Over the last 10 years the electricity reserve margin in South Africa, has been steadily declining, due to increasing demand for power and limited new generation capacity being commissioned. In 2006, regional load shedding was required due to network inadequacies and insufficient regional generation resources. In early 2007, the first incident of national load shedding occurred due to the inability to supply demand with the operational generation capacity. After successfully navigating through a winter peak demand of 37000 MW several incidents of load shedding were initiated during the generation maintenance season in October, November and December 2007. In January 2008, there was almost daily load shedding for two weeks leading to a government declaration of a national power emergency on 25 January 2008. This had a severe impact on production levels in all sectors of the economy and compromised the image of Eskom and South Africa.

Overview of the South African power system

The South African power system has 27 operational power stations with just over 39500 MW of operational capacity. The primary source of energy is from coal (~80%). Imports from Cahora Bassa are about 1520 MW. The largest 138 industrial customers (Key Industrial Customers) in the country consume nearly 40% of the energy generated and it is estimated that the largest 40,000 customers (including the KICs) consume nearly 75% of the energy generated. The nearly eight million smaller customers consume around 25% of the energy generated.

Power stations and load centers are connected by more than 28 000 km of high voltage transmission lines and more than 300 000 km of distribution lines. The South African power system is an extended network with limited flexibility.
activity and focus on the restructuring of the electricity supply industry. Eskom made several submissions to government indicating the mounting concern; however, no public statements were made.

Fig. 2 provides an overview of the evolution of some key indicators of the health of the power system. Apparent is the decline in the reserve margin, the increase in the usage of the generation fleet (measured by load factor), the increase in unplanned outages fleet (UCLF) and the decreasing overall availability (EAF). At the same time, the demand was increasing and the coal stockpiles decreased. The direct correlation between the declining reserve margin and increased load factor underlines the drive to maximise use of existing generation capacity – which in turn put pressure on plant performance levels and primary energy usage (i.e. coal).

**Plant performance levels leading to the January 2008 electricity crisis**

Higher load factors resulted in a need for more regular maintenance. This situation was exacerbated by poor quality coal being used. Higher annual generation output was consequently accompanied by a reduction in overall generation plant availability, resulting in a further depletion of the daily margin between system demand and available capacity. This further increased load factors on the plant. Arresting this decline required improved maintenance to be done in shorter time periods, and controllable unplanned outages (such as maintenance slips) to be minimised.

Fig. 3 provides an indication of how the generation plant load factor has increased over this period. Fig. 4 provides the correlation between the load factor and the unplanned outage level (UCLF). Recent benchmark exercises and independent audit reports showed that for load factors of between 65 and 70%, plant performance levels were at levels similar to peers in the industry. Deterioration in plant availability however exceeded system planning parameters at the time.

**Coal stockpile levels and coal quality**

In 2000 the coal stockpile levels were above 60 days. This reduced to just over 40 days by 2005 and to 28 days in 2007. From June to December 2007 it dropped from 20 days to 15 days and to an unsustainable 11 system days at the beginning of 2008. The direct causes for this decreasing trend were as follows:

- Increased production at certain coal fired power stations
- Lower than expected coal volumes at collieries directly supplying stations
- Lower than expected coal quality resulting in thermal inefficiency and accelerated wear on the boilers
- Challenges around coal transportation logistics.

**Impact of increased rainfall on coal**

Higher than average rainfall patterns occurred from October 2007 to February 2008. In previous years when high rainfall occurred, the level of stockpiles allowed access to dryer coal underneath the wet coal. Also, excess capacity allowed output reductions due to wet coal handling problems and combustion problems to be compensated by plant that was available in reserve.

**Use of emergency resources and level of power system risks**

Some of the emergency reserves available to the system operator are, EL1 (Emergency Level 1) capability of generators and interruptible load contracts. EL1 capacity is the ability of some of the generators in the Eskom fleet to provide power above their maximum capacity rating for a short period of time. This does cause mechanical strain leading to premature aging of plant over time if not managed properly. The interruptible load (IL) contracts are mainly with the aluminium smelters and allow a shutdown of their pot-lines for agreed time periods.

Fig. 5 illustrates an increasing trend in the use of these resources over the past nine years leading to the January 2008 electricity crisis. It was evident that the steep increase in the use of these resources from 2004 was the first clear indication of the impact of a low reserve margin, together with the difficulty in meeting evening peak demand in winter. In 2007, the use of both resources was becoming unsustainable and could not continue at an increasing rate.

Table 1 summarises the number of days that load was shed, the level of load shedding that occurred in this period (MW), the impact in terms of energy not supplied (MWh), and the level of usage of the open cycle gas turbines (OCGTs). The OCGTs are typically designed to run at a 6% load.
factor. 30 GWh is similar to not supplying the Cape Peninsula for the entire day.

What did the system operator do to contain the situation?

In response to concerns about the reducing coal stockpile levels prior to January 2008, attempts were made by the system operator to reduce generation output levels at vulnerable power stations to protect the stockpiles but the high level of unplanned outages did not provide enough opportunity to do this. From 9 January 2008, load shedding had to be initiated in addition to the use of the emergency reserves normally available to maintain stability of the power system. Load shedding continued on a daily basis for just over two weeks, whilst heavy rains persisted for this period.

In the early hours of 24 January 2008, the forecasted level of load shedding was estimated to be 4000 MW and predicted to possibly get worse. Under such conditions, the first line of defense required to prevent system collapse in the event of a sudden loss of generation, would have been the activation of under-frequency load shedding scheme. At the predicted level of load shedding, about a third of the scheme would have been compromised. If more generation units were to trip, the decline in frequency would have been difficult to arrest and could have lead to cascading tripping of other generation plant and finally system collapse.

The prognosis for the improvement of plant performance and coal stockpile levels was pessimistic. Rain was predicted for the next three to four days over the stockpiles, mining sites and transport routes. The generation fraternity could not see any relief to build dry stockpiles and to improve plant performance at that point. They indicated that they needed at least one week of dry weather to do this. The staff at certain power stations had been working around the clock for weeks and in some cases manually shoveling coal into mills to sustain combustion processes. Consequently there was general concern about the endurance of the staff and the possibilities of serious errors leading to damage of equipment and safety incidents.

The final concern was the possibility that the two black-start facilities in the country were being compromised due to the low level of primary energy resources. The first facility is a hydro power station. The dam levels were consistently at the lower limits due to the high usage of the scheme. This would restrict the number of attempts one would have for black-start purposes. The second facility is at a coal fired power station where a gas turbine would start up one of the coal fired units. The low and wet stockpile at the power station was a major concern that in the event of initiating the black start facility there would have been challenges with coal for unit start ups.

The system operator was concerned that the power system was drifting into total failure and that it was necessary to declare an emergency and warn customers to make their processes safe. A communication was then sent to the KICs to make their processes safe. This decision was subsequently deemed to be prudent by the National Energy Regulator of South Africa (Nersa) and was also supported by the parliamentary portfolio committee on Public Enterprises.
Government’s national energy response and Eskom’s road to recovery

Immediately after the declaration of the national emergency on 25 January 2008, a National Response Plan was launched focusing on demand side initiatives, sectoral interventions (government buildings and freight rail) and supply side initiatives. Eskom launched an internal recovery programme in line with this plan but also included initiatives to deal with identified weaknesses. This plan was focused on the security of supply situation.

A social dialogue was also convened in May 2008 to discuss the cost of supply precipitated by the requested tariff increase. This was done through Nedlac. Some consensus was reached on the need for a higher level of price increases but for it to be smoothed over several years. Nersa also publicly stated its view on a possible five year price path. Since then government has indicated its commitment to some level of financial support for Eskom as well as some level of guarantees for Eskom debt.

Lessons learnt
The key lessons may be categorised in the following four areas:
- Causes of the electricity emergency
- Societal resilience
- Reputation
- Systemic lessons.

Causes of the electricity emergency
Root causes of the electricity emergency can be identified as follows:
- The policy and regulatory framework of the country did not attract new independent generators and in conjunction with a restriction on Eskom to build new generation plant resulted in a deficit in supply that was built up over the years
- The generation planning assumptions were optimistic in terms of long-term generation performance availability and high plant load factors
- The economic and electricity growth projections were underestimated
- Decision-making processes around new generation capacity were not aligned and resulted in timely decisions not being taken

Direct causes of the electricity emergency can be identified as follows:
- The increase in generation plant load factor was not supported by the correct levels of maintenance required for such an operational regime
- Fundamental power system vulnerability due to inadequate reserve margins resulted in a limited capacity to withstand systemic shocks
- This vulnerability was exacerbated by low coal stockpile levels. The immediate coal related problems were due to poor quality, lower than expected volumes, and logistic constraints which accelerated the generation plant performance decline
- The final condition that led to the power system emergency declaration in January 2008 was the heavy rainfall which made the handling of coal a near impossibility at power stations
- The long term primary energy contracts were structured for a 60% generation plant load factor and the subsequent inability to support the increased plant load factor lead to restricted coal availability.

Societal resilience
Societal resilience encompasses the challenges that society faced in dealing with the electricity crisis. At a residential and commercial level, consumers experienced difficulty in coping with the absence of certainty in energy supply:
- People had great difficulty initially in adjusting their lifestyles and dealing with security issues
- Businesses had difficulty in adjusting to the random nature of the interruptions
- Portable emergency lighting was not prevalent and sales picked up of devices to provide this
- There was a significant pick up in uninterruptible power supply and diesel generator sales.

At the local government level, there was difficulty in ensuring that the essential services of the municipalities continued effectively:
- The traffic systems did not cope well but over time, points people were deployed to direct traffic, based on load shedding schedules
- The essential water and sewage services were interrupted
- There was difficulty in isolating essential services such as health facilities from rotating load shedding.

At the large industrial and mining customer level, the challenge was the “binary” nature of their production processes (“on” or “off”) and the importance of maintaining human safety levels:
- The deep level mines stopped production for five days until they had adequate electrical supplies to guarantee the safety of their people, plant and maintain some level of production
- Certain ferrous smelters shut down while non-ferrous smelters continued production
- Many industries had to re-evaluate their production processes to cope with the request for a 10% reduction in energy supply. They are still in the process of adjusting to this paradigm of energy shortage but the outlook is positive

Reputation of Eskom
Eskom’s reputation experienced a major setback with the onset of the electricity emergency of January 2008. This had to be managed through intensive communication and stakeholder engagement. This process continues.

Key systemic lessons learnt
Key systemic lessons learnt are as follows:
- One national security of supply plan is required for the country, with an appropriate funding plan associated with it, is needed
- A power system needs adequate buffers on many fronts to deal with the unknown, with systemic shocks and to contain impact and allow for rapid recovery
- Sustainable plant performance requires appropriate load factors and associated maintenance regimes
- Intensive work done with 138 largest customers in the previous 4 years on energy constraints assisted in obtaining immediate support for a call to reduce energy
- The system operator had the mandate ensuring short-term system security and was supported throughout to make the necessary calls to prevent system collapse. This position was since confirmed as prudent by both Nersa and Parliament’s Public Enterprises portfolio committee.

Prognosis for the medium term
It is anticipated that in the medium term the management of demand through energy efficiency, demand side management and the power conservation programme are the key levers to ensure power system stability. For the longer term, the successful execution of the currently approved Eskom build programme and further deliberation
for prompt decisions on the possible third base load power station as a country decision is critical. This is obviously being done in line with the economic downturn and future growth trajectories.

Building system and societal resilience

The electricity crisis of 2008 and the fact that it will take several years to regain a healthy reserve margin, have highlighted the need to target a range of measures to increase the resilience of the system and society as a whole.

In addition to some of the key initiatives currently underway to manage the reserve margin (i.e. increasing generation capacity, increasing generation availability, and demand management interventions), Fig. 7 illustrates some of the key areas that Eskom is focusing on to build resilience. Resilience here is defined as the ability to:

- Identify, anticipate, and adapt rapidly to vulnerabilities arising from changes in the internal and external environment
- Operate at elevated levels of stress without failure for extended periods of time
- Respond to a shock by containing the impact (severity/duration) of the event
- Recover quickly in a coordinated manner, and
- Implement learning from near-misses and recovery experiences

Some of the key initiatives are:

- Reviewing and increasing buffers (for example, increased coal stockpiles, the establishment of special strategic “dry-coal” stockpiles, increased system margins, and strategic spares)
- Significantly increasing situational awareness and the ability of the organisation to visualise operational trends and emerging risks at the frontlines of the organisation
- The establishment of regional reliability teams, which aim at developing a consolidated view of supply risks and societal resilience in each of the Eskom supply regions. This focused risk management (across all Eskom divisions operating in the region) significantly increases the ability to identify and respond to current and emerging vulnerabilities
- The development of a national code of practice which addresses: (i) load shedding and curtailment under system emergencies, (ii) restoration of supply after a regional or national blackout, (iii) the identification and treatment of critical loads, and (iv) essential load requirements of customers
- Updating and publishing of load shedding schedules, and engagement with metro’s, municipalities, and end-customers on essential load requirements during a system emergency
- Engagement with various government and industry sectors to develop an integrated emergency preparedness plan in the event of a regional or national blackout
- Undertaking emergency simulations and exercises – both at a technical level and multistakeholder exercises (e.g. communication with and interaction with stakeholders)

Conclusion

South Africa has to add up to 40 GW of additional generation capacity over the next 20 to 25 years to the existing asset base while meeting financial sustainability and climate change imperatives. An added dimension is the impact of the economic slowdown on planning and executing of projects to ensure the correct levels of infrastructure to match supply and demand together with the optimum reserve margin levels for power system security.

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