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Hybrid Energy Storage Enhanced STATCOMs

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What services are required to operate a stable and secure grid?

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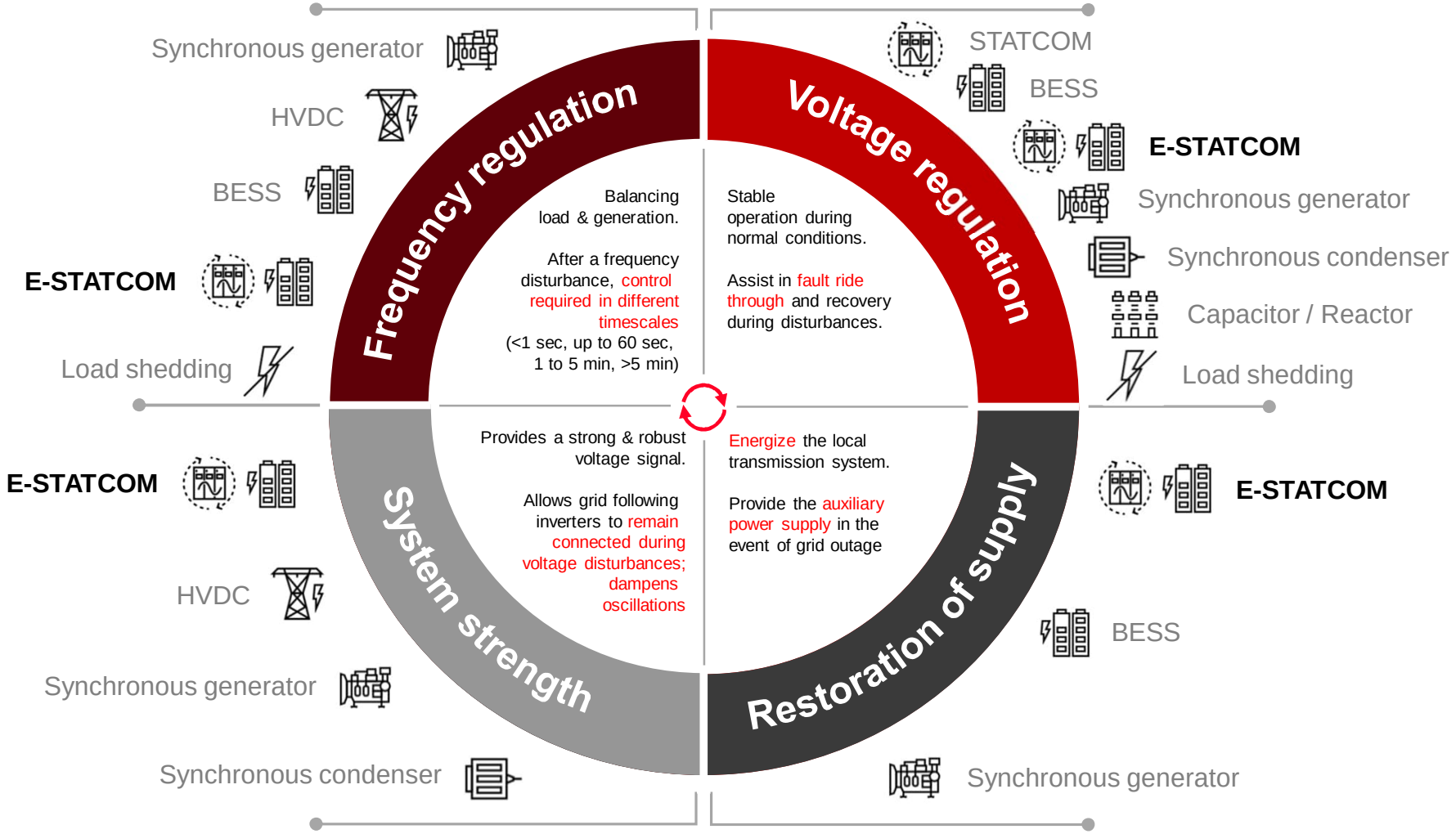
Highlights:

- Energy-storage enhanced STATCOM (E-STATCOM) emerges as a promising solution, promoting massive adoption of renewable generation.
- Different types of energy storage in E-STATCOM, like supercapacitors or batteries, could cater to different grid service requirements.
- Supercapacitors are ideal for quick response services, while batteries are better for long-duration energy provision.



A novel **Hybrid E-STATCOM** design could combine both storage types to leverage their respective advantages

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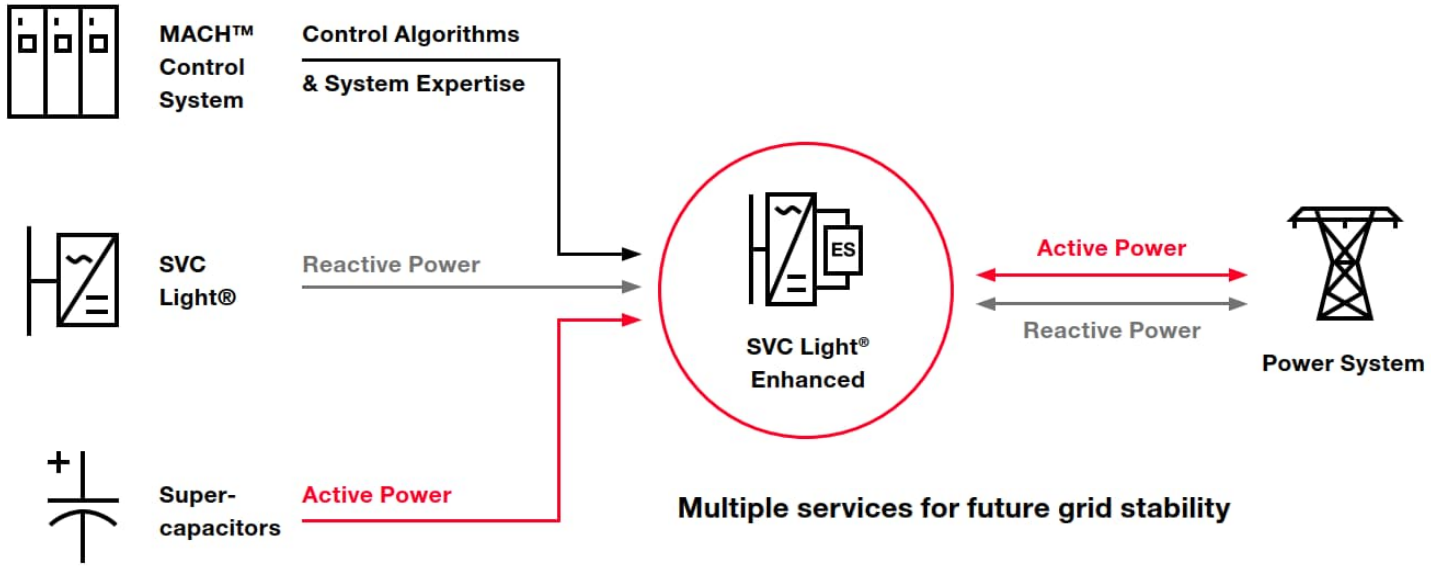
Concept of an Enhanced STATCOM



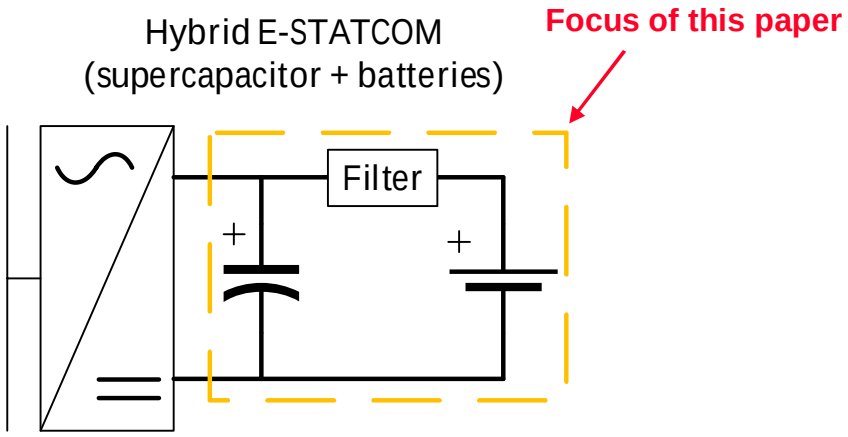
Multiple services for future grid stability

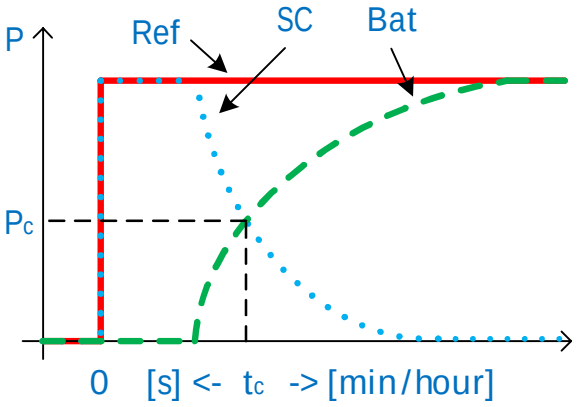
Grid-stabilizing services	Traditional STATCOM	Synchronous condenser	SVC Light® Enhanced
Voltage regulation	●●●	●●	●●●
Inertia		●●	●●●
Short-circuit contribution	●	●●●	●●
Flexibility/modularity	●●●		●●●
Controllability	●●	●	●●●

All-in-one solution providing both **active** and **reactive power**

Source: SVC Light® Enhanced Brochure

Potential system configuration of Hybrid E-STATCOM

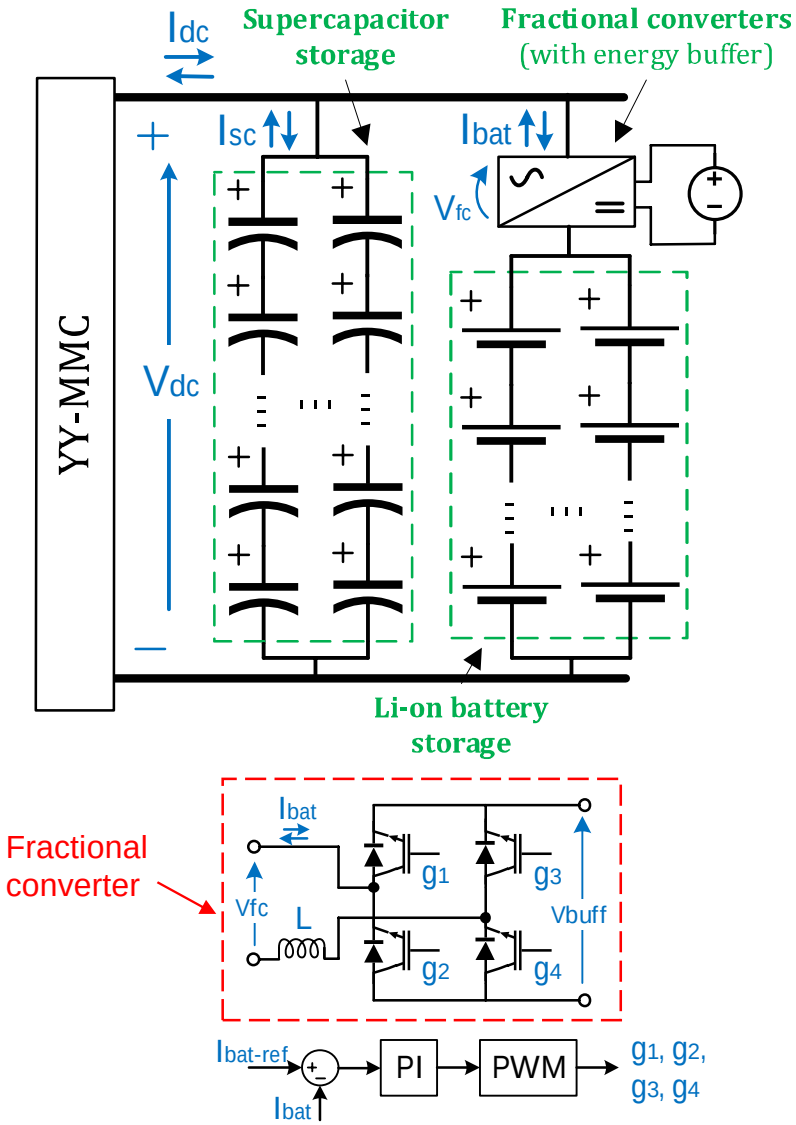




Hybrid E-STATCOM:

- Utilizes a front-end converter (e.g., a double-star modular multilevel converter (YY-MMC) topology).
- Employs centralized supercapacitor-based and battery-based energy storage systems.
- DC-link is decoupled by a filter that is positioned between supercapacitor and battery branches of the energy storage.
- Filter regulates current in the battery branch while allowing natural supercapacitor response.
- Filter can be passive (e.g., inductor) or active (e.g., fractional converter).
- Implementation options: Concentrated (one device per battery branch) or distributed (multiple low-rated devices per battery strings/groups).

Performance of Hybrid E-STATCOM

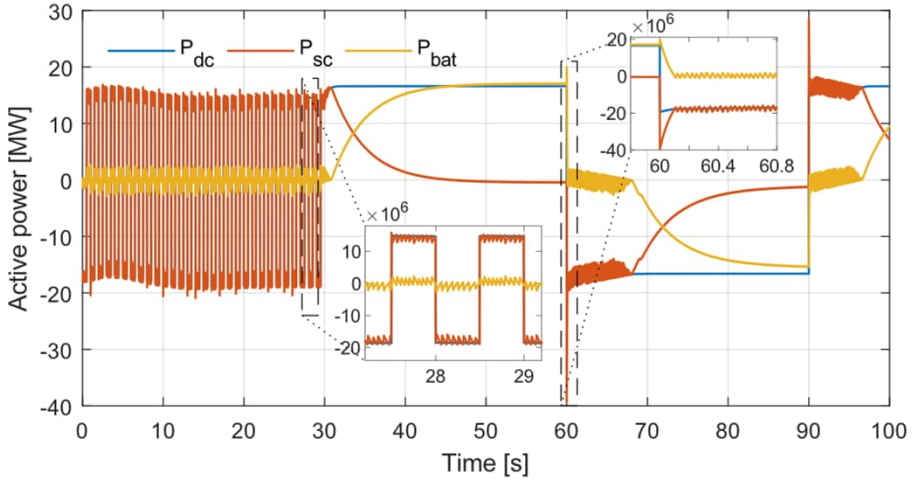


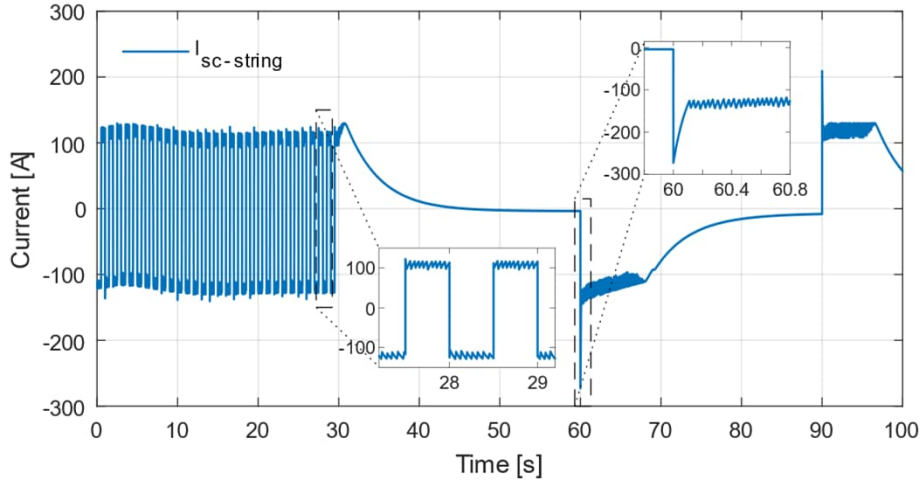
Highlights:

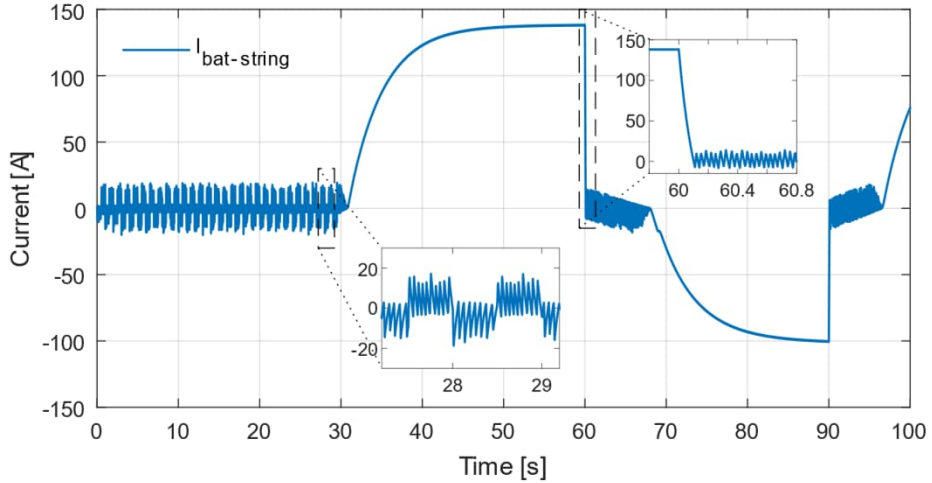
- Focus on energy storage performance.
- MMC converter modeled as a controlled voltage source with a current controller.
- Supercapacitor branch:
  - Supercapacitors are modeled using the three-branch model[1].
  - 144 series-connected modules per string / 10 parallel strings.
- Battery branch:
  - Battery cell electro-thermal dynamics considered (SoC, SoH, temperature, current direction).
  - 80 series-connected modules per string / 10 parallel strings.

[1] Zubieta, L. and R. Bonert. "Characterization of Double-Layer Capacitors for Power Electronics Applications." IEEE Transactions on Industry Applications, Vol. 36, No. 1, 2000, pp. 199-205.

Performance of Hybrid E-STATCOM Modelled



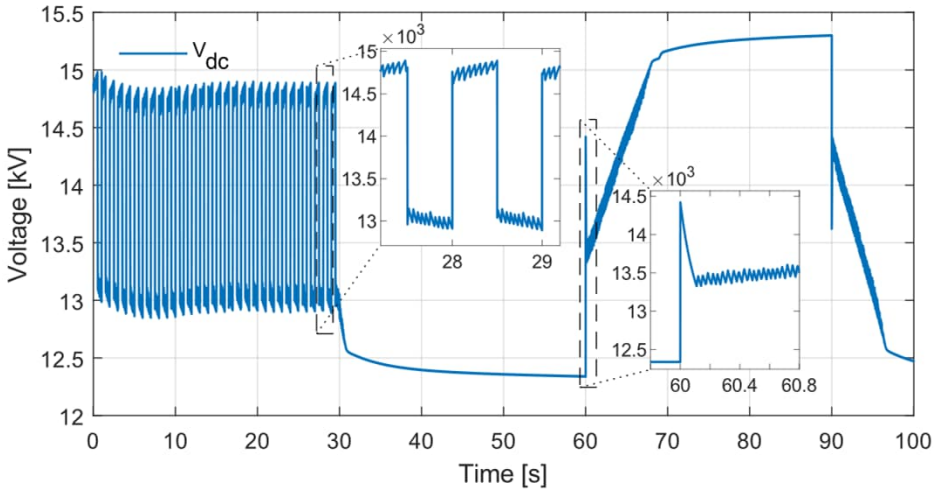


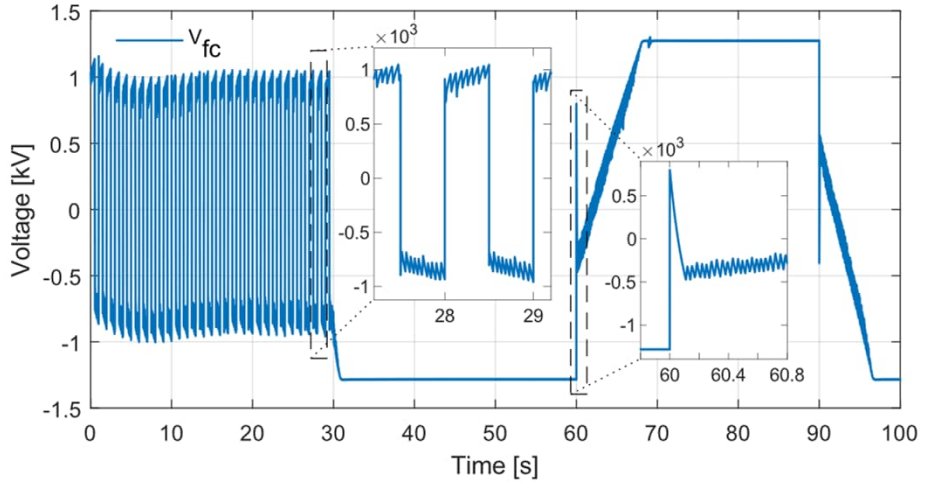


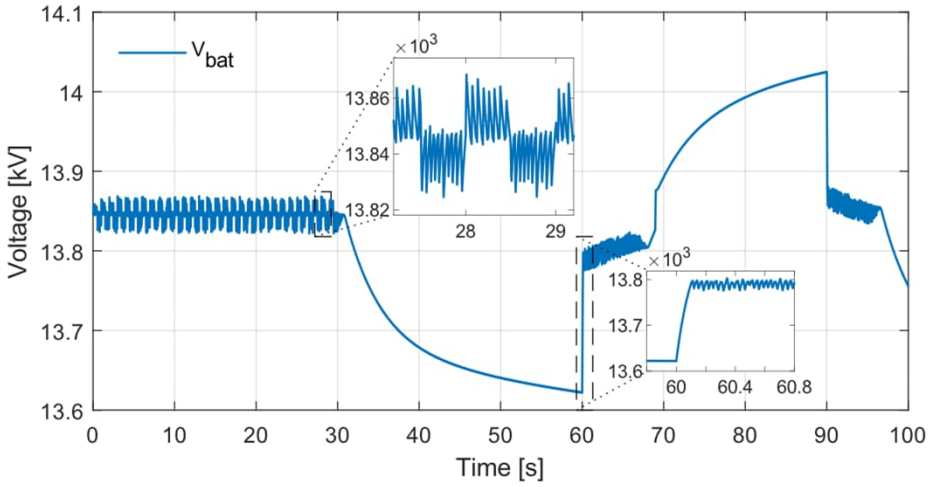
- Reference power profile (P_{dc}) includes high-frequency (1Hz) and low-frequency (0.017Hz) sections.
- Supercapacitor branch (P_{sc}) supports high-frequency waveform.
- Battery branch (P_{bat}) contributes residual power (mainly fractional converter switching).
- Super capacitors handle initial high-power demand; battery branch takes over.
- String currents remain within rated values during transitions.
- Residual switching ripple in the battery string current does not affect the aging mechanism of the batteries[1].

[1] A. Bessman, R. Soares, O. Wallmark, P. Svens and G. Lindbergh, “Aging effects of AC harmonics on lithium-ion cells.” *Journal of Energy Storage*, Vol. 21, 2019, pp. 741-749.

Performance of Hybrid E-STATCOM Modelled







- Fractional converter minimizes dc voltage fluctuations in battery branch.
- Output voltage of the fractional converter varies within the rated values.

Potential Advantages of Hybrid E-STATCOM

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a) Modular design (MMC alone or combined with energy storage), ability to operate as a conventional STATCOM using only MMC.

b) Combined hybrid energy storage potentially supports a wide range of grid ancillary services:
   - Short-term supply (high power, low energy) with frequent charge/discharge cycles.
   - Long-term supply (low/moderate/high power, high energy) with fewer charge/discharge cycles.

c) Reduced cycling aging for supercapacitors and batteries due to lower depth of discharge and discharge/charge rates.
   - Potentially results in smaller energy storage sizing and reduced maintenance costs.

d) Compact volume/footprint could be achieved by using a single STATCOM platform for various grid services.

e) Decoupling dynamic responses of supercapacitors and batteries simplifies control and protection strategies.

Conclusions and outlook

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- The paper presents the potential of a **Hybrid E-STATCOM** solution for stability and power quality challenges in grid integration of large-scale renewable energy sources.
- The Hybrid E-STATCOM would integrate supercapacitors and batteries storages under a single **unique platform** to achieve a **true inertial response behavior – fast activation and prolonged energy delivery**.
- Based on the proven MMC and fractional converter technology, Hybrid E-STATCOMs could offer high scalability, compact, modular design.

Interesting research direction: **optimal sizing** of supercapacitor and battery branches


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