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**User Guide for the connection of generators of up  
to 10 MW to the Western Power SWIN distribution  
system**

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# 1 Introduction

## 1.1 Who the guidelines apply to

This document is intended to assist Users planning to connect small generators to the Western Power south west distribution system (SWIN) in the south west of Western Australia. It addresses planning, design and operational issues.

It explains the requirements of section 3.6 of the SWIN Technical Rules that covers generators of all types up to 10 MW (except inverter connected generators up to 30 kVA that are covered by section 3.7 of the Technical Rules). The requirements of section 3.6 of the Technical Rules are discussed clause by clause and example calculations are also provided.

This document complements another document “*Detailed customer connection schedules for small generator installations*” and both documents are available from the Western Power internet site:

[http://www.westernpower.com.au/mainContent/workingWithPower/NetworkAccessServices/accessArrangement/Technical\\_Rules.html](http://www.westernpower.com.au/mainContent/workingWithPower/NetworkAccessServices/accessArrangement/Technical_Rules.html)

The approved Technical Rules are available from the Western Power and Economic Regulation Authority (ERA) internet sites at:

<http://www.westernpower.com.au/documents/AccessArrangement/2007/Technical%20Rules/TECHNICALRULES.pdf>

[http://www.era.wa.gov.au/2/156/48/technical\\_rules.pm](http://www.era.wa.gov.au/2/156/48/technical_rules.pm)

## 1.2 Qualifier

The purpose of this document is to provide transparency by explaining the rationale and illustrating the application of the Technical Rules when assessing applications for connecting small power stations under section 3.6. However, it should not be construed that the requirements of the Technical Rules are in any way diminished by this document. In the event of any unintended inconsistency or omission, the relevant clause of the Technical Rules shall prevail.

# 2 Western Power policy

Western Power will provide connection of generation to the SWIN distribution network provided that:

- a) the safety of Western Power operational personnel, other customers, contractors and the general public is not put at risk
- b) the integrity of other customers' plant and equipment is not put at risk
- c) reliability and quality of supply to other customers is not adversely affected, and
- d) the proposed plant meets the requirements of the SWIN Technical Rules.

## 3 Approvals required

### 3.1 Western Power

To gain connection to the Western Power SWIN distribution networks, whether or not export of electricity is contemplated, and irrespective of the planned duration of connection, it is necessary to make a formal application for network access in accordance with Western Power policies and procedures and the Western Power SWIN Access Arrangement (as approved by the ERA) as set out in this document.

### 3.2 Other approvals

Generators 5 kW and above are currently obliged to meet certain registration requirements of the Independent Market Operator (IMO).

It is also the responsibility of the proponent to meet all environmental and safety codes and to seek approval from all relevant bodies including the following:

#### 3.2.1 Economic Regulation Authority (ERA)

The ERA administers the Electricity Access Code 2004 and has approved the Western Power SWIN Access Arrangement including the Technical Rules as required by the Access Code.

The role of licensing generators in WA has passed from the Office of Energy to the ERA. Generators should familiarise themselves with ERA licensing requirements.

#### 3.2.2 Energy Safety

The customer's facility must comply with the requirements of the WA Electrical Rules administered by EnergySafety.

#### 3.2.3 Local Government

The User must obtain all necessary approvals in relation to land zoning and usage.

#### 3.2.4 Environment

The requirements of the Environmental Protection Authority in regard to the assessment of environmental impact.

#### 3.2.5 Dangerous goods

While this guideline does not specifically address requirements for the prime mover and fuel sources connected to the generator it is expected that this plant would comply with the relevant requirements for dangerous goods set by the Resources Safety Division of the Department of Consumer and Employment Protection WA and the relevant national standards, including AS 3010 -2005 'Electrical installations – Generating sets' and AS 1940 'The storage and handling of flammable and combustible liquids'.

## 4 Key technical issues

Promotion of renewable sources of energy is likely to result in an increasing amount of distribution connected generation in the SWIN, both intermittent and non-intermittent. Of initial concern to Western Power in evaluating applications will be the impact of proposed generators on other users and on the distribution system in the vicinity of the point of

connection. However the collective impact of all distribution connected generators on system operation is also important.

#### 4.1 System issues

As the penetration of distributed generation increases it will become increasingly important that a power system disturbance does not result in the disconnection of multiple small generators, which would compound the effect of the disturbance. This could eventually have significant impact on the control of system frequency in the SWIN, which being a small isolated system, is more vulnerable to frequency excursions than larger systems and those with interconnection and support from neighbouring systems.

If multiple small generators were to disconnect in sympathy with a large transmission connected generator, it would be necessary to carry an increased amount of spinning reserve thus increasing the cost of system operation. Consequently Section 3.6 of the Technical Rules also addresses fault ride through (FRT) capability, rotor angle stability and the frequency performance of distribution connected generators.

#### 4.2 Connection issues

Issues that arise when connecting generators to the distribution system and which are addressed by section 3.6 are:

- a) Network operators must be confident of the status of embedded generation when performing switching and maintenance. Depending on the degree of risk posed by facilities, this will require varying combinations of automatic protections, interlocks, inter-tripping, and remote indication, control and interlocking from the network control centre.
- b) Embedded generators exporting to the network may create switching hazards for network operators by causing switch ratings to be exceeded.
- c) Embedded generation is not common in the network at present and distribution switchgear is generally not equipped with synchronizing and check facilities
- d) Inadvertent islanding of an embedded generator on to part of the distribution network may create operator safety and quality of supply problems. The generator protection may be unable to detect certain network faults. Inadvertent reclosing of a switch on to an undetected island may result in severe customer plant damage.
- e) An embedded generator may substantially increase distribution network fault levels and thermal loadings so that plant ratings may be exceeded in the network and at other customer facilities.
- f) The connection and disconnection of a generator will cause disturbing voltage transients and step voltage changes to the extent that the voltage limits at the point of connection and at other customer connections on the same feeder may be exceeded.
- g) Inverter connected and wind generation will contribute to network harmonics and flicker at other customer installations.
- h) Distribution connected generators are generally more likely to become unstable during power system disturbances than transmission connected generators because of low inertia, higher interconnecting impedances and slower distribution system fault clearing times.

In the assessment of an application for embedded generator access, the main issues Western Power will cover are:

- i) risks to the safety of public, operating personnel and plant
- j) the proportion of time the generator will remain connected and implications for protection and operational safety
- k) the performance of proposed protection systems and compliance with relevant standards
- l) protection against islanding of a generator with parts of the local distribution system
- m) visibility to maintenance staff and control centre operators of generating plant status and requirements for isolation and remote control
- n) short circuit currents, plant and switchgear ratings
- o) local voltage rise and voltage transients caused by the generator
- p) Network thermal loadings
- q) Levels of harmonics and flicker
- r) Generator instability and the likely consequences

In terms of the collective effect of small generators on overall system security, the main issues Western Power will consider are:

- s) Generator fault ride through capability
- t) Generator under and over frequency performance, including islanding

## 5 Requirements of the SWIN Technical Rules

### 5.1 Applicable clauses

Whereas the entire Technical Rules document applies to small generators, the requirements for embedded generators are found primarily in Section 3.6 “Requirements for connection of small generators to the distribution network”.

An effort has been made to consolidate as much of the technical requirements for small generators as possible into section 3.6. In particular, Table 3.5 of section 3.6 provides references to the applicable clauses of section 3.3 “Requirements for connection of generators”.

To assist Users, sections of the Technical Rules (other than 3.6) that may be of significance to an embedded generator facility are listed in Table 1 below.

**Table 1 - Clauses of SWIN Technical Rules applicable to distribution connected generators.**

Clause	Requirement	Notes
1.	General	
2.2	Power system performance standards	Standards for voltage, frequency, harmonics, flicker etc to the extent required by clause 3.6.8
2.3	Obligation of the Network Service Provider in relation to power system performance	NSP study of system performance with proposed connections may determine particular User performance requirements and network augmentations
2.5.4	Planning criteria: High Voltage Distribution System	Relates to standards of reliability of the network
2.5.5	Planning criteria: Low Voltage Distribution System	Relates to standards of reliability of the network. Obligation to connect underground.
2.5.6	Fault limits	Relates to permissible User contribution to fault current at point of connection
2.5.7	Maximum fault currents	Design and construction standards for fault current withstand
2.7	Design and construction standards	Obligation of the NSP (and hence User) to comply with recognised standards
2.8	Distribution conductor or cable selection	Obligation of the NSP to accommodate forecast load growth in selection of conductor or cable size
2.9	Distribution system protection	Includes reference to requirement for independence of islanding protection types
3.2.3	User's power quality monitoring equipment	Possible requirement for the User to accommodate NSP power quality monitoring and recording equipment
3.3	Requirements for connection of generators (parts thereof referred to in Table 3.5 of clause 3.6)	
3.4	Requirements for connection of loads (as applicable)	Where the facility subject of the access application includes an associated load
3.5	User's protection requirements	The qualifier of clause 3.5.1(a) applies to the islanding protection for all small power stations under clause 3.6
3.7	Requirements for connection via inverters	Whereas clause 3.7 only covers installations up to 30 kVA in accordance with AS 4777, the requirements nevertheless apply in principle to larger

		inverter-connected energy systems otherwise covered by clause 3.6.
4.1.1	Right of entry and inspection	
4.1.2	Right of Testing	Where there are grounds for believing that equipment does not comply with the Rules
4.1.3	Tests to demonstrate compliance with connection requirements for generators	Small power stations are covered by relevant testing and commissioning requirements. Relevant for power stations of aggregate capacity exceeding 5 MW or exporting more than 1MW or where system studies indicate difficulties in meeting requirements of 3.6.8
4.1.4	Routine testing of protection equipment	
4.1.5	Testing by users of own equipment requiring changes to agreed operation	For those systems for which operation could affect the network.
4.1.6	Tests of generating units requiring changes to agreed operation	Verification of required performance parameters where the facility has potential for significant impact on network operation
4.1.7.	Power system tests	For those <i>power stations</i> that could affect system performance
4.2	Commissioning of User's equipment	The requirements of clause 4.2 form part of the commissioning requirements for distribution connected generators
4.3	Disconnection and reconnection	Defines circumstances under which the NSP will exercise right to disconnect. Relevant for power stations of all sizes
5.1	System operation and coordination: application	Relates to roles of market operations and network operations
5.3	System operation coordination: responsibilities & obligations	Defines both NSP and User obligations
5.7	Power system security operation and coordination	Relates to the obligations of the User to advise the NSP and NSP management of supply shortfall events, including requirement to reduce loads.
5.8	Operation and maintenance planning	For power stations exporting more than 1MW
5.9	Power system operating procedures	Requirement for User to follow procedures and rules
5.10	Power system operation support	Relates to remote control and monitoring, standards and protocols
5.11	Nomenclature standards	

Attachment 10	Information to be supplied with application for connection	
Attachment 12	Testing and commissioning requirements	

## 6 Initial assessment of impact of a generator on the distribution system

Whereas a formal Western Power response to an application for access will usually require loadflow, fault level, and in some cases, harmonic and dynamic studies, it is usually possible to conduct an approximate initial assessment of the extent to which a proposed installation would impact the local power system.

This assessment would also assist in deciding what standards of protection, SCADA and communication should be specified.

Sections that follow provide methods for quick assessment (where feasible) of the extent to which a proposed installation might affect the integrity of the network and operational safety.

## 7 Requirements of Clause 3.6 of the SWIN Technical Rules

The purpose of this section is to convey the background and intention of the technical rules for embedded generators. Clause numbers are those of the Technical Rules section 3.6.

### 7.1 3.6.1 Overview

The main issues arising from connecting embedded generation to distribution systems are summarized earlier in this document. Others include aggregate capacity and stability.

#### 7.1.1 Aggregate capacity

Aggregate rated generator capacity, rather than individual generator capacity, is referred to in this clause. This is because, for both steady state and dynamic performance, the impact on the distribution system at the point of connection will be substantially that of the aggregate generator capacity. However transients arising from connection and disconnection of generators may be mitigated by synchronising or disconnecting generators successively as discussed in clause 3.6.8.

#### 7.1.2 Stability

Generator groups in excess of 5 MW aggregate capacity may require evaluation of dynamic performance for which additional data will be required, similar to that required for transmission connected generators.

The major issue to be studied would be transient instability of the generators and the consequences of out-of-synchronism operation. For smaller generators the consequences may be limited to voltage fluctuations that may exceed the flicker limits specified in clause 3.6.8. For larger generators causing much wider voltage excursions and large out-of-synchronism current flows limited only by generator and network impedances, potential damage to network and customer plant may be an issue.

## 7.2 3.6.2 Categorisation of Facilities

### 7.2.1 Point of connection

The requirement of subclause 3.6.2 (b) for performance requirements for non-synchronous (wind) generating units to apply at the point of connection reflects the fact that it is the net aggregate impact at the point of connection of a multiplicity of small generators rather than individual performance that matters. It is also consistent with the way charges for ancillary services are levied in the WEM and promotes flexibility in design.

Subclause 3.6.2 (b) for synchronous generators is consistent with the requirements for larger transmission connected generators. Generator reactive power performance requirements would become more onerous if specified at the point of connection because of generator step-up transformer reactive losses.

It should be noted that in the context of section 3.6, HV refers to voltages above 1.0 kV. Reference to HV or LV refers to the voltage at the point of connection to the SWIN distribution system, *not* the generated voltage. For example a 150 kVA 415 V generator connected to the User's 415 V network that is in turn connected to the SWIN distribution network by the User's 22 kV/0.415 V transformer, is considered HV connected.

### 7.2.2 Selection of point of connection

The location of embedded generation is usually determined by fuel sources, proximity to on-site loads, cost of network augmentations and upgrades, and probably, to a lesser extent, by network access charges and network energy losses.

For each nominated point of connection it will be necessary to determine, in the first instance:

- a) transient and step voltage changes at the point of connection;
- b) the impact on voltages at other connected loads
- c) contributions to line thermal loadings
- d) contributions to fault levels
- e) whether the rating of network plant is likely to be exceeded
- f) the risk that inadvertent islanding could occur
- g) network operator access requirements, and
- h) for large generator installations, transient stability study requirements.

Having determined these issues it should be evident whether connection at a particular voltage level is satisfactory or whether a connection at a higher voltage level or some other remedial measure is required.

### 7.2.3 Modes of operation

Several modes of operation have been covered to avoid 'one size fits all' and so reduce the burden of compliance for prospective users. For some modes there will be reduced impact on the network in terms of power flows, voltage changes and the amount of time connected. Where possible this has been reflected in relaxed requirements in regard to equipment standards, protection functions and remote monitoring and control requirements. For example, a generator not exporting to the network would be unlikely to require a *continuous* communication link with the control centre.

It is likely that the modes of operation and their associated technical requirements will be refined from time to time to meet industry needs. An example of this is the situation where a generator provides voltage support and back up at a network extremity. Any such a situation will be managed through the relevant access contract, by defining duties and responsibilities of both parties.

### 7.3 3.6.3 Information to be provided by the Generator

The application form for connection of a distribution generator is available on-line from Western Power:

<http://www.westernpower.com.au/mainContent/connectionsUpgrades/newConnections/Generators.html>

This document is based on Attachment 10 of the Technical Rules. Not all of the information requested in the form is required for a preliminary Access Enquiry for which the 'Applicants General Information' and 'Power Station General Information' sheets generally suffice.

This application form assumes that no transient stability studies will be required. Should such studies be required, Western Power will request additional information similar to that specified for transmission connected generators including models for dynamic simulation.

### 7.4 3.6.4 Safety and Reliability

This section lists the safety and reliability issues considered when processing an access application.

#### 7.4.1 Safety

The generator is required to comply with all relevant standards, good industry practice and manufacturer's recommendations in both design and operations.

Issues related to plant rating, such as fault level contributions and voltage change, are addressed at the design stage by Western Power by specifying network plant upgrades and/or imposing constraints on generator operation.

Operational and operator safety issues are addressed by specifying operating procedures, interlocks, intertripping, and remote control and monitoring.

#### 7.4.2 System reliability

New connection proposals will generally be on the basis of single feeder supply and power system feasibility studies will accordingly be restricted to one feeder. Additional security for dispatch of generation output could be provided by a back-up feeder facility where feasible and upon request. However this may also involve additional plant upgrades, interlocking, communications, intertripping facilities and operating constraints for the alternative facility.

Should the user require additional security, supply arrangements and any necessary augmentations should be determined up-front at the application stage. In contrast to the high redundancy of the transmission system, supply options in the distribution network are limited and alternative network configurations, triggered by maintenance, replacement or reinforcement reasons, may last for extended periods of time. These alternative supply paths may, with or without prior notice, severely constrain the operation of the generator for extended periods of time, if their capacity is not checked up-front.

Operational experience has resulted in a Western Power policy to limit feeder loading to 4.5 MVA, whether due to load or generation. This provides some flexibility in redistributing loads during outages. A generator installation exporting in excess of 4.5 MVA would be required to split the output between two feeders.

In the case where an express (dedicated) feeder is used, generator exports of up to 10 MW are feasible.

#### 7.4.3 Reliability of User's facilities

Whereas reliability of export to the network will not always be an important issue for the network operator, it is important that the disconnection and reconnection of the generator does not produce disturbances beyond the limits specified.

It is implicit when an application to connect is approved, that all primary and secondary equipment will be operated, tested and maintained by suitably qualified personnel in accordance with good power industry practice. Similarly, it is vital that any change to protection, protection settings and interlocks be agreed with Western Power.

#### 7.5 3.6.5 Requirements of clause 3.3 applicable to small power stations

Clause 3.6.5 lists in Table 3.5 the main technical requirements for embedded generators that are not included in clause 3.6. The performance requirements of clause 3.3 referred to in Table 3.5 generally apply to generators of all sizes connected to both the transmission and distribution systems. Whereas embedded generators should generally not experience difficulty in meeting these requirements, in a case where non-compliance of a small installation would not jeopardise power system security, Western Power may grant an exemption.

#### 7.5.1 Other applicable clauses

Table 1 of this document provides a more comprehensive list of clauses of the Technical Rules that may be relevant to a particular installation. It references clauses for design, commissioning and operation.

#### 7.6 3.6.6 Generating unit characteristics

##### 7.6.1 3.6.6 (a) and (b) Fault current contributions

The connection of a generator to the distribution system may well cause the fault level ratings (both maximum and short time withstand) of network plant to be exceeded. In this case network plant may need to be upgraded or replaced.

Similarly, connection to the network may result in the short circuit current capacity of the User's plant to be exceeded in which case upgrading may be required or switching procedures introduced to limit the potential fault current. Current limiting reactors may also be an option.

In some cases Western Power may be able to supply fault level and/or impedance data to enable the User to make a preliminary assessment of fault levels. Calculation of fault levels is covered in the accompanying examples.

*Minimum* fault current contribution may be of concern in the coordination of protective devices, because of the duration and magnitude of the generator fault current contributions that are insufficient for protections to see the fault.

## 7.7 3.6.7 Connection and operation

This clause relates to general design and operational requirements necessary for the safe operation of plant

### 7.7.1 Visible point of isolation

3.6.7.2 (c) refers to a point of visible isolation accessible to NSP operational personnel. Where deemed to be of sufficient capacity to constitute a possible switching hazard to operators, the point of isolation will be required to be accessible at all times.

The NSP may also require facilities for remote monitoring, interlocking and control.

### 7.7.2 Synchronising

3.6.7.3 sets out synchronising and interlocking requirements. It is expected that synchronising, both manual and automatic would take place within the following parameters:

Voltage difference  $< \pm 10\%$

Frequency difference  $< \pm 0.5$  Hz

Phase angle difference  $< \pm 10^\circ$

## 7.8 3.6.8 Power quality and voltage change

It is expected that the majority of generators connected to the distribution network will be the synchronous, non-intermittent type. For these harmonics will generally not be an issue, but *step voltage change* on connection/disconnection and *steady state voltage rise* during operation will be important issues in determining the size of plant that can be connected, or conversely, the network augmentations required to accommodate a plant of a given size should network capacity be exceeded.

Clause 3.6.8 (a) specifies compliance with Clause 2.2 - Power system performance standards. Whereas the standards of 2.2 refer to the aggregate impact of all connected plant, the obligation of each User is to ensure that connection of proposed plant should not cause these limits to be exceeded. The NSP may allocate only a portion of that overall limit to an individual User because of other customers.

The main issues of clause 2.2 to be addressed are *flicker* (clause 2.2.3) and *harmonics* (clause 2.2.4) as discussed below.

Clause 3.6.8 (b) defines *step voltage change* performance in terms of the flicker requirements of clause 2.2.3. In context of small generators, the requirements of clause 2.2.3 take precedence over those of Table 2.2.

Clause 3.6.8 (c) requires that the *steady state voltage rise* due to generator operation does not exceed the stated limit also discussed below.

### 7.8.1 Typical generator transients

The User should provide information on expected generator transient currents during connection and disconnection. Actual performance data or manufacturer's data where available is preferred. However, where unavailable, the values in Table 2 below must be used.

**Table 2 - Overcurrent factors for generator types.**

Type	RMS Short Circuit	Connection and Disconnection	Comment
Synchronous	8x	1x	Short term internal transients may momentarily double the 1x
Induction	6x	4x 8x	Connection at 95-105% rated speed Accelerating from zero speed
Inverter	1x	1x	
Wind			Special network specific factors

Table 2 represents multiples of rated current or rated apparent power (MVA). In the case of connection of synchronous generators, the 1x factor represents momentary transients that may occur due to differences in voltage phase and magnitude.

#### 7.8.2 Assessment of voltage change and voltage rise

In a radial distribution system, a simple assessment of power system voltage impact can be readily performed given the right data.

Let's consider an exporting generator located at the end of a feeder. The voltage rise  $dV$  at the end of a lightly loaded radial distribution feeder is given approximately by the following equation:

$$dV = (PR+QX)/V$$

where

P is real power injected

Q is active power injected

R is line resistance

X is line reactance

V is (nominal) voltage

As discussed below and in Appendix A, this formula can be extended to include the system source impedance. This is necessary to enable calculation of voltage transients that occur prior to the compensating effect of transformer automatic tap changing at the zone substation. A transformer automatic tap change in response to a load changes may take several minutes.

### 7.8.3 Voltage changes

As shown in Appendix A, a conservative estimate of the voltage change  $dV$  at the point of connection when a step change in injected power occurs is given by:

$$V\% = 100 S / S_{sc} \quad (A6)$$

where

$dV\%$  is the percentage change in voltage magnitude

$S$  is the injected apparent power (MVA)

$S_{sc}$  is the system short circuit apparent power

It has been assumed here that no on-load transformer tap changing occurs in the timeframe of the calculation and the relevant voltage change is that which occurs before tap changing.

As shown in Appendix A, voltage changes of up to about 5% can be approximated by a simple algebraic formula that gives a less conservative answer than (A6) and provides more insight into the relative contributions to voltage change of real and reactive power flows:

$$dV\% = PR_{th} + QX_{th} \quad (A7)$$

where

$dV\%$  is the percentage change in voltage

$P$  is the real power change in MW

$Q$  is the reactive power change in MVAR

$R_{th}$  is the Thevenin equivalent resistance of the system in per unit on 100 MVA base at the point of connection

$X_{th}$  is the Thevenin equivalent reactance on the same basis

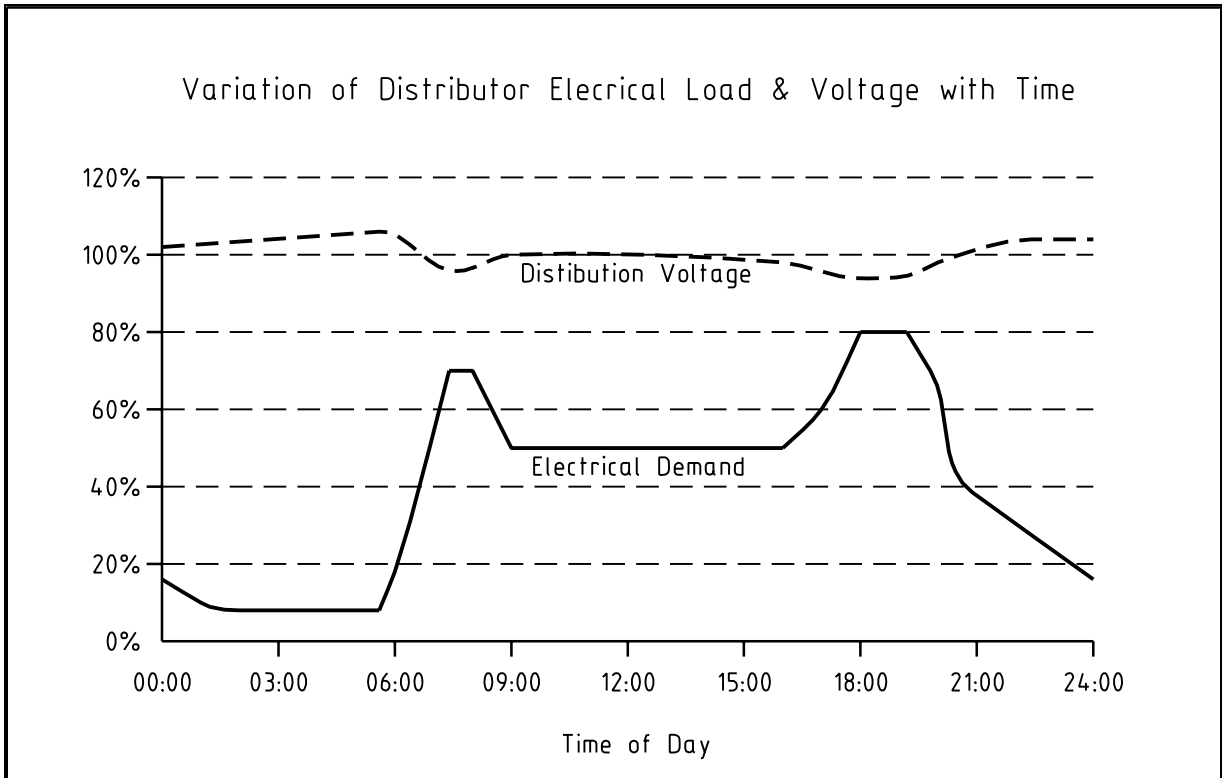
It can be seen for example that if the generator were operated in leading power factor mode, i.e. absorbing reactive power, then  $Q$  would be negative so that the component of voltage rise due to real power injection ( $PR_{th}$ ) could be fully or partially offset by the  $QX_{th}$  component.

Use of formulas (A6) and (A7) is illustrated in the example calculations appended.

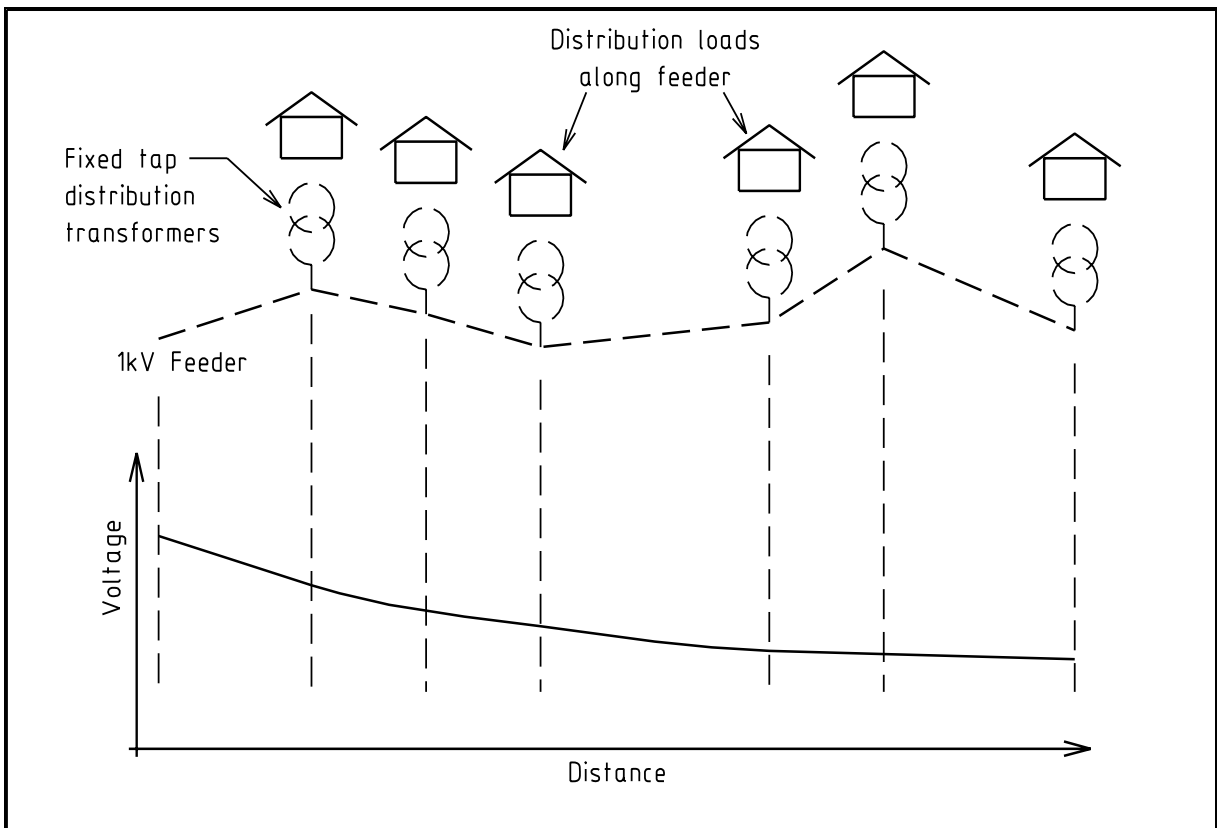
### 7.8.4 Determining the permissible range of connection point voltage

Clause 3.6.8 (c) limits the steady state connection point voltage change to 2% but also requires that the steady state voltage limits of clause 2.2 must not be exceeded.

It will be appreciated that the incremental voltage change is only part of the impact on system operation. If a feeder is heavily loaded it may require power system simulation to identify constraints on voltage at the point of connection to ensure that the +/-6% voltage limit over the full range of system operating conditions is not exceeded on LV networks fed by fixed tap transformers and connected to the same feeder. This is illustrated in Figures 1 and 2 below:



**Figure 1 - Daily variation of feeder electrical load**



**Figure 2 - Voltages at LV points of connection supplied by fixed tap distribution transformers**

Permissible voltage levels along heavily loaded HV distribution feeders will be constrained by the need to keep the voltage at LV points of connection within the +/- 6% prescribed limit for normal operation. Whereas an embedded generator may be beneficial in reducing feeder voltage drop at times of heavy load, it is likely to contribute to voltage rise during light loads. If the generator is not subject to dispatch, its impact on voltage levels will be random which may result in the need to constrain the range of voltages at the point of connection of the generator to the HV feeder.

#### 7.8.5 Automatic voltage control

Zone substation transformers with on-load tap changing (OLTC) are, following a load change, able to restore the LV busbar voltage to the prescribed level (eg 22 kV + 2%) within a time frame of several minutes. Line drop compensation (LDC) when utilised may be used to control the voltage at a notional point downstream of the substation by varying the LV busbar voltage in proportion to the aggregate transformer load. Judicious use of these controls may limit the range of voltage variations on an HV feeder thereby allowing more load to be connected. Conversely, where these can be used effectively, there may be benefits in reducing the impact on line voltages of export from an embedded generator. However in the first instance this would not be used as it would constrain the potential loading of other feeders connected to the same transformer with different load patterns.

Assessment of OLTC and LDC settings generally requires detailed system modelling and is therefore beyond the scope of a simple preliminary calculation. Use of line drop compensation (LDC) to mitigate voltage changes is only feasible for small generators (<2 MW aggregate) as it is not reliable and embedded generation corrupts (reduces) transformer current on which LDC is based.

Depending on actual operating conditions, Western Power will generally require a generator to control, within its capacity, the connection point voltage to an agreed target or alternatively export at an agreed constant power factor that would maintain voltage variations within prescribed limits.

Where the generator has insufficient reactive generation capability to control voltage under all operating conditions, reversion to operation in a constant power factor mode within the capability of reactive power generation or absorption may be permitted. Alternatively supplementary sources of reactive power (eg SVCs, reactors or capacitors) or network reinforcements may be specified. The use of capacitors however may exacerbate levels of harmonics and this may in turn precipitate the need for harmonic propagation studies.

#### 7.8.6 Calculation of impact on voltages at other points of connection

As shown in Appendix A, by using the same approximation as equation (A7) the voltage change at bus 2 due to injection of power  $P_1$  MW and  $Q_1$  MVAR at bus 1 is given by:

$$dV_2\% = P_1 R_{12} + Q_1 X_{12} \quad (A11)$$

where  $R_{12}$  and  $X_{12}$  are the per unit resistance and reactance the of buses 1 and 2.

Equation (A11) provides a means of assessing the amounts by which the HV & LV voltage profiles will be incrementally affected by the connection of a generator to a node in the distribution system. It is easy to use where there are a small number of nodes, as illustrated in the example calculations.

However to determine the impact on the absolute voltage magnitude at each LV connection point, it would be necessary to conduct loadflow simulations for full load and light load

before and after the proposed generator is connected. This presumes a knowledge of the actual loads and tap settings.

#### 7.8.7 Voltage change requirements of clause 3.6.8

The outcome of subclauses 3.6.8 (b) and (c) is that the following is permitted:

- (1) *a transient voltage change* not exceeding the requirements of Table 3 of AS/NZS 61000.3.7:2001 when a generator is connected or disconnected.

Where connection of an entire power station causes the requirements of Table 3 to be exceeded it may be possible to meet the requirements by synchronising individual generating units sequentially at intervals of at least two minutes apart within the constraints of the table. Overcurrent factors used to determine the magnitude of current transients may be those of Table 2 of these Guidelines or preferably data provided by the manufacturer.

Voltage changes resulting from an infrequent switching event such as the tripping of the entire power station at the customer main switch as a result of a fault should be within the limits specified in Table 2.2 of the Technical Rules.

**Table 3 - Part of Table 3 of AS/NZS 61000.3.7:2001 –  
Pst =1 for regular rectangular voltage changes**

<b>r</b>	<b><math>\Delta U/U</math> (%)</b>
<b>min<sup>-1</sup></b>	<b>230V</b>
<b>0.1</b>	<b>7.364</b>
<b>0.2</b>	<b>4.545</b>
<b>0.4</b>	<b>3.537</b>
<b>0.6</b>	<b>3.155</b>
<b>0.84</b>	<b>2.894</b>
<b>1</b>	<b>2.724</b>
<b>2</b>	<b>2.211</b>

- (2) *a pre-tap change voltage rise* not exceeding the requirements of Table 4, which is Table 7 of AS/NZS 61000.3.7:2001. Where connection of an entire power station causes the requirements of Table 4 to be exceeded it may be possible to meet the requirements by synchronising individual generating units sequentially at intervals stated in the table.

**Table 4 - Table 7 of AS/NZS 61000.3.7:2001 – Emission limits for voltage changes in function of the number of changes per hour**

r (hour <sup>-1</sup> )	$\Delta U_{dyn}/U$ (%)	
	MV	HV
$r \leq 1$	4	3
$1 < r \leq 10$	3	2.5
$10 < r \leq 100$	2	1.5
$100 < r \leq 1000$	1.25	1

- (3) a *post-tap change rise in voltage* of 2% maximum at the point of connection. In this context the relevant transformer tap change is that of the zone substation transformer connected to the feeder. Note that it may be necessary to determine the extent to which the zone substation transformer OLTC facility is able to respond to small load changes. Where the tap-changer is relatively insensitive, the permitted pre-tap change voltage rise in point (2) above may need to be reduced in order for the 2% maximum to be achieved

#### 7.8.8 Use of reactive compensation

If the generator export raises the post-tap change voltage rise in point (3) above beyond the prescribed limit then various other means of controlling connection point voltage should be explored. This would include limiting generator reactive power export, control of the connection point voltage level by generator automatic voltage regulator action (if sufficient reactive power absorption capability is available), specifying installation of a shunt reactor, reinforcing the network, or requiring that an overvoltage relay disconnect the generator when limits are exceeded.

#### 7.8.9 Reduction of real power output

Overvoltage can also be controlled through a generator closed loop voltage control scheme that reduces generator output (energy sacrifice) when upper voltage limits are exceeded.

#### 7.8.10 Limitation on feeder loading

Western Power also currently requires generator installations larger than 4.5 MVA to be split across two feeders (as is the case for loads) to limit adverse voltage rise impact and to improve operational flexibility.

#### 7.8.11 Flicker limits for non-synchronous and intermittent generators

In addition to the requirements discussed above, generators that produce fluctuating output, such as wind generators, must not cause the limits allocated in clause 2.2.3 to be exceeded. The Network Service Provider will perform an analysis of the impact of proposed generators based on data provided by the User and other sources of interfering loads and

generators. As stated in subclause 3.6.3 (e), data on power quality characteristics of wind turbines must be provided in accordance with standard IEC 61400-21.

#### 7.8.12 Harmonics generation limits of clause 3.6.8

Subclause 3.6.8 (a) requires that generators that produce waveform distortion such as inverter connected generators must ensure that the harmonic limits specified in clause 2.2.4 are not exceeded. The Network Service Provider will perform an analysis of the impact of proposed generators based on data provided by the User and other sources of interfering loads and generators. As stated in subclause 3.6.3 (e), data on power quality characteristics of wind turbines must be provided in accordance with standard IEC 61400-21.

#### 7.9 3.6.9 Remote control and monitoring

Clause 3.6.9 (a): The requirement for remote control and monitoring for >1 MW export arises from the increased hazard associated with inadvertent network switching during maintenance of power exported from an embedded generator. Visibility at the network control centre will ensure that generator status is known with a high degree of certainty at all times.

#### 7.10 3.6.10 Protection

Protection requirements for small generators are defined by clause 3.6.10. Section 2.9, clause 2.9.1(b)(2), requires duplication of the islanding protection. This duplication is not required for bumpless transfer generators, as per clause 3.6.10.1(l) for rapid bumpless transfer and clause 3.6.10.3(b) for gradual bumpless transfer. To provide guidance in what Western Power may require for individual applications the following Table 5 summarises one realisation of these protection requirements. Western Power document "*Detailed customer connection schedules for small generator installations*", Schedule A –Specific Technical requirements for Generators connected to the Western Power Distribution System, provides a more detailed template of protection functions.

##### 7.10.1 Connection voltage

In regard to Table 5 of these guidelines it should be understood that reference to HV or LV connected generators refers to the voltage at which the User's facility connects to the distribution network, irrespective of the voltage at which power is generated. Therefore, for example, a 100 kVA generator, generating at 415 volts but connected to the distribution network by the facility's 22 kV/415 V 1000 kVA transformer is considered HV connected.

The applicant may request assessment as an LV generator, pursuant to clause 3.6.2(c)(3), however, the resulting transient and steady state voltage changes would be higher.

##### 7.10.2 Standards

Interconnection protection equipment necessary to satisfy clause 3.6.10 and Table 5 of these guidelines is required to comply with the relevant parts of the IEC 60255 series of standards. This includes the disconnection timer in case of the rapid (1second) bumpless transfer mode of operation.

Nevertheless it is implicit that the User's protection system be fail-safe so that failure of AC or DC protection supplies will trip the main switch or generator.

**Table 5 Summary of protection requirements for small generating units**

Protection required for distribution system (Note 1)		Permanent parallel operation Occasional parallel operation					Short term test parallel					Bumpless Transfer	
		HV generating equipment		LV generating equipment			HV generating equipment	LV generating equipment					
Type	Reference (clause in Technical Rules)	No export	Export	Aggregate capacity kVA				Aggregate capacity kVA			Rapid (≤ 1s)	Gradual (≤ 60s)	
				<150	150 - 250	>250		<150	150 - 250	>250			
Under / over voltage & frequency	3.6.10.1(f) & 3.6.10.3	×	×	×	×	×	×	×	×	×		×	
Overcurrent	3.6.10.1 (f)	×	×	×	×	×	×	×	×	×		×	
Loss of one or more phases	3.6.10.1(h)	×	×	×	×	×	×	×	×	×		×	
Directional power (export)	3.6.10.1(h) & (i)	×	×	×	×	×	×	×	×	×		×	
Directional overcurrent	3.6.10.1(h) & (i)	×	×			×							
Rate of change of frequency	3.6.10.1(h)	×	×	×	×	×	×	×	×	×			
Voltage vector shift	3.6.10.1(h)	×	×	×	×	×	×	×	×	×		×	
Earth fault	3.6.10.1(g)	×	×	×	×	×	×	×	×	×		×	
Neutral voltage displacement	3.6.10.1(g)	×	×	×	×	×	×	×	×	×			
Sensitive earth fault	3.6.10.1(g)	×	×				×						
Disconnection by timer	3.6.10.1(k)						×	×	×	×	×	×	
Pole slipping	3.6.10.2 Note 3	a/r	a/r	a/r	a/r	a/r	a/r	a/r	a/r	a/r			

**Notes:**

1. The symbol × indicates required *protection*.
2. Loss of a *protection supply* must immediately trip all switches that depend on that *supply* for operation of their *protection*.
3. a/r means 'as required', as determined by clause 3.6.10.2
4. Requirements are determined by the Technical Rules. This table is for guidance only.
5. Protection functions shaded green are alternatives for export limiting. Directional power (export) protection monitors power in the export direction not to exceed the export limit.
6. Protection functions shaded blue are alternatives for loss of mains protection.
7. Protection functions shaded yellow are alternatives for earth fault protection. The use of overcurrent earth fault protection or neutral voltage displacement depends on the type of the earthing arrangement in the installation (earthed/unearthed). For example, the earth fault overcurrent protection is required in earthed systems.

### 7.10.3 Pole slip protection

Whereas this is normally a generator protection, unchecked pole slipping may have an undesirable effect on the power system, not to mention generator damage.

Without performing stability studies, the risk of pole slipping cannot be accurately quantified. Whereas one pole slip may be tolerable, unchecked pole slipping could potentially cause unacceptable levels of voltage flicker. Hence there is a requirement that the flicker levels of AS/NZS 61000.3.7:2001 be met or alternatively pole slip protection be installed.

### 7.10.4 Islanding protection

Following network switching both manual and automatic, there is the possibility that an embedded generator will become islanded with a section of the Western Power network. This constitutes a hazard with implications for operator safety, quality of supply, protection incompatibility, and potential damage to the embedded generators through out of synchronism switching.

Required islanding protection would normally detect this situation and disconnect the embedded generator. It is obviously important that the islanding protection operates within the specified 2 seconds to avoid out-of-synchronism operation of a recloser and thus avoid damage to the generator.

Where sustained parallel operation is the mode of the generating unit, a specialist loss of mains protection function must be included in each of two independent *protection schemes*. Generating units designed for gradual bumpless transfer must be protected with at least one type of loss of mains protection. The protection functions used must be selected and set to enable them to detect the islanding condition.

Where there is no export of power into the network and the aggregate rating is less than 150kVA, both independent islanding *protection schemes* can be in the form of a directional power function that will operate for power export. Directional overcurrent relays may also be used for this purpose.

There is the possibility that, should the residual network load approximately match the generator export at the time, the loss of mains protection would not detect the abnormal situation. In these circumstances, when Western Power believes that rate of change of frequency and voltage vector shift will not adequately safeguard from islanding, then, Western Power may also specify remote control and/or interlocking so that, for example, the operation of a zone substation circuit breaker also trips the connection to the generator.

## 7.11 3.6.11 Commissioning and testing

As stated, requirements for embedded generators are listed in Attachment 12.

Western Power document "*Detailed customer connection schedules for small generator installations*", Schedule C Part 1 – Commissioning and, Part 2 –Approval to Operate are templates based on Attachment 12 .

### 7.12 3.6.12 Technical matters to be coordinated

Matters to be coordinated include the general design of the User's facility in accordance with good engineering practice and relevant standards. Some of these issues are beyond the scope of this document. However of particular importance will be the vector grouping and tap range of the connecting transformer and the load and fault ratings of other primary plant such as circuit breakers and switches. These will be the most costly items in terms of the viability of connecting to the network.

### 7.13 5.3 Power system operation co-ordination responsibilities

The title of this section explains well its purpose. Relevant clauses from this section of the Rules are listed in Table 1 of this document. Obligations of the user in relation to operation and coordination are summarised in Western Power template document "*Detailed customer connection schedules for small generator installations*", Schedule B Part 1 – Operating Procedures and Part 2 –Remote control monitoring and communications.

## Appendix A - Formulas for voltage change

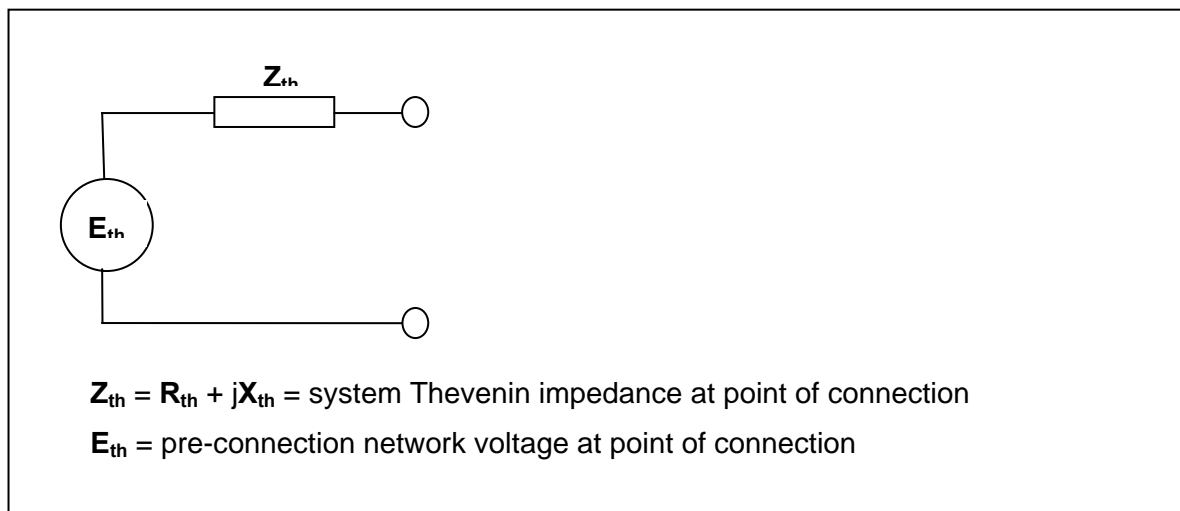
A1 – Simplified network representation

A2 – Voltage changes

A2.1 Calculation of impact on voltages at other points of connection

### A.1 Simplified network representation

The SWIN power system at a point of supply to the distribution system (eg a zone substation LV busbar) can conveniently be represented by the Thevenin Equivalent [2] of the SWIN at that point as shown in Figure A1 below:



**Figure A1 – Thevenin equivalent of power system at a point of connection**

The Thevenin impedance is the impedance seen looking back into the system from the point of connection with all voltage sources short circuited. The components of the complex quantities  $Z_{th}$  and  $E_{th}$  can be readily derived from fault level and loadflow simulation. For radial distribution systems, good approximations can be derived from a simple inspection of the network. [In this section bold letters are used to denote vector (phasor) quantities]

For the purpose of determining step changes in voltage, the system equivalent at a point of connection on the distribution system can often be conveniently approximated by assuming  $E_{th} = 1.0 \angle 0$  deg. per unit and  $Z_{th}$  = sum of the impedances of the connecting feeder ( $R_f + jX_f$ ) and the impedance of the zone substation transformers ( $0 + jX_t$ ) normally in parallel. This assumes that the impedance of the transmission system beyond the HV terminals zone substation transformer is sufficiently small enough to be ignored. In the first approximation it would also be reasonable to ignore feeder shunt susceptance (capacitance) for 50 Hz effects and impedances of connected loads.

Converting impedances to per unit (p.u.) on a 100 MVA base simplifies calculations and unless otherwise stated, values of impedance, resistance and reactance used in this document will be on this basis.

For the initial assessment of voltage transients and step voltage change, the network configuration likely to yield the highest impedance, with a reasonable likelihood of occurrence, would be used. For the impact on network fault levels the network configuration likely to yield the lowest impedance, with a reasonable likelihood of occurrence, should be used. This might include the paralleling of one or more zone substation transformers. However currently zone substation transformers are normally run split on the LV side except for some country locations.

## A.2 Voltage changes

The voltage change  $dV$  at the point of connection when a step change in injected power occurs is given by:

$$dV = |\mathbf{V}| - |\mathbf{E}_{th}| \quad (A1)$$

$$\mathbf{V} = \mathbf{I}Z_{th} + \mathbf{E}_{th} = (\mathbf{S}^*/\mathbf{V}^*) \mathbf{Z}_{th} + \mathbf{E}_{th} \quad (A2)$$

where

$dV$  is the change in voltage magnitude

$\mathbf{V}$  is the (post disturbance) voltage at point of connection

$\mathbf{V}^*$  is the complex conjugate of  $\mathbf{V}$ ,

$\mathbf{S} = P + jQ$  is the complex apparent power,

$\mathbf{S}^*$  is the complex conjugate of  $\mathbf{S}$  i.e.  $P - jQ$

*(Note that the operator \* is not to be confused with the multiplication sign for scalar numbers in the examples in the appendix. It should be apparent from the context what is intended. To avoid confusion implied multiplication has been used here for formulas),*

$P$  is the step change in injected real power,

$Q$  is the step change in reactive power ( $Q$  is positive for a lagging reactive load),

$j$  is the complex operator,

$\mathbf{E}_{th}$  and  $\mathbf{Z}_{th}$  are as before.

The following relations are also useful:

$$|\mathbf{S}| = S = (P^2 + Q^2)^{0.5} \quad (A3)$$

$$\mathbf{I}_{sc} = \mathbf{E}_{th} / \mathbf{Z}_{th} \quad (A4)$$

where

$\mathbf{I}_{sc}$  is the short circuit current.

Assuming that  $E_{th}$  is close to 1.0 pu, it follows that:

$$|S_{sc}| = S_{sc} = 100 / |Z_{th}| \text{ MVA} \quad (A5)$$

and

$$dV\% = 100 S / S_{sc} \quad (A6)$$

where

$S_{sc}$  is the system complex short circuit apparent power

$dV\%$  is the (approximate) percentage change in voltage magnitude

It has been assumed here that no on-load transformer tap changing occurs in the timeframe of the calculation and the relevant voltage change is that which occurs before tap changing.

It is not that difficult to calculate  $dV$  (equation (A1)) by resolving each of the phasor quantities into their real and reactive parts and solving, even to the extent of assuming an initial value of  $V=1+j0$  in (A2) and performing an iteration if needed to improve accuracy. However for voltage changes up to about 5%, equations (A1) and (A2) can be approximated by a simple algebraic formula that gives a less conservative answer than (A6) and provides more insight into relative contributions to voltage change of real and reactive power flows:

$$dV\% = PR_{th} + QX_{th} \quad (A7)$$

where

$dV\%$  is the percentage change in voltage

$P$  is the real power change in MW

$Q$  is the reactive power change in MVAR

$R_{th}$  is the Thevenin equivalent resistance of the system in per unit on 100 MVA base at the point of connection

$X_{th}$  is the Thevenin equivalent reactance on the same basis

Use of formulas (A6) and (A7) is illustrated in the example calculations in Appendix B.

### A.2.1 Calculation of impact on voltages at other points of connection

It is likely to be the case that voltage limits on the LV system will constrain the permissible range of voltages at the connection point on the feeder to less than the limits of clause 2.2. Therefore it will be necessary to examine the system HV and LV voltage profiles for a range of operating conditions.

The relationship between the voltages at the various points on the sub-system is given by:

$$[d\mathbf{V}] = [\mathbf{Z}][\mathbf{I}] \quad (\text{A8})$$

where

$[d\mathbf{V}]$  is the voltage vector of the points of connection,

$[\mathbf{Z}]$  is the bus impedance matrix with the slack bus as the reference bus

$[\mathbf{I}]$  is the current vector for the points of connection

$[d\mathbf{V}] = [E - \mathbf{V}]$  and  $E$  is the voltage at the reference bus and  $[\mathbf{V}]$  is the connection points voltage vector

from (A8) it follows that for a 4 bus system with the reference bus as bus 0

$$d\mathbf{V}_2 = \mathbf{Z}_{22}i_2 + \mathbf{Z}_{12}i_1 + \mathbf{Z}_{23}i_3 \quad (\text{A9})$$

where

$\mathbf{Z}_{22}$  is the self impedance of point a ( $\mathbf{Z}_{th}$  of equation (A2))

$\mathbf{Z}_{12}$  is the mutual impedance of connection points 1 and 2 etc

For a meshed system  $[\mathbf{Z}]$  may be derived by inverting the  $[\mathbf{Y}]$  admittance matrix. However in a radial system each self (diagonal) and mutual (off diagonal) impedance of  $[\mathbf{Z}]$  can be determined from inspection of the network.

The self impedance is, in this context, the same as the Thevenin equivalent impedance discussed earlier.

The mutual impedance is the impedance of that part of the Thevenin equivalent network that forms a common current path and in a simple distribution network is evident from inspection. In the example of Figure B1, Appendix B,  $\mathbf{Z}_{12}$  is the impedance of 5km of feeder from the zone substation (assumed destination of the exported power) to bus 2. Similarly,  $\mathbf{Z}_{13}$  is the impedance of 10km of feeder from zone substation to bus 1, not the 2 km impedance between busses 1 and 3.

It would be necessary to decide whether to include the transformer impedance in  $\mathbf{Z}_{22}$  and  $\mathbf{Z}_{12}$ . If after the load change the OLTC effectively returns the LV busbar to the preset voltage, then the LV busbar can be considered an infinite busbar for the purpose of calculation of steady state voltage rise and the transformer impedance should not be included. If no automatic tap changing occurs, then the transformer impedance should be included in steady state voltage rise calculations.

If we assume that the line is lightly loaded and a generator connecting at point producing a voltage change at a bus does not cause a significant change to the current inputs/outputs at other points, it follows that the voltage change at point 2 due to the injection of current at point 1 follows from equation (A9), i.e.

$$dV_2 = Z_{12}I_1 \quad (A10)$$

and using the same approximation as equation (A7), the voltage change at bus 2 due to injection of power  $P_1 + jQ_1$  MVA at bus 1 can be calculated as

$$dV_2\% = P_1R_{12} + Q_1X_{12} \quad (A11)$$

where  $R_{12}$  and  $X_{12}$  are the per unit resistance and reactance components of mutual impedance  $Z_{12}$ .

Equation (A11) provides a means of assessing the amounts by which the HV & LV voltage profiles will be incrementally affected by the connection of a generator to a node in the distribution system.

It is easy to use where there are a small number of nodes, as illustrated in the example calculations. However where the situation is critical, or there is a need to determine the absolute ranges of voltage at each connection point, it may be necessary to conduct loadflow simulations for before and after the proposed generator is connected.

## Appendix B - Example calculation

### Example 1: Connection of 3\*1500 kVA synchronous generators to a 22 kV feeder, occasional parallel operation.

The schematic of the proposed connection of a plant with three identical synchronous generators rated 1500kVA to a 22kV feeder is given in Figure B1.

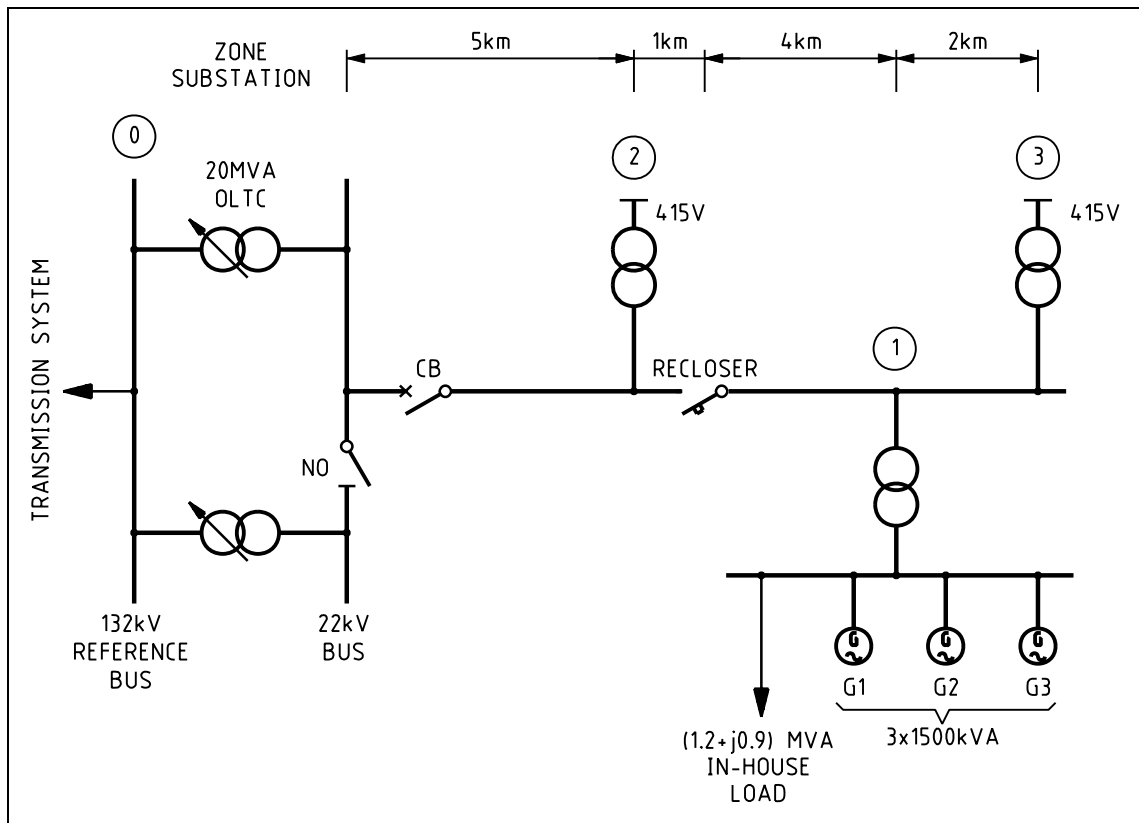


Figure B1 - Single line diagram for the intended connection of Example 1.

#### Assumptions

- Mode of operation: occasional parallel operation (for exercising, trading and peak shaving) i.e. up to 200 hrs per year
- Length of feeder from generator to zone substation 10 km, fixed tap distribution transformers located at 5 km and 12 km from sub on same feeder
- In-house load  $1.2 + j0.9$  MVA
- Expected maximum net export: 1.5 MW at 0.8 power factor i.e. 1.9 MVA or  $1.5 + j1.125$  MVA

#### Data

- 22kV feeder aerial conductor: Mercury 7/4.5 AAC,  $R=.315$  ohms/km,  $X= .259$  ohms/km (from reference [6])
- Substation transformer:  $X = 12\%$  on 20 MVA base =  $60\%$  on 100 MVA =  $j0.6$  per unit
- Synchronous generators =  $3 \times 1500$  kVA @ 0.8 power factor = 4.5 MVA =  $3.6 + j2.7$  MVA aggregate output

- Aerial conductor thermal rating from reference [6], industrial weathered, 1 m/s wind speed = 378 A =  $1.73 \times 22 \times 378 / 1000 = 14.3$  MVA [note that Western Power may use different atmospheric conditions and different formulae to calculate a conductor thermal rating]
- Feeder impedance  $Z_c = 10 \times (0.315 + j0.259) \times 100 / 22^2$  per unit 100 MVA base =  $0.651 + j0.535$  per unit

*(Note that the resistance figure will vary with temperature. The reactance figure given is for 0.3 m conductor spacing and is therefore approximate. Reactance in fact varies logarithmically with conductor spacing.)*

### B.1 Access to network data

Network data in terms of fault levels at zone substations is generally available from Western Power. In some circumstances Western Power may also be able to supply fault levels at proposed points of connection and, zone sub transformer rating data and line and cable conductor data. Typical data on feeder loadings may also be available. Where fault levels are not available, estimates can usually be made using typical conductor data.

Whereas access to this information should enable a User to perform a preliminary evaluation of system compatibility, it should be understood that in most cases Western Power will need to perform detailed loadflow and other simulation studies to accurately identify plant limitations and required augmentations.

### B.2 Thevenin impedance

The Thevenin impedance, the short circuit impedance at the point of connection, can be approximated by the sum of the line impedance and the impedances of the transformers normally paralleled. This assumes that the impedance of the system beyond the zone substation transformer HV terminals is negligible compared to that of the substation transformers and distribution feeder.

Assuming that there is only one substation transformer normally supplying the feeder,

$$Z_{th} = 0.651 + j(0.535 + 0.6) = 0.651 + j1.135 \text{ per unit}$$

### B.3 Generator short circuit apparent power

Generator short circuit current or power is required to be supplied with the application. As indicated in Table 2, a conservative estimate is 8 times full load. Therefore the potential contribution to short circuit apparent power of the generators is:

$$S = 8 \times 4.5 = 36 \text{ MVA}$$

This is usually calculated more accurately using the generator subtransient or transient reactances and its pre-fault voltage. Alternatively it can be calculated by one of the methodologies in AS 3851 – 1991 'The calculation of short-circuit currents in three-phase AC systems'.

### B.4 System short circuit apparent power

The system short circuit power at the point of connection is most accurately derived from power system simulation studies. However equation (A5) provides an estimate of  $S_{sc}$ . In this case the value of  $Z_{th}$  to derive the maximum short circuit value would be the impedance of the network configuration with the maximum number of substation transformers and feeders likely to be paralleled for a significant period of time. Assuming that the appropriate

configuration here is one transformer and one feeder and that the pre-fault voltage is 1.0 pu,

$$|Z_{th}| = (R_{th}^2 + X_{th}^2)^{0.5} = (0.651^2 + (0.535 + .6)^2)^{0.5} = 1.305 \text{ p.u.}, \text{ so that from (A5)}$$

$$S_{sc} = 100 / |Z_{th}| \text{ MVA} = 100 / 1.305 = 76 \text{ MVA}$$

Therefore the proposed generators could increase the network fault level at the point of connection to 36+76=112 MVA i.e. by 47%. However the generator fault current contribution would be lessened by the impedance of the transformer(s) connecting the generators to the 22 kV.

If this increased network fault level from connection of the generators causes the short circuit current ratings of network plant to be exceeded it will be necessary to upgrade plant or limit the contribution from the generators. This could take the form of limiting the generator size, increasing the transformer impedance or installing current limiting reactors.

Similarly, the fault current contribution from the network may cause the rating of the User's facility to be exceeded, requiring upgrading before connection.

## B.5 Thermal ratings

At 4.5 MVA the aggregate output of the 3 generators is significant compared to the line thermal rating of 14.3 MVA but is unlikely to cause a line rating problem per se and will tend to reduce load on some segments of the feeder. The CMS and customer transformer must of course be adequately rated for maximum export current. The expected maximum net export of 1.9 MVA would be less of a thermal rating problem. There is however more potential for a network switching hazard as the 1 MW criterion of clause 3.6.9 is exceeded.

When assessing the spare capacity available Western Power also considers the need for redundant capacity to supply additional load when other feeders are taken out of service. Generally feeders are not loaded beyond 4.5 MVA and often the limitation is not thermal capacity but voltage considerations as discussed below.

## B.6 Step voltage changes clause 3.6.8

This section refers to both transient voltage changes caused by connection disconnection and step voltage rise due to power export.

### B.6.1 Transient voltage change 3.6.8(b)

Assuming the incremental change in injection into the network is the full rating of the generators at rated power factor, i.e. 4.5 MVA. The system short circuit apparent power calculated above is 76 MVA.

Table 2 provides a multiplying factor of 1.0 for estimating the transient injection on initial synchronisation of the generators. From equation (A6), the transient voltage change is given approximately by

$$dV\% = 100 S / S_{sc} = 100 * 1.0 * 4.5 / 76 = 5.9\%$$

which is within the acceptable limit of Table 3 of AS/NZS 61000.3.7:2001 that allows up to 7.3% for infrequent switching i.e. no more than every 10 minutes.

### B.6.2 Pre-tap change voltage rise 3.6.8(b)

With the generators synchronised, the initial voltage rise at the point of connection before any compensating effect of substation transformer tap changing, will be given by equation (A7) for which the system Thevenin impedance =  $0.651 + j1.135$  per unit as given above.

Assuming initially that the full generator output of  $3.6 + j2.7$  MVA is exported the step change in voltage  $dV\%$  would be:

$$dV\% = P R_{th} + Q X_{th} = 3.6 \cdot 0.651 + 2.7 \cdot 1.135 = 5.41\%$$

which, as expected, is a similar value to the more conservative 5.9% value calculated above. However this figure does exceed the maximum voltage change permitted by Table 7 of AS/NZS 61000 of 4%.

If the export power factor was raised to say 0.95, the voltage rise would then become:

$$dV\% = P R_{th} + Q X_{th} = 3.6 \cdot 0.651 + 1.18 \cdot 1.135 = 3.7\% \text{ which would be acceptable.}$$

Alternatively, sequentially synchronising generators at intervals of at least 2 minutes apart determined from Table 7 could also reduce the disturbances to acceptable levels. However in this case, as the proposed maximum export power is only  $1.5 + j1.13$  MVA,

$$dV\% = P R_{th} + Q X_{th} = 1.5 \cdot 0.651 + 1.13 \cdot 1.135 = 2.3\% \text{ which is well within the limit.}$$

### B.6.3 Post-tap change steady state voltage rise 3.6.8(c)

The steady state voltage rise is limited to 2%. If it is true that the zone substation OLTC facility returns the 22kV bus voltage to the target value after a short time delay, then the transformer impedance need not be included in the calculation of steady state voltage rise. In this case the voltage rise produced by the export of power at the proposed level is:

$$dV\% = P R_{th} + Q X_{th} = 1.5 \cdot 0.651 + 1.13 \cdot 0.535 = 1.6\% \text{ which is acceptable.}$$

### B.6.4 Voltage levels on the LV network 3.6.8(c)

The connection of the generator(s) must not cause voltage limits in other parts of the network to be exceeded. When a line is heavily loaded it is possible that the full permitted +/-6% range of voltage for points connected to the LV network supplied by fixed tap distribution transformers is utilised as the feeder loading varies from maximum to minimum. The additional variations in voltage imposed by the connection of an unscheduled generator may cause these limits to be exceeded.

Whereas a loadflow simulation may be necessary to establish tap settings and voltage ranges, it is a fairly simple matter to estimate the magnitude of the superimposed voltage changes caused by the connection of the generator. One has to assume first destination of the exported power, into the source zone substation transformer.

The mutual impedances of equation (A9) are derived from inspection of the network so that for buses 1 and 2,  $Z_{12}$  is simply the impedance of 5 km of line and for buses 1 and 3,  $Z_{13}$  is the impedance of 10 km of line (the mutual impedance is the impedance of the common path from the assumed destination of the power flow to the respective busses).

Therefore from the data section and equation (A11),

$$dV_2\% = P_1 R_{12} + Q_1 X_{12} = 1.5 \cdot (5/10) \cdot 0.651 + 1.13 \cdot (5/10) \cdot 0.535 = 0.8\% \text{ and,}$$

$$dV_3\% = P_1R_{13} + Q_1X_{13} = \dots = 1.6\%$$

Therefore the impact of power injection at bus 1 on bus 2 is fairly small at 0.8%, and it could be assumed, in the first approximation, that the same voltage change applies to bus 3. However only a series of loadflow studies could accurately identify the range of voltage regulation at bus 1, and at any other point along the feeder, and how close it is to the +/- 6% limit. Having said that, loads fed from distribution transformers closer to the zone substation would be likely to experience smaller voltage variations than those at a feeder extremity. If line drop compensation is used this advantage may be diminished.

At bus 3, the imposed additional voltage variation of 1.6% is significant especially as the load is at the feeder extremity. Voltage rise due to export of power is often critical during periods of low system loads, and load flow studies may be needed if the additional variation of 0.8% cannot be accommodated. If there proves to be no leeway for accepting a greater voltage variation (as determined by loadflow simulation), then it would be necessary to restrict the voltage variation at the connection point of the generators by some means such as limiting the reactive or real power export.

#### B.6.5 Harmonics

As the generators are synchronous no significant additional harmonic current generation is expected. Nevertheless as the addition of each new item of plant changes the resonant states of the network, a check on harmonic levels may be justified.

#### B.6.6 Flicker

Short term considerations have been covered by the section on step voltage changes above. Long term flicker is not expected to be a problem for gas reciprocating engine technology (as opposed to say wind energy generation). The issue of pole slipping is addressed below.

#### B.6.7 Impact on power line carrier communications

As Western Power does not currently employ power line signalling, this is not an issue at present.

#### B.7 Remote control monitoring and communications 3.6.9

As export potentially exceeds 1 MW, the functions of 3.6.9 (a) are required. 3.6.9 (c) requires a continuous communication link with the control centre for monitoring and control. 3.6.9 (d) requires a telephone link for voice communications.

#### B8 Protection requirements 3.6.10

The relevant mode of operation is permanent/occasional parallel operation, HV connection, export. In this mode of operation all the protection functions specified, other than the disconnect timer, may be required. Generally the User will be required to itemise the proposed protection relays in the distribution generator application form. Following power system studies Western Power would then detail its requirements for protection coordination.

#### B.8.1 Pole slipping clause 3.6.10.2

With a potential fault contribution of some 36 MVA, compared to the system fault level of 76 MVA, there is no doubt that, in the absence of stability studies, pole slip protection will be required.

#### B.8.2 Islanding protection and intertripping 3.6.10.2

As shown on the figure at the beginning of this example, The operation of the upstream recloser on this feeder could potentially result in the load connected to 6 km of feeder (or a section of this) forming an island with the embedded generation. The required islanding protection would normally detect this situation, however it would be necessary to examine the likely minimum network loads to see whether it is plausible that such an island could exist. If this proves to be the case, Western Power may specify some additional safeguards including monitoring or intertripping.

## Appendix C - Further reading

### C.1 Australian and international standards

<b>AS 3010 (2005)</b>	Electrical installations – Generating sets
<b>AS 1359 (1997)</b>	General requirements for rotating electrical machines
<b>AS/NZS 3000</b>	SAA Wiring Rules - in particular sections relating to earthing, clearances and hazardous areas
<b>AS/NZS 4777 (2005)</b>	Grid Connection of Energy Systems via Inverters
<b>AS 1940</b>	The storage and handling of flammable and combustible liquids
<b>AS 60947.6.2 (2004)</b>	Automatic transfer switches
<b>IEC 60255</b>	Protective relays series of standards

### C.2 WA legislation and subsidiary documents

Relevant legislation and other industry information is listed at URL:

[http://www.energy.wa.gov.au/2/3198/64/electricity\\_leg.pm](http://www.energy.wa.gov.au/2/3198/64/electricity_leg.pm)

Relevant legislation and other relevant subsidiary documents are listed below:

Electricity Industry Act 2004

Electricity Act 1945

Customer Transfer Code 2004

Electricity Industry Metering Code 2005

Electricity Industry (Wholesale Electricity Market) Regulations 2004

Wholesale Electricity Market Rules

Renewable Energy (Electricity) Regulations 2001

Electricity Industry (Networks Quality and Reliability of Supply) Code 2005

Electricity Networks Access Code 2004

Western Power's Access Arrangement for the SWIN

[http://www.era.wa.gov.au/2/157/48/western\\_powers\\_.pm](http://www.era.wa.gov.au/2/157/48/western_powers_.pm)

## Western Power's Technical Rules

[http://www.era.wa.gov.au/2/156/48/technical\\_rules.pm](http://www.era.wa.gov.au/2/156/48/technical_rules.pm)

## Distribution generator application form

<http://www.westernpower.com.au/mainContent/connectionsUpgrades/newConnections/Generators.html>

## C.3 Other documents

- [1] Olex Australia P/L Catalogue – Bare Overhead Conductors [www.olex.com.au](http://www.olex.com.au)
- [2] Technical Guide for Connection of Renewable Generators to the local Electricity Network, August 2004. Australian Business Council for Sustainable Energy [www.bcse.org.au](http://www.bcse.org.au)
- [3] Engineering Technical Report No 113, Revision (1) 1995, "Notes Guidance for the protection of embedded generation plant up to 5 MW for operation in parallel with public electricity suppliers' distribution systems", Energy Networks Association, UK.

## C.4 Reference texts

- [4] Nick Jenkins et al. *Embedded Generation, 2000*, The Institution of Electrical Engineers UK
- [5] Geradino A Pete, *Electric Power Systems Manual*, 1992, McGraw-Hill
- [6] Arthur Seidman et al. *Handbook of Electric Power Calculations*, 1996, McGraw-Hill