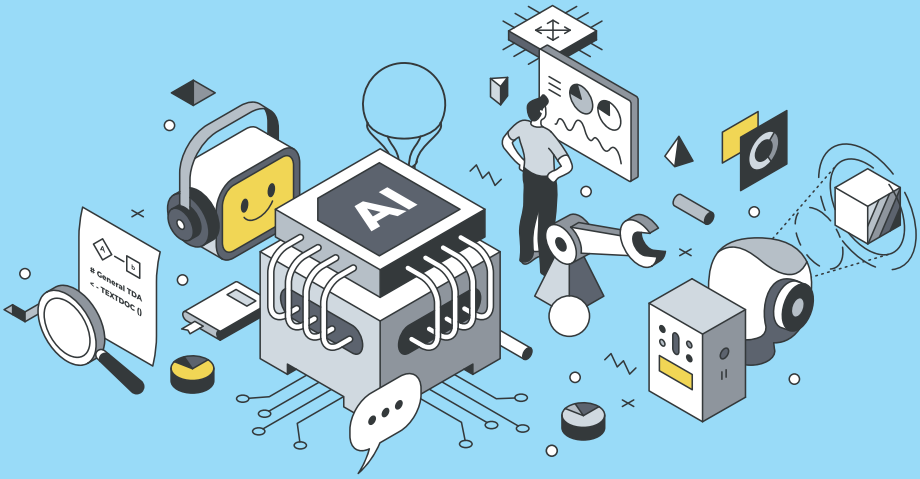


LS ULTRACAPACITOR

LS Ultracapacitor, Leading Solution in AIDC and Grid Energy Storage

LS Materials

Vision Statement

In order to become a leader in the competitive global market LG has been divided into three business groups based upon their core competencies, Industrial Electric-Electronic Energy & Materials(LS), Electronic & Chemical(LG), and Energy & Retail(GS).

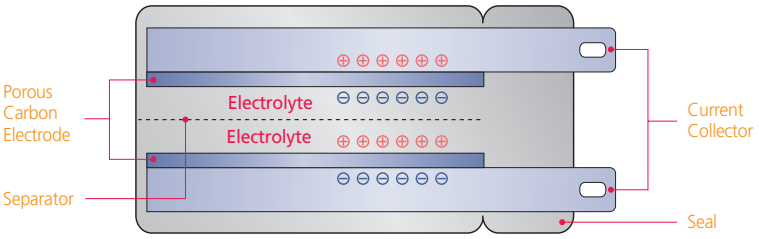
Leading Power Storage Partner - LS Materials

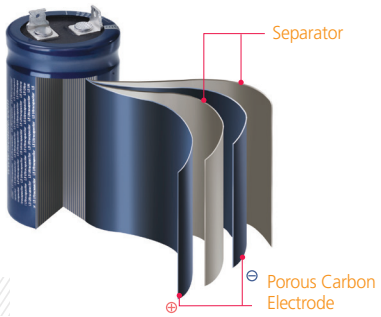
Ultracapacitor division split off from LS Mtron in January, 2021, incorporated a new company named LS Materials in order to solely focus its resources and human capital in the ultracapacitor business. LS has been engaged in research & development, and production of ultracapacitor cells and modules for 20 years, leading the market with its cutting edge power storage solution. It has been serving top tier customers in sectors ranging from renewable energy, industrial automation, to power quality management and automotive. LS Materials, taking over the baton from LS Mtron, will continue the relentless endeavors to develop and provide the most cost-effective power solutions to all of existing and potential customers all across the world.

Introduction to LS Ultracapacitor Technology

Structure

An Ultracapacitor consists of two electrodes immersed in an electrolyte and
a separator which prevents the charge from moving between two electrodes of opposite polarity.



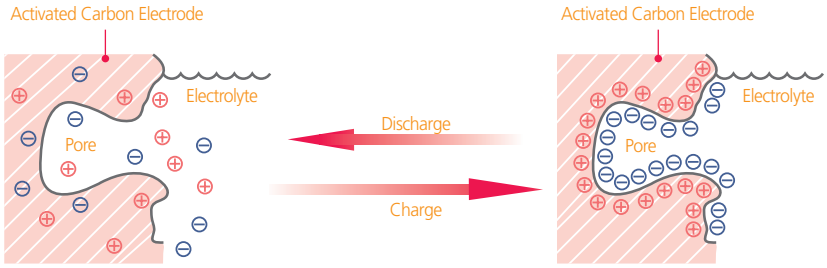


· LS Ultracapacitor Cylindrical Type

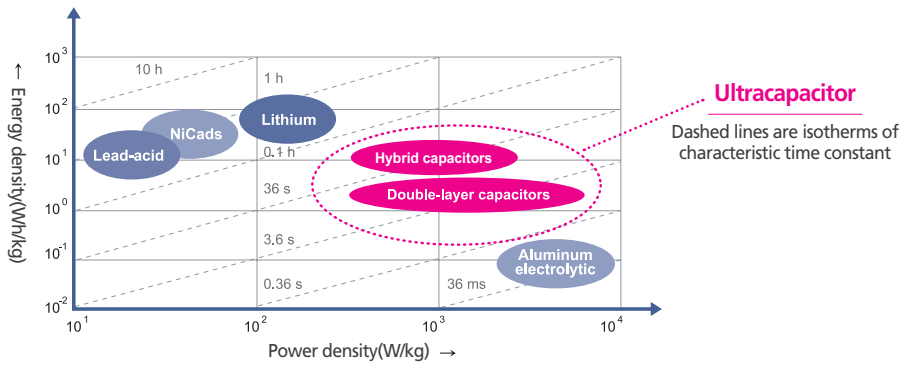
LS Materials provides optimal package design to provide the best in performance and reliability.

High Energy & High Power

Ultracapacitors are unique energy storage devices offering high power and high energy simultaneously, compared with conventional electrolytic capacitors and batteries. The high energy stored by Ultracapacitors in comparison to conventional electrolytic capacitors is derived from activated carbon electrode material having the extremely high surface area and the short distance of charge separation created by the opposite charges in the interface between electrode and electrolyte.



High power, long shelf and cycle life performance of Ultracapacitors originate in the energy storage mechanism differing from batteries. With batteries, energy is stored and released via chemical reaction inside electrode material that causes degradation of the entire system. On the other hand, Ultracapacitors use physical charge separation phenomena between the charge on an electrode and ions in electrolyte at the interface. Since the charge and discharge processes are purely physical and highly reversible, Ultracapacitors can release energy much faster and with more power compared to batteries which rely on slow chemical reactions and can be cycled hundreds of thousands of times without significant effect on performance.



Ultracapacitor VS LIB

Ultracapacitor

Fast and Versatile

Physical absorption-desorption

- Specific energy : ~15 Wh/kg
- Operation Temperature : -40 ~ 85°C
- Charge/discharge efficiency : 99.2 ~ 99.8%
- Specific Power : ~18 kW/kg
- Cycle durability : 1000k Cycles

Li-ion Battery

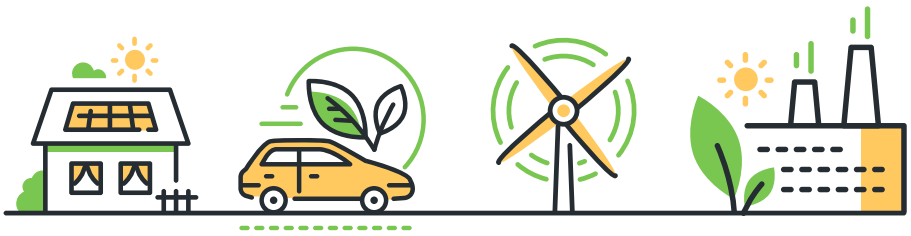
High Energy

Chemical reaction

- Specific energy : ~200 Wh/kg
- Operation Temperature : 0 ~ 45°C
- Charge/discharge efficiency : 80 ~ 90%
- Specific Power : 0.2 ~ 0.4 kW/kg
- Cycle durability : 0.4k Cycles (100% DoD basis)

Ultracapacitor + Li-ion Battery

By combining Ultracapacitor and Li-ion battery



Ultracapacitor provides substantial benefits in terms of performances battery life and energy economy

- To improve the application efficiency and energy economy over variable operating conditions
- To assure reliable performance and fast response even with battery degradation
- To extend battery life by shaving peak load

Cell LS Materials has more than 45 types of cells in mass production

22Ø Series PCB mounting type cell

Series	Rated Voltage	Capa citance	Part No.	Max. ESR(DC)	Max. Current	Leakage Current	Max. Stored Energy	Weight	Type	Dimension	
	V	F		mΩ	A	mA	Wh	kg		Ø x mm	
22 Ø	2.8	100	LSUC 002R8S 0100F EA	9.0	74	<0.3	0.10	0.023	Snap-in	22 x L46	
		120	LSUC 002R8S 0120F EA	9.0	81	<0.4	0.13	0.023		22 x L46	
	3.0	100	LSUC 003R0S 0100F EA	7.0	88	<0.3	0.13	0.023		22 x L46	

33Ø Series PCB mounting type cell

Series	Rated Voltage	Capa citance	Part No.	Max. ESR(DC)	Max. Current	Leakage Current	Max. Stored Energy	Weight	Type	Dimension
	V	F		mΩ	A	mA	Wh	kg		Ø x mm
33 Ø	2.8	360	LSUC 002R8L 0360F CU03	3.2	234	<1.0	0.39	0.065	Lug	33 x L61

35Ø Series PCB mounting type cell

Series	Rated Voltage	Capa citance	Part No.	Max. ESR(DC)	Max. Current	Leakage Current	Max. Stored Energy	Weight	Type	Dimension	
	V	F		mΩ	A	mA	Wh	kg		Ø x mm	
35 Ø	2.8	320	LSUC 002R8L 0320F EM	2.0	273	<1.0	0.34	0.078	Lug	35 x L61	
		350	LSUC 002R8L 0350F EA	3.2	231	<1.0	0.38	0.072	Lug or Snap-in	35 x L61	
		400	LSUC 002R8L 0400F EA	3.0	255	<1.0	0.43	0.080		35 x L66	
		450	LSUC 002R8L 0450F EA	3.0	268	<1.0	0.49	0.088		35 x L71	
		600	LSUC 002R8L 0600F EA	3.2	288	<1.3	0.65	0.090		35 x L71	
		720	LSUC 002R8L 0720F EA	2.0	413	<1.5	0.78	0.130		35 x L105	
	3.0	360	LSUC 003R0L 0360F LE	**1.7**	335	<1.0	0.45	0.080	Lug	35 x L61	New!!
		380	LSUC 003R0L 0380F EA	3.2	257	<1.0	0.47	0.072	Lug or Snap-in	35 x L61	
		430	LSUC 003R0L 0430F EA	3.0	282	<1.0	0.53	0.080		35 x L66	
		480	LSUC 003R0L 0480F EA	3.0	295	<1.2	0.60	0.088		35 x L71	
		600	LSUC 003R0L 0600F EA	3.2	308	<1.5	**0.75**	0.090		35 x L71	New!!

60Ø Series Busbar connection type cell

Series	Rated Voltage	Capa citance	Part No.	Max. ESR(DC)	Max. Current	Leakage Current	Max. Stored Energy	Weight	Type	Dimension	
	V	F		mΩ	A	mA	Wh	kg		Ø x mm	
60 Ø	2.7	650	LSUC 002R7C 0650F NH	0.57	640	<1.5	0.65	0.200	Cylindrical	60 x L51.5	
		1200	LSUC 002R7C 1200F NH	0.33	1160	<2.7	1.21	0.280		60 x L74	
		1500	LSUC 002R7C 1500F NH	0.28	1426	<3.0	1.51	0.320		60 x L85	
		2000	LSUC 002R7C 2000F NH	0.27	1753	<4.0	2.02	0.380		60 x L102	
		3000	LSUC 002R7C 3000F NH	0.20	2531	<5.0	3.03	0.515		60 x L138	
	2.85	3400	LSUC 02R85C 3400F NH	0.23	2719	<8.0	3.83	0.515		60 x L138	
	3.0	3000	LSUC 003R0C 3000F NH	0.20	2813	<5.0	3.75	0.515		60 x L138	
		3400	LSUC 003R0C 3400F NH	0.20	3000	<8.0	4.25	0.515		60 x L138	
		3400	LSUC 003R0C 3400F LE	**0.14**	3400	<8.0	4.25	0.515		60 x L138	New!!
		4000	LSUC 003R0C 4000F NH	0.23	3125	<8.0	**5.00**	0.515		60 x L138	New!!

• Max. Current : Non-repeated (Calculated value)

• Operating Temperature Range : -40 ~ 65˚C

Products

• 22/33/35 ⌀ Series Cell

Lug & Snap-in Terminal Type (22/33/35 Ø Series)

• Snap-in (100F/ 120F)

• Lug (320F ~ 720F)

• Snap-in (4pin, 350F ~ 720F)

• 60 ⌀ Series Cell

Cylindrical Terminal Type (60 ø Series)

• Short Screw (ST01)

• Weldable (WT01)

• Long Screw (LT01) M16 Terminal

• Long Screw (LT02) M12 Terminal

Cell/Module Part No. Rule

LS □□ □□□R□□ □□□□F □□ (□□□□)

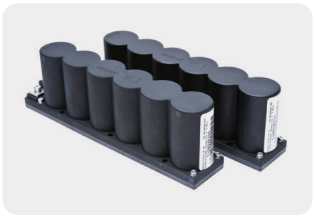
- **LS □□**
  - • Code U
  - • Product(Cell) - Code C
  - • Product(Module) - Code M
- **□□□R□□** • Voltage
- **□□□□F** • Capacitance
- **□□** • Internal Code
- **(□□□□)** • Internal Code
- **□** (Cell Type)
  - • Cell Type(Snap-in) - Code S
  - • Cell Type(Lug) - Code L
  - • Cell Type (Cylindrical) - Code C

Module LS Materials has more than 20 types of modules in mass production

PCB type series

PCB type series is modules built up with Ø22, Ø33 and Ø35 series cells on PCB board

Part No.	Rated Voltage	Capa citance	Max. ESR(DC)	Max. Continuous Current	Leakage Current	Stored Energy	Weight	Balancing	Monitoring	Dimension
	V	F	mΩ	A	mA	Wh	kg			L x W x H(mm)
LSUM 016R8L 0058F EA	16.8	58	22	20	<11.0	2.3	0.7	Active or Passive	-	245 x 47 x 76.6
LSUM 168R0L 0005F EA	168	5.8	240	12	<25.0	22.7	6.5	Passive	Temperature(NTC)/Half Voltage monitoring	235 x 367 x 79



LSUM 016R8L 0058F EA

LSUM 168R0L 0005F EA

Busbar type series

Busbar type Series is modules built up with 60Ø series cells connected with busbar

Part No.	Rated Voltage	Capa citance	Max. ESR(DC)	Max. Continuous Current	Leakage Current	Stored Energy	Weight	Balancing	Monitoring	Dimension
	V	F	mΩ	A	mA	Wh	kg			L x W x H(mm)
LSUM 016R2C 0500F EA	16.2	500	1.5	200	<5.0	18.2	5.6	Active or Passive	Temperature(NTC)	67.2 x 416.2 x 175.9
LSUM 032R4C 0250F EA	32.4	250	3.3	150	<11.0	36.5	10.0	Passive	-	137.1 x 426.6 x 184
LSUM 048R6C 0166F EA DC	48.6	166	4.4	130	<5.0	54.5	14.0	Active or Passive	Temperature (NTC)/Over Voltage	194.5 x 419.5 x 177
LSUM 051R3C 0166F EA	51.3	166	5.0	100	<28.5	60.7	12.0	Active and Passive	Temperature (PTC)/Over Voltage	590.4 x 136 x 171
LSUM 086R4C 0093F EA	86.4	93	11.3	80	<120.0	96.4	27.0	Passive	Temperature (PT100)	517 x 265 x 210.5
LSUM 129R6C 0062F EA	129.6	62	11.5	240	<10.0	144.6	55.0	Active or Passive	Temperature & Group Voltage(CAN 2.0B)	720 x 405 x 226
LSUM 054R0C 0188F EA AMD1	54	188	4.4	230	<9.0	76.4	14	Smart (active + passive)	**Temperature & Single cell voltage (CAN2.0B)**	194.5 x 419.5 x 177 New!!
LSUM 144R0C 0070F EA	144	70	8.1	-	<8.0	204	38.6	Smart (active + passive)	**Temperature & Single cell voltage, SoH, SoA (CAN J1939)**	482 x 174 x 597.4 (4U) New!!

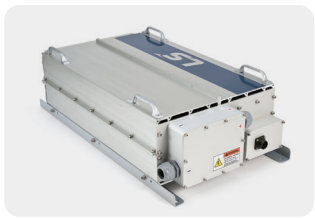
LSUM 016R2C 0500F EA

LSUM 032R4C 0250F EA

LSUM 048R6C 0166F EA DC

LSUM 051R3C 0166F EA

LSUM 086R4C 0093F EA



LSUM 129R6C 0062F EA

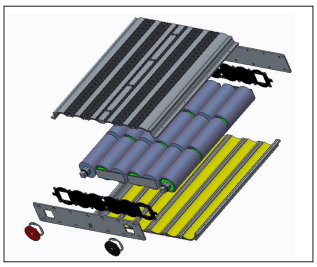
LSUM 054R0C 0188F EA AMD1

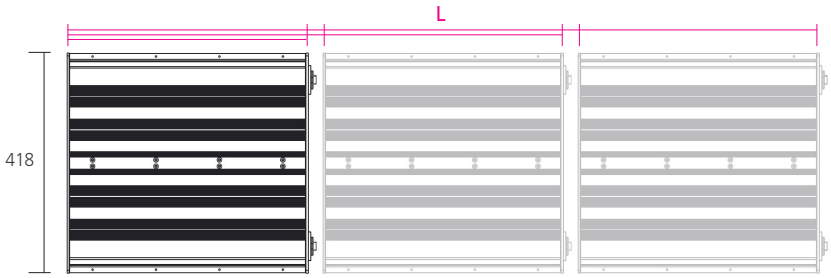
LSUM 144R0C 0070F EA

- Leakage Current can be changed by Balancing method
- Customized module can be supplied under the customer's requirement
- Max Continuous Current may be different depending on the cooling method
- NTC Thermistor & Group voltage monitoring is analog method
- Max Continuous Current : $\Delta T = 40^{\circ}C$

CTC Description

The CTC (Cell-to-Cell) series module features an aluminum case that is in contact with all cells, **ensuring excellent heat dissipation and the ability to withstand heavy cycling.** Additionally, the case size can be adjusted along the module's length to accommodate various customer requirements.





Monitoring for CTC series module

Temperature sensor	Temperature interface	Connector	Cell voltage monitoring	Balancing
NTC Thermistor	Analog	4pin	OVA(Optional)	Active or Passive

CTC series

CTC (Cell To Cell) series module is available from 16V to 108V, is extendable and customizable without additional costs to the customer

Part No.	Adapted Cell Module			Rated Voltage	Capa citance	Max. ESR(DC)	Max. Continuous Current	Leakage Current	Stored Energy	Weight	Dimension
	Rated Voltage	Capacitance	Series								
	V	F		V	F	mΩ	A	mA	Wh	kg	L x W x H(mm)
LSUM 048R6C 0066F EA YJ	2.7	1200	18	48.6	66	7.2	160	< 2.7 (Active)	21.7	10.3	279 x 418 x 71
LSUM 064R8C 0050F EA YJ			24	64.8	50	9.6	130	< 27 (Passive)	29.1	13.2	362 x 418 x 71
LSUM 048R6C 0083F EA YJ		1500	18	48.6	83	6.1	180	< 3.0 (Active)	27.2	11.5	312 x 418 x 71
LSUM 064R8C 0062F EA YJ			24	64.8	62	8.1	140	< 27 (Passive)	36.1	14.8	406 x 418 x 71
LSUM 048R6C 0111F EA YJ		2000	18	48.6	111	5.9	180	< 4.0 (Active)	36.4	13.5	363 x 418 x 71
LSUM 064R8C 0083F EA YJ			24	64.8	83	7.8	150	< 27 (Passive)	48.4	17.5	474 x 418 x 71
LSUM 048R6C 0166F EA YJ		3000	18	48.6	166	4.4	200	< 5.0 (Active)	54.5	17.2	471 x 418 x 71
LSUM 064R8C 0125F EA YJ			24	64.8	125	5.8	160	< 27 (Passive)	72.9	22.5	618 x 418 x 71
LSUM 016R2C 0250F EA AG	2.7	1500	6	16.2	250	2.0	150	< 3.0 (Active) < 27 (Passive)	9.1	3.9	311 x 166 x 70
LSUM 016R2C 0500F EA AG		3000			500	1.5	200	< 5.0 (Active) < 27 (Passive)	18.2	5.9	470 x 166 x 70

LSUM 048R6C 0166F EA YJ

LSUM 016R2C 0500F EA AG

LSUM 016R2C 0250F EA AG

UltraGrid

LS UltraGrid (19" Rack)

MW-scale Ultracapacitor ESS for Enhanced STATCOM

Supplying several hundred MW of active power
as a reliable ESS for Enhanced STATCOM

- Smart Single Cell Balancing
- Module to Module Balancing Algorithm
- Rack to Rack Balancing Algorithm
- SoH / SoA Software (Life Simulation)
- CMS (Capacitor Management System)

Specification

• Voltage	1,440V
• Capacitance	7.1F
• Max. DC ESR	88mΩ
• Max. Current	3.1kA
• Number of Units	10 Rack modules + 1 CPU module
• Size	600W x 700D x 2100H mm - 44U(19")

LS UltraGrid Module (19" Rack Module)

- CAN 2.0B communication & Remote FW Update
- 19" Rack-Compatible
  (Designed for industrial Standard Cabinets)
- Smart Single Cell Balancing

Specification

• Voltage	144V
• Capacitance	70.8F
• Max. DC ESR	8.1mΩ
• Max. Current	3.2kA
• Number of Units	3V 3400F cell in 48series
• Size	482W x 597.4D x 174H mm - 4U(19")

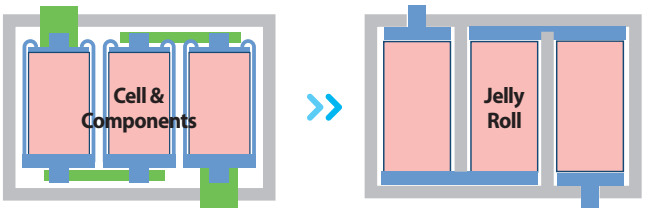
CellDule

CellDule 16.2V 200F

Innovation Structure Jelly Roll directly into the Module High Voltage & Capacitance cell with Module - Level performance

CELLDULE™
LS ULTRACAPACITOR

50% ↓ Module Components Manufacturing Procedures



- Existing Module - - CellDule -

Advantage

Cost Effectiveness	Double Power Density	Double Energy Density	Compact Size & Lightweight	Quality Improvement

Specification

- Stored Energy 7.29Wh (4.05/kg)
- Size 1.8kg / 258.5L x 168.5W x 47.5H mm
- Max. DC ESR 4.0mΩ
- Max. Current 1,000A

	CellDule 16.2V 200F	LSUM 016R2C 0200F EA AG	LSUM 016R2C 0200F EA MH
Size(mm)	258.5 x 168.5 x 47.5	278.1 x 166 x 71	416.2 x 67.2 x 111.9
Weight(kg)	1.8kg	3.6kg	3.2kg
Stored Energy(Wh)	7.29Wh	7.29Wh	7.29Wh
Energy Density (Wh/kg)	4.05Wh/kg	2.03Wh/kg	2.29Wh/kg
Energy Density (Wh/L)	3.95Wh/L	2.36Wh/L	2.82Wh/L

Markets for LS Ultracapacitors

AGV

- Numerous charge & discharge cycles, long life span
- Peak power shaving, minimizing power infrastructure investment
- Energy saving

Wind Turbine

- Maintenance free in all environments and long service life
- Ultra-safe, eliminating concerns for fire or explosion

Power Quality Solution (UPS)

- Instant back up for voltage sag or dip
- Maintenance free for up to 20 years
- Ultra-safe, eliminating concerns for fire or explosion

Hybrid Heavy Equipment

- Peak power shaving, downsizing motor and engine requirement
- Improve fuel economy and meet emission regulations
- Long service life and maintenance free

Passenger Car and Vehicle

- Stabilize DC power supply and extend battery life
- Improve fuel economy by reducing alternator loadings
- Jumpstart in all seasons

Transportation

- Numerous charge & discharge cycles, maintenance free
- Capture regenerative braking energy, improving energy efficiency
- Ultra-safe, eliminating concerns for fire or explosion

Hybrid Harbor Crane

- Peak shaving and reduction, improving crane reliability
- Significant savings in power infrastructure investment
- Long term return in energy savings

HEV (Hybrid Electric Vehicle)

- Provide peak power, extending battery life
- Capture regenerative braking energy
- Jumpstart in all seasons

Photovoltaic and Solar Lighting

- Provides a reliable ESS solution in extreme environments
- Long service life and maintenance free

Power Grid

- Improving inertia for power grid of renewable energy
- Supplying active power to power grid
- Space-saving compared to LIB due to the ultracapacitor's high power

ESS

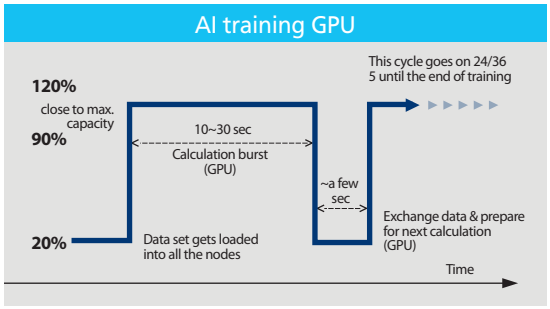
- Reduction maintenance cost by initial out put power and long life cycle
- Ultra-safe, eliminating concerns for fire or explosion

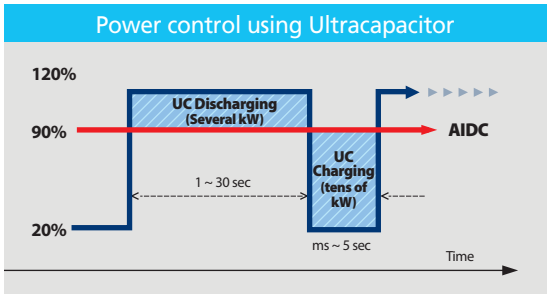
Railway Signal

- Outstanding operating temperature range (-45°C~ 60°C)
- Reduction maintenance cost due to its numerous charge & discharge cycles

AIDC & Grid Forming Solution

AI Data Center UC Solution





Technical Challenge

The power load pattern of GPUs fluctuates significantly, making it difficult for existing power systems to respond effectively, and potentially causing damage to the power grid.

- The grid power cannot keep up with the rapidly changing GPU load patterns
- Leading to increased risks of voltage drops and arc flashes.
- This can cause upstream circuit breakers to trip or power connections to be interrupted.
- In the worst-case scenario, this could lead to widespread blackouts, causing damage on a regional or even national scale.

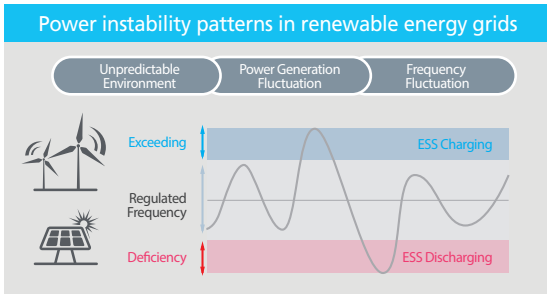
AI Data Center UC Solution

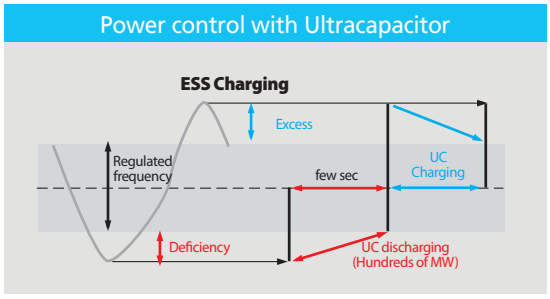
The power load of GPU clusters can be managed stably by utilizing UC with fast charge/discharge speeds, high power output, and long lifespan characteristics

- To reduce the load and respond to peak power demands, charging and discharging tens of kW within a few seconds is required
- Multiple charge and discharge cycles are required within a minute, which means approximately 1 million cycles may be needed annually

UC is the only energy storage solution capable of handling over 1 million charge-discharge cycles and supplying tens of kW within a few seconds.

Grid Forming(Enhanced STATCOM)





Technical Challenge

As renewable energy sources increase, the stability of the grid becomes a concern, potentially causing damage to the power network.

- Sudden load fluctuations cause temporary frequency variations, resulting in significant shocks to the grid.
- Due to the lack of inertia, it is impossible to compensate for the instability of the power system.
- In the worst-case scenario, this could lead to widespread blackouts, causing damage on a national disaster scale.

Grid Forming UC Solution

UC with fast charge/discharge speeds, high power output, and long lifespan characteristics can quickly and reliably respond to load variations in the national power grid

- UC can provide active power to inertia-less renewable energy grids.
- They can supply several hundred MW of power within a few seconds, requiring a system lifespan of 20 years.

The high power output and long lifespan characteristics of UC make them an effective Energy Storage Solution for supplying active power to power grids.

LS Materials Sales Network

2001~2005

2005 Research and development kick off at LS Cable
2005 Set-up of pilot line in Anyang-factory
2005 Development of 2.8V EDLC with 3000F
2002 Research and Development into ultracapacitor started at LG Cable

2006~2010

2008 LS Mtron bringing UC team separated from LS Cable
2008 LS Cable was divided into three companies (LS Mtron, LS Cable and LS Holdings)
2007 TS 16949:2002 was certificated by UL Inc.
2006 Set-up of mass production line in Gumi-factory

2011~2015

2014 Successfully developed Cell t
2014 Set-up of automation Cylind
2013 3000F large cell production
2013 Mass production line moved
2011 The world's first developmer

Capability

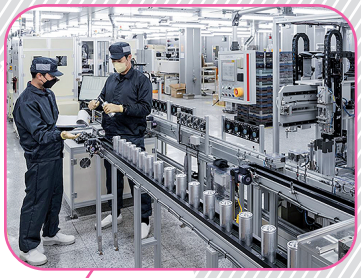
· Φ22~Φ35 Series Cell : 6Million/Year

· Φ60 Series Cell : 1.5million/Year

Major Plants

· Global No.1 ultracapacitor manufacturer

· Develop high-voltage, ultra-low resistance products, and new technology-applied modules



USA

Mexico

Brazil

2016~2020

2020 Launched and put into mass production 3400F 3V cell
2018 Launched and put into mass production 3000F 3V cell
2016 Starting mass production of 3V series medium cells up to 480F
2016 Launch of 2.85V 3400F Cylindrical type cell
2016 Development of 3V EDLC with Lug type

to Cell connection module and patented globally
rical type cell line
lines expanded and fully automated
l to LS Mtron Hi-tech Center in Anyang
nt of 3V EDLC

2021~

2024 Mass production of 3V 4000F cell
2023 Introducing LS UltraGrid
2023 LS Materials IPO in Korean stock market (KOSDAQ)
2023 Launch of Low ESR 3V 360F cell
2021 LS Materials spun off from LS Mtron with UC team

LS Tower, Hi-Tech Center, 2nd Factory

Head office, Ultracapacitor plant

LS ULTRACAPACITOR

LS Materials
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