Traction Brake Energy Regeneration By Supercapacitor Energy Storage System

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Panama Canal

Energizing the Panama Canal to take on double the traffic

Facebook

Energizing data center as forward-thinking as Facebook itself

Valero

Energizing a refinery to take arc flash danger out of the operation

Schaltanlagenbau Gormanns GmbH

Energizing a potato plant to make sorting 120 tons of potatoes a one-man job

Johann Cruijff ArenA

Energizing by stored energy saving 117.000 tons of CO2

TriRiver Health Partners

Energizing IT systems to power the transformation of healthcare

Beijing subway

Energizing a subway system to move even faster than the speed of a growing Beijing

PGE Salem Smart Power Center

Energizing a working smart grid for energy intelligence.

What matters to our customers, matters to us

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30-40% - the traction energy potentially to be saved by regenerative braking

- AUX supplies during braking
- Powering other trains on the same section
- Energy return to the AC grid by reversible substations
- Inject in Energy Storage Systems (ESS)

Effectiveness & Complexity

15-25% - the traction energy cost efficiently could be saved

ESS CHALLENGE

- High power (MWs) to absorb in short time (30-60s)
- Braking power and energy differs from train to train – depending on the train's powertrain and weight
- Unpredictable charge and discharge sequence – multiple trains in the same section interfere with each other

There is an OPTIMAL ESS DESIGN for all sections which maximize the return-on-investment

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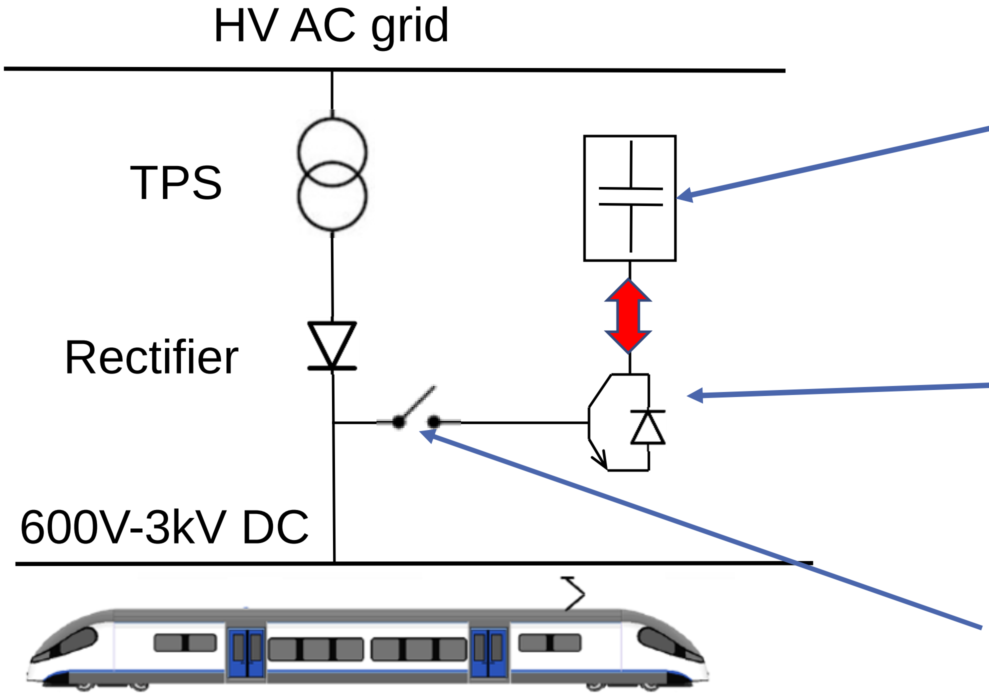
Key Elements Of The ESS



Energy Storage Unit

Bidirectional Converter

Switchgear

High Power Density Energy Storage Technologies

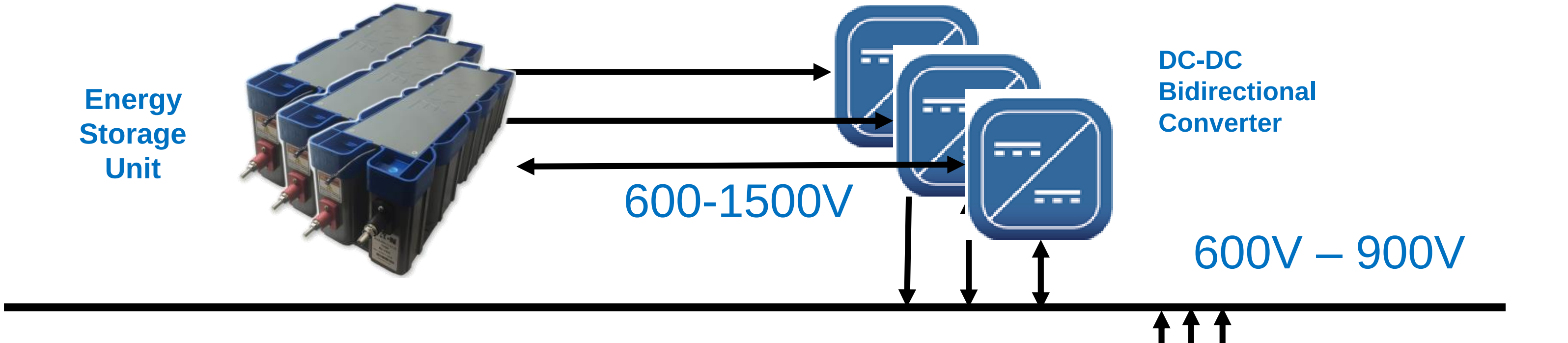
Key Characteristic	Units	Supercapacitor	Li-ion Batteries	Flywheel
Voltage per base unit	V	2.5-3	3.6-4.2	400-500
Cold Operating Temp	°C	**-40**	-20	-10
Hot Temperature	°C	**+70 (85)**	+45	+40
Cycle Life		**>1,000,000**	10,000	unk
Calendar Life	Years	**5-20**	3-10	20
Energy Density	Wh/L	1 – 10	**250-650**	0.6 – 1.2 incl converter
Power Density	W/L	**1000 – 10,000**	850 - 3000	98 - 275
Efficiency	%	**>98**	80 - 90	98
Charge Rate	C/x	**>1,500**	<40	~4
Discharge Time		Sec or Minutes	**Hours**	**Seconds**
Cost per kWh	$	10.000-15.000	**100-500**	2.000-5.000
Cost per kW	$	**0.1-0.2**	100-500 (1C)	300-500 (many factors)

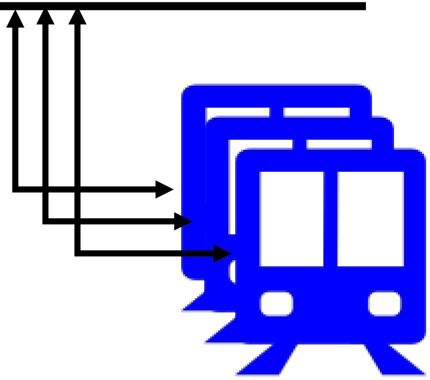
Supercap – Electrostatic

Li-Ion – Electrochemical

Flywheel – mechanical

Train Braking Energy Regeneration Example





- Inputs taken into consideration for the sizing:
- V catenary train brake = 800-900VDC
- I regenerative brake = 1000A / ~ 800kW considering efficiencies, but can be more available
- T regen = 30s - considering only 20+Km/h
- V boost during train acceleration = 750VDC
- Frequency of regenerative cycle is 1 per 5 minutes => ~ 100.000 cycles per year

Which One Is The Ideal ESU Technology?

ESU Technology	Required Capacity	Total Volume	Total Weight	Expected ESU Cost *	Estimated Lifetime	Roundtrip Efficiency	Regenerated energy during lifetime
Supercap (Eaton XLM)	35F @ 1500V => 6.7kWh	~3m3	~3 Tons	$200k	12yrs, 1M+ cycles – continues to operate with lower capacity year by year	96%	5.7 GWh
Li-Ion (LMO)	192kWh @ 800V (1C considered)	~2m3	~2.7 Tons	$50k	3yrs, 300k cycles – EOL condition	90%	1.62 GWh

*: ESU cost only, no converter and switchgear considered

For the energy regeneration cost per return is similar for supercapacitor and Li-Ion technology

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Advantageus Use Cases Supercap and LiIon Batteries

SUPERCAP

- More cost effective if the regeneration **frequency is higher than 1 in 5 minutes** due to the infinite cycle life
- Better for **outside installations** as highly efficient in cold and hot temperatures as well (-40/+65C)
- Better in case stored energy is used for **substation power boost** due to better overall efficiency
- Better where maintanance and replaceability is difficult due to **maintanance free** and long life being

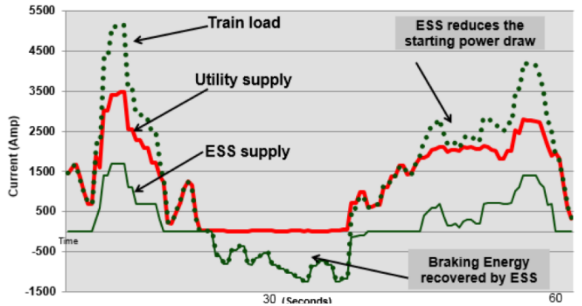
Li-Ion BATTERY

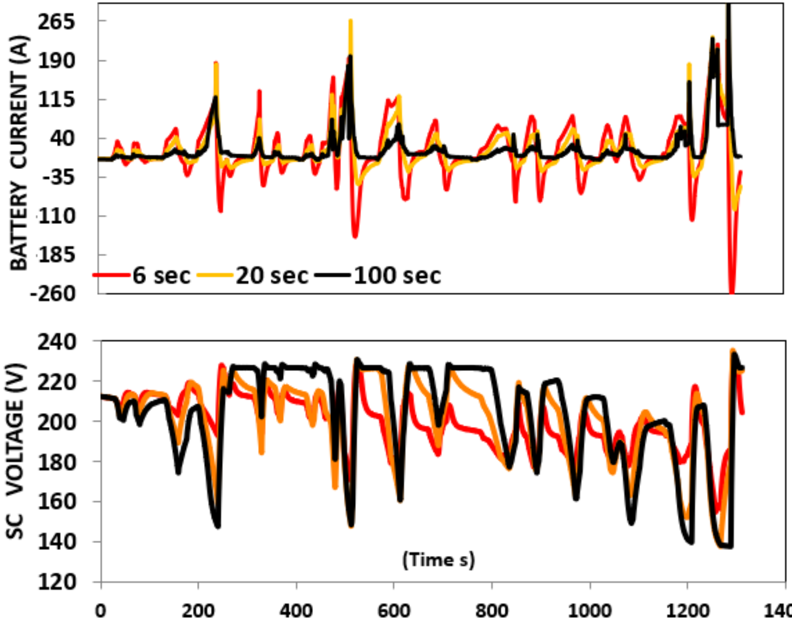
- More cost effective if the regeneration **frequency is lower than 1 in 5 minutes**
- Better in case the stored energy is to be used to **power the train station** energy needs during peak consumption by the accumulated energy
- Better if the stored energy is planned to be used to **power the catenary for longer periods** (up to 30min) in case of failure in external power supply and move trains around in this down period

Supercapacitor – Battery Hybrids

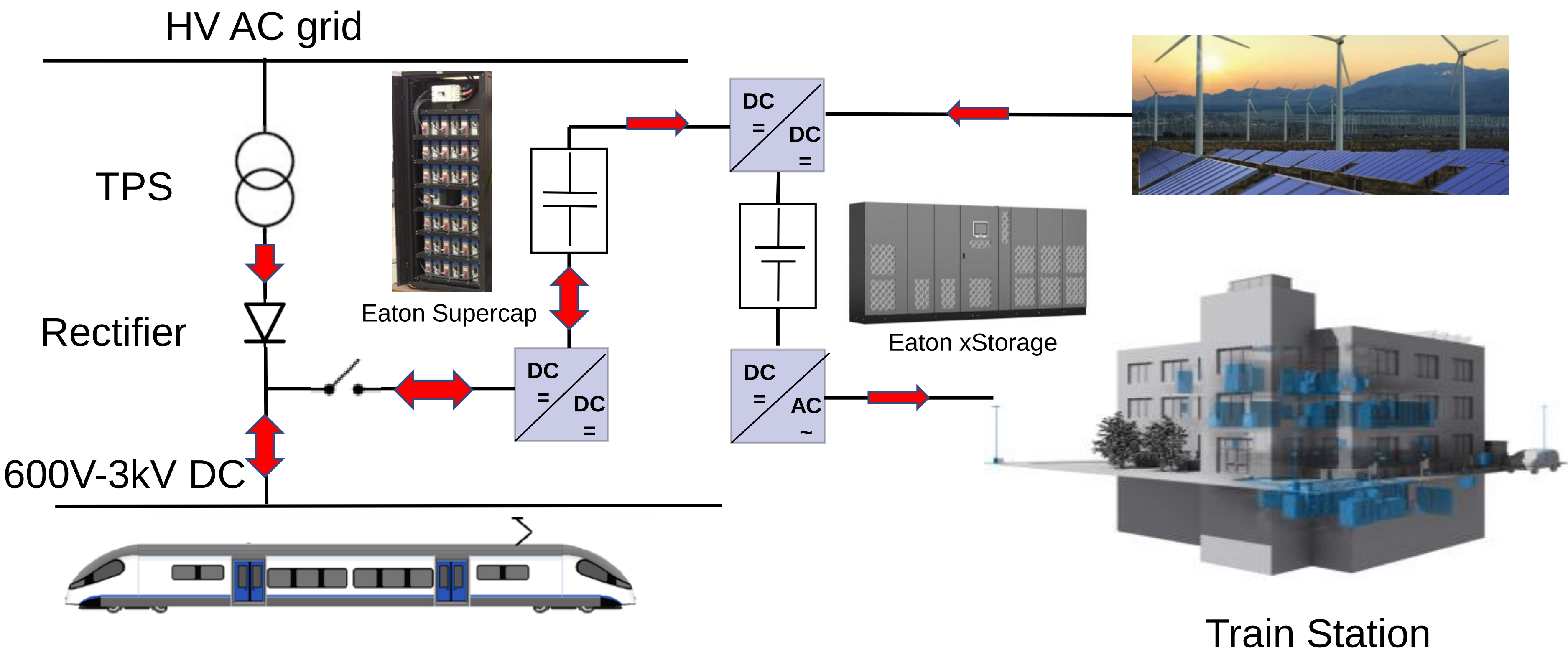
- In rapidly fluctuating regeneration cycles a supercap-battery hybrid solution is beneficial
- Supercaps are handling the high rise current portions both for charge and discharge
- Benefits of a hybrid solution:
    - Longer battery life ~2x
    - Less thermal stress on the battery
    - Efficiency improvement ~5%

Eaton Developed A Simulation Program To Evaluate Battery-Supercap Hybrids For Different Drive and Recovery Cycles/Profiles





The Ultimate Solution



THANK YOU!