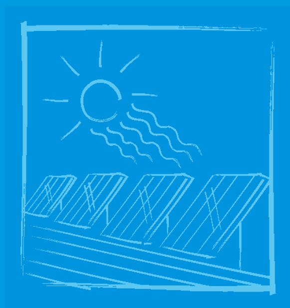
Guide for the Connection of Generating Plant

October 2007



Engineering Excellence

Electricity Engineers' Association

GUIDE FOR THE CONNECTION OF GENERATING PLANT

October 2007

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CONTENTS

1. INTRODUCTION

An electricity distribution network or owner may receive applications to connect and operate private generating plant in parallel with the network.

The applications may arise from the developers of facilities designed solely for the production and sale of electricity. Other applicants may be industrial and commercial enterprises wishing to maximise the utilisation of an energy source by the installation of cogeneration capable of producing from the source both useful heat and electricity. Alternatively, the cogeneration facility may generate electricity using waste heat available from a process.

Efficient parallel-generation requires that all the electrical energy available be fully and profitably utilised either within the plant and/or by sale to an outside organisation. To provide operational flexibility a cogeneration facility normally operates in parallel with an external public power system (external system). Such an arrangement enables the external system to buffer the plant power demand against variations in the internal generation and maintain supply whenever the parallel-generation system is inoperative.

A generation plant that supplies electricity and heat on a stand-alone basis and not in parallel with an external system is normally known as a total energy installation. It does not have the capability to export or import power from an external source and its heat and electrical loads must be carefully balanced. Provision must also be made for a standby electrical supply in the event of a breakdown of the plant.

For a distribution network operator the essential considerations with parallel operation are the safety of the public, personnel and plant under both normal and fault conditions and the effect that parallel-generation may have on the quality and continuity of supply to other consumers.

The parallel-generation plant operator is concerned with similar safety considerations and also the effects that disturbances on the external system may have on the operation of the plant. This will be particularly so if one of the reasons for the installation of parallel-generation is the maintenance of supply to critical processes during power system disturbances.

2. SCOPE

The guide has been produced to:

(a) Assist distribution network engineers with determining the most appropriate electrical arrangements for the connection and protection of parallel-generation plant so that it does not compromise the operation of the external system or endanger staff or the general public; and

(b) Advise distribution network engineers of the protection and supervisory equipment that should be included in parallel-generation plant.

The guide notes specific issues to be addressed for the safe operation of parallel-generation and gives guidance on the manner in which they may be resolved but does not detail specific requirements as each proposal will require a review of the function of the plant and the external supply arrangements. The protection of the parallel generation plant is basically the responsibility of the owner except where by agreement with the distribution network it includes protection arrangements that contribute to the safety of the external system.

Non-technical aspects of parallel-generation such as financial arrangements for the provision of standby capacity and the purchase of energy exported to the external system are not considered as they can only determined by negotiation between the distribution network and the plant owner. The Electricity Governance (Connection of Distributed Generation) Regulations (2007) provide guidance for setting connection contracts between the distribution network (distributor) and generation plant owner (generator). Distribution network companies may also have their own connection agreements.

3. REQUIREMENTS

The installation of private generating plant must comply with:

(a) Electricity Regulations 1997;

(b) The Electricity Governance (Connection of Distributed Generation) Regulations 2007;

(c) AS:NZS 3000 Wiring Rules;

(d) Part C of the Electricity Commission's Electricity Governance Rules for Generators Greater than 1 MV;

(e) Electrical Code of Practice 35.

The Ministry of Economic Development (MED) regulations encourage the development of embedded generation and enable connection of distributed generation where connection is consistent with connection and operation standards.

The regulations specify processes (including timeframes) under which generators may apply to distributors for approval to connect distributed generation (including the information to be exchanged and the criteria for approval); regulated terms that apply to the connection of distributed generation in the absences of contractually agreed terms; pricing principles to be applied for the purposes of the regulations; and a default dispute resolution process for disputes relating to the regulations.

4. PARALLEL-GENERATION PLANT

The main types of generation plant suitable for operation in parallel with an external supply are discussed in Appendix 2.

The characteristics and operation of the prime mover and related plant such as boilers must be considered by the parallel-generation plant designer as they may affect the design or operation of the generator. These considerations are not within the scope of the guide.

5. PLANT SELECTION

5.1 Introduction

The generation plant selected by the owners will be determined primarily by the intended function of the installation, the type of prime mover and the equipment rating. The selection procedure should also consider the requirements of the distribution network with whom parallel operation will be required.

5.2 Generation Voltage

Generators above 1250 kVA are unlikely to be rated for operation at 400 V as the resultant high currents require the installation of costly switchgear and cabling. Depending on the plant distribution arrangements more economic generation voltages may be 660, 3300 or 11000 V. For reliability the lower voltages may be preferred but the final selection will depend on the overall requirements of the installation.

6. SPECIAL ASPECTS OF PARALLEL-GENERATION

A customer installation without parallel-generation may be expected to have little effect on an adequately rated supply system and will not require active day to day consideration by the operations staff of a distribution network. With parallel-generation the operations of the customer may, to an extent depending on the size of the plant, affect the distribution network. The following aspects must be considered for any proposed installation:

(a) Ability of plant to energise (backfeed) the external system;

(b) Possibility of inadvertent asynchronous paralleling with the cogenerator on restoration of the external supply;

(c) System earthing;

(d) Fault level contribution (to external and plant systems);

(e) Isolation facilities available to distribution network personnel;

(f) Effects of supply network faults or power quality (frequency and voltage tolerances) on the consumer's installation.

The above considerations apply irrespective of the generation voltage or power level but the measures to be adopted to satisfy a particular aspect will be dependent on the intended function and operating parameters of the installation.

To prevent inadvertent energisation of the external system or asynchronous paralleling on restoration of supply, the parallel connection between the parallel-generation plant and the external system must be opened on failure of the external supply. The point of disconnection will depend upon the intended function of the cogeneration particularly in respect of emergency and back-up power. Cogeneration plant intended to provide a no-break supply to the site may have as the disconnection point the main switchboard external supply incoming circuit breaker. Disconnection in other circumstances may be expected to be at the generator.

In general disconnection of the parallel connection on failure of the external supply should always be automatic but this may be subject to modification for some attended sites.

7. CUSTOMER │ ELECTRICITY DISTRIBUTION NETWORK INTERFACE

7.1 Consultation

A distribution network with whom parallel operation is required must examine closely the impact of parallel-generation on its network. Early consultation and exchange of information is required between the parties concerned so that the distribution network requirements and system parameters may be taken into account during the plant selection process.

7.2 *Information Required by Distribution Network*

A distribution network will require the following information to examine a proposal for the parallel operation:

(a) Type of generator unit (synchronous, asynchronous, inverter, etc)

(i) Plant function, rating and type of prime mover.

(ii) Plant operation and supervision, eg:

- Attended plant with skilled operators.
- Remote supervision and control.
- Unattended with fully automatic operation.

(iii) Estimated daily peak, minimum and average import / export power flows:

- With generation.
- Without generation.
- For asynchronous generators, reactive power requirements (kVAr).

(iv) Process start-up or other infrequent peak demands (if not included in item (c) above).

(v) Plant electrical single line diagram showing:

- External supply connection points, all relevant switchboards and switchgear, generator and associated neutral earthing arrangements.

- Generation and plant distribution voltages.

- Fault and normal ratings of associated site switchboards and switchgear, current and voltage transformer ratios, rated burdens and overcurrent / overvoltage factors.

- Synchronising points.

- Protection and control systems.

- Generator transformer details.

- Electrical Parameters of generator.

(vi) Parallel-generation plant fault contribution.

(vii) Maximum motor starting currents.

(viii) Customer requirements for external supply reliability.

The above information will enable the distribution network to assess the plant category, required capacity of the external supply, system configuration, and protection. Other aspects to be reviewed will be:

(b) Earthing.

(c) Metering.

(d) Protection.

(e) System control.

(f) Auto-reclosing on the external system.

(g) Generator.

7.3 Categories of Operation

Co-generation plant may be put into three main categories.

7.3.1 Category 1

Plants intended to:

(a) Export power to the distribution network system either continuously or at irregular times as dictated by the site heat or process requirements or by the external system peaks;

(b) Provide a no-break supply to all or part of the site in the event of disturbance or loss of the external supply.

Many installations will be required to incorporate both functions and may be expected to be the subject of specialist design and specification.

These plants may be of some megawatts rating and be capable of energising, without significant disturbance in their operation, an isolated section of the external system. The distribution network will need to carefully review the protection of such plants to ensure that they will discontinue parallel operation on loss of the external supply or incorporate protection for the detection and clearance of faults in the external system.

For the safety of personnel and prevention of damage on restoration of supply the distribution network may need to be able to determine and control, either by direct communication with a plant operator or some other means, the position of the switchgear at the paralleling point.

7.3.2 Category 2A

Plant not required or permitted to export power even though there may at times be generation capacity in excess of the plant demand. The generator output may be limited by a prime mover control system to be less than the site load so power is always imported from the external system. Loss of the external system will be manifested by the loss of import power. Export power may occur briefly as the controller adjusts for sudden reductions in plant load or changes in system frequency.

The parallel-generation system may be designed so that parallel connection is disconnected whenever the import power falls below a predetermined minimum value. Should the control system then detect that the external supply is defective or missing the prime mover may be stopped and inhibited from restarting until the external supply voltage is restored and the plant load is at a suitable level.

7.3.3 *Category 2B*

Category 2A plant intended to provide emergency or standby power. The distribution network will need to be assured that the plant will automatically isolate the external system by changeover devices or other means before the parallel-generation plant restores power to the site.

7.3.4 *Category 3A*

Co-generation with a continuous site demand at all times of parallel operation of greater than 150% of the maximum possible on-site generation.

Provided they incorporate undervoltage and underfrequency (underspeed) protection such parallel-generation plants are essentially self protecting as failure of the external supply may be expected to cause on or both protective systems to operate and disconnect the generator.

Note: It is important that the plant load be of a type that will remain connected to the generator until disconnected by the operation of either the generator undervoltage or underfrequency protection.

7.3.5 *Category 3B*

Category 3A plants which are intended to provide emergency power to essential services on failure of the external supply. For these plants, the distribution network needs to be assured that the external system will be isolated from the site system in the same manner as category 2B plant.

8. PLANT MANNING

The supervision and operation of parallel-generation plant will be dependent upon the intended function of the equipment and the staff arrangements at the installation site.

Co-generation facilities associated with an industrial process may have continuous attendance by operators with the skills necessary for the operation and synchronising of generating plant. Such attendance may be expected to provide distribution network operations personnel with good communications and enable them to readily obtain information on the status of the plant.

Co-generation facilities designed for the production of heat and electricity for buildings and similar purposes may be automatic unattended packaged units. For these an distribution network may require the customer to provide equipment and facilities for remote monitoring of the unit unless they are satisfied that in the event of a loss of the external supply the paralleling connection will be reliably disconnected so that the generator will not be a hazard to personnel or delay the restoration of supply.

9. TECHNICAL ASPECTS

9.1 *Generator Earthing*

The Electricity Regulations 1997 require earthing be such that protective devices operate effectively; that the voltage is controlled within the design voltage rating; and that step, touch and transfer voltages are controlled to a safe level. Electrical Code of Practice 35 is a method of compliance. High voltage systems are to be provided with an earthing point at the source of supply and that the neutral conductor of low voltage systems be multiple earthed in a prescribed manner. Commonly high voltage systems are earthed at only one point.

A high voltage generator may be unearthed when connected in parallel with an earthed external supply system but must be provided with an earth point when operating as an independent (islanded) source of supply.

In circumstances where an embedded generator is of sufficient capacity to export onto the distribution network and there is a possibility of a viable island being formed in the event of the feeder tripping, provision of a high voltage side earth point for the generator is required. Hence the vector group of the generator transformer should be equipped with a HV side star point. The earth reference provided will ensure that earth faults on a feeder will be deleted by the generator protection and the unit tripped. Failure to provide an earth reference may result in an un-earthed island being maintained by the generator, with consequential safety risks and potential damage to other network equipment.

The choice of the vector group for a generator transformer must be carefully approached. If a core type star-star transformer with solidly bonded neutrals is used, network earth faults will be reflected into high earth currents in the generator. As a result, if a star-star vector group is to be used, the use of impedance earthing for the generator / or side star point should be specified to limit earth currents in the generator.

Low voltage synchronous generators operating on an islanded basis and supplying phase to neutral connected loads must have in accordance with **NZS 6104 or AS3010.1** their star point directly connected to an earthed neutral to minimise, in the event of a single phase to earth fault, the phase to earth potential rise of the sound phases. Other earthing arrangements may be acceptable but will require expert assessment in respect of system safety.

The requirements for earthing, apart from enclosure / frame protective earthing in accordance with normal safety requirements, do not apply to asynchronous generators as they are unable to generate, unless provided with a means of self-excitation, until connected to a supply.

The connection of a generator with an earthed star point to an external system provides an additional source of earth fault current and a path for circulating currents arising from third harmonic voltages present in the generator output waveform. The consequences of these effects depend on whether the generator is connected directly to the external system or through a transformer. The former will generally apply if the generation and external supply voltages are the same. Differing generation and external system voltages will require the generator to be connected through a transformer and this will generally apply at a site with low voltage generation and a transformer substation with a high voltage incoming supply.

Various methods of generator earthing, their effects and some design considerations are discussed in Appendix 3.

10. PROTECTION

10.1 Electricity Supply Authority Requirements

The overall protection scheme required for any particular installation will be influenced by the method of connection of the generator to the Electrical Supply Authority's system and the classification of the plant in accordance with the criteria noted in Section 7.3.

The distribution network will need to ensure that its system is protected against:

(a) Customer site faults;

(b) Fault current available from the generation plant;

(c) Generation plant maloperation;

(d) Islanding or backfeed of sections of the external system when isolated from the normal distribution network source of supply.

(e) Backfeed of faults on isolated sections of the external system.

The external system will be protected against overload and internal site faults by the incoming protection normally provided by the distribution network. This may also be sufficient for the protection of the external system from the fault currents available from the site. The plant owner may elect to install additional protection to ensure that an external fault will no shut down the site generation.

The distribution network must ensure that the parallel connection of the parallel-generation plant will not compromise the operation of the protection arrangements provided on the external system.

The operation of private generation plant should not affect the external system or other customers. The plant should incorporate controls and protection that will ensure that paralleling operations do not cause excessive voltage fluctuations and that maloperation will not result in the application of a fault condition.

To implement these objectives the generation control and protective equipment should:

(a) Inhibit parallel operation unless all phases of the supply are available and within normal limits;

(b) Disconnect the generator in the event of unacceptable deviations of voltage or frequency;

(c) Disconnect the generator in the event of loss of the distribution network supply;

(d) Disconnect the generator at unattended installations and inhibit parallel operation on failure of any supplies that will prevent the correct operation of protective equipment;

(e) Raise, at attended installations, audible and visual alarms on the failure of any supplies that will prevent the correct operation of protective equipment.

To prevent backfeed of sections of the external system isolated from their normal distribution network source of supply the generation plant should be able to reliably detect, under all conditions of parallel operation, loss of the external supply. Should the distribution network permit the parallel-generation plant to operate without such protection it will be necessary to provide other protection that will ensure that the external system remains safe and that any faults are cleared within an acceptable time. It will also be necessary to ensure that all distribution network staff are aware of the possibility of maintained energisation from the parallel-generation site.

Category 1 parallel-generation plant will generally be expected to overcome loss or disturbances of the distribution network supply and maintain, without loss of continuity, power to all or part of the customer's site. In such circumstances the point of disconnection between the energised site distribution and the external system will be an open circuit breaker. The distribution network will need to take appropriate measures to ensure the safety of personnel working on parts of the external system connected to the parallel-generation site. This may include the provision at the site of a means of isolation accessible to distribution network personnel at all times.

Co-generation plant powered by an internal combustion engine or other prime mover which may be started in the absence of a power supply will have the capability to energise parts of the external system. The parallel-generation equipment should include interlocking and changeover arrangements to preclude such an occurrence but work practices on the external system should also make allowance for inadvertent energisation from an appropriate parallel-generation source.

10.2 Customer Protective Systems

To protect against maloperation and achieve the disconnection objectives outlined above the minimum protection to be provided by the customer for unattended automatic parallel-generation plant will comprise:

(a) Loss of external supply;
(b) External system over-voltage;
(c) External system under-voltage and phase balance;
(d) External system over and under frequency.

Monitoring of the external system voltages and phase balance should be immediately adjacent to the contactor or circuit breaker making the parallel connection to ensure that the supplies are healthy at that point and have not been compromised by the operation of fuses or other switching / protection.

Attended parallel-generation plant with manually initiated synchronising should be provided with a minimum of undervoltage, phase balance and underfrequency protection, all operative under parallel operation.

The plant owner will be responsible for ensuring that the generator and associated plant incorporate protective systems that will protect and safeguard them against any damage or other effects arising from faults on, or loss of, the distribution network system.

Detection of loss of the external supply will depend upon the category of the parallel-generation plant and the resultant load seen by generator. Should the latter be considerably in excess of the plant rating it will appear as a severe overload or partial short circuit on the generator and operate one or more protective systems.

For category 1 systems (export power permissable) the type of protection that will detect loss of the external supply is dependent on the load that may be guaranteed to remain connected to the co-generator. Should the generator system be able to maintain supply to the remaining external load the primary protection systems (underfrequency, undervoltage or overcurrent) will be unable to determine that an abnormal condition exists and the generator may backfeed the external system.

Loss of the external supply may be determined by providing the external system with a fixed amount of export reactive power that it is able to accept under normal operation but will reject in the event of a supply failure. To implement this, the co-generator must be provided with a control system that sets the export reactive power to a fixed value and discontinues parallel operation if this cannot be maintained.

Other common techniques for the detection of loss of external supply are risks of change of frequency (ROCOF) and vector shift.

ROCOF protection operates on the principle that if generation is islanded with a portion of feeder load, the resulting generation deficit will cause a rate of change of frequency on the islanded system. ROCOF has the advantage of sensitivity and dependability in detecting the loss of network connection when the rate of change of frequency is relatively slow. This occurs when the capacity of the generator is closely matched to the islanded load, which is the most onerous condition for protection to detect. However, stability of ROCOF relays is often considered inadequate, due to nuisance trips caused by frequency exclusions due to grid generation trippings or phase shifts caused by faults and switching the local network.

Vector shift protection is a technique which monitors the motor displacement angle of the embedded generator, for a shift caused by the disconnection of the network supply. The rotor displacement angle and the voltage difference between the synchronous electromotive force and the terminal voltage of the machine. When the network supply is disconnected the increased load on the generator causes a shift in the rotor displacement angle. A recommended vector shift setting is 6 degrees, but a setting of 12 degrees may be required on a weak network to avoid nuisance operation for switching of heavy consumer goods.

For category 2A and 2B systems (export power not permitted) loss of the external supply may be determined by the detection of loss of power flow into the site.

Category 3A and 3B systems will be overloaded by their guaranteed site load on loss of external power and will disconnect the generator through their undervoltage or underfrequency protection. The controls systems for category 3B plant will then configure the switchgear so that the generator may provide emergency or standby power.

The setting of the protection equipment will be dependent upon both the Electrical Supply Authority's system and the requirements of the co-generator. Suggested settings for low voltage plant are given in Appendix 1.

Plants that automatically restore parallel operation should be arranged with a time delay to ensure that all parameters remain continuously within acceptable tolerances for at least 60 seconds before attempting to reset. This time may need to be extended for areas where the external supply may be subject to frequency supply disturbances under storm conditions. It should also exceed the reclosure intervals of any auto-reclosing scheme affecting the generation site. Internal faults on the generation equipment should also inhibit the automatic reset facility.

10.3 Generator and Prime Mover Protection

10.3.1 General

The owner of private generating plant will be responsible for ensuring that the plant design, installation and operation complies with all safety and other statutory and regulatory requirements and the recommendations of the plant designer and manufacturer.

10.3.2 HV Generators

HV generators should be provided, as a minimum, with overcurrent, earth fault and reverse power protection. To minimise damage in the event of a fault the plant owner may also apply:

(a) Restricted earth fault or winding differential current protection;
(b) Loss of excitation protection;
(c) Winding temperature monitoring.

Winding temperature monitoring should in the first instance cause an alarm. All other conditions should open the generator circuit breaker. Restricted earth fault and differential current protection should also remove the generator excitation and stop the prime mover.

10.3.3 LV Generator

The installation, control and protection of the prime movers and generators of engine driven low voltage generation plant must comply with the appropriate clauses of **NZS 6104 or AS3010.1**. These standards require that generators be provided with overcurrent protection and also detail requirements for the changeover devices for plant intended for standby and emergency generation.

To provide increased protection and minimise damage the plant owner may incorporate:

(a) Core balance restricted earth fault protection;
(b) Loss of excitation;
(c) Reverse power.

All the above should disconnect the generator. The core balance protection should also remove excitation and stop the prime mover. Reverse power should also stop the prime mover.

10.3.4 Prime Movers

Generator reverse power protects prime movers against motoring. Prime mover shutdown systems should be arranged to open the generator circuit breaker or other disconnecting device. The system initiating the trip should be identifiable and remain so until reset by authorised personnel.

10.4 Inverter Corrected Energy Systems

Inverters are used to connect various types of energy sources operating on direct current to an ac distribution system. Photo voltaic (PV) star parcels are the most common example with small wind generators also using this method. Information within the Australian Standard Grid Correction of energy systems via inverters (AS 4777-2002) is a useful reference when considering technical aspects of installation, testing and protection of these devices.

The standard is in three parts; part 1 covers installation requirements, part 2 inverter requirements, and part 3 grid operation requirements. The standard applies to inverter energy systems with ratings up to 10 kVA for single phase units, or up to 30 kVA for three-phase units. However, similar principles can be used for the installation of larger systems.

(a) The main provisions of part 1: Installation Requirements cover:

- illustration of possible connection arrangements including UPS connections;
- inverter and grid protection device requirements;
- ac circuit arrangements;
- isolation of inverter from energy source;
- labelling of the installation to ensure safe isolation and generation; and
- requirements for UPS systems.

(b) The main provisions of part 2: Inverter Requirements cover the following:

- compatibility with electrical installation;
- power flow to be ________directional;
- power factor limits;
- harmonic current limits;
- electromagnetic compatibility;
- voltage fluctuations and flicker compliance;
- impulse protection;
- transient voltage limits;
- direct current injection devices; and
- date logging and communications devices.

(c) The main provisions of part 3: Grid Protection Requirements are as follows:

(i) As general and safety requirements:

- electrical safety requirements;
- connection to low voltage network;
- electromagnetic compatibility;
- voltage flicker;
- impulse protection; and
- data logging and communication devices.

(ii) As grid protection requirements:

- operation of the protection is required if a supply from the grid is disrupted; orbs when the grid goes outside present voltage and frequency parameters; or c) to prevent islanding;
- requirements for a disconnection device;
- voltage and frequency limits;
- limits for sustained operation (under consideration);
- active anti-islanding protection;
- reconnection procedure;
- security of protection settings; and
- **compliance with grid protection requirements including type testing procedures.**

11. INSTRUMENTATION

The basic instrumentation for a generator should comprise:

(a) Voltmeter;
(b) Ammeter;
(c) Wattmeter;
(d) Power factor indicator (leading and lagging quadrants) or VAr meter.

The distribution network incoming circuit breaker should be similarly equipped. If the plant is to export power the wattmeter and VAr meter must be capable of displaying both import and export conditions.

12. METERING

Energy revenue metering must be provided (generally by the generator owner or retailer) and must be capable of accurately recording energy used under the following conditions:

(a) Maximum import demands (parallel-generation on and off);
(b) Maximum export capability;
(c) Normal operating conditions.

The latter condition may be one where the parallel-generation output is equal or close to the site demand and the customer 'floats' on the external system for long periods of time. Under such conditions the small changes in reactive power flow will cause considerable variation of the plant incoming power factor. The metering arrangements and the plant demand must therefore be carefully reviewed to ensure accurate metering under all conditions.

13. SYNCHRONISING ARRANGEMENTS

The synchronising arrangements to be provided will depend upon the category of the parallel-generation plant. Category 1 plant that is required to maintain continuity of supply should allow, with suitable switching and interlocking, for synchronising across all switches capable of paralleling the external supply and the parallel-generation equipment without shutdown of either system. In general, this will encompass:

(a) Supply authority main incoming circuit breakers;
(b) Generator circuit breakers;
(c) Bus-section switches.

Categories 2 and 3 plant will require synchronising facilities only across the generator switching device (contactor or circuit breaker).

All switches across which synchronising will take place must be rated for the maximum fault currents that they may be required to make or break and the maximum voltage that will be impressed across their open contacts.

Synchronising should preferably be performed automatically by a synchronising relay. For emergency operation manual synchronising facilities may also be provided.

14. OPERATIONAL ASPECTS

14.1 Introduction

When privately owned generating plant is operated in parallel with an external system, such plant must be regarded as part of that system.

For safety all distribution network staff operating and working on the system should be aware of the location of parallel-generation sites and their points of connection with the system.

Communication and procedures for the safe operation of the parallel-generation plant should be agreed and implemented by all parties concerned. Where applicable they should form part of the operating agreement between the distribution network and the customer.

The requirements of the distribution network will need to consider both the size of the plant and whether it is to be an attended or an automatic unattended installation. The latter may require that the distribution network be able to disconnect or restore supply to the consumer's premises, without notice, should the presence of the generator be considered a potential hazard to work being carried out on the system.

14.2 Communications

The distribution network control engineer should be able to contact a member of the generation plant staff authorised to deal with any emergency situation. For an attended site the distribution network and the plant management should formulate procedures that will enable the distribution network engineer to readily contact the appropriate plant operations personnel. For unattended plant the distribution network engineer should have available the names, addresses and after-hours telephone numbers or other means of contacting nominated plant personnel.

The distribution network should also agree with the operators of parallel generation plant procedures regarding the reporting of any occurrence within the plant which may have caused disturbance to the external system and other distribution network customers.

14.3 Personnel

Customer's employees responsible for the operation of attended generating plant who may be required to operate high or extra high voltage switchgear should be 'competent' in accordance with the Electricity Regulations 1997, the Health Safety and Employment Act, and the technical/safety requirement relating to the work they are undertaking. Such personnel need not have a recognised electrical qualification but must receive training in the work and attend regular refresher courses. In the absence of such personnel arrangements may be made for the distribution network to carry out the operations required.

It is essential that the operating personnel of attended generation plant are instructed in the electrical aspects of the plant operation and are trained to deal with emergency situations.

14.4 Plant Diagram

A legible plant diagram should be prepared and displayed in an appropriate area of the generation plant. The diagram should show the connections between the distribution network system and the plant, ownership boundaries and any other details necessary for a proper understanding of the scheme.

14.5 System Diagrams

The location of the generating plant and associated HV switchgear should be noted on all HV system diagrams used by the distribution network switching and control room operators. Notices, warning of the possibility of an unsynchronised supply, should be fixed to main substation circuit breakers controlling the HV feeders to the generating plant.

14.6 Isolation

Where any work is carried out on the distribution network's HV lines, cables or equipment in the vicinity of the generating plant should be isolated from the generating plant in accordance with the safety procedures of the distribution network.

14.7 Commissioning Tests

The distribution network's engineer must be given, with an agreed period of notice, the opportunity to witness all testing and be satisfied that, prior to the first synchronisation, all protective systems are in place and operating correctly. The first synchronisation may not be carried out without the permission of the distribution network but such permission should not be unreasonably withheld once the distribution network is satisfied that the plant meets the appropriate electrical regulatory requirements and that all protective systems are operating correctly.

Testing must include full functional testing of synchronisation equipment prior to first synchronisation, protection equipment and all other tests as may be appropriate for a particular generator and its associated network.

Following synchronisation the distribution network should check that the equipment provided for the detection of loss of the external supply is fully and reliably functional. These tests should be repeated on an annual basis, or such other period as the distribution network may decide, to verify the serviceability of the protection.

15. TECHNICAL DISPUTES

Should the distribution network and the private generation plant owner or operator not be able to resolve disputes over technical aspects of interfacing the plant with the distribution network system, the matter should firstly be referred to a mutually acceptable independent expert for resolution. If the matter can then not be resolved, dispute resolution shall be in accordance with the Electricity (Connection of Distributed Generation) Regulations (not available yet).

APPENDIX A

A1 Recommended Protection Settings for Parallel-Generation Plant

RECOMMENDED PROTECTIVE SETTINGS			
Protection	**Phases**	**Trip Setting**	**Tripping Time**
Overvoltage	All to neutral	+10%	1.0 second
Undervoltage	All to neutral	-10%	1.0 second
Underfrequency	One	-2%	1.0 second
Overfrequency	One	+2%	1.0 second
Vector shift	One	6 to 12 degrees	1.0 second

The total tripping time is the elapsed time between the initiation of the trip and the opening of the parallel connection.

The above settings and tripping times are for guidance and may be varied in consultation with the Distribution Network Operator to suit the requirements of any particular site.

For inverter Connected Energy Systems refer to AS/NZS4777 for protections elements and settings.

APPENDIX B

A2 Generating Plant

This Appendix discusses the main types of generating plant suitable for parallel operation with a public supply system but does not form a complete list.

A2.1 Synchronous Generators

Synchronous generators provide an a.c. voltage at a frequency determined by the number of poles and speed of the machine. They are capable of independent (isolated) or parallel operation, the latter with either an extensive supply system or one or more other generators. To avoid unbalanced loading only 3 phase machines are suitable for parallel operation with a public supply system.

The frequency of the supply provided by an isolated generator is determined by the speed of the prime mover and the voltage by the field excitation. The generator power output and power factor will always match and be determined by the applied load.

A generator operating in parallel with an extensive supply system is effectively connected to an 'infinite bus' that will determine both its frequency (speed) and voltage. The power output of the generator will nearly equal that of the associated power mover. The power factor will be determined by the field excitation. An increase in prime mover power and generator field excitation will increase respectively the generator power and lagging reactive Volt Ampere outputs.

Changes in system frequency will cause corresponding changes in the speed of any parallel connected generator. Depending on the characteristics of the prime mover and its fuel control (governing) system the changes may be reflected as variations in generator output. In general a generator driven by a prime mover equipped with governor responsive to speed will increase its power output with falling system frequency. This may require the provision of an automatic prime mover power limiting control system.

A group of generators operating in parallel but isolated from the grid will have an operating regime between infinite bus and isolated operation. A change in the power output of one machine will cause an overall frequency and speed change detectable by the prime mover governors of the other parallel generators. These governors will respond by adjusting fuel flows so that the power output of all other generators changes and compensates for power variation. A change in the excitation of one generator will have an effect on the overall generation voltage and through this the reactive power generated by the other generators.

Generators should always be equipped with an automatic voltage regulator (AVR) capable of maintaining the machine voltage within suitable tolerances under isolated operation. This is particularly important for generators required to maintain plant electrical supplies following disconnection from the external system.

Under parallel operation an AVR reacts to changes in system voltage adjusting the generator excitation in a direction that would, under isolated operation, restore the voltage to the AVR set level. The change in excitation modifies the generator power factor but does not alter the system voltage. A drop in system voltage will cause the AVR to increase the excitation and thus the generator lagging VAr output.

To reduce the effects of variations in system voltage an AVR is modified for parallel operation by the application of a compounding signal proportional to the generator reactive load current. The signal, obtained from a current transformer located in an appropriate generator phase, causes the AVR to reduce the excitation current with any increase in the lagging reactive current provided by the generator. Compounding degrades the AVR voltage regulation performance and may be deactivated for isolated generator operation should closer regulation then be required.

AVR's may be provided with ancillary systems that will enable the generator reactive power to be kept within close limits. They may also monitor the reactive component of the site incoming supply and adjust the alternator excitation to maintain the incoming reactive power within set limits. The generator power factor will vary with changes in the plant loading and it may be necessary to provide an overriding generator VAr limit control.

Many AVR systems derive excitation power from the generator output terminals. Voltage depressions due to system faults may cause the excitation to collapse and reduce the fault currents available from the generator. Such systems should incorporate an excitation boosting scheme that is able to maintain a generator short circuit current sufficient for the proper operation of associated protection systems.

A2.2 Asynchronous Generators

An induction motor of standard construction will normally have a rated full load speed 3 to 4% below synchronous speed. The difference between the motor synchronous and rotor speeds, the slip, generates the rotor conductor currents that enable the machine to provide a mechanical power output. The slip is dependent upon the motor load and at no-load will be close to zero. The rotor then rotates at close to the machine synchronous speed.

By connecting the stator of an induction machine to the main supply and mechanically driving the rotor above synchronous speed the machine will have negative slip and function as an asynchronous generator transferring energy from the prime mover to the supply system. By increasing the speed of the prime mover the generated output may be increased from zero to the power limit of the prime mover or the rating of the generator. To generate the machine must always have a negative slip (rotor speed higher than synchronous) which will be close to zero at low power output and a maximum at rated output.

When operating as a motor an induction machine is capable of providing a maximum torque at a speed some 8% to 12% below synchronous speed. As a generator it is able to provide peak output with a similar percentage increase above synchronous speed. At speeds above the peak power point the generation capability steeply reduces with increasing negative slip and the prime mover may quickly reach an overspeed condition.

The asynchronous generator is able to operate with simpler control equipment than that required for a synchronous machine. However, consideration may need to be given to the method of switching a machine onto the system as the magnetising inrush current may be of the order of 7 or more times full load current even if the machine is up to synchronous speed before switching in.

Asynchronous generators are dependent on the supply to which they are connected for their magnetising (excitation) current and will cease to generate on failure of the supply. However, should there be sufficient leading reactive energy available, either from the capacitance of the supply system remaining connected or from elsewhere on the consumer's installation, a rotating generator may self-excite and generate at a voltage above normal. In an extreme case with high prime mover overspeed the voltage rise may be sufficient to endanger the machine insulation.

A site with an asynchronous co-generator installation may appear to the external system as a low power factor load due to the decreased kW demand arising from the generation and increased kVAr demand arising from the machine magnetising current. This may be corrected with the installation of capacitors but the system design must ensure that they will not cause self-excitation of the generator.

An asynchronous generator may be excited with a locally connected controlled variable capacitance to provide an asynchronous generator capable of independent operation in a manner similar to a synchronous machine. The application is normally limited to low power (micro-hydro) installations.

A2.3 Static Plant

A2.3.1 General

Two types of static plant are capable of converting direct current (dc) to alternating current (ac) and are commonly used in conjunction with process plant.

A2.3.2 Self Commutated Static Inverter

Power electronic(s) equipment primarily for the conversion of dc to ac at a frequency and voltage determined by the associated control equipment but which may also be designed to transfer power in the reverse direction. The equipment is capable of independent operation similar to a synchronous generator and may be operated in parallel with other inverters to increase the system capacity or improve the security of supply.

A2.3.3 Line Commutated Static Inverter

Power electronic equipment for the conversion of dc to ac at a voltage and frequency determined by the system to which it is connected. The device can only operate in parallel with generation plant capable of determining the system frequency and voltage.

This equipment is also capable of rectifying ac to dc.

APPENDIX C

A3 Generator Earthing

This Appendix briefly discusses methods of earthing private generators and the effects on the external supply system. The subject is complex and other methods of earthing may be of advantage for particular applications. Where necessary expert advice should be obtained.

A3.1 Generator Directly Connected to External System

A3.1.1 General

Direct earthing of the generator neutral will enable third harmonic (150 Hz) voltages present in the generator waveform to circulate currents of the same frequency through the external system phase conductors, supply transformer and earth electrode. On extra high and high voltage systems the currents may operate earth fault protection relays not specifically designed to reject third harmonics and subject the external system to unnecessary shutdowns. They may also cause telephone interference particularly if they flow in overhead lines.

Direct connected low voltage systems may be expected to be applicable only to parallel-generators of relatively small rating. They may however give rise to neutral circulating currents that are a high proportion of the generator full load current and thus relatively large. Direct connection will enable them to flow in parts of the supply system external to the parallel-generation site and they may then give rise to interference with telephones and other customers.

An earthed directly connected generator provides the external system with an additional source of earth fault current and the distribution network should examine the effects of this infeed on the settings and function of their protective systems.

The above considerations and the possibility of damage to the generator on the occurrence of an earth fault make it desirable that the generator neutral to earth connection be opened or provided with a current limiting impedance when operating in parallel with the external supply.

For extra high and high voltage systems generator neutral earthing may be provided by:

(a) Switched star point earthing;
(b) Neutral resistance / impedance;
(c) Earthing transformer.

A3.1.2 Switched Star Point Earthing

The connection between the generator neutral and the earth electrode is provided through a power operated switch arranged to open automatically when the generator operates in parallel with the external system and close at all other times. The switch enables an earth to be maintained on the site distribution system and the generator whenever the external supply is isolated from the site.

The operation of the automatic switch is dependent upon the status of the incoming supply and incoming circuit breaker. For parallel-generation plant with export capability loss of the external supply, particularly due to an earth fault on the supply feeder, may be difficult to detect and may not cause the incoming circuit breaker to trip. As a consequence the star point switch will not close and the generator may continue to energise the feeder as an isolated unearthed system with an earth fault on one phase.

An earth fault on one phase of an isolated unearthed generator will cause the other phases to have line to ground potentials equal to the system line-to-line voltage. To detect such faults the generator should be provided with neutral displacement protection by a suitable voltage relay energised from the secondary of a voltage transformer connected between generator neutral and earth. The system will detect an earth fault on both the external supply and the plant systems but will be unable to provide discrimination between the two.

Consideration may need to be given to the installation of a suitably rated surge diverter connected between the neutral point and the earth electrode to suppress any transient overvoltages that may appear at the star point.

A3.1.3 Neutral Resistors and Reactors

A resistor or reactor connected between the generator neutral and the earth will reduce both the maximum earth fault current available and the third harmonic circulating currents.

The resistor may be of a value that will limit the maximum generator earth fault current to a level that will allow reliable operation of current operated earth fault protection (low resistance earthing) or a higher value (high resistance earthing) that will limit the fault current to a very low value.

A high neutral resistance system may be expected to reduce harmonic circulating currents to a manageable level but this may not be achieved with the lower value of resistance required for the operation of current operated earth fault protection. In such circumstances the low value resistor may be replaced by a reactor that will allow the same earth fault currents but will present a higher impedance to the harmonic currents.

To minimise the generation of the high transient voltages by arching faults the earth fault current should not be limited by high resistance to less than the phase capacitive current. Typically on an 11 kV system high resistance neutral resistors limit generator earth faults currents to 5 Amperes.

A high resistance neutral earthing system should be provided with neutral displacement detection in the same manner as the switched star point scheme. The scheme is unrestricted in operation and will not allow the discrimination of earth faults. An earth fault on one phase will cause the remaining phases to experience line to earth overvoltages approaching the system line to line voltage.

A3.1.4 Earthing Transformers

Harmonic circulating currents may be eliminated by the provision of a generator or busbar earthing transformer which will provide the system with an earth point without direct earthing of the generator neutral. The system is capable of providing, subject to proper design and implementation, the fault currents required for the reliable functioning current operated protection relays.

Earthing transformers may be provided with (a) low value neutral or line resistors or reactance, to limit the maximum value of earth fault currents.

A3.2 Generator Transformer Connected to External System

The power levels involved with parallel-generation, even for small applications, will generally require the establishment of a site transformer substation. Transformer connection of the parallel-generation plant to the external system may therefore be expected to apply more to low voltage systems rather than high voltage. An exception would be a site with a high voltage distribution system at a voltage level different from that of the generator.

Subject to the use of a transformer with a suitable vector grouping the connection enables harmonic circulating currents to be confined to the site and not circulate through the external system.

The neutral of any low voltage three phase power source providing single phase power for lighting or general purposes is required, for safety, to be directly earthed. If the supply is from several parallel sources the system neutral must at all times be provided from at least one of the sources in services.

Modern low voltage generators of the same manufacture, type and rating and with windings configured to minimise the third harmonic content of their voltage waveform may be expected to operate satisfactorily in parallel with all generator neutrals directly earthed. This however may not apply to the parallel connection of a generator with a supply transformer and it may be necessary to operate the system with the generator neutral unearthed. The generator manufacturer may need to be consulted to determine whether parallel operation with the transformer and generator neutrals interconnected will give rise to excessive circulating currents.

If operation with interconnected generator and transformer neutrals is not permissible, the generator neutral should be connected to the main neutral busbar by an automatic mechanically latched switching device rated to make and break the maximum neutral fault current. The device should open only when the generator is paralleled with the external supply and maintain the generator earthed at all other times.

Under parallel operation the neutral earthing device should reclose prior to the opening of the transformer circuit breaker so that neutral earthing is always maintained. The generator should be immediately disconnected from the site distribution system should the neutral earthing device fail to close.

Unless the distribution network is satisfied that the parallel-generation plant incorporates reliable detection and disconnection of parallel operation on loss of the external supply consideration should be given to the provision of neutral displacement protection on the external system side of the transformer. The protection should be arranged to trip the low voltage switchboard transformer incomer or generator circuit breaker(s) or, if provided, the supply authority incoming HV circuit breaker.