# TERMINAL STATIONS & ZONE SUBSTATIONS SECTION 15

## 1. GENERAL

Terminal Stations in Victoria are owned by the Transmission Company and serve the primary purpose of converting incoming transmission voltages to voltages suitable for distribution networks.

Zone Substations in Victoria are owned by the electricity distribution companies and are used to transform sub-transmission voltages to high voltage distribution voltages and to act as controlling points between differing high voltage networks.

## 2. ENTRY

Terminal & Zone substations are classified as HV Enclosures, therefore un-supervised access can only be gained by those persons authorised by the relevant asset owner. (See *Green Book* definitions).

Entry to stations is available to non-authorised persons where they are under the supervision of an authorised person.

When entering and/or working in a Terminal or Zone Substation, employees shall:

- Wear Personal Protective Equipment as provided.
- Notify the Control Room as to the reason for being there and the planned length of stay.
- Familiarise themselves with the status of equipment and the surrounding area, noting those parts which are energised, establish the location and placement of barriers and signs defining the limits of the working space(s), and observe which switches or breakers disconnect the equipment from the source of supply.
- Ensure all Terminal and Zone Substation and switchyard gates are kept locked or barricaded to prevent public entrance when work is being performed inside the substation.
- Ensure unauthorised persons do not enter substations or switchyards.
- In switchyards and switch rooms, erect temporary barricades and/or signage between the equipment being worked upon and the nearest energised equipment.

## 3. PERSONAL PROTECTIVE EQUIPMENT

The Green Book outlines the PPE requirements for entry to stations in Section 3.

General PPE requirements

1. Working on, near or in the vicinity electrical apparatus:
   - Headwear
   - Natural fibre clothing from wrist to ankle
   - Fully enclosed footwear

2. Operating electrical apparatus
   - Headwear
   - Natural fibre clothing from wrist to ankle
   - Fully enclosed footwear
   - Hand protection
   - Face/eye protection

3. Visits to a work site with no involvement in any work at that site and movements confined to normal access ways:
   - Headwear
   - Jacket or dustcoat
   - Leg covering to ankle length
   - Fully enclosed footwear

## 4. TERMINAL AND ZONE SUBSTATION SINGLE LINE DIAGRAMS

Terminal stations and Zone substations are drawn schematically. Schematic drawings represent the elements of a system using symbols and generally straight lines. They usually omit all details that are not relevant to the information being portrayed.

For Terminal and Zone substations, these schematic drawings are known as single line diagrams. An example is shown in Figure 1 on the following page

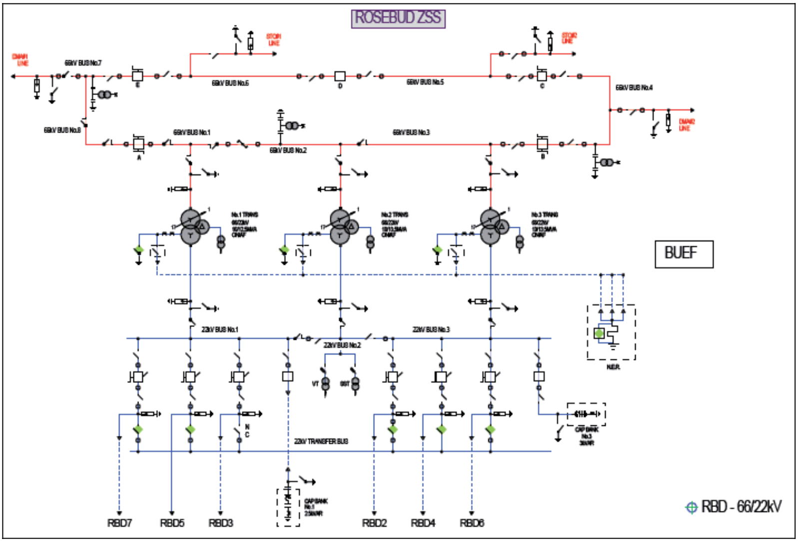



***Figure 1***

## 5. EQUIPMENT TYPES

### Transformers

***A 66/22kV transformer with separate oil cooling arrangement***

The transformer is the fundamental part of a Zone or Terminal Station. It transforms the input (primary) to the output (secondary) voltage. In a typical Zone Substation the primary voltage is 66kV from the subtransmission network and the secondary voltage is 22kV for supply to the distribution network. A typical Zone Substation transformer in an urban station is rated at 20/33MVA. The 20 MVA rating applies with natural cooling and the 33MVA rating is achieved using forced cooling which can include oil pumps and fans. A transformer of this type will contain approximately 18,000 litres of transformer oil to facilitate cooling and insulation of the transformer windings and weigh approximately 45 tonne. Transformers are located within bunded areas to prevent environmental damage should an oil spill occur.

Most transformers are also fitted with on-load tap changers to maintain the secondary voltage at a constant level with varying loads on the transformer.

## Circuit breakers (CBs)

Circuit breakers are used in Zone and Terminal Substations to control and manage the supply of electricity to and from the station. They are located on both the primary and secondary sides of the transformers. They are used to divide the Zone Substation into discrete protection zones so that if a fault should occur in a particular zone then only that zone will be isolated by the automatic operation of the circuit breakers. These zones may include the 66KV lines, the transformers and the individual distribution feeders. Circuit breakers are designed to carry load currents continuously and interrupt fault currents. Many different technologies have been used over the years in the design of Circuit breakers. Older circuit breakers use transformer oil as the interrupting medium. Today distribution circuit breakers commonly use vacuum interrupters and at high voltages (66kV and above) SF6 gas is the most common technology used in the design of circuit breakers.


***A 66kV CB***

Modern distribution circuit breakers are commonly installed indoors. Older designs and high voltage circuit breakers are general designed for outdoor installation.

## Voltage transformers (VTs)

Voltage transformers (VT's) are used in Terminal and Zone substations to transformer the very high voltages to representative values for use in protection, control and metering systems. For this reason they are known as measurement or instrument transformers. VT's are rated in VA and typically are rated at 100VA in a Zone Substation. The primary voltage may typically be 22,000, 66,000 or 220,000 volts. The secondary or output voltage is typically 110 volts. Voltage transformers can be either magnetic type or capacitive type. They can be oil filled and used outdoors or of cast epoxy design for use in indoor switchboards.

***A 66kV VT***

## Current transformers (CT's)

Current transformers (CT's) are also measurement transformers and are used in Terminal and Zone Substations to transform large load currents and fault currents to representative values for use in protection, control and measurement systems. CT's can be stand-alone units as found in outdoor high voltage switchyards or they can be incorporated in the design of circuit breakers either in switchboards or in outdoor circuit breakers. Typically CT's may have multiple primary ratings or taps such as 1200/900/600/400 ampere. The secondary rating is typically 5 amps and this is used as the input to the protection or metering systems.

## Capacitor banks

Capacitor banks are primarily used to correct the power factor in Zone Substations. As most customer loads are inductive the capacitors are used to compensate for these loads and thus achieve a power factor closer to unity. This means better utilisation of the primary plant in the stations can be achieved. Capacitor banks are also used to support voltage in Terminal Stations.

Capacitor banks are often switched on and off according to the time of day or the MVAR load on the station. Modern capacitor banks are comprised of small individual capacitor cans of approximately 300 kVAR each. These are connected together in series and parallel combinations to make capacitor banks of up to 12 MVAR rating in Zone Substations.

***A 22kV Capacitor Bank***

Substation capacitor banks, cases and support structures shall be considered energised at full potential until Isolated. A minimum delay of five minutes must be observed before earthing. Before individual units are handled they shall be short-circuited between all terminals and the case. If the cases of capacitors are in earthed substation racks, the racks shall be bonded to earth. Any line to which capacitors are connected shall be short-circuited before it is considered safe for access.

## Station services transformers

The Station Service Transformer provides the 415/240V supplies at a Terminal Station or a Zone Substation used to power all auxiliary equipment on the station. This includes the light and power to all buildings, the supply to the tap changers on the transformers, the cooling fans and pumps on the transformers and the battery chargers that maintain the DC supplies for the station. In Zone Substations the Station Services Transformer is typically rated at 50 or 100 kVA. They may be pole or platform mounted transformers or kiosk types. In Zone Substations they are often supplied at the distribution voltage from one of the feeder circuit breakers or directly from a distribution bus.

***A 22kV Station Service Transformer***

## Neutral Earth Resistors (NERs)

NER's are used in Zone Substations to limit the magnitude of any fault currents that may flow should an earth fault occur on the distribution network. They are connected between the transformer neutral/s and earth on the secondary side of Zone Substation transformers. NER's improve supply quality and network safety. A NER for a 22kV network will typically have a resistance of 8 ohms and be rated at 1500 ampere.

***A 22kV Neutral Earth Resistor***

## Isolators

Isolators are used to isolate sections of the network or individual items of plant such as circuit breakers. An isolator provides a physical break in a circuit that is appropriate for the operating voltage. Isolators are not rated for interruption of load current; they are able to de-energise plant. Isolators are rated to carry fault current and specified in ampere.

***66kV Duoroll***

Isolators can be gang operated three phase or single phase units. Gang operated isolators can be operated from an operating handle. Single-phase isolators are normally stick operated (insulated operating stick).

***22kV Single phase isolator***

***66kV ganged rotary isolator***

## Earth switches

Earth switches or earthing facilities are normally installed in conjunction with isolators. They are used to apply earths to plant in preparation for the issue of Electrical Access Permits. Earth switches are generally gang operated via an operating handle. They are incorporated in modern distribution switchboards and in these circumstances they are fully fault rated.


***66kV Earth Switch***

## Batteries

All protection, control and communications equipment is powered using DC supplies. All Terminal Stations and Zone Substations use DC supplies for all critical functions. This ensures the safe operation of all equipment even under abnormal conditions including complete loss of all AC supply. Batteries are arranged in banks to deliver a range of different control voltages. These include 24volt, 50 volt, 110 volt and 240 volt DC. Battery condition is monitored constantly to ensure the safe operation of the stations.


When working with or on batteries, employees shall:

- Be suitably trained.
- Wear appropriate personal protective clothing (eg, goggles/face shield, chemical resistant overalls or splash apron and chemical resistant gloves).
- Avoid the use of non-insulated tools in the immediate area.

- Remove contaminated clothing and wash the skin with water immediately, should electrolyte be spilled.
- NOT smoke or use naked flames.
- Use ventilation where provided.

### Control/protection panels

Control panels are used to mount protection, control and communications equipment. In modern substations this is generally done using rack mounting type panels. In older substations the equipment was mounted on a variety of panel types.

## 6. PROTECTION SYSTEMS

Protection equipment is necessary to detect and isolate faults from the system. Protection relays detect faults by comparing the quantity (and angles in some cases) of the primary circuit current or voltage to a pre-determined setting. This comparison is done electromechanically for induction-type relays and digitally or electronically for digital or static relays.

If a fault is detected, the relay will issue a command to trip the circuit breaker after a predetermined time setting. Measurement of the primary circuit uses instrument transformers (ie CT's and VT's) to allow indirect, safer and more manageable connections to high voltage and/or high current equipment.

The main protection functions for distribution and subtransmission circuits are:

## Overcurrent

The relay starts to operate (pick up) when current magnitude exceeds the preset current setting. Overcurrent can be detected in phase conductors, neutral conductors and/or the earth return path:

- Phase-overcurrent or "overcurrent" protection is where current in a phase conductor is measured.
- Ground-overcurrent or "earth fault" protection is used to detect earth faults whereby:

  (a) the current in a specific neutral or earth conductor is measured and/or

  (b) the residual current of the phase conductors of a 3 phase system is measured. This is achieved by measuring the "summed" current of the parallel connection of all phase CT's, or is calculated within the relay itself, (applicable only to digital relays).

The residual current in a typical distribution HV network is zero during normal conditions, even with extreme load unbalance. This is due to distribution transformer primary winding and earthing configuration. Sensitive settings can therefore be applied to earth fault relay, typically, a setting of 10>20% of the nominal CT secondary current is used. It is possible for a residually connected relay to operate when a high-resistance joints is present in one phase of a multiple parallel circuit

Overcurrent relays invariable contain in-built timers to enable time-graded coordination with other related relays. An inverse-time characteristic provides a time delay that is inversely proportional to the current detected, (ie the higher the current, the shorter the operating time).

Ground-overcurrent (earth fault) relays often use a definite-time characteristic only, as the earth fault current magnitude does not vary so greatly between two relaying points on a given network.

## Directional overcurrent

Same as previous, with the addition that the direction of a fault can be known by comparison of the primary circuit voltage and current. Directional overcurrent is widely used in protection of ring or parallel feeders, where fault current can flow in either direction depending on the location of the fault and supply source. Directional relays that look back directly into a source can be set sensitively, as current flowing in this direction will be abnormal, and thus considered a fault.

## Differential protection

Compares the current entering the protected circuit (or zone) to the current leaving the zone. A zone is bounded by measuring CT's at the terminals of the protected circuit. Where the terminals are some appreciable distance apart, then a communications channel or pilot wire is required between ends for differential comparison, logic and inter-tripping facilities. There are many various patented techniques available to perform differential comparison and intertripping.

As differential protection only operates for faults within a zone of protection, there is no requirement to consider the operation times of protection outside the zone; instantaneous operation is therefore often applied to differential protection.

## Distance protection

Distance relaying principles are based in impedance measurement and so require the values of primary circuit voltage and current for any instant time. The impedance of any given circuit is a fixed quality; if the impedance measured by the relay has decreased to some value below a predetermined setting, then a fault is assumed on the circuit and tripping can be initiated.

NOTE – On overhead line HV systems, many faults, particularly earth faults may be transient ones, hence earth fault and overcurrent protection systems may be associated with auto reclose relays. These relays automatically re-close the circuit breakers after a short pre-determined time and these usually lock out after a set number of unsuccessful attempts.

For HV Live Line work, auto-reclose shall be suppressed, or Live Line Sequence (LLS) enabled. LLS gives instantaneous trip and sensitive earth fault protection.

## 7. COMMUNICATION SYSTEMS

Remote control and indications of substations and field equipment are vital in ensuring safe, efficient and effective operation of an electrical distribution network. This was the primary objective for the development of SCADA systems, (Supervisory Control And Data Acquisition). As the name implies, the SCADA systems main functions are to provide remote control of remote devices and to return the status, alarm and system operating data from remote devices. Remote control is generally required from one or more strategically located control centres. The main control point is often known as the Network Control Centre, (NCC).

The SCADA master station which generally resides at the NCC, communicates to Remote Terminal Units (RTU's) located at substations and on field equipment such as pole mount Auto-Reclosers. The SCADA master interrogates the RTU's over a communications network. The medium for the communications networks can take many different forms; the most widely used are radio, pilot or supervisory wire and fibre-optic.

The substation RTU is generally equipped with digital and analogue Input/Output (I/O) to interface with substation devices. The main function of digital I/O is to provide for the display of the operating status of field equipment (eg indicating a breaker in either the open or closed position) and for operational control of field equipment (eg operating to open or close a breaker). Analogue I/O is generally used to provide for the display of real-time values of the electrical quantities seen by a particular device, (eg the load current through a breaker, or the voltage on a busbar).

Control centre communications can also be achieved with Intelligent Electronic Devices (IED's) such as digital relays via serial communications linked to the RTU or to the SCADA master itself. The main benefit of this is that event data, indication and control points available within the IED can be accessed remotely via SCADA.

## 8. EARTH GRIDS

The earth grids installed in Terminal Stations and Zone Substations serve the following purposes:

### As a Voltage Reference Point for the Network Supplied

The secondary windings of the transformers in Terminal Stations and Zone Substations are connected to the earth grid so that the voltages on the network are maintained at the specified values with respect to earth. That is the distribution network voltage (e.g. 22kV) is held constant by the connection to the earth grid.

### For the Management of Fault Current

The earth grid in Terminal Stations and Zone Substations is designed to facilitate the return of earth fault current from faults on the network it supplies to the source of the fault current, the Zone Substation transformer. This then ensures that enough fault current flows to operate protective devices such as fuses and circuit breakers. Any earth fault on a distribution feeder, such as a possum strike on a concrete high voltage pole, results in fault current flowing into the pole and the ground and then returning to the zone substation transformer via the earth grid at the Zone Substation. Consequently the earth grid has to be designed and built to carry the large currents that may be associated with network earth faults. Earth conductor sizes and the integrity of all connections are critical to the safe operation of the earth grid. All plant within a substation such as transformers, circuit breakers, surge diverters and bus support structures etc. are all bonded to the earth grid in the station so that in the event of a failure the fault current can be safely managed.

## Safety

The earth grid in Terminal Stations and Zone Substations also ensures the safety of all people working in the substation by limiting the step and touch voltages that can occur under fault conditions. When fault current flows into and earth grid dangerous voltage rises can occur on the earth grid. The design of the earth grid is intended to manage these voltage rises, should they occur, so that people within and outside the substation are not exposed to dangerous voltages.

## Work on earth grids

Special precautions must be taken when working on in service earth grids to prevent exposure to hazardous voltages should a network earth fault occur at the time the works are being undertaken. These precautions may include the use of bonders and insulating gloves.

## Station earths

Earthing receptacles and facilities are provided in Zone Substation to permit the effecting bonding to earth of plant and lines using portable earthing equipment. This then permits the safe issue of Electrical Access Permits for the maintenance of this substation equipment by ensuring that the equipment remains at earth potential.

## 9. MOBILE PLANT & EXCAVATING WITHIN STATIONS

A person shall not perform work in any station or allow mobile plant to enter any station without first obtaining the permission of the person in charge of the station and, accepting all the conditions imposed by that person.

An Access Authority shall be issued in a Terminal and Zone Substation where:

- Mobile plant or other large vehicles will be used.
- The work involves excavation or the use of explosives.
- Where Ordinary Persons are involved.

Mobile plant when in the travelling mode within Zone substations or Terminal stations shall have a trailing earth lowered. When in a stationary working mode the mobile plant shall be connected to the station earth grid.

The work party shall ensure that work does not require the earthed portions of the mobile plant to move outside the perimeter of the station earth grid;

Before starting an excavation in any energised station, the crew leader shall obtain all available information on existing subsurface structures such as power and control cables, pipes, ground wires, etc. Work in the vicinity of all such assets shall be done with great care. The crew leader in conjunction with the operating authority shall designate the limits of the excavation and the employees shall keep within these limits.

Any accidental opening in the earthing system shall be repaired using high voltage rubber gloves or by bridging out the opening. Caution must be observed, as this is possibly an energised open circuit. If a section of the substation fence is extended or removed, earthing and bonding continuity shall be maintained at all times.

## 10. ELECTRICAL TESTING AND TEST FACILITIES

**NOTE:** This section applies to fixed and temporary test sites using high voltage and/or high power, but does not include routine work such as phasing or checking for voltage on a de-energised line.

When carrying out electrical testing involving secondary Isolations in a Zone Substation, employees shall:

- Be trained and authorised.
- Protect the test areas using appropriate barriers with danger signs attached.
- Ensure test trailers and vehicles are earthed, and employees are protected against step and touch potential with bonding, insulation or isolation techniques.

## 11. GAS INSULATED EQUIPMENT

Employees shall wear company approved protective clothing to avoid skin contact with powder residue that may be found inside the SF6 gas containment system.

Manufacturer's cautions shall be followed when performing maintenance on breakers or buses. This includes product bulletins, safety bulletins, and manufacturer's warnings.

When working on SF6 equipment, special precautions should be taken not to breathe the SF6 gas or its by-product.

Employees shall use a regulator, gauge, and hose for proper PSI rating when filling or adding SF6 gas.

## 12. ZONE SUBSTATION SWITCHING

Before switching is performed in a substation where work is in progress, the employee performing the switching shall notify all personnel working within the substation.

All other personnel shall be clear of the work area during the time any circuit breaker is being racked in or out. The circuit breaker shall be in the open position and the control circuit rendered inoperative by activating the operator safety switch, if the design so permits.

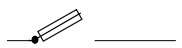
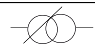
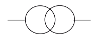
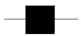
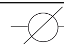
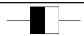
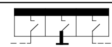
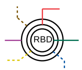
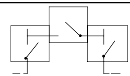
The application of earthing devices to isolated contacts within the spouts of metal-clad switchgear shall be supervised by an Authorised Person.

Any employee who has carried out switching or maintenance in a Zone Substation shall record the details of their work in the Substation logbook.

## 13. SYMBOLS AND DEFINITIONS

| | | | |
|---|---|---|---|
| | Lines crossing & connected together | | Cable head |
| | Lines crossing but not connected together | | Fused transformer |
| | SWER overhead conductors | | Unfused transformer (thinner stem) |
| | Single phase overhead conductors | A T | Auto transformer |
| | Open point | 2P | Two pole type transformer |
| | Open bridges | | Indoor type substation |
| B | Bay break | G | Ground type substation |
| M S | Mid-span break | IS | SWER Isolating |
| | Single operated arc switch | | SF6 Gas switch |
| | Gang operated arc chute FB switch | | SF6 Gas switch with fuses on same pole |
| | Single operated isolator | CB | Circuit breaker – Indoor type |
| | Rotary arc chute switch | CB | Circuit breaker – Outdoor type |

# TERMINAL STATIONS & ZONE SUBSTATIONS

| | | | |
|---|---|---|---|
|  | Rotary isolators | AS | Automatic sectionaliser |
|  | Gang operated arc chute fuse combination | AR | Automatic circuit recloser |
|  | Single operated fused isolator |  | On load tap changing transformer |
|  | Live line clamp (shown at 30° to line it controls) |  | Transformer |
|  | Over current fault indicator - Manual |  | Line voltage regulator |
|  | Over current fault indicator – Automatic |  | Capacitor |
|  | Over current fault indicator – Electronic |  | Kiosk substation with transformer switch & switched 'through feed' |
|   | Zone substation distribution feeder buses |  | Bus tie switch |
| EL | Earth leakage | BUEL | Back up earth leakage |
| MEL | Master earth leakage | GTH | Gas thermal |
| BA | Boric Acid | EDO | Expulsion drop-out |
| PFF | Powder filled fuse | O.O.S | Out of service |
| WP | Water pump | AB | Air break |
| HD | Horn deflector | FB | Flicker blade |