Supercapacitors: Traditional Versus Non Traditional Applications and Their Potential for Energy Management in Wind Energy

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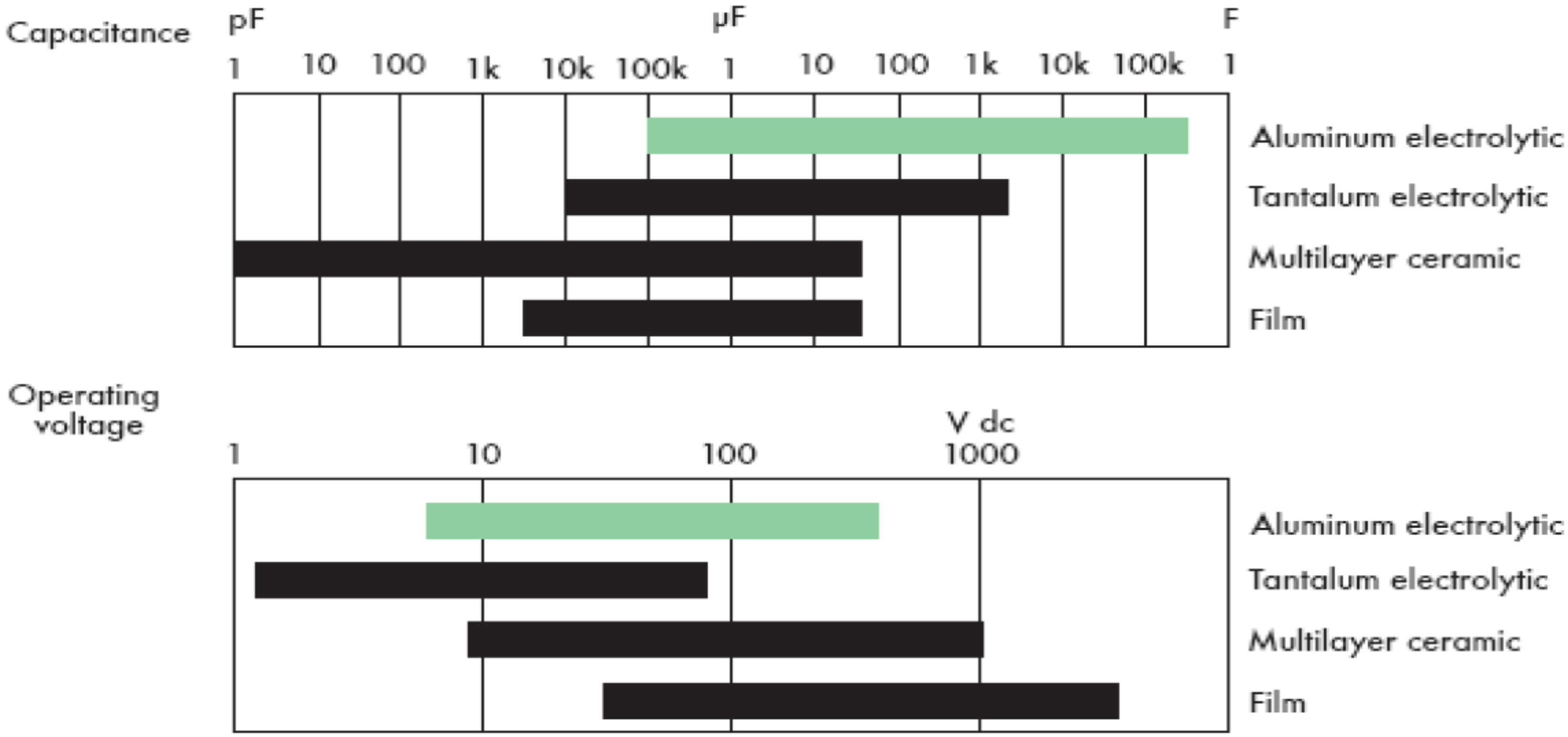
Traditional capacitors and their limits



2. Common dielectric materials, i.e., aluminum oxide, tantalum tetroxide, titanium oxide barium, and polyester polypropylene, also pose limits on capacitance level and operating-voltage capabilities.

Source: Dirjish,.M., Ultracapacitors branch out to wider markets, Electronic Design , On line ed, Nov 17, 2008

Simple capacitor basics

$$C = \frac{\varepsilon_r \varepsilon_0 A}{d}$$

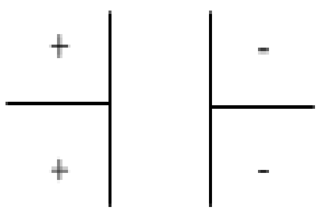
Larger area and/or closer plates- Bigger Capacitance

$$Q = CV$$

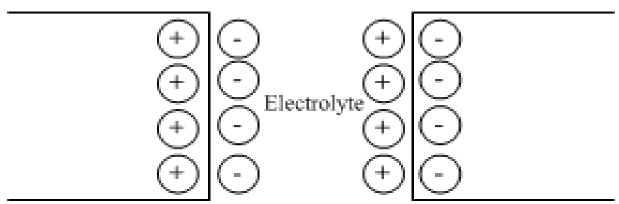
Bigger capacitance and /or higher voltage capability- Bigger Charge Storage

$$E = \frac{1}{2} C V^2$$

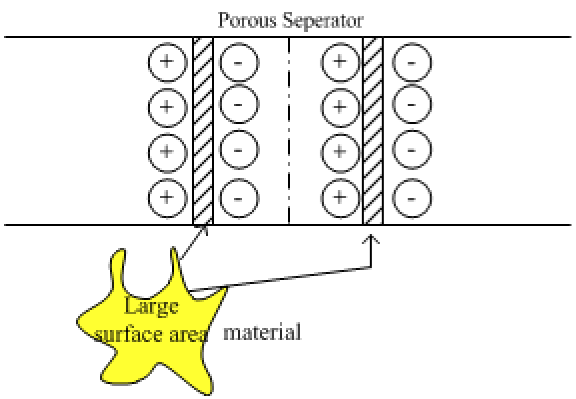
Energy storage α (Voltage^2)



Common Capacitor



Liquid electrolyte based capacitor



Large area material with porous separator

Traditional capacitors versus supercapacitors- Construction Details

What are supercaps

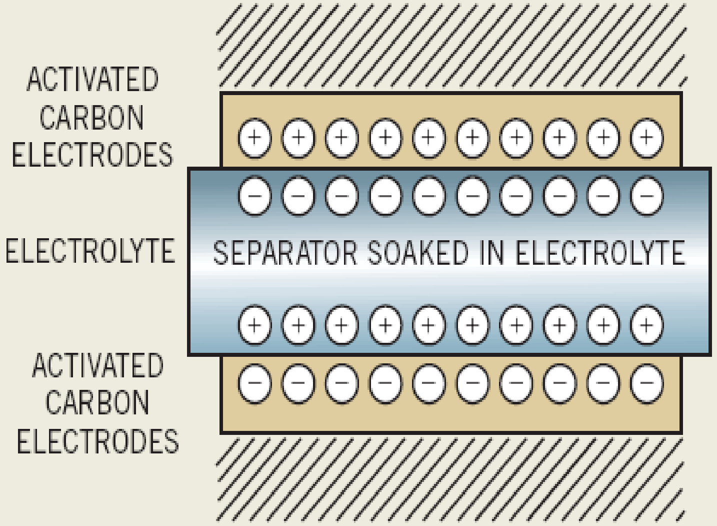


Figure A When you place a potential on the terminals of a double-layer electrochemical capacitor, charge accumulates on the surface of the carbon electrodes and is balanced by ions drawn from the separating electrolyte (courtesy Epcos).

Source: EDN

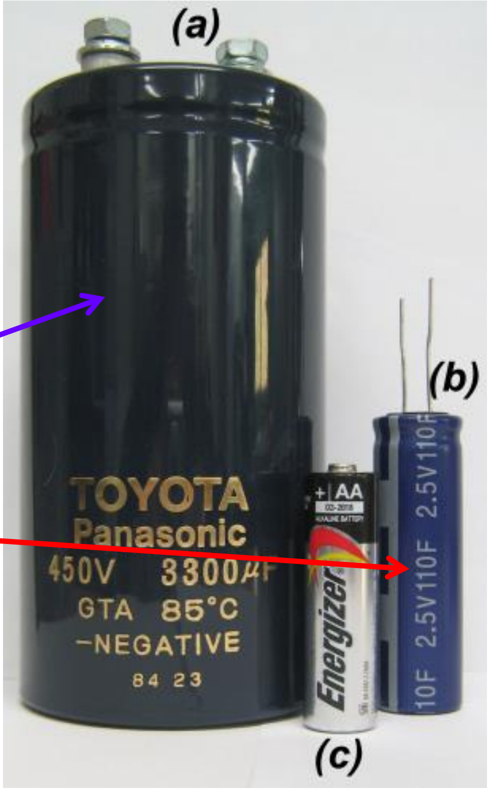
What are Supercapacitors /Ultra-capacitors?

- Supercaps or Ultracaps are very large capacitors, within the family of Electric Double Layer Capacitors (EDLC)

- fractional-farads to several thousand farads (in single cell form)

- voltages in the range of 0.7V to about 5.0 V per cell.

Component	Value	Voltage	Energy
Panasonic Capacitor	3300 μF,	450 V	$E_c = \frac{1}{2}C \times V^2 =$ 334 J
Super-Capacitor	110 F	2.5 V	$E_c = \frac{1}{2}C \times V^2 =$ 343 J
AA battery	2500 mAh, 9000 As	1.2 V	$E_b = As \times V =$ 10800 J



Supercapacitors versus batteries- Ragone Plot

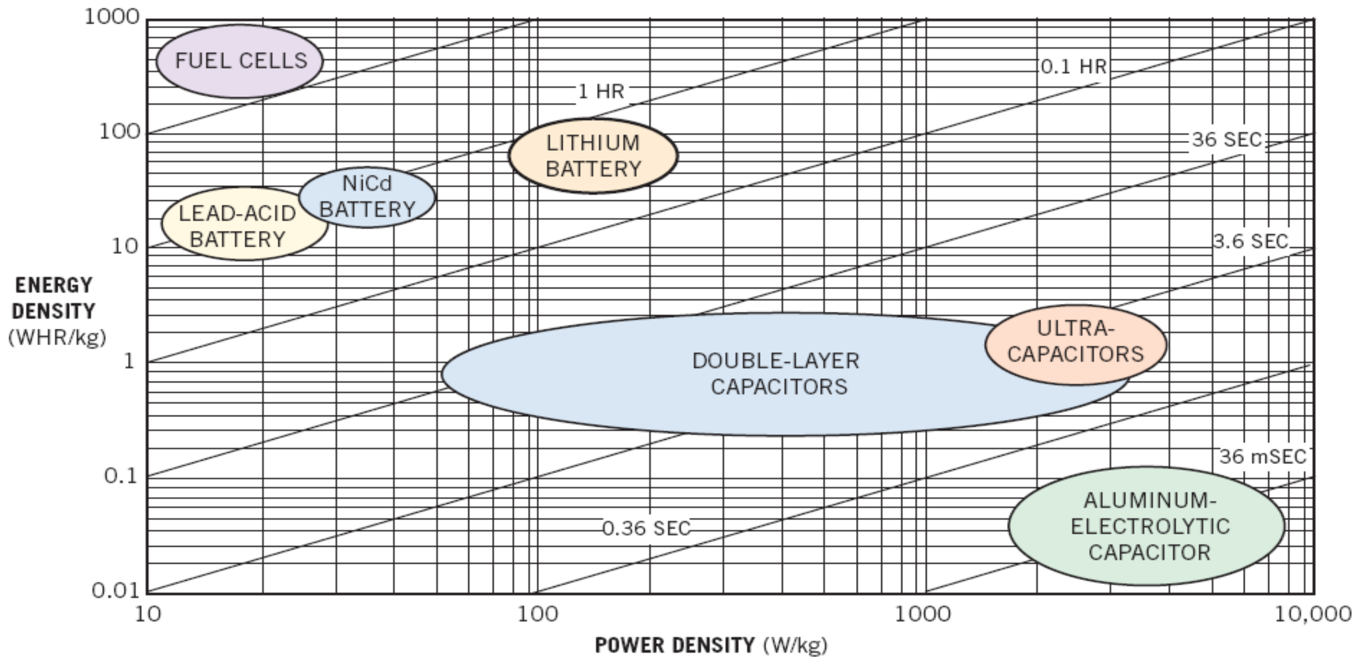


Figure 1 Graphing energy density against power density, conventional batteries occupy the top-left position, and conventional aluminum-electrolytic capacitors occupy the bottom-right. Supercapacitors bridge the space between. Diagonal lines are lines of equal discharge time into a specified load (courtesy Maxwell Technologies).

54 EDN | January 9, 2003

In this graph horizontal axis is in Watts/kg. Vertical axis is Wh/kg

Supercapacitor construction and types of supercaps

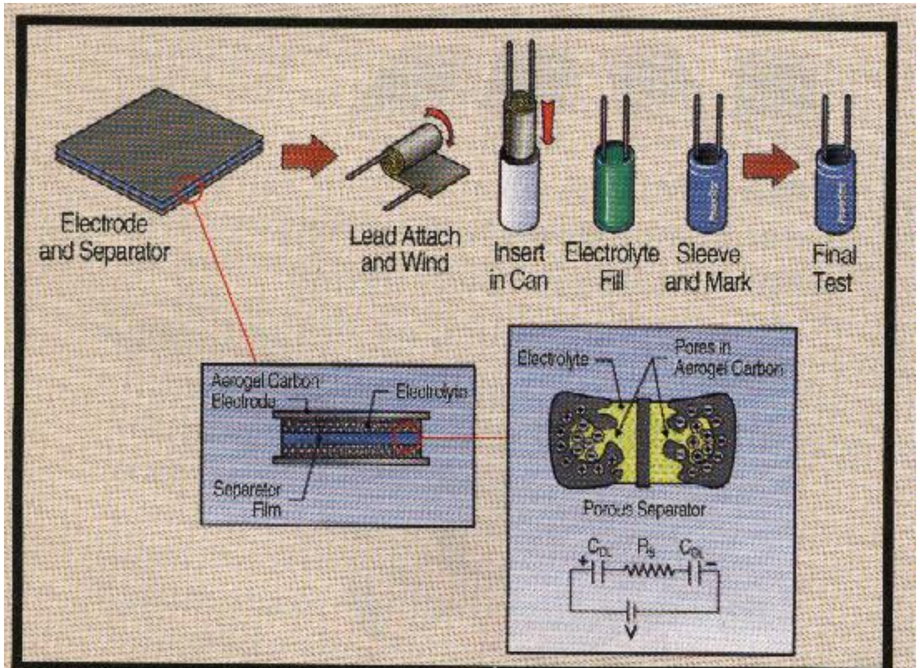
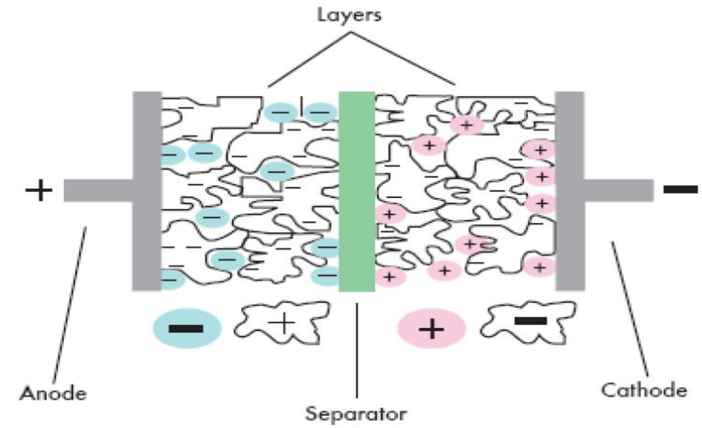
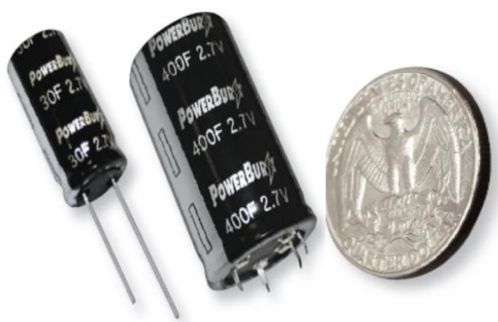


Fig. 1. *Aerogel supercapacitor construction.*



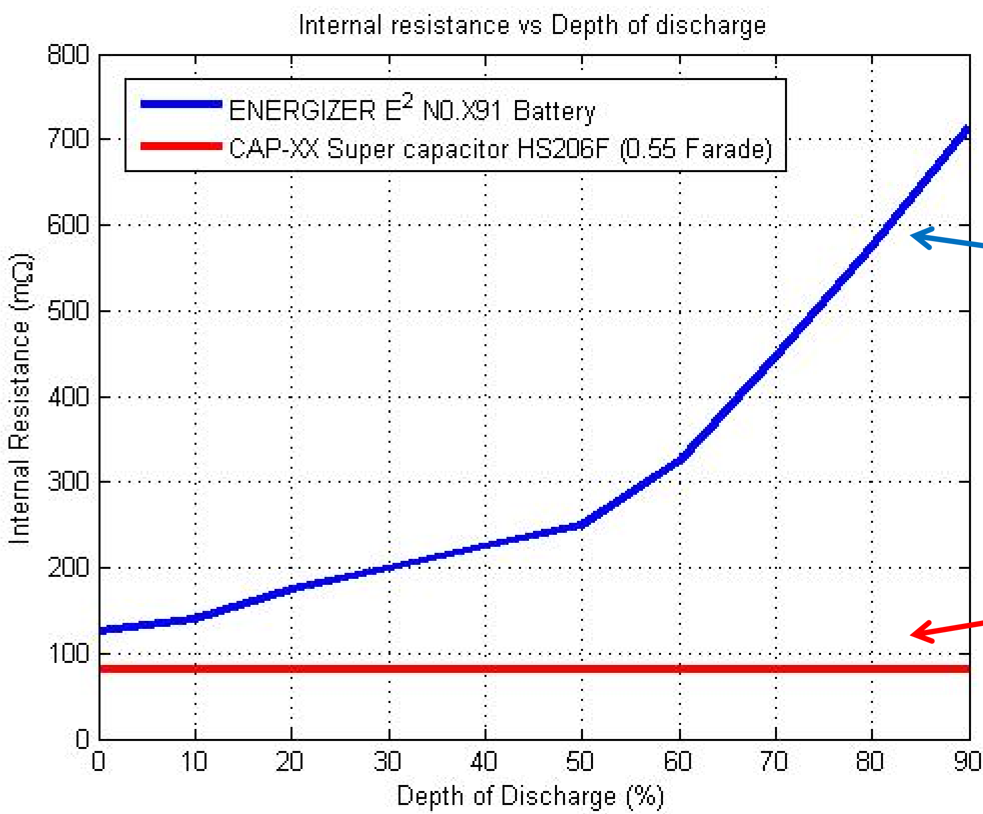
3. Ultracapacitors employ two, very thin dielectric layers that create a larger surface area than standard components, which in turn enables higher capacitance values.

Source: Dirjish,.M., Ultracapacitors branch out to wider markets, Electronic Desgin, On line ed, Nov 17, 2008

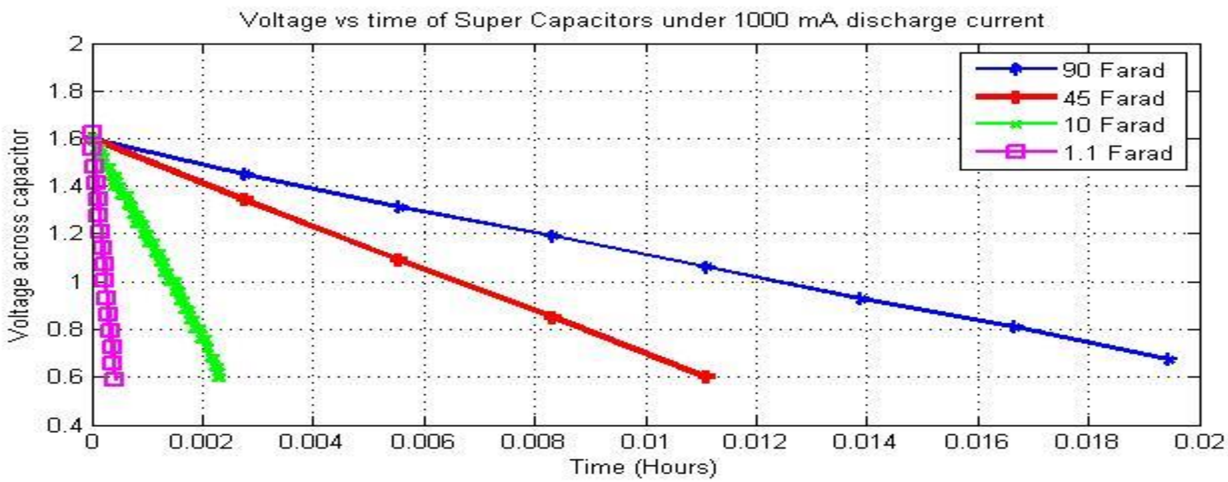


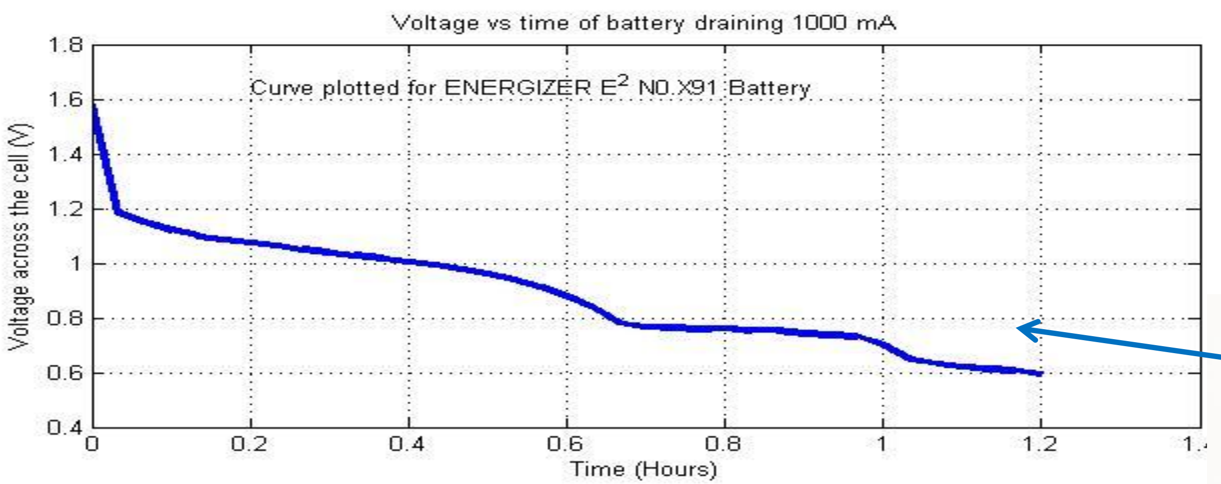
Maxwell's BMOD series modules offer capacitance values up to 500 F at 16.2 V dc and 63 F at 125 V dc.

Comparison with a battery
Internal resistance with depth of discharge



Constant current discharge - Supercap verus a battery





SCs versus electrolytics

TABLE 2. COMPARISON OF TYPICAL ELECTROLYTIC CAPACITORS AND SUPERCAPACITORS FOR THEIR ESR VALUES AND OTHER USEFUL SPECIFICATIONS

ENERGY STORAGE LIMIT	CAPACITOR TYPE	MANUFACTURER	PARAMETERS			
			CAPACITANCE (μF/F)	TERMINAL VOLTAGE (V)	SHORT CIRCUIT CURRENT (A)	ESR (m Ω)
Less than 1J	Electrolytic	RSS	2200 μF	16	104	153
1-5 J	Supercap	Maxwell	1 F	2.7	3.85	700
		Cap-xx	2.4 F	2.3	115	20
	Electrolytic	Cornell Dubilier	2200 μF	50	704	71
5-50 J	Supercap	Maxwell	10 F	2.5	14	180
		Cap-xx	1.2 F	4.5	112.5	40
		Nesscap	10 F	2.3	33	70
	Electrolytic	Cornell Dubilier	82,000μF	16	1441	11.1
		VICOR	270 μF	200	325	614
Above 50 J	Supercap	Maxwell	350 F	2.7	840	3.2
		Nesscap	120 F	2.3	144	16

Traditional Applications of Supercapacitors

- In general supercapacitors have much less energy density than batteries

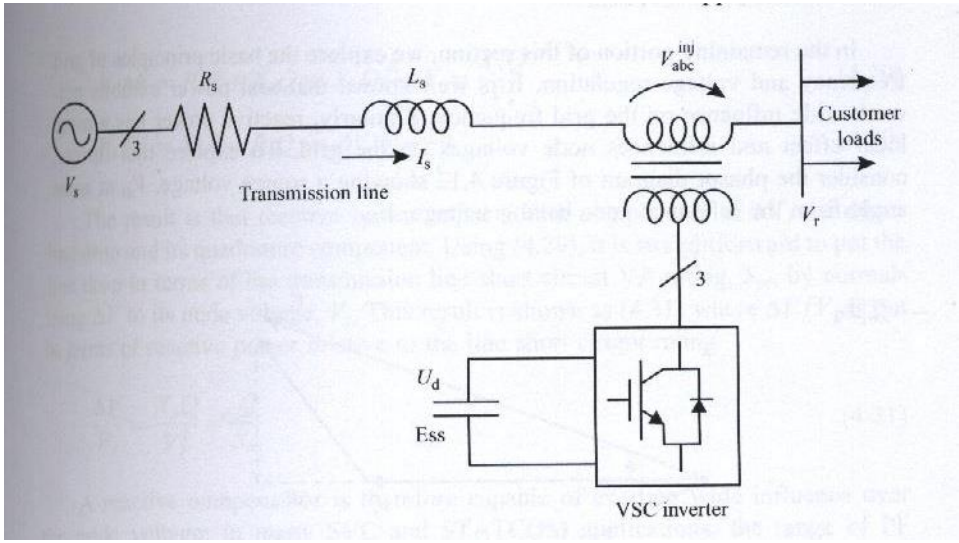
- But their power delivery capability (Watts/kg) is quite high compared to batteries

- Large supercapacitors have very low ESR in the range of few mΩs to fractional mΩs

- **Given these conditions common supercapacitor applications are in**
- UPS systems
- Portable devices
- Electric vehicles/ Fork lifts/ Hybrid buses
- Utility voltage stabilizer systems
- Photo voltaic systems
- Car ignition, start and Go (ISG) systems

- In many of these applications battery-supercapacitor hybrid systems are used
- **Manufacturers of Large SCs**
  - Maxwell
  - LS Mtron
  - Nesscap etc
  - -----they have SC cells in the range of 5F to 3000F ands over
- However due to very low cell voltage (2.2V to 2.8V) you need modules of series /parallel combinations

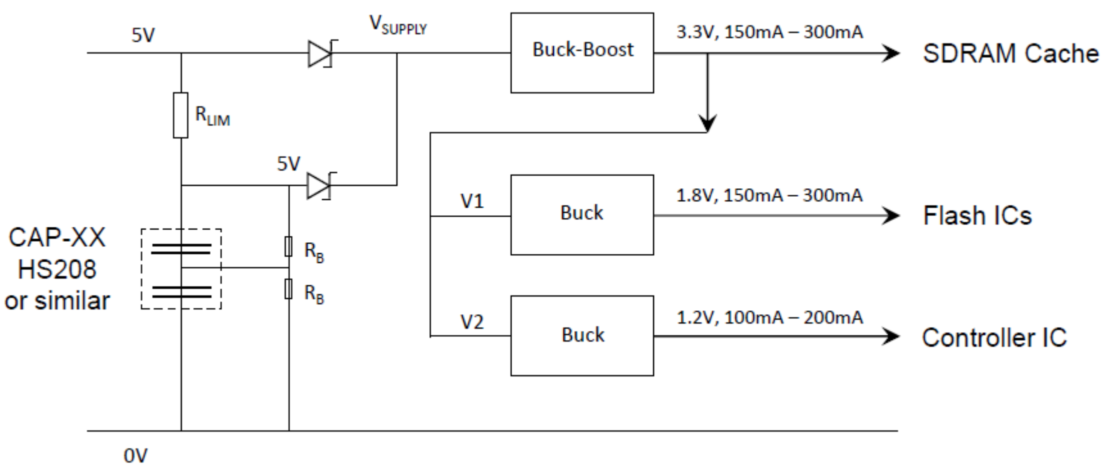
Some examples



Static synchronous series compensator- For utility voltage stabilization

Portable products and smaller value SCs

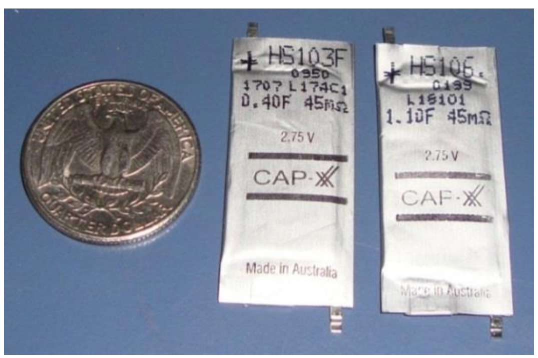
- Thin profile SCs with values in the range of .2F to 2F are avilable (ex: Cap-XX, Australia)
- Used in cellular phones, and similar applications
- Examples are
    - Powering flash memories (solid state devices-SSD)

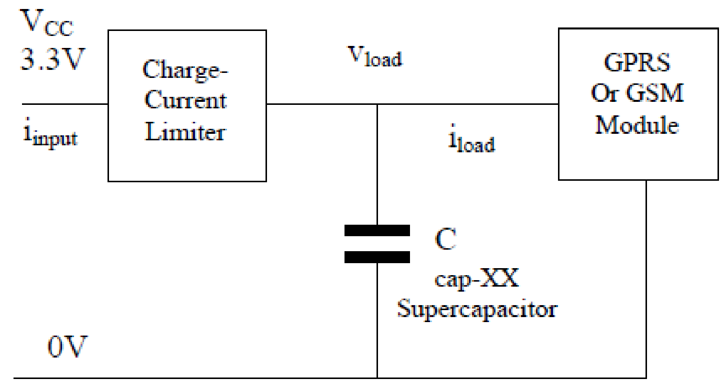


Source: Cap-XX , Australia

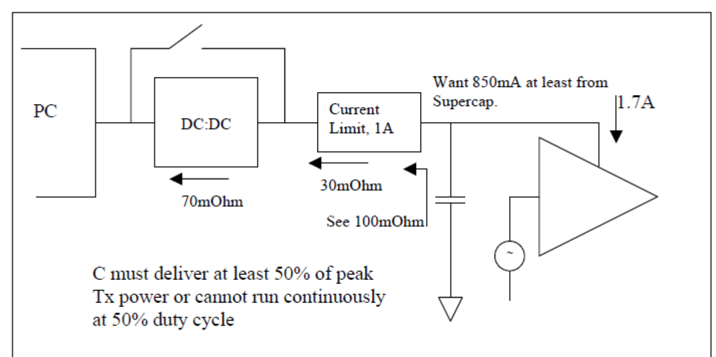
Portable products and smaller value SCs-contd

Powering GPRS/GSM Devices on CompactFlash Cards





Pulsed Load Applications



Source: Cap-XX , Australia

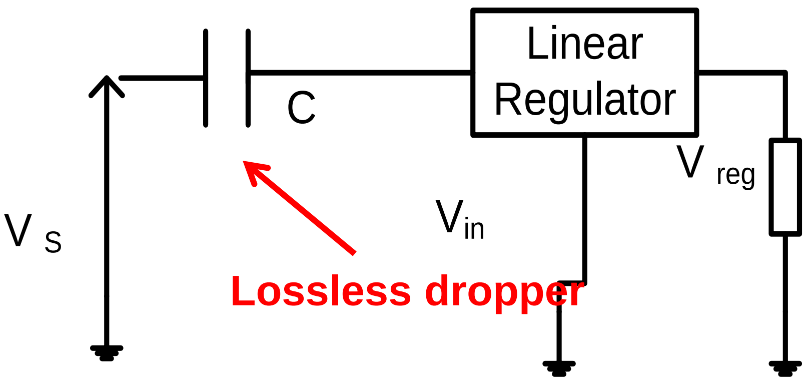
Non-Traditional Applications

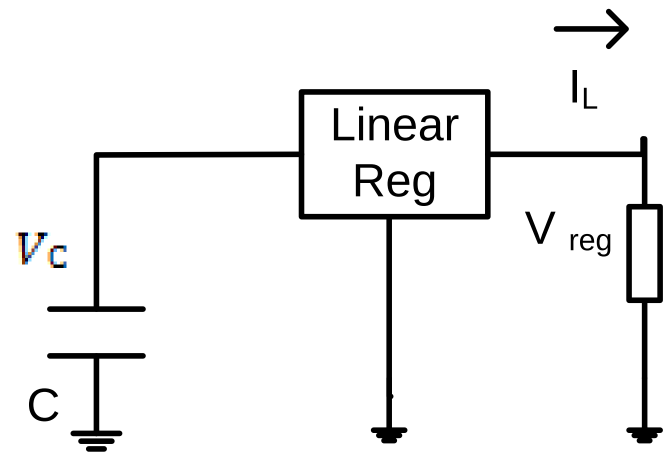
- Within the last 5 years presenter’s team kept developing non-traditional applications

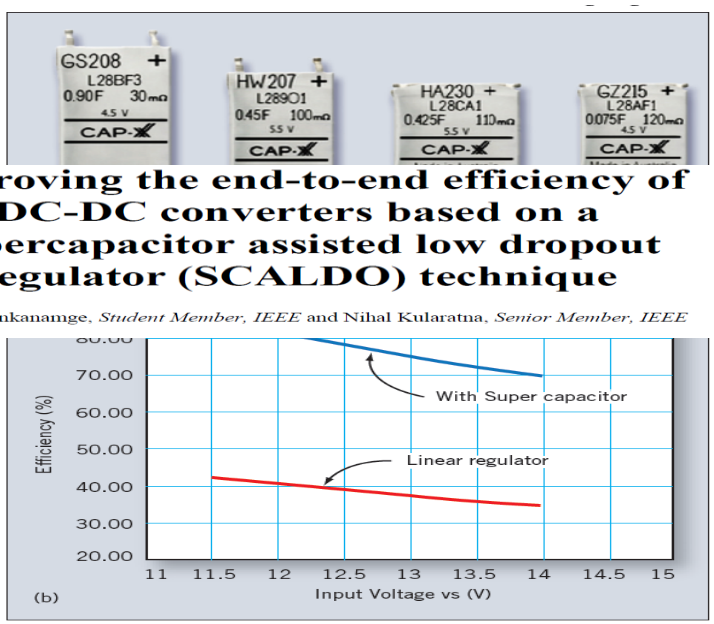
- These are quite different to the common cases we already discussed

- Several successful areas:
  - Use a SC as a lossless voltage dropper in DC-DC Converters
  - SC as a surge absorber
  - SCs in special UPS configurations
  - SCs in in-line water heating applications

Supercapacitor Assisted Low Dropout Regulator (SCALDO)



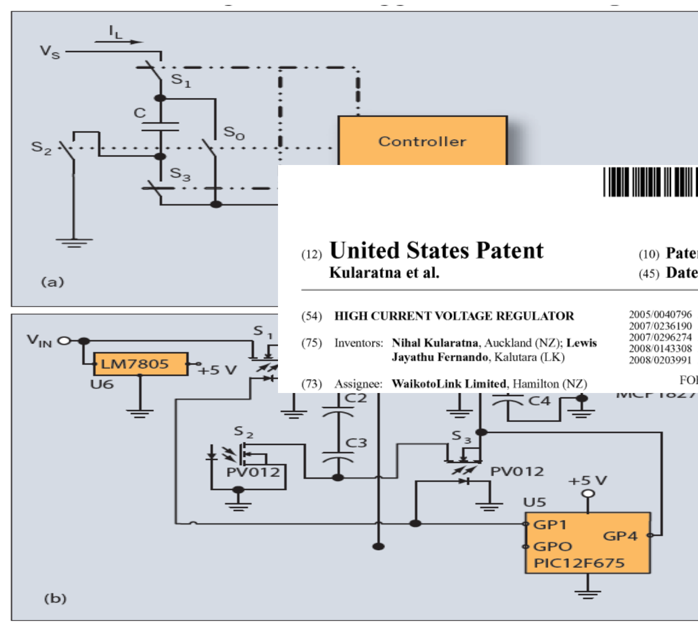




Improving the end-to-end efficiency of DC-DC converters based on a supercapacitor assisted low dropout regulator (SCALDO) technique

Kosala Kankanamge, *Student Member, IEEE* and Nihal Kularatna, *Senior Member, IEEE*

Fig. 3(a) Capacitor size reductions in an early prototype for 12-5V regulator super-caps used. (b) Shows efficiency improvements in 12-5 V regulator supercaps.



US007907430B2

(12) **United States Patent**
Kularatna et al.

(10) **Patent No.:** **US 7,907,430 B2**
(45) **Date of Patent:** **Mar. 15, 2011**

(54) **HIGH CURRENT VOLTAGE REGULATOR**

(75) Inventors: **Nihal Kularatna**, Auckland (NZ); **Lewis Jayathu Fernando**, Kalutara (LK)

(73) Assignee: **WaikotoLink Limited**, Hamilton (NZ)

2005/0040796 A1 2/2005 Sutardja
2007/0236190 A1 10/2007 Kruiskamp et al.
2007/0296274 A1 12/2007 Wang et al.
2008/0143308 A1 6/2008 Hsieh et al.
2008/0203991 A1 8/2008 Williams

FOREIGN PATENT DOCUMENTS

Fig. 4(a) The 12 V to 5V circuit to achieve efficiency improvements shown in Fig. 4(b). The implementation in Fig. 4(b) is shown using a PIC microcontroller.

Supercapacitors’ Ability to Absorb Very High Transient Voltages

Surge Capability Testing of Supercapacitor Families Using a Lightning Surge Simulator

Nihal Kularatna, *Senior Member, IEEE*, Jayathu Fernando, Amit Pandey, and Sisira James, *Student Member, IEEE*

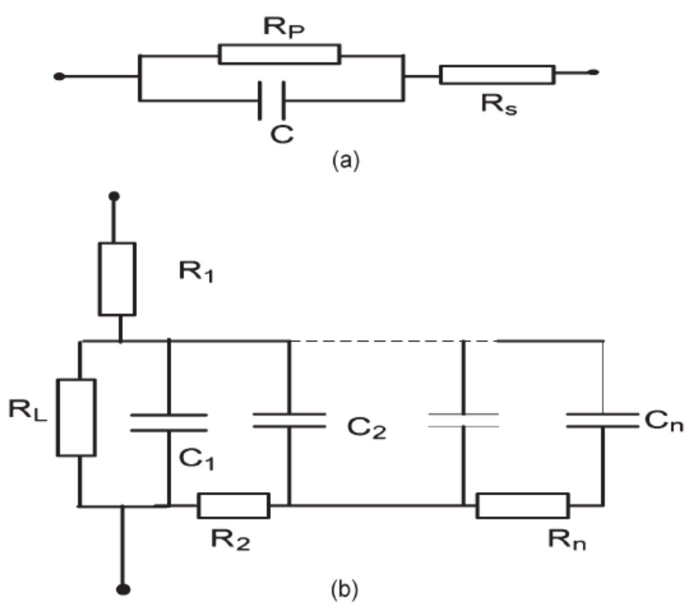


Fig. 2. SC equivalent circuits. (a) Classical equivalent circuit. (b) Ladder circuit.

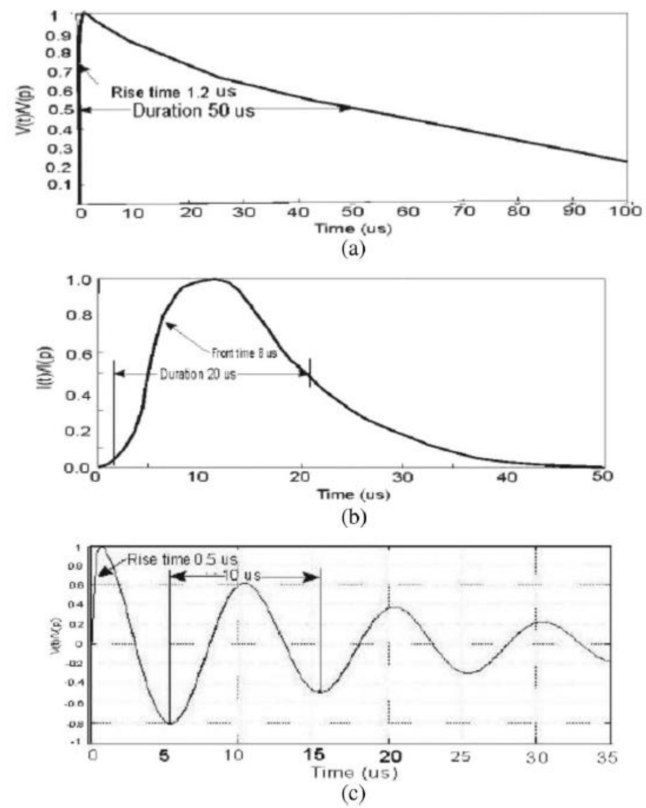


Fig. 3. Few examples of wave shapes defined in surge test standards. (a) Open-circuit voltage waveform. (b) Short-circuit current waveform. (c) Ring wave.

Supercapacitors have very long time constants

Due to their long time constant circuits SCs can absorb kilovolts order surges!

TABLE III
SUMMARY OF THE TEST RESULTS APPLICABLE TO THE THREE SC FAMILIES USED IN THE EXPERIMENT

Device data	LSS output peak voltage	Number of surges to destroy the device			
		No pre-charge	Pre-charge voltage =250mV	Pre-charge voltage =500mV	Pre-charge voltage =1.8V
Cap-xx 0.18F, 2.3V	6.6kV	220 to over 250	Over 220	Over 180	Over 160
Maxwell 230F, 2.5V	6.6kV	No pre-charge	Pre-charge voltage =200mV	Pre-charge voltage =1.0V	Pre-charge voltage =2.5V
		Did not fail after 1000	Did not fail after 600; Charge accumulation was not observed	Did not fail after 600; Over the period of 700 repeated surges 0.1V discharge was observed	Did not fail after 600; Over the period of 700 surges a discharge of 0.2V was observed
NessCap 90F , 2.7V	6.6kV	No pre-charge	Pre-charge voltage =500mV	Pre-charge voltage =1.0V	Pre-charge voltage =2.0V
		Did not fail after 600	Did not fail after 600; No charge accumulation observed	Did not fail after 600; Slight discharge of 0.15V observed during 700 surges	Did not fail after 600; Discharge of approx 350mV was observed over 700 surges.

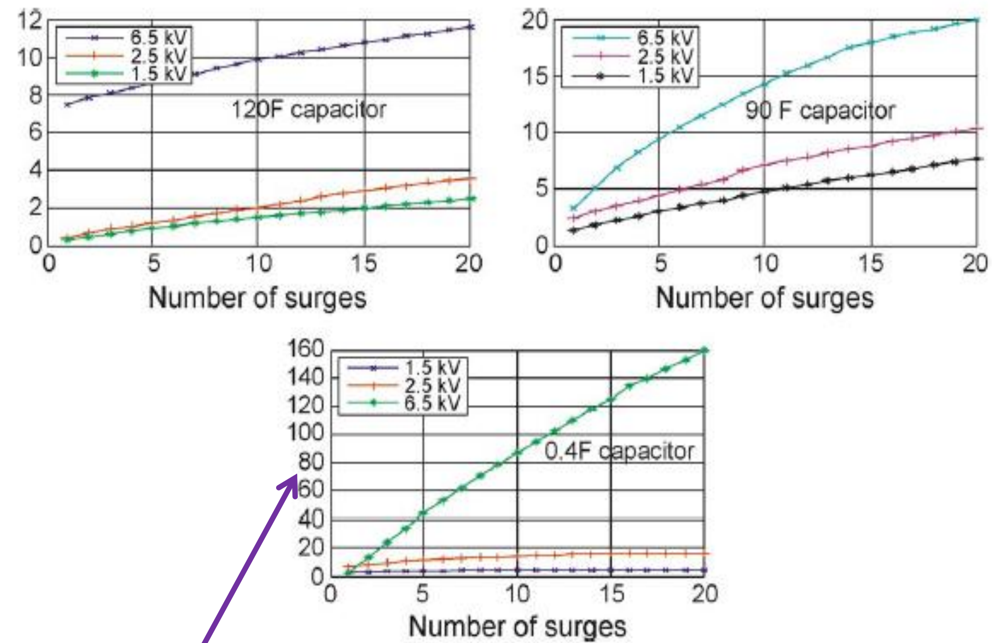
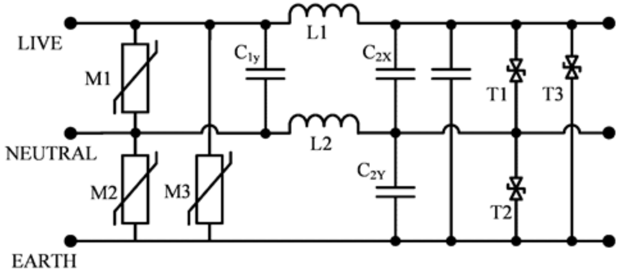


Fig. 1. Terminal voltage development versus number of surges at different peak values of a combined waveform as per IEC 61400-4-5.

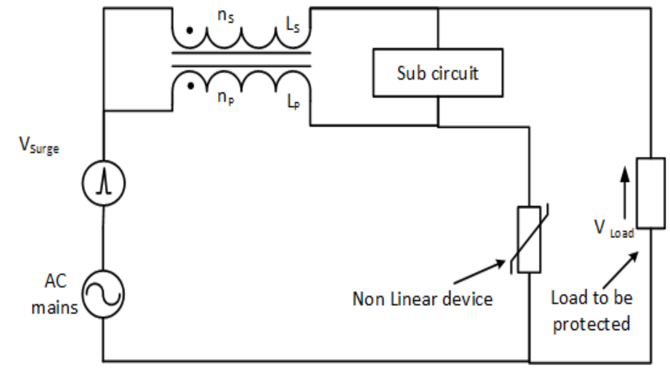
Vertical axes in these graphs are in millivolts!

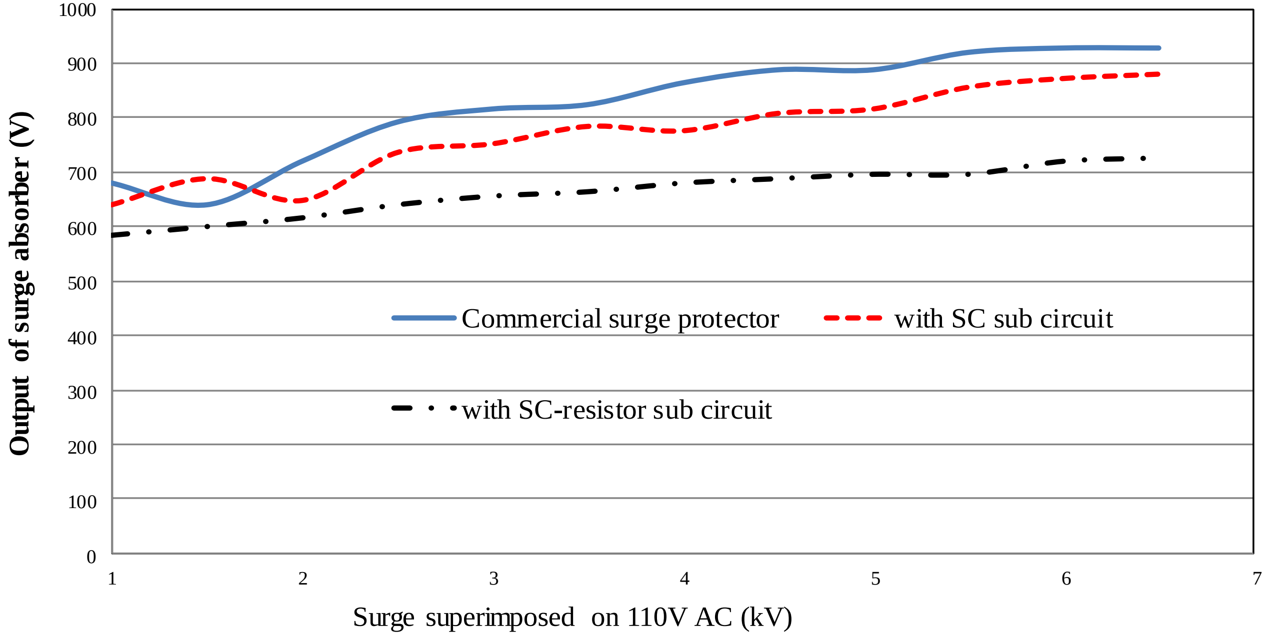
All this tells us that due to very long time constants in charging paths, SC cant be destroyed by short duration transient surge voltages

Comparison of surge absorption capabilities -- commercial versions versus SCASA technique



Typical surge protection circuit





Varistor 20V275, sub circuit of 1Ω Resistor and **25F Supercapacitor**

Surge resistant UPS approaches using SC energy storage

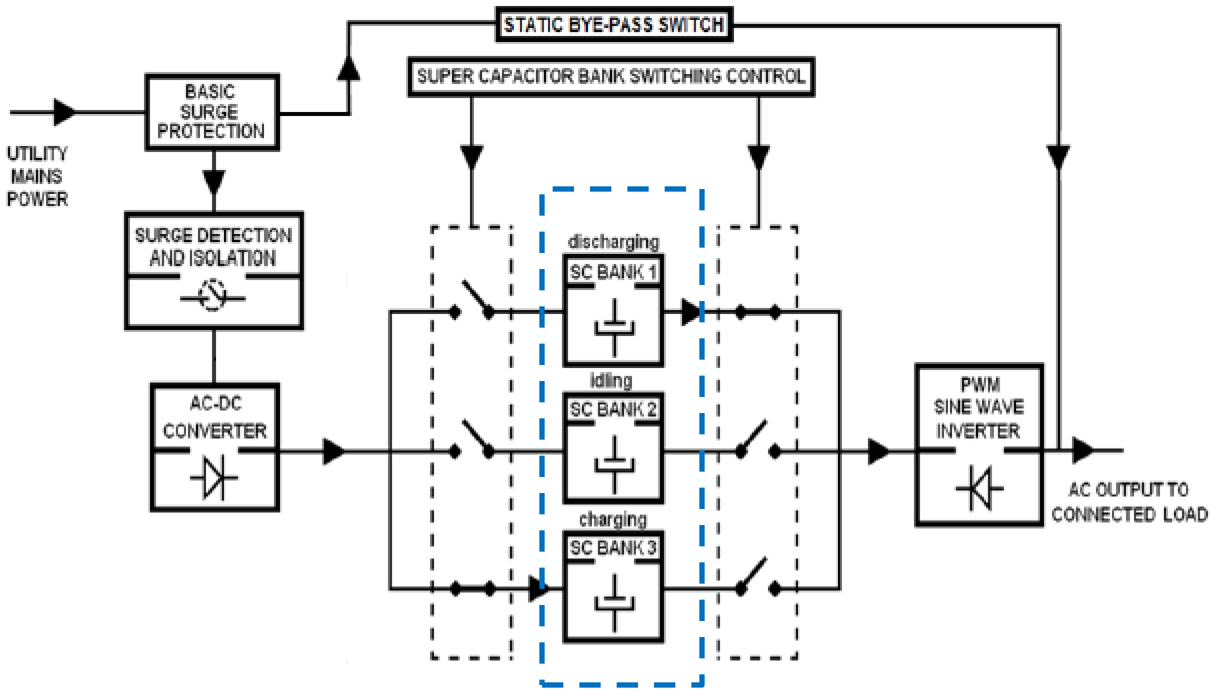
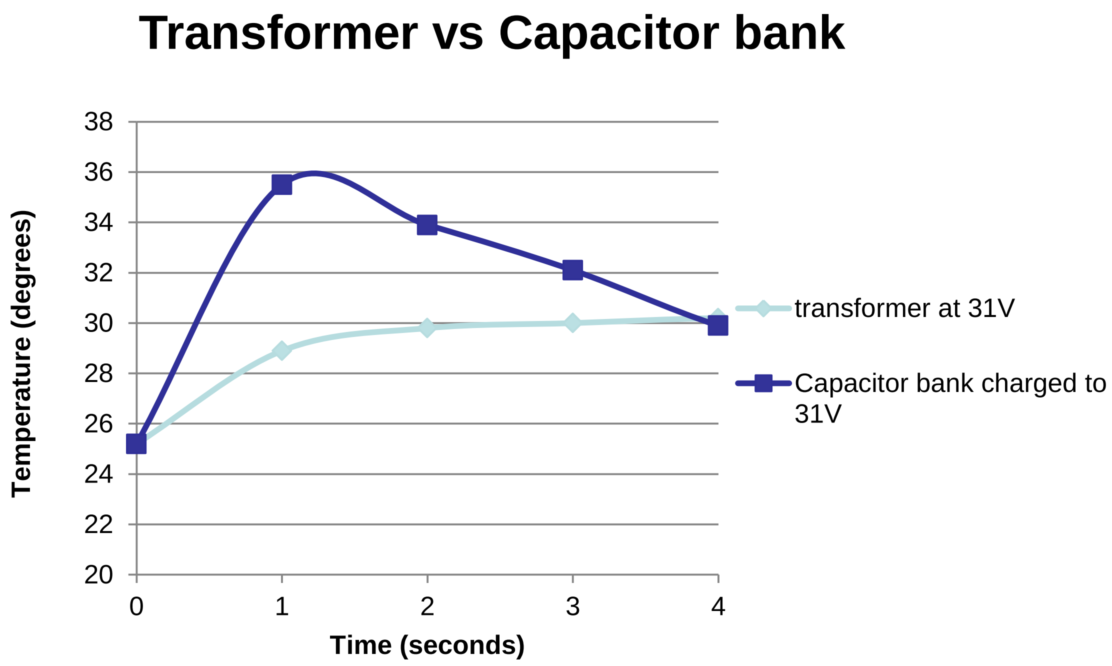


Figure 1.5: Functional block diagram of SRUPS

In SRUPS technique multiple SC banks circulate in charge-discharge cycles to keep electrical isolation for surges.

SC's ability to transfer energy very fast – Can we use it in reducing wasted water ?

- SCs are capable of dumping extreme currents into resistive loads
- They are much better than inductive supplies like – low voltage transformer based circuits



Application- An inline water heating system to fast-heat stored water in domestic pipes between the tap and fast gas heater

SC bank is more effective in heating a fluid by a resistive coil placed inside a pipe line

Basis for the Supercapacitor Assisted Temperature Modification Apparatus (SCATMA)

Lets come to the power engineering area now

Energy Storage in Power Generation Areas- Worldwide Summary

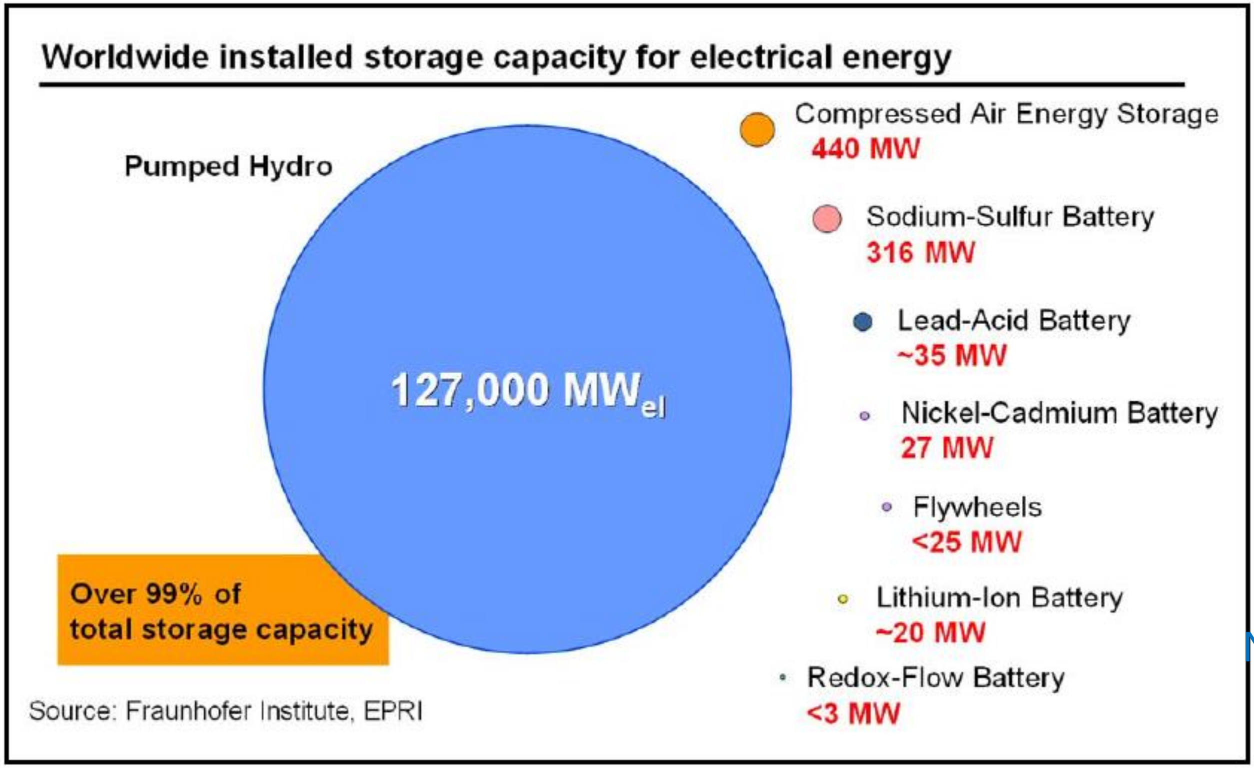


Figure 1
Worldwide Installed Storage Capacity for Electrical Energy

NZ total generation capacity -10,000 MW

PEAK 6500- 7000 MW

Source: Electricity Energy Storage Technology Options- US Govt White paper 1020676, Dec 2010

Positioning of Energy Storage Technologies

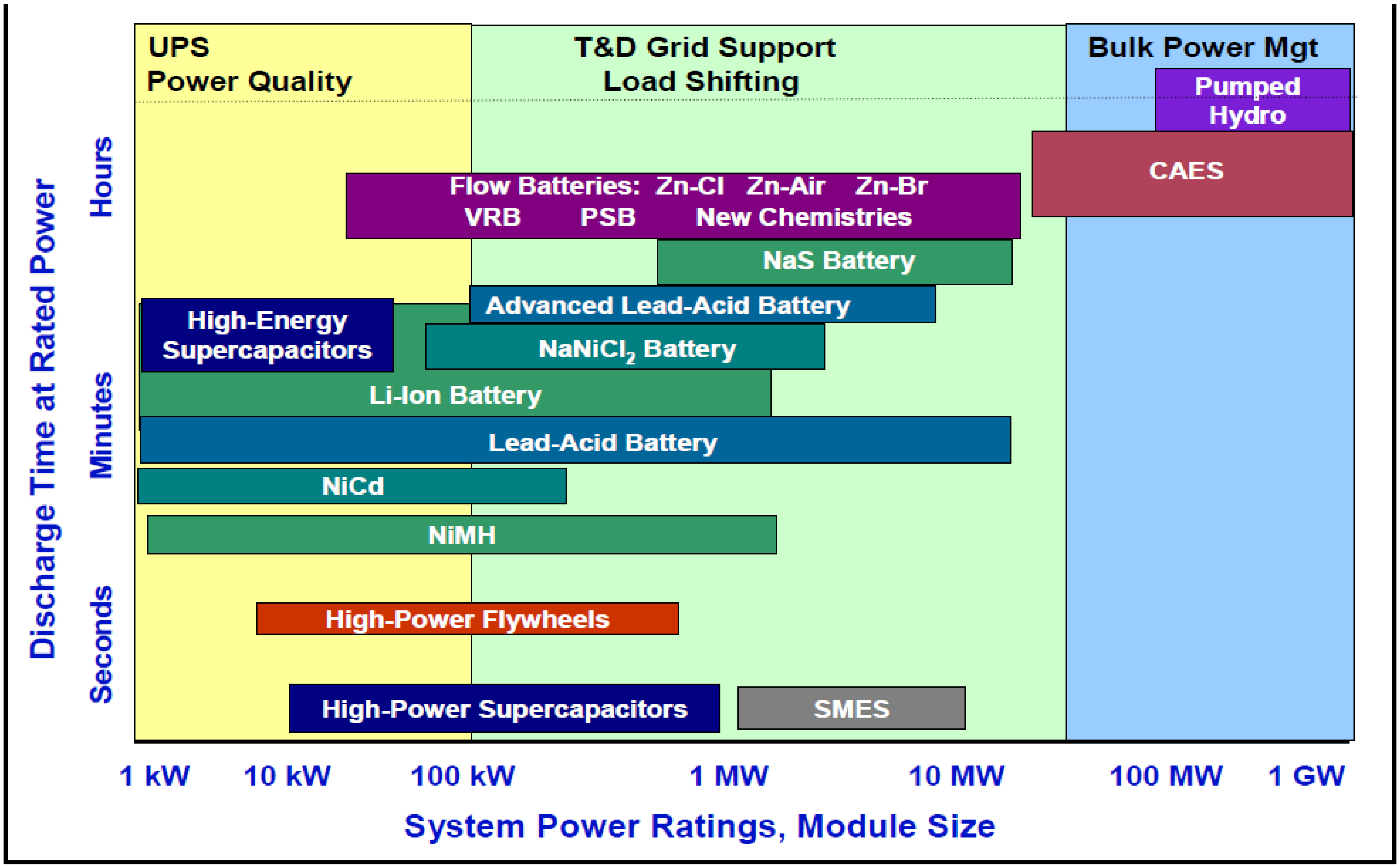


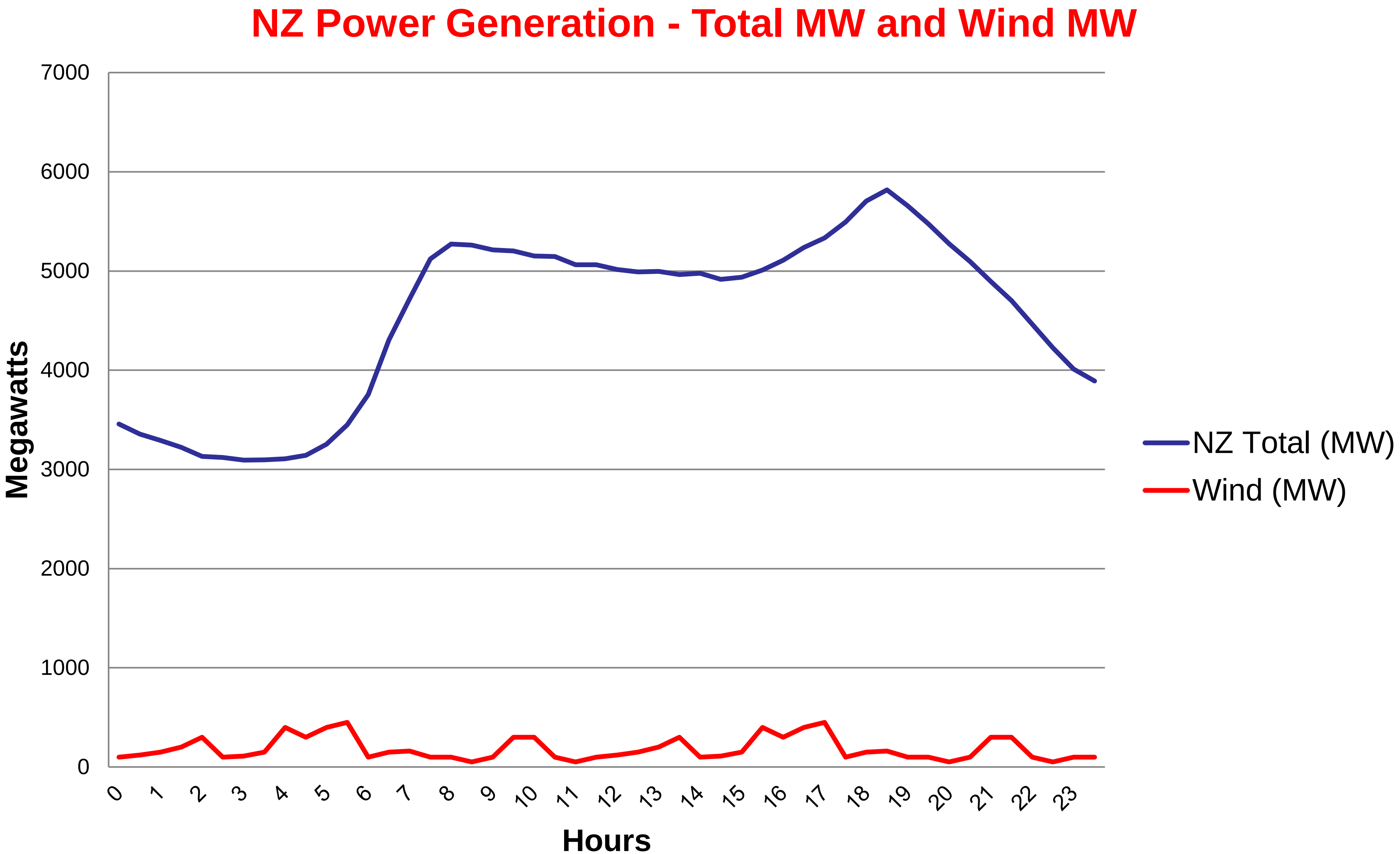
Figure 6
Positioning of Energy Storage Technologies

NZ Electrical Engineer's Observations on Wind Farms

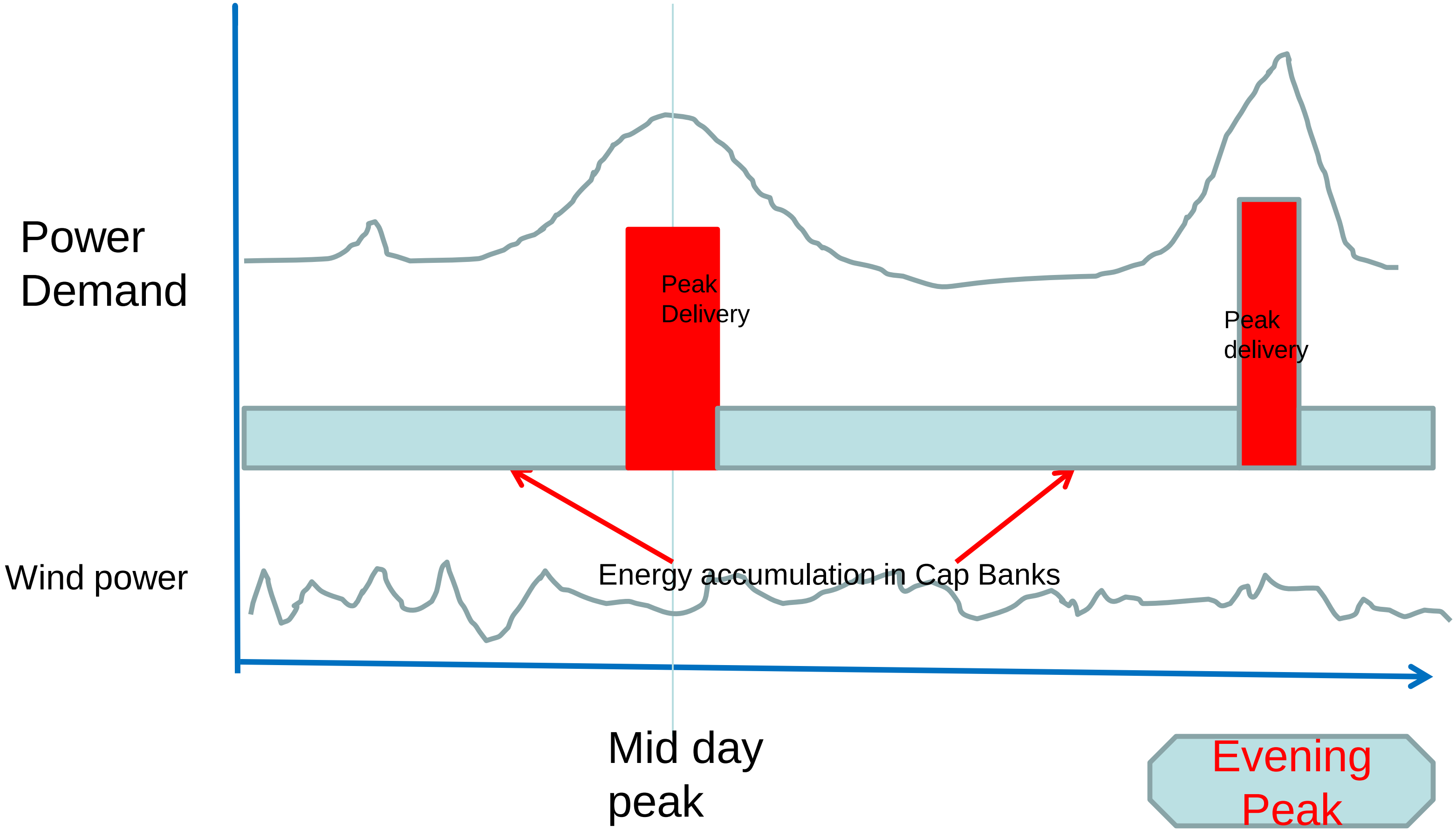
- Not available when the unit price is very high (**Peak demand times**)
- Not Useful at generator outages
- Not worth running during the wholesale energy price is low
- Demand seems to have stalled

SC banks can be configured to deliver kW to MW order powers for very short periods of time!

If so can SCs or SC-battery hybrid systems help in wind farms?


NZ Power Generation - Total MW and Wind MW
Megawatts
7000
6000
5000
4000
3000
2000
1000
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
Hours
NZ Total (MW)
Wind (MW)

Can supercapacitor based solutions to assist both parties



Conclusion

- SC technology is growing fast
- They complement battery chemistries
- Common applications are many & creative new applications are on the horizon
- **An interesting R&D area of applications- for IP Creation!!!**

Can wind farms and NZ power generation authorities can jointly develop a win-win situation based on supercapacitors ??

Thank you…..

Question Time…

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