



Transmission System Plan 2025

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Appendix C

TSP Study Methodology



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Western Power is required to publish a Transmission System Plan in accordance with the Electricity System and Market Rules (ESMR).

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Introduction

This document describes the market and power system modelling methodology applied for the Transmission System Plan (TSP) 2025.

The TSP methodology is comprised of three components:

- PLEXOS Long-term (LT) expansion planning. LT expansion planning develops a reference 10-year planning outlook for SWIS network, which includes determining the least-cost transmission, generation and storage investments considering physical and market constraints over the time horizon. Note that this can also be taken as an input from system planning studies when available.
- PLEXOS Short-term (ST) security constrained economic dispatch (SCED). PLEXOS ST takes the PLEXOS LT solution and solves the SCED problem, which involves determining the least-cost dispatch considering physical constraints, market constraints and contingencies over the time horizon.
- PowerFactory studies then read in the system investments from PLEXOS LT and system dispatch from PLEXOS ST and solves steady state power system studies to ensure the system can operate in a secure manner. The power system studies undertaken include DC N-1 load flow; future iterations of the TSP will expand to include AC N-1 load flow, fault levels studies and voltage/reactive power studies.

The regulatory requirements for the TSP outlined in the ESM Rules and Technical Rules are summarised below.

- ESM 4.5B – Transmission System Plan
 - Historical network constraint and energy uplift payment study
 - Network constraint and energy uplift payment forecast
 - Least cost investment plan and development pathway
- ESM 4.5.9 – LT PASA Planning Criterion
 - Reserve capacity constraint (peak demand and allowances)
 - Unserved energy constraint (0.0002% of underlying demand)
- Technical Rules
 - Contingency analysis
 - Steady state PQ constraints
 - Fault level constraints
 - Physical constraints

Overview

The TSP study process is tailored to the requirements of the TSP in the context of the Wholesale Electricity Market (WEM). Figure 1 provides an overview of the TSP study methodology which involves:

- Collection and preparation of data inputs,
- PowerFactory and PLEXOS model setup,
- Techno-economic modelling to identify the least cost investment pathway, dispatch of generation, and network congestion,
- Steady state power system analysis to confirm the feasibility of solutions and validate that it allows for operation of a secure and reliable power system; and
- Stakeholder consultation and publication of report.

The TSP is based on a central demand scenario and does not consider potential changes to energy policy or technology. It is driven by committed load, generation, storage and network projects with a focus on transmission network modelling. While the distribution network is not modelled explicitly, the impact of DER is considered at a zone substation level, including its impact on energy and demand forecasts, as well as its flexibility to be controlled to assist with managing power system security and reliability.

The techno-economic model applies inputs (see Figure 1) to develop a co-optimised forward-looking generation, storage and transmission investment plan. It determines an investment pathway

that enables a least cost, SCED based plan to be implemented, and forecasts congestion for each transmission line. The results of techno-economic modelling feed into the power system model for feasibility assessment.

The power system model takes outputs from the techno-economic model and verifies, using detailed models of the AC power system, that the investment plan enables operation of the power system in a secure manner. The power system modelling for the TSP does not include dynamic studies; this is addressed in the Power System Security and Reliability (PSSR) studies. Both the power system model and the techno-economic model include additional system investments and constraints to reflect the outcomes of the PSSR work. The power system modelling process can identify shortcomings with the ability of the investment plan to meet power system performance expectations requiring further (or adjusted) investment and iterations of the techno-economic model.

The TSP study process is iterative with power system analysis being used at certain stages in the techno-economic modelling. The power system analysis ultimately verifies that each investment pathway is operable and will achieve expected levels of power system performance.

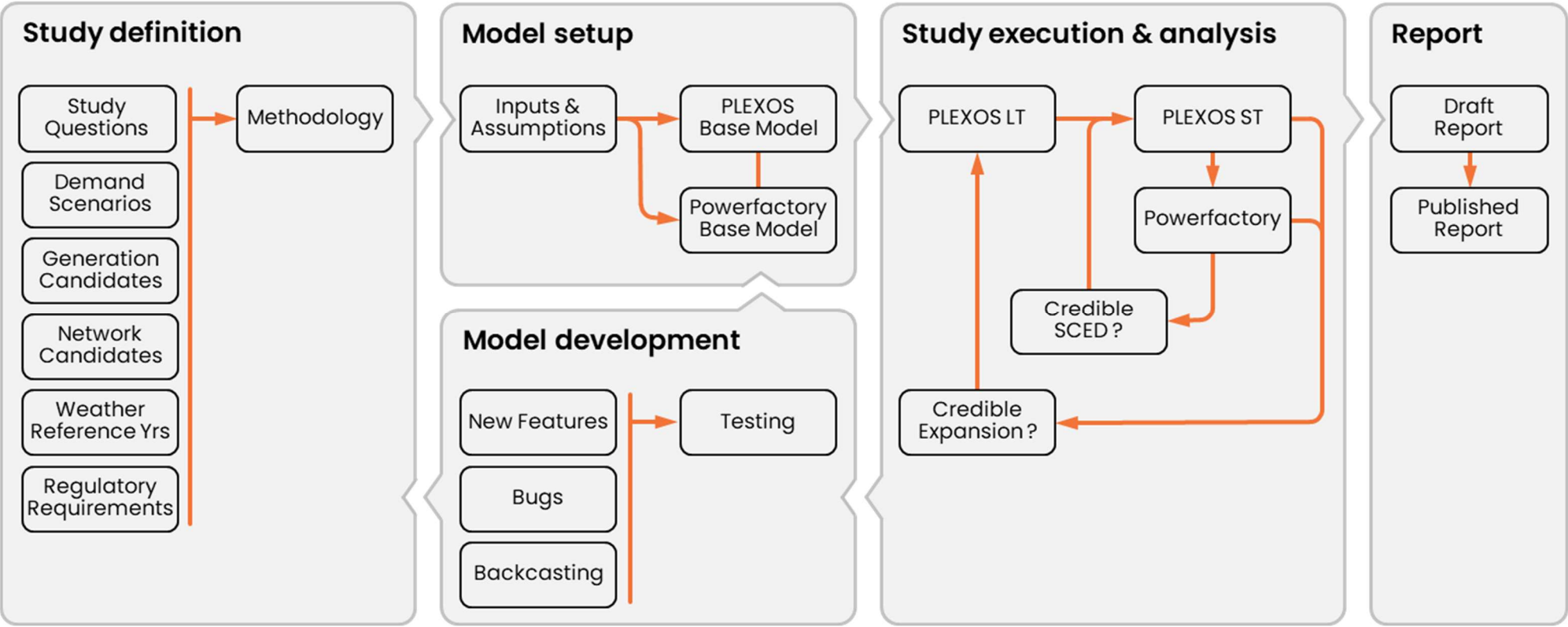


Figure 1. High level study methodology

Study definition

Each TSP study cycle defines the key inputs, model improvements and methodology needed to meet Regulatory obligations and address strategic developments across the SWIS. Table 1 summarises the TSP 2025 study definition noting that this will evolve across studies. Key points of note regarding the TSP study definition:

- Techno-economic modelling co-optimises transmission, generation and storage build and operation costs whilst ensuring electrical demand can be met according to the WEM Planning Criteria over the planning horizon.
- A single central scenario is modelled followed by sensitivities on key variables. There are no Monte Carlo simulations that vary renewable profiles and outages, as is typical in a generation adequacy study [such as the Electricity Statement of Opportunities (ESOO)].
- The reserve capacity target is based on the ESOO and defines a constraint to ensure sufficient firm generation is available in each year over the planning horizon.
- Binding hours and shadow price of each network element is forecast for each interval over the planning horizon.
- There is no assessment of generation / storage project revenue sufficiency.
- There is no assessment of Network Access Quantities (NAQ).

Key inputs & considerations

- Substation nodal representation – SWIS PowerFactory | PLEXOS model
- Substation time series demand forecast – 30 min intervals with DER control embedded
- Committed Network | Generation | Storage projects – based on system & grid planning
- Candidate Network | Generation | Storage projects – based on project pipeline
- Co-optimised dispatch for energy & ESS – SCED
- Batteries are able to provide raise and lower services, but not RoCoF
- Time Horizon – 10 years @ 30 minute interval

Objective – minimise total cost

- Build – customer facilities & network
- Fixed O&M – customer & network
- Variable O&M – customer & network
- Fuel costs
- Unserved energy (USE)
- Penalties

Constraints

- Thermal constraints – DC OPF
- Reserve margin – AEMO Planning Criterion
- Essential system service (ESS)
- System strength constraints
- Minimum inertia constraints – RoCoF
- WEM Reliability Standard
- Battery operation constraints

Exclusions

- Network net benefits assessment
- Generator revenue sufficiency – capacity factor used as a proxy
- Renewable energy targets – treated as a study output
- Controllable DER – embedded in demand input based on uptake / operation forecasts
- Gas supply constraints
- Network Access Quantities (NAQ) assessment

Table 1. TSP study definition

Demand forecast

A 30-minute time-series operational demand forecast is presented at the substation level. Non-market generators (e.g. DPV) are modelled within operational demand. Refer to demand forecast methodology document for detail in Appendix D.

Renewable generation forecast

Production forecasts for renewable generators are derived from historical meter data and wind resource modelling. TSP 2025 utilises Renewables Ninja¹ as a primary source for renewable (wind and solar) generator forecasting. Western Power has improved renewable generation forecasting for future TSP studies to utilise the Bureau of Meteorology (BOM) reanalysis products e.g. BARRA2. BOM wind and solar resource simulations are calibrated based on historical meter generation for existing wind and solar generators.

Project treatment

Committed projects are treated as Fixed builds in PLEXOS – the scope, and entry year is defined and the project is represented in all solutions. All other projects are treated as Candidate builds in PLEXOS – the scope, cost and earliest entry year is defined; however, the inclusion in a solution is dependent on the outcome of the techno-economic least cost optimisation.

1. <https://www.renewables.ninja/>

Network projects

The network projects considered in the study include the Clean Energy Link (CEL) Projects and Reserve Capacity Mechanism (RCM) Projects. The dependencies and staging of the candidate CEL Project are incorporated into PLEXOS through build generic constraints.

The network expansion modelling is part of the overall optimisation framework. The expansion model evaluates different augmentation options and selects the most cost-effective solutions to meet system demand and operational constraints with objective to reduce congestion in the network, increase capacity, and improve reliability.

Generation projects

Generation and storage projects include existing, committed, and candidate facilities. The committed and candidate facilities list is obtained from Western Power's Connection Management System (CMS) supplemented with input from Government.

NCESS projects

There are several projects run by WP aimed at enhancing network support services to maintain the reliability and security of electricity networks in the region. The Non Co-optimised Essential System Services (NCESS) committed projects are only considered for the TSP and are obtained from the WP internal planning team.

Network costs

Network project costs are determined based on project scoping inputs – some projects that are at the concept stage have less certainty regarding scope. AEMO’s Transmission Cost Database (TCD) methodology is applied to develop network project costs as outlined in Figure 2.

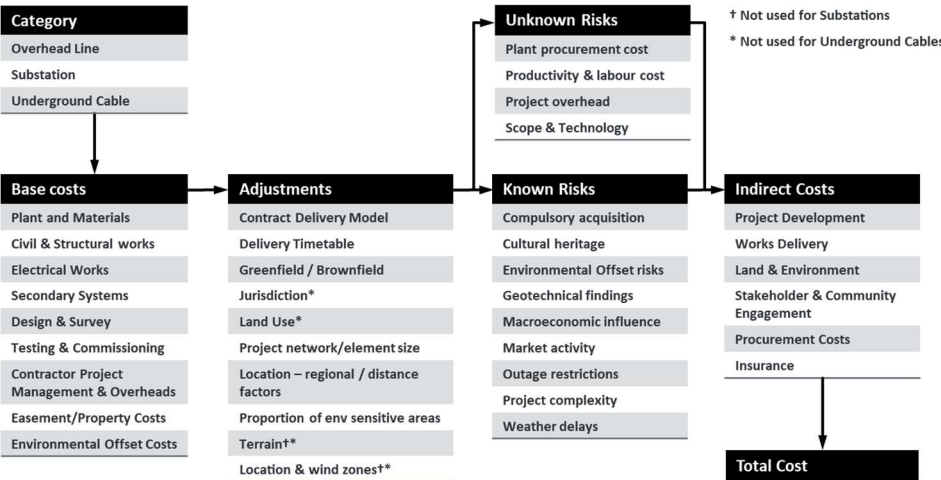


Figure 2. Network cost estimation

Generation costs

Generation and storage project capital costs are sourced from the most recent CSIRO GenCost report. Connection costs are calculated based on the most likely connection option, considering latest information provided by customer to Western Power. This ensures that the cost estimates reflect, site-specific conditions and the most probable pathway for integrating the facility into the network.

Generator operating costs are derived from short-run marginal cost (SRMC), which reflects underlying inputs such as heat rates, fuel costs, and variable operating and maintenance (VOM) costs. Generator bidding behaviour is modelled based on their SRMC value which is further adjusted with marginal loss factors (MLF) and calibrated markups. In addition, price–quantity bid and offer pairs are applied to represent storage charge and discharge behaviour.

Sensitivities

Sensitivity cases are variations to the TSP base case used to assess the impact of alternative demand trajectories, resource mixes, network configurations, or operating conditions. Sensitivities are designed to test solution robustness and identify potential risks or constraints under plausible conditions. The sensitivities developed and studied for TSP 2025 are outlined in the main TSP report.

Expansion

Expansion modelling is performed using the PLEXOS LT module to determine the optimal timing and selection of candidate network, generation and storage investments over the study horizon. The model solves a large-scale optimisation problem that co-optimises investment and operation costs while satisfying physical and market constraints. Due to the high temporal and spatial resolution (particularly when modelling 30-minute intervals with numerous candidate facilities and constraints) the LT can be computationally intensive and challenging to converge. As a result, a number of simplifications are applied to reduce model complexity and ensure that simulations can be completed within a reasonable timeframe (typically less than three days). The TSP expansion modelling therefore adopts the following model setup.

- 10 year expansion plan is solved into 2 x 5 year blocks,
- 2 hr time interval,
- linearised unit commitment,
- linearised generation build and integer line build decisions,
- simplified chronology (fitted 8 blocks / week),
- simplified heat rate, contingencies list and outages, and
- no min / max downtime, ramp rates and minimum system load.

Network model

The PLEXOS base model is developed with network inputs sourced from SWIS PowerFactory base model. The network is modelled at the substation level and includes more than 500 nodes, transformers and lines. The network is assumed to be operating in a system normal state, with normally open points as per the PowerFactory base model. The network structure is modified through both committed and candidate network projects. Committed network projects add nodes, transformers and lines to the model from a specific year onwards. Candidate network projects add nodes and transformers to the model from a specific year onwards. Lines are separately added through the decisions made within the PLEXOS expansion planning optimisation. Committed and candidate network projects add a significant number (i.e. 100's) of nodes, transformers and lines to the model.

Preliminary expansion methodology

Preliminary Expansion (Figure 3) identifies and resolves issues with a simplified expansion model. Using a simplified model speeds up this process and makes it easier to isolate the causes of issues when they occur. Typical areas of focus in this stage include failure to converge on a feasible solution, excessive run times / memory use and implausible solutions.

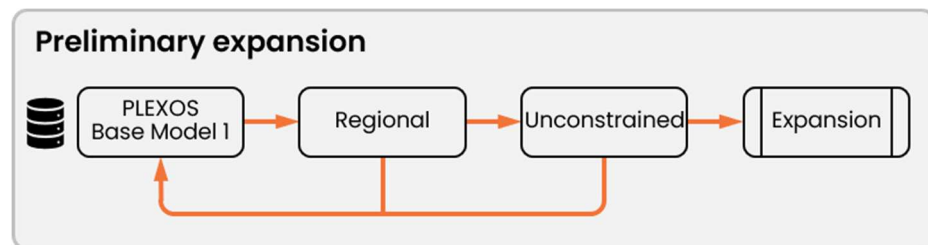


Figure 3. Preliminary expansion methodology

The preliminary expansion modelling is undertaken as follows:

- A **Regional** network model is used; this reduces the system to a single node and removes all network constraints. This allows a generation adequacy assessment to be performed in isolation to ensure there is sufficient generation and storage projects available for the solver to build to meet reliability constraints.
- **Unconstrained** simulations simplify the system through removing transmission limits. This allows the network topology to be tested, though removes network congestion.

Expansion methodology

Expansion modelling (Figure 4) determines the least cost expansion solution – this is presented as the generation, storage and network projects required to be built in each year to supply demand and meet constraints. The expansion modelling is undertaken as follows:

- **Constrained** simulations using the PLEXOS base model from the **Preliminary Expansion** are run to determine the optimal generation, storage and network investments over the planning horizon.
- The solution is analysed sequentially for **Feasibility**, **Performance** and **Validation** before an **Analysis** of the simulation results are performed.
- **Feasibility** assesses whether computational infeasibilities occurred with the solver during the simulation. The solver may be able to repair infeasible solutions to complete the simulation, though reasoning behind the infeasibilities occurring is important as it indicates an issue with the solution.
- **Performance** assesses the runtime and memory requirements of the solution. If the runtime or memory requirements are excessive, the model needs to be simplified following further investigation.
- **Validation** involves generic testing of the simulation outcomes. While the solution may be technically feasible, it may not be practical. These tests filter out solutions which are impractical, or potentially software issues.

- If the constrained solution passes **Feasibility, Performance** and **Validation** checks, an **Analysis** of the results can be performed. **Analysis** requires an extraction and preparation of data from the PLEXOS solution and diagnostic files, followed by an assessment by the technical project team.
- Pending the outcomes of the **Analysis**, one or more **Sensitivities** may need to be run to investigate one or more variables.
- At any of the above stages, the model may require one or more modifications, and the simulations would need to be rerun. If the analysis is satisfactory, the constrained **Expansion Solutions** are extracted, including the new generation, storage and network builds.

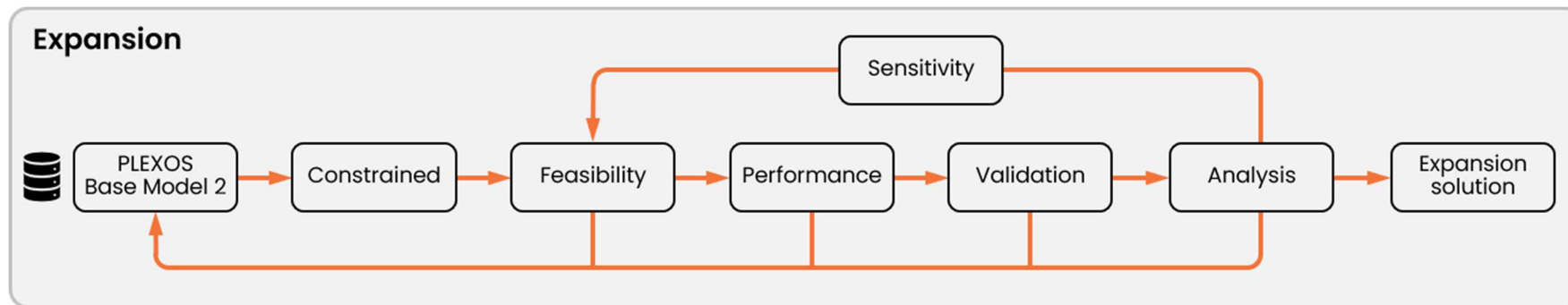


Figure 4. Expansion methodology

Dispatch

Dispatch modelling is performed using the PLEXOS ST module. TSP dispatch modelling applies the following model setup:

- 30-min time step,
- 365 x 1 day x 10 years,
- integer unit commitment,
- detailed heat rates,
- all single contingencies included,
- includes ESS,
- includes ramping, min load and minimum stable load,
- Outages are stochastic, and
- system strength constraints.

Preliminary dispatch methodology

Preliminary Dispatch (Figure 5) includes the screening and validity of the developed model. Like the **Preliminary Expansion**, **Regional** and **Unconstrained** simulations are undertaken.

- **Preliminary Dispatch** filters out inefficient build decisions from the **Expansion** stage.
- The **Expansion** stage makes several temporal and operational simplifications to find a converged solution in a reasonable amount of time. These simplifications may not be feasible when the full complexity of the model is considered in the constrained **Dispatch** simulation.

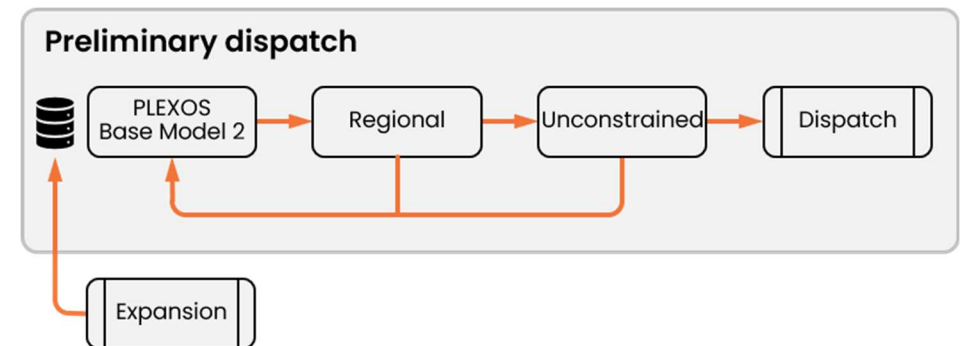


Figure 5. Preliminary dispatch methodology

Dispatch methodology

The Dispatch methodology (Figure 6) develops the final **Dispatch Solution**. Dispatch solutions are tested sequentially through **Feasibility**, **Performance** and **Validation** stages prior to undertaking detailed **Analysis** to ensure the solutions are acceptable.

- **Analysis** requires extraction and preparation of data from the PLEXOS solution and diagnostic files.
- At any stage, the model may require modifications, and reruns.
- Where a modification(s) need made to the model this may require either rerunning **Dispatch** only, or potentially rerunning **Expansion** followed by **Dispatch**.
- **Dispatch Solutions** include generation and storage facility dispatch, binding constraints, proposed solutions, price, line utilisation and other market and system information.

Energy Uplift Payments

The forward-looking energy uplift value calculation is performed through post-processing the **Dispatch Solution**. It requires an extraction and preparation of data from the **Dispatch Solution** and diagnostic files. The method identifies facilities in each dispatch interval where the marginal offer price is higher than the market clearing price. For these facilities, the uplift quantity is determined based on their dispatched generation, and the uplift payment is calculated on a 30 minute interval basis. The relevant binding network constraints are then identified for each uplift interval. Results are reported by facility or by binding constraints and can be further aggregated to annual values. If multiple constraints are binding in the same interval, the uplift payment is assigned equally across the constraints.

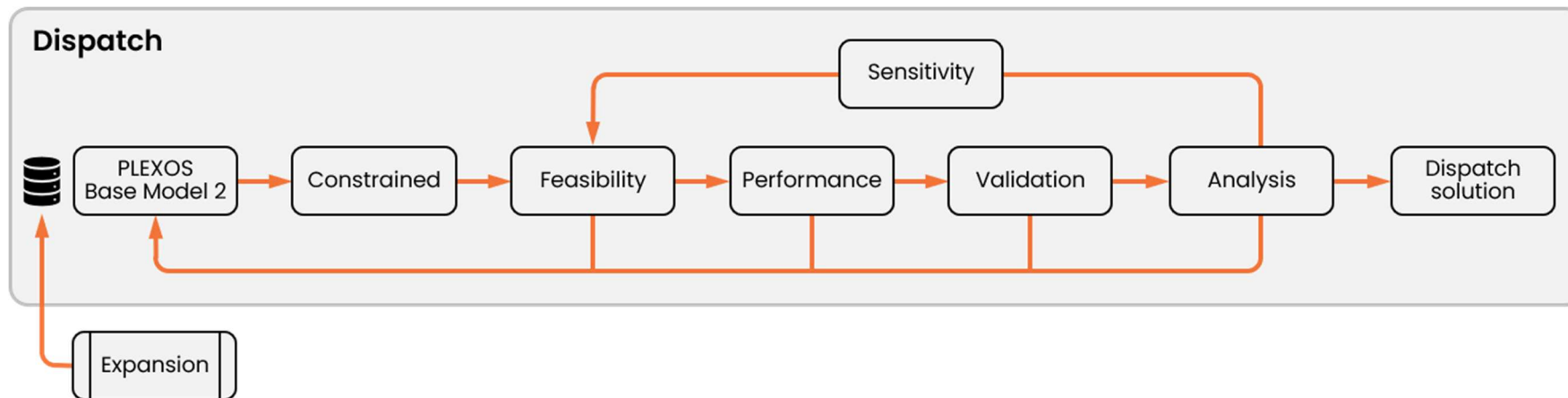


Figure 6. Dispatch methodology

Power system analysis

The TSP PowerFactory model is created from the SWIS Base PowerFactory model with adjustment based on the **Expansion Solution**. Power system analysis validation case studies may be undertaken as shown in Figure 7. TSP 2025 addresses only DC N-1 load flow studies.

The **Dispatch Solution** is compared with a PowerFactory simulated dispatch to check the alignment and accuracy as follows:

- The **Expansion Solution** and **Dispatch Solution** are used to create an updated PowerFactory model.
- Steady state simulations are performed in PowerFactory i.e., **DC N-1** load flow studies, **AC N-1** load flow studies, **Fault Level** studies, and **Voltage & Reactive Power** studies (as required).
- Inconsistencies identified from the validation may require either rerunning **Dispatch**, or potentially rerunning **Expansion** followed by **Dispatch**.
- Once validation has been achieved, the outcomes of the PowerFactory modelling are extracted and processed for use in the TSP report.

The process to update the PowerFactory model using the PLEXOS outputs is presently a manual process and is time consuming. If multiple scenarios are required for the TSP, the time to update the PowerFactory model will scale accordingly.

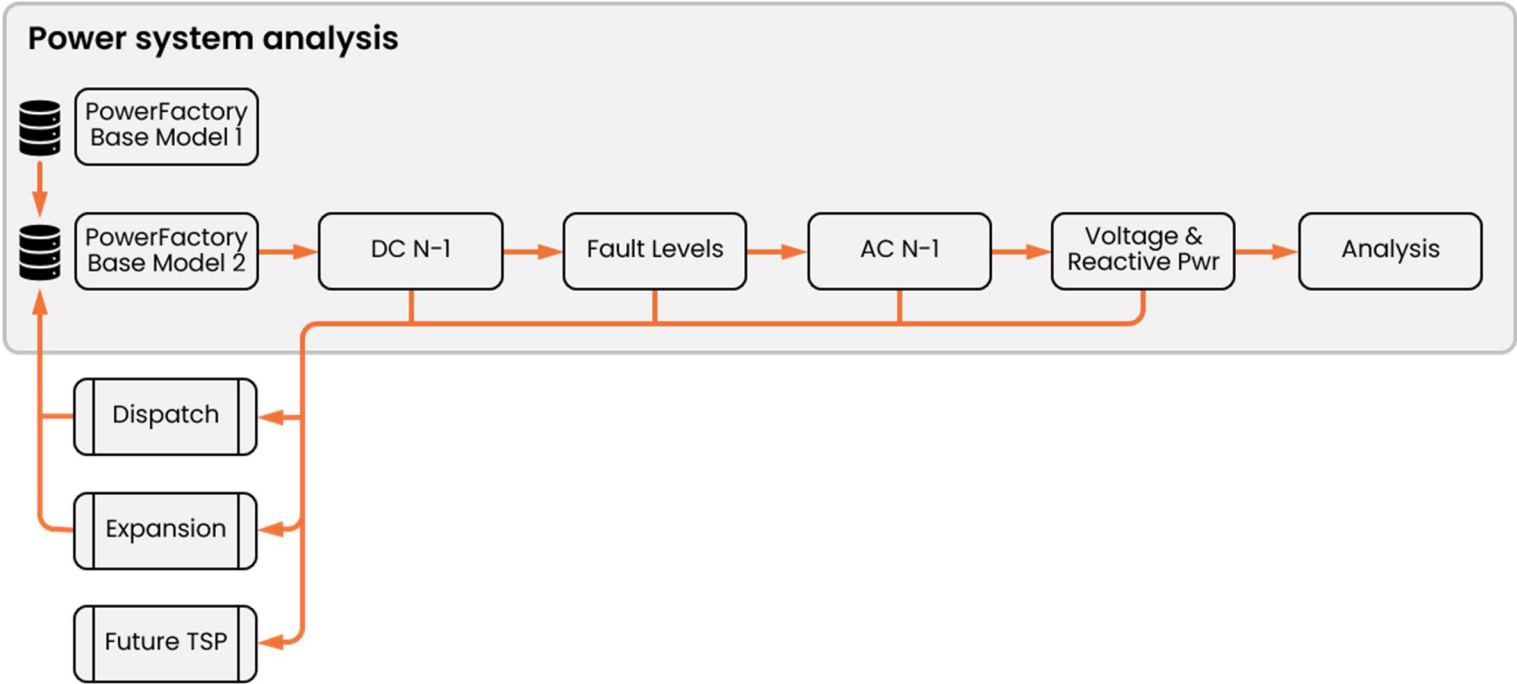


Figure 7. Power system analysis methodology

Essential system services

To represent Essential system services (ESS) in the TSP, all five ESS are included as constraints in the **Dispatch** modelling as follows:

- Regulation Raise: Static value set to an annually increasing day / night-time value.
- Regulation Lower: Static value set to an annually increasing day / night-time value.
- Contingency Reserve Raise: Dynamic value set based on either:
 - the largest generator contingency, or
 - the load ramping from DPV.
- Contingency Reserve Lower: Static value set to a minimum provision of 300MW to represent the largest load contingency.
- Rate of Change of Frequency (RoCoF) Control Service set.

Note that ESS constraints are applied only to the **Dispatch** modelling. If ESS constraints impact on **Dispatch** is limited, it is assumed there will be limited impact on the **Expansion Solution**.

Other constraints

There are several constraints and penalties included in the TSP to better represent the WEM.

- **Constraint Violation Penalty:** For each ESS, the penalty is set as the value of reserve shortage (VoRS). For TSP 2025, this is set to either a very large value (100,000) or -1, effectively making it a hard constraint.
- **Energy Target Constraints:** BESS must be fully charged before the Electric Storage Resource Obligation Duration (ESROD) period.
- **Hybrid Constraints:** For hybrid renewable and BESS facilities, operating scenarios are constrained to limit generation output to the declared sent out capacity (DSOC) value.
- **System Strength Constraints:** Based on the system strength study conducted by AEMO, system strength constraints are applied at four critical nodes in the network. The generation contribution coefficients for these constraints are calculated based on each generator's fault level contribution at the nodes of interest.

Further development

Cost benefit analysis

A cost-benefit analysis (CBA) step will be developed for inclusion in the constrained **Dispatch** compared with the constrained **Expansion**. The CBA will investigate specific network and non-network solutions to issues identified in the **Analysis** to determine which, if any, solution is provides a net benefit to the system.

Bid & offer

A bid base model that reflects observed WEM patterns is being developed.

System strength

AEMO is undertaking a comprehensive system strength study of the SWIS – future TSP will seek to align to the methodology applied to this study.

Generation forecasting

Western Power is working with EPWA to develop improved renewable generation forecasting – the intention is that this will be applied to the Whole of System Plan (WOSP) and will be reflected in future TSP.

