The 2025 Iberian Blackout and Its Lessons for South Africa: RE Integration and Its Impact on Balancing and Ancillary Services

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The Iberian Blackout suffered by Spain and Portugal, that occurred on 28 April 2025 is well documented as one of the most significant power grid failures in modern European history. This unprecedented event offers critical insights for South Africa and other electricity grids transitioning to higher renewable energy penetration. Although renewable energy sources cannot be pinned as the direct cause, the incident highlighted the complexities of integrating variable renewable energy into power systems and underscored the vital need for enhanced grid security and resilience. All nations pursuing a future renewable energy rich electricity supply sector should use this as a learning opportunity to ensure that the appropriate measures are implemented.

The Iberian Peninsula is a leader in renewable energy adoption in Europe, having made remarkable progress in transitioning to cleaner energy sources. Portugal leads the European Union in renewable energy integration, achieving an impressive average renewable energy penetration of over 85% in the first half of 2025, with solar photovoltaic (PV) and wind energy accounting for 37% of its energy mix. Spain follows closely, with an average renewable energy penetration of 60% annually in the first quarter of 2025, where solar PV and wind energy contributed 39% to the total energy supply.

These advancements highlight the peninsula's commitment to sustainable energy and serve as a model for other regions aiming to increase renewable energy integration while maintaining grid stability.

Lead-up and Initial Observations of the Iberian Blackout

The recently released final technical reports provide a comprehensive analysis of the event, drawing on 300 GB of data meticulously examined by multiple committees comprising key stakeholders from the operators, state authorities, and field experts and sheds light on some of the possible causes, by analysing the state of the broader Portugal, Spain and France grids and their interconnectors, initiating events, grid protocol actions taken to mitigate the initiating events, and the events that followed. While the debate is ongoing, it is still useful to examine the events and some of the findings to draw parallels with South African system to learn from this unfortunate incident.

Without going into the highly complex study of the grid, it is important to describe the grid situation just prior to the collapse, some of the anomalies and what initiated the collapse to understand why the system components could not ride through the events. The detail technical analysis is far beyond the scope of this article so what follows is by no means an attempt to give a technical analysis but rather to share some background to appreciate the learnings.

Grid Status On the morning of 28 April 2025[1]

- The Spanish system is endowed with a large amount of decentralised urban inverter-based generation
- This leads to the internal Spanish transmission being very lightly loaded, the same as the north and south interconnectors between Spain and France
- Majority of the nighttime load provided by single shaft combined cycle gas turbines were taken off load as the solar PV capacity ramped
- A minimum required level of gas and nuclear was retained on the system to provide stability, however, the gas units were maintained at minimum load levels dictated by the machines minimum generation specifications
- This meant that the system was heavily biased towards renewable energy generation sources

Important Points to Ponder

[1] The system is very complex; we thought that a very high-level account of only a few parameters would assist with understanding some of the complexities that the system operators faced.

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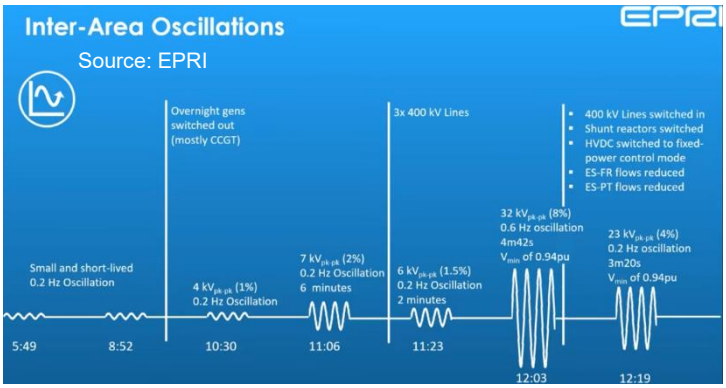
- At the time in Spain, inverter-based generation was forced to operate in fixed power factor mode i.e. they were not allowed by regulation to provide voltage support (this has now been changed, after the collapse in April)
- Thermal units operating at or near minimum loads are not very stable operationally and have reduced capability to respond to dampening
- Most of the gas plant in Spain are single shaft units, which meant that the units can only synchronise when the steam turbine has reached a point to be put on load, the shortest declared start up time at that point was 1.5 hours
- Long lightly loaded interconnectors that behave as capacitors under certain load conditions due to a complicated electrical phenomenon called the Ferranti effect in which the voltage at the receiving end of a long AC transmission line is higher than at the sending end, particularly under light-load or no-load conditions
- Nuclear units on load did not have power system stabilisers
- There was a lack of autonomous response to oscillation and overvoltage conditions; operator intervention was required

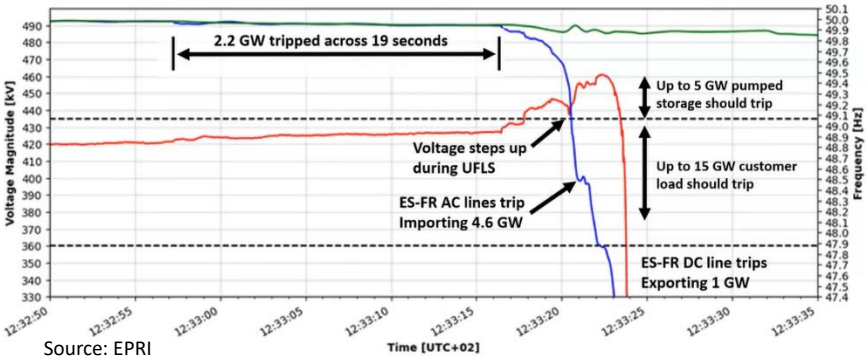
Incidents and interventions

When the first oscillations were experienced, operators responded by followed grid protocols. The following are some of the barriers that they faced.



- Several oscillations were experienced, with the consensus opinion from the investigations that none were of such a magnitude or duration that the thresholds were compromised; units on the system should have been able to ride through the incident
- Switched on transmission lines that were previously switched off
- Open cycle gas turbines recalled about 30 minutes prior to the collapse but as we know they fasted declared startup was 1.5 hours – they were still offline when the system collapsed
- Shunt reactors switched off to increase voltage and then just before the collapse, switched on again to try to control the increase in voltage
- At 12:32 Central European Summer Time (CEST) three clusters of generators in Spain totalling 2.2 GW was lost 20 seconds, taking a large part of the mega VARs on the system with it, triggering the voltage to increase (capacity effect when lines are lightly loaded) and the frequency to plunge
- Frequency continued to drop, at which point pumped hydro schemes and other large loads should have separated from the grid to prevent frequency and voltage drops but this did not happen, and the system collapsed
- The French interconnectors tripped to protect the French grid

The chart below shows the voltage and frequency trace leading up to the event. Frequency and voltage changes with each cluster of trips can be seen below. At this point the system defence scheme should have kicked in.

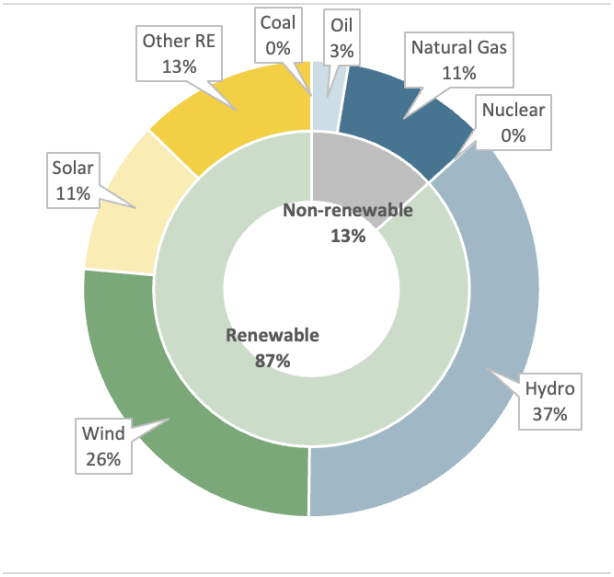


Source: EPRI

Expert opinion is that the clusters of units should not have tripped as the voltage threshold in the 400kV system was not breached; the synchronous generators online at the time should have been able to ride through the oscillations. Although no data is available on the actual cause of the clusters of units tripping, it is speculated and needs further investigation, that they tripped on overvoltage protection, or mis-operation, or incorrect operating setpoints, or some other reason.

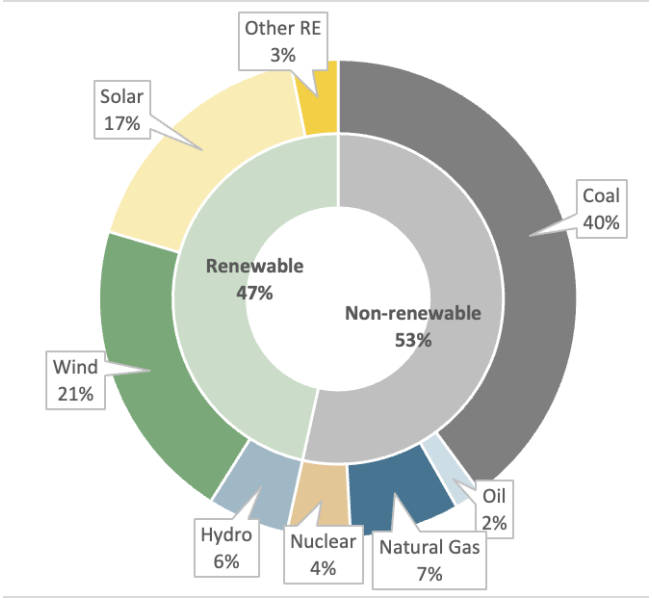
What Parallels can be Drawn with The South African Electricity Supply Sector

Generation Mix in Portugal
January to June 2025



Source: Apren

Generation Mix in South Africa
estimate for 2035



Source: Cresco based on IRP2024

South Africa's energy sector is experiencing a profound transformation, driven by a strategic pivot toward renewable energy sources as outlined in the Draft Integrated Resource Plan 2024 (IRP 2024). The nation has made significant strides, achieving over 10 GW of installed solar and wind capacity by 2024. Projections from Cresco's proprietary South African Energy Balance model indicate that total installed capacity will expand to approximately 55 GW by 2035, with solar and wind energy contributing nearly 21 GW, or about 38% of the country's total capacity mix. This ambitious growth underscores South Africa's dedication to building a sustainable, resilient, and diversified energy landscape.

The management and balancing of power grids dominated by synchronous generators, such as those powered by fossil fuels and nuclear energy, are well understood and backed by decades of operational experience. As South Africa shifts toward a power system increasingly powered by renewable energy sources, particularly inverter-based resources (IBRs) like solar and wind, its grid dynamics will increasingly mirror those of the Iberian Peninsula. Effective grid balancing extends beyond matching real-time supply and demand. It requires careful consideration of the generation mix, load characteristics and geographic distribution, system configuration, and

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the growing influence of regional interconnector status. To extract actionable insights from the Iberian Blackout, a detailed comparison of the similarities and differences between South Africa's and the Iberian Peninsula's energy systems is crucial. A preliminary, non-exhaustive analysis highlights key factors essential for maintaining grid stability and resilience throughout this transition.

The challenges of grid management become critical when load and generation forecasting fail, threatening system stability. The primary goal must be to maintain balance, resilience and stability within the power system. To achieve this, comprehensive education and awareness campaigns are essential to empower all consumers—both energy-intensive industries and small-scale households—with the knowledge and tools to act as responsible participants in the energy ecosystem. Without such engagement, even the most advanced technical solutions and protocols will fall short.

Equally important is the responsibility of all system participants, including Eskom, private generators, the national grid, the system operator, and consumers to ensure that all equipment is properly maintained. This is critical to minimizing unplanned outages, while correctly configured operating setpoints ensure appropriate responses during system events. By fostering accountability across all stakeholders and prioritizing proactive measures, South Africa can strengthen its grid reliability and support a sustainable energy future.

On the bright side of things, it is noteworthy that the Iberian grid restoration process took only 11 hours. This is a remarkable achievement considering the size and complexity of the Iberian grid; however, it was possible because of Spain's location and the ability to rely on its neighbours as the restoration process began with the re-energization of a France-Spain transmission interconnector and involved the coordinated efforts of multiple grid operators including those in Morocco. Now South Africa, due to its location and the lack of neighbours with strong grids that can be relied on in case of a national blackout will not be able to restore any grid collapse in such a short time. In fact, given the relative size of the South Africa grid to its neighbours, any significant grid event in South Africa could result in the entire regional grid collapse depending on the transfer levels at the time of any incident. We guess that given South Africa's position, it will take substantially longer for the grid to be restored if a collapse is to take place.

The table below highlight some of the lessons that can be learnt to prevent such an occurrence in South Africa.

Iberian Peninsula	South Africa – 2035	Comment
High level of Penetration of IBR	Still relatively low – 38% target	South Africa has the highest penetration in the SAPP region and is still a long way from reaching levels seen in Iberia
Urban based IBR	Utility scale in the provinces	Generators are near loads, previously heavily loaded transmission lines under utilised
Lightly loaded high voltage transmissions lines	Transmission system not geared up for location of wind and solar sources	Transmission system will remain under strain for a long time; new highly loaded lines will be in place to transmit generation to load locations
Highly interconnect Western European system	Almost isolated dominated by interconnections to SAPP countries	Limited number off and limited transfer capacity
Regulatory environmental did not recognise the important part that IBR could play in system damping	This could also be an investment incentive for potential IPPs as an additional income stream	Regulation Issue: to be examined to ensure that South Africa is ready for dominance by renewable energy
Single shaft gas generation fleet	Gas fleet consisting mainly of OCGT used as peaking plants	SA grid will benefit from fast startup times if faced with grid stability issues
The inverter-based generation fleet ability to provide voltage and frequency support not known – suspect that being first adopters, could still be old technology	South Africa's fleet relatively new could leapfrog technology barriers – should be included in SANS, NRS and requirements as well	Technical Standards issue; technical standards to be reviewed to ensure proper mechanism in place to ride out excursions
Although not explicit in the findings, it seems that some generators and some loads did not closely follow protocols for dealing with ride through of system excursions	RSA has similar protocols which are managed by the system operator and enforced rigorously	South Africa system operator protocols to be reviewed and updated where necessary to mitigate the risks shown by the Iberian Peninsula experience
The reports do not mention ancillary market participation and incentives	An important facet of South Africa's proposed multi market model is the buying and selling of ancillary services	The market to be designed to send strong signals to incentivise investors in generation facilities to consider participating in ancillary services market
Although not directly responsible for the outage, some comments were targeted at transformer tap changer operations	Most of the coal fleet is fitted with on-load tap changers. These mechanism needs to be kept in optimal operating condition.	This is not the preferred option to respond to voltage fluctuations but is a useful tool when required
The Iberian case did not mention BESS as an active participant in providing system damping. The restriction in Spain for IBR to participate has been lifted so BESS like other IBR options would have played an important role	Implementation of BESS is speeding up and manufacturing technology advancements makes BESS commercially viable	BESS will play an important role in providing system stability options due to its almost instant deployment
The concept of balance responsible party is not mentioned	This useful concept is entrenched in the South Africa context	Now used as a stick. To get better returns from market participants, an incentive type scheme might be more appropriate

Revisit the conversations	Date
Optimise Resilience of Supply (Grid tied and Off Grid) presentation slide	14 August 2025
Behind the Meter (BTM) Energy Solutions	5 June 2025
SA Carbon Market – Working Through the Noise – What is Reality / Real Impact	20 March 2025
Practical working session to calculate Eskom Retail Tariff impacts using the Eskom tariff calculator	20 February 2025
Mitigating Energy Forecasting Inconsistencies	14 November 2024
Logistic and Transport Infrastructure	29 October 2024
The Future of Solar in South Africa CRESCO	10 October 2024
Security of Supply Webinar – Cresco Approach for Clients	19 July 2024
Navigating Curtailment Challenges	12 June 2024
Navigating the SA Gas Landscape: Assessing Risks and Exploring Private Sector Opportunities	31 January 2024
The New Approach to the Market and How Changes to the Eskom Tariffs will Impact "Financial Returns"	31 January 2024
Logistics Opportunities / Blockages	31 January 2024

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