

## Capital Expenditure: Expenditure Justification Cover Sheet

<b>Project name</b>	Earth Grid Refurbishment
<b>Expenditure type</b>	Capital Expenditure
<b>Business Group</b>	Asset Strategy & Planning
<b>Period</b>	1 July 2014 to 30 June 2019
<b>Five year total spend</b>	\$1.2 Million
<b>CAPEX category &amp; Primary Drivers</b>	Refurbishment / Replacement CAPEX <ul style="list-style-type: none"> <li>• Compliance with Safety Regulations</li> <li>• Replacement of obsolete (operating past economic life) assets</li> <li>• Establishing baseline data for the asset (earth grid) performance</li> </ul>

## Version control

Date	Version	Description	Reviewed	Author
22/11/12	0.3	Final draft	F Gotla	Select Solutions
01/07/14	1.0	First issue	F Gotla	Jacobs
17/11/14	1.2	Reconciled methodology, updated program & cash-flow to match methodology	G Pallesen	S Turki
05/12/14	2.2	Added reference documents. Ready for issue.	D Stanley S Devlin	G Pallesen
15/01/15	3.0	Incorporate GM comments to change to probability based results to moderate capex request	D Stanley	G Pallesen

## Referenced documents

Document	Version
Asset Specific Plan Earthing (Zones) , AAD Internal document	16-06-2014
National Electricity Law Chapter 7A "Revenue and Pricing Principals"	19.12.2013
National Electricity Rules Chapter 6.5.7 Forecast capital expenditure	V66
ENA EG1 – <i>Substation Earthing Guide</i>	2006
Utilities Act (ACT)	2000
Utilities (Management of Electricity Network Assets Code) Determination	2013

## Approval

----- Manager Primary Systems Strategy	----- Signature	----- Date
----- Branch Manager Asset Strategy and Planning	----- Signature	----- Date

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## Executive Summary

This Project Justification Report (PJR) demonstrates the requirement for AAD (AAD) to undertake investigations of the condition of existing zone substation earth grids and recommends on a probabilistic basis that, of the fourteen (14) zone substations / switchyard, one (1) will require a major earth grid upgrade and three (3) will require earth grid refurbishments. The approach complies with the Utilities Act 2000 (ACT), National Electricity Rules and National Electricity Law obligations for operation of a safe and reliable power distribution system. This specifically meets the obligations of the National Electricity Rules Chapter 6.5.7.

### 6.5.7 Forecast capital expenditure

(a) A *building block proposal* must include the total forecast capital expenditure for the relevant *regulatory control period* which the *Distribution Network Service Provider* considers is required in order to achieve each of the following (the *capital expenditure objectives*):

- (1) meet or manage the expected demand for *standard control services* over that period;
- (2) **comply with all applicable regulatory obligations or requirements** associated with the provision of *standard control services*;
- (3) to the extent that there is no applicable *regulatory obligation or requirement* in relation to:
  - (i) the quality, reliability or security of supply of *standard control services*; or
  - (ii) the reliability or security of the *distribution system* through the supply of *standard control services*, to the relevant extent:
  - (iii) **maintain the quality, reliability and security of supply** of *standard control services*; and
  - (iv) **maintain the reliability and security of the distribution system** through the supply of *standard control services*; and
- (4) **maintain the safety** of the *distribution system* through the supply of *standard control services*.

The methodology and estimated costs for this earth grid condition assessment and refurbishment program are developed through the application of industry knowledge and Good Engineering Operating Practices. This approach complies with paragraphs 6 & 7 of National Electricity Law (NEL):

### **NATIONAL ELECTRICITY (NSW) LAW - SECT 7A**

#### **Revenue and pricing principles**

*When providing an estimate for a project, state that the estimate is commensurate with the economic costs and risks of the potential for under and over investment by a regulated network service in reference to Section 7A of the National Electricity Law, paragraph 6 & 7.*

Furthermore, this program of works is required to comply with the Workplace Health and Safety Act 2011. In particular Division 2.2 Primary Duty of Care, which is also commensurate with NEL clause 7A (2) (b).

NEL clause 7A (2) (b)

- (1) *The revenue and pricing principles are the principles set out in subsections (2) to (7).*
- (2) *A regulated network service provider should be provided with a reasonable opportunity to recover at least the efficient costs the operator incurs in-*
  - (a) *providing direct control network services; and*
  - (b) ***complying with a regulatory obligation or requirement or making a regulatory payment.***

## **WHS Act 2011: Division 2.2 Primary duty of care**

### **19 Primary duty of care**

- (1) A person conducting a business or undertaking must ensure, so far as is reasonably practicable, the health and safety of—*
- (a) workers engaged, or caused to be engaged, by the person; and*
  - (b) workers whose activities in carrying out work are influenced or directed by the person, while the workers are at work in the business or undertaking.*
- (2) A person conducting a business or undertaking must ensure, so far as is reasonably practicable, that the health and safety of other persons is not put at risk from work carried out as part of the conduct of the business or undertaking.*
- (3) Without limiting subsections (1) and (2), a person conducting a business or undertaking must ensure, so far as is reasonably practicable—*
- (a) the provision and maintenance of a work environment without risks to health and safety; and*
  - (b) the provision and maintenance of safe plant and structures; and*
  - (c) the provision and maintenance of safe systems of work; and*
  - (d) the safe use, handling, storage and transport of plant, structures and substances; and*
  - (e) the provision of adequate facilities for the welfare at work of workers in carrying out work for the business or undertaking, including ensuring access to those facilities; and*
  - (f) the provision of any information, training, instruction or supervision that is necessary to protect all persons from risks to their health and safety arising from work carried out as part of the conduct of the business or undertaking; and*
  - (g) that the health of workers and the conditions at the workplace are monitored for the purpose of preventing illness or injury of workers arising from the conduct of the business or undertaking.*

AAD has an obligation to comply with the Utilities Act 2000 (ACT) which imposes specific technical, safety and reliability obligations on AAD.

#### **Utilities (Management of Electricity Network Assets Code) Determination 2013**

The Management of Electricity Network Assets Code is a technical code under Part 5 of the *Utilities Act 2000* (the Act).

#### **4 WHEN UTILITIES' OBLIGATIONS DO NOT APPLY**

The obligations imposed on an electricity distributor under this Code do not apply when:

- (1) the events or conditions are outside the control of the electricity distributor and prevent the electricity distributor from complying with this Code; and
- (2) the consequences of the events or conditions are not created by the electricity distributor's actions or lack of actions.

#### **5.3 Safe Design, Construction, Operation and Maintenance**

(1) An electricity distributor must design, construct, operate and maintain its aerial lines, underground lines, substations, equipment and metering with reasonable care to avoid injury to any persons or damage to property or the environment and to provide a reliable and efficient power supply.

(4) The electricity distributor must ensure that the earthing and protection systems of its electricity network are designed, installed, operated and maintained with reasonable care to avoid injury to any persons or damage to property or the environment.

#### **5.5 Compliance with the National Electricity Network Safety Code**

(1) An electricity distributor must comply with ENA Doc 001 National Electricity Network Safety Code.

(2) The obligations set out under the National Electricity Network Safety Code shall apply to the electricity distributor and any of its contractors or third parties authorised to carry out any design, construction, testing, operation or maintenance on its electricity network.

(3) Provisions of the National Electricity Network Safety Code on the design, construction, testing, operation and maintenance shall apply to all electricity networks, whether or not the network or its components are in service, out of service or under construction.

#### **Schedule: Electricity Network Standards and Guidelines**

This schedule sets out the minimum safety standards and guidelines for the design, construction, operation and maintenance of electricity networks.

The principal source of Standards, Codes and Guides relating to the Design, Construction, Maintenance and Safe Electrical Operation and Work Practices for Distribution Systems are sourced from;

- Standards Australia (AS or AS/NZS)
- International Standards Organisation (ISO)
- International Electrotechnical Commission (IEC)
- Energy Networks Association (ENA)
- Institute of Electrical and Electronic Engineers (IEEE)
- American national Standards Institute (ANSI)

The standards and publications listed below, as published or amended from time to time, are relevant to this Code but do not necessarily represent all the standards that may need to be consulted in meeting the requirements of this Code.

The Management of Electricity Networks Asset Code (per Utilities Act 2000 (ACT)) imposes specific obligations requiring compliance with PAS55 “the Optimised Management of Physical Assets”. AAD’s asset management systems and processes have been developed in accordance with the principles of PAS55. AAD has completed a pre-certification audit for PAS55 compliance and is working towards certification in the 2014-19 regulatory period.

**Utilities (Management of Electricity Network Assets Code) Determination 2013**

The Management of Electricity Network Assets Code is a technical code under Part 5 of the *Utilities Act 2000* (the Act).

**5.3 Safe Design, Construction, Operation and Maintenance**

(1) An electricity distributor must design, construct, operate and maintain its aerial lines, underground lines, substations, equipment and metering with reasonable care to avoid injury to any persons or damage to property or the environment and to provide a reliable and efficient power supply.

(3) The electricity distributor must have an up to date asset management system consistent with **PAS 55 Asset Management** and ISO 55000 Asset Management.

(4) The electricity distributor must ensure that the earthing and protection systems of its electricity network are designed, installed, operated and maintained with reasonable care to avoid injury to any persons or damage to property or the environment.

Section G of the Management of Electricity Networks Asset Code (per Utilities Act 2000 (ACT)) imposes specific obligations relating the safe operation of substation earthing systems.

**Section G: Standards, Codes and Guides Relating to Earthing, Protection and Testing Systems**

The standards and publications listed below, as published or amended from time to time, are relevant to this Code but do not necessarily represent all the standards that may need to be consulted in meeting the requirements of this Code.

- AS/NZS 7000 Overhead line design – Detailed procedures
- ENA Doc 014 National low voltage electricity network electrical protection guideline
- ENA EG1 Substation Earthing Guide
- ENA EG0 Power System Earthing Guide
- AS/NZS 3000 Electrical installations
- AS/NZS 3001 Electrical installations – transportable structures and vehicles including their site supplies
- IEEE 80 IEEE Guide for safety in ac substation grounding
- AS 2067 Substations and high voltage installations exceeding 1 kV a.c.
- AS 60044 (series) Instrument transformers
- AS 60947 (series) Low voltage switchgear and control gear
- AS 1033 (series) High voltage fuses
- AS 60269 (series) Low voltage fuses
- IEC 60255 (series) Measuring relays and protection equipment

**Zone Substation : Earth Grid Refurbishment**

AAD’s network comprises of thirteen (13) zone substations and two (2) switching stations. The majority of these facilities operate at 132/11 kV with the exception of the Fyshwick zone substation which operates at 66/11 kV. The Causeway Switching Station is expected to be decommissioned during the 2014-19 regulatory period and is not assessed as part of this proposed capital works program. The earth grids at the respective stations were installed when the stations were first commissioned. Over 80% of earth grids in AAD’s network have been in operation for over twenty-five (25) years, with the oldest installation approaching fifty-five (55) years of age. As such the conditions of these earth grids are largely unknown.

System growth has resulted in significant augmentation and expansion works in zone substations over the past fifteen (15) years. The earth grids have been in-service for a long time raising a concern about their integrity to be adequate / effective given that substation loads have increased with consequent increase in network fault levels. Therefore, it is necessary to undertake necessary remedial works to ensure that AAD fulfils its duty of care and regulatory obligation with respect to safe, reliable and efficient operation of its network. A ‘Run to Failure’ approach to operating these assets beyond their useful life is not acceptable, as AAD considers it would be in breach of WHS legislation and regulatory obligations under the National Electricity Law and the National Electricity Rules.

The key drivers of the CAPEX investment in earth grids are safety to public and personnel and to ensure correct operation of network protection relays to maintain the security and reliability of supply.

There were two options considered to alleviate the risks of the existing earthing systems:

- Option 1: Do Nothing
- Option 2: Condition Assessment based refurbishment

The risks to personnel safety and the risk of protection relay malfunctions are significant in the **Do Nothing** option (**option 1**) and the option to defer investment is not available as a majority of these assets are operating well beyond their economic lives.

Under **option 2 (condition based refurbishment)**, there are two stages:

**Stage 1:** incorporates the sample inspections, electrical testing, fault level validation and overall condition assessment of the earth grids. Testing of the earth grids will have the following required outcomes:

- assessing the adequacy of the existing station earth grids to provide the requisite levels of safety for the prevailing network conditions;
- evaluating AAD’s ability to demonstrate compliance with industry guidelines, regulations and the overarching legislation;
- calculating (or estimating) the rate of deterioration of the respective station earth grids and hence a means for forecasting their future service lives; and
- definitive scope of works and costing for necessary refurbishment/upgrade works.

**Stage 2:** covers the necessary refurbishment and upgrading of the earth grids as determined by Stage 1 outcomes.

Condition Assessment Based Refurbishment (Option 2) is the most prudent and cost effective solution to ensure compliance with the safety requirements whilst minimising AAD’s residual risk of incidents occurring due to deteriorated earth grids. It is cost effective to conduct testing as part of stage 1 to accurately define the scope of works and undertake necessary refurbishment / upgrade / replacement as required in stage 2.

A probabilistic approach has been taken to prepare this justification. AAD has considered that out of the fourteen (14) zone substations / switchyard, one (1) will require a major earth grid upgrade and three (3) will require earth grid refurbishments. It is recommended that the capital expenditure budget of \$1.2 Million over a 5 year period be approved for the earth grid refurbishment works across all of AAD’s zone substations. Table 1 below illustrates the CAPEX budget for refurbishment of earth grids.

**Table 1:** Option 2 - CAPEX Budget for Zone Substation Earthing Conditional Assessment and Refurbishment Program

	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Budget 2012/13 \$s	2014-15	2015-16	2016-17	2017-18	2018-19	Yrs 1-5
Total CAPEX Budget for approval	\$75,000	\$310,000	\$310,000	\$310,000	\$240,000	<b>\$1,245,000</b>



# 1. Strategic context & Expenditure need (prudence)

## 1.1 Asset Overview

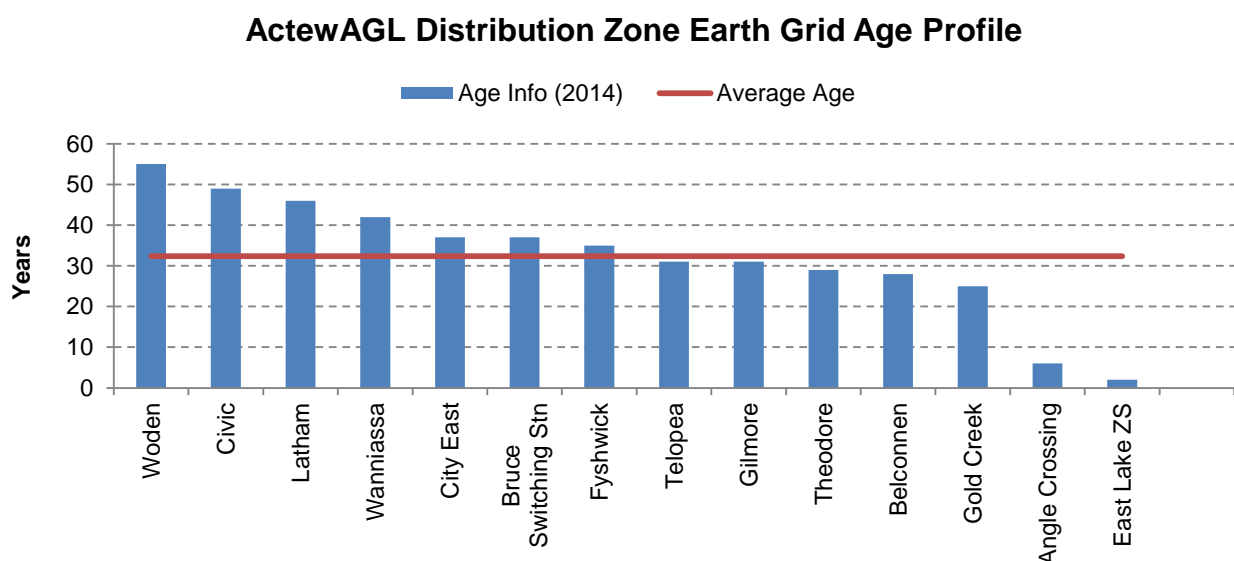
AAD’s network includes thirteen (13) zone substations and two (2) switching stations. One switching station (Causeway) is likely to be decommissioned during the 2014-19 regulatory period and has not been considered in this program of works. The majority of these facilities operate at 132/11 kV with the exception of the Fyshwick zone substation which operates at 66/11 kV. The age profile of the AAD earth grids shows that more than 80% have been in operation for over 25 years, with the oldest installation approaching 55 years of age. Both substations and switching station infrastructure is referred to as “station” within this report. Within this profile of zone substations, there are two substations which are under 6 years from having been commissioned. The age profile of AAD’s assets is given in figure 1 below, showing an average age of 32.

The standard life of earth grids is around 30 years, however the soil conditions within the ACT are reactive and corrosive, and therefore, the effective life of the earth grids is assessed to be 25 years, beyond which there is expected to be significant deterioration with refurbishment works required.

Published data (Soil Landscapes of the Canberra - NSW Department of Environment and Heritage) shows that most soils around Canberra are Podzols which generally derive from either quartz-rich sands and sandstones or sedimentary debris from magmatic rocks. Being mostly sandy, these soils are low in moisture and nutrients with phosphate deficiencies and aluminium toxicity with the result that they are aggressive on buried copper of earth grids.

Chapter 12 of the Energy Networks Association document ENA EG1 – 2006 titled “*Substation Earthing Guide*” provides specific guidance on Maintenance and Refurbishment. Section 12.3 on Major Review and Refurbishment states that the ongoing maintenance strategies recommended for the substations match test and inspection frequencies to the expected deterioration whilst providing safeguards to detect unexpected deterioration (vandalism). Section 12.2.1 on Physical Inspection suggests an annual above- ground inspection and five (5) yearly below ground inspection for the earth grids, while section 12.2.2 on Electrical Performance indicates earth grid continuity testing at fifteen (15) year intervals.

Figure 1: Age Profile of AAD Earth Grid at Zone Substations



## 1.2 Earth Grids & Safety

The effectiveness of each earth grid is a function of the surface area of grid conductive material (usually copper) that is in contact with the general mass of earth. Hence factors such as age related deterioration and soil conditions which erode the grid conductors can have a significant impact on the effectiveness and service life of the earth grids.

The earth grid at each station must be designed for the prevailing conditions at the respective sites, importantly soil resistivity and the station fault levels. Whilst the soil conditions are unlikely to change, progressive augmentations to the electricity network will result in an increase in fault levels. Thus, unless the station fault level is within the design tolerance of the earth grid, the effectiveness and hence the level of safety provided is diminished.

An earthing grid's location (type of soil – reactive or non-reactive), severity of the faults interrupted, physical damage and other factors (e.g. moisture in soil, ground movement) can impact its earthing grid resistance. Earth grids are vital for public and staff safety and also for the correct operation of the network protection relays.

Each zone station and switching station has an earth grid installed, the purpose of which is to maintain the safety of personnel at and near the site through:

- prevention of hazardous touch, step and transfer potentials during fault conditions;
- ensuring all accessible, non-current carrying structures and equipment are maintained at the same potential;
- preventing the build-up of static charges on equipment;
- ensuring a continuous, low impedance path to earth for lightning surges, switching surges and 50 Hertz fault currents; and
- providing a consistent reference for the network voltage levels for the correct operation of the network protective devices.

Therefore, it is necessary for AAD to determine the current state of these aged earthing grids through condition assessment testing, and to undertake necessary remedial works promptly to mitigate risks associated with the deterioration in order to ensure that AAD fulfils its duty of care and regulatory obligation with respect to safe and efficient operation of its network.

As the earth grids are buried beneath the station surfaces, and also beneath some equipment foundations, there is no easy method for its physical inspection to determine its existing condition. Modern testing includes frequency injection testing which replicates fault conditions and provides information on the impedance, health and fault paths of the earth grid.

## 1.3 Key Drivers

- The key business and regulatory compliance drivers for this expenditure are:
  - safety; safety to public and personnel;
  - system security and reliability
  - The secondary business drivers are for AAD to develop an effective refurbishment strategy for:
    - under-performing assets; and
    - Establishing an end of asset life profile to mitigate the risk of premature failure.

## 1.4 Regulatory Compliance

AAD is a Distribution Network Service Provider in the regulated Australian National Electricity Network. To fulfil its regulatory obligations AAD must comply with the National Electricity Rules, National Electricity Law and various other regulatory instruments, including the core safety compliance obligations set out in the Workplace Health and Safety Act.

### ▪ Safety compliance:

Under a range of regulations, industry guidelines and legislation which include the Utilities Act 2000 (ACT), Electricity Supply (Safety and Network Management) Regulation 2008, ENA “National Electricity Safety Code” and Work Health and Safety Act ACT 2011, AAD is obligated to maintain the safety of its electricity network for employees, contractors and the general public. To that end each zone station and switching station has an earth grid installed, the purpose of which is to maintain the safety of personnel at and near the site through:

- prevention of hazardous touch, step and transfer potentials during fault conditions;
- ensuring all accessible, non-current carrying structures and equipment are maintained at the same potential;
- preventing the build-up of static charges on equipment;
- ensuring a continuous, low impedance path to earth for lightning surges, switching surges and 50 Hertz fault currents; and
- providing a consistent reference for the network voltage levels for the correct operation of the network protective devices.

This program of works is required to comply with the Utilities Act 2000 (ACT), Workplace Health and Safety Act 2011. In particular Division 2.2 of the WHS Act “Primary Duty of Care” and the Management of Electricity Networks Asset Code (per Utilities Act 2000 (ACT) “Section G “Standards, Codes and Guides relating to Earthing, Protection and Testing Systems”, which is commensurate with NEL clause 7A (2) (b)

**NEL clause 7A (2) (b)**

- (1) The revenue and pricing principles are the principles set out in subsections (2) to (7).*
- (2) A regulated network service provider should be provided with a reasonable opportunity to recover at least the efficient costs the operator incurs in-*
  - (a) providing direct control network services; and*
  - (b) complying with a regulatory obligation or requirement or making a regulatory payment.*

**WHS Act 2011: Division 2.2****19 Primary duty of care**

- (1) A person conducting a business or undertaking must ensure, so far as is reasonably practicable, the health and safety of—*
  - (a) workers engaged, or caused to be engaged, by the person; and*
  - (b) workers whose activities in carrying out work are influenced or directed by the person, while the workers are at work in the business or undertaking.*
- (2) A person conducting a business or undertaking must ensure, so far as is reasonably practicable, that the health and safety of other persons is not put at risk from work carried out as part of the conduct of the business or undertaking.*
- (3) Without limiting subsections (1) and (2), a person conducting a business or undertaking must ensure, so far as is reasonably practicable—*
  - (a) the provision and maintenance of a work environment without risks to health and safety; and*
  - (b) the provision and maintenance of safe plant and structures; and*
  - (c) the provision and maintenance of safe systems of work; and*
  - (d) the safe use, handling, storage and transport of plant, structures and substances; and*
  - (e) the provision of adequate facilities for the welfare at work of workers in carrying out work for the business or undertaking, including ensuring access to those facilities; and*
  - (f) the provision of any information, training, instruction or supervision that is necessary to protect all persons from risks to their health and safety arising from work carried out as part of the conduct of the business or undertaking; and*
  - (g) that the health of workers and the conditions at the workplace are monitored for the purpose of preventing illness or injury of workers arising from the conduct of the business or undertaking.*

Section G of the Management of Electricity Networks Asset Code (per Utilities Act 2000 (ACT)) imposes specific obligations relating to the safe operation of substation earthing systems.

### **Section G: Standards, Codes and Guides Relating to Earthing, Protection and Testing Systems**

The standards and publications listed below, as published or amended from time to time, are relevant to this Code but do not necessarily represent all the standards that may need to be consulted in meeting the requirements of this Code.

- AS/NZS 7000 Overhead line design – Detailed procedures
- ENA Doc 014 National low voltage electricity network electrical protection guideline
- ENA EG1 Substation Earthing Guide
- ENA EG0 Power System Earthing Guide
- AS/NZS 3000 Electrical installations
- AS/NZS 3001 Electrical installations – transportable structures and vehicles including their site supplies
- IEEE 80 IEEE Guide for safety in ac substation grounding
- AS 2067 Substations and high voltage installations exceeding 1 kV a.c.
- AS 60044 (series) Instrument transformers
- AS 60947 (series) Low voltage switchgear and control gear
- AS 1033 (series) High voltage fuses
- AS 60269 (series) Low voltage fuses
- IEC 60255 (series) Measuring relays and protection equipment

- **Cost compliance** is achieved by applying a delivery methodology of assessing the earth grid condition prior to confirming the required scope, but acknowledging that any metal structure that has been in the ground or in service for twenty-five (25) to > forty (40) years will have degradation thereby requiring refurbishment. Historical costs from greenfield (new) zone substation earth grid installations have been used to establish nominal costs of refurbishment for each zone substation and the delivery of this program is expected to see some zone substations cost less than the proposed cost and some zone substations to cost more than the proposed cost. This approach adheres to the “under and over investment” principle, which is recognised in National Electricity Law Sect 7A paragraph 6 & 7.

### ***NATIONAL ELECTRICITY (NSW) LAW - SECT 7A***

#### ***Revenue and pricing principles***

*When providing an estimate for a project, state that the estimate is commensurate with the economic costs and risks of the potential for under and over investment by a regulated network service in reference to Section 7A of the National Electricity Law, paragraph 6 & 7.*

- **Quality, reliability and security of supply:**

This program of works is required to meet the 'quality, reliability and security of supply obligations in the capital expenditure objectives in the National Electricity Rules. Without this program of works being completed AAD would need to adopt a 'run to failure' capital replacement regime (i.e. the "Do Nothing Option") for critical network assets that are foundational for the safety of personnel and the community and foundational for maintaining a secure and reliable supply for the consumers.

#### **6.5.7 Forecast capital expenditure**

(a) A *building block proposal* must include the total forecast capital expenditure for the relevant *regulatory control period* which the *Distribution Network Service Provider* considers is required in order to achieve each of the following (the *capital expenditure objectives*):

- (1) meet or manage the expected demand for *standard control services* over that period;
- (2) **comply with all applicable regulatory obligations or requirements** associated with the provision of *standard control services*;
- (3) to the extent that there is no applicable *regulatory obligation or requirement* in relation to:
  - (i) the quality, reliability or security of supply of *standard control services*; or
  - (ii) the reliability or security of the *distribution system* through the supply of *standard control services*, to the relevant extent:
  - (iii) **maintain the quality, reliability and security of supply** of *standard control services*; and
  - (iv) **maintain the reliability and security of the distribution system** through the supply of *standard control services*; and
- (4) **maintain the safety** of the *distribution system* through the supply of *standard control services*.

The Management of Electricity Networks Asset Code (per Utilities Act 2000 (ACT) imposes specific obligations requiring compliance with PAS55 "the Optimised Management of Physical Assets". AAD's asset management systems and processes have been developed in accordance with the principles of PAS55. AAD has completed a pre-certification audit for PAS55 compliance and is working towards certification in the 2014-19 regulatory period.

#### **Utilities (Management of Electricity Network Assets Code) Determination 2013**

The Management of Electricity Network Assets Code is a technical code under Part 5 of the *Utilities Act 2000* (the Act).

#### **5.3 Safe Design, Construction, Operation and Maintenance**

- (1) An electricity distributor must design, construct, operate and maintain its aerial lines, underground lines, substations, equipment and metering with reasonable care to avoid injury to any persons or damage to property or the environment and to provide a reliable and efficient power supply.
- (3) The electricity distributor must have an up to date asset management system consistent with **PAS 55 Asset Management** and ISO 55000 Asset Management.
- (4) The electricity distributor must ensure that the earthing and protection systems of its electricity network are designed, installed, operated and maintained with reasonable care to avoid injury to any persons or damage to property or the environment.

## 2. Option Assessment and Recommended Expenditure

### 2.1 Option 1: Do Nothing (Run to Failure)

The Do Nothing option assumes that there is no investment in condition assessment over and above that allowed for in the Asset Specific Plan (ASP) which may include general earth grid condition assessment (checking the degree of deterioration, integrity of any connections, resistance measurements within acceptable ranges of each station), but may not include electrical testing that would relate to the overall integrity of the earth grid assuming increased fault levels. AAD's network has been progressively augmented; resulting in the increased fault levels in a number of zone substations. Thus, unless the station fault level is within the design tolerance of the earth grid the effectiveness and hence the level of safety provided is diminished. Adopting a "run to failure" model for earth grid refurbishment would result in an increased risk of failure over the 2014-19 regulatory period which impacts the safety of AAD field staff and members of the public.

Section 12.3 of ENA EG1 - 2006 states that the philosophy of ignoring or disregarding earthing systems is dangerous in view of maintenance and refurbishment experience of engineers from many countries. Further the same section states that the review of older earthing systems has been found necessary in many cases due to failure to meet safety criteria or inadequate equipment rating or condition.

The Do Nothing option leaves AAD exposed to potential safety incidents - refer **Personnel Health and safety** (section 2.1.1), **Public Safety** (section 2.1.2) and **Network Protection Malfunction** (section 2.1.3).

### 2.1.1 Personnel Health and safety

#### a. Step and Touch and Transfer Potential

An earth fault within the station or a lightning strike on, or in the vicinity of, incoming lines can result in a transient rise in the voltage at ground level. This in turn can result in the development of a voltage across personnel standing within the switchyard according to the spacing of their feet (step potential), or between a person and an earthed metallic structure (touch potential). If the earth grid is not functioning correctly to maintain this rise within prescribed limits it can present a direct risk to personnel in terms of electric shock and can also result in consequential accidents such as falling from equipment or structures as a result of the initial electric shock caused by the “Step and Touch and Transfer Potential”.

Transfer potential is a special case of a touch potential in which a voltage is transferred into or out of a substation for some distance by means of an earth referenced metallic conductor. This can still be a very high potential as, during fault conditions, the resulting potential to earth may equal the full earth potential rise.

#### b. Mesh Potential

The mesh potential is defined as the potential difference between the centre of an earthing grid mesh and a structure earthed to the buried grid conductors. This is effectively a worst-case touch potential. For a substation grid consisting of equal size meshes, it is the meshes at the corner of the earth grid that will have the highest mesh potential.

#### c. Standing Charges

As a result of the power frequency electric fields within stations, capacitive coupling can result in the development of “static” charges on earthed metallic components such as support structures etc. Whilst such charges are unlikely to result in electrocution they are typically sufficient to cause startling of personnel who come into contact with an earthed structure and thus present a “consequential” risk of falls, unplanned movements, dropping of tools etc.

The station earth grids are therefore vital in order to maintain the safety of personnel working within the stations. Their failure to do so can present a direct risk to personnel as well as related Regulation / Legislation non-compliance and consequential risks.

### 2.1.2 Public Safety

In the same manner as the transient ground potential rise can present a risk to personnel within a station, if the station earth grid is ineffective, it can also result in a rise in the potential of the station perimeter fence. In such an event the safety of persons who are outside the perimeter fence but in contact with it can be compromised. This scenario places AAD in breach of its obligations under the WHS Act. It is likely that such an event would, at a minimum, result in exposure of AAD to adverse publicity and result in civil and legal action from the parties involved.



### 2.1.3 Network Protection Malfunction

The effectiveness of the station earth grids directly relates to the correct functioning of the network protection. Incorrect protection operations can result in a range of outcomes as follows:

a. Tripping of Circuits When not Required

Incorrect and spurious tripping of circuit(s) will result in disruption to customer supplies with the potential for widespread network impacts;

b. Tripping of Circuits When Required

In the event of a circuit breaker failing to trip due to a fault on the network, the protection system will revert to “back-up” tripping “upstream” of the circuit breaker which should have tripped. This will result in a significant increase in the disruption to customer supplies as well as the potential for public risk and major asset damage due to the longer fault clearance time.

Thus the scenario of compromised network protection would expose AAD to adverse attention from the Regulator and very high direct costs associated with the supply disruptions.

**Therefore maintaining the ‘Do Nothing’ option is not in line with AAD fulfilling its duty of care and regulatory obligations under the WHS Act, National Electricity Rules or National Electricity Law, with respect to safety or system reliability and security.**

## 2.2 Option 2: Condition Assessment Based Refurbishment

Chapter 12 of ENA EG1 – 2006 titled “*Substation Earthing Guide*” provides specific guidance that deterioration of earth grids at substations can begin to undermine the integrity of a zone substation earth grid.

Typical problems include systems where **even** if the original design was adequate, hazards have been compounded by increases in fault levels coupled with equipment deterioration. A responsible review strategy is needed to ensure correct protection system operation, and safety criteria compliance. The review procedure recommended is aimed at satisfying professional responsibilities related to duty of care, whilst controlling expenditure, by targeting hazardous sites and providing economical designs.

Whilst section 12.2.2 of ENA EG1 – 2006 indicatively states a fifteen (15) year interval for earth grid continuity testing, it is inferred and assessed by AAD that this is an industry best practice timeframe at which a level of refurbishment may be required. AAD have assessed their substation portfolio and established an initial invasive condition assessment and refurbishment interval of twenty-five (25) years is deemed adequate due to the fact that a majority of ActewAGL’s zone substations are already past this age with a population average of thirty (30) years. However, any further delay in completing the earth grid refurbishments will substantially increase the risk of non-compliance particularly with safety legislation which may potentially lead to a fatality in near future. Therefore, it is prudent for a Distribution Network Service Provider (DNSP) to have a program to assess the condition of its zone substation earth grids. ActewAGL have a routine annual visual inspection program in place and have assessed the need to undertake additional age related earth grid condition tests and subsequent earth grid refurbishment / augmentation works during the 2014-19 regulatory period.

The condition based refurbishment program, is a program of required earth grid restoration works carried out following testing to determine the asset condition. The level of refurbishment required and the associated locations will be determined in the first stage of work. The level of deterioration of the earth grids at the zone substations will depend on local soil conditions, moisture, and other corrosive conditions (eg stray electrical currents). A forecast modest expenditure of \$1.2 million has been proposed as the likely estimate of expenditure required over the regulatory period.

Published data (Soil Landscapes of the Canberra - NSW Department of Environment and Heritage) shows that most soils around Canberra are Podzols which generally derive from either quartz-rich sands and sandstones or sedimentary debris from magmatic rocks. Being mostly sandy, these soils are low in moisture and nutrients with phosphate deficiencies and aluminium toxicity with the result that they are aggressive on buried copper of earth grids. For each zone substation, the work program aligns with the following requirements of Figure 12-1 of ENA EG-1 – 2006 which comprises of two stages.

- **Stage 1:** incorporates inspections, electrical testing, fault level validation and overall condition assessment of the earth grids. Typically the assessment process in stage 1 will involve a combination of:
  - ✚ sample visual inspections of the grid conductors with measurement of grid conductor size;
  - ✚ electrical testing of the grid to establish grid resistance;
  - ✚ review of the design, present and future station fault levels in conjunction with grid resistance;
  - ✚ condition assessment report and costs; and
  - ✚ development of refurbishment/upgrade scopes.

A budget of \$37,500 per site has been allocated for the stage 1 scope of work. The order in which stage 1 will be implemented will be based on zone substation age.

**Zone Substation : Earth Grid Refurbishment**

- **Stage 2:** covers the necessary refurbishment and upgrading of the earth grids as determined by the outcome of the condition assessment undertaken in stage 1.

A probabilistic approach has been taken to prepare this justification. AAD has considered that out of the fourteen (14) zone substations / switchyard, one (1) will require a major earth grid upgrade and three (3) will require earth grid refurbishments. This approach is considered prudent, given that the condition of the earth grids is not known until after Stage 1 is complete.

There are two levels of refurbishment costs established for the earth grid upgrade based on an estimated percentage of cost required to establish a new (greenfield) earth grid. Using a bottom up forecast, the estimated cost of establishing a complete new earth grid for a 'greenfield' zone substation site is estimated to be \$282,500. To estimate the cost of refurbishment of 'brownfield' substations, the following categories of replacement are assumed and the following cost assumptions have been made in the Table 2:

**Table 2:** Estimate of Cost of CAPEX refurbishment (Stage 2) for option 2

Refurbishment Type	Cost (2012/13 \$s) <sup>1</sup>	Basis
▪ <b>Greenfield Earth Grid</b>	\$282,500	Baseline for greenfield (new) earth grid for a zone substation
▪ <b>Major Earth Grid Upgrade:</b>	\$240,000	the estimated cost of replacement applied to earth grids over 30 years.
▪ <b>Earth Grid Improvements:</b>	\$160,000	the estimated cost of replacement applied to earth grids between 25-30 years

The estimates will be refined as the work scope of each substation works becomes clear. These estimated costs are in accordance with the level of tolerance required to provide a preliminary forecast budget for planning as provided in the following Table 3.

**Table 3:** Probabilistic Estimate of Cost of CAPEX refurbishment for option 2

Earth Grid Refurbishment Program	Cost Estimate - \$2012/13					
	14/15	15/16	16/17	17/18	18/19	Total 2014-19
Stage 1 Condition Assessment	\$75,000	\$150,000	\$150,000	\$150,000		\$525,000
Earth Grid Improvements (x 3)		\$160,000	\$160,000	\$160,000		\$480,000
Earth Grid Major Upgrade (x 1)					\$240,000	\$240,000
<b>Total</b>	<b>\$75,000</b>	<b>\$310,000</b>	<b>\$310,000</b>	<b>\$310,000</b>	<b>\$240,000</b>	<b>\$1,245,000</b>

<sup>1</sup> These costs are inclusive of \$25k to \$50k stage 1 costs for the condition assessment works.

### 3. Option Assessment

A Comparison of the options above is summarised in Table 5 below.

**Table 4:** Summary of options

Options Considered	Residual Risk	<sup>2</sup> Cost	Assessment
<b>Option 1</b>  Do Nothing	<ul style="list-style-type: none"> <li>▪ Risk of malfunction of network protection relays causing serious power system incidents including potential for damage to other major assets</li> <li>▪ Risk of Safety incidents due to deteriorated or inadequate earth grid configurations</li> <li>▪ Potential excessive reactive investment post incident</li> <li>▪ Increase in risk due to CAPEX deferral</li> <li>▪ Potential risk of legal penalties if safety incidents result in injuries and/ or fatalities.</li> </ul>	No CAPEX investment	<b>Not assessed to be a credible option</b>  Significant compliance risks to AAD;
<b>Option 2</b>  Condition Assessment based Refurbishment  <b>(Recommended)</b>	<ul style="list-style-type: none"> <li>▪ Prudent investment based on staged condition assessment.</li> <li>▪ Baseline data on deterioration rates at various zone substation sites.</li> <li>▪ CAPEX cost estimate may reduce if deterioration is lower than anticipated from age.</li> <li>▪ Potential CAPEX-OPEX trade off</li> </ul>	<b>\$1.2M</b>  (estimate only, based on age)	Residual risks are minimised  Prudent and efficient option  <b>Preferred Option – Assessed to be prudent and efficient</b>

#### 3.1 Assessment Criteria

The major criterion used for evaluating the options is:

- Risk Reduction (Safety to general public and ActewAGL personnel);
- Maintaining reliability and security of supply; and
- Compliance with the relevant WHS legislation.

<sup>2</sup> All costs in this report are estimated at 2012/13 direct costs and include overheads.

### 3.2 Options Comparison

Option 1: This is not assessed to be a credible/ prudent option, as it does not address the need identified and this option also has an unacceptably high level of residual risk to the safety of general public and ActewAGL personnel including the risk of network protection malfunction and collateral damage to other major network assets. The case for deferral of capital expenditure is not considered as part of this option as most of the assets have been in-service beyond the 'economic' asset life.

*Residual Risk: Increase in residual risk for loss of supply and safety to personnel and public over time if capital expenditure is deferred further.*

Option 2: The significant advantage of condition assessment based refurbishment is that only assets that have deteriorated will be replaced or refurbished making this option prudent and cost efficient. In addition AAD will be able to get a baseline data for deterioration at various sites for the earth grids, which will assist in better management of zone substation related assets in the future.

AAD's earth grid assets are close to the end of their economic life; therefore, the option of possible life extension following condition assessment may be limited. This approach of undertaking condition assessment testing prior to completion of renewals and refurbishment also aligns with the typical review procedure specified in section 12.3: Major Review and Refurbishment of ENA EG1 – 2006.

A properly conducted review of older earthing systems, including their condition assessment testing, assists with making judicious investment decisions where renewal, restoration and refurbishment works are carried out on the identified deterioration of the existing earth grids to provide value for money.

*Residual Risk: The risks of loss of supply, and safety of personnel & public due to inadequate and ineffective earth grid is reduced and therefore the residual risk is minimised.*

### 3.3 Preferred Solution

The recommended option (Option 2) meets the criteria of being able to reduce the risk of deteriorated earth grid assets using a probabilistic approach, and is considered to be cost effective as the outcome of condition assessment will provide a cost effective level of CAPEX investment required whilst meeting compliance requirements.

The two credible and practical alternatives have been considered – do nothing and condition assessed basis. There are no other known credible and practical solutions to address deteriorated earth grid replacement available to AAD.

### 3.4 High Level Implementation Risks

High level mitigation measures are identified for the preferred option in Table 6 below. Implementation risks will be considered in detail in the next stages of the project implementation.

**Table 5:** Risk Evaluation of preferred option

Risk	Risks / Assumptions	Mitigation Measures
1. Variation of estimated costs for condition assessment and refurbishment	The project assumes there will be no extreme geological conditions at the sites such as major rock formation which would impact on the scope of works and cost for any earth grid renewal, restoration and refurbishment works, therefore a uniform cost has been used across the network area and no additional contingency fund has been included in the CAPEX budget.	<ul style="list-style-type: none"> <li>▪ Review existing earth grid designs to ascertain any “unusual” requirements such as rock, very high soil resistivity etc.;</li> <li>▪ Include sensitivity analysis in business case for each earth grid refurbishment project; and</li> <li>▪ Cost increase / decrease will be identified in stage 1 prior to proceeding with stage 2.</li> </ul>
2. Project delays and cost increases due to the requirement for adjacent circuit outages	Depending upon the layout and physical size of the stations, site access for excavation and/or boring machinery may be constrained. In such an event, the works may require a number of circuit outages due to proximity reasons associated with maintenance of Safe Approach Distances (SAD_ and as such would require coordination with other network outages.	<ul style="list-style-type: none"> <li>▪ Review station layouts and existing earth grid arrangement to identify any potential outage requirements; and</li> <li>▪ Ensure outage requirements are included into the overall works program so as to enable effective coordination and planning.</li> </ul>
3. Special requirements and hence additional costs for access to the earth grids. e.g. concrete cutting etc.	The project is premised upon ready access to the earth grid conductors at a number of locations within each station both for inspection and for electrical testing.	<ul style="list-style-type: none"> <li>▪ Review existing station designs to identify potential problems and obtain additional costings as required.</li> </ul>
4. Concerns for personnel safety in accessing the earth grid in terms of transient ground potential rise.	A major dependency of this project is the ability for the works to be undertaken safely, in particular with regard to earth grid potential rises during the course of the works. Particular care will be required when accessing the earth grids to ensure that the personnel are adequately protected from any transient potential rise of the earth grid due to a fault within or close to the station.	<ul style="list-style-type: none"> <li>▪ Identify likelihood of the earth fault condition and develop mitigation measures; e.g. additional local earths, special procedures for handling of existing earth conductors;</li> <li>▪ Additional care has to be taken to decide on on-line or off-line frequency injection testing for stage 1; and</li> <li>▪ Comprehensive assessment of all risks present in stage 1 &amp; 2 with appropriate Safe Work Method Statements (SWMS) in place.</li> </ul>

## 4. Recommendations

Due to the combined effects of time based deterioration and increasing system fault levels the effectiveness of the existing earth grids together with the level of safety they provide within the zone substations / switch yard and their immediate vicinity is uncertain.

A typical method of seeking definition sufficient to enable planning to commence for an, initially, unclear scope is to undertake sufficient minimal works to clarify the scope (and risk). The preferred option of 'condition assessment based refurbishment' is a two staged approach, with Stage 1 being a condition assessment program of all earth grids at AAD's zone substations. The outcome of stage 1 drives the CAPEX investment into stage 2 to ensure AAD meets its compliance, safety requirements and business strategy for replacement CAPEX. In other words, subsequent to undertaking a staged program of physical inspection and electrical testing e.g. earth impedance and resistivity testing following a critical review which considers fault levels and existing design, the refurbishment/upgrading works of the station earth grids is undertaken as necessary.

Condition Assessment based Refurbishment (Option 2) is the most prudent and cost effective solution for ensuring compliance to safety requirements and minimises AAD's residual risk of incidents occurring due to deteriorated earth grids. It is recommended that the CAPEX budget for the condition based refurbishment of \$1.2 Million as shown in Table 7 below be approved for implementation in the 2014-19 regulatory period.

The exact level of earth grid refurbishment works will not be known with a high degree of certainty until the Stage 1 condition assessment has been undertaken. The CAPEX budget for this program is based on a probabilistic approach. AAD has considered that out of the fourteen (14) zone substations / switchyard, one (1) will require a major earth grid upgrade and three (3) will require earth grid refurbishments.

**Table 6:** CAPEX Budget for Zone Substation Earthing Conditional Assessment and Refurbishment Program

	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Budget 2012/13 \$s	2014-15	2015-16	2016-17	2017-18	2018-19	Yrs 1-5
Total CAPEX Budget for approval	\$75,000	\$310,000	\$310,000	\$310,000	\$240,000	<b>\$1,245,000</b>

The anticipated outcomes from this program of works are:

- assessing the adequacy of the existing zone substation / switching station earth grids to provide the requisite levels of safety for the prevailing network conditions;
- evaluating AAD's ability to demonstrate compliance with industry guidelines, regulations and the overarching legislation;
- calculating (or estimating) the rate of deterioration of the respective station earth grids and hence a means for forecasting their future service lives; and
- definitive scope of works and costing for necessary refurbishment/upgrade works.