**STATCOM**
White paper

# Challenges of adding renewables to electric networks

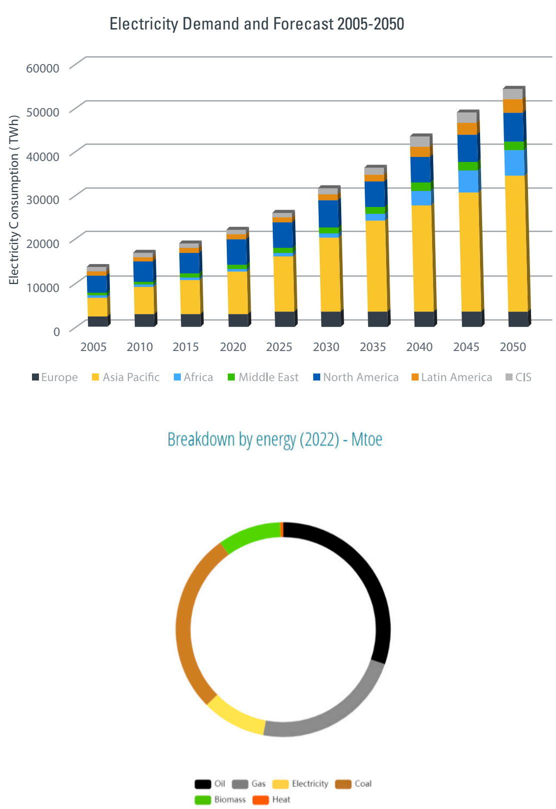


**Figure 1.** Global electricity demand forecast. 2050 projection of electricity generation by source.
Source: Enerdata **www.enerdata.net**

Engineers have put a heavy focus on delivering more and more energy efficient devices on the market in the last two decades. Just think about LED lighting and digital inverters all around in our home appliances and HVAC units. However, due to increasing electromobility (cars, ships, rail) and growing processing power (graphic, AI, smart appliances etc.), the global electric energy demand is on a continuous rise.

Electric energy is historically produced by coal or gas powered generators which had a great amount of inertia and flexibility to respond to rapid increases in active and reactive power requirements (eg. large manufacturing equipment startup, train departure etc.) without distorting the grid frequency and responding to low power factor consumers. This is also known as system strength.

Greenhouse gas emission reduction initiatives and energy supply stability measures are driving steady and heavy growth in renewable energy production. Renewables, particularly wind and solar, require an DC/AC inverter to be able to supply energy to national grids. Since inverters are set to a specific max power output, they don't reserve inertia — which would be able to boost the output at a peak load. They simply transmit the actual power output which is available. As more wind and solar are added to the grid, there is less inertia in the grid and system strength is reduced, making it less stable. To support low power factor consumers, renewable sources need to be heavily oversized, which would make them less cost effective, or pay for corresponding "spinning reserves." Spinning reserves are typically fast reacting gas turbines which can provide inertia but are costly to run (due to efficiency and standby burning of gas) and generate green house gasses.

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In reality, grid operators try to combine rotary generated energy sources (nuclear, coal, gas, oil, hydro etc.) with the right balance of renewables. This balance is a strong limiting factor to introduce more renewables to many local or national grids. Shutting down polluting fossil power plants and nuclear plants (Germany, Sweden) makes this balance even more challenging. Resources are needed to allow a higher percentage of renewables in a cost effective and stable way and not lose the environmental advantages.

### Methods of effectively stabilizing the grid

To overcome the challenge of decreasing grid inertia and system strength loss, various grid connected compensation techniques and devices are utilized, such as:

- Synchronous generators (mostly gas turbines)
- Synchronous condensers
- Grid forming battery energy storage systems (BESS)
- Static VAR Compensator (SVC)
- Static Synchronous Compensator (STATCOM)


**Figure 2.** STATCOMs can add active power compensation to their reactive power capability.

All of the above are great at increasing reactive power management, but have challenges to compensate for inertia in the manner the grid requires. Normally, the frequency is continuously fluctuating depending on the load and the unpredictable supply balance. Though these events of over or underfrequency last only for a few seconds, damage to all types of electronic equipment can occur. This calls for a grid compensating device which instantly detects under or over-frequency and has the capability to quasi instantly and efficiently absorb or deliver energy.

- Synchronous generators are great to compensate for hours of power needed, but they need time to respond. They are, therefore, not ideal for times when sub-second or a few seconds are needed.
- BESS is a suitable way to deliver power and it responds quickly. However, battery performance, especially when absorbing heavy currents, requires oversizing and is quite costly for just a few seconds of compensation. BESS ideally stores renewable energy to compensate for under-production for hours. While battery life is being improved, life time is still an issue. Even the best lithium-ion batteries last 10,000 cycles, or less than 1.5 cycles per day, with the required 20-year life time.
- Synchronous condensers and SVCs compensate for local voltage variations, but do not store sufficient energy for even the few seconds needed on a grid-wide scale.
- STATCOMs can provide reactive energy as needed, but do not currently have the capability to provide active power.

### Providing active power and energy to a STATCOM

Enhanced-STATCOMs are in development to add active power compensation to the reactive power capability. Energy storage control is added to a STATCOM to make it an e-STATCOM or grid-forming STATCOM. This new device allows grid operators to compensate for both active power and reactive power needs, instantaneously for several seconds.

What may be the ideal method to provide instant power to the grid or absorb as renewable sources increase and turbines decrease? Flywheels have been used to improve inertia on the generation side. However, they require a relatively high constant power to keep spinning and, similar to batteries, do not absorb energy quickly. They tend to require high installation costs for site stability, as well as ongoing costs for maintenance.

The ideal solution where the grid industry has settled is the EDLC (Electric Double Layer Capacitor) technology also known as supercapacitors. Some defining features of the technology which can output power immediately upon demand:

- can be charged / discharged millions of times
- can be charged and discharged at high current (so called, C rates) making them ideal for frequency compensation in both directions
- roundtrip efficiency normally exceeds 90%
- low standby current requirements allow for low cost operation
- maintenance free
- support 20+ years operating life
- safe with no thermal runaway
- environmentally friendly ("green"), made from aluminum, carbon, paper, some plastics and a metal-free electrolyte
- sustainable – no heavy metals or rare earth materials used

Supercapacitors have been used for decades in electronic devices, from utility meters to metro busses and many applications in between. The capability for long lifetime makes them ideal for maintenance-free backup power in industrial applications requiring high temperatures (up to +85°C). In other applications, the high efficiency and instantaneous power for millions of cycles enables cost-effective electrification of vehicles, ships and trains.

### Active power by the scale:

Active power may be necessary at different levels of the electric network, from the low voltage users (around 400 Vac) to transmission voltages (70 kVac-1 MVac).

**A: Low voltage / Industrial:** Users with low power factor may install a booster / supercapacitor UPS to improve their internal power factor to avoid high electricity costs. This may avoid higher capital investment needed to upgrade a utility transformer and reduce operating expenses (OPEX) by avoiding higher charges due to low power factor / high reactive power. These have been implemented especially for new installations like elevators in buildings, high power manufacturing equipment and health diagnosis equipment such as CT / MR / X-ray. Eaton provides complete solutions for such systems. Depending upon the power required, this can utilize just a few cabinets of space.

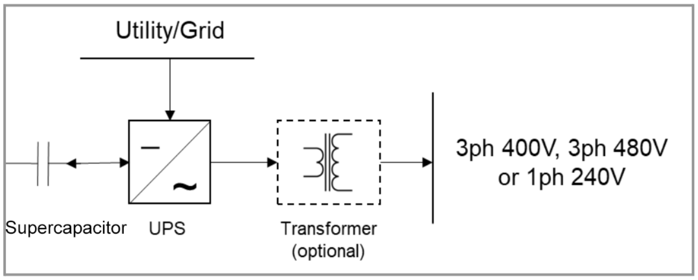


**Figure 3.** UPS configuration with supercapacitors as energy storage for short term backup or pulse power.

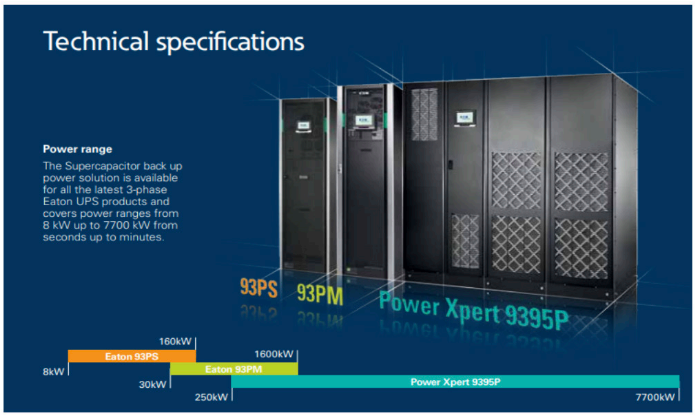


**Figure 4.** Technical specifications highlighting Eaton UPS products.

**B: Low to Medium voltage AC networks (1-35 kV) / Microgrid, solar.** On a facility/site level, there may be a need for a boost to cover peak power. If the peaks last for seconds, supercapacitors can offer the best solution up to 10's of MW of power. This may be a large community, industrial facility, AI datacenter or solar PV generation site. The supercapacitor bank's nominal voltage is normally maintained between 1000-1400 Vdc. Space of the installation can be up to a 40-foot container size.

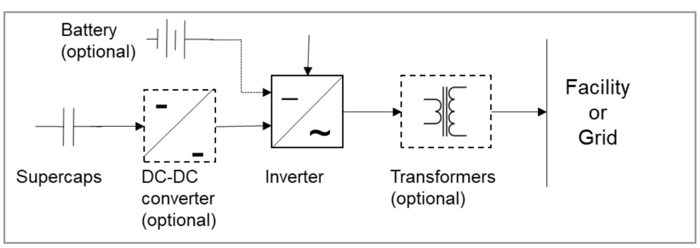


**Figure 5.** Block diagram of microgrid or utility scale solar.

**C: Medium and high voltage AC Networks >35 kV / Grid:** The AC grid is on the distribution or transmission system level, depending upon the country, is typically greater than 35 kV. The power range here falls between 50-300 MW normally. The HV grid connected power storage device needs to be bidirectional, since it compensates for over-frequency events as well as under-frequencies. The size of installation requires a building of at least 100 m$^2$.

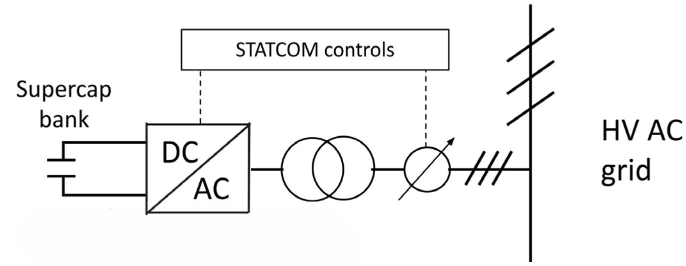


**Figure 6.** STATCOM block diagram. Details of the STATCOM are critical to properly configure XLHV modules to meet medium and high voltage STATCOM inputs.

## Eaton's STATCOM ready XLHV

**Eaton supercapacitors and a STATCOM ready supercapacitor module**

Eaton is the broadest portfolio supercapacitor manufacturer with the richest history in the industry, having started mass production of EDLCs in 1999. Since 2016, Eaton has been providing supercapacitor modules suitable for low and medium voltage requirements. Standard modules are preferred to build the various system needs of each installation in terms of voltage, power and time / energy requirements.

High voltage grids require new supercapacitor modules. Isolation compatible with high voltage and monitoring must be met. While all grid installations require high reliability, high voltage installations require >99% availability for systems up to 100 kVdc. The base module must have reliability to support this, but must also provide status information for users to know if an issue is occurring inside the module. Even with all of this, there are system level challenges to isolation, circuit protection and operational aspects (how to isolate a module, how to discharge high voltage strings, etc.).

**Figure 7.** Eaton's XLHV Supercapacitor module with CANbus and MODbus, a building block for safe, reliable active power compensation.

Eaton's XLHV supercapacitor module family is an easily configurable 19" rack mount stackable power storage module up to 1500 Vdc in series connection. Each module consists of 48 series connected 3000 F / 3 V cells, resulting in a total capacitance of 62.5 F. The cells are precision laser welded to an array of busbars connected to special terminals, resulting in as low of an ESR as 12.5 mΩ. (8-9 mΩ typ.). The XLHV modules can provide 20 years of service life in a STATCOM installation environment, thanks to the advanced electrode and electrolyte design. A self-powered advanced active cell balancing / monitoring solution maintains the right balance between cells over the entire string of cells / modules. Digital communications standards for the communication of module status through CAN or Modbus interfaces ensure safe operation. The digital interface can communicate cell temperature, module voltage, overvoltage warnings, delta voltages and overtemperature warnings, as well as self diagnostics of the electronics.

For power electronics inputs above 1500 Vdc, where the supercapacitors are connected in series up to 100 kVdc, the system can be broken into banks of modules each running at 1500 Vdc maximum. Each bank requires special grounding and isolation methods, as well as safety evaluation for arc flash, corona discharge and total site safety. System integration into a site is a complicated endeavor specific to an installation and a topic to be discussed for specific design opportunities. Eaton has experts in systems to assist with a complete supercapacitor sub-system.

Electricity demand is ever increasing on a global scale, as are sources to generate this electricity. Most new generation technologies reduce the inertia in the grid and system strength. These trends will require short duration energy to help the grid function safely and efficiently. Supercapacitors offer such energy storage for active power compensation, whether for back up or pulse power in industrial and microgrid applications. Supercapacitors are also being applied to larger grid scale compensation systems.

Eaton's supercapacitor modules and cabinets have been applied to DC energy storage for low and the lower end of medium voltage systems. New modules and racks are now available to apply for the upper end of medium voltage systems, as well as high voltage systems. Advanced communications and monitoring critical for grid energy storage have been added to the bulk storage capability. Eaton's applications and simulation expertise are critical to address safety and reliability requirements of these applications.

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