2024 Energy Technology Cost and Technical Parameter Review – Mid Size Solar PV and BESS

2024 Energy Technology Cost and Technical Parameter Review – Mid Size Solar PV and BESS along with Commercial/Roof Top Solar PV and community BESS

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1 Introduction

1.1 Background

The Australian Energy Market Operator (AEMO) is responsible for operating the National Electricity Market (NEM) in Eastern and South-Eastern Australia, and the Wholesale Electricity Market (WEM) in Western Australia.

AEMO's forecasting functions can influence the behaviour of existing generation assets and the economics and location of future investment and retirement decisions. These forecasts rely on various input assumptions.

AEMO has engaged Aurecon to research and prepare an updated set of generation and storage technology input data to be used in AEMO forecasting studies and to be published on the AEMO's website.

The updated dataset includes mid-size utility-scale solar PV (5MW – 20MW) and battery energy storage system (BESS) and associated connection costs, and commercial/roof top solar PV (100kW – 5MW) and BESS (~500kWh).

The dataset is intended to be used by AEMO, and shared with industry, to conduct market simulation studies for medium and long-term forecasting purposes. This data will be then used in various AEMO forecasting publications.

1.2 Scope of study

The study is based on plants that are NEM connected, but in distributed network (e.g. 66kV). The size of the solar PV plant and BESS will be 5-40 MW and the BESS storage duration will be 1-2 hours. Costs for solar PV and BESS are provided in two tranches (i.e. 5-20MW and 20-40MW). However, a single connection cost is provided for both tranches as the hardware and other connection related costs remain the same.

In addition to above, costs of commercial/roof top solar PV (100kW – 4.99MW) and BESS (~500kWh) have been provided. Cost estimates of these are separately undertaken. Connection costs are included in the overall costs as such plants are integrated (e.g. inverters, solar distribution boards, and typical cabling to the connection point, etc are integrated with equipment provided).

The scope includes connection cost for a 5MW to 40MW solar farm or Battery Energy Storage System (BESS) to a 66kV network within the Australian National Electricity Market (NEM).

1.3 Abbreviations

Table 1-1 Acronyms / abbreviations

Acronym	Definition
AC	Alternating circuit
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
AUD	Australian Dollar
BESS	Battery Energy Storage System
BOL	Beginning of Life
BOP	Balance of Plant
CAPEX	Capital Expenditure
C-FCAS	Contingency Frequency Control Ancillary Services
C&I	Commercial & Industrial
CAC	Connection Asset Customer
COD	Commercial Operation Date

Acronym	Definition
DA	Development Application
DBT	Dry Bulb Temperature
DC	Direct Current
DNSP	Distribution Network Service Provider
EFOR	Effective Forced Outage Rate
EG	Embedded Generator
EIA	Environmental Impact Assessment
EPC	Engineer Procure and Construct
EUR	Euro Currency
FCAS	Frequency Control Ancillary Services
FFR	Fast Frequency Response
GPS	Generator Performance Standards
GST	Goods and Services Tax
ICC	Individual Calculated Customer
LFP	Lithium Iron Phosphate
LRET	Large-scale Renewable Energy Target
LTMA	Long Term Maintenance Agreement
LV	Low Voltage
MPPT	Maximum Power Point Tracking
MV	Medium Voltage
MW	Megawatt
MWh	Megawatt-hour
NEM	National Electricity Market
NER	National Electricity Rules
NTP	Notice to Proceed
O&M	Operations and Maintenance
OEM	Original Equipment Manufacturer
OPEX	Operational Expenditure
PCC	Project Connection Contract
PFR	Primary Frequency Response
POC	Point of Connection
PPA	Power Purchase Agreement
PV	Photovoltaic
RE	Renewable Energy
REZs	Renewable Energy Zones
R-FCAS	Regulation Frequency Control Ancillary Services
RTE	Round Trip Efficiency
SAT	Single-axis Tracking
SOC	State of Charge
USD	United States Dollar
VRE	Variable Renewable Energy

2 Limitations

2.1 General

This report has been prepared by Aurecon on behalf of, and for the exclusive use of, AEMO. It is subject to and issued in connection with the provisions of the agreement between Aurecon and AEMO.

Power generation using solar PV and energy storage conceptual design is not an exact science, and there are several variables that may affect the results. Bearing this in mind, the results provide general guidance as to the ability of the power generation facility and energy storage facility to perform adequately, rather than an exact analysis of all the parameters involved.

This report is not a certification, warranty, or guarantee. It is a report scoped in accordance with the instructions given by AEMO and limited by the agreed time allowed.

The findings, observations, and conclusions expressed by Aurecon in this report are not and should not be considered an opinion concerning the commercial feasibility of such a project.

This report is partly based on information provided to Aurecon by AEMO. This report is provided strictly on the basis that the information provided to Aurecon is accurate, complete and adequate, unless stated otherwise.

If AEMO or a third party should become aware of any inaccuracy in, or change to, any of the facts, findings or assumptions made either in this report or elsewhere, AEMO or a third party should inform Aurecon so that Aurecon can assess its significance and review its comments and recommendations.

2.2 Costs and budget

Aurecon has no control over the cost of labour, materials, equipment, or services furnished by others. Aurecon similarly has no control over contractors' methods of determining prices, or over competitive bidding or market conditions. Any opinion or estimate of costs by Aurecon is made on the basis of Aurecon's experience and qualifications and represents Aurecon's judgment as an experienced and qualified professional engineering organisation, familiar with the construction industry. However, Aurecon cannot and does not guarantee that proposals, bids, or actual construction costs will not vary from Aurecon's estimates.

3 Methodology

3.1 Methodology

The size and configuration for each hypothetical project has been selected based on Aurecon's current experience with existing and recent / proposed projects.

The performance figures and technical parameters have been based on actual project information where available, or vendor provided information.

The cost estimates have been developed based on collating information from the following sources:

- Aurecon's internal database of projects – recently constructed or under development or construction
- Recent bid information from competitive tendering processes
- Industry publications, publicly available data, recognised reputable commercially available software package and vendor information

This cost data has been normalised or adjusted to account for differences in battery limits, scope, technical factors (where relevant), etc.

A representative cost has been selected for the hypothetical project from the data available, and cost certainty qualified based on the spread and quality of data available.

3.2 Assumptions and basis

3.2.1 General

This section defines the basis used for the hypothetical projects and for determining the technical parameters and cost estimates.

3.2.2 Utility-scale solar PV/storage facility

Power generation using the utility-scale solar PV or storage facility equipment and installation scope is based on the assumptions described in the Table 3-1.

Table 3-1 Utility-scale power generation / storage facility key assumptions

Item	Detail
Site	Greenfield site: clear, flat, no significant cut and fill required, NEM installation, coastal location (within 200 km of coast within metro areas)
Base ambient conditions	Dry Bulb Temperature: 25 °C Elevation above sea level: 110 metres Relative Humidity: 60%
Grid connection voltage	33 – 66 kV
Grid connection infrastructure	Step-up transformer included in solar PV and BESS costs
Energy Storage	BESS – 1 - 2 hours energy storage options considered
Project delivery	EPC turn-key basis
O&M approach	Solar PV or storage: Owner appoints a third-party O&M provider

The assumed terminal points for the solar PV or storage facility are described in Table 3-2.

Table 3-2 Power generation / storage facility terminal points

No.	Terminal point	Terminal point location and details
1	Grid connection	HV side of 33kV/66kV transformer
2	Road access	Site boundary

3.2.3 Commercial-scale, rooftop, small-scale solar PV/storage facility

Power generation using the commercial-scale rooftop solar PV or storage facility equipment and installation scope is based on the assumptions described in the Table 3-3.

Table 3-3 Commercial scale power generation / storage facility key assumptions

Item	Detail
Site	Brownfield site: existing building with reasonably simple/easy access, NEM installation, coastal location (within 200 km of coast within metro areas)
Base ambient conditions	Dry Bulb Temperature: 25 °C Elevation above sea level: 110 metres Relative Humidity: 60%
Grid connection voltage	LV
Grid connection infrastructure	Connection point is site/customer LV switchboard
Energy Storage	BESS – 1 - 2 hours energy storage options considered
Project delivery	EPC turn-key basis
O&M approach	Solar PV or storage: Owner appoints a third-party O&M provider to provide limited/periodic checks

The assumed terminal points for the solar PV or storage facility are described in Table 3-4.

Table 3-4 Power generation / storage facility terminal points

No.	Terminal point	Terminal point location and details
1	Grid connection	Site/customer LV switchboard
2	Road access	Site boundary

3.2.4 Development and land costs

The development and land costs for a solar PV generation project typically include the following components:

- Legal and technical advisory costs
- Financing and insurance (no interest during construction considered)
- Project administration, grid connection studies, and agreements
- Permits and licences, approvals (development, environmental, etc)
- Land procurement and applications

The costs for project and land procurement are highly variable and project specific. For the purposes of this report and outlining development and land costs for a general project within each technology category, a simplified approach must be taken. Land and development costs are calculated as a percentage of capital equipment, and as a result, absolute values associated with these costs will change for those technologies whose equipment capital costs have changed. These costs do not include any applicable fees, such as fees paid to councils, local authorities, electrical connection fee etc. An indicative estimate has been determined based on a percentage of CAPEX estimate for each technology from recent projects, and experience with development processes.

Land costs can vary significantly depending upon its development potential (e.g. proximity to grid, environmental considerations, logistics considerations, location, etc). These numbers are provided as a guide only.

3.2.5 Financial assumptions

The following key assumptions have been made regarding the cost estimates:

- Prices in AUD, July 2024 basis for financial close in July 2024. The Contractor's prices are fixed at this point for the execution of the project which may take several months or years depending upon the technology.
- New plant (no second-hand or refurbished equipment assumed)
- Competitive tender process for the plant and equipment
- Taxes and import / custom duties excluded
- No interest during construction considered
- Assumes foreign exchange rates of 0.65 AUD: USD and 0.60 AUD: EUR
- No contingency applied
- No development premium considered.

It is important to note that without specific engagement with potential OEMs and/or issuing a detailed EPC specification for tender, it is not possible to obtain a high accuracy estimate of costs. The risk and profit components of EPC contracts can vary considerably from project to project and are dependent upon factors such as:

- Project location
- Site complexity
- Cost of labour
- Cost of materials
- Market conditions
- Exchange rates.

Costs provided in this report assumes that projects are located in the metropolitan areas in the National Electricity Market (NEM) region. For renewable projects that are located in renewable energy zones (REZ) rather than the metropolitan areas, a location cost factor needs to apply for equipment, installation, land and development and operation and maintenance.

The accuracy / certainty of the cost estimates is targeted at +/- 30% based on the spread and quality of data available and our experience with the impact of the above factors.

3.2.6 Market volatility and construction cost estimates

The global construction industry is currently quite volatile, and it is difficult to predict the long-term inflationary impact on construction and operating costs. For industries using a high number of materials like stainless steel, copper and aluminium, the increase in capital costs for industrial equipment could be above 10%.

In addition to typical construction materials, developers/owners should factor in considerable contingency for:

- Global competition for key components and technologies impacting wind turbine prices
- Contractor resourcing constraints and risk appetites increasing pricing in general
- Rising fuel and energy costs
- Labour shortages
- Geopolitical uncertainties impacting international supply chains

Construction cost growth adds a further element of uncertainty to new construction projects and maintenance activities, as well as inflationary pressures to the economy. With construction costs up more than 25% over the past five years, project proponents need to factor in considerable contingencies in addition to prices stated in this report to allow for uncertainty and movement in construction costs, as well as for operating costs over the life of the project.

3.3 Definitions

The following table provides definitions for each of the key terms used throughout this document and in the Excel-based dataset.

Table 3-5 Definition of key terms

Term	Definition
Summer rating conditions	DBT: 35°C
Base / design conditions	DBT: 25°C, RH: 60%, 110 m elevation
Not summer rating conditions	DBT: 15°C
Economic life (design life)	Typical design life of major components.
Technical life (operational life)	Typical elapsed time between first commercial operation and decommissioning for that technology (mid-life refurbishment typically required to achieve this Technical Life).
Development time	Time to undertake feasibility studies, procurement, and contract negotiations, obtain permits and approvals (DA, EIA), secure land agreements and offtake agreements, secure grid connection, and obtain financing. This period lasts up until financial close.
EPC total programme	Total time from granting of Notice to Proceed (NTP) to the EPC Contractor until Commercial Operation Date (COD).
Total lead time	Time from issue of NTP to the EPC contractor up to the delivery of all major equipment to site.
Construction time	Time from receipt of major equipment to site up to the commercial operation date (COD). *Note that for simplicity it has been assumed that the total EPC programme = lead time + construction time. In reality lead time and construction time will overlap which would result in a shorter actual construction time to that stated.*
Gross output	Electrical output as measured at the generator terminals.
Auxiliary load	The percentage of rated generation output of each unit - *as measured at the generator terminals* - that is consumed by the station and not available for export to the grid. This includes cable and transformer losses. The auxiliary load is provided as a percentage of the rated output at full load.
Net output	Electrical output exported to the grid as measured at the HV side of the generator step-up transformer. The net output of the unit can be calculated as the rated gross output at the generator terminals minus the auxiliary load.
Battery storage: Charge efficiency	The efficiency of the battery energy storage system (in %) when the battery is being charged.
Battery storage: Discharge efficiency	The efficiency of the battery energy storage system (in %) when the battery is being discharged.
Battery storage: Allowable maximum state of charge (%)	The maximum charge % of the battery system.
Battery storage: Allowable minimum state of charge (%)	The minimum charge % of the battery system.
Battery storage: Maximum number of cycles	The maximum total number of cycles within a typical battery lifetime.
Battery storage: Depth of discharge (DoD)	The percentage to which the battery can be discharged – ie the difference between the maximum allowable charge and minimum allowance charge states.
Total EPC cost	The EPC contract sum (exclusive of taxes).

Term	Definition
Equipment cost	The component of the EPC contract sum that is primarily attributed to the supply of the major equipment. *Note that the total EPC cost has been split into "equipment cost" and "installation cost" for the purpose of this study, based on a typical proportion for that technology. Other EPC cost factors such as engineering, overhead, risk, profit, etc have been distributed evenly between the two.*
Installation cost	The component of the EPC contract sum that is primarily attributed to the site construction, installation, and commissioning works. *Note that the total EPC cost has been split into "equipment cost" and "installation cost" for the purpose of this study, based on a typical proportion for that technology. Other EPC cost factors such as engineering, overhead, risk, profit, etc have been distributed evenly between the two.*
Fixed operating cost ($/MW Net/year)	Fixed costs include; plant O&M staff, insurance, minor contract work, and miscellaneous fixed charges such as service contracts, overheads, and licences. For some technologies where operation and maintenance are holistically covered by O&M and/or Long Term Maintenance Agreement (LTMA) type contracts, all of the operating costs have been classed as "fixed" for the purposes of this study.
Variable operating cost ($/MWh Net)	Variable costs include; spare parts, scheduled maintenance, and consumables.
Total annual O&M Cost	Annual average O&M cost over the design life.

4 Solar PV Plants

4.1 Overview

This report on solar PV plants has been split into mid-size utility-scale solar PV (5MW – 40MW) systems, and small-size solar PV (100kW – 4.99MW) covering commercial, rooftop, and smaller ground-mount solar PV. Capacity figures provided are generally AC sizing (inverter nameplate capacity) unless otherwise noted.

As AEMO registration applies for plants 5MW nameplate rating and above, there is a natural split between these sizes due to the higher registration requirements and cost. Developers will therefore tend to size plants up to 5MW for the smaller-scale systems, and there are many installations at this limit. Due to the fixed costs of development (registration, grid connection costs, etc) it is more typical to maximise system sizes to utilise economies of scale to help offset these costs. Therefore, systems in the 5-20MW range are less common, however details are still provided in the relevant section below. At the 5MW range there may be some overlap with the designs and trends which apply from the lower and the higher sections.

4.2 Mid-size solar PV plant (5MW – 40MW)

4.2.1 Overview and recent trends

This section focuses on mid-scale PV plants with capacity range between 5MW and 40MW. These projects usually fill the gap between rooftop PV plants and the large-scale utility projects. They offer a balance between scalability, grid integration and investment feasibility.

Recent trends for mid-size solar largely follow those of the larger size projects (refer to our full 2024 Energy Technology report). In comparison to large-scale plants, mid-size projects can more easily connect to existing distribution networks (11 – 66 kV) rather than requiring high-voltage transmission upgrades, reducing connection costs and approval time. This size may also be selected due to constraints identified – e.g. land or network capacities. These projects are more likely than the larger-scale projects to be connected behind-the-meter i.e. connected to client/site MV/HV internal networks and used to offset customer loads directly.

The cost of solar modules has undergone a fluctuation over the years, driven by a variety of factors including the technological advancements, supply chain dynamics and shifts in market demand. Overall, the price of solar modules has decreased, particularly over the past decade, making solar energy increasingly accessible and competitive in comparison to traditional energy sources[1]. Modules used for mid-size solar projects will be largely identical to the larger project sizes – rated at around 600-700 Wp for projects in construction, and 650-750 Wp for projects in development, with bifacial generation, and n-type cells.

Similar to large-scale plants, mid-size projects tend to be ground-mount installations, with single-axis-tracking the most widely adopted system, and fixed-tilt installations (either north-facing or east-west) being the next most common. The single-axis-trackers rotate around a single axis, typically moving panels from east to west to follow the sun’s path. This improves efficiency without requiring additional PV modules, making them a cost-effective option despite their higher initial installation cost. Due to concerns such as land constraints, maintenance cost and high wind areas, fixed-tilt installation can become a more viable alternative. The systems are simple to install and maintain, reducing upfront costs compared to single-axis-tracking systems.

In mid-size solar farms, central inverters are widely applied and are typically the same inverters used for larger-scale application as they have already undergone grid modelling and testing for the larger plants. The central configuration provides advantages including lower cost capacity and a simplified design. However, one disadvantage of this configuration is that all connected arrays must operate under a single MPPT (Maximum Power Point Tracking) system, making the system less adaptable to changes in irradiance, temperature or shading conditions, causing lower performance. Mid-size PV plants are more likely than

[1] Solar (photovoltaic) panel prices

larger-scale sites to use string inverters (typically in the 100-250kW range), though overall application is still much less common than central inverters. This configuration minimises mismatch and partial shading losses, as each string functions separately. Additionally, it allows for flexibility in system design, supporting strings with different module counts or even different module types.

4.2.2 Selected hypothetical project (40MW ground-mount)

The following tables outline the technical parameters for the hypothetical project. The hypothetical project has been selected based on what is envisaged as a plausible project for installation in the NEM in 2024, given the above discussion on typical options and current trends.

Table 4-1 Solar PV configuration and performance (40MW ground-mount)

Item	Unit	Value	Comment
Configuration			
Technology		Single Axis Tracking (SAT) Central Inverter	Based on typical options and recent trends.
Performance			
Plant DC Capacity	MW_p	52	Calculated from DC:AC ratio below.
Plant AC Inverter Capacity	MVA	48	Additional reactive power allowance for NER compliance – typical 1.2 oversizing.
Plant AC Grid connection	MW	40	Active power at point of connection.
DC:AC Ratio (solar PV to grid)		1.3	Typical range from 1.15 to 1.4. Slightly higher than large-scale systems as this maximises DC capacity for a given connection limit.
Auxiliary power consumption	%	2.9%	Very little auxiliary power consumption during operation but this figure is used to account for electrical distribution losses as well.
Total plant size (Net)	MW (AC)	40	Auxiliary losses above are expected to be covered by module and inverter oversizing and accounted for in the energy generation model.
Seasonal Rating – Summer (Net)	MW (AC)	40	Thermal derating expected above 35°C with approximately 10% de-rate at 50°C, however these occurrences should be rare.
Seasonal Rating – Not Summer (Net)	MW (AC)	30	Highly dependent on location. Approximately 20-30% reduction in peak power output in winter due to reduced irradiance. Slightly higher than large-scale PV due to higher DC:AC ratio.
Annual Performance			
Average Planned Maintenance	Days / yr.	-	Included in EFOR below.
Equivalent forced outage rate (EFOR)	%	1.5	Based on 98.5% O&M availability.
Effective annual capacity factor	%	29	AC MW basis, highly dependent on location. Number based on a system installed in regional NSW.
Annual generation	MWh / yr.	101,616	Calculated from capacity factor above.
Annual degradation over design life	% / yr	0.35	Using nameplate DC capacity as a basis.

Table 4-2 Solar PV technical parameters and project timeline (40MW ground-mount)

Item	Unit	Value	Comment
Technical parameters			
Ramp Up Rate	MW/min	Resource dependent	
Ramp Down Rate	MW/min	Resource and system dependent	

Item	Unit	Value	Comment
Start-up time	Min	N/A	Within 5-10 minutes of sufficient irradiance after sunrise.
Min Stable Generation	% of installed capacity	Near 0	
Project timeline			
Lead time for development	Years	1.5	
First Year Assumed Commercially Viable for construction	Year	2024	
EPC Programme	Years	1.1	13 months for NTP to COD.
Total lead time	Years	0.5	Time from NTP to first module on site.
Construction time	Weeks	26	Time from first inverter on site to COD.
Economic Life (Design Life)	Years	30	Typical given current PV module warranties
Technical Life (Operational Life)	Years	30	40 if piles don't corrode and the spare parts remain available.

4.2.3 Cost estimates (40MW ground-mount)

The following table provides the cost parameters for the hypothetical project as outlined above.

Table 4-3 Solar PV cost estimates (40MW ground-mount)

Item	Unit	Value	Comment
CAPEX – EPC cost			
Relative cost	$ / W (DC)	1.3	Relative cost considers EPC equipment and installation costs. This does not include land and development costs. Slightly higher than large-scale due to limited economies of scale and fixed-cost impacts.
Total EPC cost	$	67,600,000	
▪ Equipment cost	$	40,560,000	60% of EPC cost – typical.
▪ Installation cost	$	27,040,000	40% of EPC cost – typical.
Other costs			
Cost of land and development	$	4,056,000	Assuming 10% of equipment cost.
OPEX – Annual			
Fixed O&M Cost	$ / MW_p (Net DC)/year	12,000	Includes allowance for general spare parts and scheduled replacement capex. No change expected compared to large-scale.
Variable O&M Cost	$ / MWh (Net)	-	Included in the fixed component.
Total annual O&M Cost	$	624,000	Annual average cost over the design life.

4.2.4 Selected hypothetical project (20MW ground-mount)

The following tables outline the technical parameters for the hypothetical project. The hypothetical project has been selected based on what is envisaged as a plausible project for installation in the NEM in 2024, given the above discussion on typical options and current trends.

Table 4-4 Solar PV configuration and performance (20MW ground-mount)

Item	Unit	Value	Comment
Configuration			
Technology		Single Axis Tracking (SAT) Central Inverter	Based on typical options and recent trends.
Performance			
Plant DC Capacity	MW_p	26	Calculated from DC:AC ratio below.
Plant AC Inverter Capacity	MVA	24	Additional reactive power allowance for NER compliance – typical 1.2 oversizing.
Plant AC Grid connection	MW	20	Active power at point of connection.
DC:AC Ratio (solar PV to grid)		1.3	Typical range from 1.15 to 1.4. Slightly higher than large-scale systems as this maximises DC capacity for a given connection limit.
Auxiliary power consumption	%	2.9%	Very little auxiliary power consumption during operation but this figure is used to account for electrical distribution losses as well.
Total plant size (Net)	MW (AC)	20	Auxiliary losses above are expected to be covered by module and inverter oversizing and accounted for in the energy generation model.
Seasonal Rating – Summer (Net)	MW (AC)	20	Thermal derating expected above 35°C with approximately 10% de-rate at 50°C, however these occurrences should be rare.
Seasonal Rating – Not Summer (Net)	MW (AC)	15	Highly dependent on location. Approximately 20-30% reduction in peak power output in winter due to reduced irradiance. Slightly higher than large-scale PV due to higher DC:AC ratio.
Annual Performance			
Average Planned Maintenance	Days / yr.	-	Included in EFOR below.
Equivalent forced outage rate (EFOR)	%	1.5	Based on 98.5% O&M availability.
Effective annual capacity factor	%	29	AC MW basis, highly dependent on location. Number based on a system installed in regional NSW.
Annual generation	MWh / yr.	50,808	Calculated from capacity factor above.
Annual degradation over design life	% / yr	0.35	Using nameplate DC capacity as a basis.

Table 4-5 Solar PV technical parameters and project timeline (20MW ground-mount)

Item	Unit	Value	Comment
Technical parameters			
Ramp Up Rate	MW/min	Resource dependent	
Ramp Down Rate	MW/min	Resource and system dependent	
Start-up time	Min	N/A	Within 5-10 minutes of sufficient irradiance after sunrise.
Min Stable Generation	% of installed capacity	Near 0	
Project timeline			
Lead time for development	Years	1.5	
First Year Assumed Commercially Viable for construction	Year	2024	
EPC Programme	Years	1.1	13 months for NTP to COD.

Item	Unit	Value	Comment
Total lead time	Years	0.5	Time from NTP to first module on site. Similar to 40MW system due to mobilisation timeframes.
Construction time	Weeks	26	Time from first inverter on site to COD. Similar to 40MW system due to fewer work fronts used by contractors.
Economic Life (Design Life)	Years	30	Typical given current PV module warranties
Technical Life (Operational Life)	Years	30	40 if piles don't corrode and the spare parts remain available.

4.2.5 Cost estimates (20MW ground-mount)

The following table provides the cost parameters for the hypothetical project as outlined above.

Table 4-6 Solar PV cost estimates (20MW ground-mount)

Item	Unit	Value	Comment
CAPEX – EPC cost			
Relative cost	$ / W (DC)	1.45	Relative cost considers EPC equipment and installation costs. This does not include land and development costs. Higher than large-scale due to limited economies of scale and fixed-cost impacts.
Total EPC cost	$	37,700,000	
▪ Equipment cost	$	22,620,000	60% of EPC cost – typical.
▪ Installation cost	$	15,080,000	40% of EPC cost – typical.
Other costs			
Cost of land and development	$	2,262,000	Assuming 10% of equipment cost.
OPEX – Annual			
Fixed O&M Cost	$ / MW_p (Net DC)/year	12,000	Includes allowance for general spare parts and scheduled replacement capex. No change expected compared to large-scale.
Variable O&M Cost	$ / MWh (Net)	-	Included in the fixed component.
Total annual O&M Cost	$	312,000	Annual average cost over the design life.

4.3 Small-size solar PV plant (100kW – 4.99MW)

4.3.1 Overview and recent trends

This section focuses on small-size PV plants with capacity range between 100kW and 4.99MW. This range covers a wide variety of installations – from commercial-scale PV installations on rooftops and carparks, to larger ground-mount systems. On the low end of this range, 100kW (total module DC capacity) has been selected as this refers to the lower limit of the Large-scale Renewable Energy Target (LRET) scheme[2]. On the high end, 4.99MW (inverter AC capacity) allows for an exemption to the AEMO registration process.

Commercial and rooftop solar PV is an important part of the renewable energy industry, as it allows businesses and consumers to effectively reduce energy costs and promote sustainability. The adoption of commercial-scale solar PV has been mainly influenced by reduction in cost, higher panel efficiency and rising electricity price. Fixed rooftop solar installations remain the most common configuration for urban and commercial projects, given their cost-effectiveness and ease of installation.

[2] Eligibility for the Renewable Energy Target | Clean Energy Regulator

Small-size solar systems are typically behind-the-meter, installed within the customer's site and directly offsetting their electricity loads at the time of generation. Any excess generation is then either exported back into the electricity network, or curtailed and therefore lost. The rates that the electricity retailers offer for this exported generation (the feed-in-tariffs) are typically quite low (and much lower than the cost of importing electricity), reducing the benefits of this excess generation. As such, it is more feasible at this scale to implement hybrid solar PV and BESS systems to capture this excess generation. However, this report will only consider solar PV installations.

Commercial rooftop 100kW to 1MW systems are very common in infrastructure such as schools, shopping centres, carparks, etc. Rooftop installations are inherently limited by the available area, roof space, structural integrity, shading, and site electricity loads – resulting in a typical maximum size of approximately 2MW. These installations will typically be directly flush-mounted on the existing roof – resulting in lower efficiency due to non-optimal tilt and orientation compared to ground-mount systems. However, these rooftop systems make up for this lower efficiency with ease of installation and maintenance. Carport-mounted and carpark solar systems also contribute to this trend, offering an alternative for commercial facilities with limited rooftop space.

Larger installations (1MW-5MW) are more typical options for industrial-scale sites (e.g. manufacturing, farming, water utility plants) with higher electricity loads and available land. These systems are more typically ground-mounted systems, where there is a mix of fixed-tilt and tracking options. East-west mounting configurations are increasingly favoured, as they enable a more balanced generation profile throughout the day, reducing reliance on battery storage or grid exports. Single-axis tracking technology is sometimes used, as it enables higher energy yields compared to fixed installations.

Similarly to larger-scale installations, silicon-based PV panels remain the industry standard for small-size, primarily due to their cost-effectiveness and well-established supply chains. Rooftop solar PV installations tend to use modules with similar efficiency as the larger systems, however in a smaller form factor (i.e. module area) due to considerations on wind loading and handling. Another common difference for rooftop PV is the use of monofacial modules, as there is limited uplift due to insufficient back irradiance on rooftops. Therefore, while manufacturers are moving to simplify their product range and discontinue older technologies such as p-type cells, monofacial modules remain a key offering from manufacturers targeting rooftop PV.

In comparison to the mid-size and large-scale systems, string inverters are the most common choice for systems in this range, particularly for installations below 2MW, where they offer better product/model selection, power mismatch management and lower losses than central inverters. String inverters have not changed significantly in recent years, with manufacturers focusing on incremental improvements in efficiency and monitoring capabilities. String inverters continue to offer greater reliability, ease of maintenance, and reduced mismatch losses compared to central inverters, thus explained their popularity in this size.

For higher-capacity systems, central inverters are sometimes used, particularly in larger commercial sites seeking to optimize efficiency at scale. It is noted that central inverter models from manufacturers typically starts around the 4-5MW range, so would only be feasible for the larger end of this range and could suffer from lack of redundancy. It could also be more difficult to obtain Connection Agreements in certain DNSPs due to lack of prior experience and installations.

Another common option in this range is to install systems which connect directly into the distribution network without offsetting any customer/site loads i.e. a front-of-meter installation in comparison to the typical behind-the-meter systems described above. Several of these installations can be aggregated into a larger total capacity and be used for off-take agreements and PPAs. These sites are typically rated at 4.99MW to avoid registration, allowing for ease of approvals and construction. These sites can also be geographically diverse and feature different technologies/manufacturers to reduce risk. East-west fixed-tilt framing are very common for these installations due to the reduced cost and maintenance as noted above.

4.3.2 Selected hypothetical project (4.99MW ground-mount)

The following tables outline the technical parameters for the hypothetical project. The hypothetical project has been selected based on what is envisaged as a plausible project for installation in the NEM in 2024, given the above discussion on typical options and current trends.

Table 4-7 Solar PV configuration and performance (4.99MW ground-mount)

Item	Unit	Value	Comment
Configuration			
Technology		East-west solar PV module mounting structure	Based on recent trends.
Performance			
Plant DC Capacity	MW_p	7.49	Calculated from DC:AC ratio below.
Plant AC Inverter Capacity	MVA	4.99	Limited by grid connection below.
Plant AC Grid connection	MW	4.99	Active power at point of connection.
DC:AC Ratio (solar PV to grid)		1.50	Typical range from 1.15 to 1.6. Higher than large-scale systems as this maximises DC capacity for a given connection limit.
Auxiliary power consumption	%	2.9	Very little auxiliary power consumption during operation but this figure is used to account for electrical distribution losses as well.
Total plant size (Net)	MW (AC)	4.99	Auxiliary losses above are expected to be covered by module and inverter oversizing and accounted for in the energy generation model.
Seasonal Rating – Summer (Net)	MW (AC)	4.99	Thermal derating expected above 35°C with approximately 10% de-rate at 50°C, however these occurrences should be rare.
Seasonal Rating – Not Summer (Net)	MW (AC)	3.49	Highly dependent on location. Approximately 20-30% reduction in peak power output in winter due to reduced irradiance.
Annual Performance			
Average Planned Maintenance	Days / yr.	-	Included in EFOR below.
Equivalent forced outage rate (EFOR)	%	1.5	Based on 98.5% O&M availability generally expected for installations of this type.
Effective annual capacity factor	%	25	AC MW basis, highly dependent on location. Number based on a system installed in regional NSW.
Annual generation	MWh / yr.	10,928	Calculated from capacity factor above.
Annual degradation over design life	%	0.35	Using nameplate DC capacity as a basis.

Table 4-8 Solar PV technical parameters and project timeline (4.99MW ground-mount)

Item	Unit	Value	Comment
Technical parameters			
Ramp Up Rate	MW/min	Resource dependent	
Ramp Down Rate	MW/min	Resource and system dependent	
Start-up time	Min	N/A	Within 5-10 minutes of sufficient irradiance after sunrise.
Min Stable Generation	% of installed capacity	Near 0	
Project timeline			
Time for development	Years	1	

Item	Unit	Value	Comment
First Year Assumed Commercially Viable for construction	Year	2024	
EPC Programme	Years	0.5	6 months for NTP to COD.
Total lead time	Years	0.25	Time from NTP to first module on site.
Construction time	Weeks	12	Time from first inverter on site to COD.
Economic Life (Design Life)	Years	30	Typical given current PV module warranties.
Technical Life (Operational Life)	Years	30	40 if piles don't corrode and the spare parts remain available.

4.3.3 Cost estimates (4.99MW ground-mount)

The following table provides the cost parameters for the hypothetical project as outlined above.

Table 4-9 Solar PV cost estimates (4.99MW ground-mount)

Item	Unit	Value	Comment
CAPEX – EPC cost			
Relative cost	$ / W (DC)	1.6	Relative cost does not include land and development costs but does include typical grid connection costs.
Total EPC cost	$	11,976,000	
▪ Equipment cost	$	7,185,600	60% of EPC cost – typical.
▪ Installation cost	$	4,790,400	40% of EPC cost – typical.
Other costs			
Cost of land and development	$	718,560	Assuming 10% of equipment cost.
OPEX – Annual			
Fixed O&M Cost	$ / MW_p (Net DC)/year	13,360	While maintenance is simpler, pricing is higher than larger systems since it does not have scale of economies.
Variable O&M Cost	$ / MWh (Net)	-	Included in the fixed component.
Total annual O&M Cost	$	100,000	Annual average cost over the design life.

4.3.4 Selected hypothetical project (1MW commercial/rooftop)

The following tables outline the technical parameters for the hypothetical project. The hypothetical project has been selected based on what is envisaged as a plausible project for installation in the NEM in 2024, given the above discussion on typical options and current trends.

Table 4-10 Solar PV configuration and performance (1MW rooftop)

Item	Unit	Value	Comment
Configuration			
Technology		Flush-mount installation on roof String inverter	Typical 2-3 degree tilt roof
Performance			
Plant DC Capacity	MW_p	1.2	Calculated from DC:AC ratio below.
Plant AC Inverter Capacity	MVA	1.0	Limited by grid connection below.
Plant AC Grid connection	MW	1.0	Active power at point of connection.

Item	Unit	Value	Comment
DC:AC Ratio (solar PV to grid)		1.2	Typical range from 1.15 to 1.3. Lower than large-scale systems as rooftop systems more typically limited by DC:AC clipping losses.
Auxiliary power consumption	%	2.9%	Very little auxiliary power consumption during operation but this figure is used to account for electrical distribution losses as well.
Total plant size (Net)	MW (AC)	1	Auxiliary losses above are expected to be covered by module and inverter oversizing and accounted for in the energy generation model.
Seasonal Rating – Summer (Net)	MW (AC)	1	Thermal derating expected above 35°C with approximately 10% de-rate at 50°C, however these occurrences should be rare.
Seasonal Rating – Not Summer (Net)	MW (AC)	0.75	Highly dependent on location. Approximately 20-30% reduction in peak power output in winter due to reduced irradiance.
Annual Performance			
Average Planned Maintenance	Days / yr.	-	Included in EFOR below.
Equivalent forced outage rate (EFOR)	%	1.5	Based on 98.5% O&M availability.
Effective annual capacity factor	%	17	AC MW basis, highly dependent on location. Number based on a system installed in regional NSW.
Annual generation	MWh / yr.	1,489	Calculated from capacity factor above.
Annual degradation over design life	% / yr	0.35	Using nameplate DC capacity as a basis.

Table 4-11 Solar PV technical parameters and project timeline (1MW rooftop)

Item	Unit	Value	Comment
Technical parameters			
Ramp Up Rate	MW/min	Resource dependent	
Ramp Down Rate	MW/min	Resource and system dependent	
Start-up time	Min	N/A	Within 5-10 minutes of sufficient irradiance after sunrise.
Min Stable Generation	% of installed capacity	Near 0	
Project timeline			
Lead time for development	Years	0.5	
First Year Assumed Commercially Viable for construction	Year	2024	
EPC Programme	Years	0.5	6 months for NTP to COD.
Total lead time	Years	0.25	Time from NTP to first module on site.
Construction time	Weeks	12	Time from first inverter on site to COD.
Economic Life (Design Life)	Years	25	Typical given current PV module warranties. Slightly lower than utility-scale due to typically different modules used
Technical Life (Operational Life)	Years	25	Limited by module design life above.

4.3.5 Cost estimates (1MW rooftop)

The following table provides the cost parameters for the hypothetical project as outlined above.

Table 4-12 Solar PV cost estimates (1MW rooftop)

Item	Unit	Value	Comment
CAPEX – EPC cost			
Relative cost	$ / W (DC)	1.3	Relative cost does not include land and development costs but does include typical grid connection costs.
Total EPC cost	$	1,560,000	
▪ Equipment cost	$	936,000	60% of EPC cost – typical.
▪ Installation cost	$	624,000	40% of EPC cost – typical.
Other costs			
Cost of land and development	$	0	Excluded
Fuel connection costs	$	0	
OPEX – Annual			
Fixed O&M Cost	$ / MW_p (Net DC)/year	15,000	Minimal preventative maintenance allowed for, 1 panel clean allowed for.
Variable O&M Cost	$ / MWh (Net)	-	Included in the fixed component.
Total annual O&M Cost	$	18,000	Annual average cost over the design life.

5 BESS

5.1 Recent trends

Applications

BESS projects are being developed by a range of electricity sector players, including generators, transmission and distribution operators, renewable energy developers and C&I customers (particularly in the mining industry). Recently there has been increased interest in deployment of mid-size BESS and community BESS which may have lower development and connection costs and are quicker to construct. The modular design of a BESS allows for precise sizing to meet varied project needs.

Mid-size and community BESS can offer a similar range of services to large scale BESS, but some services may need to be provided as part of an aggregated generation portfolio. Applications for mid-size and community BESS include:

Arbitrage: Buying energy at lower prices for charging and selling it at higher prices.

Load Shifting: Managing energy use by storing excess generation during high variable renewable energy (VRE) periods and discharging during low-generation times.

Local Capacity Firming: Providing consistent energy during variable RE generation to mitigate power fluctuations.

Primary Frequency Response (PFR): Adjusting real power output rapidly in response to frequency changes, as mandated by AEMO.

Frequency Control: Managing reactive power during contingency (C-FCAS) and regulation events (R-FCAS) to maintain grid stability.

Voltage Support: Using four quadrant inverters to inject or absorb reactive power and stabilise voltage levels.

Black Start & Islanding: Enabling system recovery after blackouts and maintaining operational sections of the grid independently.

System Strength: Enhancing grid voltage and frequency stability.

Peak Shaving: Reducing network charges by discharging the BESS during period of peak demand.

Power Factor Support: Adjusting reactive power to improve grid voltage stability.

Reliability & Fuel Savings: Supporting large load increases and optimising generator usage at sites with variable loads.

5.2 Mid-size BESS (40MW)

5.2.1 Overview

Thes Mid-sized Battery Energy Storage Systems (BESS), with a capacity ranging from 40 MW, are designed to be integrated into the high-voltage (HV) grid, operating at voltage levels between 33 kV and 66 kV. This system plays a crucial role in storing energy generated from renewable sources, thereby ensuring that Transmission Substations maintain a stable and reliable energy supply. By effectively managing fluctuations in renewable generation, the 40 MW BESS enhances grid resilience and supports the transition to a more sustainable energy landscape.

5.2.2 Selected hypothetical project

The following tables outline the technical parameters for the hypothetical project. The hypothetical project has been selected based on what is envisaged as a plausible project for installation in the NEM, given the above discussion on typical options and current trends.

Table 5-1 BESS configuration and performance

Item	Unit	2 hours	Comment
Configuration			
Technology		Li-ion	
Performance			
Power Capacity (gross)	MW	40	
Energy Capacity	MWh	80	
Auxiliary power consumption (operating)	kW	380	Indicative figures (highly variable, dependent on BESS arrangement, cooling systems etc).
Auxiliary power consumption (standby)	kW	120	Based on Aurecon internal database of similarly sized projects, Indicative figures (highly dependent on BESS arrangement, cooling systems etc).
Connection Voltage Level	kV	33	Voltage at connection point.
Auxiliary load (operating)	%	0.95	Based on auxiliary power consumption (operating).
Auxiliary load (standby)	%	0.30	Based on standby auxiliary power above.
Power Capacity (Net)	MW	39.62	
Seasonal Rating – Summer (Net)	MW	39.62	Dependent on inverter supplier. Potentially no de-rate or up to approximately 4% at 35°C.
Seasonal Rating – Not Summer (Net)	MW	39.62	
Annual Performance			
Equivalent forced outage rate (EFOR)	%	1-2	This will be highly variable depending on Equipment and Spares Strategy for a particular BESS.
Annual number of cycles		365	Typical default assumption is one cycle per day; however, this is highly dependent on functional requirements and operating strategy.
Annual degradation over design life	%	1.8	Indicative average annual degradation figure provided for 20-year BESS, assuming LFP battery chemistry. Significant range dependent battery supplier, or approx. 60 – 65% energy retention after 20 years (based on one cycle per day). Degradation dependent on factors such as energy throughput, charge / discharge rates, depth of discharge, and resting state of charge.
Annual RTE degradation over design life	%	0.2	Indicative average annual RTE degradation figure provided for 20-year BESS (resulting in total of approx. 4% reduction in RTE over project life), assuming LFP battery chemistry. Significant range of 2-6% total degradation in RTE after 20 years (based on one cycle day) observed across different battery suppliers.

Table 5-2 BESS technical parameters and project timeline

Item	Unit	2 hours	Comment
Technical Parameters			
Ramp Up Rate	kW/min	10,000+	0 to 100% rated MW capacity within less than a second (150ms typical however for specific applications higher performance is available).
Ramp Down Rate	kW/min	10,000+	As above.
Round-trip efficiency [BOL]	%	84	Typical round-trip efficiency (@ BOL), at the point of connection (including auxiliaries), for a full cycle of charge and discharge.
Charge efficiency [BOL]	%	92	Assumed to be half of the round-trip efficiency.
Discharge efficiency [BOL]	%	92	Assumed to be half of the round-trip efficiency.
Allowable maximum state of charge (SOC)	%	100	Performance and costs presented relate to the useable BESS energy storage capacity / state of charge (SOC), with operation permissible throughout this full range. Some battery OEMs quote battery capacity inclusive of unusable capacity. For these OEMs, a max and min SOC of 90% and 10% respectively could be expected. It is not however necessary to apply these adjustments to the performance and cost figures presented in this report.
Allowable minimum state of charge (SOC)	%	0	As above.
Maximum number of cycles		7,300	Typical warranty conditions based on one cycle per day for 20 years for LFP batteries. Warranties to cover a 20-year battery life may incur additional cost, as indicated herein. Design life for lithium-ion deployed on grid scale BESS projects varies from approx. 3,650 to 7,300 depending on the application and lithium-ion battery chemistry.
Depth of Discharge	%	100	100% in terms of typically defined ‘useable state of charge’.
Project Timeline			
Lead time for development	Years	1.5	
EPC Programme	Years	1.5	18 months for NTP to COD.
Total lead time	Years	0.5	Time from NTP to BESS module on site.
Construction time	Weeks	52	
Economic Life (Design Life)	Years	20	Dependent on battery chemistry. 20 years available at one cycle per day with LFP batteries, which are of increasing prominence in grid scale BESS proposals. Warranties to cover a 20-year battery life may incur additional cost, as indicated herein.
Technical Life (Operational Life)	Years	20	Life may potentially be extended to approx. 25 years depending on condition assessment after initial 20-year life. Thereafter potential to extend project life with battery upgrades.

5.2.3 Cost estimates

Table 5-3 BESS cost estimate 40MW 80MWh BESS

Item	Unit	2 hours	Comment
Capex – 40MW 80MWh BESS			
Relative cost - Power component	$ / kW	516	Indicative cost for power related components and other costs independent of storage duration.
Relative cost - Energy component	$ / kWh	344	Indicative cost for energy related components.
Total EPC cost	$M	48.2	Based on Aurecon internal database of similarly sized projects and scaled for additional energy storage capacity.
Equipment Cost	$M	40.0	As above.
Installation Cost	$M	8.1	As above.
Cost of land and development	$M	2.0	Based on 5% of equipment cost
Opex - annual			
Fixed O&M Cost	$/kW (Net)	8.5	Provided on $/kW p.a. basis.
Variable O&M Cost	$/kWh (Net)	-	Long Term Service Agreement costs for BESS typically do not have variable costs.
Total annual O&M Cost (excluding extended warranties)	$k p.a.	236	Indicative annual average cost for 20-year extended warranties for LFP batteries.
Extended warranty (20-year battery life)	$k p.a.	102	Highly variable between OEMs. Indicative annual average cost over the design life.

5.3 Mid-size BESS (20MW)

5.3.1 Overview

Thes Mid-sized Battery Energy Storage Systems (BESS), with a capacity ranging from 20 MW, are designed to be integrated into the high-voltage (HV) grid, operating at voltage levels between 33 kV and 66 kV. Such systems are primarily utilised for storing energy generated by renewable sources, ensuring that Transmission Substations have access to a stable and reliable energy supply.

5.3.2 Selected hypothetical project

The following tables outline the technical parameters for the hypothetical project. The hypothetical project has been selected based on what is envisaged as a plausible project for installation in the NEM, given the above discussion on typical options and current trends.

Table 5-4 BESS configuration and performance

Item	Unit	2 hours	Comment
Configuration			
Technology		Li-ion	
Performance			
Power Capacity (gross)	MW	20	
Energy Capacity	MWh	40	

Item	Unit	2 hours	Comment
Auxiliary power consumption (operating)	kW	190.00	Indicative figures (highly variable, dependent on BESS arrangement, cooling systems etc).
Auxiliary power consumption (standby)	kW	60.00	Based on Aurecon internal database of similarly sized projects. Indicative figures (highly dependent on BESS arrangement, cooling systems etc).
Auxiliary load (operating)	%	0.95	Based on auxiliary power consumption (operating).
Auxiliary load (standby)	%	0.3	Based on standby auxiliary power above.
Connection Voltage Level	kV	33	Voltage at connection point
Power Capacity (Net)	MW	19.72	
Seasonal Rating – Summer (Net)	MW	19.72	Dependent on inverter supplier. Potentially no de-rate or up to approximately 4% at 35°C.
Seasonal Rating – Not Summer (Net)	MW	19.72	
Annual Performance			
Equivalent forced outage rate (EFOR)	%	1-2	This will be highly variable depending on Equipment and Spares Strategy for a particular BESS.
Annual number of cycles		365	Typical default assumption is one cycle per day; however, this is highly dependent on functional requirements and operating strategy.
Annual degradation over design life	%	1.8	Indicative average annual degradation figure provided for 20-year BESS, assuming LFP battery chemistry. Significant range dependent battery supplier, or approx. 60 – 65% energy retention after 20 years (based on one cycle per day). Degradation dependent on factors such as energy throughput, charge / discharge rates, depth of discharge, and resting state of charge.
Annual RTE degradation over design life	%	0.2	Indicative average annual RTE degradation figure provided for 20-year BESS (resulting in total of approx. 4% reduction in RTE over project life), assuming LFP battery chemistry. Significant range of 2-6% total degradation in RTE after 20 years (based on one cycle day) observed across different battery suppliers.

Table 5-5 BESS technical parameters and project timeline

Item	Unit	2 hours	Comment
Technical Parameters			
Ramp Up Rate	kW/min	10,000+	0 to 100% rated MW capacity within less than a second (150ms typical however for specific applications higher performance is available).
Ramp Down Rate	kW/min	10,000+	As above.
Round-trip efficiency [BOL]	%	84	Typical round-trip efficiency (@ BOL), at the point of connection (including auxiliaries), for a full cycle of charge and discharge.

Item	Unit	2 hours	Comment
Charge efficiency [BOL]	%	92	Assumed to be half of the round-trip efficiency.
Discharge efficiency [BOL]	%	92	Assumed to be half of the round-trip efficiency.
Allowable maximum state of charge (SOC)	%	100	Performance and costs presented relate to the useable BESS energy storage capacity / state of charge (SOC), with operation permissible throughout this full range. Some battery OEMs quote battery capacity inclusive of unusable capacity. For these OEMs, a max and min SOC of 90% and 10% respectively could be expected. It is not however necessary to apply these adjustments to the performance and cost figures presented in this report.
Allowable minimum state of charge (SOC)	%	0	As above.
Maximum number of cycles		7,300	Typical warranty conditions based on one cycle per day for 20 years for LFP batteries. Warranties to cover a 20-year battery life may incur additional cost, as indicated herein. Design life for lithium-ion deployed on grid scale BESS projects varies from approx. 3,650 to 7,300 depending on the application and lithium-ion battery chemistry.
Depth of Discharge	%	100	100% in terms of typically defined 'useable state of charge'.
Project Timeline			
Time for development	Years	1.5	
EPC Programme	Years	1.5	18 months for NTP to COD.
Total lead time	Years	0.5	Time from NTP to BESS module on site.
Construction time	Weeks	52	
Economic Life (Design Life)	Years	20	Dependent on battery chemistry. 20 years available at one cycle per day with LFP batteries, which are of increasing prominence in grid scale BESS proposals. Warranties to cover a 20-year battery life may incur additional cost, as indicated herein.
Technical Life (Operational Life)	Years	20	Life may potentially be extended to approx. 25 years depending on condition assessment after the initial 20-year life. Thereafter potential to extend project life with battery upgrades.

5.3.3 Cost estimates

Table 5-6 BESS cost estimate 20MW 40MWh BESS

Item	Unit	2 hours	Comment
Capex – 20MW 40MWh BESS			
Relative cost - Power component	$ / kW	567	Indicative cost for power related components and other costs independent of storage duration.
Relative cost - Energy component	$ / kWh	378	Indicative cost for energy related components.

Item	Unit	2 hours	Comment
Total EPC cost	$M	26.4	Based on Aurecon internal database of similarly sized projects and scaled for additional energy storage capacity.
Equipment Cost	$M	22.0	As above.
Installation Cost	$M	4.4	As above.
Cost of land and development	$M	1.1	Based on 5% of equipment cost
Opex - annual			
Fixed O&M Cost	$/kW (Net)	8.8	Provided on $/kW p.a. basis.
Variable O&M Cost	$/kWh (Net)	-	Long Term Service Agreement costs for BESS typically do not have variable costs.
Total annual O&M Cost (excluding extended warranties)	$k p.a.	120	Indicative annual average cost for 20-year extended warranties for LFP batteries.
Extended warranty (20-year battery life)	$k p.a.	56	Highly variable between OEMs. Indicative annual average cost over the design life.

5.4 Mid-size BESS (4.99MW)

5.4.1 Overview

The Community Battery Energy Storage System (BESS), with a capacity of 4.99 MW, is specifically designed to operate as a standalone solution, interfacing with medium-voltage (MV) distribution networks at voltage levels ranging from 11 kV to 22 kV. This innovative system plays a pivotal role in enhancing local energy resilience and sustainability.

5.4.2 Selected hypothetical project

The following tables outline the technical parameters for the hypothetical project. The hypothetical project has been selected based on what is envisaged as a plausible project for installation in the NEM, given the above discussion on typical options and current trends.

Table 5-7 BESS configuration and performance

Item	Unit	2 hours	Comment
Configuration			
Technology		Li-ion	
Performance			
Power Capacity (gross)	MW	4.99	
Energy Capacity	MWh	10	
Auxiliary power consumption (operating)	kW	48	Indicative figures (highly variable, dependent on BESS arrangement, cooling systems etc).
Auxiliary power consumption (standby)	kW	15	Based on Aurecon internal database of similarly sized projects, Indicative figures (highly dependent on BESS arrangement, cooling systems etc).
Auxiliary load (operating)	%	0.95	Based on auxiliary power consumption (operating).
Auxiliary load (standby)	%	0.30	Based on standby auxiliary power above.
Connection Voltage Level	kV	11	Voltage at connection point.
Power Capacity (Net)	MW	4.94	

Item	Unit	2 hours	Comment
Seasonal Rating – Summer (Net)	MW	4.94	Dependent on inverter supplier. Potentially no de-rate or up to approximately 4% at 35°C.
Seasonal Rating – Not Summer (Net)	MW	4.94	
Annual Performance			
Equivalent forced outage rate (EFOR)	%	1-3	This will be highly variable depending on Equipment and Spares Strategy for a particular BESS.
Annual number of cycles		365	Typical default assumption is one cycle per day; however, this is highly dependent on functional requirements and operating strategy.
Annual degradation over design life	%	1.8	Indicative average annual degradation figure provided for 20-year BESS, assuming LFP battery chemistry. Significant range dependent battery supplier, or approx. 60 – 65% energy retention after 20 years (based on one cycle per day). Degradation dependent on factors such as energy throughput, charge / discharge rates, depth of discharge, and resting state of charge.
Annual RTE degradation over design life	%	0.2	Indicative average annual RTE degradation figure provided for 20-year BESS (resulting in total of approx. 4% reduction in RTE over project life), assuming LFP battery chemistry. Significant range of 2-6% total degradation in RTE after 20 years (based on one cycle day) observed across different battery suppliers.

Table 5-8 BESS technical parameters and project timeline

Item	Unit	2 hours	Comment
Technical Parameters			
Ramp Up Rate	kW/min	10,000+	0 to 100% rated MW capacity within less than a second (150ms typical however for specific applications higher performance is available).
Ramp Down Rate	kW/min	10,000+	As above.
Round-trip efficiency [BOL]	%	84	Typical round-trip efficiency (@ BOL), at the point of connection (including auxiliaries), for a full cycle of charge and discharge.
Charge efficiency [BOL]	%	92	Assumed to be half of the round-trip efficiency.
Discharge efficiency [BOL]	%	92	Assumed to be half of the round-trip efficiency.
Allowable maximum state of charge (SOC)	%	100	Performance and costs presented relate to the useable BESS energy storage capacity / state of charge (SOC), with operation permissible throughout this full range. Some battery OEMs quote battery capacity inclusive of unusable capacity. For these OEMs, a max and min SOC of 90% and 10% respectively could be expected. It is not however necessary to apply these adjustments to the performance and cost figures presented in this report.
Allowable minimum state of charge (SOC)	%	0	As above.

Item	Unit	2 hours	Comment
Maximum number of cycles		7,300	Typical warranty conditions based on one cycle per day for 20 years for LFP batteries. Warranties to cover a 20-year battery life may incur additional cost, as indicated herein. Design life for lithium-ion deployed on grid scale BESS projects varies from approx. 3,650 to 7,300 depending on the application and lithium-ion battery chemistry.
Depth of Discharge	%	100	100% in terms of typically defined 'useable state of charge'.
Project Timeline			
Time for development	Years	0.5	
EPC Programme	Years	1.5	18 months for NTP to COD.
Total lead time	Years	0.5	Time from NTP to BESS module on site.
Construction time	Weeks	52	
Economic Life (Design Life)	Years	10-20	Dependent on battery chemistry, 10- 20 years available at one cycle per day with LFP batteries, which are of increasing prominence in grid scale BESS proposals. Warranties to cover a 20-year battery life may incur additional cost, as indicated herein.
Technical Life (Operational Life)	Years	20	Life may potentially be extended, depending on condition assessment and subject to extended warranty availability from vendors.

5.4.3 Cost estimates

Table 5-9 BESS cost estimate 4.99MW 10MWh BESS

Item	Unit	2 hours	Comment
Capex – 4.99MW 10MWh BESS			
Relative cost - Power component	$ / kW	588	Indicative cost for power related components and other costs independent of storage duration.
Relative cost - Energy component	$ / kWh	392	Indicative cost for energy related components.
Total EPC cost	$M	6.9	Based on Aurecon internal database of similarly sized projects and scaled for additional energy storage capacity.
Equipment Cost	$M	5.1	As above.
Installation Cost	$M	1.8	As above.
Cost of land and development	$M	0.25	Based on 5% of equipment cost
Opex - annual			
Fixed O&M Cost	$/kW (Net)	9.4	Provided on $/kW p.a. basis.
Variable O&M Cost	$/kWh (Net)	-	Long Term Service Agreement costs for BESS typically do not have variable costs.
Total annual O&M Cost (excluding extended warranties)	$k	15	Indicative annual average cost for 10-year extended warranties for LFP batteries.
Extended warranty (20-year battery life)	$k	32	Highly variable between OEMs. Indicative annual average cost over the design life.

5.5 Community BESS (250kW)

5.5.1 Overview

The 250 kW Battery Energy Storage System (BESS) is designed to connect seamlessly with low-voltage (LV) networks, specifically those operating at 400V in a three-phase configuration. This robust system is specifically geared towards behind-the-meter applications in commercial properties, providing a range of benefits that enhance energy management and operational efficiency.

5.5.2 Selected hypothetical project

The following tables outline the technical parameters for the hypothetical project. The hypothetical project has been selected based on what is envisaged as a plausible project for installation in the NEM, given the above discussion on typical options and current trends.

Table 5-10 BESS configuration and performance

Item	Unit	2 hours	Comment
Configuration			
Technology		Li-ion	
Performance			
Power Capacity (gross)	MW	0.25	
Energy Capacity	MWh	0.50	
Auxiliary power consumption (operating)	kW	3	Indicative figures (highly variable, dependent on BESS arrangement, cooling systems etc).
Auxiliary power consumption (standby)	kW	1	Based on Aurecon internal database of similarly sized projects. Indicative figures (highly dependent on BESS arrangement, cooling systems etc).
Auxiliary load (operating)	%	0.94	Based on auxiliary power consumption (operating).
Auxiliary load (standby)	%	0.30	Based on standby auxiliary power above.
Connection Voltage Level	kV	0.4	Voltage at connection point.
Power Capacity (Net)	MW	0.25	
Seasonal Rating – Summer (Net)	MW	0.25	Dependent on inverter supplier. Potentially no de-rate or up to approximately 4% at 35°C.
Seasonal Rating – Not Summer (Net)	MW	0.25	
Annual Performance			
Equivalent forced outage rate (EFOR)	%	4	This will be highly variable depending on Equipment and Spares Strategy for a particular BESS.
Annual number of cycles		365	Typical default assumption is one cycle per day; however, this is highly dependent on functional requirements and operating strategy.
Annual degradation over design life	%	1.8	Indicative average annual degradation figure provided for 20-year BESS, assuming LFP battery chemistry. Significant range dependent battery supplier, or approx. 60 – 65% energy retention after 20 years (based on one cycle per day). Degradation dependent on factors such as energy throughput, charge / discharge rates, depth of discharge, and resting state of charge.

Item	Unit	2 hours	Comment
Annual RTE degradation over design life	%	0.2	Indicative average annual RTE degradation figure provided for 20-year BESS (resulting in total of approx. 4% reduction in RTE over project life), assuming LFP battery chemistry. Significant range of 2-6% total degradation in RTE after 20 years (based on one cycle day) observed across different battery suppliers.

Table 5-11 BESS technical parameters and project timeline

Item	Unit	2 hours	Comment
Technical Parameters			
Ramp Up Rate	kW/min	10,000+	0 to 100% rated MW capacity within less than a second (150ms typical however for specific applications higher performance is available).
Ramp Down Rate	kW/min	10,000+	As above.
Round-trip efficiency [BOL]	%	84	Typical round-trip efficiency (@ BOL), at the point of connection (including auxiliaries), for a full cycle of charge and discharge.
Charge efficiency [BOL]	%	92	Assumed to be half of the round-trip efficiency.
Discharge efficiency [BOL]	%	92	Assumed to be half of the round-trip efficiency.
Allowable maximum state of charge (SOC)	%	100	Performance and costs presented relate to the useable BESS energy storage capacity / state of charge (SOC), with operation permissible throughout this full range. Some battery OEMs quote battery capacity inclusive of unusable capacity. For these OEMs a max and min SOC of 90% and 10% respectively could be expected. It is not however necessary to apply these adjustments to the performance and cost figures presented in this report.
Allowable minimum state of charge (SOC)	%	0	As above.
Maximum number of cycles		7,300	Typical warranty conditions based on one cycle per day for 20 years for LFP batteries. Warranties to cover a 20-year battery life may incur additional cost, as indicated herein. Design life for lithium-ion deployed on grid scale BESS projects vary from approx. 3,650 to 7,300 depending on the application and lithium-ion battery chemistry.
Depth of Discharge	%	100	100% in terms of typically defined 'useable state of charge'.
Project Timeline			
Time for development	Years	0.5	
EPC Programme	Years	0.75	9 months for NTP to COD.
Total lead time	Years	0.25	Time from NTP to BESS module on site.
Construction time	Weeks	26	

Item	Unit	2 hours	Comment
Economic Life (Design Life)	Years	10-15	Dependent on battery chemistry and warranty and grantee provided by vendors. 10-15 years available at one cycle per day with LFP batteries. Extended warranties to cover battery life may incur additional cost, as indicated herein.
Technical Life (Operational Life)	Years	15-20	Life may potentially be extended to depending on condition assessment and subject to extended warranty availability from vendors.

5.5.3 Cost estimates

Table 5-12 BESS cost estimate 250kW 500kWh BESS

Item	Unit	2 hours	Comment
Capex - 250kW 500kWh BESS			
Relative cost - Power component	$ / kW	1319	Indicative cost for power related components and other costs independent of storage duration.
Relative cost - Energy component	$ / kWh	879	Indicative cost for energy related components.
Total EPC cost	$M	0.77	Based on Aurecon internal database of similarly sized projects and scaled for additional energy storage capacity.
Equipment Cost	$M	0.53	As above.
Installation Cost	$M	0.24	As above.
Opex – annual			
Fixed O&M Cost	$/kW (Net)	47	Provided on $/kW p.a. basis.
Variable O&M Cost	$/kWh (Net)	-	Long Term Service Agreement costs for BESS typically do not have variable costs.
Total annual O&M Cost (excluding extended warranties)	$k	2	Indicative annual average cost for 10-year extended warranties for LFP batteries.
Extended warranty (20-year battery life)	$k	10	Highly variable between OEMs. Indicative annual average cost over the design life.

6 Grid Connection Electrical Infrastructure

6.1 Overview

The hypothetical 20MW to 40MW PV farm or BESS installation is required to be grid connected via the DNSP – Distribution Network Service Provider sub-transmission network in order to be able to participate in the wider NEM. The proposed distribution voltage for the grid connection is assumed as 33kV and up to 66kV.

The term 'Major Customer' used in this report is in reference to parties designated by the DNSP in its Annual Pricing Proposal as 'Major Customers'. Major Customer connections are those that fall within the tariff classes of Connection Asset Customers (CAC), Individual Calculated Customers (ICC), or embedded generators (EGs) or real estate developers. The PV solar farm or BESS will henceforth be referred to as a 'Major Customer' as it is considered an embedded generating system sufficient in size to require a connection agreement with AEMO.

In order to facilitate this grid connection, the following minimum requirements are needed:

- Non-contestable DNSP network augmentation works (i.e. what changes are required on the existing grid to connect the new solar PV farm or BESS)
- DNSP asset(s) dedicated for proponent connection (i.e. switching station/switchyard)
- A point of connection (POC) where the proponent (Major Customer) connects to the grid.
- Connection Application and Connection Agreement between the DNSP and the proponent

There are several different 'network configuration types' available for connecting Major Customers to the grid. A preferred network configuration will be discussed with reference to alternative arrangements in Section 6.1.1.

Note, the term 'Main Applicant', 'Major Customer' and 'Proponent' are all used interchangeably in this section of the report and are all in reference to the applicant wishing to connect their assets to the grid.

6.1.1 Network configurations/arrangement options (normative)

Table 6-1 provides a summary of different connection arrangement options typically available from a DNSP. There are other possible connection arrangements however the table below summarise the most common arrangements found within the NEM. It is important to note that connection arrangements will vary from one DNSP jurisdiction to another and that not all of the connection arrangement noted below be available for every connection. Final connection arrangements are developed based on individual project site specific requirements and alignment with DNSP operational and network planning requirements.

Table 6-1 Sub transmission connection arrangement option summary

Connecting Voltage	Description	Point of Connection	Comments
≥33 kV	Tee Connection	Customer side of line isolator	Least preferred by most DNSPs due to asset rating reasons and protection coordination difficulty.
≥33 kV	Dedicated Feeder	Customer side of line isolator	Generally limited to installations relatively close to the existing zone substation. Otherwise, extensive feeder reticulation is required which can be a costly undertaking depending on feeder route between the zone substation and proposed installation.
≥33 kV	Switching Station	Network side of line isolator	Very similar to three bay tee. Generally used within DNSP radial network and where power flow is uni-directional.

Connecting Voltage	Description	Point of Connection	Comments
≥33 kV	**Three bay Tee**	**Network side of line isolator**	**Also known as a Loop-in-loop-out and recognised by transmission and distribution professionals as a typical connection arrangement that suits most proponents and DNSPs.**
≥33 kV	Dual feeder high reliable supply with switching substation	Customer side of line isolator	Most expensive and least preferred by most proponents. Generally reserved for installations requiring high reliability.
≥33 kV	Dual feeder supply with switching substation	Customer side of line isolator	Most expensive and least preferred by most proponents.

The connection arrangement option assessed as part of this report will be the ‘Three bay Tee’ arrangement as depicted in Figure 6-1.

The following key assumptions are applicable for the proposed network configuration:

- It has been assumed the network arrangement will be for a DNSP Sub-Transmission Connection within the NEM.
- The DNSP shall own the switching substation. The cost estimates only include the DNSP owned network augmentation infrastructure as depicted in Figure 6-1.
- It has been assumed that the DNSP sub-transmission network augmentation design and construction works are contestable and can be undertaken by either the DNSP or an accredited service provider.
- It has been assumed that all assets downstream of the point of connection are owned and operated by the proponent. These assets are not included in the cost estimate.

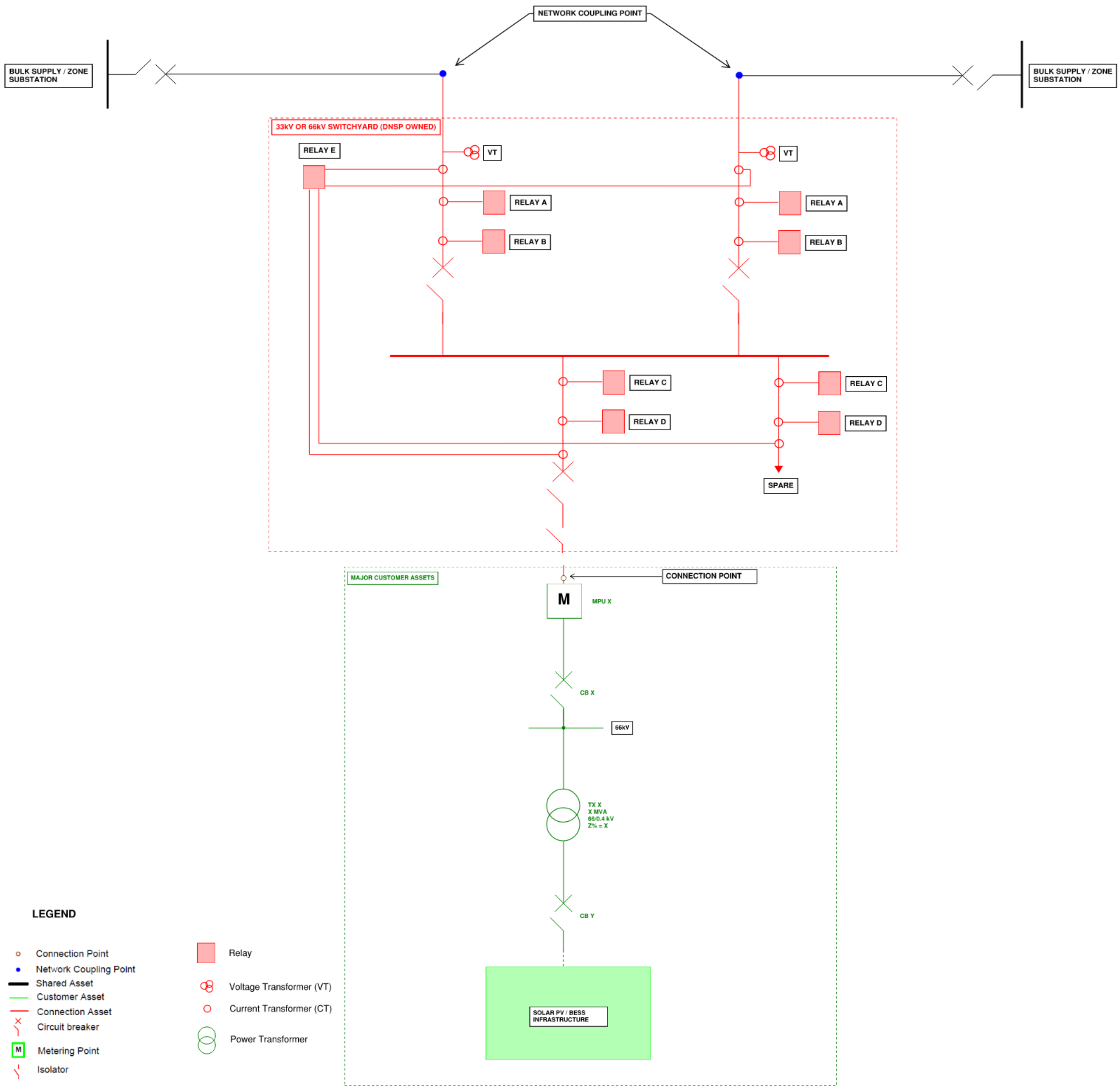

Figure 6-1 DNSP HV connection sketch - three bay tee

6.2 DNSP network augmentation cost estimate

There are several line items to consider in connection with estimating the cost for grid connection. These include:

- Connection Application costs (associated documentation/studies/approvals)
- Connection Offer costs (associated documentation/studies/approvals)
- Grid augmentation costs (infrastructure costs associated with connecting the asset to the electricity grid).

The cost estimate for required network augmentation to connect the PV farm or BESS (5MW – 40MW) to the grid is detailed in Table 6-2.

Table 6-2 Cost estimate for DNSP grid connection infrastructure

Item	Unit	Value ($ AUD excl. GST)	Comment
DNSP technical study.	AUD	125,000.00	DNSP detailed technical study to define DNSP technical requirements and extent of network augmentation scope of work.
Detailed design of network augmentation works.	AUD	645,000.00	Engineering design costs associated with the network augmentation scope of work.
Construction and commissioning connection assets to DNSP requirements.	AUD	6,000,000.00	DNSP network augmentation costs to enable a grid connection as depicted in Figure 6-1.
Total costs	AUD	6,770,000.00	

Notes:

1. Estimated Costs are ±30%

6.2.1 Connection application

Applicants who wish to connection generation to a transmission or distribution network in the National Electricity Market (NEM) are required to follow the processes defined in the NER. The DNSP is responsible for the electricity network where the Applicant intends to connect to the network, and for the connection process. The DNSP is the primary contact for the connection Applicant.

The specific process followed to connection generation to the NEM depends on the Registration status of the generator. By default, all generation in the NEM must be registered with AEMO, unless it benefits from an exemption.

For Generating Systems between 5 – 30 MW, exemption is possible however must be applied for from AEMO. Chapter 5 process of the NER is applicable.

For Generating Systems between >30 MW, exemption is not possible, and default registration is required with AEMO. Chapter 5 process of the NER is applicable.

The Applicant (i.e. Major Customer) is required to lodge a formal Connection Application with the DNSP for network connection services for their connection assets. The application shall include all substation civil and layout plans, maximum demand calculations and associated designs, as requested by the DNSP. If the Applicant uses an Accredited Service Provider for design and construction of the connection asset, completed work plans and other required design submission documentation shall also be provided to the DNSP.

The cost estimate for connection application and associated costs is detailed in Table 6-3

Table 6-3 Cost estimate for connection application

Item	Unit	Value ($ AUD excl. GST)	Comment
Connection Enquiry with DNSP	AUD	145,000.00	Applicant lodges enquiry with DNSP for connecting assets to grid. DNSP prepares a planning study and GPS requirements.
GPS (Generator Performance Standards) studies	AUD	400,000.00	An external party (Consultant) is engaged to undertake GPS engineering studies
Peer Review of Studies (DNSP)	AUD	300,000.00	DNSP is paid by Applicant to review GPS studies output prepared by Consultant.
Final Review and Approval (AEMO)	AUD	300,000.00	AEMO is paid by Applicant to review and approve GPS studies output prepared by Consultant (reviewed by DNSP).
Total costs	AUD	1,145,000.00	

Notes:

1. Estimated Costs are ±30%

6.2.2 Connection offer

It is a requirement of the National Electricity Rules (NER) that the DNSP and the Applicant (i.e. Major Customer) enter into a connection agreement for the connection. The terms and conditions of the connection agreement address the rights and obligations of parties as well as commercial terms and conditions for the connection.

Once the review of the Connection Application is completed by the DNSP, the DNSP may then issue a connection offer in the form of a Project Connection Contract (PCC). If DNSP works are required for the connection, the contract will include details of the scope of works and estimated charges.

Appendix A
Mid Size Solar PV and BESS Excel Spreadsheet

Spreadsheet to be provided separately

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