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Appendix

TransGrid's network planning approach

This document describes our approach to planning of the NSW transmission network to meet the requirements of the NER and NSW and ACT legislation.

1 General

As a Transmission Network Service Provider (TNSP), TransGrid is obliged to meet the requirements of the National Electricity Rules (NER). In particular, TransGrid is obliged to meet the requirements of clause S 5.1.2.1:

'Network Service Providers must plan, design, maintain and operate their transmission networks to allow the transfer of power from generating units to Customers with all facilities or equipment associated with the power system in service and may be required by a Registered Participant under a connection agreement to continue to allow the transfer of power with certain facilities or plant associated with the power system out of service, whether or not accompanied by the occurrence of certain faults (called 'credible contingency events').'

The NER sets out the required processes for developing networks as well as minimum performance requirements of the network and connections to the network. It also requires TransGrid to consult with Registered Participants and interested parties and to apply the Australian Energy Regulator's (AER's) Regulatory Investment Test – Transmission (RIT-T) as appropriate to development proposals.

TransGrid's planning obligations are also interlinked with the reliability obligations placed on Distribution Network Service Providers (DNSP) in NSW. TransGrid must ensure that its system is adequately planned to enable these licence requirements to be met.

TransGrid also has obligations to meet community expectations in the supply of electricity, including ensuring that developments are undertaken in a socially and environmentally responsible manner. TransGrid plans the network to achieve supply at least cost to the community, without being constrained by state borders or ownership considerations.

TransGrid's approach to network planning includes consideration of non-network options, such as demand side response and demand management and/or embedded generation, as an integral part of the planning process. Joint planning with DNSPs, directly supplied industrial customers, generators and interstate TNSPs is carried out to ensure that the most economic options, whether network options or non-network options, consistent with customer and community requirements are identified and implemented.

1.1 Jurisdictional planning requirements

In addition to meeting requirements imposed by the NER, environmental legislation and other statutory instruments, TransGrid is required to comply with the Transmission Network Design and Reliability Standard set by the NSW Government. The standard generally requires TransGrid to plan and develop its transmission network in NSW on an N–1[1] basis. That is, unless specifically agreed otherwise by TransGrid and the affected distribution network owner or major directly connected end-use customer, there will be no inadvertent loss of load (other than load which is interruptible or dispatchable) following an outage of a single circuit (a line or a cable) or transformer, during periods of forecast high load.

In fulfilling this obligation, TransGrid must recognise specific customer requirements as well as the Australian Energy Market Operator's (AEMO) role as system operator for the National Electricity Market (NEM). To accommodate this, the standard N–1 approach can be modified in the following circumstances:

> Where agreed between TransGrid and a distribution network owner or major directly connected end-use customer, agreed levels of supply interruption can be accepted for particular single outages, before augmentation of the network is undertaken (for example the situation with radial supplies)

> Where requested by a distribution network owner or major directly connected end-use customer and agreed with TransGrid, there will be no inadvertent loss of load (other than load which is interruptible or dispatchable) following events more onerous than N–1 such as concurrent outages of two network elements

> The main transmission network, which is operated by AEMO, should have sufficient capacity to accommodate AEMO's operating practices without inadvertent loss of load (other than load which is interruptible or dispatchable) or uneconomic constraints on the energy market. At present AEMO's operational practices include the re-dispatch of generation and ancillary services following a first contingency, such that within 30 minutes the system will again be 'secure' in anticipation of the next critical credible contingency.

The NSW Government requires TransGrid to provide a level of reliability in its network supplying NSW DNSPs to enable them to meet their reliability obligations.

These jurisdictional requirements and other obligations require the following to be observed in planning:

> At all times when the system is either in its normal state with all elements in service or following a credible contingency:
  - Electrical and thermal ratings of equipment will not be exceeded
  - Stable control of the interconnected system will be maintained, with system voltages maintained within acceptable levels

> A quality of electricity supply at least to NER requirements is to be provided

> A standard of connection to individual customers as specified by Connection Agreements is to be provided

> As far as possible connection of a customer is to have no adverse effect on other connected customers

> Environmental and social objectives are to be satisfied

> Acceptable safety standards are to be maintained

1 N–1 reliability means the system is planned for no loss of load on the outage of a single element such as a line, cable or transformer

> The power system in NSW is to be developed at the lowest cost possible whilst meeting the constraints imposed by the above factors.

Consistent with a responsible approach to the environment, it is also aimed to reduce system energy losses where economic.

A further consideration is the provision of sufficient capability in the system to allow components to be maintained in accordance with TransGrid's asset management strategies.

The NSW government has requested that the Independent Pricing and Regulatory Tribunal (IPART) recommend reliability standards for electricity transmission in NSW to apply from the next regulatory period which starts on 1 July 2018. It is expected that IPART will develop a reliability standard that aims to identify the level of reliability that would provide the most value to customers. This assessment takes into account both the cost of providing reliability, which is paid for by customers through their electricity prices, and the costs to customers associated with power outages. IPART's draft recommendations were published in late May 2016. Following a consultation period, final recommendations are expected to be made to the NSW Government by December 2016.

1.2 National planning requirements

AEMO has the role of the national transmission planner and is required to produce a National Transmission Network Development Plan (NTNDP). The NTNDP has regard to jurisdictional planning and regulatory documents (such as Transmission Annual Planning Reports (TAPRs)) and, in turn, the jurisdictional planning bodies need to have regard to the NTNDP in formulating their plans. The first NTNDP was published in 2010 with input from TransGrid. Through a close working relationship, TransGrid's future plans will be consistent with AEMO's.

1.3 The network planning process

The network planning process is undertaken at three levels:

1. Connection planning
Connection planning is concerned with the local network directly related to the connection of loads and generators. Connection planning typically includes connection enquiries and the formulation of draft connection agreements leading to a preliminary review of the capability of connections. Further discussions are held with specific customers where there is a need for augmentation or for provision of new connection points.

2. Network planning within the NSW region
The main 500 kV, 330 kV and 220 kV transmission system is developed in response to the overall load growth and generation requirements and may be influenced by interstate interconnection power transfers. Any developments include negotiation with affected NSW and interstate parties.

The assessment of the adequacy of 132 kV systems requires joint planning with DNSPs. This ensures that development proposals are optimal with respect to both TransGrid and DNSP requirements leading to the lowest possible cost of transmission to the end customer. This is particularly important where the DNSP's network operates in parallel with the transmission network, forming a meshed system.

3. Inter-regional planning
The development of interconnectors between regions and of augmentations within regions that have a material effect on inter-regional power transfer capability are coordinated with network owners in other states in accordance with the NER. The inter-regional developments will be consistent with the NTNDP.

1.4 Consideration of non-network alternatives

TransGrid's planning process includes consideration, and adoption where economic, of non-network alternatives which can address the emerging constraint(s) under consideration and may defer or cancel the need for network augmentations.

1.5 Compliance with NER requirements

TransGrid's approach to the development of the network since the advent of the NEM is in accordance with the NER, other rules and guidelines promulgated by the AER and the Australian Energy Market Commission (AEMC).

1.6 Planning horizons and reporting

Transmission planning is carried out over a short-term time frame of one to five years, and also over long-term time frames of five to 20 years or more. The short-term planning supports commitments to network developments with relatively short lead-times. The long-term planning considers options for future major developments and provides a framework for the orderly and economic development of the transmission network and the strategic acquisition of critical line and substation sites.

In TransGrid's TAPR, the constraints that appear over long-term time frames are considered to be indicative. The timing and capital cost of possible network options to relieve them may change significantly as system conditions evolve. TransGrid has published outline plans for long-term developments.

1.7 Identifying network constraints and assessing possible solutions

An emerging constraint is identified during various planning activities covering the planning horizon. It may be identified through:

> TransGrid's planning activities

> Joint planning with a DNSP

> The impact of prospective generation developments

> The occurrence of constraints affecting generation dispatch in the NEM

> The impact of network developments undertaken by other TNSPs

> As a result of a major load development.

During the initial planning phase, a number of options for addressing the constraint are developed. In accordance with NER requirements, consultation with interested parties is carried out to determine a range of options including network, demand management and local generation options and/or to refine existing options.

A cost effectiveness or cost-benefit analysis is carried out in which the costs and benefits of each option are compared in accordance with the AER's RIT–T. In applying the applicable test the cost and benefit factors may include:

> Avoiding unserved energy caused by either a generation shortfall or inadequate transmission capability or reliability

> Loss reductions

> Alleviating constraints affecting generation dispatch

> Avoiding the need for generation developments

> More efficient generation and fuel type alternatives

> Improvement in marginal loss factors

> Deferral of related transmission works

> Reduction in operation and maintenance costs.

Options with similar net present value would be assessed with respect to factors that may not be able to be quantified and/or included in the RIT–T, but nonetheless may be important from environmental or operational viewpoints. These factors include (but are not limited to):

> Reduction in greenhouse gas emissions or increased capability to apply greenhouse-friendly plant

> Improvement in quality of supply above minimum requirements

> Improvement in operational flexibility.

1.8 Application of power system controls and technology

TransGrid seeks to take advantage of the latest proven technologies in network control systems and electrical plant where these are found to be economic. For example, the application of static var compensators[2] has had a considerable impact on the power transfer capabilities of parts of the main grid, and has deferred or removed the need for higher cost transmission line developments.

System protection schemes have been applied in several areas of the NSW system to reduce the impact of network limitations on the operation of the NEM, and to facilitate the removal of circuits for maintenance.

The broad approach to planning and consideration of these technologies, together with related issues of protection facilities, transmission line design, substation switching arrangements and power system control and communication, is set out in the following sections. This approach is in line with international practice and provides a cost effective means of maintaining a safe, reliable, secure and economic supply system consistent with maintaining a responsible approach to environmental and social impacts.

2 A static var compensator or SVC is an electrical device installed on the high voltage transmission system to provide fast acting voltage control to regulate and stabilise the system

2 Planning criteria

The NER specifies the minimum and general technical requirements in a range of areas including:

> A definition of the minimum level of credible contingency events to be considered
> The power transfer capability during the most critical single element outage. This can range from zero in the case of a single element supply to a portion of the normal power transfer capability
> Frequency variations
> Magnitude of power frequency voltages
> Voltage fluctuations
> Voltage harmonics
> Voltage unbalance
> Voltage stability
> Synchronous stability
> Damping of power system oscillations
> Fault clearance times
> The need for two independent high speed protection systems
> Rating of transmission lines and equipment.

In addition to adherence to NER and regulatory requirements, TransGrid's transmission planning approach has been developed taking into account the historical performance of the components of the NSW system, the sensitivity of loads to supply interruption, and state-of-the-art asset maintenance procedures. It has also been recognised that there is a need for an orderly development of the system taking into account the requirement to meet future load and generation developments.

A set of criteria, detailed below, are applied as a point of first review, from which point a detailed assessment of each individual case is made.

2.1 Main transmission network

The NSW main transmission system is the transmission system connecting the major power stations and load centres and providing the interconnections from NSW to Queensland and Victoria. It includes the majority of the transmission system operating at 500 kV, 330 kV and 220 kV.

This system comprises over 7,000 kilometres of transmission circuits supplying a peak load of approximately 13,000 MW throughout NSW.

Power flows on the main transmission network are subject to overall State load patterns and the dispatch of generation within the NEM, including interstate export and import of power. AEMO operates the interconnected power system and applies operational constraints on generator dispatch to maintain power flows within the capability of the NSW and other regional networks. These constraints are based on the ability of the networks to sustain credible contingency events that are defined in the NER. These events mainly cover forced outages of single generation or transmission elements, but also provide for multiple outages to be redefined as credible from time to time. Constraints are often based on short-duration loadings on network elements, on the basis that generation can be re-dispatched to relieve the line loading within 15 minutes.

The rationale for this approach is that, if operated beyond a defined power transfer level, credible contingency disturbances could potentially lead to system-wide loss of load with severe social and economic impact.

Following any transmission outage, for example during maintenance or following a forced line outage for which line reclosure[3] has not been possible, AEMO applies more severe constraints within a short adjustment period, in anticipation of the impact of a further contingency event. This may require:

> The re-dispatch of generation and dispatchable loads
> The re-distribution of ancillary services
> Where there is no other alternative, the shedding (interruption) of load.

AEMO may direct the shedding of customer load, rather than operate for a sustained period in a manner where overall security would be at risk for a further contingency. The risk is, however, accepted over a period of up to 30 minutes. TransGrid considers AEMO's imperative to operate the network in a secure manner.

TransGrid's planning for its main network concentrates on the security of supply to load connection points under sustained outage conditions, consistent with the overall principle that supply to load connection points must be satisfactory after any single contingency.

The main 500 kV, 330 kV and 220 kV transmission system is augmented in response to the overall load growth and generation requirements and may be influenced by interstate interconnection power transfers. Any developments include negotiation with affected NSW and interstate parties including AEMO to maintain power flows within the capability of the NSW and other regional networks.

The reliability of the main system components and the ability to withstand a disturbance to the system are critically important in maintaining the security of supply to NSW customers. A high level of reliability implies the need for a robust transmission system. The capital cost of this system is balanced by:

3 TransGrid lines have automatic systems to return them to service (reclose them) following a fault.

- Avoiding the large cost to the community of widespread shortages of supply
- Providing flexibility in the choice of economical generating patterns
- Allowing reduced maintenance costs through easier access to equipment
- Minimising electrical losses which also provides benefit to the environment.

The planning of the main system must take into account the risk of forced outages of a transmission element coinciding with adverse conditions of load and generation dispatch. Two levels of load forecast (summer and winter) are considered, as follows.

Loads at or exceeding a one in two year probability of occurrence (50% probability of exceedance)

The system will be able to withstand a single contingency under all reasonably probable patterns of generation dispatch or interconnection power flow. In this context, a single contingency is defined as the forced outage of a single transmission circuit, a single generating unit, a single transformer, a single item of reactive plant or a single busbar section.

Provision will be made for a prior outage (following failure) of a single item of reactive plant.

Further, the system will be able to be secured by re-dispatching generation (AEMO action), without the need for pre-emptive shedding (interruption) of load, so as to withstand the impact of a second contingency.

Loads at or exceeding a one in ten year probability of occurrence (10% probability of exceedance)

The system will be able to withstand a single contingency under a limited set of patterns of generation dispatch or interconnection power flow.

Further, the system will be able to be secured by re-dispatching generation (AEMO action), without the need for pre-emptive load shedding, so as to withstand the impact of a second contingency.

These criteria do not apply to radial sections of the main system.

The patterns of generation applied to the 50% probability of exceedence load level cover patterns that are expected to have a relatively high probability of occurrence, based on the historical performance of the NEM and modelling of the NEM generation sources into the future. The limited set of patterns of generation applied to the 10% probability of exceedance load level cover two major power flow characteristics that occur in NSW. The first power flow characteristic involves high output from base-load generation sources throughout NSW and high import to NSW from Queensland. The second power flow characteristic involves high import to NSW from Victoria and Southern NSW generation coupled with high output from the NSW base-load generators.

Under all conditions there is a need to achieve adequate voltage control capability. TransGrid has traditionally assumed that all on-line generators can provide reactive power support within their rated capability. However, in the future, TransGrid intends to align with other utilities in relying only on the reactive capability given by performance standards. Reactive support beyond the performance standards may need to be procured under network support arrangements.

A further consideration is the provision of sufficient capability in the system to allow components to be maintained in accordance with TransGrid's asset management strategies.

Overall supply in NSW is heavily dependent on base load coal fired generation in the Hunter Valley, the western area and Central Coast. These areas are interconnected with the load centres via numerous single and double circuit lines. In planning the NSW system, taking into account AEMO's operational approach to the system, there is a need to consider the risk and impact of overlapping outages of circuits under high probability patterns of load and generation.

Presently the interests on the new generation developments are mainly concentrated on wind and solar generation. The wind and solar resources are intermittent as their availability is dependent on the wind and solar radiation prevailing at a given time. In planning the transmission system, TransGrid currently assumes wind and solar generation have a 1.2% and a 25% firm contribution of installed capacity during summer peak periods, respectively. TransGrid will review the contribution of wind and solar generation in meeting the State's peak demand as the generation mix changes in the future.

The analysis of network adequacy must take into account the probable load patterns, typical dispatch of generators and loads, the availability characteristics of generators (as influenced by maintenance and forced outages), energy limitations and other factors relevant to each case.

Options to address an emerging inability to meet all connection point loads would be considered with allowance for the lead time for a network augmentation solution.

Before this time, consideration may be given to the costs involved in re-dispatch in the energy and ancillary services markets to manage single contingencies. In situations where these costs appear to exceed the costs of a network augmentation, this will be brought to the attention of network load customers for consideration. TransGrid may then initiate the development of a network or non-network solution through a consultation process.

2.2 Relationship with inter-regional planning

TransGrid monitors the occurrence of constraints in the main transmission system that affect generator dispatch. TransGrid's planning therefore also considers the scope for network augmentations to reduce constraints that may satisfy the RIT-T.

Under the provisions of the NER, a Region may be created where constraints to generator dispatch are predicted to occur with reasonable frequency when the network is operated in the 'system normal' (all significant elements in service) condition. The creation of a Region does not consider the consequences to load connection points if there should be a network contingency.

The capacity of interconnectors that is applied in the market dispatch is the short-time capacity determined by the ability to maintain secure operation in the system normal state in anticipation of a single contingency. The operation of the interconnector at this capacity must be supported by appropriate ancillary services. However, AEMO does not operate on the basis that the contingency may be sustained but TransGrid must consider the impact of a prolonged plant outage.

As a consequence, it is probable that for parts of the network that are critical to the supply to loads, TransGrid would initiate augmentation to meet an N–1 criterion before the creation of a new Region.

The development of interconnectors between regions will be undertaken where the augmentation satisfies the RIT-T. The planning of interconnections will be undertaken in consultation with the jurisdictional planning bodies of the other states.

It is not planned to maintain the capability of an interconnector where relevant network developments would not satisfy the RIT-T.

2.3 Networks supplied from the main transmission network

Some parts of TransGrid's network are primarily concerned with supply to local loads and are not significantly impacted by the dispatch of generation (although they may contain embedded generators). The loss of a transmission element within these networks does not have to be considered by AEMO in determining network constraints, although ancillary services may need to be provided to cover load rejection in the event of a single contingency.

2.4 Supply to major load areas and sensitive loads

The NSW system contains six major load areas with indicative loads as follows:

Some of these load areas, including individual smelters, are supplied by a limited number of circuits, some of which may share double circuit line sections. It is strategically necessary to ensure that significant individual loads and load areas are not exposed to loss of supply in the event of multiple circuit failures. As a consequence, it is necessary to assess the impact of contingency levels that exceed N–1.

Outages of network elements for planned maintenance must also be considered. Generally this will require 75% of the peak load to be supplied during the outage. While every effort would be made to secure supplies in the event of a further outage, this may not be always possible. In this case attention would be directed to minimising the duration of the plant outage.

Load area	Indicative peak load
The NSW North, supplied from the Hunter Valley, Newcastle and over QNI	1,000 MW
Newcastle area	2,400 MW (this includes aluminium smelters with a load of around 1,000 MW)
Greater Sydney	6,000 MW
Western area	600 MW
South Coast	700 MW
South and South West	1,600 MW

2.5 Urban and suburban areas

Generally the urban and suburban networks are characterised by a high load density served by high capacity underground cables and relatively short transmission lines. The connection points to TransGrid's network are usually the low voltage (132 kV) busbars of 330 kV substations. There may be multiple connection points and significant capability on the part of the DNSP to transfer load between connection points, either permanently or to relieve short-time loadings on network elements after a contingency.

The focus of joint planning with the DNSP is the capability of the meshed 330/132 kV system and the capability of the existing connection points to meet expected peak loadings. Joint planning addresses the need for augmentation to the meshed 330/132 kV system and TransGrid's connection point capacity or to provide a new connection point where this is the most economic overall solution.

Consistent with good international practice, supply to high-density urban and central business districts is given special consideration. For example, the inner Sydney metropolitan network serves a large and important part of the State load. Supply to this area is largely via a 330 kV and 132 kV underground cable network. The two 330 kV cables are part of TransGrid's network and the 132 kV cable system is part of Ausgrid's network. The reliability standard for the area specified by the NSW Government in the Transmission Network Design and Reliability Standard is that the system will be capable of meeting the peak load under the following contingencies:

1. The simultaneous outage of a single 330 kV cable and any 132 kV feeder or 330/132 kV transformer; or
2. An outage of any section of 132 kV busbar.

The requirement for a reliability criterion for the overall network that is more onerous than N–1 reflects:

- The importance and sensitivity of the Sydney area load to supply interruptions
- The high cost of applying a strict N–2 criterion to the 330 kV cable network
- The large number of elements in the 132 kV network
- The past performance of the cable system
- The long time to repair cables should they fail.

The criterion applied to the inner Sydney area is consistent with that applied in the electricity supply to major cities throughout the world. Most countries use an N–2 criterion. Some countries apply an N–1 criterion with some selected N–2 contingencies that commonly include two cables sharing the one trench or a double circuit line.

The above criterion is applied in the following manner in planning analysis:

1. Under system normal conditions, all elements must be loaded within their 'recurrent cyclic' rating
2. System loadings under first contingency outages will remain within equipment recurrent cyclic ratings without corrective switching other than for automatic switching or 'auto-change-over'
3. Cyclic load shedding (in areas other than the Sydney CBD) may be required in the short term following a simultaneous outage of a single 330 kV cable, and any 132 kV transmission feeder or 330/132 kV transformer in the inner metropolitan area, until corrective switching is carried out on the 330 kV or 132 kV systems
4. The system should be designed to remove the impact of a bus section outage at existing transmission substations. New transmission substations should be designed to cater for bus section outages
5. The load forecast to be considered is based on '50% probability of exceedence'
6. Loading is regarded as unsatisfactory when 330/132 kV transformers and 330 kV or 132 kV cables are loaded beyond their recurrent cyclic rating
7. Fault interruption duty must be contained to within equipment ratings at all times.

Outages of network elements for planned maintenance must also be considered. Generally this will require 75% of the peak load to be supplied during an outage. While every effort would be made to secure supplies in the event of a further outage, this may not be always possible. In this case attention would be directed to minimising the duration of the outage.

2.6 Non urban areas

Generally these areas are characterised by lower load densities and, generally, lower reliability requirements than urban systems. The areas are sometimes supplied by relatively long, often radial, transmission systems. Connection points are either on 132 kV lines or on the low voltage busbars of 132 kV substations. Although there may be multiple connection points to a DNSP, they are often far apart and there will be little capacity for power transfer between them. Frequently supply limitations will apply to the combined capacity of several supply points together.

The focus of joint planning with the DNSP will usually relate to:

- Augmentation of connection point capacity
- Duplication of radial supplies
- Extension of the 132 kV system to reinforce or replace existing lower voltage systems and to reduce losses
- Development of a higher voltage system to provide a major augmentation and to reduce network losses.

Supply to one or more connection points would be considered for augmentation when the forecast peak load at the end of the planning horizon exceeds the load firm N–1 capacity of TransGrid's network. However, consistent with the lower level of reliability that may be appropriate in a non-urban area, an agreed level of risk of loss of supply may be accepted. Thus augmentations may actually be undertaken:

- When the forecast load exceeds the firm capacity by an agreed amount
- Where the period that some load is at risk exceeds an agreed proportion of the time
- An agreed amount of energy (or proportion of annual energy supplied is at risk.

As a result of the application of the criteria, some radial parts of the 330 kV and 220 kV network are not able to withstand the forced outage of a single circuit line at time of peak load, and in these cases provision has been made for under-voltage load shedding.

Provision is also required for the maintenance of the network. Additional redundancy in the network is required where maintenance cannot be scheduled without causing load restrictions or an unacceptable level of risk to the security of supply.

2.7 Transformer augmentation

In considering the augmentation of transformers, appropriate allowance is made for the transformer cyclic rating[4] and the practicality of load transfers between connection points. The outage of a single transformer (or single-phase unit) or a transmission line that supports the load carried by the transformer is allowed for.

Provision is also required for the maintenance of transformers. This has become a critical issue at a number of sites in NSW where there are multiple transformers in service. To enable maintenance to be carried out, additional transformer capacity or a means of transferring load to other supply points via the underlying lower voltage network may be required.

4 Transformer nominal ratings are based on them carrying a constant load. However, loads are often cyclic (they vary throughout the day). In these cases transformers may be able to carry more than their nominal rating for a short period around the time of the maximum load as they are loaded less heavily before and after that period. A cyclic loading takes this into account.

2.8 Consideration of low probability events

Although there is a low probability that loads will need to be shed (interrupted) as a result of system disturbances, no power system can be guaranteed to deliver a firm capability 100% of the time, particularly when subjected to disturbances that are severe or widespread. It is also possible that extreme loads, above the level allowed for in planning, can occur, usually under extreme weather conditions.

The NSW network contains numerous lines of double circuit construction and, whilst the probability of overlapping outages of both circuits of a line is very low, the consequences could be widespread supply disturbances.

Thus there is a potential for low probability events to cause localised or widespread disruption to the power system. These events can include:

> Loss of several transmission lines within a single corridor, as may occur during bushfires

> Loss of a number of cables sharing a common trench

> Loss of more than one section of busbar within a substation, possibly following a major plant failure

> Loss of a number of generating units

> Occurrence of three-phase faults [5], or faults with delayed clearing.

In TransGrid's network, appropriate facilities and mechanisms are put in place to minimise the probability of such events and to ameliorate their impact. The decision process considers the underlying economics of facilities or corrective actions, taking account of the low probability of the occurrence of extreme events.

TransGrid will take measures, where practicable, to minimise the impact of disturbances to the power system by implementing power system control systems at minimal cost in accordance with the NER.

2.9 Planning criteria for the transmission supply to the ACT

TransGrid has been awarded a utility services licence to provide electricity transmission services within the ACT. This licence requires, inter alia, a second 330 kV supply point to the ACT. The provision of Stockdill 330 kV switching station is part of the solution to fulfil this requirement.

3 Protection requirements

Basic protection requirements are included in the NER. The NER requires that protection systems be installed so that any fault can be detected by at least two fully independent protection systems. Backup protection is provided against circuit breaker failure. Provision is also made for detecting high resistance earth faults.

Required protection clearance times are specified by the NER and determined by stability considerations as well as the characteristics of modern power system equipment. Where special protection facilities or equipment are required for high-speed fault clearance, they are justified on either an NER compliance or a benefit/cost basis.

All modern distance protection systems on the main network include the facility for power swing blocking (PSB). PSB is utilised to control the impact of a disturbance that can cause synchronous instability. At the moment PSB is not enabled, except at locations where demonstrated advantages apply. This feature will become increasingly more important as the interconnected system is developed and extended.

5 Alternating current power systems generally have three phases. Faults on those systems can involve one, two or all three of those phases. Faults involving three phases are generally the most onerous.

4 Transient stability

In accordance with the NER, transient stability is assessed on the basis of the angular swings following a solid fault on one circuit at the most critical location that is cleared by the faster of the two protections (with intertrips assumed in service where installed). At the main system level a two phase-to-ground fault is applied and on 132 kV systems which are to be augmented a three-phase fault is applied.

Recognition of the potential impact of a three-phase fault at the main system level is made by instituting maintenance and operating precautions to minimise the risk of such a fault.

The determination of the transient stability capability of the main grid is undertaken using software that has been calibrated against commercially available system dynamic analysis software.

Where transient stability is a factor in the development of the main network, preference is given to the application of advanced control of the power system or high-speed protection systems, before consideration is given to the installation of high capital cost plant.

5 Steady state stability

The requirements for the control of steady state stability are included in the NER. For planning purposes, steady state stability (or system damping) is considered adequate under any given operating condition if, after the most critical credible contingency, simulations indicate that the halving time of the least damped electromechanical mode of oscillation is not more than five seconds.

The determination of the steady state stability performance of the system is undertaken using software that has been calibrated against commercially available software and from data derived from the monitoring of system behaviour.

In planning the network, maximum use is made of existing plant, through the optimum adjustment of plant control system settings, before consideration is given to the installation of high capital cost plant.

6 Line and equipment thermal ratings

Line thermal ratings have often traditionally been based on a fixed continuous rating and a fixed short-time rating. TransGrid applies probabilistic-based line ratings, which are dependent on the likelihood of coincident adverse weather conditions and unfavourable loading levels. This approach has been applied to selected lines whose design temperature is about 100°C or less. For these lines, a contingency rating and a short-time emergency rating have been developed. Typically, the short-time rating is based on a load duration of 15 minutes, although the duration can be adjusted to suit the particular load pattern to which the line is expected to be exposed. The duration and level of loading must take into account any requirements for re-dispatch of generation or load control.

TransGrid is presently installing ambient condition monitors on critical transmission lines to enable the application of real-time line conductor ratings in the generation dispatch systems.

Transformers are rated according to their specification. Provision is also made for use of the short-time capability of the transformers during the outage of a parallel transformer or transmission line.

TransGrid owns two 330 kV cables and these are rated according to the manufacturer's recommendations that have been checked against an appropriate thermal model of the cable.

The rating of line terminal equipment is based on the manufacturers' advice.

Under NSW legislation, TransGrid has the responsibility to plan for future NSW transmission needs, including interconnection with other networks.

7 Reactive support and voltage stability

It is necessary to maintain voltage stability, with voltages within acceptable levels, following the loss of a single element in the power system at times of peak system loading. The single element includes a generator, a single transmission circuit, a cable and single items of reactive support plant.

To cover fluctuations in system operating conditions, uncertainties of load levels, measurement errors and errors in the setting of control operating points, it is necessary to maintain a margin from operating points that may result in a loss of voltage control. A reactive power margin is maintained over the point of voltage instability or alternatively a margin is maintained with respect to the power transfer compared to the maximum feasible power transfer.

The system voltage profile is set to standard levels during generator dispatch to minimise the need for post-contingency reactive power support.

Reactive power plant generally has a low cost relative to major transmission lines, and the incremental cost of providing additional capacity in a shunt capacitor bank can be very low. Such plant can also have a very high benefit/cost ratio and therefore the timing of reactive plant installations is generally less sensitive to changes in load growth, than the timing of other network augmentations. Even so, TransGrid aims to make maximum use of existing reactive sources before new installations are considered.

TransGrid has traditionally assumed that all on-line generators can provide reactive power support within their rated capability, but in the future intends to align with other utilities in relying only on the reactive capability given by performance standards. Reactive support beyond the performance standards may need to be procured under network support arrangements.

Reactive power plant is installed to support planned power flows up to the capability defined by limit equations, and is often the critical factor determining network capability. On the main network, allowance is made for the unavailability of a single major source of reactive power support in the critical area affected at times of high load, but not at the maximum load level.

It is also necessary to maintain control of the supply voltage to the connected loads under minimum load conditions.

The factors that determine the need for reactive plant installations are:

- In general it has proven prudent and economic to limit the voltage change between the pre- and post-contingency operating conditions
- It has also proven prudent, in general, and economic to ensure that the post-contingency operating voltage at major 330 kV busbars lies above a lower limit
- The reactive margin from the point of voltage collapse is maintained to be greater than a minimum acceptable level
- A margin between the power transmitted and the maximum feasible power transmission is maintained
- At times of light system load, it is essential to ensure that voltages can be maintained within the system highest voltage limits of equipment.

Following forced outages, relatively large voltage changes are accepted at some locations on the main network, and agreed with customers, providing voltage stability is not placed at risk. These voltage changes can approach, and in certain cases, exceed 10% at peak load.

On some sections of the network, the possibility of loss of load due to depressed voltages following a contingency is also accepted. However, there is a preference to install load shedding initiated by under-voltage so that the disconnection of load occurs in a controlled manner.

When determining the allowable rating of switched reactive plant, the requirements of the NER are observed.

8 Transmission line voltage and conductor sizes determined by economic considerations

Consideration is given to the selection of line design voltages within the standard nominal 132 kV, 220 kV, 275 kV, 330 kV and 500 kV range, taking due account of transformation costs.

Minimum conductor sizes are governed by losses, radio interference and field strength considerations.

TransGrid strives to reduce the overall cost of energy and network services by the economic selection of line conductor size. The actual losses that occur are governed by generation dispatch in the market.

For a line whose design is governed by economic loading limits, the conductor size is determined by a rigorous consideration of capital cost versus loss costs. Hence the impact of the development on generator and load marginal loss factors in the market is considered. For other lines, the rating requirements will determine the conductor requirements.

Double circuit lines are built in place of two single circuit lines where this is considered to be both economic and to provide adequate reliability. Consideration would be given to the impact of a double circuit line failure, both over relatively short terms and for extended durations. This means that supply to a relatively large load may require single rather than double circuit transmission line construction where environmentally acceptable.

In areas prone to bushfire, any parallel single circuit lines would preferably be routed well apart.

9 Short-circuit rating requirements

Substation high voltage equipment is designed to withstand the maximum expected short circuit duty in accordance with the applicable Australian Standard.

Operating constraints are enforced to ensure equipment is not exposed to fault duties beyond the plant rating.

In general, the short circuit capability of all of the plant at a site would be designed to match or exceed the maximum short circuit duty at the relevant busbar. In order to achieve cost efficiencies when augmenting an existing substation, the maximum possible short circuit duty on individual substation components may be calculated and applied in order to establish the adequacy of the equipment.

Short circuit duty calculations are based on the following assumptions:

> All main network generators that are capable of operating, as set out in connection agreements, are assumed to be in service

> All generating units that are embedded in distribution networks are assumed to be in service

> The maximum fault contribution from interstate interconnections is assumed

> The worst-case pre-fault power flow conditions are assumed

> Normally open connections are treated as open

> Networks are modeled in full

> Motor load contributions are not modeled at load substations

> Generators are modelled as a constant voltage behind sub-transient reactance.

At power station switchyards, allowance is made for the contribution of the motor component of loads. TransGrid is further analysing the impact of the motor component of loads and is assessing the need to include such contributions when assessing the adequacy of the rating of load substation equipment.

10 Substation configurations

Substation configurations are adopted that provide acceptable reliability at minimum cost, consistent with the overall reliability of the transmission network. In determining a switching arrangement, consideration is also given to:

> Site constraints
> Reliability expectations with respect to connected loads and generators
> The physical location of 'incoming' and 'outgoing' circuits
> Maintenance requirements
> Operating requirements
> Transformer arrangements.

TransGrid has applied the following configurations in the past:

> Single busbar
> Double busbar
> Multiple element mesh
> Breaker-and-a-half.

In general, at main system locations, a mesh or breaker-and-a-half arrangement is now usually adopted.

Where necessary, the expected reliability performance of potential substation configurations can be compared using equipment reliability parameters derived from local and international data.

The forced outage of a single busbar zone is generally provided for. Under this condition, the main network is planned to have adequate capability although loss of load may eventuate. In general, the forced outage of a single busbar zone should not result in the outage of any base-load generating unit.

Where appropriate a 330 kV bus section breaker would ordinarily be provided, to segregate 'incoming' lines, when a second 'incoming' 330 kV line is connected to the substation.

A 132 kV bus section circuit breaker would generally be considered necessary when the peak load supplied via that busbar exceeds 120 MW. A bus section breaker is generally provided on the low voltage busbar of 132 kV substations when supply to a particular location or area is taken over more than two low voltage feeders.

11 Autoreclosure

As most line faults are of a transient nature, all of TransGrid's overhead transmission lines are equipped with autoreclose facilities.

Slow speed three-pole reclosure is applied to most overhead circuits. On the remaining overhead circuits, under special circumstances, high-speed single-pole autoreclosing may be applied.

For public safety reasons, reclosure is not applied to underground cables.

Autoreclose is inhibited following the operation of breaker-fail protection.

6 The maximum fault current that the equipment may be subjected to.

12 Power system control and communication

In the design of the network and its operation to designed power transfer levels, reliance is generally placed on the provision of some of the following control facilities:

> Automatic excitation control on generators
> Power system stabilisers on generators and static var compensators
> Load drop compensation on generators and transformers
> Supervisory control over main network circuit breakers
> Under-frequency load shedding
> Under-voltage load shedding
> Under and over-voltage initiation of reactive plant switching
> High speed transformer tap changing
> Network connection control
> Check and voltage block synchronisation
> Control of reactive output from SVCs
> System Protection Schemes (SPS).

The following communication, monitoring and indication facilities are also provided where appropriate:

> Network wide SCADA and Energy Management System (EMS)
> Telecommunications and data links
> Mobile radio
> Fault locators and disturbance monitors
> Protection signalling
> Load monitors.

Protection signalling and communication is provided over a range of media including pilot wire, power line carrier, microwave links and, increasingly, optical fibres in overhead earthwires.

13 Scenario planning

Scenario planning assesses network capacity, based on the factors described above, for a number of NEM load and generation scenarios. The process entails:

1. Identification of possible future load growth scenarios. These are developed based on AEMO's forecasts to be used in the next NTNDP. TransGrid uses the key data for each scenario to prepare load forecasts for NSW. These are published in the TAPR and by AEMO in the National Electricity Forecasting Report. The forecast can also incorporate specific possible local developments such as the establishment of new loads or the expansion or closure of existing industrial loads.
2. Development of a number of generation scenarios for each load growth scenario. These generation scenarios relate to the development of new generators and utilisation (including retirement) of existing generators. This is generally undertaken by a specialist electricity market modelling consultant, using their knowledge of relevant factors, including:
   > Generation costs
   > Impacts of government policies
   > Impacts of energy related developments such as gas pipeline projects.
3. Modelling of the NEM for load and generation scenarios to quantify factors which affect network performance, including:
   > Generation from individual power stations
   > Interconnector flows.
4. Modelling of network performance for the load and generation scenarios utilising the data from the market modelling.

The resulting set of scenarios is then assessed over the planning horizon to establish the adequacy of the system and to assess network and non-network augmentation options.

The future planning scenarios developed by TransGrid will take into account AEMO's future scenarios from the NTNDP.