Overview of Electrical Power System and the Role of the System Operator

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22 August 2008

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Why should electrical systems be operated with a reserve margin and other buffers?

- The Electrical Power System is considered the most complex system around. It is a mix of electrical, communication, mechanical, civil, information and management systems.
- A comprehensive list of things that could go wrong and the possible impact on other risks cannot be modelled. The ability to continuously visualise the current risk status is incredibly difficult and stressful.
- The impact of failures can be significant to catastrophic (i.e. blackout). There are various global examples of where this has occurred.
- Buffers in the system such as operating reserves, stockpile days, transmission and distribution network redundancy and resources allow the System Operator to deal with multiple events in real time while enabling sustainable medium to long term performance
- By continuously operating “on the edge”, you will not need many things to go wrong before you test your defence systems. You do not want to test your defence systems too often as the increased exposure will increase the likelihood of something going wrong and these barriers failing.
- South Africa’s ability to deal with a nationwide black out is untested and we cannnot rely on our neighbours to assist.

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Electricity Supply Chain

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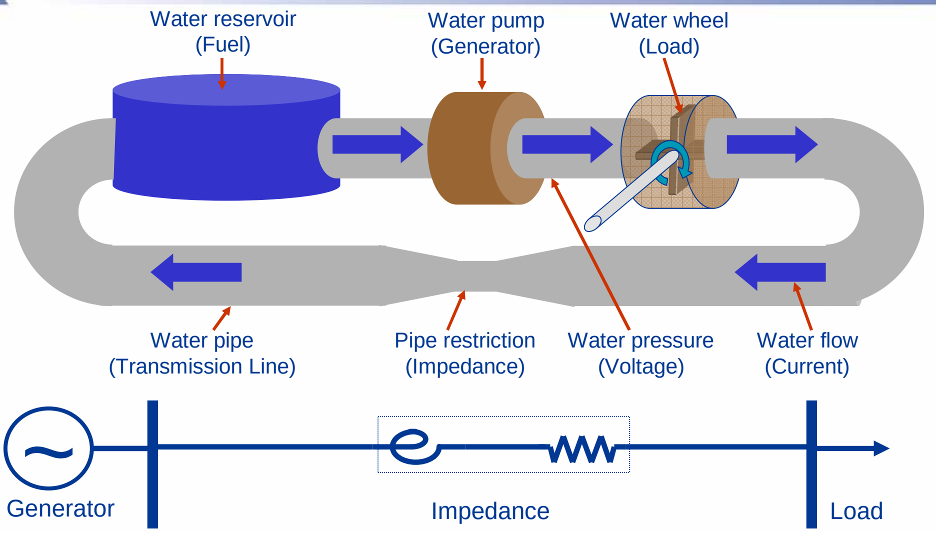
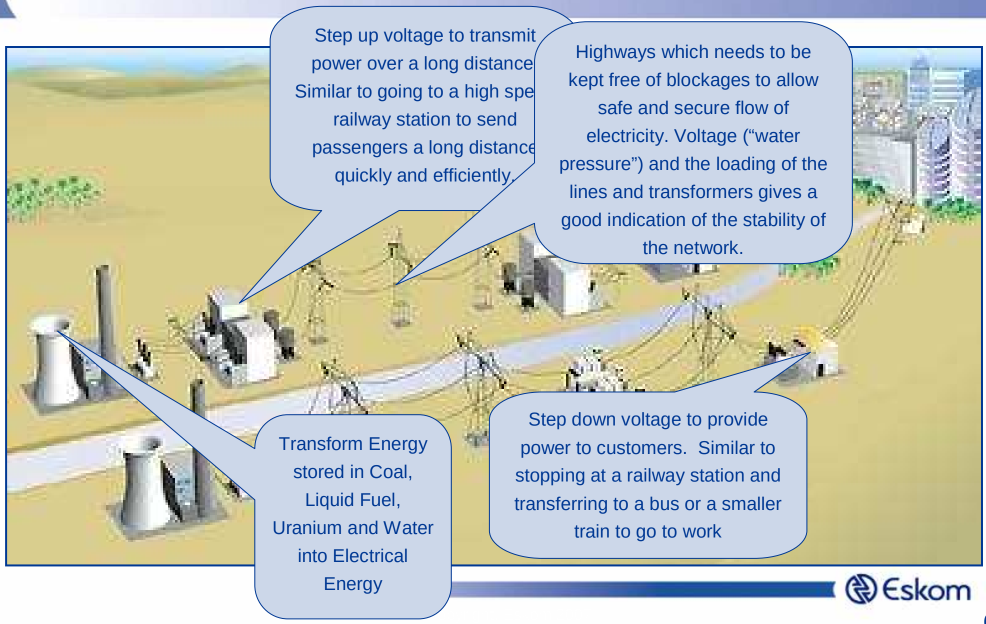
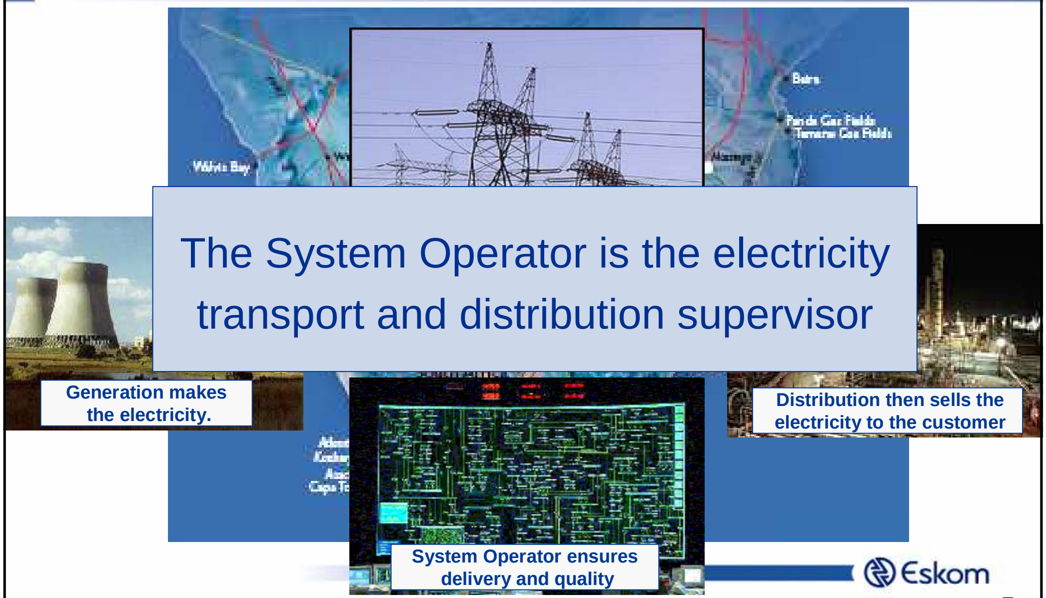
Basic electrical quantities



Overview of an Electrical Power System



What is the System Operator?



The System Operator is the electricity transport and distribution supervisor

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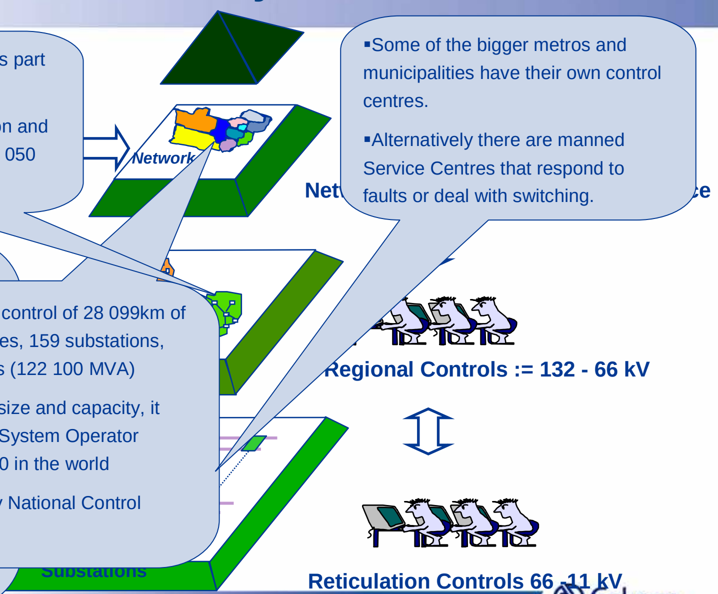
National Control Hierarchy

- 6 Regional Control Centres as part of the Distribution Division.
- Over 300 000km of distribution and reticulation level lines and 324 050 transformers.

- Some of the bigger metros and municipalities have their own control centres.
- Alternatively there are manned Service Centres that respond to faults or deal with switching.

- Eskom has 99 operational generators as (12 coal stati... station, 2 pu... stations, 2 hy... gas turbine s...
- By capacity ... in the world (...
- As a System ... Eskom in the to... world.

- Supervises the control of 28 099km of Transmission lines, 159 substations, 385 transformers (122 100 MVA)
- By geographic size and capacity, it puts the Eskom System Operator among the top 10 in the world
- Have a standby National Control Centre.



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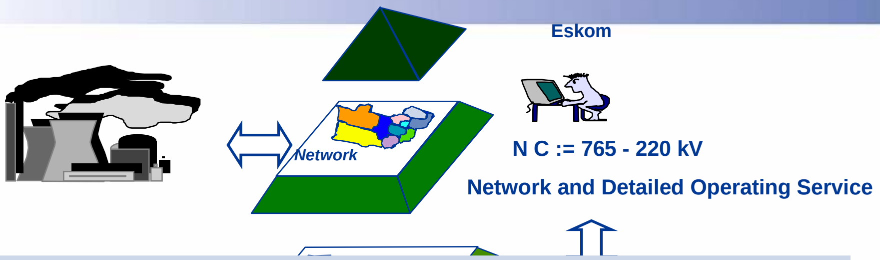
National Control Hierarchy



The current hierarchy of control centres in Eskom has the following benefits:

- Integrated approach to network management in a constrained environment.
- Alignment of technology choices to view and control the power system (computer systems and telecommunications).
- Better resolution and control of load shedding protocols and immediate response in emergencies.

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System Operator Responsibilities

- Balance Supply and Demand
  - Second by second
  - Ensuring there is adequate reserves for credible contingencies
- Manage voltage profile throughout the grid
  - Ensure effective flow of power at the right quality to end customers
- Monitor and manage real time risks that occur on the power system
  - Manage stability of the system
  - Take necessary pre-emptive action
- Restoration after an interruption
  - Speed and accuracy
  - Safety is critical
- Provision of real time information on status of the power system

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Understanding the State of the Power System : What are the key issues to manage?

	Balancing Supply & Demand	State of the "Highways"
Real time	• Meet immediate demand needs • Frequency at 50Hz • 4 to 6% as Operating Reserves (~1500 MW to 2200MW in 2008)	• Voltage profiles • Line loading • Transformer loading
Week ahead to Year ahead	• Ability to schedule maintenance • 9 to 12% as Operating reserves and supplemental reserves (~3400MW to 4500MW in 2008/9)	• Vulnerability to single mode failures • Security margins • Scheduling of maintenance
Year ahead to 25 years ahead	• Net reserve margin of at least 15% • Adequate fuel security	• Adequate level of redundancy for contingencies, maintenance and growth.

- **Not managing either issue properly will lead to system collapse and possibly a blackout.**
- **Both issues require a short term and long term assessment and management.**
- **Changes occur in less than a second and require both automatic and manual responses.**

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Supply – Demand balance

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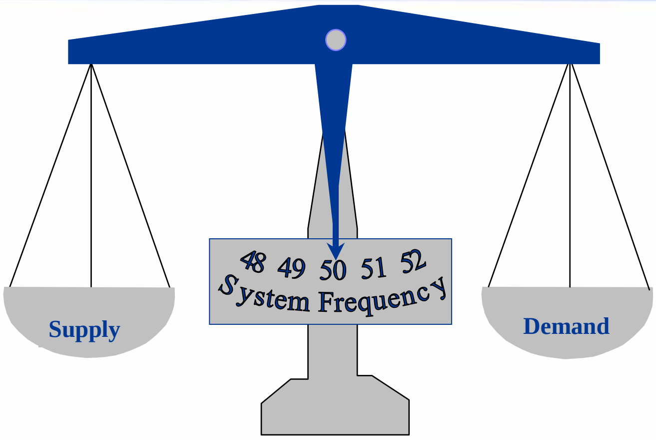
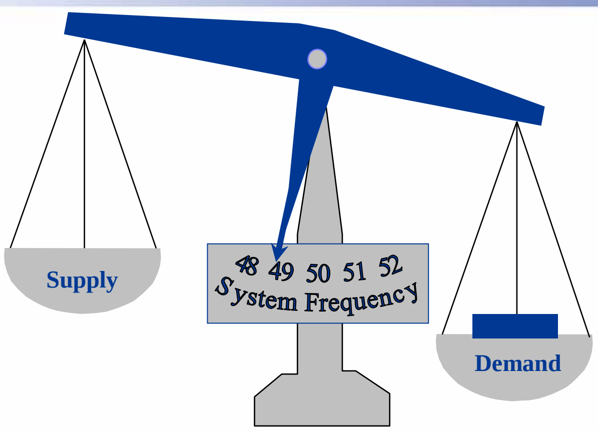
Ideal Supply - Demand Balance



Basic Premise : Electricity cannot be stored in a large power system. It has to be used is some way as soon as it is produced i.e. transformed into another form of energy or utilised to do some "work"

Supply - Demand Imbalance (Excess Demand)



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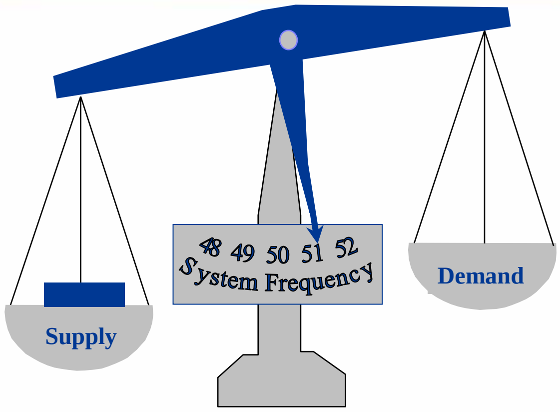

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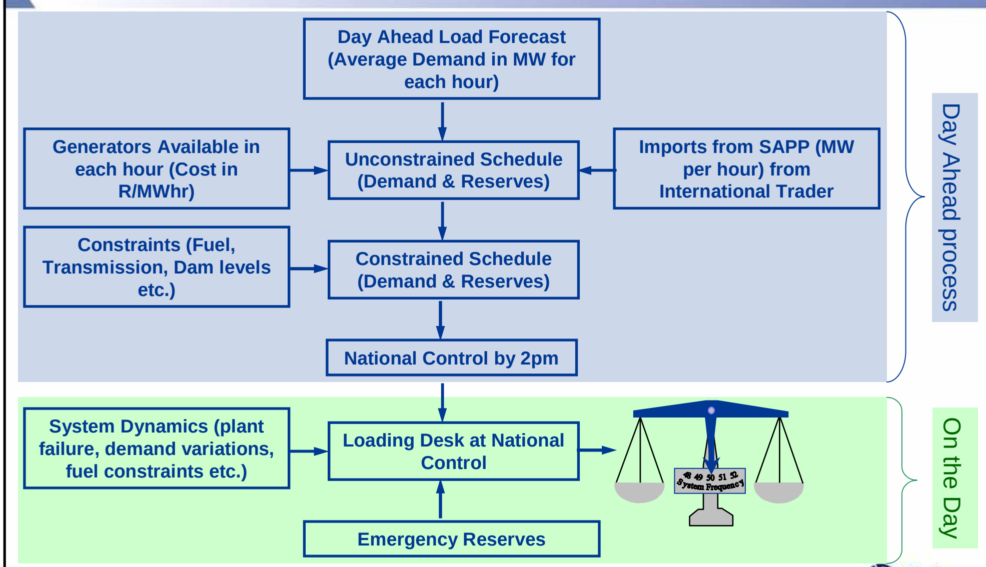
Process to meet real time Supply - Demand Balance



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Resources at System Operator's Disposal

Meeting the Normal Demand profile (load factor between 70 and 75%)	
Base demand and load following	Coal, Nuclear and Pumped storage power stations
Peaks	Pumped Storage and Hydro power stations
Providing Normal Reserves (in 2008 a total of 2 800MW)	
Operating (immediate to 10 minutes)	Demand side products, Coal, Pumped Storage and Hydro power stations
Supplemental (half hour to 6 hours)	Demand side products, Coal power stations
Providing Emergency Reserves (between 3000 and 4000MW)	
Immediate (energy constrained)	Contracted interruptible loads, Increased output from Generators above their maximum capability rating
Up to 2 hours warning	Demand side products, Open Cycle Gas turbines
Load Shedding (organised blocks up to 4500MW)	
Large Industrial customers	Given different warning periods based on process and may be out for longer periods
Residential and Commercial sector	Organised in blocks and rotated

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Utilisation of Resources to meet Demand

Requirements	Criteria for Utilization
Emergency (Mandatory) Load shedding	Based on system security & equitable load shedding in SA control area.
Emergency reserves: at least to cover loss of largest power station	
Gas Turbine Generation (Liquid fuel)	Cost of supply optimization and System Security. If available.
Interruptible loads (Energy constrained)	Cost of supply optimization and System Security.
EL1: Eskom generation at MCR	All machines that are capable and available.
Eskom generation: Energy constrained water resources	Based on Water resources in SA.
Demand Market Participation Contracts	Contractual Cost optimization. (if available)
Supplemental Reserve	
Supplemental reserves: Demand + Generation	Contractual costs optimization & generation production cost optimization
Operational Reserves	
10-minute reserves	Contractual costs optimization & generation production cost optimization
Regulating reserves	Generation production cost optimization
Instantaneous	Contractual costs optimization & generation production cost optimization
Demand: Variable MW from day to day	
Peak load	Cost of production
Base load	Cost of production

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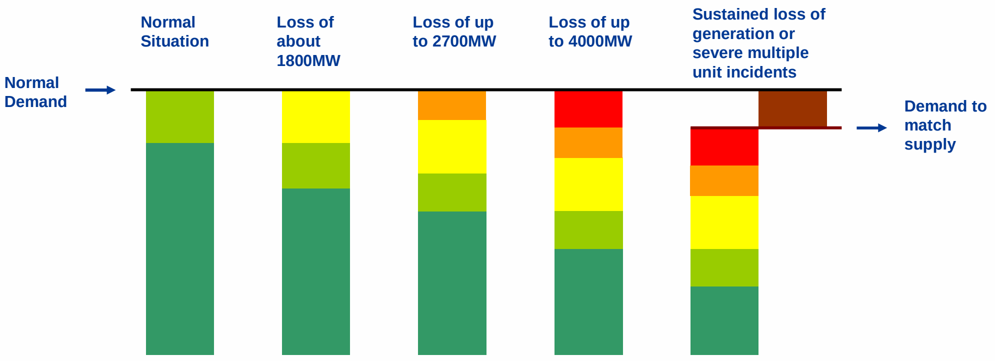
Utilisation of Resources to meet Demand



Base | Peaking — Normal Generation resources

Operational Reserves (available between 10 milliseconds and 10 minutes)

Supplemental Reserves (available between half an hour to 6 hours)

Emergency Reserves (energy constrained and available immediately)

Controlled Load Shedding

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Colour Coding used

- Green (sufficient operating reserves – 1800MW to 1900MW)
  - It is likely one may only have to use our scheduled generation resources and normal operating reserves. Green means we have the required level of operating reserves at our disposal.
- Yellow (Between1800 and 800MW of operating reserves)
  - It is likely one will make extensive use of whatever DMP contracts we have and use EL1 extensively (i.e. generate above maximum capability rating at certain power stations). One may also make use of the interruptible load contracts over peak periods.
- Orange (Up to 200MW short of meeting demand)
  - It is likely one will make extensive use of the interruptible load contracts and use the Open Cycle Gas Turbines in short bursts.
- Red (between 1200MW and 200MW short of meeting demand)
  - It is likely one will resort to a high level of use of the Open Cycle Gas Turbines and Interruptible Loads and possibly have emergency load shedding in short bursts.
- Brown (more than1200MW short of meeting demand)
  - It is likely one will have to resort to emergency load shedding.

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Load shedding will be the last mechanism used to manage the system under any scenario

		EL1	DMP	ILS	OCGT	Load shedding
Green	Sufficient operating reserves	Highly unlikely	Highly unlikely	Highly unlikely	Highly unlikely	Highly unlikely
Yellow	800 MW operating reserves	Partial usage	Partial usage	Partial usage	Highly unlikely	Highly unlikely
Orange	200 MW short on demand	Extensive use	Extensive use	Extensive use	Partial usage	Partial usage
Red	1200 MW short on demand	Extensive use	Extensive use	Extensive use	Extensive use	Partial usage
Brown	> 1200 MW short on demand	Operational control	Operational control	Extensive use	Extensive use	Extensive use

(light blue)	Highly **unlikely** that the resource will be used
(pink)	Partial usage of the resource, probably over peak periods
(dark green)	Extensive use of resource over most of the day
(grey)	Resource is utilised to maintain operational control during incidents and provide some buffer to manage frequency

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Transmission Network Power Transfer Capability

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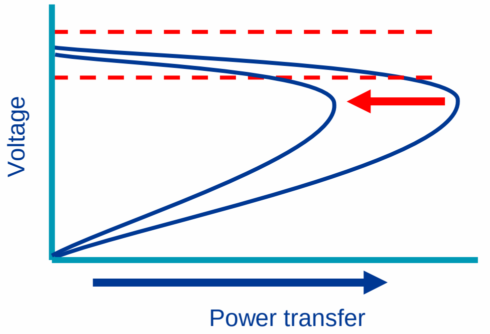
Transmission Network Power Transfer Capability

•The voltage on the transmission network is required to remain within a safe band.

•If the power transfer is increased, the voltage decreases and will collapse beyond the knee point

•The network needs to be managed between the boundaries as power transfer is increased



•Plant failures due environmental factors (lightening, fire etc) or mechanical failure will result in a reduction on the power transfer capability

•Without redundancy, this will remain the limit until the plant is returned to service.

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Load Shedding Protocols

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Determination of Load Shedding

- It is always better to load shed to ensure that security margins are maintained than to go into an uncontrolled collapse of the power system (as did not happen in the North East US blackout in August 2003).
- A generator unit can have a sustained fault that requires some time to repair or a generator unit can trip and be returned to service very quickly.
  - Sustained unplanned outages or faults – target to manage below 2500MW
  - Trips of generation plant averages about 1 unit a day in the last 5 months. This is a normal occurrence.
- What is abnormal?
  - Significant plant outages for a sustained period. Anything higher than 2000MW starts to reduce the level of reserves available to deal with short term problems.
  - Multiple unit trips within a short space of time (2 units or more). Especially concerning is if it occurs at one power station.
- Transmission plant failures can also result in a reduction in power transfer capability but the effect is localised as long as action is taken to contain the problem.
- Load shedding is required to ensure that the transmission network remains in a stable state or to balance a supply-demand imbalance. In some cases it can be predicted and in others there is insufficient time due to the speed of events.

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Protocols for Load Shedding

How is the size of load to be shed determined?

- Longer term constraints require interaction between the System Operator and other agents in the Industry to determine the appropriate level of shedding.
- The targets are determined considering the maximum demand in the region, the seasonal diversity and customers which are excluded from this type of shedding either due to their strategic nature or due to prior arrangements on how to reduce their demand. This is done proportionally with no discrimination.
- For short term constraints, National Control has to determine the level of shedding required and allocates specific targets to each region.

How is the load shed regionally?

- Where there is sufficient time, each regional control centre is warned about the possibility of shedding. The regional control centres communicate to municipal control centre and contactable customers.
- When needed, National control instructs each region to commence shedding and this is required to be actioned immediately. Each control centre is required to confirm when they achieved their targets.
- National Control also instructs each region to restore shedding and requires confirmation when done. This is done in a staggered manner to maintain operational control

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Protocols for Load Shedding (ctd…)

- If up to 2000MW is required to be shed:
  - Load blocks of 1000MW can be shed at a time by the Distribution Regions. The size of the blocks were determined based on ensuring predictability and practical implementation.
  - Excludes Key Industrial Customers
- If a further 1300MW is required to be shed (total of 3 300MW):
  - A further load block of 500MW can be obtained from the Distribution regions.
  - A maximum of 500MW of furnace load and 300MW of general production load can be reduced by Key Industrial customers with 2 hour warning.
- If a further 1250MW is required to be shed (total of 4 550MW):
  - A further load block of 500MW can be obtained from the Distribution regions.
  - A maximum of 500MW of furnace load and 250MW of general production load can be reduced by Key Industrial customers with a 2 to 4 hour warning.
  - By this stage an assessment is made if further reductions are necessary and if so customers are informed to make their processes safe.
- If the deficit is greater than 4 550MW (up to 7 550MW):
  - 2 more load blocks of 500MW each (total of 1000MW) can be obtained from the Distribution regions.
  - A maximum of 500MW of furnace load can be obtained with 2 hour warning.
  - The process of making safe will result in about at least 1 500MW reduction in demand with a 4 to 6 hour lead time.

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What is a reserve margin?

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Why should electrical systems be operated with a reserve margin and other buffers?

- The Electrical Power System is considered the most complex system around. It is a mix of electrical, communication, mechanical, civil, information and management systems.
- A comprehensive list of things that could go wrong and the possible impact on other risks cannot be modelled. The ability to continuously visualise the current risk status is incredibly difficult and stressful.
- The impact of failures can be significant to catastrophic (i.e. blackout). There are various global examples of where this has occurred.
- Buffers in the system such as operating reserves, stockpile days, transmission and distribution network redundancy and resources allow the System Operator to deal with multiple events in real time while enabling sustainable medium to long term performance
- By continuously operating "on the edge", you will not need many things to go wrong before you test your defence systems. You do not want to test your defence systems too often as the increased exposure will increase the likelihood of something going wrong and these barriers failing.
- South Africa's ability to deal with a nationwide black out is untested and we cannnot rely on our neighbours to assist.

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What is the purpose of the "Reserve Margin"?

Reserve margin gives you an indication of the medium to long term adequacy and short term security of the power system

- Adequacy enables us to deal with medium to long term issues, i.e. growth spurts, supply chain problems. It is the ability of the power system to supply the aggregate electrical demand and energy requirements of the customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements.
- Short term security enables the power system to withstand sudden disturbances such as short circuits or unanticipated loss of system elements.

These are globally acknowledged, standard CIGRE definitions

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There are two key components to the reserve margin

Operating Reserve Margin

- Meet demand and supply side deviations instantaneously and then in the short to medium term replenish resources that have been utilised.
- Deal with the loss of the single largest unit on the system or single point of import provision.
- Deal with credible cascading events in the short term (<1 day).

Generation Capacity Net Reserve Margin

- Operating reserve margin plus the ability to cater for additional situations and circumstances including:
- Deal with longer term loss of major units or significant disruptions in capacity provision (strike at a mine)
- Ability to cater for short to medium term economic growth
- Account for major seasonal variations

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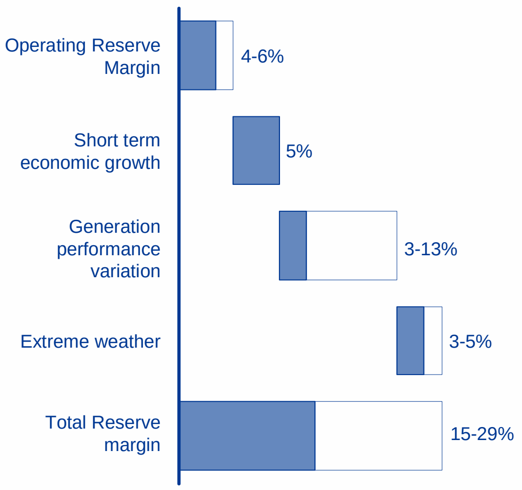
Various inputs typically determine the level of Generating Capacity Net Reserve Margin

Reserve margin build up



Comments

KEMA, in a study for NEMCO, indicated that a reserve level of 4 - 6% should be maintained for system security, if necessary, by curtailing customer load in some manner

Reserve margin allows space for growth

High range due to varying capabilities of different systems

Weather variations as seen during cold spells starting in May

Total Reserve margin

- Recommendations from KEMA, CIGRE and other Benchmarks done

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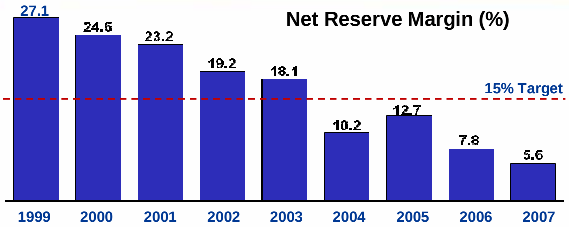
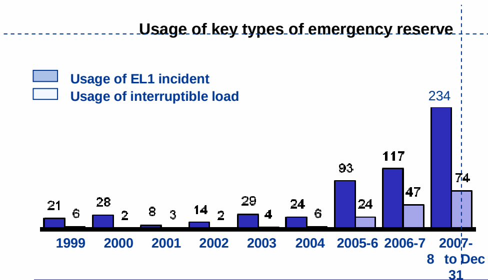
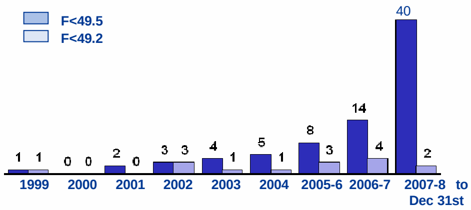
As reserve margin declines, the frequency of use of emergency reserves rises dramatically



Notes

- South Africa's reserve margin has steadily been decreasing over the past years
- As a result, the use of EL1 and Interruptible load has increased.
- The ability to generate power was further compromised by low coal stockpiles and wet coal
- Unplanned outages increased to unprecedented levels in January.
- Load shedding had to be used to ensure the security of the network



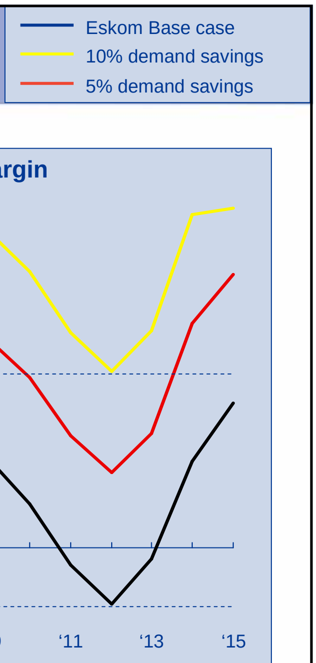


These trends Imply a declining reliability of supply

Prognosis for the Reserve Margin

Key assumptions

- **Growth:** 4% p.a
  - **Supply side assumptions:** Eskom supply base case plans including Medupi, Bravo and Mmambula (2013)
  - Excluding UCG at Majuba, extra wind capacity, OCGT/CCGT conversions, Co-Gen & DME IPP
- **Demand savings calculation** – Annual energy is reduced by 5% or 10%, and then the peak demand is calculated to derive the projected reserve margin



Conclusion

Resources in the System Operator

- People
  - National Control has 30 staffers operating in 5 shifts and the standby control centre has 20 staff operating in 5 shift. Highly trained and certified.
  - Supported by about 130 staff in the System Operator in various technical operations. Mainly engineering, science and analytical skills.
- Technology
  - State of the art, Energy Management System installed last year (AREVA).
  - Redundant telecommunication systems for observability and control.
  - Condition monitoring systems – fire, lightening, transmission line faults, transformer performance, power system security margins etc.
- International and Local Assurance
  - NERSA has conducted an audit run by international System Operator (EIRGRID) which was generally positive.
  - At least 6 internal and external audits done in the last 3 years with positive results and some areas for improvement.
  - NERSA audit into January load shedding incidents confirmed the prudence of the decision making in the System Operator during that period.

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Why should electrical systems be operated with a reserve margin and other buffers?

- The Electrical Power System is considered the most complex system around. It is a mix of electrical, communication, mechanical, civil, information and management systems.
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Back Up Slides

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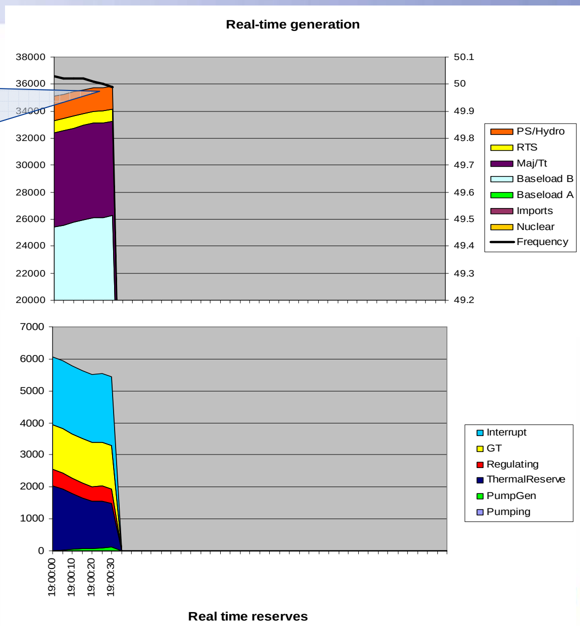
Real time event



Ramping of generation within the hour.

Frequency drifting between 49.75 and 50.15

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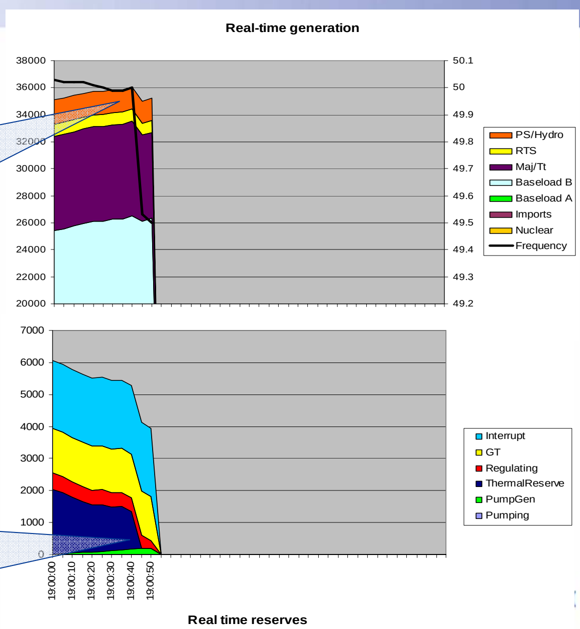
Real time event



Loss of two gen units. Frequency falls to 49.5 before instantaneous reserve arrests decline

Reduced thermal reserve from gen trip and utilisation of instantaneous reserve to arrest frequency decline

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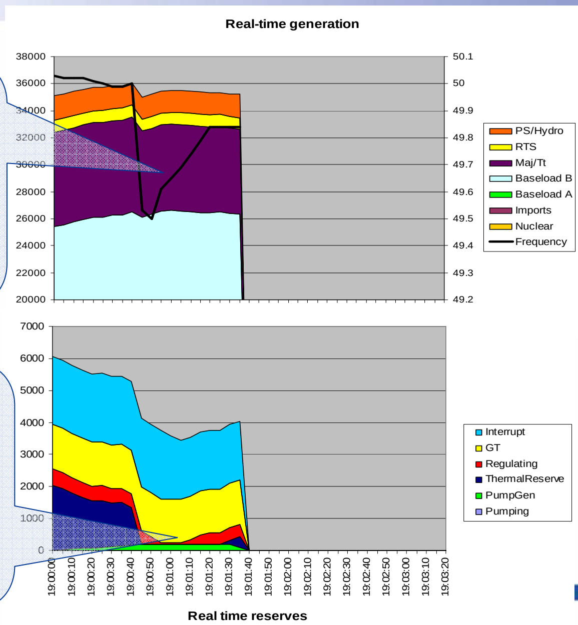
Real time event

Frequency returning to normal bounds, while longer term reserves called up to restore instantaneous and regulating reserve

With all thermal options exhausted some interruption takes place (DMP, etc) before other gen options available (ramping constraints)



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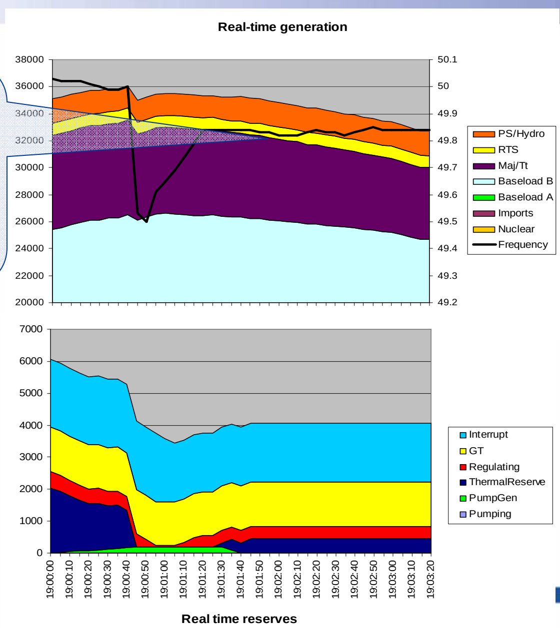
Real time event

Frequency within normal bounds. Energy from lost units replaced by thermal and pumping alternatives.



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Pre-Emptive load shedding on a very bad day ...

Board and Stakeholder Briefing
Electricity Supply Status
Monday, 17 March 2008 4:00 am

1. Supply Side Status

Capacity		Amount (MW)
Installed Eskom Capacity*		38 404
Less	Planned Maintenance	3 446
	Unplanned outages	2 298
	Output Reductions	1 820
	Outage slips	
Operational capacity		30 840
Plus	Imports (HCB)	1 240
Total Capacity		**32 080**

* includes all gas turbines (OCGTs, Port Rex and Acacia)

A. Total capacity	32 080
B. Operating & Supplemental Reserves	2 800
Safe capacity for peak (A-B)	29 280
Expected peak demand (from system report)	32 114
Excess (deficient) capacity	(2 834)

- UCLF was 4118 MW, about 60% higher than planned levels.

- Even if UCLF had been at expected levels, there would have still been some deficiency
- In this week, we had also used our emergency reserves, so our margins were even tighter

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…and on a good day

Board and Stakeholder Briefing
Electricity Supply Status
Tuesday 22 , April 2008 9:00am

1. Supply Side Status

Capacity		Amount (MW)
Installed Eskom Capacity*		38 794
Less	Planned Maintenance	2 979
	Unplanned outages	880
	Output Reductions	345
	Outage slips	
Operational capacity		34 590
Plus	Imports (HCB)	1 050
Total Capacity		**35 640**

* includes all gas turbines (OCGTs, Port Rex and Acacia)

A. Total capacity	35 640
B. Operating & Supplemental Reserves	2 800
Safe capacity for peak (A-B)	32 840
Expected peak demand (from system report)	32 365
Excess (deficient) capacity	475

- Additional Camden Capacity Installed

- UCLF was 1145 MW, less than half of what was planned for (2500 MW)

- If UCLF had been at expected levels (i.e., an additional 1355 MW off load), we would have been short
- Load shedding also ensures equity since KICs are already curtailing their load
- Load shedding also enables *predictability* for the customers

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Co-ordination of Load Shedding

Normal merit order including OCGT and ILS				
When remaining emergency reserves, only cover the loss of one additional unit				Issue Manual Load Shedding warning
	Dx load reduction	**KSACS load reduction**	**SAPP load reduction**	**Comment**
1	1000 MW		% of import equivalent to what we're shedding	Minimum of 10% CVA (UFLS) must be maintained
2	1000 MW			
3	500 MW	On request from customers execs depending on the circumstances	% of import equivalent to what we're shedding	Emergency communication protocol describes the detailed communication and actions required depending on the system status and prevailing conditions
4	500 MW			
5	500 MW			
6	500 MW			
	4000 MW (rotating)	Absolute min		

- Depending on the level of shortage, and expected duration of the problem, different actions will be taken
- Engagement with key customers regarding safety of personnel and load reduction will occur according to pre-defined triggers

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Normal merit order including OCGT and ILS						Nampower to run Gas Turbines when Eskom runs OCGT		N/C Communication
When remaining ILS only covers the loss of one additional unit (600 MW)						Issue Manual Load Shedding warning		-PSM to inform the NC Manager. -NC Manager to inform ERCC chair -Inform Dx NMCs -Follow ERCC protocol.
	Distribution load reduction	KSACS load reduction			SAPP load reduction	Communication	NC action	
		Furnaces (notification)	Emergency (notification)	Make safe (notification)				
1	1000 MW				3% of sales	KSACS warn furnaces and "emergency load" of potential request for load reduction	Minimum of 10% CVA must be maintained	-Inform Communication (Emergency Spoke person at N/C)
2	1000 MW				6% of sales	KSACS instruct furnaces and "emergency" to reduce load if expected this will not be sufficient Warning to "mines" that if we need to/shed a further 1000 MW we will then instruct "make safe" (if no units expected back within 2 hours)	Minimum of 10% CVA must be maintained	-KSACS to initiate emergency protocol. -Set up emergency control at N/C.
3	500 MW	500 MW (2)	300 MW (2)		8 % of sales		Maximise Mand UFLS availability	-Confirm load shedding emergency schedules.
4	500 MW	500 MW (2)	250 MW (4)		10% of sales	Instruct "make safe" (this should be done as soon as it is realised that we are likely to go into last 1000 MW of emergency load shedding for any extended period)		
5	500 MW	500 MW (2)		1500 (4)				
6	500 MW							
7	4000 MW	1500 MW	550 MW	1500 MW	Total Shedding			

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Ensuring Power transfer through the Transmission Network

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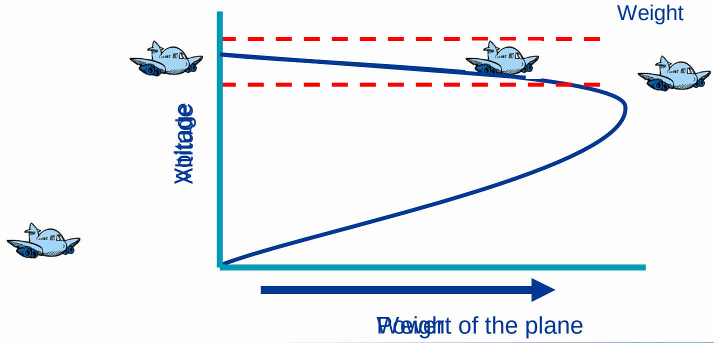
What is Redundancy in the context of the Transmission network?

Let us use the airline industry as an example

- Airplanes are required to maintain a specific altitude for safety and efficiency
- As the plane's weight increases, its altitude decreases if nothing else is done
- If the load is continually increased, the plane will not be able to maintain altitude and beyond the "knee or nose point" the plane will be unstable and crash.
- This is similar to a transmission network where : Altitude = Voltage & Weight = Power transfer



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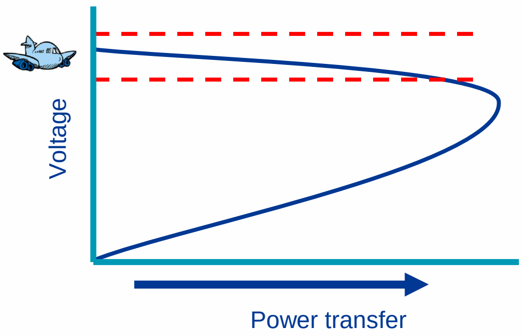
What is Redundancy in the context of the Transmission network?

•The voltage on the transmission network is required to remain within a safe band.

•If the power transfer is increased, the voltage decreases and will collapse beyond the knee point

•The network needs to be managed between the boundaries as power transfer is increased



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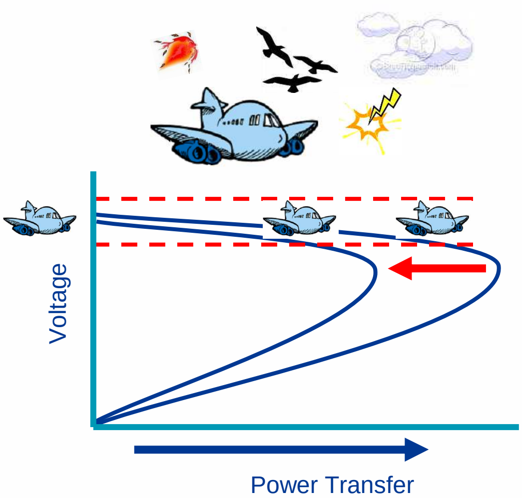
What is Redundancy in the context of the Transmission network?

However there are **various threats to this network**



•Storms = difficult operating conditions

•Unexpected events = causing loss of equipment

- Lightening,
- Birds,
- Veldt or bush fires &
- Mechanical failure

•Maximum power transfer capability is reduced

•Reducing the “knee” point

•If the network was loaded to below the new knee point, the network is stable

•However, if the network was loaded beyond the new knee point, the network is unstable,

•Resulting in uncontrolled load shedding

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What does one need to know about the reserve margin?

What are the basics regarding reserve margin?

- Why does one have a reserve margin?
- Possible definitions for measuring supply side adequacy
- How is the reserve margin typically built up?
- What is the reality for South Africa?
- What happens if you don't have sufficient reserve margin?
- What is the prognosis for the reserve margin in South Africa?

Why should electrical systems be operated with a reserve margin and other buffers?

- The Electrical Power System is considered the most complex system around. It is a mix of electrical, communication, mechanical, civil, information and management systems.
- A comprehensive list of things that could go wrong and the possible impact on other risks cannot be modelled. The ability to continuously visualise the current risk status is incredibly difficult and stressful.
- The impact of failures can be significant to catastrophic (i.e. blackout). There are various global examples of where this has occurred.
- Buffers in the system such as operating reserves, stockpile days, transmission and distribution network redundancy and resources allow the System Operator to deal with multiple events in real time while enabling sustainable medium to long term performance
- By continuously operating "on the edge", you will not need many things to go wrong before you test your defence systems. You do not want to test your defence systems too often as the increased exposure will increase the likelihood of something going wrong and these barriers failing.
- South Africa's ability to deal with a nationwide black out is untested and we cannot rely on our neighbours to assist.

Terms used in measuring the Adequacy of Supply

1) Reserve Margin (%) = $\frac{\text{Available Operational Capacity} - \text{Natural Demand}}{\text{Natural Demand}} \times 100\%$

- Ideally the level of System Adequacy should be measured using a combination of these measures.
- Generation Adequacy criteria has not been entrenched in any regulations to date.
- A proposal has been developed and will be taken through the Governance forums

2) *Loss of Load Exp* … ation (LOLE) is a reliability index that identifie … cient to meet peak demand during a … s "The expected number of days i … he available generating capac … s essentially a time-based measure a … magnitude of load that was impacted

3) *Expected Energy* … rgy that will not be supplied in a specified peri … . This reflects both the duration and mag … e term Expected Unserved Energy (EUE). It can be expressed as a number in GWhrs or as a percentage of the total energy demand for a year (sometimes called *Loss of Energy Probability*, *LOEP*).

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