ADB TA-10533 REG · Grid Resilience through High-Level Technologies · Cambodia · Tajikistan · Uzbekistan

Short Technical Note — Regional Webinar No. 2

Voltage, Reactive Power and FACTS for High-VRE Grids

Date	5 August 2026	**Funding**	ADB - High-Level Technology Fund
Speakers	Atsumasa Sakai (ADB), Gökhan Tosun (MRC Türkiye), Mevlüt Akdeniz (MRC Türkiye), Müfit Altın (Solutions Architect), Gilles Chaspierre (Expert in Power Systems dynamics, stability and control)	**Audience**	TSOs, ministries and industry from ~10 countries; strong presence from Cambodia, Tajikistan, Uzbekistan

1. Purpose and positioning

The second webinar in the series of six under ADB TA-10533 REG addressed voltage and reactive power management in systems taking on rising shares of variable renewable energy. Its purpose was threefold: to set out how voltage, reactive power and system strength constrain secure operation; to compare the technologies that relieve those constraints and how each should be specified; and to draw lessons from recent international events. It followed the working logic applied throughout the assignment — identify what is binding, define the service, select the technology, prove the benefit — and feeds the country studies now in preparation.

THE WORKING LOGIC

Constraing	▶	Service	▶	Technology	▶	Evidence
What is actually binding? Measure it.		VARs, fault Current, damping, which one?		Which device delivers it best?		Prove it with a study and a number

2. Summary of proceedings

In an opening poll, most participants identified voltage conditions that vary across the year — low voltage at peak and high voltage at light load — as their primary operational concern.

2.1 The constraint: voltage, reactive power and system strength

- **Capability is not contribution.** A datasheet states what a device can do; an event shows what it delivers. Capability must be specified in the code, built in at manufacture, activated at commissioning and verified — PMU and WAMS records of real faults are a practical check on inverter-based plant.
- **Screen with P–V and Q–V before studying in detail.** Incremental load-flow scanning, repeated under N-1, ranks the weak buses and quantifies the reactive margin at low effort. Fixed capacitors shift the curve; dynamic devices reshape it.
- **The requirement is two-sided.** Long, lightly loaded lines produce a charging surplus overnight and a deficit at peak. A line feeding a solar plant cannot simply be de-energised at night without islanding the plant, so switched reactors are the first move — but step switching introduces voltage jumps and cannot follow intraday variation.
- **Strength alone does not prevent FIDVR.** Stalled motors draw several times rated current as reactive power and hold voltage down after the fault clears. Both fault current and fast reactive reserve are needed. Devices must be coordinated as one hierarchy by response time, with tap changers and mechanical plant last.

System	Binding condition presented	Direction indicated
Uzbekistan	Charging surplus on long western lines runs voltage high overnight; Fergana valley is reactive-short and sags at peak	Automate reactor switching; dynamic absorption where the surplus varies
Tajikistan	Long southern irrigation feeders — summer undervoltage and FIDVR; TALCO industrial load; single N-1-exposed 500 kV corridor	Inertia is not the issue; fast reactive reserve and connection-rule control modes are
Cambodia	Long corridors into one load centre, low-strength solar clusters, growing and largely invisible rooftop PV	Closest match to the Iberian conditions; system strength before the next cluster connects

2.2 The toolbox: FACTS and reactive technologies

A vendor-neutral mapping of binding constraint to service to technology was presented. The devices are complementary rather than substitutable, and the comparison below is indicative only — the requirement, not the nameplate, decides.

- Batteries provide fast reactive power as a by-product of their four-quadrant inverters, and grid-forming control is entering grid codes — but converter current and voltage limits still bind.
- Modelling sequence stated plainly: load flow and short circuit, then RMS, then EMT for STATCOM, SVC and grid-forming applications.

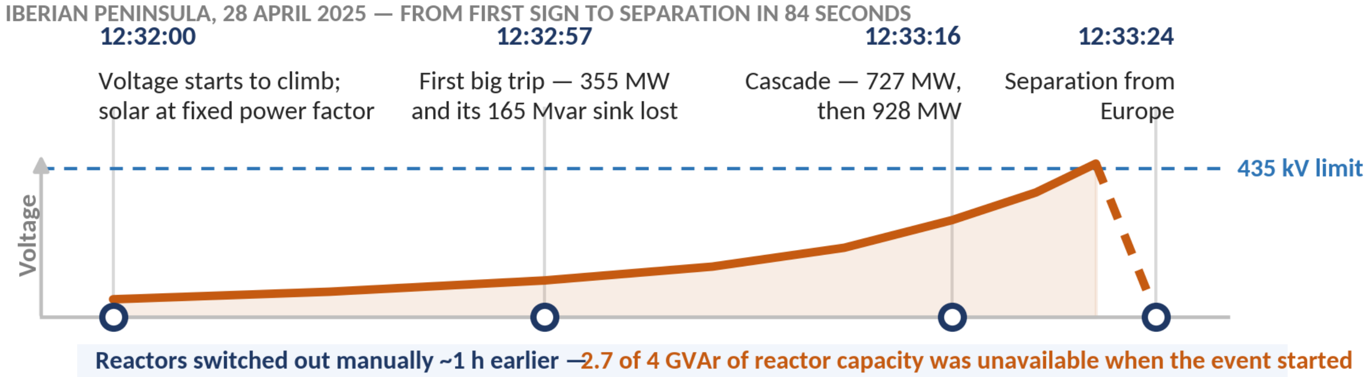
MATCHING THE CONSTRAINT TO THE TECHNOLOGY

Technology	Speed of response	Output at low voltage	Fault current & inertia	Transfer capability	Relative cost	Lead time
Shunt reactor / MCR	slow	n/a	no	no	lowest	6–18 m
Capacitor bank	slow	fades	no	no	lowest	6–12 m
SVC	20–40 ms	fades	no	partly	medium	18–30 m
STATCOM	<1 cycle	holds	no	partly	high	18–30 m
Grid-forming (E-)STATCOM	<1 cycle	holds	partly	partly	high	18–30 m
Synchronous condenser	~150 ms	holds	yes	no	high	24–36 m
Series compensation / PST	static	n/a	no	yes	low per MW	24–36 m
HTLS / DLR	n/a	n/a	no	yes	very low	6–18 m
Online V-stability monitoring	real-time	n/a	no	yes	lowest	6–12 m

2.3 Stability in weak, inverter-dominated grids

- **Short-circuit ratio is losing accuracy.** It worked because high fault current implied nearby synchronous machines. A grid-forming converter delivers voltage stiffness with very little fault current, so SCR now flags areas as weak that are not, and triggers unnecessary dynamic studies. Additional screening indicators are needed.
- **Grid-following versus grid-forming.** Grid-following plant measures terminal voltage through a PLL and injects current; in a weak grid this closes a positive feedback loop and produces growing oscillations. Grid-forming plant imposes its own voltage reference and stays stable at low strength. It is mature mainly for batteries; mandating or incentivising it through the national grid code is what causes developers to supply it. Cambodia's Pursat battery is already grid-forming.
- **RMS is no longer sufficient.** EMT is required where strength is low or converters cluster, using vendor-specific models validated against hardware-in-the-loop or on-site tests and, where available, replayed event recordings.

2.4 Case studies



Iberian Peninsula, 28 April 2025. Presented from the ENTSO-E Expert Panel final report (March 2026). A voltage event: frequency moved only once generation had already been lost. The morning was clear-sky and lightly loaded with few machines online; oscillations at 0.63 Hz and then 0.2 Hz led the operator to reduce export and manually switch out shunt reactors, removing reactive absorption about an hour before it was needed.

- **Root cause 1 — voltage control:** manual switching too slow for an 84-second event; solar in fixed power factor mode, which does not respond to voltage and reduced absorption further when active power was curtailed; synchronous machines below their Mvar targets; no dynamic requirement or compliance check.
- **Root cause 2 — unusable capacity:** capacity that cannot be activated in time is not capacity. ENTSO-E's remedy is automation and flexible devices.
- **Root cause 3 — protection margins:** the grid code permits transient operation to 435 kV while generators disconnect at 435 kV. Either the settings or the permitted voltage must change.

West Murray Zone, Australia. Sustained oscillations appeared over roughly seven months whenever one line was lost, raising impedance at a cluster of five large grid-following solar plants. EMT identified interacting controls; the remedy was vendor retuning, not hardware. Output was halved in the interim, at a cost running to millions of euros — plant tuned for the grid of ten years ago can fall outside its design envelope as the system weakens.

3. Principal conclusions

- Capability is not contribution — Spain held the capacity it needed; control mode, activation speed and protection settings prevented its use.
- The requirement is variable, not fixed: absorb at light load, supply at peak. Fixed plant covers half the duty cycle.
- Measure before procuring — rank the weak buses, run Q–V under N-1, size the support, verify the recovery.
- Do not rely on a single indicator; use EMT with validated vendor models where converters cluster.
- Three systems, three requirements — a single template does not fit Uzbekistan, Tajikistan and Cambodia.
- The near-free actions come first: verify control modes, review overvoltage and ride-through settings, and time an actual reactor switching operation.

4. Questions and answers

Q1. What is incremental change analysis?

The method underlying P–V and Q–V studies. Instead of a single steady-state snapshot, loading (P–V) or reactive injection at a bus (Q–V) is raised in small steps until the stability limit is reached, giving the remaining margin and the maximum transfer. Repeating it under N-1 and at varying renewable output ranks the weakest buses and lets the benefit of a device be assessed.

Q2. How does a grid-forming inverter operate in STATCOM mode?

It gives fast dynamic reactive support while behaving as a controlled voltage source rather than following the grid. Even with no active power exchange it regulates voltage and improves system strength in weak grids. Unlike a conventional STATCOM it establishes the local voltage reference itself, though its fault current capability stays limited relative to a synchronous condenser.

Q3. Are synchronous condensers, STATCOMs and SVCs interchangeable, or does the synchronous condenser serve a different purpose?

Not fully. All three give dynamic reactive support, but their roles differ. STATCOMs regulate fastest and hold reactive current at low voltage, which suits weak grids and FIDVR-prone areas. SVCs give economical large-scale support, but output falls with voltage. Synchronous condensers add real inertia, fault current and system strength — services power electronics cannot replicate. The choice follows the constraint, not the technology.

Q4. In a high-VRE system with several candidate locations, what methodology would you recommend for siting synchronous condensers, STATCOMs and SVCs?

Answered live and in writing. Formulate it as a multi-objective optimisation with location, technology and rating as decision variables: maximise voltage stability margin, system strength, transfer capability and hosting capacity while minimising whole-life cost and losses, subject to power flow, stability, fault level, N-1 and planning constraints. Screen candidate locations first, then evaluate with steady-state, dynamic and EMT studies. A synchronous condenser raises system strength, so using it where only reactive margin is missing risks over-investment.

Q5. Can STATCOMs prevent FIDVR on their own, or must they work in combination with other devices?

Usually the strongest first line of defence, because it injects fast reactive current even at deeply depressed voltage. It is not a standalone remedy: performance depends on siting, sizing, the share of induction-motor load, fault-clearing time, protection settings and grid strength. Severe cases need a coordinated response, with the distribution-side motor load modelled in detail.