International perspectives on electricity system resilience

Matthew Wittenstein

Tokyo, Japan, December 19, 2018

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Putting outage length in context: transmission outages in the US

Number and length of transmission-level outages > 200 MW, US, 2017, plus average for all outages

Utility	Type of disturbance	Loss (MW)	# of customers	Recovery time (hours)
PSC New Mexico	Transmission interruption	396	149 223	3.9
PG&E	Severe weather	254	169 250	131.4
Southern Company	Severe weather	857	257 000	13.3
Southern Company	Severe weather	290	86 330	9.0
Duke Energy Carolinas	Severe weather	240	74 698	1.0
Southern Company	Severe weather	200	60 377	17.0
LA DWP	Transmission interruption	645	176 867	13.1
Duke Energy Florida	Severe weather	4 500	1 000 000	70.4
SC Electric and Gas	Severe weather	687	154 832	13.1
Duke Energy Carolinas	Severe weather	365	265 729	40.0
Duke Energy Carolinas	Severe weather	440	151 144	24.5
Southern Company	Severe weather	865	301 872	58.8
Average (including outages < 200 MW)		**487**	**153 375**	**40.8**

Note: List excludes outages where number of customers affected zero or unknown or loss is less than 200 MW. Average value includes outages not listed in table. Source: EIA Electric Power Monthly

The Hokkaido blackout recovery time of 45 hours is not out of line with average recovery times in the U.S.

Another view on outages: SAIDI and SAIFI in OECD economies

Country	Total duration and frequency of outages per year (0-3)*	System average interruption duration index (SAIDI)**	System average interruption frequency index (SAIFI)
Australia	1	4.2	8.2
Austria	2	1.2	0.6
Belgium	3	0.7	0.6
Canada	2	0.9	1.3
France	3	0.2	0.1
Germany	3	0.2	0.2
Japan (Osaka)	**3**	**0.0**	**0.0**
Japan (Tokyo)	**3**	**0.0**	**0.0**
Korea (Rep.)	3	0.1	0.0
Norway	3	0.7	0.9
OECD Average	2.7	1.3	0.9

A higher score indicates fewer outages and shorter average durations

SAIDI is in terms of hours per year: lower score = shorter outages

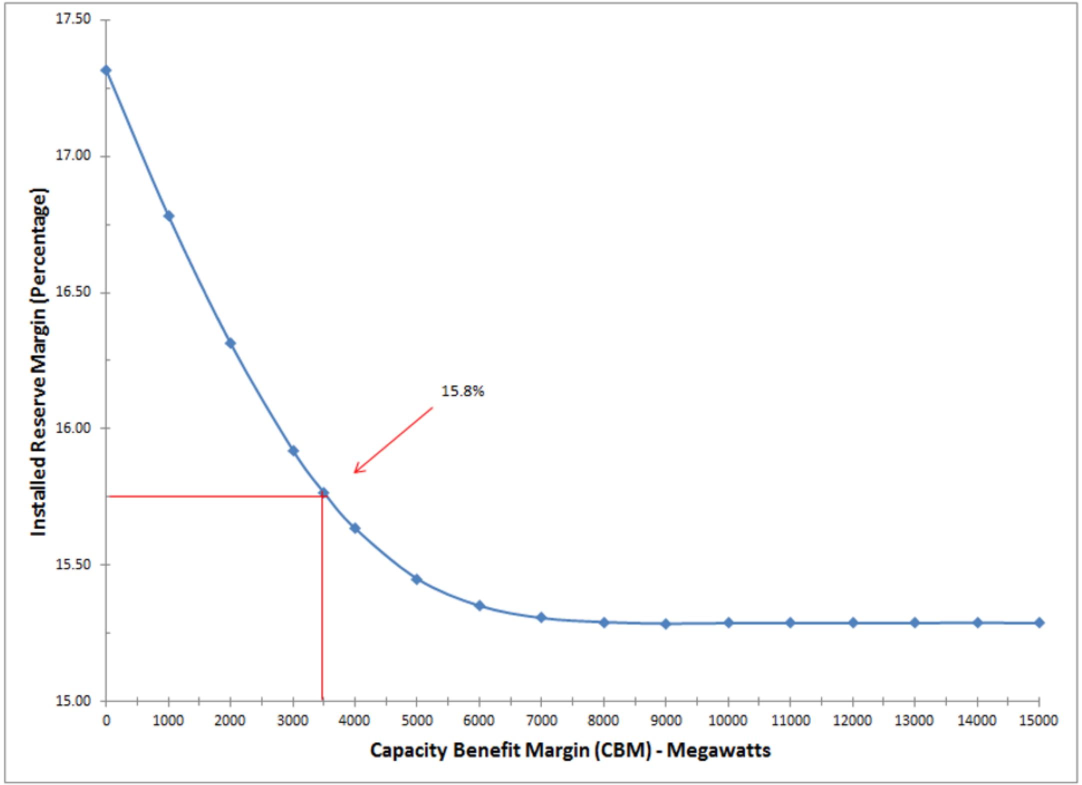
SAIFI is number of incidents per year: lower score = fewer outages

Source: World Bank Doing Business survey 2018

Reliability benefits of interconnections

- Expansion of transmission capacity between regions can also provide security benefits

- For example, if PJM were an isolated system, the reserve margin requirement would be 17.3%, versus 15.8% with interconnectors.



Security of supply: transmission infrastructure is critical

Number of incidents reported for 2017, Continental Europe

Dominant criteria	Number of incidents
Lack of reserves	13
Voltage standard violations	48
Generator	84
Transmission network	556
N-1 violations	66
Other	19
Total	**797**

Source: ENTSO-E, https://docstore.entsoe.eu/Documents/SOC%20documents/Incident_Classification_Scale/180925_ICS_report_2017.pdf

Most incidents (even where there was no load shedding) occurred at the transmission level. Capacity mechanisms target generation adequacy, and aren't a substitute for grid investment and reliability standards.

Grid codes – crucial for reliability at high shares of wind, solar

- Wind and solar PV power plants use power electronics to connect to the grid
  - Advantage: behavior during periods of system stress can be controlled via software settings; can be more versatile than conventional synchronous generators
  - Challenge: up-to-date, forward-looking, enforceable and harmonized standards needed that specify power plant behavior (grid connection code)

- IEA analysis identifies minimum capabilities in respective system integration phase
  - Capabilities are a recommended minimum
  - Forward-looking means that grid code developed today needs to be consistent with future system integration phases

- A systematic review of Japan's grid codes may be appropriate
  - In particular to ensure VRE contribution to system stability is maximized

- Stakeholder process is critical for developing good grid code
  - TSOs, power generators (especially VRE industry), independent experts, government

Grid codes – crucial for reliability at high shares of wind, solar

- Japan is moving into phase two of renewables system integration
  - In Kyushu phase three has already been reached

Grid code requirements according to system integration phase

	Always	Phase One	Phase Two	Phase Three	Phase Four
Typical technical requirements	• protection systems • power quality • frequency and voltage ranges of operation • visibility and control of large generators • communication systems for larger generators	• output reduction during high frequency events • voltage control • FRT capability for large units	• FRT capability for smaller (distributed) units • communication systems • VRE forecasting tools	• Frequency regulation • reduced output operation mode for reserve provision	• integration of general frequency and voltage control schemes • synthetic inertia • stand-alone frequency and voltage control

- *Best practice example:* development of European Network Codes by ENTSO-E / ACER
  - Binding rules, harmonized throughout Europe, but flexibility for individual TSOs to adjust
  - Adopted after problems with older grid codes (e.g. low voltage ride through, 50.2 Hertz problem)

Resource adequacy: reliability standards and capacity mechanisms

- Reliability standards
  - In the U.S., reliability standards were first introduced in 1965 following a major blackout
    - However, these standards were voluntary
  - After the 2003 blackout, reliability standards were made mandatory
    - Standards are set by the North American Electric Reliability Corporation (NERC)
  - Systems are built to withstand N-1 or “single contingency” events
    - However, a “single contingency” may be a single element or multiple elements that are physically or electrically linked – so losing two elements simultaneously may still be considered an N-1 event

- Capacity mechanisms
  - Though capacity mechanism design varies, the overall goal is the same:
    - Ensuring sufficient resources are available to meet system needs at times of peak demand and system stress
  - Design options: market-wide versus targeted
    - Market wide: appropriate for ensuring long-term resource adequacy
    - Targeted (e.g. strategic reserve): appropriate for meeting near-term (and potentially temporary) system needs

Capacity mechanisms: lessons from international experiences

- Capacity mechanisms should be thought of primarily as a tool for ensuring a <u>minimum level of capacity adequacy</u> is always met

- The reserve margin target is a critical, but <u>system specific</u>, component of capacity mechanisms that depends on:
  - Number, size, and types of generation;
  - Grid topology (e.g. radial vs mesh, grid constraints)

- For systems with high shares of VRE, <u>probalistic</u> (as opposed to deterministic) reserve margin targets are more appropriate

- Must differentiate resource <u>capacity value</u> from <u>energy value</u>
  - E.g. run-of-river hydro vs. reservoir hydro

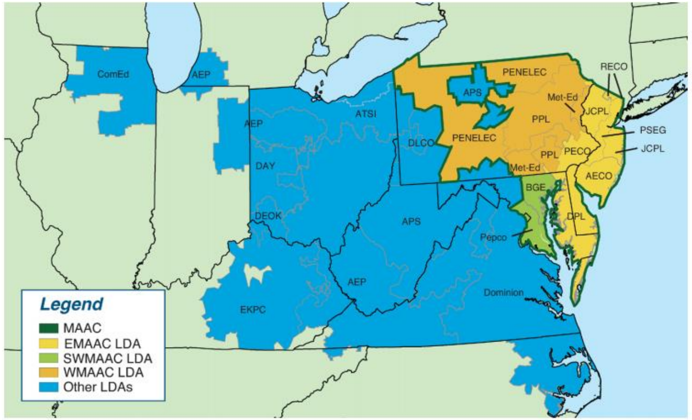
- VRE can contribute to capacity needs, but their capacity credit must be calculated appropriately

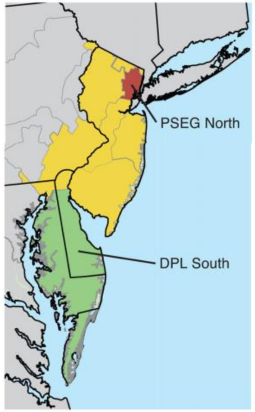
- Capacity mechanisms are not a guard against <u>systemic</u> failures
  - They are not a "catch-all" tool for ensuring operations under all possible circumstances

Capacity mechanisms: key takeaways for Japan

- Ensure reserve margin targets are system appropriate
  - If short-term gaps are envisioned, a short-term strategic reserve may be appropriate
  - However, this should be phased out when full capacity market is introduced

- Include <u>locational (e.g. zonal) pricing</u> to signal when and where investment is needed





- Allow participation of distributed and demand-side resources (renewables, storage, energy efficiency, demand response, etc.)

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