning of the circuit breaker with respect to the high and low attachment points to ensure all clearances are met and that the arrangement of the high and low connections are appropriate for the installed circuit. See Engineering Design Instruction – Safety and Maintenance Clearances – for information on clearances.

12.4 Current Transformer

Current transformers shall be positioned such that the marshalling box can be easily accessed by maintenance or operational staff. Current transformer orientation (position of P1 and P2) shall be clearly depicted on the primary bay elevation drawing to ensure the correct polarity of the current transformer when it is being installed. P1 is pointing towards the protection plant.

12.5 Voltage Transformer

The connection of the voltage transformer (VT) to the network is particularly important as incorrect design and installation can cause a significant safety risk. The construction of the VT includes bellows at the top which operate upwards to reduce the internal pressure in the event of a fault. If the bellows cannot operate as designed, the VT could shatter violently, causing a safety risk. The connection onto the VT must be a dropper connection (rather than a flat horizontal type connection) and be of sufficient length so that the stiffness of the joints does not restrict the operation of the bellows. The minimum dropper length to be used is 1.2m.

12.6 Disconnectors

The purpose of a disconnector is to provide a visual point of circuit isolation and provide safe access to de-energised assets. The positioning of the disconnector shall ensure that section safety clearance and horizontal safety clearance are achieved to assets between the intended disconnect, allowing safe access for personnel.

Disconnector switch handles must face towards a reference point for overall site consistency. The reference point for greenfield sites is typically the relay room. For brownfield sites, the designer shall ensure that the positioning of disconnector handles is consistent with the existing site layout and equipment. Disconnector switch handle orientation should align logically with surrounding disconnectors when moving through the site.

Disconnector earth switches can be ordered in different arrangements, such as left hand or right-hand earth switch orientation. When standing at the disconnector mechanism box, the side the earth blades are on determines if the arrangement is a left or right hand earth switch. Refer to Appendix A for examples. The designer must ensure the earth switch blades are facing the required side while maintaining disconnector switch handle alignment as per requirements above when ordering the disconnectors.

When positioning the operators earth mat, the designer must ensure that the mat position does not interfere with the cable trench location.

12.7 Earth Switches

12.7.1 Busbar Earth Switches

Because of the relatively low cost and reduction of complexity of permits a busbar earth switch is included in each bay of a breaker and a half yard. This requirement is typically met by the bay busbar disconnector / earth switch.

12.7.2 Outgoing Circuit Earth Switches

All outgoing circuits in both zone and terminal substations must include an earth switch on the outgoing side of the circuit disconnector. This earth switch is typically integral with the circuit disconnector. This requirement applies to all outgoing transmission line circuits as well as customer connection circuits which are an “over the fence” type connection.

12.8 Busbar Voltage Transformers

Busbar voltage transformers are typically required in breaker and a half yards for interlocking, sync check and point on wave switching.

12.9 Surge Arrestors

Surge arrestors are typically installed at transition points where a difference in impedance at these points increases the probability of surge wave reflection. A typical example is an overhead line to cable transition point. This is more critical for overhead circuits that are susceptible to lightning strikes such as outdoor feeder circuits or HV overhead lines

In the circuit design, it is important to ensure that surge arrestors are not used as a conductor support point. The SA should be connected to the circuit via a dropper which can be removed to disconnect the surge arrestor from the circuit (in the event of failure) and the circuit can then be energised again.

Surge arrestors must be placed as close as practically possible to the equipment that the surge arrestor is protecting:

- Line circuits – the surge arrestor should be the first piece of equipment that a fault encounters when entering the substation on a transmission line. In a zone substation, the surge arrestor is generally connected off the dropper from the line onto the disconnector. In a terminal yard, the surge arrestor can also be connected directly off the line incomer to the gantry, but in this case, care must be given to ensure that the force on the palm is not too high. Refer to Figure 12.1.

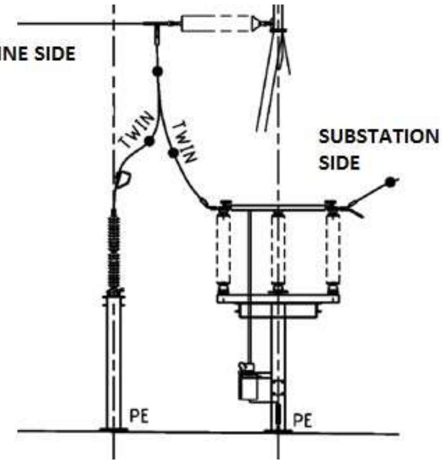


Figure 12.1: Surge Arrestor Connection to Line

- Transformer circuits – the surge arrestor shall be located as close as possible to the transformer. The surge arrestors should be mounted on brackets connected to the transformer tank when possible. Surge Arrestors are typically mounted on the transformer tank for 33 MVA and 66 MVA transformers. Depending on the site they may be installed on the transformer tank for 100 MVA transformers and are usually not installed on the transformer tank for 250 MVA and 490 MVA transformers. In most brownfield sites, the surge arrestor is on its own structure located within the transformer bund.

The length of conductor from the surge arrestor to earth must be reduced as much as possible as the length affects the effectiveness of the surge arrestor. The connection to the surge arrestor should be a parallel groove clamp. The connection to the main conductor should curve towards the incoming surge. For transformers this curve is towards the CT.

Care must be taken to reduce the length of the earth path from the surge arrestor to ground as this affects the effectiveness of the surge arrestor. The connector to the surge arrestor should be a parallel groove clamp and the connection point to the main conductor should be curved towards the incoming surge. This is towards the CT for a transformer circuit. Refer to Figure 12.2.

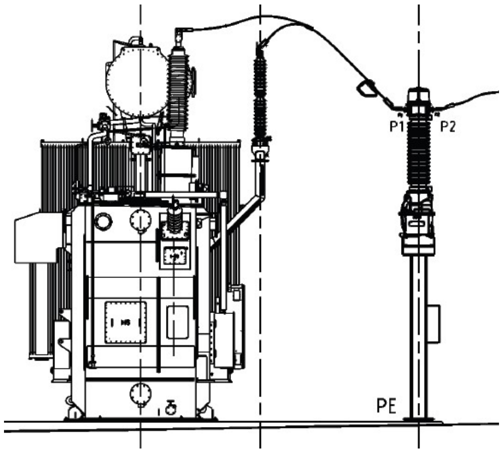


Figure 12.2: Surge Arrestor Connection to Power Transformer

For Surge Arrestor installations adjacent to HV cables, refer to Engineering Design Instruction – Substation HV Power Cables and Terminations.

12.10 Indoor Switchgear

New zone substation MV busbars are generally in the form of indoor switchboards housed in separate buildings, with each switchboard connected to a separate transformer. The switchboard busbars are interconnected via underground cables that run between the buildings.

Even though these buildings can be located remotely from their related transformers, it is required to maintain the same geographic relationship as the transformers to keep cable installations straightforward and assist operational staff to be able to orientate within the substation.

12.11 Capacitor and Reactor banks[15]

The standard installation includes two capacitor banks for each LV switchboard. In some circumstances switched reactor banks are also required to be connected to the LV switchboard. The location of the capacitor or reactor bank shall consider the following requirements:

- Minimise the cable route between the switchboard and capacitor/reactor bank
- The distance between the substation boundary fence and the capacitor/reactor fence shall be a minimum of 6m, otherwise a solid wall must be used. If the capacitor/reactor bank is closer than 6m to the fence then a roof on the capacitor/reactor bank compound may be required to ensure an intruder cannot climb straight into the capacitor/reactor bank compound from outside the fence.

15 See Western Power Internal Document

- Clear access for maintenance is required. The proposed layout for any new capacitor/reactor banks shall undertake a C.O.M review to ensure that maintenance requirements are met.
- Adjacent capacitor/reactor banks require a fence higher than the highest point of both capacitor/reactor banks. This allows work to take place on a capacitor/reactor bank without the need to isolate the adjacent capacitor/reactor bank.

12.12 Rapid Response Standby Transformer (RRST)

In the event of a transformer failure in a zone substation, the RRST may need to be deployed to the site. The RRST should be able to be deployed and positioned on site:

- Without restricting the replacement or repair of the damaged transformer.
- As close as possible to the MV switchboards to assist in convenient connection of MV and secondary cables.
- As close as possible to the low voltage switchboards to assist in convenient connection of low voltage and secondary cables.

RRST access roads must be a minimum of 7m wide and have a maximum gradient of 5%, to allow the RRST to navigate to its designated position within the substation.

For more information, refer to Engineering Design Instruction – Earthworks Roads and Drainage.

The Grid Transformation function shall be consulted for advice on the RRST requirements for new greenfield substations.

12.13 Lightning masts

A lightning study shall be completed by the designer for new substations and major additions to brownfield sites that may not be part of the protected zone of the substation. Buildings may be added to the model and used as part of the lightning protection system. All new lightning masts installed in the substation shall be either fixed masts (with lights mounted on separate low level posts) or see saw masts with flood lights. In any cases where see saw masts must be used, the placement of the mast must be checked for clearances for the mast swing. Attention must be maid to the orientation of the mast and the direction of the swing. Refer to Engineering Design Instruction – Substation Lighting for more information.

12.14 Field Cubicle[16]

Protection field cubicles can house remote input / output relays, transformer AVR/MVR relays and bund valve supplies.

For zone substations, the field cubicle shall be positioned adjacent to the cable trench and next to each transformer. This position will ensure that the cable route is minimised for all transformer and bund valve

[16] See Western Power Internal Document

cabling. The line circuit remote input/output relays will typically be in the transformer field cubicle when the line circuit is opposite a transformer circuit.

Each bay section in terminal switchyards shall have its own field cubicle to reduce cabling and volt drop.

12.15 Insulators[17]

For some substations subject to certain conditions, all porcelain insulators on all items of primary plant within the substation require a hydrophobic silicone coating to be applied. Conditions which affect the need to coat porcelain insulators include criticality of plant, proximity to the coast, proximity to polluting industries, historical flashover issues, locations subject to heavy dust or agriculture, proximity of cement / lime producing facilities.

For greenfield sites, contact OAP to assess the site location to determine if it requires silicone coating of porcelain insulators.

13 Drawings

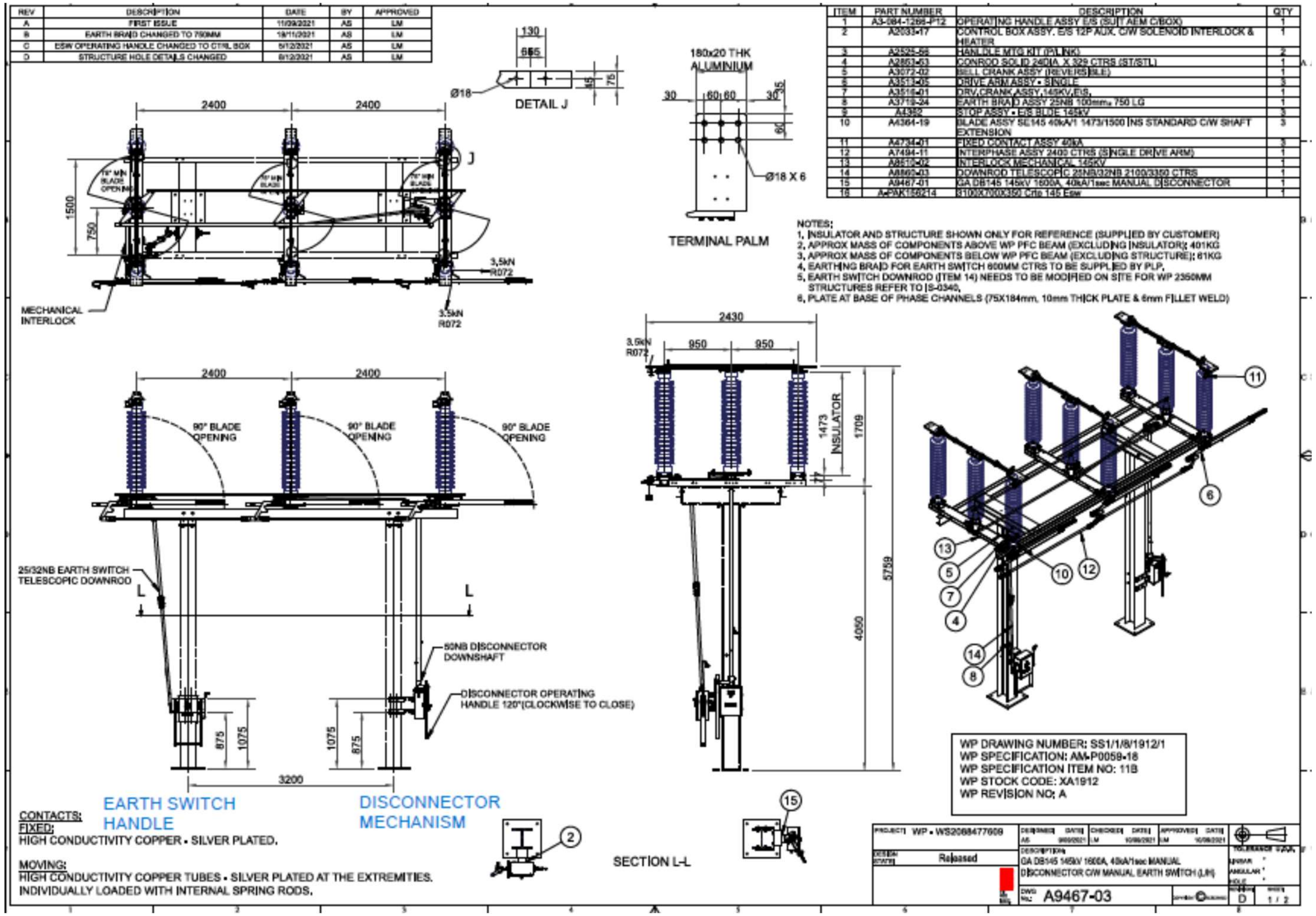
Template and example drawings of substation layouts can be found in the Register - Substation Design Drawings - EXTERNAL Version.

This register is provided to external consultants as a reference for Substation Standard and Template drawings.

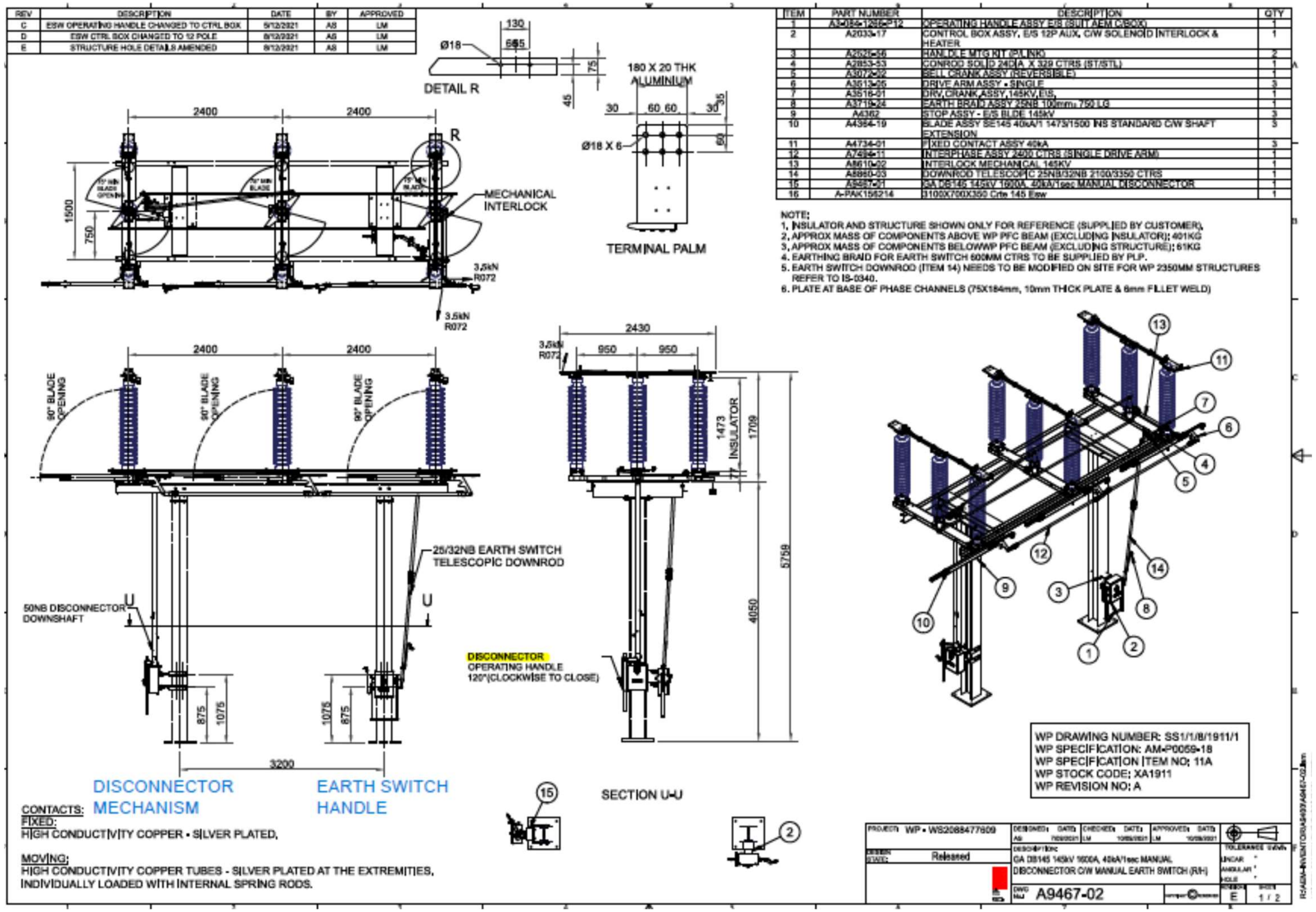
[17] See Western Power Internal Document

Appendix A: Disconnector Earth Switch Orientation

A.1 Left Hand



A.2 Right Hand



Appendix B: Approval Record and Document Control[18]

[18] See Western Power Internal Document