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Welcome to the Generator Grid Connection Guide V2.

All sections in this version have been revised to improve clarity and to bring the material up to date. This guide provides a high level overview of the issues associated with the connection of a generator to the South West Interconnected System. It is intended to assist in understanding the requirements of the Technical Rules but does not replace the Technical Rules.

The power system is complex. The rules governing connection to the system are, necessarily, highly technical. This document provides background information on aspects of power systems that are particularly pertinent to generators. For readers without a background in the field, it provides a non-technical introduction to the terminology and some of the basic concepts.

It should be noted that this is a highly simplified overview. A fully informed understanding of the power system requires significant professional engineering expertise. The physics involved is complicated and generally requires advanced mathematical analysis to gain a full understanding. Most generator proponents will require the advice and services of specialised power system analysis engineers in order to provide required data and meet the requirements for connection. Particularly for a large generator, the connection process can be involved, and the engineering data that must be provided for a full assessment is highly technical. This is because any user of a power system can affect other users. Therefore connection of new generators to the power system must be carefully assessed to ensure that there will not be adverse consequences and that all users will continue to receive acceptable system performance.

We value your feedback about the format and content of this guide and any additional information you believe we need to take into account. Comments on this document should be sent to:

Manager Network Planning & Development
Western Power Corporation
GPO Box L921, Perth WA 6842
Telephone: (08) 9326 6293
Facsimile: (08) 92185167
genconnection@westernpower.com.au

Western Power looks forward to working with you.

David Bones
Manager, Network Planning & Development
Western Power
# Contents

1 Power system technical overview 5
   1.1 What is a power system? 5
   1.2 Key components of large electrical power systems 5
      1.2.1 Generators that convert mechanical energy to electrical energy 5
      1.2.2 Transformers that prepare for efficient transmission of electrical energy 5
      1.2.3 Transmission and distribution lines to carry the power between generation and load 6
      1.2.4 Substations where electrical energy can be redirected and modified (reformed) 6
      1.2.5 Loads where electrical energy is consumed 6
      1.2.6 Auxiliary systems 6
2 Generation 7
   2.1 Introduction – how a generator works 7
   2.2 Generator types 7
      2.2.1 Synchronous machines 7
      2.2.2 Induction machines 7
      2.2.3 Inverter connected 8
      2.2.4 Comment 8
   2.3 Energy sources / types of generation 8
      2.3.1 Thermal Turbines 8
      2.3.2 Photovoltaic 9
      2.3.3 Wind 9
      2.3.4 Cogeneration 9
      2.3.5 Water 10
      2.3.6 Distributed generation 10
3 Power quality issues 11
   3.1 Voltage 11
   3.2 Frequency 12
   3.3 Current 12
   3.4 Impedance 12
   3.5 Power 12
   3.6 Complex power or apparent power 12
      3.6.1 Reactive Power 12
      3.6.2 Real Power 13
4 Transmission and distribution systems 14
   4.1 Why we need different voltages 15
   4.2 Transmission circuits 15
      4.2.1 What is a transmission circuit? 15
      4.2.2 Transmission network types 15
   4.3 Lines 16
      4.3.1 Overhead line 16
      4.3.2 Cable 16
      4.3.3 Transmission line/cable comparison 17
      4.3.4 HVDC 17
4.4 Substations
  4.4.1 What are substations for?  17
  4.4.2 Substation equipment  17
    4.4.2.1 Transformer  17
    4.4.2.2 Circuit breaker  18
    4.4.2.3 Bus  18
    4.4.2.4 Disconnector  18
    4.4.2.5 Earth switch  18
    4.4.2.6 Instrument transformer  19
    4.4.2.7 Surge arrestors  19
    4.4.2.8 Reactive power support  19
    4.4.2.9 Earthing  20
    4.4.2.10 Relay room  20
  4.4.3 Substation configurations  20
    4.4.3.1 Single busbar (Single breaker per circuit)  21
    4.4.3.2 Mesh  21
    4.4.3.3 Double busbar  21
    4.4.3.4 Breaker and a half (1.5 circuit breaker)  21
5 Faults
  5.1.1 Types of faults  22
  5.1.2 Stages of a fault  23
  5.1.3 Factors influencing fault currents  23
  5.1.4 Fault ratings  23
6 Earthing
  6.1 Introduction  24
    6.1.1 What is earthing?  24
    6.1.2 Why is it required?  24
  6.2 Earthing  24
    6.2.1 Transformer and generator earthing  24
  6.3 Lightning protection  26
  6.4 Surge protection  26
7 Protection
  7.1 What is protection?  27
  7.2 Why is protection required?  27
    7.2.1 System stability  27
    7.2.2 Voltage stability  28
    7.2.3 Security of supply  28
  7.3 Generator protection principles  28
    7.3.1 Overcurrent protection  28
    7.3.2 Overvoltage protection  28
    7.3.3 Low forward power/reverse power protection  28
    7.3.4 Unbalanced loading  29
  7.4 Protection equipment  29
    7.4.1 Fuse  29
    7.4.2 Circuit breaker  29
    7.4.3 Relay  29
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Operation</td>
<td>30</td>
</tr>
<tr>
<td>8.1</td>
<td>Synchronising equipment</td>
<td>30</td>
</tr>
<tr>
<td>8.2</td>
<td>Modes of generator operation</td>
<td>30</td>
</tr>
<tr>
<td>8.2.1</td>
<td>Frequency control</td>
<td>31</td>
</tr>
<tr>
<td>8.2.2</td>
<td>Voltage control</td>
<td>31</td>
</tr>
<tr>
<td>8.2.3</td>
<td>Power factor control</td>
<td>31</td>
</tr>
<tr>
<td>8.2.4</td>
<td>Islanded operation</td>
<td>31</td>
</tr>
<tr>
<td>9</td>
<td>Generation/load balance</td>
<td>32</td>
</tr>
<tr>
<td>9.1</td>
<td>Swinging generators</td>
<td>32</td>
</tr>
<tr>
<td>9.2</td>
<td>Dispatch of generators</td>
<td>32</td>
</tr>
<tr>
<td>9.3</td>
<td>Reserve generation</td>
<td>32</td>
</tr>
<tr>
<td>10</td>
<td>Governance of power systems</td>
<td>33</td>
</tr>
<tr>
<td>10.1</td>
<td>Explanation of relevant legislation and codes</td>
<td>33</td>
</tr>
<tr>
<td>10.2</td>
<td>Differences between Eastern and Western Australia</td>
<td>35</td>
</tr>
<tr>
<td>11</td>
<td>Grid connection process</td>
<td>36</td>
</tr>
<tr>
<td>11.1</td>
<td>Costs to connect</td>
<td>37</td>
</tr>
<tr>
<td>11.2</td>
<td>Self evaluations – connection checklist</td>
<td>37</td>
</tr>
<tr>
<td>12</td>
<td>Planning studies</td>
<td>38</td>
</tr>
<tr>
<td>12.1</td>
<td>Required technical information</td>
<td>38</td>
</tr>
<tr>
<td>12.2</td>
<td>Importance of accurate data</td>
<td>38</td>
</tr>
<tr>
<td>12.3</td>
<td>Generator modelling requirements</td>
<td>38</td>
</tr>
<tr>
<td>12.3.1</td>
<td>Main Simulation Types</td>
<td>39</td>
</tr>
<tr>
<td>12.3.2</td>
<td>Additional simulation types</td>
<td>41</td>
</tr>
<tr>
<td>12.3.3</td>
<td>Application of studies with respect to the Technical Rules</td>
<td>41</td>
</tr>
<tr>
<td>13</td>
<td>List of Abbreviations</td>
<td>42</td>
</tr>
<tr>
<td>14</td>
<td>Glossary</td>
<td>43</td>
</tr>
</tbody>
</table>
1.1 WHAT IS A POWER SYSTEM?
A power system provides a means of harnessing power from energy sources, and transporting the power to areas where it can be used for production and consumption. Three factors motivate the use of large electric power systems:

1. The conversion of mechanical power to electrical power is relatively efficient. The transport of electricity over long distances is cheap, efficient and convenient (it is usually better to move the electricity than to move the fuel). Electricity is therefore an effective form in which to transport energy.
2. Electrical power is convenient for many end-uses.
3. Large power systems have significant efficiencies of scale that bring both economic and technical benefits. For instance:
   - The cheapest fuel source can be used even when it is far from the load (or consumption).
   - Reserve plant can be shared among many users, allowing a more reliable supply to be provided at lower cost.
   - In a large system, the frequency disturbance from the accidental shutdown of a power station is smaller than for the same shutdown in a small system.

1.2 KEY COMPONENTS OF LARGE ELECTRICAL POWER SYSTEMS
Key components include: generation, transmission and distribution systems:

1.2.1 GENERATORS THAT CONVERT MECHANICAL ENERGY TO ELECTRICAL ENERGY
A generator manufactures electricity by converting energy from a source into electrical energy. Sources can include diesel engines, gas, steam or an alternative energy system.

1.2.2 TRANSFORMERS THAT PREPARE FOR EFFICIENT TRANSMISSION OF ELECTRICAL ENERGY
Once created electricity travels to a transformer and is changed from low to high voltage electricity using a ‘step-up transformer’. This allows the energy to be transported long distances to where it is required. Using high voltage reduces power losses. The losses are proportional to the square of the current. Increasing the voltage reduces the required current to provide the same power.

Transformers often have manually or automatically operated tap changers that allow the voltage level on one side of the transformer to be adjusted relative to the other side. Compared with synchronous generator voltage control, this is a relatively slow and coarse mechanism.
1.2.3 TRANSMISSION AND DISTRIBUTION LINES TO CARRY THE POWER BETWEEN GENERATION AND LOAD

The energy is transferred at high voltage from one geographical area to another using transmission lines. Using high voltage reduces power losses in the lines. At high voltage the lines require a lot of insulation (for example, large air gaps for overhead lines) to stop the energy from flowing to the line structures and on to the ground causing faults.

The almost universal use of rapidly alternating voltage allows the voltage level to be changed easily by using transformers. However, this means that the energy delivered on an individual line also alternates. Large power systems therefore use three separate lines (called ‘phases’) so that the individual fluctuations cancel out and a steady power can be delivered. Consequently, a three-phase system allows the sizes of its motors and transformers to be smaller and uses less conductor material to transmit electric power than equivalent single-phase, two-phase or direct current (DC) systems at the same voltage. Large generators (and large loads) have three output (or input) phases to match this system.

The direction of power flow on bulk transmission networks varies with different generation schedules. Like a freeway system, high capacity must be provided to accommodate flows throughout the bulk transmission network.

By contrast, distribution networks historically have only served loads. The power flow direction is predictable, and the required capacity is smaller towards the ends of the network. A distribution network usually resembles a tree structure or a road feeder network.

In recent times, distributed generation has become more common, with large quantities of small-scale power generation being connected directly to the distribution network. Connection of generators directly to the distribution network is making it increasingly difficult to predict the power flow through the distribution network, and many existing distribution networks require modification to cater for the new generation sources.

1.2.4 SUBSTATIONS WHERE ELECTRICAL ENERGY CAN BE REDIRECTED AND MODIFIED (REFORMED)

At each end of a transmission line there are switching stations (also called substations) that can direct the energy where required and allow lines to be taken out of service when necessary. If there is large demand for energy close by, the voltage may then be stepped down using a supply transformer. The lower voltage level is suitable for distribution of the energy over moderate distances to central points of residential, commercial and industrial load.

1.2.5 LOADS WHERE ELECTRICAL ENERGY IS CONSUMED

After the energy is stepped down from transmission voltage, the energy feeds out to local street supplies, where the voltage is further reduced to a level directly usable by consumer loads.

Industrial and some large consumer loads may use the energy distributed over three phases. However, most small consumer loads use the energy from a single phase, and are balanced evenly between all three phases.

1.2.6 AUXILIARY SYSTEMS

In order to ensure the effective operation of the key primary systems described above, various secondary systems are necessary to provide control and monitoring functionality and to deal appropriately with equipment problems, particularly power system faults. Refer to section 5 for detailed information of power system faults.
2.1 INTRODUCTION – HOW A GENERATOR WORKS

A generator has an input shaft that is driven by a ‘prime mover’ such as a diesel engine, or a steam, wind, or water (hydro) turbine. The prime mover supplies mechanical energy to the generator input shaft. Inside the generator, the input shaft turns a ‘rotor’ that creates a rotating magnetic field. This field crosses ‘stator’ (fixed or static) ‘windings’ (wire coils) in the generator housing. These windings are connected to the generator output. The changing magnetic field creates a voltage on the generator output by the process of ‘magnetic induction’.

When the generator output is connected (through a transmission system) to a load, currents flow that carry electrical energy to the load.

2.2 GENERATOR TYPES

There are two main types of generator in common use in power systems: synchronous generators and induction generators. Most generators are synchronous generators. Electric motors are available in corresponding forms; however, synchronous motors are rare and used only in special applications.

2.2.1 SYNCHRONOUS MACHINES

A synchronous machine, as indicated by its name, requires the rotor to spin at a fixed speed relative to the frequency of the power system. The rotor spinning frequency can be equal to that of the power system (3000 RPM in Australia), or can be reduced to a fraction of the frequency (to give, for instance, 1500 RPM or 750 RPM) by adding additional sets of coils in each phase in the stator and additional coils in the rotor. The additional rotor coils are called ‘poles’. The turbine (or prime mover) can spin at other fixed speeds (e.g. 6300 RPM) if a mechanical gearbox is used to change the speed to one that a synchronous machine accepts.

The rotor has a winding that is powered by a steady (direct current - DC) power supply. The constant current forms a magnetic field, which rotates with the rotor. A synchronous generator can control its output voltage by changing the amount of current fed into the rotor winding. Historically, this has generally been the cheapest way to provide fast voltage control on power systems, and so almost all generators (and all large generators) have been of the synchronous type.

2.2.2 INDUCTION MACHINES

Induction machines are not speed-locked to the system frequency, although in normal operation they operate within a small speed range. Their chief advantage is that they are mechanically simpler, and cheaper to manufacture. However, they have adverse effects on power system performance (compared with synchronous machines or other types of load). Two common induction machines are the ‘squirrel cage’ and the ‘Doubly Fed Induction Generator (DFIG)’. 
The squirrel cage induction machine is named because of the use of a cylindrical rotor cage inside the rotor, which resembles a cage on which squirrels exercise, or a mouse wheel.

The rotor does not require a power supply to maintain a magnetic field. Instead the energised stator windings induce currents to flow along the rotating rotor bars, forming a magnetic field. The rotor is very tolerant to changes in speed because the magnetic field present on the rotor is not ‘held in place’, as it would by an external power supply in a synchronous machine.

A Doubly Fed Induction Generator (DFIG) operates like a combination of a normal induction machine (such as the Squirrel Cage) and a synchronous machine. Inverter fed three-phase windings on the rotor allows the magnetomotive force (mmf) of the rotor to rotate independently of the mechanical rotation. With a suitable control system for the inverter the rotor mmf stays in synchronism with the power system frequency while the rotor speed varies.

A DFIG is very useful in wind generation, as the blades can spin at a range of speeds. The aerodynamic efficiency of wind turbines is greatest at a particular rotation speed, and the optimal speed varies when the wind speed changes. Therefore variable speed operation maximises the efficiency of the wind capture. In addition, this type of generator can help to control system voltage (unlike a squirrel cage induction machine). Usually the inverter is only small (relative to the machine size) and so the speed range and amount of voltage support are both limited.

### 2.2.3 INVERTER CONNECTED

An inverter is an electronic device that can be used to connect generators to the network. The inverter outputs an alternating current (AC), from a direct current (DC) input or from an input that is oscillating at a different frequency to the power system. This allows a source that produces DC (such as a photovoltaic system) to be connected to the power system (which uses AC).

An inverter can also enable a synchronous machine to be operated at variable speed. Compared with a DFIG, a mechanically simpler arrangement can be used (by avoiding the use of high power slip-rings) so long as the inverter does not have a smaller rating than the main machine output.

Inverters can provide excellent voltage control, even when the energy source is unavailable.

### 2.2.4 COMMENT

In practice, most generators on power systems are synchronous (and regulate voltage), and most loads are induction motors (with the remainder being resistive or static). In principle, it would be possible to reverse this and have a power system with induction generators and synchronous motor loads (with the loads regulating voltage). It could even be argued that this is preferred, because the load voltage is of most interest and it is better that the regulation occurs near the load.

However there are few generators, and there are very many loads. Generally, it is cheaper and more efficient to provide the expensive (and somewhat complicated) voltage control equipment on the small number of generators. In principle, it is not necessary to provide this control on every generator. There have been proposals in the technical literature to use large, induction generators; however, this has not eventuated in practice.

Many early wind generators used induction machines. These are cheaper and, importantly, require a lighter, mechanically simpler, and less maintenance-intensive machine in the turbine nacelle. This was acceptable while the machines and wind farms were relatively small but they are now approaching or exceeding the size of conventional power plants. Given the circumstances outlined above, induction generators are increasingly being required to install supplementary voltage control equipment to overcome the inherent limitations of the generators.

### 2.3 ENERGY SOURCES / TYPES OF GENERATION

The quality of power available through a power system not only depends on having an adequate amount of generation present, with a suitable reserve margin, but also the type of energy source used for the generation. It is important to model the physical control of the energy source when considering the effect the generator will have on system stability. In some cases the design of a generating unit can be tailored to suit the stability characteristics required on the system.

#### 2.3.1 THERMAL TURBINES

The energy source for thermal generation can be fuels (such as coal, gas, biomass, or any material that can be burnt to produce heat energy) or other heat sources (such as nuclear, geothermal, or solar-thermal energy). The energy produced is captured and converted by steam, gas or combination turbines.
For steam turbines, the stored energy in the source is used to heat water to generate high pressure, high temperature steam that is passed through a set of turbines. The turbine sets convert heat energy into rotational energy. The waste steam is then condensed and the water returned to the boiler where the cycle continues.

Gas turbines do not use an intermediate stage of water heating; instead they directly pass the hot, high-pressure combustion gasses through a series of turbine blades.

Combined cycle turbines can increase efficiency by initially using a gas turbine stage, with the gas exhaust then used to heat water to feed a steam turbine.

Steam turbine thermal generation generally requires a significant amount of time to ramp up to full power output after an initial start, due to the time taken to raise the equipment to operating temperatures. After operating at constant output for some time, it can also take time to respond to a signal to ramp the power output up or down. This limits the ability of steam thermal generation to pick up extra load that may appear with little warning.

2.3.2 PHOTOVOLTAIC

Photovoltaic (PV) generation involves converting energy from the light spectrum directly into electrical energy through the use of semi-conducting materials. Photovoltaic generation produces power in DC. This means the current does not alternate direction at 50 cycles a second, as in conventional AC generation. An inverter is used to connect to the power system.

The inverter can provide fast voltage control, even at night when the sun is unavailable. Photovoltaic generation has the advantage that the output is likely to be available during system peak loads as consumer demand is generally driven by temperature.

Although inverters could be capable of providing voltage control without output from the PV system they generally do not. There are issues with the fault ride through capability (ability to remain connected during faults) of a domestic connected PV system that could present issues as more PV systems are being connected to the distribution system. Also the power output from PV systems can be quite variable particularly on cloudy days. The power system, therefore, needs to be adequately designed to respond to uncontrollable variations in PV output.

2.3.3 WIND

A ‘wind farm’ is typically made up of numerous turbine sets distributed over a moderate geographical area with each turbine producing a small amount of power, presently in the order of 0.5-3 MW.

As wind is a renewable resource meaning that there is no fuel cost, there are initial capital cost and on-going maintenance costs.

Wind generation has a variable output based on wind speed so cannot be scheduled using conventional techniques. This is a particular issue when the portion of wind generation is high, relative to the total generation pool. Other types of generation must be provided and are required to step in should the wind speed and resulting power output fall unexpectedly.

Traditionally wind farms have used induction generators; however, these will no longer meet the requirements of the Technical Rules unless they have significant reactive support.

Wind farms that use DFIG machines can provide voltage control although often within a limited range, and may not require additional reactive support to meet the requirements of the Technical Rules. In principle, inverter connected machines are able to provide full voltage control even when the wind is unavailable. This option is generally available at additional cost.

2.3.4 COGENERATION

Industrial or commercial plants with a requirement for steam/hot water now often include generating plant utilising or producing steam to improve overall economics, as a ‘cogeneration’ or ‘combined heat and power’ (CHP) scheme.

The plant will typically have a connection to the public utility system; such generation is referred to as ‘embedded’ generation. The generating plant may be capable of exporting surplus power, or simply reducing the importation of power from the utility.

A cogeneration scheme directly coupled to the plant heating system has limited ability to vary its electrical output to meet power system needs without also varying the heat output to the rest of the plant. The scheme can have an auxiliary firing system fitted to allow the generator to have minimum electrical output even when the plant heat demand is high, increasing the flexibility of power supply.
2.3.6 DISTRIBUTED GENERATION

‘Distributed generation’ involves the connection of small-scale power generation technologies to the distribution network. The power is usually generated close to where it is used. Often it is consumed on the network to which it is connected, without having to be increased in voltage for transmission over long distances.

Existing distribution networks have been developed in an environment where distributed generation was rare and small. Network design has taken advantage of simplifications that this allows (such as tapering the capacity towards the end of the network, low fault ratings, and the use of much simpler control and protection systems than are used on transmission networks). However, power generation using small-scale technology is increasing and connecting large amounts of generation to existing distribution networks is often problematic. Safety issues that arise include: ensuring adequate clearance of faults, and issues associated with the voltage profiles, conductor ratings and fault ratings. Many existing distribution networks require modification to cater for the new generation sources.

2.3.5 WATER

Hydro generation converts potential energy into electrical energy using a water turbine connected by a shaft to the generating unit. The turbine can be designed for generation with differing levels of waterhead. The responsiveness of the generating unit to change power output varies significantly with the design of the turbine and penstock unit.

Compared with thermal generation, hydro generation is generally quicker to respond to small load fluctuations and can come online much faster.
The power system needs to run in a stable state and be able to deliver power to consumers at an acceptable quality. All connected equipment must operate in the desired manner.

The correct operation of a network requires the voltage to stay within an operational range, which all electrical equipment is designed to handle. Broadly, the essential qualities are:

- sinusoidal waveform, with a low level of disturbances (from motor starting, harmonics etc.)
- a constant power system frequency of 50 Hz.

At times of heavy loading on the power system, the current flowing through any piece of equipment should not be above its design rated level. During a fault all equipment must be able to handle the current.

The impedance of generators, transformers, and transmission circuits should be low enough to allow power to flow to where it is required without excessive voltage drop from generation to load. The impedance should be sufficient to ensure that the fault current on any one piece of equipment will not be excessive.

A new generator has the responsibility to ensure that they can output power across their full output range, while meeting the power quality requirements of the Technical Rules.

### 3.1 VOLTAGE

The voltage at which the grid is designed to operate is referred to as ‘nominal voltage’.

Nominal voltage can also be referred to as 1 per unit (pu) or 100 per cent (of nominal voltage).

When a point at the grid is operating at 1.05 pu or 105 per cent, this means that the voltage measured at that point is 5 per cent higher than the nominal voltage.

The voltage varies on a power system depending on the size and location of loading, and the route the power has to travel from generation to load.

Normally, if the voltage at any point on a network rises above 110 per cent or drops below 90 per cent, the quality of power delivered is unacceptable as it may cause damage to connected equipment.

Closer to the power consumer, the range of acceptable voltage variation during normal operation decreases to plus or minus 6 per cent.

Transformers play a vital role in voltage regulation by changing their voltage conversion ratio (called ‘tap changing’) depending on loading conditions of the system to keep the system within voltage limits. However, transformers take time to change taps, and are not able to smooth out surges and other short-term voltage variation.
The quality of power transfer on a network may also be poor if the voltage varies erratically. The most common problems are:

- **Flicker.** Large loads connected to the network that vary or switch regularly can cause small voltage variations on the surrounding network. These cause brightness of incandescent lights to change, which is irritating to users.
- **Dips.** Starting a large motor on a weak network, usually the distribution network, can cause a large voltage dip lasting up to ten seconds. A dip in voltage can cause other loads connected nearby to switch off. In severe cases, damage may be caused.
- **Harmonics.** The connection of large variable speed drives to a network introduces power noise onto the surrounding network. This is called ‘harmonics’. The current flow caused by harmonics can cause other electrical devices to overheat and malfunction. The prolonged presence of harmonics on a system will shorten the life of sensitive equipment.
- **Unbalance.** Voltage unbalance will cause heating of three phase machines and reduction in motor output torque which leads to increased machine losses and reduced efficiency. Some reasons for voltage unbalance are:
  - unequal loading on each of three phases of the power system;
  - incomplete transposition of long transmission lines; and
  - railway traction loads.

### 3.2 FREQUENCY

The frequency of the power system directly relates to the rotational speed of machines connected to the power system. The frequency needs to be maintained to avoid damage to motors. If the frequency drops, normally due to load increase, generation must be increased to bring the frequency back to normal levels and vice versa. Generation needs to be able to run over the full range of allowable network frequency, as the unscheduled trip of a generator can decrease system frequency.

### 3.3 CURRENT

The current flowing through a given circuit in the network should not exceed the rating of connected equipment. Currents above the rated current can cause equipment to suffer excessive mechanical stress and overheat. This may result in permanent damage to equipment.

A fault at some point along a circuit can cause large currents to flow in the network to the fault point. The equipment surrounding the fault needs to be capable of handling large currents without overheating until protection can isolate the supply of power to the fault.

### 3.4 IMPEDANCE

The impedance of an electrical circuit needs to be low enough so that the generator can supply the maximum desired export power without causing the voltage to drop too low at either end.

Occasionally, when new generation is connected to strong points on the network, usually near the existing generators, additional impedance may be required to prevent the fault contribution of the generator from exceeding the fault ratings of nearby network equipment.

### 3.5 POWER

Occasionally, limits are placed on generator power output. This may occur during the outage of an electrical circuit, which helps transfer the generator power output to the load centres, or when voltages on the system reach the limits of allowable range.

Typical operating constraints are normally discovered before a new generator is installed by simulating a range of operating scenarios with proposed generation. If limits are considered too restrictive other electrical equipment can be installed to increase the range of operation.

### 3.6 COMPLEX POWER OR APPARENT POWER

‘Complex power’ (kVA) is the combination of the power required to enable power transfer across a power system (the reactive, or imaginary part) and the usable power being transferred from generation to load (the real part). The real and reactive power parts are discussed separately as they behave differently on the power system.

#### 3.6.1 REACTIVE POWER

‘Reactive (or imaginary) power’ (kvar) provides the force that enables power transfer across the power system. It supports the voltage necessary to drive real power through the electrical circuits to the areas of load. Transformers and many motors absorb reactive power, and use it to establish a magnetic field, allowing energy to flow through the magnetic coupling. Generators and capacitors produce reactive power, and their output is balanced to meet total reactive demand on the power system. Generators can provide a variable
level of reactive power by changing the excitation of the rotor, and can provide continuous voltage control with the help of voltage monitoring control circuits. Capacitors are fixed devices that can switch in blocks to provide a set level of reactive power and are used to boost the voltage.

Reactive power support is required to stabilise the voltage. If there is insufficient reactive power the voltage will reduce. If the shortfall is great enough, it will lead to voltage collapse. If there is too much reactive power then there are issues with over voltages. This is a particular problem with long lightly loaded lines.

3.6.2 REAL POWER

'Real power' (kW) is the power available on a power system to be converted by loads into other forms of energy. The real power output of generation must be balanced by the power consumed by loads and losses. If the generation is greater than the energy used then the frequency will increase. If the generation is less than the energy used then the frequency will fall. To maintain a constant power system frequency the generation must be exactly matched to the loads and losses.
In road networks, a range of designs are used depending on the circumstances. Freeways allow many cars to travel at once, with many lanes (so that travel is still possible even if a lane is closed due to an accident or maintenance), and with no interruption from traffic controls. Smaller regional roads that feed into and out of the freeways have traffic lights and lower carrying capacities.

In the suburbs, lanes are even narrower and stop signs are common.

Power systems have similar characteristics. A useful distinction is between transmission and distribution subsystems. Typical characteristics are as follows:

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>TRANSMISSION</th>
<th>DISTRIBUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage level</td>
<td>Extremely high (66,000 Volts up to 330,000 Volts or more)</td>
<td>High (33,000 Volts) and low (415 Volts and 240 Volts)</td>
</tr>
<tr>
<td>Degree of redundancy</td>
<td>High (backups provided)</td>
<td>Lower (backup limited)</td>
</tr>
<tr>
<td>Structure</td>
<td>Meshed (alternate paths always in service)</td>
<td>Radial (branching and tapering, like a tree)</td>
</tr>
<tr>
<td>Transfer levels</td>
<td>High (tens to hundreds of MW or more)</td>
<td>Lower (ten MW or less)</td>
</tr>
<tr>
<td>Protection</td>
<td>High speed, sophisticated (unit or distance), duplicated</td>
<td>Slower, simpler (overcurrent and earth fault), limited or remote backup</td>
</tr>
<tr>
<td>Number of connections</td>
<td>Low (less than ten)</td>
<td>Very high (hundreds)</td>
</tr>
<tr>
<td>Neutral</td>
<td>No neutral</td>
<td>Neutral may be present</td>
</tr>
<tr>
<td>Earthwire</td>
<td>Overhead earthwire commonly used</td>
<td>Underslung or, usually, no earthwire</td>
</tr>
</tbody>
</table>
4.1 WHY WE NEED DIFFERENT VOLTAGES

Low voltages are used in general, low power applications as they hold a sufficient amount of energy for most consumer needs, without being too destructive during a fault.

Medium voltage and relatively high current is used in generation and loads to enhance the magnetic coupling. This allows the conversion of large amounts of power between mechanical and electrical form.

High voltage is used in distribution to allow bulk power to be distributed moderate distances with relatively little voltage drop. Distribution voltages allow economic plant configurations to be deployed over a wide area where a large number of equipment items need to be utilised.

A relatively higher level of losses is tolerated to save on capital cost.

Extra high voltage is used in transmission to allow a high level of power transfer per ampere of current flowing through the line. As line losses are proportional to the square of the current and are not influenced by an increase in the system voltage, power can be transferred more efficiently, with fewer losses over the length of the transmission line per MW transferred. This means that at a higher system voltage, more power can be transferred for the same conductor size. This makes extra high voltage systems more economical for transferring large amounts of power.

Transmission lines operating at extra high voltage form the backbone of a large power system. They are able to transfer large quantities of power over large distances, without losing excessive amounts of power in losses.

4.2 TRANSMISSION CIRCUITS

4.2.1 WHAT IS A TRANSMISSION CIRCUIT?

A transmission circuit is a connection between two points (sometimes three) to allow the transfer of electrical energy. One circuit for a three-phase AC power system will have three conductors.

There is an advantage to have two points connected together by more than one electrical circuit, as this avoids loss of supply (or blackout) if one circuit has a fault or is out of service for maintenance.

A transmission circuit may be overhead or underground or a combination of both.

4.2.2 TRANSMISSION NETWORK TYPES

The transmission system is constructed to provide an economic and reliable link between the generation and the load centres.

TRANSMISSION SYSTEM

![Diagram of a transmission system]

Sub-transmission systems distribute the power from load centres (or ‘points of supply’) to the specific local area substations (also called ‘zone substations’) where the power is further distributed.

Large power consumers, such as industrial sites or large commercial sites, may require their own zone substation, in which case they have a dedicated sub-transmission connection to their premises.

TYPICAL SUB TRANSMISSION SYSTEM

![Diagram of a typical sub-transmission system]

Distribution systems distribute the power from zone substations to roadside substations or other local reticulation, forming the final link to bring the power down to a voltage level where it is safe to use. Mostly, these systems are radial from each zone substation, with an open point between feeders of adjacent networks to allow transfer of loads between adjacent points of supply.
4.3 LINES

4.3.1 OVERHEAD LINE

An overhead transmission line uses steel towers, or wooden, concrete or metal poles, that hold the conductors at a safe distance above ground to avoid a short-circuit (or fault).

Between the cross arm installed on the pole or tower and the electrical conductor, there are a stack of insulators. These prevent current from flowing to the pole and on to the ground, causing faults.

4.3.2 CABLE

A cable surrounds each electrical conductor with an insulating material and a grounded conductive screen. This allows the cable to be installed in buildings or directly in the ground without the conductor short-circuiting.
### 4.3.3 Transmission Line/Cable Comparison

<table>
<thead>
<tr>
<th>Property</th>
<th>Overhead Line</th>
<th>Cable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ease of installation</td>
<td>Simple</td>
<td>Difficult</td>
</tr>
<tr>
<td>Transmission over long distances</td>
<td>Good</td>
<td>Poor</td>
</tr>
<tr>
<td>Use indoors, and in highly populated areas</td>
<td>Difficult</td>
<td>Very good</td>
</tr>
<tr>
<td>Visual impact</td>
<td>High</td>
<td>None</td>
</tr>
<tr>
<td>Reliability</td>
<td>Good</td>
<td>Very good</td>
</tr>
<tr>
<td>Complexity of repair</td>
<td>Simple</td>
<td>Difficult</td>
</tr>
<tr>
<td>Cost of material</td>
<td>Low</td>
<td>Very high</td>
</tr>
<tr>
<td>Cost of installation</td>
<td>Low</td>
<td>Very high</td>
</tr>
</tbody>
</table>

#### 4.3.4 HVDC

HVDC stands for High Voltage Direct Current. There are 'classical HVDC' and 'HVDC Light'. The classical HVDC is useful for the transmission of large amounts of power, from a few hundreds of MW to about 3000 MW, over long distances. The HVDC Light is most cost effective in the lower power range, from a few tens of MW to about 1200 MW. Complex equipment is required for the installation of an HVDC circuit, and does not compete economically with an AC transmission line over short distances. For transmitting high power over long distances (several hundred km) HVDC offers the following advantages:

- only two conductors are needed (or even one conductor if the ground is used as return)
- better system stability, i.e. two networks that are not synchronised or do not have the same frequency can be connected.

#### 4.4 Substations

#### 4.4.1 What Are Substations For?

A substation is a point on the power system that connects multiple circuits and may also change the voltage to more useable levels. The common uses for a substation are:

- connection of a generator to a transmission network by means of a step-up transformer;
- connection of a customer network by means of a step-down transformer;
- the ability to share power between multiple electrical circuits;
- in the event of a fault on a connected circuit, faults can be cleared and power redistributed therefore minimising disruption to power supply
- planned disconnection of circuits to allow maintenance to occur on power system equipment, without disrupting power supply.

A substation may consist solely of a transformer and two switches mounted on a pole. A main substation on a particular network, however, is more likely to be a site complete with control room, indoor and/or outdoor switchgear and transformers.

#### 4.4.2 Substation Equipment

##### 4.4.2.1 Transformer

Transformers allow the voltage level of a network to be increased to transfer large amounts of power over long distances, and then bring the voltage level back down to a level useable by consumers. Transformers serve two purposes: they can transfer power across two systems of different voltages; and/or they can provide electrical isolation between electrical systems.

A two-winding transformer can connect a network of one voltage level to the primary winding, and one network to the secondary winding. Transformers commonly contain all three phases in the same enclosure, so there are three primary windings (one for each phase), and three secondary windings.

The ratio between the number of turns on the primary and secondary windings determines the voltage conversion ratio.
As transmission voltages can vary depending on network loading, the voltage conversion ratio of a transformer can be fine-tuned using a tap changer. A tap changer can increase or decrease the number of turns on one side of a transformer to change the voltage conversion ratio. The significance of this is that the voltage of the primary network can vary while the transformer regulates the voltage of the secondary network.

The electrical isolation between the primary and the secondary network is achieved by having no direct electrical connection between the conductors on the primary and secondary sides. Furthermore, the magnetic coupling resists changes in the amount of current flowing (presented as an impedance), which limits the magnitude of fault current.

There are three main types of transformers that are used for power transfer between transmission networks.

- **Generator step-up (or generator transformer).** A generator transformer is made to accept the large currents generated at medium voltage, and transfer the power to the transmission system at a high voltage level and relatively low current. Generator transformers typically have a large voltage ratio and have a delta connection on the generator side to limit the flow of zero sequence current, which limits the generator earth fault level.

- **Interconnection transformer.** An interconnection transformer transfers power between transmission networks of different voltages. These transformers have a small voltage ratio.

- **Step-down transformer.** A step-down transformer reduces the voltage from one level to another. There are two main categories for step-down transformers:
  - Supply (zone substation) transformer – this steps the voltage down from transmission or sub-transmission to distribution voltage levels
  - Distribution transformer – steps the voltage down from distribution high voltage to low voltage.

Other types of transformers used in the power systems include earthing transformers, current transformers and voltage transformers.

### 4.4.2.2 CIRCUIT BREAKER

Circuit breakers (usually abbreviated as ‘CB’) are switches which are used commonly in substations that are capable of breaking fault current.

In the event of a fault, circuit breakers can be switched very rapidly to minimise the amount of damage that occurs at the fault location and all connected equipment, as well as minimising the disturbance to customers.

During fault conditions, it is likely that large currents (possibly due to a short-circuit) will flow through the circuit breaker. In order to successfully clear the fault, the circuit breaker must be designed to be able to open the switch (or break the connection) during this maximum current flow.

#### 4.4.2.3 BUS

The bus describes the electrical conductor that connects all the circuits together in a substation. It allows the current from any connected circuit to flow to any other circuit. The current flow through the bus cannot be directly controlled; however, the switching of equipment can change the current flow. Different bus configurations are used in different circumstances. These are discussed further below.

#### 4.4.2.4 DISCONNECTOR

Disconnectors provide an essential, visible, electrical isolation gap between two points on an electrical network.

If maintenance was required on a transmission line, theoretically, it would be sufficient to open the circuit breakers at each end and link a connection to earth on each side of the maintenance crew for safety. However, circuit breakers, unlike disconnectors, do not show a visible break in the network, and do not adequately demonstrate to local personnel that a section of the network is isolated.

Disconnectors also provide a mechanism for isolating both terminals of the circuit breakers so that maintenance can be carried out on the circuit breaker itself. Disconnectors can also allow the quick reinstatement of all non-faulted equipment after a fault has occurred. This is particularly important when dealing with circuit breaker failure.

#### 4.4.2.5 EARTH SWITCH

An earth switch allows the earthing of parts of a circuit, as a safety precaution during maintenance. The earth switch will protect against inadvertent re-livening of an electrical circuit during maintenance; and will provide a path for any stray currents that may flow if the circuit is in close proximity to other live circuits.
4.4.2.6 INSTRUMENT TRANSFORMER

Instrument transformers form the eyes and ears of the power system. These devices allow the safe measurement of current and voltage present on the main conductors. As indicated by the name, these measurement devices transform the electrical property they are measuring down to a level suitable for input into electronic devices as well as insulating the measuring devices from the power system. These devices feed information to relays which monitor the system; and to the network operator, so they can manage the power flow.

Voltage transformer

A voltage transformer operates similarly to a step-down power transformer, in that it reduces the voltage from any system voltage (i.e. 6.6 kV – 330 kV) down to 110 V. However, the main difference with a voltage transformer is that it is not designed for power transfer, and is only designed to transfer the minimum amount of power necessary to make an accurate voltage measurement (typically 100-200 VA).

Current transformer

A current transformer generally uses the primary conductor as the primary winding. It uses a secondary coil that is wired around a toroidal core that is positioned around the main conductor to measure the current. The number of turns of the secondary coil determines the current reduction ratio; the ratio is chosen to reduce normal operating current down to a level that protection equipment can use to make measurements.

An open circuit of the secondary winding of a current transformer is very dangerous as the secondary winding acts as a current source. This means that the secondary winding would try to ‘drive’ the current through whatever material forms the open point of the circuit. It could deliver a fatal level of current to personnel in close proximity, as well as damaging the insulation on the secondary winding.

4.4.2.7 SURGE ARRESTORS

Surge arrestors are a form of ‘pressure release’ for a power system. They allow current to flow to earth through them if the voltage becomes too high. Surge arrestors are very useful at preventing equipment damage caused by lightning strikes, switching surges, and other unexpected over-voltages that can occur.

A surge arrestor is not the same as a short-circuit; when a surge arrestor allows current to flow to earth it does not reduce the voltage level of the connected electrical network below its nominal operating value.

4.4.2.8 REACTIVE POWER SUPPORT

Reactive power gives the power system the voltage support it needs to transfer real power from generation to loads.

Reactive power support can be installed at any point on a network (although substations are commonly chosen) to help stabilise the surrounding network and ensure normal operation. Common types of reactive power support include:

- Capacitor bank. At times of large loading on a power system at points that are distant to generation, the voltage can drop to undesirable operational levels. In extreme cases it can lead to unplanned load tripping.

  The net effect of installing capacitors is a boost in voltage, which helps to alleviate voltage sag during heavy loading. Voltage sag is caused by an increase in the reactive power flow in the supply circuit, and a subsequent increase in the voltage drop along the length of the circuit. Capacitors can also cause voltage rise if the reactive power flow is reversed.

- Shunt reactor. A shunt reactor can be required to prevent over-voltages from occurring at parts of the network, either during periods of light loading or when a supply point in the network rises with the export of large volumes of power.

- Static Var Compensator (SVC). An SVC allows a variable amount of reactive power to be supplied or consumed which is consequently used to control the voltage of a point on the network to a desired level over a range of different operating scenarios.

  An SVC employs the use of heavy-duty electronic switches, which switch many times a second to regulate the amount of reactive power produced or consumed.
4.4.2.9 EARTHING
At most substations all equipment with metallic parts, which are not part of the main electrical circuit, are earthed to ensure safety and provide a common reference for the power system.

At large substations the physical connection to the ground is usually made by buried copper conductors connected together in grid like fashion. In smaller installations or for transmission poles the earthing connection can consist of a single pin driven into the ground.

See section 6 for more information on earthing.

4.4.2.10 RELAY ROOM
The relay room contains the ‘brains’ of a substation. The relay room has three essential roles to ensure the substation is operated reliably and safely:

- **Control.** Substation control allows the operation of equipment within the substation by operators. If maintenance is required on a piece of equipment, an operator can switch out sections of the substation to make the equipment safe to work on, while maintaining power supply to consumers.

  If there is a fault on a circuit connected to the substation, the protection will automatically disconnect the faulty equipment. An operator may then reconfigure the network to restore supply.

- **Protection.** The role of protection is to initiate the operation of a circuit breaker to clear a fault at or near the substation as quickly as possible to minimise damage to equipment, people, and loss of power to consumers. More information on the role of protection is available in section 7.

- **Communications.** A substation has communications equipment installed so the status of the power flow through multiple substations can be observed from a central operating room. This allows the power system to be monitored as a whole; and plays a vital part in the dispatch of generation, and the allocation of sufficient reserve capacity on the power system. A Supervisory Control And Data Acquisition System (SCADA) interface forms the main backbone of the power system communications system. Communication is also used to aid the operation of protection equipment.

  As the power supply to the control room is essential for managing the flow of power through the substation, there are back-up battery power supplies to maintain operation for a sufficient amount of time during a conventional power outage.

4.4.3 SUBSTATION CONFIGURATIONS
Different substation configurations are used for substations with differing levels of importance.

For a 330 kV bus, Western Power requires a minimum of a mesh configuration to provide some security against a bus fault occurrence in order to meet the reliability requirements of the Technical Rules. A mesh configuration is not readily expandable and so if the site is likely to have more than six switches, a breaker and a half configuration is used.
4.4.3.1 SINGLE BUSBAR [SINGLE BREAKER PER CIRCUIT]

The ‘single busbar’ arrangement is simple to operate, places minimum reliance on signalling for satisfactory operation of protection, and facilitates the economical addition of future feeder bays.

A single busbar arrangement generally will have a circuit breaker present on each connected circuit, which will protect the substation from outage during an external fault. However, a bus fault will cause a complete outage of the substation until the cause of the fault can be resolved.

A single busbar arrangement can have extra security of supply by installing a ‘bus section breaker’. A bus section breaker will split the bus into two sections, allowing half the bus to continue operating following a bus fault on either section.

4.4.3.2 MESH

A substation with a ‘mesh configuration’ has the same number of circuit breakers as the number of circuits. The scheme offers better features and facilities than the single busbar without a bus section breaker. However, it cannot easily be expanded in the event that additional circuits are required unless the initial design has been made suitable for future expansion. A mesh substation is usually limited to six circuits.

4.4.3.3 DOUBLE BUSBAR

A ‘double busbar’ arrangement allows for the connection of each circuit to either of two busbars (bus ‘A’ or bus ‘B’) using busbar selector disconnectors. In the event of a fault on either busbar, each circuit can be rapidly switched across to the other busbar with minimum disruption. High importance circuits can be connected to each busbar via a circuit breaker to ensure minimal loss of supply for busbar faults.

4.4.3.4 BREAKER AND A HALF (1.5 CIRCUIT BREAKER)

A ‘breaker and a half configuration’ uses three circuit breakers to connect two circuits (or 1.5 circuit breakers per circuit). This arrangement offers the benefits of a double busbar arrangement, as well as offering an increased level of security. The breaker and a half arrangement has the ability for each circuit to switch between busbars without an outage. Supply is maintained for a single busbar outage. Some level of supply is also maintained for the outage of both busbars depending upon the arrangement of the circuits.

This configuration provides the same level of reliability as the double busbar, double breaker arrangement, with fewer circuit breakers.
A fault on a power system is caused by a breakdown of insulation between the main electrical conductor (or conductors) causing an interruption to normal power flow. These events are unpredictable and unavoidable. In order to avoid damage to the remainder of the network, and (further) disruption to users, the faulted components are disconnected by ‘protection systems’.

Factors that may cause the insulation to breakdown include:

- temporary over-voltages on the power system, caused by system resonance, lightly loaded circuits etc.
- atmospheric conditions, such as lightning, wind etc.
- pollution forming a current leakage path across exposed insulators
- vermin
- equipment failure
- human error (incorrect switching)

5.1.1 TYPES OF FAULTS

There are two types of faults: ‘balanced faults’ and ‘unbalanced faults’. Unbalanced faults are most common and are usually caused by ‘single-phase to ground’ faults.

**Balanced fault**

A three-phase fault involves the short-circuit of all three phases of one electrical circuit. A three-phase fault is also referred to as being a balanced fault as all fault current flows through the conductors without flowing through ground; and all three phases are affected evenly by the fault.

A three-phase fault on a system generally causes the greatest amount of disruption to the power system. This is because the short-circuit causes the voltage and corresponding power transfer capability to collapse on all three phases.

**Unbalanced fault**

An unbalanced fault describes any fault that causes fault current to flow unevenly in the three phases of the faulted circuit. The most common kind of unbalanced fault is a ‘single-phase to ground’ fault. This is especially true on transmission lines, where the likelihood of short-circuiting between two phases is low due to a large separation between phases.
A single-phase to ground fault within a terminal substation will have higher fault current than a three-phase fault; however, will generally cause less disruption to the overall power transfer capability as the two ‘healthy’ phases are able to transfer a limited amount of power.

5.1.2 STAGES OF A FAULT

Pre-fault. The ‘pre-fault’ conditions of the power system largely determine the amount of current that will flow, should a fault occur.

Sub-transient. The ‘sub-transient stage’ deals with the initial surge of current that flows into the fault once a fault has been established. The current peak within this stage determines the mechanical shock loading on equipment. The energy contained in the current surge determines how quickly equipment will overheat.

Transient. The ‘transient stage’ looks at the tail end of the current surge that occurs after the fault inception. Circuit breakers are often required to break the current flow during this stage to isolate the fault and help the system recover. However, technology advances made in circuit breakers and relays are allowing more responsive action, and may require the circuit breaker to be rated to breaking current at sub-transient levels.

Steady state. The ‘steady state fault current’ is an indication of the current that would flow if the fault was left uncleared on the system, after the initial surge has stabilised. The steady state of a fault is rarely observed on transmission circuits as a fault is generally cleared during the initial current surge. However, in distribution circuits, a remote fault on the system is more likely to appear similar to a large load. The fault may take longer to clear, therefore approaching the steady state current value.

5.1.3 FACTORS INFLUENCING FAULT CURRENTS

The total current that flows at the point of a fault is made up of the contributions from many sources on an electrical network. The current contributed does not come solely from generators; motors may also contribute current to the fault that comes from the energy stored in the motor’s rotating magnetic field.

Generally, a fault that occurs close to generation will have a high fault current, while a fault on a network point that is distant to generation will have low fault current.

Impedance

The impedance of the lines between the fault point and the points of generation on the network will largely determine the value of fault current that will flow at the fault. The total impedance from the fault to the points of supply is known as the ‘source impedance’ (or sometimes called ‘system impedance’).

If the system impedance at a particular network point is small, then the point will have a large fault current, should a fault occur. The size of impedance is dependant on the number of circuits to which the point is connected and the voltage level. A point with small power transfer capacity will have high system impedance.

The initial peak fault current is also affected by the ratio between the resistance and reactance of the source impedance. If the system reactance is significantly larger than the system resistance, then the initial DC current flow will be sustained for a longer period of time.

Network strength

A network point that would have a large fault current flowing if there were to be a fault, is said to have a ‘high fault level’. Conversely a network point with a small fault current can be referred to as a point with a ‘low fault level’.

The fault level of a network point determines the ‘strength’ of the point, or the ability of the point to transfer power in a stable condition.

From this it can be said that a new generator connected to a strong point in the network (point with a high fault level) will have less trouble exporting power, from a stability point of view, than the connection of the generator to a weak point (low fault level) in the network.

5.1.4 FAULT RATINGS

In order to limit the scale of damage from a fault, all unfaulted equipment needs to be able to handle current flowing to the fault location until the fault can be cleared by protection. If this were not the case one fault would cause cascading failures and damage to the surrounding network.

The addition of new generation to an existing network may cause the fault level to increase beyond the fault ratings of equipment currently connected at this point. In this case equipment may need to be replaced with equipment of higher fault rating, or a device that reduces the fault contribution from the generator.
6.1 INTRODUCTION

6.1.1 WHAT IS EARTHING?

The earth has been used, almost as long as there have been large power systems, as a reference point from which to measure the voltage of the power system.

The earth, generally, has the same voltage in any geographical area because it is a very good conductor (except for some areas where there are certain non-metallic rock formations).

Equipment connected to the power system is earthed (connected by a metal conductor to ground), to ensure the equipment operates safely and reliably.

6.1.2 WHY IS IT REQUIRED?

The earthing of power system equipment is important for two main reasons:

- When an insulation fault occurs in a piece of earthed equipment, the majority of the fault current will be safely diverted into the ground without causing damage to people or other equipment.
- A fault where a live conductor comes in contact with the earth can be detected more easily by protection, allowing the fault to be cleared more rapidly and protecting other equipment in the power system.

6.2 EARTHING

An earth-grid is installed at a substation to limit the rise in voltage of the surrounding ground area during a fault where a large amount is flowing into or out of the earth grid via the earth itself.

The earth grid also evens out the voltage rise around the substation, so that no current flows through people working in the general area of the substation.

6.2.1 TRANSFORMER AND GENERATOR EARTHING

The neutrals of power system transformers are grounded to allow out-of-balance earth currents to flow during faults thus limiting voltage rise on healthy phases and permitting selective ground fault relaying to be installed. Supply transformers, generator transformers and distribution transformers usually, but not all, have star connected secondary windings with solidly grounded neutrals and delta connected primaries.

The method of grounding determines how a system behaves during earth faults.

- ‘Solid’ or ‘effective grounding’ results in high earth fault currents and a dramatic voltage drop while the fault is present. The neutral reference remains approximately fixed with respect to the unfaulted phases and therefore there is little rise in the voltage to ground on the un-faulted phases.
• ‘High impedance system grounding’ will result in minimal earth fault current. The phase to earth voltages of the unfaulted phases can rise to the full pre-fault phase to phase voltages as the neutral reference shifts to be equal in potential to the faulted phase potential. In extended systems the system reactance and capacitance can combine to raise the voltage further, sometimes to dangerous levels.

• ‘Low impedance grounding’ is being increasingly used. The phase to earth voltages of the unfaulted phases will rise however they will not rise to the full pre-fault phase to phase values during the fault as the grounding impedance is small.

The generators have gone through an evolution of stator grounding techniques. Large generators with their own unit transformers are now almost universally high resistance grounded to limit stator damage by restricting fault currents to a very low level. Smaller generators which are directly connected to 11 kV distribution systems are often low resistance grounded.

THE FOLLOWING TABLE SUMMARISES COMMON EARTHING SYSTEMS AND THEIR ATTRIBUTES:

<table>
<thead>
<tr>
<th>EARTHING METHOD</th>
<th>USED IN</th>
<th>EARTH FAULT CURRENT</th>
<th>SYSTEM VOLTAGES DURING THE FAULT</th>
<th>PROTECTION CONSEQUENCES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Impedance Earthing (Typically 4.84 ohms used on WPC country transmission systems)</td>
<td>Sub-transmission systems, industrial or distribution systems with embedded generation or other rotating plant.</td>
<td>Fault current is much higher than load current Potential fault damage is limited.</td>
<td>Unfaulted voltages rise to less than full line-to-line voltage above earth.</td>
<td>Adequate current available for discriminative conventional feeder earth fault protection and smaller distribution transformers protected by fuses.</td>
</tr>
<tr>
<td>System High Impedance Earthing. Typically 30-36 ohms used on WPC metropolitan transmission systems</td>
<td>Transmission system.</td>
<td>Kept small. (around or even below load current)</td>
<td>Unfaulted phase voltage goes to line to line voltage above earth potential. Voltage transients minimised.</td>
<td>Insufficient current may be available for discriminative earth fault protection. Some applications of directional earth fault protection available.</td>
</tr>
<tr>
<td>Generator High Impedance Earthing</td>
<td>Generator earthing where individual generator transformers are available. Also generation bus earthing.</td>
<td>Kept small. Typically 5 to 15 Amps to limit damage.</td>
<td>Unfaulted phase voltage goes to line to line voltage above earth potential. Voltage transients minimised.</td>
<td>Insufficient current usually available for discriminative earth fault protection. Some applications of directional earth fault protection available.</td>
</tr>
<tr>
<td>Ungrounded Systems</td>
<td>Very small and limited local systems.</td>
<td>Current limited by system capacitance to less than five amps.</td>
<td>Voltages uncontrolled and can reach high values in adverse conditions.</td>
<td>Specialised protection and current transformers are required.</td>
</tr>
</tbody>
</table>
The transformer construction vector group is important in determining the effectiveness of system earthing. Transformers with delta/star configuration provide a solid earth point on the star side but none on the delta side. Star/star transformers with one neutral earthed can provide adequate earthing in some cases; such as for a three-phase transformer where neutral flux can pass through the tank; i.e. the tank serves as a delta winding.

**6.3 LIGHTNING PROTECTION**

As most power systems have a network of overhead wires and tall metal structures carrying those wires, the system is prone to lightning strikes. A lightning strike to any conductors in an electrical circuit causes a surge in the power flow, and can lead to cascading failures of equipment along the circuit.

Lightning protection is used to guard against this by diverting the lightning strike directly to ground, without flowing through the main circuit.

A lightning protection system comprises three parts:

1. an air termination system, which consists of wires placed above the power conductors to capture the lightning strike;
2. down conductors, which are the steel towers and/or conductors that take the current from the overhead wires to ground; and
3. earthing system, which allows the current to flow from the down conductor into the ground. The earthing system can be an earth-grid, the reinforcing bar used in concrete, earth pin, etc.

**6.4 SURGE PROTECTION**

Surge arrestors may be installed on a power system to protect equipment against voltage and current spikes that may flow along a circuit due to a lightning strike (should it not be adequately protected by lightning protection), or switching surges.

Surge protection is commonly installed near transformers to prevent a power surge from causing an insulation fault in the transformer, which can involve lengthy repair times and significant expense. They are also installed on the lines at the entry to substations to prevent damage to instrument transformers.

**THE FOLLOWING TABLE SUMMARISES THE PRIMARY EQUIPMENT USED TO ACHIEVE EACH TYPE OF EARTHING ARRANGEMENT AS USED ON THE SWIS.**

<table>
<thead>
<tr>
<th>AREA OF APPLICATION</th>
<th>EARTHING METHOD</th>
<th>EQUIPMENT REQUIRED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substation earthing</td>
<td>Solid earthing</td>
<td>Dy supply transformers with high voltage delta and low voltage star winding and low voltage neutral connected solidly to an earth electrode. Three-phase transformers are used. Yy transformers with steel tanks and three limbed core construction provide an alternative solid earthing system when one or both of the neutrals is earthed. Three single-phase transformers would not work in this situation because of the high zero sequence reactance of the arrangement.</td>
</tr>
<tr>
<td>Substation earthing</td>
<td>High and low impedance earthing</td>
<td>A Yd transformer is commonly used together with an low voltage earthing transformer. The high voltage neutral solidly connected to earth to provide solid earthing for the transmission system. The low voltage delta is taken to a zigzag earthing transformer of suitable impedance with its neutral solidly grounded to provide the earth reference.</td>
</tr>
<tr>
<td>Generator earthing</td>
<td>High impedance earthing</td>
<td>Commonly, generator or transformer neutrals are high resistance earthed through a single-phase distribution transformer primary winding which is rated to the system voltage. The secondary low voltage winding has as resistor connected across its terminals and this controls the current through the transformer, and hence the primary neutral.</td>
</tr>
<tr>
<td>Generator earthing (rare)</td>
<td>Unearthed</td>
<td>Rarely, generator connections are unearthed in some system conditions.</td>
</tr>
</tbody>
</table>

| 261 | Generation Grid Connection Guide V2 |
7 PROTECTION

7.1 WHAT IS PROTECTION?
Protection equipment takes continuous measurements of various electrical properties of the power system to make sure the system is operating correctly. Protection relays look for indications that there are faults on the system, and then make decisions as to whether it should switch the power off on its allocated protection area. Once a fault has been diagnosed as being within the area the relay is meant to protect, the relay sends a signal to a circuit breaker to switch it off (trip), consequently shutting off the power supply to the fault. The relay should be able to clear a fault to prevent damage to other plant and to maintain system stability.

Protection is designed to detect and trip for a multitude of different fault types. As a result, setting the relay requires care as the relay needs to be set so that it does not trip for normal operating conditions but does trip correctly for all fault types.

7.2 WHY IS PROTECTION REQUIRED?
Protection serves a number of purposes in a reliable power system:

- **The protection of people.** A fault releases a large amount of energy at the point of a fault. This energy can easily pass through people standing in the general area of the fault, as well as people near the point of supply. The quicker a fault can be disconnected from the network, the smaller the chance of harm occurring to personnel.

- **The protection of assets.** If the fault is not cleared quickly enough the equipment supplying a faulted point on a network will overheat, and likely fail, consequently becoming damaged.

- **The security of supply.** The quick operation of protection to isolate a fault will preserve the supply of power to other parts of the network, reducing disruption to a minimum number of consumers.

- **System stability.** The quick operation of protection stops the whole power system from becoming unstable. An uncleared fault may cause the system voltage to collapse and generation to become unstable, leading to incorrect operation and possible damage.

7.2.1 SYSTEM STABILITY
The system stability largely depends on the ability of a generator to ride through a fault.

If one generator trips off the system, a load imbalance will be created equal to the power output of the tripped generator prior to the trip. Unless other generation can be ramped up to re-balance the system, the network will have an unstable frequency.

Generators are required by the network operator to ride through a fault in accordance with the requirements of the Technical Rules.

The limit at which a fault needs to be cleared before the generator itself needs to be tripped is called the Critical Fault Clearance Time (CFCT).
7.2.2 VOLTAGE STABILITY
A system’s ‘voltage stability’ depends on the amount of reactive power reserves available to the system during a contingency event. In the event of a fault, the voltage can reduce to 20 to 30 per cent of its typical operating value. At low voltages, capacitor banks lose their ability to supply sufficient amounts of reactive power. Dynamic forms of reactive power supply (such as generation) become critical to restore the system to an acceptable operating voltage.

7.2.3 SECURITY OF SUPPLY
‘Security of supply’ refers to the probability of a fault on the power system causing subsequent loss of supply to consumers. A high security (hence more reliable) supply can be obtained by having backup options for power supply.

In most power systems it is common to build two transmission circuits connecting supply points to load. Installation of two circuits allows for one circuit to be removed from service for any reason, while still maintaining supply. This level of security is referred to as ‘N-1 security’.

A higher security of supply can be desired for critical services by providing more than one level of redundancy, i.e. ‘N-1-1 security’.

7.3 GENERATOR PROTECTION PRINCIPLES
Each type of equipment can have various types of protection installed to protect against the incorrect and potentially damaging operation of that equipment. For example, a circuit breaker needs a protection device that knows whether the breaker has switched successfully; whereas the protection for a transformer needs to know if a winding fault has occurred.

The following list outlines abnormal generator operating conditions, which may require some form of protection:
- stator electrical faults
- overload
- overvoltage
- unbalanced loading
- overfluxing
- inadvertent energisation
- rotor electrical faults
- loss of excitation
- loss of synchronism
- failure of prime mover
- lubrication oil failure
- overspeeding
- rotor distortion
- difference in expansion between rotating and stationary parts
- excessive vibration
- core lamination faults

Protection can be installed to detect these abnormal operating conditions and trip the generator if the condition is sufficiently severe. The most common types of protection are explained below. For more information see the generator protection section in Areva’s Network Protection & Automation Guide.

7.3.1 OVERCURRENT PROTECTION
Overcurrent protection is an essential part of a generator protection scheme. High currents that are above the generator design ratings will cause overheating and subsequent damage to the generator.

7.3.2 OVERVOLTAGE PROTECTION
Overvoltage protection is important to prevent excessive voltages from breaking down the winding insulation in the generator and causing a fault.

7.3.3 LOW FORWARD POWER/REVERSE POWER PROTECTION
If the mechanical driving power of the rotor fails in some way, the generator will cease to output power and begin to operate as a motor, possibly causing damage to mechanical machinery connected to the rotor. Protection can detect if the power output of the generator drops to an undesired level, and can also detect if the generator begins to absorb power.
7.3.4 UNBALANCED LOADING

A generator may become unbalanced if a fault occurs on only one or two phases of a three-phase system. This can cause the rotor to vibrate and wobble, potentially causing mechanical damage. Protection can be installed to compare all three phases to ensure the power output is balanced.

7.4 PROTECTION EQUIPMENT

Various types of protection are used depending on the likelihood of faults, the nature of the protected equipment, and the value of the protected equipment and load.

7.4.1 FUSE

A fuse offers a compact solution for the protection of parts of a circuit; however, once a fuse is blown, the circuit must be switched off to install a new fuse. Fuses are of significant value when limiting the scale of faults on distribution networks which are spread over significant geographical area.

7.4.2 CIRCUIT BREAKER

A circuit breaker is a device that is capable of interrupting a fault current, on receipt of an initiating signal. After the fault is removed, circuit breakers can be closed to restore supply.

7.4.3 RELAY

Relays detect the presence of faults and initiate circuit breaker operation.
8.1 SYNCHRONISING EQUIPMENT

It is important that a generator is fully running and synchronised with an external power network before it is physically connected, so that no equipment is damaged. To be ready to connect to a power network, the following conditions should be present:

- The voltage level of generation should match the voltage level of the external network.
- The frequency of generation should match the frequency of the external network.
- The point of cycle (or phase angle) for each phase of generation should equal the point of cycle for each corresponding phase of the external network.

A ‘synchronising relay’ checks these conditions by measuring the voltage on both sides of the circuit breaker used for connecting the generator to the grid. Once synchronous conditions are met, the circuit breaker is allowed to close.

Modern synchronising relays and control equipment can fine-tune the generator to a point where the generator and external network are closely matched, and then automatically close the electrical circuit to bring the generator online.

Care is required to prevent the incorrect operation of protection from connecting two power systems that are out of synchronism. Protection schemes generally take care of this by ensuring that connection of two power systems occurs at circuit breakers that are monitored by synchronising relays.

8.2 MODES OF GENERATOR OPERATION

There are various modes of controlling real and reactive power output from a generator. Each mode affects the quality of the surrounding power system in different ways.

Some generators will take responsibility for the frequency control on the network. For any power system, there must be at least one generator controlling the frequency. These generators balance any instantaneous changes in active and reactive power demand on the network.

Other generators may take a joint responsibility for the voltage control for parts of the network. There is no minimum number of generators that are required to run in voltage control mode; however, a particular generator may be required to run in voltage control mode to keep the voltage stable on weak areas of the network.

A generator can also output power without providing frequency regulation and voltage control of the system. This mode allows the generator to put out a constant level of power, regardless of the load.
8.2.1 FREQUENCY CONTROL

The frequency of the power system needs to be kept relatively constant, so that equipment connected to the power system will act reliably. The frequency of the power system affects the rotation speed of synchronous machines. Some electric clocks also use the power frequency to measure time.

There are two methods for controlling the frequency of the power system:

- **Isochronous mode.** When operating in isochronous mode the generator will vary its power output as power demand changes to fix the frequency to 50 Hz. Additional generators on the same power system will continue to produce a scheduled amount of power unless manual intervention is necessary (i.e. during extreme loading scenarios).

- **Droop mode.** Multiple generators can share the responsibility of generator/load balance by operating in droop mode. The generator control in droop mode looks at the power system frequency, and adjusts the output of the generator from its nominal setpoint depending on the extent of the system frequency variation from the target value. For instance; at 50.1 Hz the generator may put out 10 MW (or minimum setpoint) and at 40.9 Hz the generator puts out 100 MW. Normally a four per cent change in frequency results in a 100 per cent change in output. This mode allows for load sharing between generators of different size during system frequency changes. However, the frequency is not fixed like in isochronous mode. Isochronous mode can also provide a droop response in the short-term and then over a longer time frame return the frequency to 50 Hz.

8.2.2 VOLTAGE CONTROL

Synchronous generators (and reactive compensation plant associated with induction generators) are able to deliberately affect the voltage at their connection points. Operation of these types of generation with automatic voltage control is preferred as it gives the best system performance. The voltage control setpoints may need to be carefully coordinated with other system components. This mode can be helpful by allowing a generator to have greater flexibility with scheduling power output with respect to varying system conditions. This is especially true when considering a generator exporting power from a weak area of the network.

A method of sharing the contribution to voltage control based on machine size is to have the machine control the voltage at the generator terminals rather than at the point of connection. This effectively provides a level of voltage droop control.

8.2.3 POWER FACTOR CONTROL

An alternative is for a generator to give an amount of voltage support that increases in proportion to the generator output. This mode is often used when a relatively weak generator is connected to a relatively strong network. The disadvantage is that the support provided by the generator is not adjusted to suit varying network conditions.

8.2.4 ISLANDED OPERATION

An “island” on the power system refers to an electrical separation in the network that causes the power system to break up into two or more power systems. These systems can then operate independently of each other if there is a sufficient balance between generation and load. An island can often occur when a single circuit supplying a network area faults, and is disconnected by protection.

Generation can be designed to continue operation if the section of network to which it is connected becomes ‘islanded’. In this role the generator needs to take responsibility for the frequency control and voltage control on the islanded power system.

A power system split requires careful generator control to avoid an outage of the power supply on either side of the split. The more power flowing through the circuit where the network is split, the harder it will be to maintain a continuous power supply without outage.

Additionally, care needs to be taken when re-connecting an island to the main grid without a power outage. Synchronising relays are required to check that both systems are in synchronism with each other.
9.1 SWINGING GENERATORS

Swinging generators take the role of the real-time balance of power supply and demand, as well as maintaining a constant power system frequency of 50 Hertz. These generators are controlled by electronic control systems (known as Automatic Generator Control or AGC) in isochronous mode (see section 8.2.1), which are managed by the System Management (SM) on a continuous basis.

The total capacity of swinging generation needs to have enough range to handle short-term demand and balance variations in the output of non-scheduled generators (such as PV systems and wind farms). Additional generation can be scheduled over the medium and long-term to meet the daily trend of power consumption.

If the swinging generators are producing close to their power output limits, the SM can request that the power output of some reserve generation is ramped up or ramped down. This will allow the swinging generators to operate more comfortably within their range of power output.

9.2 DISPATCH OF GENERATORS

The Independent Market Operator (IMO) takes the role of administrating the Wholesale Electricity Market for the South West Interconnected System (SWIS). The IMO also has created a set of Market Rules, which outline the needs of all market participants who use the power system in some forms.

Generators must subscribe to the Market Rules as a ‘Market Generator’ if the size of generation is 10 MW or larger.

Generation smaller than 10 MW have the option of subscription. This may be an option if power is generated on a large consumers’ network, where power is never anticipated to be exported onto the larger grid.

A large, consistent source of generation will require a generator to register to the Market Rules as a ‘scheduled generator’. This allows the IMO to allocate enough generation to meet demand through the following day of operation.

A generation source that cannot be forecast to provide a consistent level of power needs to be registered as a ‘non-scheduled generator’. Wind and solar generation operate in this category.

9.3 RESERVE GENERATION

The IMO and SM have to make sure that there is sufficient extra generation installed or demand side management capacity available for any increase in load above forecast values, as well as providing a safety margin should any generator on the system trip and leave a large load imbalance.

The IMO allocates a larger generation capacity than the anticipated demand to leave a margin for either unforeseen loss of the largest generator, or unforeseen load increase. During either of these scenarios a generator may be asked to ramp up power output to balance generation to the current level of demand.

Non-scheduled generation will not usually form part of the generation reserves.
The Office of Energy governs, and administers the legal framework for, the operation of the power system in Western Australia, on behalf of the State Government.

The Economic Regulation Authority (ERA) administers the economic regulation of the power system. The ERA is also responsible for Gas, Rail and Water networks. Economic regulation allows for the Independent Market Operator (IMO) to manage the wholesale energy market, according to the Market Rules written and agreed to by the ERA.

Technical Rules have been written by Western Power to ensure the satisfactory operation of the power system and have been agreed to by the ERA. These rules ensure the operation of the power system reflects the interests of all stakeholders.

10.1 EXPLANATION OF RELEVANT LEGISLATION AND CODES

Electricity Industry Act 2004 (Office of Energy). This legislation gives responsibility for the economic administration of the power system to the ERA. Provision is also made for the formation of the Electricity Networks Access Code. Refer to:

Electricity Networks Access Code 2004 (ERA). This code outlines commercial arrangements, including charges that apply to electricity generators and retailers accessing Western Power’s electricity network within the SWIS. Initially, only the SWIS is covered under the Access Code, but there is potential for other networks to be covered. Refer to:

Technical Rules (Western Power). The Technical Rules promote the economically efficient, safe and reliable production and supply of electricity and electricity related services in the SWIS. These rules are written by Western Power and approved by the ERA. Refer to:

Wholesale Electricity Market Design Summary (IMO). This document outlines the structure of the wholesale electricity market, and gives a general overview of the Market Rules. Refer to:

The Wholesale Market Objectives are defined in the Wholesale Electricity Market Rules. They are:

1. to promote the economically efficient, safe and reliable production and supply of electricity and electricity related services in the SWIS;
2. to encourage competition among generators and retailers in the SWIS, including by facilitating efficient entry of new competitors;
3. to avoid discrimination in that market against particular energy options and technologies, including sustainable energy options and technologies such as those that make use of renewable resources or that reduce overall greenhouse gas emissions;
4. to minimise the long-term cost of electricity supplied to customers from the SWIS; and
5. to encourage the taking of measures to manage the amount of electricity used and when it is used.

Network Quality and Reliability of Supply Code (Office of Energy). This Code sets out the limits of acceptable variation of power quality on the power system, and the penalties for exceeding these limits. These standards include the maximum amount in minutes per year that a customer is without power.
www.energy.wa.gov.au/2/3193/64/network_quality.pm

Electricity Industry Metering Code 2005 (Office of Energy). This Code the generators metering requirements for the power they generate.

Registration as a Market Generator with the IMO. Companies that plan on adding new generation are required to register as a market participant with the IMO. The registration process will establish the financial framework used to engage in trading and complete financial transactions.
Further details of the registration process with the IMO are given here:

Registration of generation facilities with the IMO. Once the company has registered as a market participant, the company is then required to apply for registration of each new generation facility with the IMO. The application is an online process. It requires information about contractual agreements for operation as well as relevant technical information about the generator facility.
Further details of the registration process with the IMO are given here:

Generating License with ERA
Application for a generating license is required if the amount of generation at the connection point is greater than 30 MW. A guide to the application process is given on the ERA website. Refer to:
www.erawa.com.au/2/420/51/electricity_licensing__licensing_information.pm

Applications and Queuing Policy
The processing of applications is managed in accordance with the applications and Queuing Policy which is available at:

A Queue rules fact sheet is also available at:

Detailed Customer connection schedules for small generator installations
This document provides schedules of detailed technical information for connection of small generator installations.

All website links in this document may change from time to time.
10.2 DIFFERENCES BETWEEN EASTERN AND WESTERN AUSTRALIA

Requirements to enter into the market as a prospective generator in Western Australia differ from the East Coast of Australia, due to differences in the regulatory framework between Australian states.

A prospective generator in Western Australia needs to invest in network upgrades, should they be required. This allows the generator to operate at full capacity without exceeding normal limits. Unlike other jurisdictions, the generator then has the right to transfer their full capacity into the network in the future without making further capital investment. This protects a generator already connected to the system from being constrained in the future or having to contribute towards grid investment necessary for removing the network constraints triggered by the new generation. The Access Charges cover the cost of maintaining this capability.

The present unconstraint access arrangement for generators in Western Australia is being reviewed as part of the strategic energy initiatives. A move to a constraint access model similar to the one in the East Coast is being considered. The constraint access model offers the potential for more efficient development of the power system as it allows for an efficient level of congestion.
There are two processes available to proponents: a comprehensive formal assessment or an informal preliminary study. The option chosen by the proponent will depend on the stage of project development with each stage requiring quite different levels of technical detail, engineering design, financial commitment, etc.

The formal connection process involves participation in a queue of applications (to enable first-come, first-served access to unused capacity in the network) and culminates in a legally binding Connection Offer. Particularly for large generators (or generators that are large relative to the network strength at the proposed connection point) it requires significant technical and economic studies to be carried out, using information specific to the design of the individual generator to be connected.

The formal application process to connect to the Western Power network and its indicative timeline are available at:

The informal preliminary study (that is, without queue reservation and processing of an access offer) may be more appropriate when generator proponents are unable or unwilling to commit to the full connection process. For instance:

- The project may be at a preliminary stage of assessment and require only an indication of feasibility, rather than reservation of a place in the queue followed by a connection offer.
- The project may be at a preliminary funding stage and not yet ready to commit the funds required for preparation of an access offer.
- The engineering design of the project (including selection of a particular manufacturer and model of generator) may not yet be finalised and so engineering data cannot yet be provided.

The Connection Application form is a spreadsheet requiring general and technical data. The Connection Application forms for transmission connections and distribution connections are available at:
11.1 COSTS TO CONNECT

The following list identifies the typical costs that a prospective generator can expect when connecting generation of 10 MW or more to the SWIS.

- **ERA license processing fee.** This fee is payable to license the generation facility with the ERA. An ERA license is not required for generators below 30 MW.

- **IMO registration fees.** One fee is payable to register as a market generator with the IMO. This fee covers the administration cost of the admission of the generation company to the Wholesale Electricity Market. An additional fee is payable for each new generation facility registered with the IMO. Registration with IMO is not required for generators under 10 MW.

- **Western Power Lodgement fee.** Refer to the price list (as defined in the Electricity Network Access Code 2004) in the access arrangement.

- **Western Power Processing Costs.** Western Power charges a cost for planning studies to ensure a new generation facility meets the Technical Rules for connection to the SWIS. This involves modelling the network with the new generator connected to check system performance. Western Power will estimate a processing cost based on information contained in the application for access before any modelling is carried out. Refer to the next section for more information on planning studies.

- **Capital Contribution towards grid upgrades** (if required). If the system performance limits are not met over the full range of generation, Western Power will suggest a grid upgrade solution. The generator will be required to contribute towards the cost of any required upgrades in accordance with the Capital Contributions Policy which is available at:


Western Power will then assure that the generator will be able to produce power over its entire range without any future capital investment in the grid.

Capital contribution costs can be broken up into two categories:

1. **Shallow network reinforcements** – Grid upgrades required at or near the point of connection are referred to as ‘shallow network reinforcements’. The shallow network reinforcements are the costs associated with the extra connection assets required to connect the generator to the grid.

2. **Deep network reinforcements** – The addition of a new generator to the system may also cause operational limits to be exceeded at distant points on the transmission network. In this case the system will require ‘deep network reinforcements’ to ensure the network can transfer the generator power output to the load. The deep reinforcements could be new transformers, static var compensators (SVCs), capacitor banks and lines that are remote from the new generator.

- **Western Power Connection Costs.** These are charges to ‘use the system’ on an ongoing basis.

11.2 SELF EVALUATIONS – CONNECTION CHECKLIST

The following checklist should be completed before approaching Western Power for access to the SWIS.

1. The requirements for connection of generation outlined in sections 3.2 and 3.3 of the Technical Rules should be read, understood and incorporated into the generation design.

2. The application to Western Power for connection should include the following information:

   a) generator technical data and modelling information (most of this data is obtainable from the generator manufacturer);

   b) provision of a single line diagram(s) showing generators, the generator switchboard, loads powered by local supply, transformer information etc;

   c) details of the protection design (type of protection used, as well as protection configuration), outlining compliance with generator’s tolerance to acceptable variations in power quality;

   d) the requested services start date and requested services end date, for works and

   e) the capacity requested for power transfer into the grid.

The technical data must be completed in the Connection Application form.
12.1 REQUIRED TECHNICAL INFORMATION
Western Power requires technical information about the generating unit to be installed, fuel source to be used, and various design characteristics that determine the response of the generator to system changes. Western Power then runs system impact studies, which assess the performance of the generator with respect to the operating ranges outlined in the Technical Rules. More information on the studies performed by Western Power is given in section 12.3.1.

12.2 IMPORTANCE OF ACCURATE DATA
In order to obtain realistic results from simulation studies, accurate data must be used. In general, this will require the details of the proposed design to be finalised before studies can begin. The generator type (manufacturer and model) and, in many cases, details of particular control systems (manufacturer and model for excitation and governor systems) are key inputs to the studies and accurate data is required.

Studies use data specific to the individual type of machine being proposed for installation. This includes measured “type test” data, and physical models based on the details of the particular installation and its controls. This test data must be based on or measured from the performance of real machines so that a definitive answer can be obtained from the studies. Study results can differ significantly even for machines of the same general type, as they depend on the details of the individual equipment.

Each power quality issue identified in section 3 can pose a problem to the power system if inadequate or inaccurate data is provided for studies.

The results of the generator modelling studies are used to fine-tune protection and control systems so that the system will perform correctly during normal operating conditions, and will recover quickly from faults.

Inaccurate generator data can lead to the control systems being inappropriately tuned. This can cause the system to oscillate under normal operating conditions and the system can take longer to recover after faults have occurred.

DATA WHICH HAVE A CRITICAL ROLE IN THE STABILITY OF THE GENERATOR ARE AS FOLLOWS:
- Inertia of the prime mover and generator;
- Time constants of the fuel delivery system;
- Governor/exciter time constants; and
- Overall response time of the generator to changes on the power system.
12.3 Generator Modelling Requirements

The operation of a generator needs to be modelled and simulated as part of the power system before commissioning to check the generator can follow the guidelines for operation outlined in the Technical Rules.

The modelling process includes several types of simulation, with each simulation testing the performance of the generator against a different group of requirements as outlined in the Technical Rules.

During the analysis process, particular attention is paid to the operation of the generation during a time where the power system is under stress (most likely due to a contingency event).

The analysis results provide the basis for managing the generation output and local network over a full range of contingency events in a stable and reliable manner. The results will also indicate whether extra electrical equipment is required to achieve the desired power output over a full range of contingency events, while complying with the requirements of the Technical Rules.

12.3.1 Main Simulation Types

Table 1 outlines the main types of simulation required before connecting to a power system. The generator proponent can engage its consultant to undertake any of these studies. The consultant must sign Western Power’s confidentiality agreement to obtain the required system data.
<table>
<thead>
<tr>
<th>SIMULATION TYPE</th>
<th>DESCRIPTION/PURPOSE</th>
<th>POTENTIAL ISSUES DETECTED</th>
<th>DATA REQUIRED</th>
</tr>
</thead>
</table>
| Load flow       | Load flow analysis checks that a generator can produce any level of power during any feasible loading condition placed on the power system, without being constrained by the operating limits of the power system. Contingency events such as the planned or unplanned outage of major electrical equipment are studied comprehensively to check what generation operating constraints will apply during the contingency. | • Over/under voltages  
• Overloading  
• Adequate active and reactive power reserves  
• Operational constraints/precautions required. | • Single Line Diagram showing major transformers, bus names, voltage levels, lines/cables/other electrical equipment and point of connection to transmission system, as well as local network.  
• Resistance and reactance data for all major equipment in the modelled network. This includes line lengths.  
• Size of generator(s) and operating limits.  
• Rated current, voltage range of existing and proposed electrical equipment.  
• Load size in active and reactive power.  
• Information on voltage and tapping control. |
| Short circuit    | Short-circuit analysis serves the following purposes:  
• Allowing the current trigger level of protection relays to be accurately set.  
• Ensuring electrical equipment is adequately rated to handle fault current.  
• Providing information required to design the earthing system. | • Fault rating of connected equipment exceeded. | • Complete set of load flow data  
• Zero sequence impedance for all equipment (necessary for earth faults)  
• Generation and load sub-transient reactance values.  
• Earthing details for transformers, generators and other miscellaneous electrical equipment. |
| Stability studies| Stability studies look at how a power system operates during disturbances. A common objective is to see how long a protection device can take to clear a fault before the generator (and possibly the surrounding power system) becomes unstable. Stability studies also aid in fine-tuning the generation control systems that manage power transfer. | • Insufficient time to clear a fault.  
• Frequent interruptions to power transfer caused by unplanned generator/equipment outage.  
• Unwanted or poorly damped. Power transfer fluctuations and oscillations arising from control system conflicts.  
• Excessive frequency variations.  
• Insufficient voltage recovery after transient events. | Complete set of data including:  
• Load Flow and Fault Level Data  
• Generation and load sub-transient reactance values and time constants and other modelling parameters.  
• Mechanical constants and physical properties for the generator and loads  
• Block diagram outlining the logic used to control the generator’s real and reactive power output  
• A model of the generator and control scheme suitable for operating on Western Power’s analysis program. |
12.3.2 ADDITIONAL SIMULATION TYPES

The following simulation types can be used to simulate other disruptions to the power system:

- **Harmonics.** It is necessary to perform harmonics studies for connected generation if a significant amount of the installed equipment use variable speed drives, inverters or any other power electronic equipment. These types of equipment switch many times per second, and can degrade the quality of power delivered to other equipment.

- **Motor starting.** If large motors are present on the generation system, then motor starting studies are required to ensure that the voltage during start does not drop low enough to cause disruption to other equipment. Motor studies may also be required to ensure that power plant auxiliaries (especially boiler feed pumps) can recover successfully from a system voltage disturbance.

The necessity of these studies will depend on the characteristics of the generator as well as the type of auxiliary electrical plant installed.

12.3.3 APPLICATION OF STUDIES WITH RESPECT TO THE TECHNICAL RULES

Each type of study will check for problems using the Technical Rules as a basis for investigation. Table 2 shows the sections of the Technical Rules that are applicable to each type of study.

<table>
<thead>
<tr>
<th>SIMULATION TYPE</th>
<th>RELEVANT SECTIONS OF THE TECHNICAL RULES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load Flow</td>
<td>2.2.2 – Steady State Power Frequency Voltage</td>
</tr>
<tr>
<td></td>
<td>2.2.5 – Negative Phase Sequence Voltage (Unbalanced Load Flow)</td>
</tr>
<tr>
<td>Short Circuit</td>
<td>2.5.7 – Maximum Fault Currents</td>
</tr>
<tr>
<td>Stability Studies</td>
<td>2.2.1 – Frequency Variations</td>
</tr>
<tr>
<td></td>
<td>2.2.7 – Transient Rotor Angle Stability</td>
</tr>
<tr>
<td></td>
<td>2.2.8 – Oscillatory Rotor Angle Stability</td>
</tr>
<tr>
<td></td>
<td>2.2.9 – Short Term Voltage Stability</td>
</tr>
<tr>
<td></td>
<td>2.2.10 – Temporary Over-Voltages</td>
</tr>
<tr>
<td></td>
<td>2.2.11 – Long Term Voltage Stability</td>
</tr>
<tr>
<td></td>
<td>2.3.7 – Power System Stability and Dynamic Performance</td>
</tr>
<tr>
<td></td>
<td>2.9.4 – Maximum Total Fault Clearance Times</td>
</tr>
<tr>
<td>Power Quality</td>
<td>2.2.3 – Flicker</td>
</tr>
<tr>
<td></td>
<td>2.2.4 – Harmonics</td>
</tr>
<tr>
<td>Motor Starting</td>
<td>2.2.2(b) – Step Changes in steady state voltage levels</td>
</tr>
<tr>
<td></td>
<td>2.2.3 – Flicker</td>
</tr>
</tbody>
</table>
# List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>Alternating current</td>
</tr>
<tr>
<td>CFCT</td>
<td>Critical Fault Clearance Time</td>
</tr>
<tr>
<td>CHP</td>
<td>‘cogeneration’ or ‘combined heat and power’ scheme</td>
</tr>
<tr>
<td>DC</td>
<td>Direct current</td>
</tr>
<tr>
<td>DFIG</td>
<td>Doubly Fed Induction Generator</td>
</tr>
<tr>
<td>ERA</td>
<td>Economic Regulation Authority</td>
</tr>
<tr>
<td>HVDC</td>
<td>High voltage direct current</td>
</tr>
<tr>
<td>IMO</td>
<td>Independent Market Operator</td>
</tr>
<tr>
<td>kVA</td>
<td>Complex, or apparent, power</td>
</tr>
<tr>
<td>kvar</td>
<td>Reactive (or imaginary) power</td>
</tr>
<tr>
<td>kW</td>
<td>Real power</td>
</tr>
<tr>
<td>MW</td>
<td>Megawatt electrical</td>
</tr>
<tr>
<td>PV</td>
<td>Photovoltaic</td>
</tr>
<tr>
<td>SCADA</td>
<td>Supervisory Control and Data Acquisition</td>
</tr>
<tr>
<td>SWIS</td>
<td>South West Interconnected System</td>
</tr>
</tbody>
</table>
## Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circuit breakers</td>
<td>A device capable of disconnecting a circuit during a fault</td>
</tr>
<tr>
<td>Earthing</td>
<td>See section 6.0</td>
</tr>
<tr>
<td>Faults</td>
<td>Breakdown of insulation causing current to flow between phases or from phases to earth</td>
</tr>
<tr>
<td>Load</td>
<td>Power supply demand</td>
</tr>
<tr>
<td>Market Rules</td>
<td>Wholesale Electricity Market Rules</td>
</tr>
<tr>
<td>Poles</td>
<td>Additional sets of coils in the rotor of a generator</td>
</tr>
<tr>
<td>Power quality</td>
<td>Measure of the degree to which the shape of the voltage wave matches the ideal.</td>
</tr>
<tr>
<td>Prime mover</td>
<td>Driver for a generator such as a diesel engine, or a steam, wind, or water (hydro) turbine.</td>
</tr>
<tr>
<td>Protection</td>
<td>Devices used to detect network faults and initiate isolation of the faulted equipment.</td>
</tr>
<tr>
<td>Real power</td>
<td>The supply of energy per second</td>
</tr>
<tr>
<td>Reactive power</td>
<td>The type of power that flows in capacitors and inductors and is used to control voltage in the network.</td>
</tr>
<tr>
<td>SCADA</td>
<td>A Supervisory Control And Data Acquisition System consists of a software package that collects real time data from the communications interface of relays, alarms and control systems. The SCADA system allows a system operator to get an overview of the system health from a centralised location – without having to visit the substation.</td>
</tr>
<tr>
<td>Short-circuit</td>
<td>See Faults</td>
</tr>
<tr>
<td>Sinusoidal</td>
<td>Shaped as a Sine wave</td>
</tr>
<tr>
<td>Stator</td>
<td>Fixed or static</td>
</tr>
<tr>
<td>Step-up/step-down transformer</td>
<td>A transformer used to raise/lower voltage as measured from source to load side.</td>
</tr>
<tr>
<td>Sub-transient reactance</td>
<td>The impedance of a generator presented to the network immediately following the application of a fault.</td>
</tr>
<tr>
<td>Surge arrestors</td>
<td>A device for limiting the overvoltages on the network</td>
</tr>
<tr>
<td>Synchronising relays</td>
<td>A relay that provides signals to a generator so that the generators speed, phase angle and voltage match the network prior to closing the generator circuit breaker.</td>
</tr>
<tr>
<td>Tap changers</td>
<td>A device used to change the ratio of a transformer and hence assist with the control of voltage.</td>
</tr>
<tr>
<td>Technical Rules</td>
<td>Technical Rules written by Western Power and agreed to by the ERA to promote the economically efficient, safe and reliable production and supply of electricity and electricity related services in the SWIS.</td>
</tr>
<tr>
<td>Waterhead</td>
<td>The height of the water column supplying a hydraulic turbine</td>
</tr>
<tr>
<td>Windings</td>
<td>Wire coils inside generators and transformers</td>
</tr>
</tbody>
</table>