Automatic Under Frequency Load Shedding (AUFLS) scheme change Cost Benefit Assessment (CBA)

Electricity Authority

24 March 2021

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Disclaimer

Ernst & Young was engaged on the instructions of the Electricity Authority ("Client") to provide a cost-benefit analysis (CBA) of switching between the current 2-block Automatic Under Frequency Load Shedding (AUFLS) scheme to a 4-block AUFLS scheme with df/dt tripping enabled in the North Island of New Zealand ("Project"), in accordance with the engagement agreement dated 16 December 2020.

The results of Ernst & Young's work, including the assumptions and qualifications made in preparing the report, are set out in Ernst & Young's report dated 23 March 2021 ("Report"). The Report should be read in its entirety including the cover letter, the applicable scope of the work and any limitations. A reference to the Report includes any part of the Report. No further work has been undertaken by Ernst & Young since the date of the Report to update it.

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24 March 2021

Chris Otton
Senior Advisor Market Design
Electricity Authority - Te Mana Hiko
Level 7, Harbour Tower, 2 Hunter Street,
Wellington, New Zealand

Electricity Authority – 4 Block AUFLS Scheme Cost Benefit Analysis Report

Dear Chris,

In accordance with our Engagement Agreement dated 16 December 2020 (“Agreement”), Ernst & Young (“we” or “EY”) has been engaged by the Electricity Authority (“you”, or the “Client”) to provide a cost-benefit analysis (CBA) of switching between the current 2-block Automatic Under Frequency Load Shedding (AUFLS) scheme to a 4-block AUFLS scheme with rate of change of frequency tripping enabled in the North Island of New Zealand ("Project"). The enclosed report (the “Report”) sets out the outcomes of our work. You should read the Report in its entirety. A reference to the report includes any part of the Report.

Purpose of our Report and restrictions on its use

Please refer to a copy of the Agreement for the restrictions relating to the use of our Report. We understand that the deliverable by EY will be used for the purpose of assisting the EA in its investment decision of switching from a 2 block Automatic Under Frequency Load Shedding (AUFLS) scheme to a 4 block AUFLS scheme in the North Island of New Zealand (the “Purpose”).

This Report was prepared on the specific instructions of the Electricity Authority solely for the Purpose and should not be used or relied upon for any other purpose.

This Report and its contents may not be quoted, referred to or shown to any other parties except as provided in the Agreement. We accept no responsibility or liability to any person other than to the Electricity Authority or to such party to whom we have agreed in writing to accept a duty of care in respect of this Report, and accordingly if such other persons choose to rely upon any of the contents of this Report they do so at their own risk.

Nature and scope of our work

The scope of our work, including the basis and limitations, are detailed in our Agreement and in this Report.

Our work commenced on 18 January 2021 and was completed on 22 March 2021. Therefore, our Report does not take account of events or circumstances arising after 22 March 2021 and we have no responsibility to update the Report for such events or circumstances.

In preparing this Report we have considered and relied upon information from a range of sources believed to be reliable and accurate. We have not been informed that any information supplied to us, or obtained from public sources, was false or that any material information has been withheld from us.

We do not imply and it should not be construed that we have verified any of the information provided to us, or that our enquiries could have identified any matter that a more extensive examination might disclose.

The work performed as part of our scope considers information provided to us and only a combination of input assumptions relating to future conditions, which may not necessarily represent actual or most likely future conditions. Additionally, modelling work performed as part of our scope inherently requires assumptions about future behaviours and market interactions, which may result in forecasts that deviate from future conditions. There will usually be differences between estimated and actual results, because events and circumstances frequently do not occur as expected, and those differences may be material. We take no responsibility that the projected outcomes will be achieved, if any.

We highlight that our analysis and Report do not constitute investment advice or a recommendation to you on a future course of action. We provide no assurance that the scenarios we have modelled will be accepted by any relevant authority or third party.

Our conclusions are based, in part, on the assumptions stated and on information provided by the Electricity Authority and other information sources used during the course of the engagement. The modelled outcomes are contingent on the collection of assumptions as agreed with the Electricity Authority and no consideration of other market events, announcements or other changing circumstances are reflected in this Report. Neither EY nor any member or employee thereof undertakes responsibility in any way whatsoever to any person in respect of errors in this Report arising from incorrect information provided by the Electricity Authority or other information sources used.

This letter should be read in conjunction with our Report, which is attached.

Thank you for the opportunity to work on this project for you. Should you wish to discuss any aspect of this Report, please do not hesitate to contact Paul Melville on +64 21 657 406 or Ben Vanderwaal on +61 7 3227 1414.

Yours sincerely,

Paul Melville	Ben Vanderwaal
Partner	Partner

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Terms, Acronyms, and Abbreviations

Glossary	Definition
AUFLS – Automatic Under Frequency Load Shedding	Load shedding frequency management tool used to arrest frequency fall during ECEs
ECE – Extended Contingent Event	Defined in Table 3: Credible event classification
CE – Contingent Event	Defined in Table 3: Credible event classification
AC - Alternative Current	An electrical current periodically reversing direction and changes its magnitude continuously with time in contrast to direct current (DC), which flows only in one direction. AC is the most common form of electrical current transport
DC - Direct Current	An alternative method of current transfer where the flow is only in one direction
HVDC – High Voltage Direct Current	Refers to the HVDC interconnection link between the North and South Island, consisting of 2 HVDC monopoles. Refer to section 2.2.6 for further details
IR – Instantaneous Reserves	A frequency management tool used to arrest frequency fall during CEs, see IL and PLSR/TWD below
IL – Interruptible load	Fast acting load shedding offered by industrial or commercial off-takers which is a form of IR
PLSR/TWD – Partially loaded spinning reserve/ Tailwater depressed	Fast-acting standby generation that can come on to replace lost generation usually offered by hydro generation, which is also a form of IR
The Code – Electricity Industry Participation Code	Rules guiding all electricity participants in the New Zealand electricity system
NI – North Island	The North Island of New Zealand
VoLL – Value of lost load	The total economic cost of the unplanned interruption of 1 MW of load for 1 hour
Return period	The time duration before the same event reoccurs
OFA – Over frequency arming	Generators armed to disconnect from the power system when the frequency rises above a set frequency setpoint to reduce supply and bring frequency back into the normal range of operation
SO – System Operator	Operator of the high voltage electricity transmission network (Transpower in New Zealand)
PPO - Principal Performance Obligations	The SO's performance obligations as mandated by The Code
Frequency Keeping	Ancillary grid service offered by highly responsive generation plant to maintain frequency at 50 Hz by increasing/decreasing plant output
ROCOF – Rate of Change of Frequency	The change in frequency per second
Relay	A type of high-reliability switch used in power systems, generally programmed to turn circuit-breakers on/off for a given condition
Cascade Failure	Failure of one element of the power system creating a cascade effect, tripping additional parts of the power system leading to a blackout
RMT – Reserve Management Tool	SO tool that calculates reserve energy requirements
Feeder	A distributor circuit supplying a part of its network

1. Executive Summary

The Electricity Authority (EA) commissioned EY to complete a Cost Benefit Analysis (CBA) to assist it in its investment decision for switching from a 2-block Automatic Under Frequency Load Shedding (AUFLS) scheme to a 4-block AUFLS scheme in the North Island (NI) of New Zealand (NZ).

The AUFLS scheme is an under-frequency management tool used to manage power system stability and prevent total system blackouts. The scheme disconnects large blocks of demand in the event of a large loss in energy supply. The automatic disconnection of demand aims to restore the supply-demand balance necessary to maintain the stability of the power system and prevent blackouts.

The System Operator (SO) identified significant shortcomings in the existing AUFLS scheme, namely a lack of discrimination between the total amount of load shed and over-provision of AUFLS that makes the scheme less effective. The SO then completed extensive technical studies to recommend changes to the existing scheme to improve its reliability, detailed in Table 1 below.

Table 1: Existing scheme and new scheme properties in the NI

Properties	Existing scheme	New scheme
Blocks	2 blocks	4 blocks
Block 1 details	16% of NI load Tripping at 47.8 Hz	10% of NI load Tripping at 47.9 Hz
Block 2 details	16% of NI load Tripping at 47.5 Hz	10% of NI load Tripping at 47.7 Hz
Block 3 details	n/a	6% of NI load Tripping at 47.5 Hz
Block 4 details	n/a	6% of NI load Tripping at 47.3 Hz Can also trip if frequency fall rate of change reaches -1.2 Hz/s
Monitoring	Ex post reporting of AUFLS performance	Half hourly monitoring of AUFLS load reported yearly to the SO

This report quantifies the benefit of switching to the new scheme compared to the costs of setting up the new scheme. While there are a range of benefits to switching to the new scheme, the majority of benefits accrue due to an increase in expected reliability over the existing scheme. The Electricity Authority has asked EY to focus exclusively on the reliability benefit.

The report identified a net benefit in the range of $67.5M to $142.9M and a Benefit to Cost Ratio (BCR) of 9.58 to 19.16, which implies an apparent economic case for the implementation of the new scheme.

The report also identified that a 4.5% improvement in reliability benefit breaks even with the cost of implementation whereas the estimated improvement in reliability from implementing the new scheme is 43%.

The benefits and costs, and a summary of methodology used for their calculation have been summarised in Table 2 below.

Table 2: Net benefits of switching from the existing AUFLS scheme to the new AUFLS scheme

Costs and Benefits	Present Value over 15 years
Benefits	
Reduced probability of blackouts due to increased reliability of the new AUFLS scheme compared to the existing scheme As there have been no blackouts in NZ in at least the last 50 years, the benefit has been calculated using the probability of a blackout generated for the larger Australian power system.[1] Given the Australian systems is almost 5 times larger and more interconnected and therefore more resilient to blackouts, this is considered prudent. The total cost of a NI blackout assuming a 24-hour restoration period for load is multiplied by the 43% improvement in reliability[2] against blackout of the new scheme, for a 60 year and 120-year blackout return period. The present value of benefits over 15 years is then calculated.	
	$75.4m to $150.8M
Costs	
Upgrade and install relays The cost of upgrading/installing new AUFLS relays was calculated using the 2011 SO calculated costs inflated by the Statistics New Zealand's changes to capital good price movements for electrical works.[3] No additional, ongoing operational expenditure beyond the current scheme is anticipated.	
	($7.4M)
AUFLS monitoring information systems The monitoring system will host information used to maintain SO AUFLS monitoring. No additional, ongoing operational expenditure is anticipated.[4]	
	($0.5M)
Net Present Value (Benefits / Costs)	**$67.5M to $142.9M**
Benefit to Cost Ratio (BCR)	**9.58 to 19.16**

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[1] https://www.aemc.gov.au/sites/default/files/content/0120e698-568c-4d8b-aa7c-0b74422687c9/National-Generators-Forum.PDF

[2] 20130807 AUFLS Scheme Design Report

[3] https://www.stats.govt.nz/assets/Uploads/Business-price-indexes/Business-price-indexes-September-2020-quarter/Download-data/business-price-indexes-september-2020-quarter-capital-goods-price-index.xlsx

[4] As advised by the Electricity Authority

2. Purpose, Context and Scope

2.1 Scope

The SO review of AUFLS arrangements identified that the existing scheme could be amended to provide a better level of cover for both large defined risks and a broader range of undefined larger 'other' risks. This report provides a cost-benefit analysis to assist EA in its investment decision of switching from the existing 2-block AUFLS scheme to the SO proposed 4-block AUFLS scheme in the NI of NZ.

The CBA undertaken by EY:

- Uses the existing 2012 Electricity Authority commissioned CBA[5] as a starting point for the analysis
- Relies on the existing work completed by the SO to quantify technical benefits and calculate the costs for implementation in the 2010-2013 extended reserves body of work
- Recognises there are a myriad of benefits but only quantifies the benefits of an improvement in reliability under the new scheme as requested by the client

The report does not:

- Complete a CBA of any other AUFLS scheme other than the SO proposed scheme (i.e. it does not compare potential alternative options)
- Complete any independent research into technical parameters of the AUFLS scheme
- Complete any independent research into implementation costs
- Investigate any other benefit other than an improvement in reliability

2.2 Key Power System and Reserve Concepts

This section details critical power system concepts underpinning this cost-benefit analysis (CBA). The concepts have been simplified to allow greater understanding by non-technical readers.

2.2.1 Maintaining AC Frequency: balancing supply and demand

The NZ power system is designed to operate at a frequency of 50 Hz (hertz or cycles-per-second). This is the speed with which the polarity of current fluctuates back and forth in an alternating current supply. A failure to maintain this frequency within a precise band can damage some industrial and consumer equipment. Critically, generators connected to the national grid are also designed to operate within a specific frequency range, as specified in their Asset Owner Performance Obligations (AOPO). Operating outside this range can cause generator damage.

To maintain this frequency, the supply (generation) and demand (load) for electricity must be balanced. When the NZ power system is balanced, the system frequency is 50 Hz. When there is an imbalance in supply and demand, the system frequency moves away from 50 Hz. Excess demand will cause the frequency to drop, which means the system is under-frequency, whereas excess supply causes the frequency to rise, causing the system to be over-frequency.

2.2.2 Types of Credible Events

The SO is required to prevent cascade failure and maintain its performance obligations during various credible events on the power system. These credible events are then classified into Contingent Events (CE), Extended Contingent Events (ECE), Stability Events and Other events as tabulated in Table 3.

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[5] AUFLS_Stage_II_Appendix_D_High-level_economic_evaluation_of_proposed_changes_to_AUFLS_arrangements

Table 3: Credible event classification[6]

Classification	Credible event	Management
CE	The loss of: ▶ a transmission circuit ▶ HVDC link monopole ▶ a single generation unit ▶ both circuits of a line when the SO has determined a high level of likelihood of occurrence ▶ reactive injections ▶ the largest load block because of any of the above events ▶ select 220 kV, 110 kV or 66 kV busbar and interconnectors identified by the SO as high risk with a high probability of occurrence	Impact probability, cost and benefits of mitigation warrants management and incorporation in the scheduling and dispatch processes pre-event
ECE	The loss of: ▶ HVDC link bipole ▶ Select 220 kV, 110 kV or 66 kV busbar and select 220 kV or 110 kV interconnecting transformer as identified as having a lower probability of failure than a CE but not as low as an Other event	Impact probability, cost and benefits of mitigation not considered high enough to avoid demand shedding
Stability event	Severe power system fault that might lead to a CE or ECE event or loss of an interconnecting transformer or busbar section	Managed as per CE or ECE
Other event	The loss of: ▶ 220 kV, 110 kV, or 66 kV busbar and 220 kV or 110 kV interconnecting transformers not considered CEs or ECEs ▶ The loss of both transmission circuits of a double circuit line ▶ Simultaneous loss of two or more CE classified events ▶ The close consecutive loss of two or more CE classified events	Managed through demand shedding and other emergency procedures or restoration measures

2.2.3 North Island frequency management

The SO, as part of the Electricity Industry Participation Code (The Code), mandated Principal Performance Obligations (PPOs) must manage the NI frequency within a tight band under various system conditions. The frequency barometer[7] (extracted from a report published by the SO) shown in Figure 1 and further detailed in Table 4 sets out SO's PPOs.

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[6] https://www.ea.govt.nz/assets/dms-assets/24/24557Certified-Policy-Statement-11-January-2019.pdf

[7] https://www.transpower.co.nz/sites/default/files/bulk-upload/documents/Frequency-barometer.pdf

Figure 1: SO frequency management barometer[8]

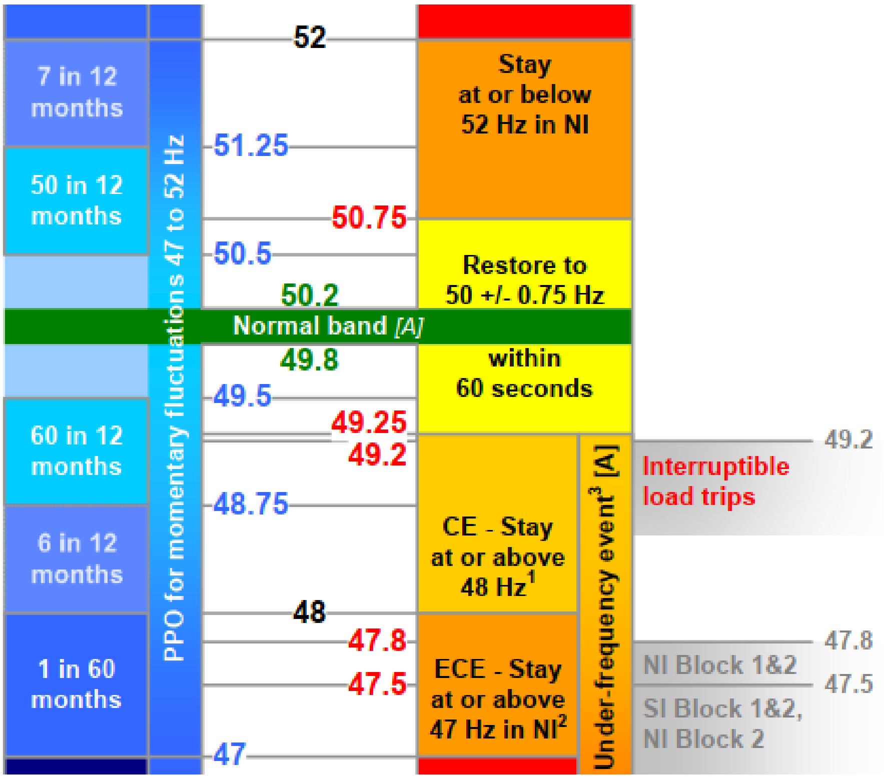

Table 4: SO frequency obligations in the NI and management actions available

Frequency Range (Hz)	Description	SO actions
49.80 - 50.20	Normal band	No action required. This is the normal range of operation for NZ's power system.
49.25 - 49.80 and 50.20 - 50.75	Outside normal band	Restore to 50.00 ±0.20 Hz using frequency keeping and generation dispatch
48.00 - 49.20	Contingent Event (CE) range. Power system frequency not allowed to drop below 48.00 Hz for a CE	The SO can dispatch instantaneous reserves (IR) to arrest frequency fall and restore frequency to the normal band
47.00 - 48.00	Extended Contingent Event (ECE) range. Power system frequency not allowed to drop below 47 Hz for an ECE	The SO can dispatch IR and AUFLS to arrest frequency fall and restore to the normal band
50.75 - 52.00	Over frequency range. Power system frequency not allowed to exceed 52 Hz	The SO allowed to dispatch over frequency arming reserves to restore frequency to the normal band

2.2.4 Instantaneous Reserves

Instantaneous Reserves (IR) can be either standby generation that can instantaneously ramp up or standby load called Interruptible Load (IL) that can be instantaneously tripped to restore supply balance during a contingent event. Instantaneous reserve providers operate in a competitive reserves market and are compensated based on the IR dispatched and the reserve price for the half-hour.

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[8] https://www.transpower.co.nz/sites/default/files/bulk-upload/documents/Frequency-barometer.pdf

It is important to note that IL is a different product from AUFLS described below. While both products offer the same benefits to the power system, IL is a market product offered by market participants who are compensated for being available to turn off. IL availability is clearly communicated to the SO and offered into the market every half hour like generation, and there are strict penalties for non-compliance.

2.2.5 AUFLS

Automatic Under-Frequency Load Shedding is the focus of this CBA. It is a scheme designed to automatically shed demand following a credible event that creates a large under-supply event that cannot be managed using instantaneous reserves alone.

AUFLS operate by disconnecting distributor feeders armed with AUFLS relays. While the amount of demand shed required might vary by the nature of the credible event, the current AUFLS scheme always tries to arm at least 32% of NZ's load into two blocks. These blocks are shed at set frequency triggers. There is no compensation for demand tripped during an AUFLS event.

The NI AUFLS scheme has the characteristics set out in Table 5.

Table 5. NI AUFLS Characteristics[9]

Block	Load	Trip Setting	Reporting
1	16% of NI load	400 ms after frequency drops and remains at or below 47.8 Hz	Compliance measured post-event to see if the required percentage was met
2	16% of NI load	15 seconds after the frequency drops and remains at or below 47.8 Hz or 400 ms after the frequency drops and remains at or below 47.5 Hz	

2.2.6 The HVDC Interconnector

The HVDC interconnecting link, commonly shortened to HVDC, is the set of transmission lines and their ancillary equipment that connects the North and South islands of NZ. The HVDC consists of two poles, essentially two separate transmission pathways that allow the South Island's abundant hydro-generation capacity to power the NI and allows for NI generation to supply the South Island (SI) during periods of drought.

As significant quantities of generation can be transferred across the HVDC, at a time up to a third of NI's requirement, a trip of the HVDC can result in significant under-supply. Therefore, the loss of one transmission pathway, known as the loss of a monopole, is considered a CE. Given redundancies and various protection systems, the simultaneous loss of both transmission pathways, known as the loss of the bipole, is considered low risk and is treated as an ECE.

2.3 Proposed Scheme

The SO proposed[10] AUFLS scheme is detailed in Table 6.

The same 32% of load offered into the current AUFLS scheme has been proposed to be split into 4 smaller blocks with different trigger points. Block 1 and 2 are large 10% blocks NI load-blocks, and Block 3 and 4 are smaller 6% NI load-blocks allowing for greater discrimination of blocks. In addition, Block 4 is armed using a special rate of change of frequency (RoCoF) relay which enables tripping at a frequency set-point as well as for a set rate of change in frequency. In the case of the proposed scheme, a RoCoF greater than negative1.2 Hz every second will trigger the relay to shed load.

In addition to an increase in the number of blocks, the new scheme proposes half-hourly monitoring of AUFLS feeders by block to assist the SO better monitor compliance.

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[9] 20130807 AUFLS Scheme Design Report

[10] AUFLS Technical Requirements Report

Table 6: Proposed AUFLS scheme characteristics

Block	Load	Trip Setting	Reporting
1	10% of NI load	300 ms after the frequency reduces and remains at or below 47.9 Hz	Half-hourly monitoring of AUFLS enabled feeder demand by load block submitted to the SO yearly
2	10% of NI load	300 ms after the frequency reduces and remains at or below 47.7 Hz	
3	6% of NI load	300 ms after the frequency reduces and remains at or below 47.5 Hz	
4	6% of NI load	300 ms after the frequency reduces and remains at or below 47.3 Hz or If the rate of change of frequency (RoCoF) is greater than -1.2 Hz/s	

3. Cost-Benefit Analysis

This section outlines the methodology undertaken to assess the CBA.

The benefit of switching from the existing scheme to the new scheme are due to increased scheme reliability to prevent blackouts. The benefits accrue due to:

- better ability to arrest frequency fall from major "Other events" due to the addition of a df/dt relay
- reduced load-shedding during an AUFLS event due to an increased number of blocks and therefore better discrimination of load
- reduction in block sizes and therefore better targeted load shedding and reduction in over-frequency response

The costs of implementing the scheme are:

1. equipment and contractor costs to setup new relays and modify existing relays as required
2. information technology (IT) costs required to monitor AUFLS provision

The nature of low probability high impact events mean they are inherently hard to predict and therefore quantify. Where possible actual market and simulation data has been used, and where this data is unavailable, scenario testing has been applied.

3.1 Pertinent Assumptions

The pertinent assumptions used in this CBA are detailed in Table 7.

Table 7: Pertinent CBA assumptions

<table>
<tr><th>Assumption</th><th>Description</th></tr>
<tr><td>VoLL- Value of Lost Load</td><td>The 2018 SO report[11] identified the VoLL in NZ as $17000- $40,000 per MWh with a central figure of $25,000 per MWh. A VoLL of $25,000 has been assumed in this study.</td></tr>
<tr><td>VoLL GDP adjuster</td><td>A factor scaling VoLL in real terms in line with forecast growth in NZ's GDP. The factor accounts for the real increases in VoLL as the economy grows.</td></tr>
<tr><td>Electricity Intensity Factor</td><td>The increase in real VoLL because of increasing electrification of transportation and process heat is acknowledged but has not been included for simplicity.</td></tr>
<tr><td>Real, pre-tax discount rate</td><td>NZ Treasury recommends a 5% p.a. discount rate[12].</td></tr>
<tr><td>Blackout Restoration Time</td><td>NZ does not have regulated targets for system restoration times; however, Transpower's desktop studies indicate system restoration times between 18 and 48 hours[13]. It should be noted that this figure is from a study completed before the commissioning of Transpower's auto-synchronization technology, which may reduce blackout restoration time.
A conservative blackout restoration time of 24 hours is assumed.</td></tr>
<tr><td>Mean NI Load</td><td>The mean half-hourly NI load for the previous two calendar years were
<table>
<tr><th>Year</th><th>Load (MW)</th></tr>
<tr><td>2019</td><td>2847</td></tr>
<tr><td>2020</td><td>2831</td></tr>
</table>
This CBA uses the 2019 average as a mean NI load to remove any distortions due to the impact of the COVID-19 pandemic. The overwhelming consensus is that NZ's electricity demand is expected to grow; however, for simplicity, it is assumed that load remains static at mean 2019 levels and therefore the benefits calculated are considered conservative.</td></tr>
</table>

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[11] https://www.transpower.co.nz/resources/value-lost-load-voll-study

[12] https://www.treasury.govt.nz/information-and-services/state-sector-leadership/guidance/financial-reporting-policies-and-guidance/discount-rates

[13] Security and Reliability Council – Arrangement for power system restoration, including black start

3.2 Benefit(s)

Primary benefits of the new scheme accrue from its greater reliability reducing the risk of blackouts. There are a range of other benefits from switching to the proposed scheme. However, these benefits are smaller than the benefits from an avoided blackout, and therefore EY has been instructed by the EA to ignore these for the sake of simplicity in this analysis.

NZ has never had a full system blackout, however, the probability of such an event may not be zero. To provide some context, the National Generators Forum of Australia in 2014 commissioned ROAM Consulting, now part of EY, to calculate the potential for a full Australian National Electricity Market (NEM) wide blackout[14]. The NEM is more than 5 times larger than NZ's electricity system, and because it is larger and more interconnected is considered more stable. The report calculated the probability of a 25,000 MW blackout (near full system) as once every 63.4 years.

The Australian Energy Market Operator completed a review[15] of the 28 September 2016 power system event, which disconnected 850,000 South Australian customers. The review highlighted the increase in non-synchronous and inverter-connected generation (wind and solar) having different characteristics, including complex software and control systems compared to conventional generation (hydro and thermal), as one of the reasons for the blackout.

NZ is expected to connect a large amount of new generation due to the rapid electrification of heat and transport, and large thermal generators expected to retire over time. Transpower's 2020 report Whakamana i Te Mauri Hiko forecasts a 68% increase in electricity generation by 2050[16], the majority to be met by renewable energy (RE) resources.

The penetration of RE, while enabling a much-needed transition to a lower-carbon future, is inherently riskier, given their intermittent nature and connection to the power system through inverters. Inverters are necessary to convert the direct current (DC) generation produced by these technologies to alternating currents (AC) that is required to transport power in the NZ power system.

Conventional technologies such as hydro and thermal generation directly produce AC which is tightly 'coupled' with the power system. This tight coupling provides 'inertia' to the system and acts in the opposite direction of frequency fall or frequency rise as a force against instantaneous change in frequency. This inertia provides IR and AUFLS additional time to act, potentially reducing the probability of blackout. Wind and Solar generation produce DC which is then converted to AC using inverters. Inverters break the tight coupling between generation and the power system, providing no inertia. While this is not an issue when the number of inverter connections are low, it can create system challenges as the number of connections increase. Modern inverters try to address these issues through the production of artificial inertia, but artificial inertia technology is in its infancy and the quality of the inertia is considered to be inferior.

The SO has identified the new AUFLS scheme as having greater resiliency to blackouts due to a faster acting, better load matched product[17]. The faster-acting nature of the new scheme helps future-proof the scheme to an increasingly renewable energy future.

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[14] https://www.aemc.gov.au/sites/default/files/content/0120e698-568c-4d8b-aa7c-0b74422687c9/National-Generators-Forum.PDF

[15] https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2017/integrated-final-report-sa-black-system-28-september-2016.pdf?la=en&hash=7C24C97478319A0F21F7B17F470DCA65

[16] https://www.transpower.co.nz/sites/default/files/publications/resources/TP%20Whakamana%20i%20Te%20Mauri%20Hiko.pdf

[17] 20130807 AUFLS Scheme Design Report

3.2.1 Blackout costs

Central to the benefits of reduced probability of blackouts is the cost of a blackout. Using values from Table 7 above, blackout costs are calculated as:

$$2{,}847\ MW\ \times 24\ hours\ \times \$25{,}000/MWh\ = \$1.7B$$

3.2.2 Benefit calculation

The SO has identified that the use of RoCoF relays in the new scheme has the ability to react quickly to large events – characterised by extremely fast rate of change of frequency falls – and trip AUFLS load even before instantaneous reserves have the ability to act. This ability to "sense" extremely large events and react instantly will arrest frequency fall much faster than the current scheme and buy the system much needed time to then allow both IR and the remaining AUFLS blocks to trigger (if necessary) and prevent a blackout. In addition, the increase in the number of blocks and reduction in block size in the new scheme prevents too much load tripping at any one time. This prevents an over-frequency response which can lead to additional generation trips, which in turn leads to another under-frequency event without any IR or AUFLS to prevent cascade failure.

The SO identified the four-block scheme with RoCoF relays on block four showed a 43% improvement in reliability over the existing AUFLS scheme[18].

Based on the above, assuming 43% of all blackouts can be prevented under the new scheme, the annual average benefit of the scheme due to improvement in reliability (at a VoLL of $25,000/MWh) for various blackout return periods can be calculated using the formula below:

$$\frac{\$1.7B}{return\ period} \times 43\%$$

The benefit due to a reduction in the probability of blackouts over various blackout return periods is provided in Table 8.

Based on the Australian experience detailed at the start of this section, we consider that a 60-year return period for a total blackout is reasonable for NZ. It is worth noting, however, that NZ has had an integrated system for close to 100-years and has yet to experience a blackout. Therefore, our central estimate for a return period lies somewhere between 60-120 years. This equates to a present value (PV) of $150.8M for a 60 -year return event and $75.4M for a 120-year event based on the present value of average annualised loss estimates for the system. This range will be used in the remainder of the report.

Given the inherent uncertainty in these estimates, however, it is worth noting that even a 500-year event provides an $18.1m benefit in 15-year PV terms which is mathematically sufficient to justify investment in the new system.

Again, given the inherent uncertainty in estimates the reliability improvement required to break even with total costs was determined. A 4.5% improvement in reliability provides a $7.9M benefit for a 120-year blackout return period. Costs are discussed in section 3.3 below.

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Table 8: Benefit due to reduction in the probability of blackouts

Return Period (years)	PV over 15 years with a 43% improvement in reliability	PV over 15 years with a 4.5% improvement in reliability
50	$181.0M	
60	$150.8M	$15.8M
70	$129.3M	
80	$113.1M	
90	$100.5M	
100	$90.5M	
120	$75.4M	$7.9M
250	$36.2M	
500	$18.1M	

3.3 Costs

3.3.1 Capital costs

There are two capital expenditure costs associated with moving from a 2-block AUFLS scheme to a 4-block scheme:

3.3.1.1 Relay costs

The 2011 implementation costs, including new hardware and project management, was calculated as $6M[19]. The 2011 cost inflated to 2021 is calculated as $7.4M, using mean Statistics New Zealand's changes to capital good price movements for electrical works. A mean inflation per quarter of 0.533[20] based on the last 3 years to September 2020 quarter was used to inflate the 2011 value each quarter through to 2021.

There are no direct costs to consumers in implementing the new AUFLS scheme. The costs of the new scheme will be added to the distributor's regulated asset base (RAB) and costs recovered through distribution pricing.

3.3.1.2 Information system costs required to monitor AUFLS relays

As part of the relay upgrades the SO will be spending $0.5M implementing an information technology (IT) system to monitor distributor level AUFLS provisioning at half-hourly intervals.[21] The monitoring regime will ensure an improved SO compliance response.

3.3.2 Operating costs

Ongoing OPEX costs of maintaining the monitoring platform and ensuring regular reporting for AUFLS providers is anticipated to be the same as in the existing system. As such, there are no marginal changes to operating costs to include in this CBA, so they are excluded.

3.3.3 Total Costs

The total cost of implementing the new scheme is $7.9M and is summarised in Table 9 below.

Table 9: Total cost of switching from the 2-Block scheme to a 4-Block scheme with df/dt

Cost Item	Capex	Associated Opex
Upgrade and install relays	$7.4M	None
AUFLS monitoring information systems	$0.5M	None
Total	**$7.9M**	**None**

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[19] 20130807 AUFLS Scheme Design Report

[20] https://www.stats.govt.nz/assets/Uploads/Business-price-indexes/Business-price-indexes-September-2020-quarter/Download-data/business-price-indexes-september-2020-quarter-capital-goods-price-index.xlsx

[21] As advised by the Electricity Authority

4. Cost Benefit Analysis Results

The benefits and costs are presented in Net Present Value (NPV) terms, being the single present value calculated from the costs and benefits over time and the treasury energy infrastructure real discount rate.

The results are presented as benefit cost ratios (BCRs) which are the total additional net present benefits of a proposed intervention divided by their total additional net present costs relative to a business as usual solution. As such, Table 10 tabulates the following:

- The benefits associated with the scheme is between $75.4M to $150.8M, while the implementation costs are $7.9M, resulting in an NPV range for this investment of between $67.5M to $142.9M over the 15-year assessment period.
- BCR range of 9.58 to 19.16, where, even at a low end, the BCR is very high for infrastructure investment, suggesting a strong value-for-money case for this investment.
- Even with only a 4.5% improvement in reliability and a 120-year blackout return period the benefits break even with the costs of implementation

Table 10: Costs and Benefits Summary (15y)

Costs and Benefits	Present Value over 15 years ($)
Benefits	
Reduced probability of blackouts due to increased reliability (60 to 120-year return period)	$75.4m to $150.8M
Costs	
Upgrade and install relays	($7.4M)
AUFLS monitoring information systems	($0.5M)
Subtotal	**($7.9M)**
Net Present Value (Benefits / Costs)	$67.5M to $142.9M
Benefit Cost Ratio (BCR)	9.58 to 19.16

Appendix A Historical AUFLS Trips

<table>
<tr><th>Date</th><th>Island</th><th>Cause</th><th>AUFLS Load Shed</th><th>Restoration Time</th></tr>
<tr><td rowspan="2">December 2012[22]</td><td>NI</td><td>Huntly units 1, 2 & 5 Tripped</td><td>8.4% of NI</td><td>~3 hours</td></tr>
<tr><td colspan="4">The SO review of the event noted that the full 16% of load did not trip due to oscillations in system frequency resetting the tripping signal, which requires 400 ms of frequency below 47.8 Hz in order to trip. In addition, had all 16% of load tripped, the over-frequency could've been above 52 Hz, causing over-frequency generation tripping.</td></tr>
<tr><td rowspan="2">November 2013[23]</td><td>NI</td><td>Sudden HVDC ramp-down during Pole 3 Commissioning tests</td><td>10% of NI demand</td><td>~ 1 hour</td></tr>
<tr><td colspan="4">SO review of the event noted the frequency didn't stay below 47.8 long enough for the entire 16% of AUFLS in block 1 to trip. "Acceptable frequency measurement errors and different relays having different time delays account for the fact 10% of AUFLS tripped."</td></tr>
<tr><td>March 2017[24]</td><td>SI</td><td>Clyde – Twizel 1 and Clyde – Twizel 2 circuits tripped, leading to a separation of the Lower South Island from the rest of the South Island.</td><td>16% of Upper SI demand</td><td>~1.5 hours</td></tr>
</table>

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[22] https://www.transpower.co.nz/sites/default/files/bulk-upload/documents/AUFLS%20event%2013%20Dec%202011%20report.pdf

[23] https://www.transpower.co.nz/resources/aufls-activation-12-november-2013

[24] https://www.transpower.co.nz/resources/report-2-march-2017-south-island-aufls-event

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