TransGrid

# TransGrid's Submission to the Australian Competition & Consumer Commission

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## Revised Transmission Capital Investment Program 2004-2009

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## Attachment 5A

## TransGrid's Network Planning Approach

*November 2004*

# ATTACHMENT 5A

## TRANSGRID'S NETWORK PLANNING APPROACH

### (i) General

The NSW transmission network has been planned and developed by TransGrid and its predecessor organisations, commencing with the Electricity Commission of NSW, for over 50 years.

Under NSW legislation TransGrid has responsibilities that include planning for future NSW transmission needs, including interconnection with other networks.

In addition, as a Transmission Network Service Provider (TNSP) TransGrid, is obliged to meet the requirements of Schedule 5.1 of the NEC. 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 *Code 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 NEC 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 Code Participants and interested parties and to apply the ACCC's Regulatory Test to development proposals.

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

In meeting these obligations TransGrid's approach to network planning is socially and economically based and is consistent with both the NEC and the Regulatory Test. Joint planning with DNSPs, directly supplied industrial customers, generators and interstate TNSPs is carried out to ensure that the most economic options consistent with customer and community requirements are identified and implemented.

TransGrid has traditionally planned the network to achieve supply at least community cost, without being constrained by State borders or ownership considerations. Transmission augmentations have been subjected to a cost-benefit assessment according to NSW State Treasury guidelines since the 1980s. This approach has been carried forward into the NEM in meeting the requirements of Chapter 5 of the NEC.

### *Jurisdictional Planning Requirements*

In addition to meeting requirements imposed by the NEC, environmental legislation and other statutory instruments, TransGrid is expected by the NSW jurisdiction to plan and develop its transmission network on an "n-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 NEMMCO's role as system operator for the 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 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 an outage of a section of busbar or coincident outages of agreed combinations of two circuits, two transformers or a circuit and a transformer (for example supply to the inner metropolitan/CBD area).

- The main transmission network, which is operated by NEMMCO, should have sufficient capacity to accommodate NEMMCO'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 NEMMCO'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.

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

- At all times:
  - Electrical and thermal ratings of equipment will not be exceeded;
  - Stable control of system voltage will be maintained, with system voltages maintained within acceptable levels, and
  - Synchronous stability of the interconnected power system will be maintained.
- A quality of electricity supply at least to NEC requirements is to be provided.
- A standard of connection to individual customers determined 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 constraints are to be satisfied.
- Acceptable safety standards are to be maintained.
- 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 Network Planning Process*

The network planning process is undertaken at three levels:

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.

Network Planning within the New South Wales 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. Development includes 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.

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, under the NEC, by the Inter-regional Planning Committee convened by NEMMCO. Network Service Providers may also apply to NEMMCO for interconnection works to be classified as regulated.

The IRPC conducts an annual planning review of the inter-regional networks, and assists NEMMCO in preparing the annual SOO. This document identifies actual and potential constraints on the interconnectors that may be addressed by transmission augmentations, generation developments or demand management developments. A timetable for addressing inter-regional constraints follows from this work. TransGrid's approach to the development of the network since the advent of the NEM is in accordance with rules and guidelines promulgated by the ACCC.

### *Planning Horizons*

Transmission planning is carried out over a short time frame of one to five years and also over a longer-term time frame of five to 15 years. The shorter-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.

In this Annual Planning Report the constraints that appear over a longer time frame are considered to be indicative. The timing and capital cost of possible network options to relieve them may change significantly as system conditions evolve.

### *Identifying Network Constraints and Assessing Possible Solutions*

An emerging constraint may be 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 NEC requirements, consultation with interested parties is carried out to determine a range of options including network, local generation and DM 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 ACCC's Regulatory Test. In applying the Regulatory 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.
- Fuel cost savings.
- Improvement in marginal loss factors.
- Deferral of related transmission works, and
- 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 Regulatory Test, but nonetheless may be important from environmental or operational viewpoints. These factors include:

- Reduction in greenhouse gas emissions or increased capability to apply greenhouse-friendly plant;
- Improvement in quality of supply above minimum requirements; and
- Improvement in operational flexibility.

***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 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.

Network control systems 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 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.

## (ii) Planning Criteria

The NEC 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;
- Automatic reclosure of overhead transmission lines; and
- Rating of transmission lines and equipment.

In addition to adherence to NEC 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.

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

***Main Transmission Network***

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. NEMMCO applies operational constraints on generator dispatch to maintain power flows within the capability of regional networks. These constraints are based on the ability of the networks to sustain credible contingency events that are defined in the NEC. 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 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 has not been possible, NEMMCO 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; and
- where there is no other alternative, the shedding of load.

NEMMCO 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. In performing its planning analysis, TransGrid must consider NEMMCO's imperative to operate the network in a secure manner.

Therefore in the first instance, 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.

Although TransGrid performs much of its transmission line maintenance using live line techniques, provision must be made for outages of line and terminal equipment in accordance with TransGrid's asset management plan.

Overall supply in NSW is heavily dependent on base-load coal-fired generation in the Hunter Valley, 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 NEMMCO'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.

The analysis of network adequacy requires the application of probabilistic-based security analysis, taking 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.

***Relationship with Inter-Regional Planning***

Under the provisions of the NEC, NEMMCO may recommend the creation of a Region 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 NEC currently does not require NEMMCO, in making such a recommendation, to consider either the size of the price difference that is likely to occur, or the consequences to load connection points if there should be a network contingency.

In effect 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 NEMMCO 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 Region would be recommended by NEMMCO.

***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 NEMMCO in determining network constraints, although ancillary services may need to be provided to cover load rejection in the event of a single contingency.

***Supply to Major Load Areas and Sensitive Loads***

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

| Load Area | Indicative Peak Load |
|---|---|
| The NSW north, supplied from the Hunter Valley, Newcastle and over QNI | 1000 MW |
| Newcastle area | 2400 MW (this includes aluminium smelters with a load greater than 1000 MW) |
| Greater Sydney | 6000 MW |
| Western Area | 630 MW |
| South Coast | 720 MW |
| South and South West | 1520 MW |

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’.

***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 Distributor 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 330 kV cable is part of TransGrid’s network and the 132 kV cable system is part of EnergyAustralia’s network. The jointly developed target reliability standard for the area is that the system will be capable of meeting the peak load under the following contingencies:

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

Thus a ‘n-1’ criterion is applied separately to the two networks. The decision to adopt a reliability criterion for the overall network that is more onerous than ‘n-1’ was made jointly by TransGrid and EnergyAustralia after consideration of:

- 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; and
- The long times 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.

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 outage.

***Non Urban Areas***

Generally these areas are characterised by lower load densities and, generally, lower reliability requirements than urban systems. The areas are often 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 Distributor 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; and
- Development of a higher voltage system to provide a major augmentation and to reduce network losses.

TransGrid's aim is to provide a level and reliability of supply at connection points that is complementary to that provided by the DNSP within its own network. For example Country Energy provides fully duplicated supply ('n-1' reliability) to a load area of 15 MW or more in the former Advance Energy area, and will provide a switched alternative supply if the load exceeds about 5 MW.

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; or
- an agreed amount of energy (or proportion of annual energy supplied) is at risk.

As a result of the application of these 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.

***Transformer Augmentation***

In considering the augmentation of transformers, appropriate allowance is made for the transformer cyclic rating 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.

#### *Consideration of Low Probability Events*

Although there is a high probability that loads will not be shed 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. In addition 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; and
- Occurrence of three-phase faults, or faults with delayed clearing.

In TransGrid's network appropriate facilities and mechanisms are frequently 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.

### (iii) Protection Requirements

Basic protection requirements are included in the NEC. The NEC 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 breaker failure. Provision is also made for detecting high resistance earth faults.

Required protection clearance times are specified by the NEC 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 a NEC 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.

## (iv) Transient Stability

In accordance with the NEC transient stability is assessed on the basis of the first angular swing following a solid two phase-to-ground fault on one circuit at the most critical location that is cleared by the faster of the two protections with inter-trips available.

Historically, the incidence of particular types of faults on the NSW main transmission system has been:

| Fault Type | Frequency of Occurrence |
|---|---|
| Single-phase-to-ground | 75% |
| Two-phase and two-phase-to-ground | 11% |
| Three-phase | 4% |
| Uncertain | 10% |

The two phase-to-ground criterion has been adopted as:

- Two-phase-to-ground faults are reasonably common, and
- It is a compromise between the more frequent but less onerous single-phase faults and the less frequent but more onerous three-phase faults.

Recognition of the potential impact of a three-phase fault 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 thoroughly tested international system dynamic analysis software.

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

## (v) Steady State Stability

The requirements for control of steady state stability are included in the NEC. 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 staged system tests.

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.

## (vi) Line and Equipment Thermal Ratings

Line thermal ratings have traditionally been based on a fixed continuous rating and a fixed short time rating. Recently, probabilistic-based line ratings, which are dependent on the likelihood of coincident adverse weather conditions and unfavourable loading levels, have been developed. This approach has been applied to selected lines whose design temperature is 85 degrees Celsius or less. For these lines a sustained emergency 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.

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 a single 330 kV cable and this cable is rated according to manufacturer's recommendations that have been checked against an appropriate thermal model of the cable.

## (vii) 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. A reactive power margin is maintained over the point of voltage instability. The system voltage profile is set 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.

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. Allowance is also made for the outage of two circuits in succession or both circuits of a double circuit line under reasonably probable patterns of power transfer across the main network.

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

The Code specifies reference power factors for generators and Distributors at points of connection.

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, and
- At times of light system load it is essential to ensure that voltages can be maintained within the system highest voltage limits of equipment.

At some locations on the main network relatively large voltage changes are accepted, and agreed with customers, following forced outages, 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 bank sizes of reactive plant the requirements of the Code are considered.

## (viii) 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 and 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.

## (ix) Short-circuit Rating Requirements

Substation high voltage equipment is designed to withstand a maximum design 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.

Where necessary the maximum possible short-circuit duty on individual substation components is calculated in order to establish the adequacy of the equipment. These calculations are based on:

- 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.
- Maximum fault contribution from interstate interconnections is assumed.
- Worst-case pre-fault power flow conditions are assumed.
- Normally open connections are treated as open.
- Networks are modelled in full.
- Motor load contributions are not modelled, and
- Generators are modelled as a constant voltage behind sub-transient reactance.

## (x) Substation Switching Arrangements

Substation switching arrangements 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.
- The physical location of “incoming” and “outgoing” circuits.
- Maintenance requirements.
- Operating requirements, and
- Transformer arrangements.

TransGrid has applied, or has in hand, the following arrangements:

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

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 be secure although loss of load may eventuate.

Where appropriate a 330 kV bus section breaker would ordinarily be provided 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 is taken over more than two low voltage feeders.

## (xi) Autoreclosure

As most line faults are of a transient nature all 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.

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

## (xii) 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.
- 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, and
- Control of reactive output from SVCs.

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, and
- 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.

## (xiii) Scenario Planning

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

1. Identification of possible future load growth scenarios. These are generally based on the high, medium and low economic growth scenarios in the most recent TransGrid load forecast for NSW or the Statement of Opportunities, published by NEMMCO for other states. They can also incorporate specific possible local developments such as the establishment of new or expansion 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 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/generation scenarios to quantify factors which affect network performance, including:

   - Generation from individual power stations; and
   - Interconnector flows.

4. Modelling of network performance for the load/generation scenarios utilising the data from the market modelling.