Security and Reliability Council

Arrangements for power system restoration, including black start

Current arrangements and possible future development

6 March 2015

Note: This paper has been prepared for the purpose of SRC discussion. Content should not be interpreted as representing the views or policy of the Electricity Authority.

Contents

Executive summary

The Electricity Authority Board requested advice from the Security and Reliability Council on the topic of system restoration and black start.

This paper explains the current arrangements for system restoration and black start. Key features of the current arrangements are that:

- the Electricity Authority's regulatory instruments require the system operator to restore the power system as soon as possible following a supply disruption (the 'least delayed' approach)
- the system operator performs extensive planning, testing, training and reviewing to mitigate the impacts of supply disruptions
- an island-wide black-out is an extremely unlikely event due to a variety of preventative measures.

This paper observes that:

- there is likely a gap between the expectations of stakeholders and the system operator with respect to the time it could take to restore supply to all consumers following an island-wide black-out
- the 'least delayed' approach is suitable for now and not in need of review
- an industry-wide exercise simulating an island-wide black-out appears to offer benefits through enhanced industry coordination and identifying opportunities for improvement.

1 Introduction

1.1 The purpose of this paper is to request advice from the Security and Reliability Council (SRC) on restoration of the power system

1.1.1 This paper:

a) outlines the current black start and system restoration objectives and arrangements

b) considers if the current objective for least-delayed system restoration remains appropriate or whether a prescriptive restoration objective (such as a target restoration time) is necessary to provide greater confidence of restoration from black.

1.1.2 This paper has been jointly prepared by system operator and Electricity Authority (Authority) staff.

1.2 The Authority Board requested advice from the SRC

1.2.1 In October 2014 the Authority Board considered a paper discussing power system restoration. The paper raised questions as to whether the current approach to regulating system restoration (a mix of principle- and objective-based regulation) remains appropriate and whether a more prescriptive approach might be preferable.

1.2.2 The Board directed Authority staff to discuss the subject further with the system operator and prepare a paper for the SRC.

1.2.3 The Authority and the system operator presented initial papers to the Authority's System Operations Committee at its 21 November 2014 meeting, for their review and input.

1.3 Black start and system restoration are not synonymous

1.3.1 The terms "black start" and "system restoration" are sometimes used interchangeably, but in fact have their own distinct meanings. This paper uses the following definitions.

1.3.2 **Black start** is the *first step* in the process of system restoration following an island-wide black-out. It can only be carried out by a generating station that can self-start without reliance on external energy sources such as the power system. The term therefore describes the *initialisation* of the system restoration process, although it is sometimes confused with the subsequent actions of restoring the grid from a black-out.

1.3.3 **System restoration** is the *entire process* of restoring the power system after a widespread loss of supply.

1.3.4 Any instance of system restoration will be triggered by either of the following situations:

a) **regional loss of supply**: a widespread loss of supply to a region such as the upper North Island or the Hawkes Bay. While the possible scenarios for this type of restoration are numerous, the system operator has proven experience with restorations of this scale

b) **island-wide black-out**: a loss of either or both the North and South Islands. The system operator has no practical experience with this since no event of this type has occurred in its institutional memory.

2 Current system restoration arrangements

2.1 The Electricity Industry Participation Code 2010 (Code) places obligations on the system operator

The system operator must be reasonable and prudent

2.1.1 The Code outlines the broad restoration principles to apply after any major event impacting the system operator's ability to meet its principal performance obligations (PPOs).[1] These restoration principles apply to any system restoration, regardless of whether the cause was a regional loss of supply or an island-wide black-out.

2.1.2 In essence, the system operator is required to act as a reasonable and prudent system operator to re-establish normal operation of the power system as soon as possible. The system operator describes this as a 'least-delayed' objective and approach to restoration. There is currently no mandated restoration objective for island or regional restorations beyond the 'least-delayed' approach.

2.1.3 The Code specifies a list of priorities the system operator must have regard to when restoring the power system:

a) safety

b) avoidance of damage to assets

c) restoration of load

d) compliance with the PPOs

e) re-establishment of economic dispatch.

2.1.4 The general Code principles are expanded upon in the Policy Statement, which outlines the system restoration methodology the system operator will follow when re-establishing normal operation of the power system. [2]

The system operator must procure black start service

2.1.5 While the total loss of the power system in either island is extremely unlikely, the consequences of an island-wide black-out are sufficiently significant that the Code mandates that the system operator must procure black start services.[3] The system operator has been successful in contracting two black start stations in each island.[4]

[1] Clause 8.5 of the Code – see Appendix A for full text

[2] Clause 84 of the Policy Statement - see Appendix A for full text

[3] Paragraphs 36-38 of the Procurement Plan – see Appendix A for full text

[4] The current contracted black start stations are [redacted].

2.2 The system operator has extensive planning, testing, training and reviewing in place

Planning

2.2.1 The system operator prepares specific restoration plans for defined regional loss of supply events.[5] However, restoration plans for island-wide black-out events requiring black start are inevitably generic in nature.[6] There are many potential restoration scenarios (each dependent on the nature of the event, time of day, availability of assets, availability of trained personnel, availability of a functional SCADA system to monitor and control assets, suitable loads for stability etc.) rendering it impractical to prepare detailed plans for all scenarios in advance.

2.2.2 All system operator restoration plans are based upon the system operator acting as co-ordinator of the roles of the other participants (i.e. grid owner, generators and distributors), although they do not detail the respective restoration procedures of those other parties (except for some switching sequences of the grid owner).

2.2.3 Transpower also has an external communications policy and specifically an outage communications protocol for dealing with major system events. This protocol and delivery of communications is a well-established process and the usual lines of communication will continue after an event. Transpower will communicate with generators, distribution companies and direct connect customers (as well as keeping the Minister and the regulator informed), while distribution and retail companies will deal directly with their customers (i.e. end-consumers).

Testing and training

2.2.4 Since 2005, the system operator has operated a test programme for contracted black start providers.[7] Testing of the black start service from each contracted station is conducted at one station each year, meaning each provider is tested once every four years.[8] Testing alternates between the North and South Islands.

2.2.5 As well as confirming the black start capability of a contracted station, the annual black start service test also exercises system operator processes for managing a black start scenario in each island and is therefore useful for enhancing the system operator's capacity to manage and recover from such an event. Learnings from each test inform future testing and system restoration plans.

2.2.6 However, the nature of the testing environment limits the extent to which such tests can accurately simulate the circumstances of a real black-out scenario.[9]

2.2.7 System co-ordinator simulator training also includes an annual simulated black start event (alternating between the North and South Islands). Often this event will include participation by grid owner controllers. Simulator training for regional restoration events is carried out on a more regular basis.

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[5] These are for each of the following, with many regions having a 'restore from the 220kV' and a 'restore from the 110kV' option: Northland, Auckland, Bay of Plenty, Waikato, Hawkes Bay, Wellington, Upper South Island, Canterbury, Otago Southland 110kV.

[6] See Appendix C for more details

[7] See Appendix B for further details.

[8] Each contracted provider must also self-test its offered equipment on a six-weekly basis (except where the equipment has been generating for 66% or more of the time since the prior test).

[9] See Appendix B for further details

Reviewing

2.2.8 In the last quarter of 2014, Transpower conducted a review of its current black start arrangements to identify potential risks and appropriateness of mitigation strategies. The review confirmed Transpower has the people and plans in place to manage a black start event. It also recommended some areas for further investigation in relation to certain assets and sites to verify sufficient capability and resilience exists. Some preparatory work is underway to better inform these investigations.

2.2.9 In early 2015 the system operator also completed a review of its black start restoration plans. This was part of a normal lifecycle review. Periodic reviews ensure restoration priorities remain appropriate and up to date.[10] The most recent review did not identify any changes of perceived priorities or associated logic.

2.3 Island-wide black-outs are extremely unlikely

2.3.1 Decades of operation without an island-wide black-out provides prima facie evidence that such an event is extremely unlikely. The hydro-dominated generation fleet provides a good reason to suppose that New Zealand is less likely than most countries to undergo an event requiring black-start.[11]

2.3.2 The New Zealand power system is also configured to operate in preventive mode, meaning that failure of the single most-critical generator or transmission facility shouldn't jeopardise remaining connected equipment, nor cause operation capabilities or stability limits to be exceeded.[12]

2.3.3 If multiple equipment failures were to occur, it is likely one or more of the operational and planning standards would be violated. In a worst case scenario, this could lead to cascade tripping of other power system equipment (to protect from damage). However, other defence schemes such as extended reserve (formerly known as automatic under-frequency load shedding (AUFLS)) and special protection schemes are designed to limit the impact of cascade failure (effectively, to stop the propagation of a cascading situation), meaning that even multiple equipment failures are unlikely to result in a complete island black-out.

2.3.4 For these reasons, it is difficult to predict a credible scenario which could result in an island-wide black-out. However, since the possibility cannot be fully ruled out and the potential consequences of such an event are severe, the system operator still plans for such an eventuality.

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[10] Changes in these periodic reviews are both routine (inclusion of any grid or generator asset changes in the region) and non-routine (addition of any service provider change, addition of switching sequences, incorporation of a changed requirement from the grid owner for the livening of transformers when restoring supplies after an unplanned outage).

[11] New Zealand's core hydro plant gives the power system its great robustness, to be able to 'hang in there when the going gets tough'. Additional elements support the robustness of the hydro base: demonstrated asset performance; the adequacy of protection systems, the adequacy of automated systems (governors, AVRs, RPC's, HVDC, SVC/STC's etc) and asset owners continued compliance with Code asset performance standards and the role of the system operator in monitoring compliance.

[12] See Appendix D for more details

2.4 Restoration is likely to take longer than stakeholders expect

2.4.1 Unlike some other larger power systems, New Zealand does not have regulated targets for overall system restoration times, nor are end–to-end simulation exercises undertaken to demonstrate industry capability.

2.4.2 The exact nature of how a major failure requiring a system restoration may occur is unknowable. It may be the result of a combination of factors including loss of major power system assets. Any pre-prepared restoration process – such as those of the system operator and the grid owner - can therefore only be a proxy for an actual event.

2.4.3 Ability to restore the system will depend on the assets immediately available after an event and the time to make other assets available, including repair of damage. For example, an event involving significant asset damage might have a materially different recovery time from one resulting from a system voltage collapse. Predictability of recovery time will be affected by unforeseen circumstances and secondary impacts on the availability of people, back-up systems, communications and non-critical assets etc.

2.4.4 As it has practical experience with restoring parts of the system following minor scheduled and larger, unscheduled regional outages, the system operator is able to predict with some degree of confidence the times for restoring the system in cases of regional loss of supply. Experience from the 12 November 2013 AUFLS event (where final load restoration instructions were issued within an hour) provides evidence that recovery from significant events *can* occur quickly, minimising consumer disruption.

2.4.5 Transpower recently invested $7 million on auto-synchronisation points in its network which will assist recovery from regional failure and system separation events. [13]

2.4.6 However, in the absence of any actual experience with an island-wide blackout, it is only possible for the system operator to make a coarse estimate of restoration times, using its experience from black start testing and regional restorations.

2.4.7 Preliminary system operator studies in 2008 suggested there may be a material difference in the restoration expectations of key stakeholders and end-users on one hand and the system operator on the other. The system operator believes key stakeholders and end-users would expect restoration from an island black-out to be achieved in well under 24 hours. However, Transpower's current view, based on a desktop exercise in 2008, is that end-to-end restoration of all consumers may be more likely to be between 18 and 48 hours.

[13] System separation can occur where some generation remains in service, supplying separated regions. In this case, system restoration would include reconnection of the separated regions.

3 Possible future development

3.1 An industry-wide simulation exercise would be valuable

3.1.1 The costs to New Zealand of a North Island black-out have been estimated at $1.5 billion per day[14]. It may therefore be arguable that some degree of investment to assure restoration times might be worthwhile. One possibility is to introduce a system restoration standard which mandates restoration times.

3.1.2 Although not directly comparable because of differing industry structures in New Zealand and Australia, the Australian Energy Market Operator (AEMO) noted that the introduction of a prescriptive system restoration standard[15] for black start events led to an increase in procurement costs from $10 million AUD/year to $60 million AUD/year. Even assuming this figure is much higher than what might be required in the New Zealand context, it seems likely a mandated restoration time would lead to significant investment across the electricity sector.

3.1.3 In general, Authority and system operator staff favour restoration arrangements that balance the operating (preparedness) costs against the likelihood of an event and the resultant costs of an island-wide black. This approach promotes the Authority's objective of achieving an efficient level of reliability. However, in practice, the inability to meaningfully quantify the likelihood of island-wide blackouts and the resulting system restoration times (under a range of circumstances) means such estimates are of limited value.

3.1.4 The benefits of introducing a restoration standard therefore need to be balanced against the extremely low likelihood of an event occurring, the fact that a prescriptive restoration standard does not guarantee those times can be achieved in all circumstances, and the potentially significant costs to the industry of developing and implementing the standard.

3.1.5 Authority and system operator staff believe the need for such a standard might therefore be better considered following an investigation into the comprehensiveness and co-ordination of current system restoration arrangements.

3.1.6 This might be achieved by way of a desktop simulation exercise in each island, involving all key participants in the system restoration process (from black start providers through to individual distribution companies). Such an exercise would require significant planning, co-ordination and commitment from the parties to ensure the benefits of such an exercise could be fully realised.

4 Summary

4.1.1 The system operator is reasonably confident of its ability to restore the system from an island wide black-out given current contracted and operational arrangements, relying on a least-delayed objective. This confidence arises primarily from experience gained from regional restoration events and the current black start testing regime.

4.1.2 While the system operator can provide a reasonable degree of certainty about restoration times for regional events, it is unable to do so for an island wide black-out event. The current estimate of a North Island full restoration is between 18 and 48 hours.

[14] This estimate was arrived at during the development of the forthcoming Extended Reserve arrangements.

[15] AEMO's restoration standard is 1.5 hours to restore generation and 4 hours to restore 40% of peak demand.

4.1.3 A mandated restoration standard may provide greater certainty of restoration times as key participants would be required to devote whatever resources are necessary to ensure the objective could be met. However, given the variety and number of potential causation scenarios that would need to be covered, the investment required to assure the standard could be met is likely to be significant. Ultimately, any such efforts would be unlikely to guarantee that such timeframes will be able to be achieved in an actual event.

4.1.4 In the short term at least, efforts are better directed at understanding the current capabilities of the key participants in the process to achieve comprehensive co-ordination and planning for an event.

4.1.5 Steps to manage any possible mismatch between the current expectations of stakeholders and industry regarding the time taken to restore the power system could be beneficial for overall event preparedness and planning.

Q1. Does the SRC require any further information about the arrangements relating to black start or system restoration?

Q2. Does the SRC agree that there will be a significant gap between the expectations of most stakeholders and the 18-48 hours estimated by the system operator?

Q3. Does the SRC agree that an industry-wide simulation exercise is warranted, in order to achieve comprehensive co-ordination of system restoration planning, with the ultimate objective of reducing the duration of system restoration events?

Q4. Does the SRC agree that the current 'least delayed' restoration objective is suitable and that reviewing it is unnecessary at this time?

Appendix A Regulatory framework

A.1 Clause 8.5 of the Code

8.5 Restoration

(1) If an event disrupts the **system operator's** ability to comply with the **principal performance obligations**, the **system operator** must act as a **reasonable and prudent system operator** to re-establish normal operation of the power system as soon as possible, given—

(a) the capability of **generation**, **ancillary services**, and **extended reserve**; and

(b) the configuration and capacity of the **grid**; and

(c) the information made available by **asset owners**.

(2) When re-establishing normal operation of the power system under subclause (1), the **system operator** must have regard to the following priorities:

(a) first, the safety of natural persons:

(b) second, the avoidance of damage to **assets**:

(c) third, the restoration of **offtake**:

(d) fourth, conformance with the **principal performance obligations**:

(e) fifth, full conformance with the **dispatch objective**.

A.2 System restoration provisions in the Policy Statement

Restoration

82. The **system operator** must procure black start capability. The procurement details for these facilities are included in the **procurement plan**.

83. The **system operator** may rely on the synchronising facilities defined in **Technical Code** A of Schedule 8.3 of the Code to allow reconnection of sections of the **grid** and to connect generation to the **grid** during restoration.

84. Where restoration is required, the **system operator** must use the following methodology to re-establish normal operation of the power system by:

    84.1 Addressing any aspects involving public safety.

    84.2 Addressing any aspects involving avoidance of damage to **assets**.

    84.3 Stabilising any remaining sections of the **grid** and connected **assets** and the voltage and frequency of the **grid**, through the combination of manual **dispatch instruction** and allowing automatic action of **ancillary services** and governor and voltage regulation operation by **generating plant**, and including any necessary disconnection of **demand**.

    84.4 Actioning the steps set out in clauses 84.5, 84.6, 84.7 and 84.8 below in the order or in parallel as is judged by the **system operator**, at the time, as most effectively allowing reconnection of **demand**. The order that **assets** are **dispatched** will be influenced by availability, technical, geographic and other factors influencing rapid restoration of **demand**.

84.5 Restoring the transmission, generation, and/or **ancillary service assets** that failed when such restoration assists commencement of steps set out in clauses 84.6 and 84.7, where necessary utilising black start facilities.

84.6 Restoring any disconnected **demand** (which includes any triggered **interruptible load**) at the rate permitted by the security and capability of the available combined generation and transmission system.

84.7 **Dispatching** additional generation and **ancillary services**, where such additional resources are needed to allow **demand** to be reinstated and necessary quality levels to be maintained.

84.8 Seeking revised **offers** where insufficient **offers** exist to achieve the restoration objectives.

84.9 Restoring normal security and power quality of the **grid** system to the levels set out in the **PPOs** and this Security Policy. If the reserve requirements have been set to zero under clause 33A, the actions taken under this clause must include restoring the reserve requirements to the levels set out in the Under-Frequency Management Policy.

84.10 Restoring energy injection levels to the values contained in an updated **dispatch schedule**.

A.3 Black start provisions in the Procurement Plan

Assessment methodology for black start

36. The **system operator** may procure **black start** from parties that can offer **black start** compliant with the **system operator's** technical requirements and the Code and who are prepared to enter into an **ancillary service** procurement contract with the **system operator** to provide **black start** on a firm quantity procurement basis.

37. The **system operator** must assess the net purchase quantity of **black start** during the term of this **procurement plan** in accordance with the processes set out in paragraphs 12 to 23 and taking into account historic performance of the power system, including (but not limited to) information about previous events on the system and the **system operator's** reasonable opinion about the risk and location of future events.

38. The **system operator** must use reasonable endeavours to procure **black start** at two sites in each **island** for the term of this **procurement plan**.

B68.6 such **generating units** and the **black start equipment** are maintained in accordance with good industry practice to enable the provision of **black start** in accordance with the **ancillary service** procurement contract.

Monitoring requirements for black start

B69. Any failure of the starting equipment that compromises the ability of the **ancillary service agent** to perform **black start** must be reported to the **system operator** immediately. The cause of the failure must be determined and rectified as soon as practicable, and the **system operator** advised of the expected date of completion.

Special testing requirements for black start

B70. The **ancillary service agent** must conduct a **baseline test** of each item of **black start equipment** at least once every six weeks during the term of this **procurement plan**, provided that the **ancillary service agent** is not required to conduct such a **baseline test** if the **black start equipment** has been generating for 66% or more of the time since the last such **baseline test**.

B71. Without limiting any other rights the **system operator** may have to request tests of **black start**, the **system operator** may require the **ancillary service agent** to conduct a **baseline test** of **black start** no more than once during the term of this **procurement plan**. There are no other **baseline tests** for equipment used to provide or monitor **black start** during the term of this **procurement plan**.

B72. A **baseline test** or **on-demand test** of **black start equipment** must verify whether or not the **black start equipment** meets the performance requirements in paragraph B68.2.

B73. A **baseline test** or **on-demand test** of **black start** must verify whether or not the **black start** meets the performance requirements in paragraphs B67 and B68, or such lesser performance requirements as the **system operator** may determine in consultation with the **ancillary service agent**.

Black start

Performance requirements and technical specifications for black start

B67. The **ancillary service agent** must ensure that, when requested to provide **black start**, it provides such services by:

B67.1 starting a **generating unit** and raising it to synchronous speed, without any power being obtained from the **grid** or any **local network**;

B67.2 operating the **generating unit** at zero load at synchronous speed for 15 minutes (or such shorter period as instructed by the **system operator**);

B67.3 having the **generating unit** switched on to de-energised **network** busbar(s);

B67.4 providing generation output that supports the initial charging of transmission circuits and **assets,** and the progressive energising of the **grid** at **network** busbar(s);

B67.5 providing the **reactive capability** specified in clause 8.23 for the **generating unit**;

B67.6 subject to paragraph B67.5, controlling the **network** voltage as instructed by the **system operator**; and

B67.7 providing an emergency frequency regulating reserve service by maintaining the frequency to between 49.25 Hertz and 50.75 Hertz, to the extent practicable.

B68. The **ancillary service agent** must ensure that:

B68.1 sufficient **black start equipment** is available at all times to provide **black start** in accordance with the **ancillary service** procurement contract;

B68.2 the **black start equipment** is able to start without power being obtained from the **grid** or any **local network**;

B68.3 sufficient **generating units** are available continuously to provide **black start**, except where there is an **allowed outage** preventing the provision of **black start**;

B68.4 such **generating units** are able to achieve the response times to synchronous speed specified in the **ancillary service** procurement contract;

B68.5 such **generating units** otherwise have the capabilities specified in the **ancillary service** procurement contract; and

Appendix B Black start testing

B.1.1 Black start testing is complex and requires substantial planning and real-time co-ordination between relevant participants – system operator, grid owner, Transpower's information technology and communications teams, the black start provider and, for some tests, distribution companies.

B.1.2 Each test aims to simulate a potential black start scenario through creation of a separate island within the wider grid, within which the testing can safely occur. Once the test island is created, the generator is instructed to:

a) shut down a unit

b) attempt to start on its own without drawing electrical power from the external grid

c) once started, operate at zero export supplying its own house load for a minimum of 5 minutes to prove stability

d) connect a unit to a nominated de-energised or "dead' bus and demonstrate ability to charge a designated transmission circuit and transformer.

B.1.3 Although black start testing has proven an invaluable tool for increasing awareness and understanding of the system operator's and relevant participant's ability to manage a restoration from an island black, there are inherent limitations with such testing. Limitations include:

a) it is not practically possible to conduct a proper end-to-end system test of the black start service because the simulation environment created for the test to proceed safely and without disruption to the power system is a unique scenario that would not be replicated in a real event

b) the system operator cannot connect a sufficiently large load to the end of the energised transmission line to test whether the generator could maintain its output once load is connected. This is because any failure during testing would cause a loss of supply to consumers, something large industrial users and distribution companies have been unwilling to risk

c) while the planning and co-ordination of tests ensures all appropriate people and resources are available on the day of the test, this is unlikely to be the case in a real black start event.

B.1.4 Currently, the system operator is limited to procuring black start from generators whose stations comply with relevant technical requirements and which are prepared to enter into an ancillary services contract with the system operator. To date, potential providers with the relevant capability have chosen to offer the service.

Appendix C System operator restoration plans

C.1.1 System operator restoration plans include three black start plans (1 x North and 2 x South Island plans) and a variety of regional restoration plans.

C.1.2 These restoration plans cover system operator and grid owner roles. The system operator is responsible for developing the plans and keeping them current while the grid owner provides the operating sequences required to execute a particular plan. The plans are routinely revised and practiced in individual exercises (system co-ordinator simulator training), as well as joint training exercises with the grid owner.

C.1.3 Restoration plans for an island-wide black out necessarily assume:

a) all grid assets are available and can be operated effectively

b) all communications and systems needed to effect operations remain functional

c) control rooms and support services for all parties involved (system co-ordinator, grid owner, generator controller and distribution company controller) remain functioning.

C.1.4 Restoration plans set parameters around when connections can be made during the process, for example:

a) recognising the importance of connecting load early, but with a need to carefully manage the size of load increments and the amount of generation connected as the restoration progresses

b) recognising generators provide system inertia that in turn allows some "cushioning" from the effects of the load coming on, and the load in turn provides stability for generators

c) recognising that having too much unloaded or lightly loaded connected generation risks generator instability

d) managing the combined capacity of transformers being livened at any one time to avoid voltage issues.

C.2 Restoration priorities

North Island

C.2.1 System operator black start restoration priorities for the North Island assume:

a) thermal generation will be needed as system loading increases and that generation will need supplies of gas

b) a core grid backbone (the 220kV network) needs to be established between Wellington and Auckland

c) voltage management (provided through generators and load) will be needed as additional transmission gets connected.

C.2.2 The current black start restoration priority targets in the North Island are (in sequence):

a) black start a (contracted) station [redacted]

b) connect load at Hamilton and Palmerston North

c) connect additional generation on the Waikato river chain

d) restore local service to allow preparation for an Otahuhu combined cycle generation start

e) restore local service to allow preparation for a Huntly generation start

f) restore supplies to the Taranaki gas pumping stations

g) restore load in the Wellington region

h) restore local service and an AC reference for the HVDC to start (which requires filters and ideally condensers to be available)

i) restore transmission in the Wairakei area to allow for a start of geothermal generation

j) progressively build regional areas via the regional contingency plans.

South Island

C.2.3 The system operator's restoration plans for the South Island assume having supply restored to Tiwai within 2.5 hours is critical for the smelter's continued operation and is the priority objective.

C.2.4 The current restoration priority targets in the South Island are:

a) black start a station [redacted]

b) voltage management (through generators and load) will be needed as additional transmission gets connected

c) connect transmission through to Clyde and Roxburgh and connect additional generation

d) connect local service at Tiwai to allow health and safety matters at Tiwai to be addressed

e) load each reduction line in turn

f) connect Invercargill area load

g) connect Queenstown and Dunedin load

h) connect Twizel and mid Waitaki area generation

i) restore Benmore local service for the HVDC and an AC reference for the HVDC to start (requires filters to be available)

j) connect Christchurch area load

k) connect Ashburton and Timaru area load

l) connect Nelson, Marlborough and West Coast load.

[redacted]

Appendix D The system operator manages the power system to prevent an island-wide black-out

D.1.1 Maintaining reliability and security of the power system is a complex exercise that requires trained and skilled operators, sound planning and design practices and sophisticated operational tools.

D.1.2 Multiple equipment failure, usually caused by common mode failure of equipment, can overload other power system components or cause operation outside design specifications. In the context of black start, common mode failure means a failure of one piece of equipment will lead to multiple pieces of equipment going out of service (a cascade failure). Examples include:

a) power station service supply transformer: If this transformer trips, all generators in the power station will trip. Usually, a power station has a redundant service supply transformer to mitigate this event

b) HVDC capacitor banks and STATCOMs: An example is the 2012 HVDC filter AUFLS event. Common mode of failure is this event was the relay which tripped the capacitor banks at Benmore the resulting in HVDC ramp down

c) protection mal-operation: This usually has a significant effect as such mal-operation is likely to disconnect more than 1 component from the grid. Depending on the robustness of the grid, there may be either ride through or collapse.

D.1.3 Cascade failure (very rapid, widespread loss of connected elements of the power system) may ensue, causing large scale outages or, in a worst case scenario, an island black-out. In this context, island-wide black-out can be understood as a last defence against damage to national grid equipment leaving equipment available to restore the power system.

D.1.4 The Code prescribes operating and planning standards for ensuring reliability of the power system. These are based on a need to:

a) balance generation and demand continuously to maintain system frequency

b) balance reactive power supply and demand to maintain scheduled voltage

c) monitor flows over transmission circuits and transformers to ensure thermal limits are not exceeded

d) keep the system in a stable condition (by managing the above)

e) plan and prepare for emergencies.

D.2 Balancing power generation and demand

D.2.1 When power generation matches demand system frequency will be maintained at nominal value, 50 Hz. Failure to match generation to demand will cause system frequency to increase or decrease. It is common to have small deviations as demand changes over time and generators change output to match demand. Disconnection of a large quantum of generation or load can cause a large fluctuation of frequency (a relevant example was the disconnection of the Huntly station in December 2011).

D.2.2 Large frequency fluctuations cause generator rotational speeds to fluctuate leading to vibration that can damage turbine blade and other equipment. Generator protection will activate to disconnect generation plant from the grid if frequency is not restored to within operating range within a set (very short) time frame. This cascade failure effect may cause a power system blackout.

D.3 Balancing reactive power supply and demand to maintain scheduled voltage

D.3.1 Capacitor banks, generators, SVCs and STATCOMs must be continuously adjusted to regulate their reactive power output to maintain the voltage within a secure range for safe operation of equipment connected to the grid system. Low voltage can cause instability which in turn leads to voltage collapse, damage to motors and failure of electronic equipment. High voltage can cause insulation deterioration and, if insulation capabilities are exceeded, electric arcs or flashover can occur, which may lead to voltage collapse and a power system blackout.

D.4 Monitoring flows over transmission circuits and transformers to ensure thermal limits are not exceeded

D.4.1 Transmission circuits, transformers and other equipment are heated by electricity flowing through them. The flow must be controlled to within stated limits to prevent overheating causing equipment damage. For transmission circuits, overheating will sag conductors into obstructions below, creating a short circuit or flashover which can start fires, damage equipment and present hazardous to public. Power flow through a faulted circuit is transferred to other circuits that can cause cascading disconnection of transmission circuits, leading to widespread outage or blackout.

D.5 Keep the system in a stable condition

D.5.1 The power system is interconnected and dynamic, with stability limits that must be observed to prevent loss of power system synchronism or uncontrolled collapse. There are two types of instability, as follows.

a) Voltage stability limit: Unplanned disconnection of transmission circuits, generator, capacitor banks, SVCs or STATCOMs can deprive local reactive power support and cause voltage to fall to dangerously low levels that may then begin to collapse uncontrollably. Protection systems will be activate to disconnect equipment form the power system to avoid damage (a cascading effect that may lead to a black-out).

b) Power angle limit: A fault or an unplanned loss of a transmission circuit, transformer or generator can cause remaining generators to lose synchronism. This condition exists when generators in the power system operate out-of-step with one another. It is vital to disconnect generators from the power system to avoid damaging those generators once a loss of synchronism condition is detected. Protection systems ensure this action is taken and, if widespread, may result in a black-out.