



Future Energy System Outlook

Draft

October 2026

Appendix J

**Distribution & Sub-transmission
planning methodology**



Western Power

363 Wellington Street
Perth WA 6000
GPO Box L921 Perth WA 6842

T: 13 10 87 | Fax: 08 9225 2660
TTY 1800 13 13 51 | TIS 13 14 50

Electricity Networks Corporation
ABN 18 540 492 861

An appropriate citation for this paper is:

Future Energy System Outlook – 2027

Enquiries about this report should be directed to:

Western Power Mailbox
Transmission Grid Strategy & Planning
Email: NOM.TSP@westernpower.com.au

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Introduction

The Distribution & Sub-Transmission (DXST) model translates long-term demand, customer generation and flexible-resource scenarios into indicative distribution and sub-transmission network development pathways as illustrated in Figure 1. The model assesses bi-directional electricity flows, identifies potential capacity constraints and assesses technically feasible network and non-network solutions options. The model compares staged pathways over time and quantifies the network cost of enabling distributed energy resources (DER) that would otherwise be curtailed.

The equations in this methodology show the main calculation principles in simplified form. DXST applies these principles across 30 minute time-series intervals, network elements, scenarios and future network states. Detailed transformations, allocation rules, limits, tolerances and validation tests are maintained in supporting technical specifications.

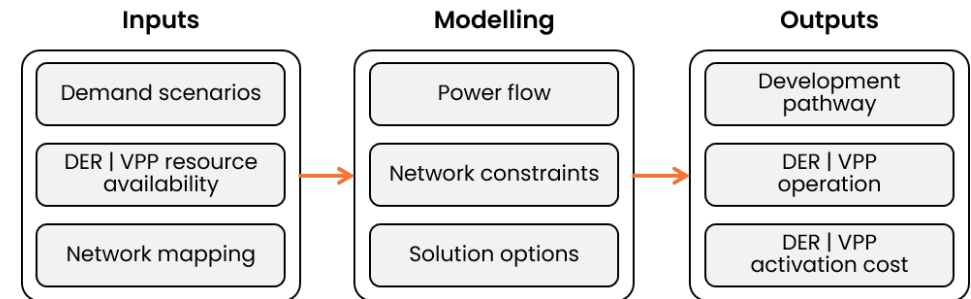


Figure 1. DXST overview

Purpose

DXST modelling supports strategic planning by providing a scenario based view of how electricity demand, customer energy resources and the wider power system may change over the long term. It does not replace Western Power's established annual distribution and sub-transmission network planning, detailed engineering, project assessment, investment approval or operational processes.

As customers adopt rooftop solar, batteries, electric vehicles and other energy technologies, the amount, direction and timing of electricity flowing through the network will change. New homes, businesses, industries and electrification may increase demand, while customer generation and batteries may increase exports back into the network. DXST assesses how these changes may affect the networks that connect customers to the wider electricity system.

- Maps future demand and distributed energy scenarios to the network.
- Identifies where and when network capacity may become constrained.
- Prepares alternative ways of addressing those constraints.
- Compares staged network pathways over the forecast horizon.
- Assesses the potential role of batteries and other flexible resources.
- Records remaining constraints and uncertainties.
- Estimates the network cost of enabling distributed energy that would otherwise be curtailed.

DXST considers changes that may affect the amount, direction, location and timing of electricity flowing through distribution and sub-transmission networks.

- Residential, commercial and industrial demand growth.
- New customer connections and developments.
- Electrification of transport and other energy uses.
- Electric vehicle charging.
- Rooftop solar and embedded generation.
- Customer and community batteries.
- Coordinated distributed energy resources, including virtual power plants.
- Flexible customer demand and changing minimum-demand conditions.
- Electricity exports from customers back into the network.

A network element may experience its highest loading either during high customer demand or during high distributed generation and low local demand. The causes, effects and appropriate responses may differ between these conditions.

Demand scenarios

A critical input to DXST modelling is a 30-minute time-series demand scenario. Each scenario defines how demand, customer generation and flexible resources may change over time and within each forecast year. Year-specific attributes, including customer numbers and technology uptake, are presented at the interval level.



Figure 2. Net demand definition

A positive net demand represents electricity supplied from the network to customers. A negative net demand represents net export back into the network.

Interval-level assessment allows the model to capture short peaks, sustained seasonal loading, frequent or prolonged reverse flows, repeated rooftop solar export constraints, battery operation, electric vehicle charging and constraints that persist across a substantial proportion of the year.

The scenarios do not predict one certain future. They provide alternative, internally consistent futures for testing how network requirements and possible responses may change.

Network modelling

Network model definition

DXST utilises a reference network model based on the distribution and sub-transmission as-operated state (addressing switch states). This includes low-voltage networks, distribution transformers, branches and conductors, distribution feeders, power transformers, zone substations and sub-transmission interfaces.

Demand is mapped to the reference network model reflecting existing customer connections (including generators and flexible resources). Two reconciliation methods are applied to ensure data and model integrity.

- Upstream network flow = $\sum$ downstream network flows
- $\sum$ allocated flow = source flow

Reconciliation is undertaken to ensure that demand and exports are not lost or double-counted as they are traced through the network.

Electricity flows

DXST distinguishes forward flow, where electricity is supplied from the wider network to customers, from reverse flow, where local generation or battery discharge exceeds local demand and electricity flows back towards the wider network.

- Forward flow = $\max(\text{net flow}, 0)$
- Reverse flow = $\max(-\text{net flow}, 0)$

For each demand scenario interval, loading is compared with the network capacity limit.

- Available headroom = capacity limit - loading
- Constraint magnitude = $\max(0, \text{loading} - \text{capacity limit})$

Solution requirements

A solution requirement may include location, affected elements, flow direction, forecast year, constrained intervals, required relief, duration, contributing customer or network areas and connected downstream or upstream constraints.

- Residual constraint = $\max(0, \text{required relief} - \text{relief provided})$
- A network solution is complete when residual constraint = 0 for all applicable requirements

Potential solutions are assessed against all requirements rather than only the highest-loading interval (peak demand). Flexible-resource and curtailment options receive credit only for the relief they can provide, and any remaining requirement stays visible.

A local solution may transfer load to another feeder or transformer, while several local constraints may combine into an upstream solution requirement. DXST reassesses each solution through the connected hierarchy.

Solution options

Depending on the constraint, DXST will develop solution options involving available capacity, transformer balancing, network reconfiguration, load transfer, equipment reinforcement, new feeders, additional transformer capacity, voltage conversion, new zone substations, export curtailment, batteries, coordinated resources or staged combinations of compatible actions.

Network balancing & reinforcement solutions

Where a power transformer is constrained within an existing zone substation, DXST determines if another transformer at the same substation has sufficient capacity to provide relief.

- Source loading after transfer = source loading before transfer - transferred loading
- Receiving loading after transfer = receiving loading before transfer + transferred loading

Network topology solutions

DXST develops solutions that change network topology such as new feeders, power transformers, zone substations, interconnections or transfer. Each solution is linked to the network area it supports and identifies the constraint relieved, catchment affected, demand or export transferred, post-action capacity and indicative cost. Network topology solutions are developed at concept level and do not define final asset locations, routes, land requirements, engineering designs or construction methods.

Coordinated DER

Batteries and coordinated resources may provide network support in suitable circumstances. DXST does not assume that all installed battery capacity is available or controllable. It considers connection location, participation rights, required network service, power, usable energy, efficiency, inverter capacity, battery state of charge, timing, duration, pre-charging, recovery and other demands on the resource.

- $\text{Stored energy}_{t+1} = \text{stored energy}_t + \eta c \times \text{charging energy}_t - \text{discharging energy}_t / \eta d$
- $0 \leq \text{stored energy}_t \leq \text{usable battery capacity}$

Sufficient power in megawatts does not guarantee sufficient energy in megawatt-hours. Battery operation is traced across intervals and does not reset between days or events. Resources used for local network support are not available for other purposes simultaneously.

DER curtailment

Where controllable exports contribute to a reverse-flow constraint, DXST may apply export curtailment as a response.

- $\text{Required curtailment} = \max(0, \text{potential export} - \text{network-feasible export})$
- $\text{Network-feasible export} = \text{potential export} - \text{effective curtailment}$

The model retains potential energy, feasible export, required and applied curtailment, the causing constraint and any residual separately.

Comparing staged pathways

DXST compares pathways across the forecast horizon because an early action may avoid, defer or reshape later investment. A pathway may combine initial reconfiguration, later reinforcement, replacement of temporary measures, progressive expansion or a larger early action that addresses several future requirements.

- Pathway cost = $\sum_y [(capital\ cost_y + operating\ cost_y) / (1 + r)^{(y - y_0)}]$

The comparison considers technical coverage, timing, sequence, capacity created, costs, dependencies, compatibility and continuing adequacy. Each cost is assigned to the year in which it occurs.

DXST identifies the lowest-cost technically complete pathway applying scenario cost and planning assumptions.

Network-state changes

Pathway actions may change connectivity, equipment capacity, network membership, customer or load allocation and export capability. DXST records these as date stamped planning actions and applies them to the future network state. The pathway is applied across the scenario time series to confirm coverage and identify remaining or newly created constraints.

Unlocking DER

After establishing the network pathway, DXST evaluates optional actions that could unlock DER for other uses:

- Gross DER unlocked = reference curtailment - curtailment after the option
- Net DER unlocked = gross DER unlocked - new curtailment created elsewhere
- Net DER unlocked_t = max(0, Cref_t - Coption_t) - max(0, Coption_t - Cref_t)
- Net DER unlocked in MWh = $\sum_t [net\ DER\ unlocked_t \times interval\ duration]$
- Incremental unlock cost = cost with optional DER unlock - cost of reference pathway

This approach avoids assigning the full cost of an investment to DER where that investment is already required for customer demand or another network need. Two methods of evaluating the cost to unlock DER through network investment are developed:

- Cost per unlocked MW = incremental unlock cost / maximum net DER unlocked
- Cost per annual unlocked MWh = incremental unlock cost / net DER unlocked in the forecast year

The second measure is a planning indicator, not a conventional levelised cost of energy.

Forecast-year treatment & reporting

DXST assesses the forecast intervals supplied for each scenario regardless of time horizon. The methodology is not dependent on fixed milestone years and can assess partial-horizons without the need to interpolate or substitute missing years. For a long term scenario (e.g. 20-years), annual results are retained and may be presented at five-year blocks.

Model outputs

DXST provides outputs required to support strategic planning such as:

- Timing, location, direction, magnitude, frequency and duration of constraints.
- Affected network areas and indicative capacity requirements.
- Technically feasible alternatives and staged pathways.
- Indicative capital and operating costs.
- Network-state and membership changes.
- Residual constraints and unresolved limitations.
- Potential battery and coordinated-resource support.
- DER curtailment and network-feasible DER.
- Additional DER enabled by optional investment and its incremental network cost.

Transmission & system planning alignment

DXST provides the distribution and sub-transmission network-planning output that can be integrated into grid or system planning studies. Other study components may consider customer demand and technology uptake, generation and storage, transmission development, power-system operation, reliability, commercial outcomes, customer impacts and policy considerations. While DXST determines the network-feasible DER and the cost of enabling additional DER; wider market and system value realisation of DER is not addressed by DXST.

Engineering & governance

DXST uses concept planning technical representations. Before any solution option can be progressed as a project, further assessment is needed including detailed power flow and voltage studies, fault level assessments, protection coordination, equipment duty, operability, constructability, land and access, environmental and heritage matters, detailed cost, procurement, delivery, outages, customer impacts, regulatory assessment, business-case development and formal approval.

DXST outputs are not approved projects, committed construction programmes, engineering designs, switching instructions, customer export entitlements, procurement decisions, wholesale-price forecasts or final government, regulatory or Western Power positions. Human review and applicable governance remain necessary.

Further development

The following areas will be progressed to drive DXST improvements:

- The impact of and value of accommodating tariff feedback from downstream system planning activities will be investigated.

