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Challenges in setting resilience measures and metrics

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As we know, power systems are subject to disturbances. These give rise to phenomena across a wide range of the temporal scale, from challenges raised by replacement of synchronous generation by inverter based resources – triggering sub-synchronous oscillations or affecting the operation of protection – to the need to find sources of energy that can fill the gaps left during 'wind droughts' lasting many days and ramp sufficiently quickly to balance changes in net demand. We also need to ensure that network infrastructure is resilient against different weather patterns caused by climate change and can satisfy energy users' increased dependency on electricity.

Those considerations of sources of energy remind us that resilient supply of electricity is not only about networks. With the variability of weather-dependent renewables, we need the right mix of sources or sinks of electrical energy, having the following characteristics:

1. Flexibility: able to adjust production or consumption quickly and at short notice. (How quick is quick?)
2. Schedulability: we can, with high confidence, schedule power to be produced at any given time on a given day in the future.
3. Persistence: increase in production or decrease in consumption can be sustained for a period of time.

We also need to consider location and the capability to deliver reactive power and short circuit current, and whether the resource might be vulnerable to 'common mode' or 'compound' effects or interactions that have a major, adverse impact on the system.

As can be seen from the Table, none of the envisaged energy or 'flexible' energy resources have a perfect mix of characteristics.

Source or sink of energy	Flexible?	Schedulable?	Persistent?
Wind	If it's windy, yes	No	Sometimes
Nuclear	No, not really	Yes, for the most part	Yes
CCGT burning blue or green H_2	Yes	Yes, for the most part	Yes, if fuel is available
CCGT burning CH_4, with CCS	Perhaps, but at a cost	Yes, for the most part	Yes, if fuel is available
Batteries	Yes	Yes, for the most part	To an extent, if power is rationed
Pumped hydro	Yes	Yes, for the most part	Only if power is rationed
Flexible demand	Yes	Depends what it is	Not beyond an hour or two?
Interconnection	Yes	Yes, for the most part	Yes, depending on conditions at the far end

Resilience is not only about physical systems. Many – perhaps even the majority – of the major power system disturbances around the world in which large regions or whole countries have been blacked-out have involved failure of human action on some way, whether through commission or omission. In many of these events, quite simple disturbances that should not normally have a significant impact become 'extreme events' through failure to correct the immediate impact. If we are to evaluate the likelihood of a power system suffering a collapse, we need to take account of, in particular, action by operators. A study in the UK attempted to do that a few years ago, adopting methods from management science and conducting a Structured Expert Judgment exercise, reported in paper C1-112 from the 48th CIGRE Session in 2020.

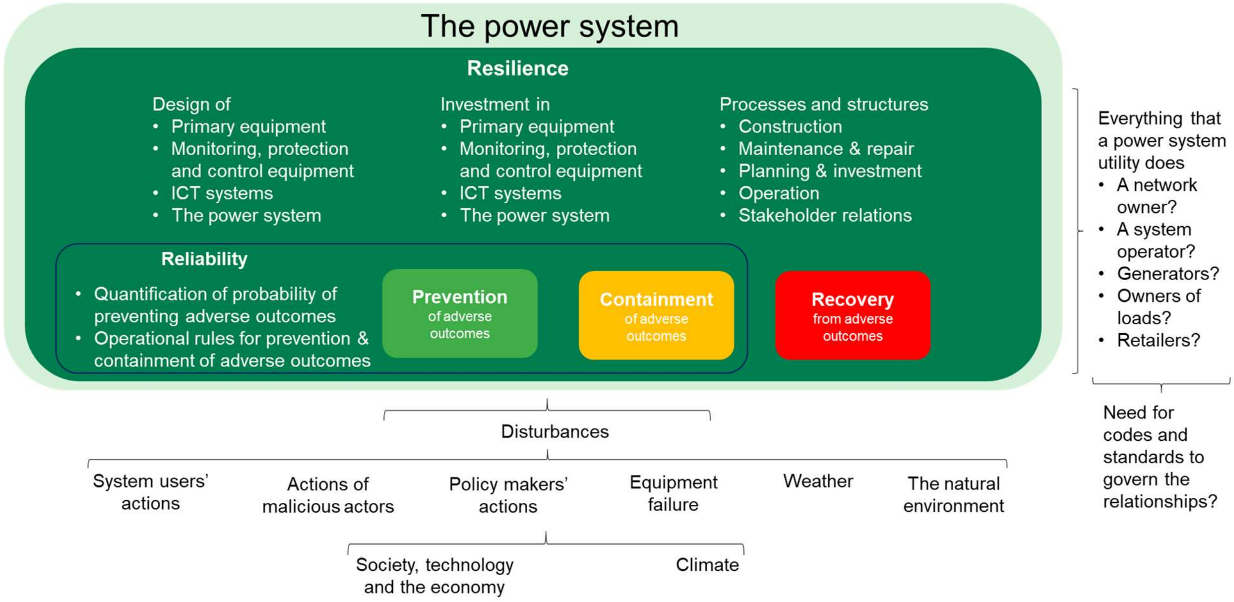
Resilience of the service electricity companies provide and society's ability to survive and recover from interruptions is not only about engineering. For example, the British regulator, Ofgem conducted an investigation into distribution network operators' performance during and after Storm Arwen that hit the UK in early December 2021 and found weaknesses in planning and preparation, communication and advice, and payment of compensation.

As was noted by CIGRE WG C1.17 in Technical Brochure 433 from 2010, resilience of electricity supply encompasses a wide range of elements adding up to the prevention and containment of interruptions and recovery from them. The measures to achieve that include defence plans, special protection schemes, restoration plans, security standards, and planning, maintenance and design policies. Answers need to be provided to questions such as the following. Is there enough generation to meet demand? Can it respond quickly enough? Is there enough network capacity to get power from generators to demand? Can the system perform a black start? How does the system respond to unplanned changes, e.g. faults? Are generation and network responses (protection, reactive compensation, UFLS, …) coordinated well? What is the frequency and size of supply interruptions and how quickly is supply restored? What happens to energy users in the meantime, in particular essential societal services and electricity supplies to vulnerable individuals?

A framework for understanding the many different disturbances that can affect a power system and the different interventions that can be taken by different actors is set out in the figure below. A particular challenge lies in justifying the cost of particular interventions, something that regulators often want to see relative to the probabilities of different impacts arising. To quantify that is especially difficult in the context of rare 'common mode', 'compound' or correlated events, such as type faults on a large part of the generation fleet, adverse weather such as wind lulls, storms, droughts or forest fires, or geopolitical disturbances to global energy markets.

As we transition sources of electricity, the ways we use power, and face changes to the climate, are we, as a sector, well prepared? How do we identify what new interventions are required? In particular:

- Are infrastructure standards and guidance adequate against changing climate and dependency on electricity? (Climate change means that history may not be a good indicator of future risk).
- How can we quantify reduction in the impact of rare compound/common mode/correlated events and justify investment?
    - Where are quantifications used now? What are the key weaknesses in those analyses? Where is quantified analysis not available?
    - Given limits to knowledge (data and situational awareness), complexity and inherent uncertainty, what is realistically possible?
- Where should monitoring and data gathering be prioritised?
- Do we need outcome-focused resilience standards to set public expectations on restoration times during widespread power disruptions, and guide investment (both inside and outside the power sector)?


The power system
Resilience
Design of
Primary equipment
Monitoring, protection and control equipment
ICT systems
The power system
Investment in
Primary equipment
Monitoring, protection and control equipment
ICT systems
The power system
Processes and structures
Construction
Maintenance & repair
Planning & investment
Operation
Stakeholder relations
Reliability
Quantification of probability of preventing adverse outcomes
Operational rules for prevention & containment of adverse outcomes
Prevention of adverse outcomes
Containment of adverse outcomes
Recovery from adverse outcomes
Everything that a power system utility does
A network owner?
A system operator?
Generators?
Owners of loads?
Retailers?
Need for codes and standards to govern the relationships?
Disturbances
System users' actions
Actions of malicious actors
Policy makers' actions
Equipment failure
Weather
The natural environment
Society, technology and the economy
Climate