ENERGY CAPACITORS

POWER GRID STABILIZATION

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NEXT STOP

ENERGY CAPACITORS

ENERGY CAPACITORS

Double-Layer-Capacitor
EDLC

Lithium-Ion-Capacitor
Li-C

THE CONCEPT

- A suitable energy store for the desired requirement
- High power density and energy density
- Stability and safety
- Application determines use of technology

2. BENEFITS OF **ENERGY-C**

- High Power density
- High Energy density
- High cell voltage up to 4V
- > 500,000 charge- / discharge-cycles
- Wide temperature range from -40°C to +85°C
- Low self-discharge
- Safe! (No risk of burning – explosion-proof)

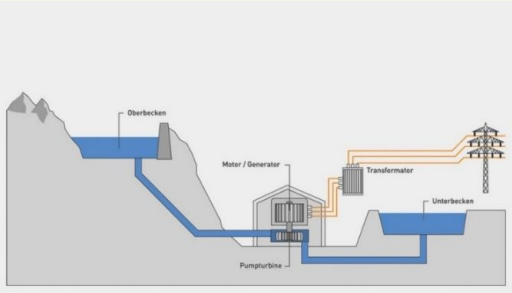
NEXT STOP

TECHNOLOGY COMPARISON

3. TECHNOLOGY COMPARISON – **ENERGY STORAGE**

1. Conversion of electrical energy

   - *Potential energy (pumped-storage power station)*
   - *Electrochemical energy (battery)*
   - *Chemical energy (hydrogen)*
   - *Thermal energy (steam reservoir)*
   - *etc.*



→ **Dissipation losses limited the efficiency**

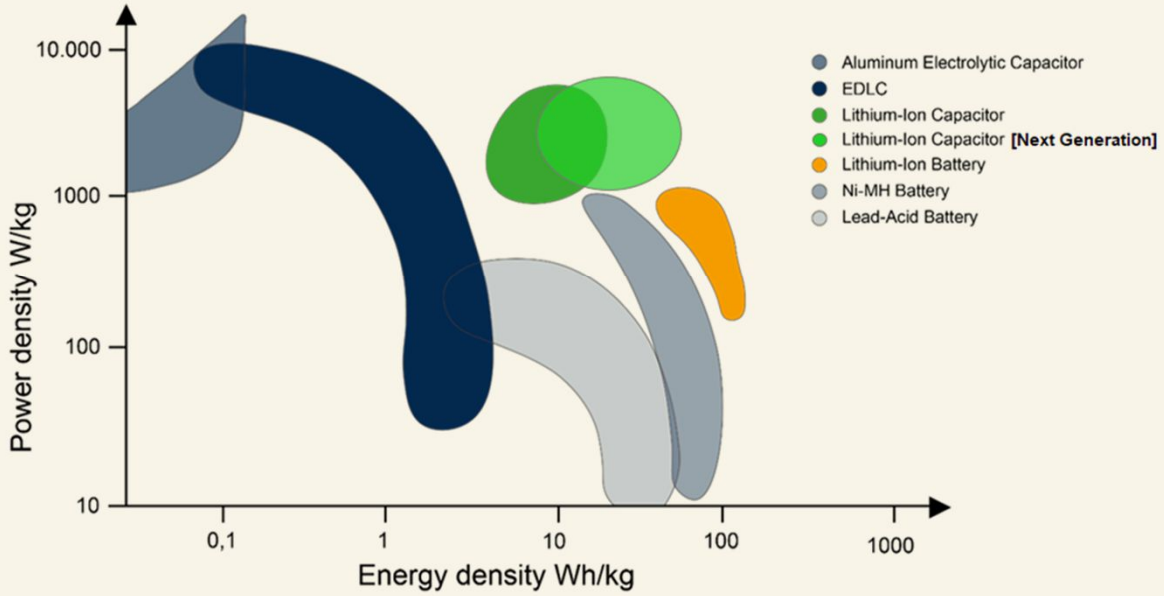
2. Direct storage

   - *Aluminum electrolytic capacitor*
   - *Film-Capacitor*
   - *Energy-Capacitor*

→ **Limited energy density per kilogram (Wh/kg)**

3. TECHNOLOGY COMPARISON – **WHO CAN WHAT?**

RAGONE PLOTS



Compared to other energy storage systems, the LiC replaces not an existing Technology, **but opens up completely new possibilities**.

- High energy density at low volume and weight
- High power density

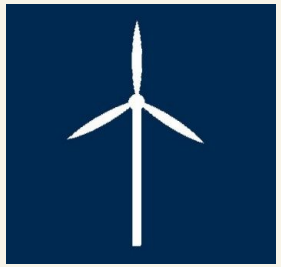
3. TECHNOLOGY COMPARISON – **MAIN MATERIALS & PROPERTIES**

	ENERGY-C (EDLC)	ENERGY-C (LIC)	LIB
ANODE	Activated carbon	Activated carbon	$LiCoO_2$ / $LiMnO_4$
CATHODE	Activated carbon	Graphite/Li-ion doped	Graphite/Li-ion doped
ELECTRIC STORAGE PRINCIPLE	Ion-adsorption	Anode: Ion-adsorption Cathode: Ion-adsorption and charge transfer	Reversible redox reaction
TEMPERATURE RANGE	–40 ~ 85 °C	–25 ~ 70 °C	–25 ~ 45 °C
MAX. RATED VOLTAGE	2.3 ~ 3 V	3.8 ~ 4.2 V	3.7 ~ 4.2 V
MAX. CHARGE RATE	approx. 1,000 C	approx. 100 C	0.5 ~ 1 C (normal)
SIZE/WEIGHT	low	low	high
CHARGE-/DISCHARGE-CYCLES	More than 500,000	50,000 ~ 500,000	1000
SELF DISCHARGE	>30 % after 2,000 h	<5 % after 2,500 h	<5 % after 2,500 h
SAFETY	safe	safe	depending on structure and material
ENERGY DENSITY	(5 ~ 8,5 Wh/kg)	(40 ~ 90 Wh/kg)	(~200-250 Wh/kg)

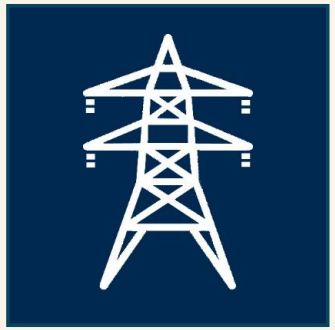
NEXT STOP

The problem for the grid with “wind and solar energy”

4. THE PROBLEM FOR THE GRID WITH “WIND AND SOLAR ENERGY”

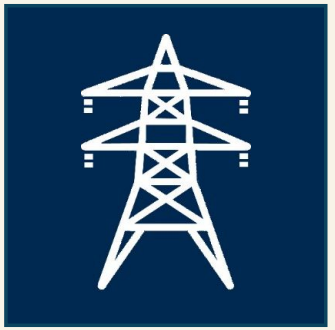


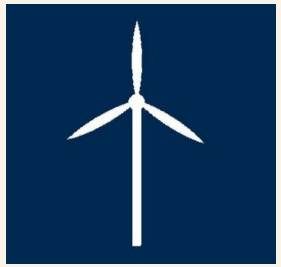
- Political switch to so-called “green energy” such as photovoltaics and wind power
- Both technologies are highly volatile in their power output
- This leads to a dynamic imbalance between the active power and the load of the system, which in turn leads to deviations in the system frequency and problems with frequency stability in the electricity grid.



4. THE PROBLEM FOR THE GRID WITH “WIND AND SOLAR ENERGY”

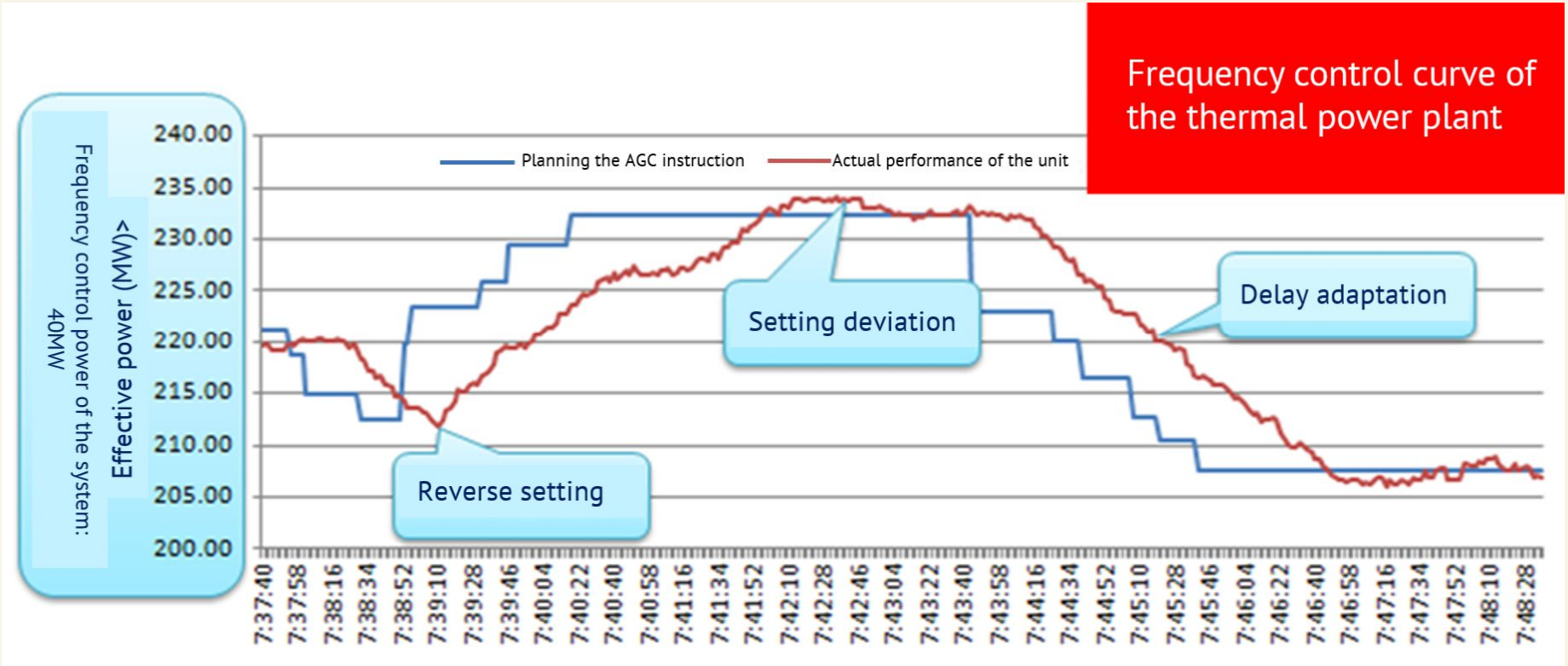
- Thermal power plants are the most important frequency-controlled power source
- Thermal power plants have long response delays and low ramp rates and are therefore unsuitable for these fluctuations.





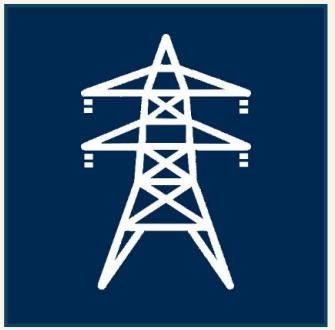
4. THE PROBLEM FOR THE GRID WITH “WIND AND SOLAR ENERGY”

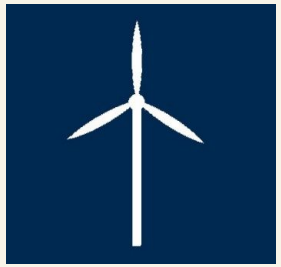
Analysis of the AGC frequency control characteristics of thermal power plants



5. SOLUTION: ENERGY STORAGE SYSTEMS

- Energy storage systems have short response times and can be switched on without interruption
- Energy storage systems can be installed regionally and do not have to operate centrally





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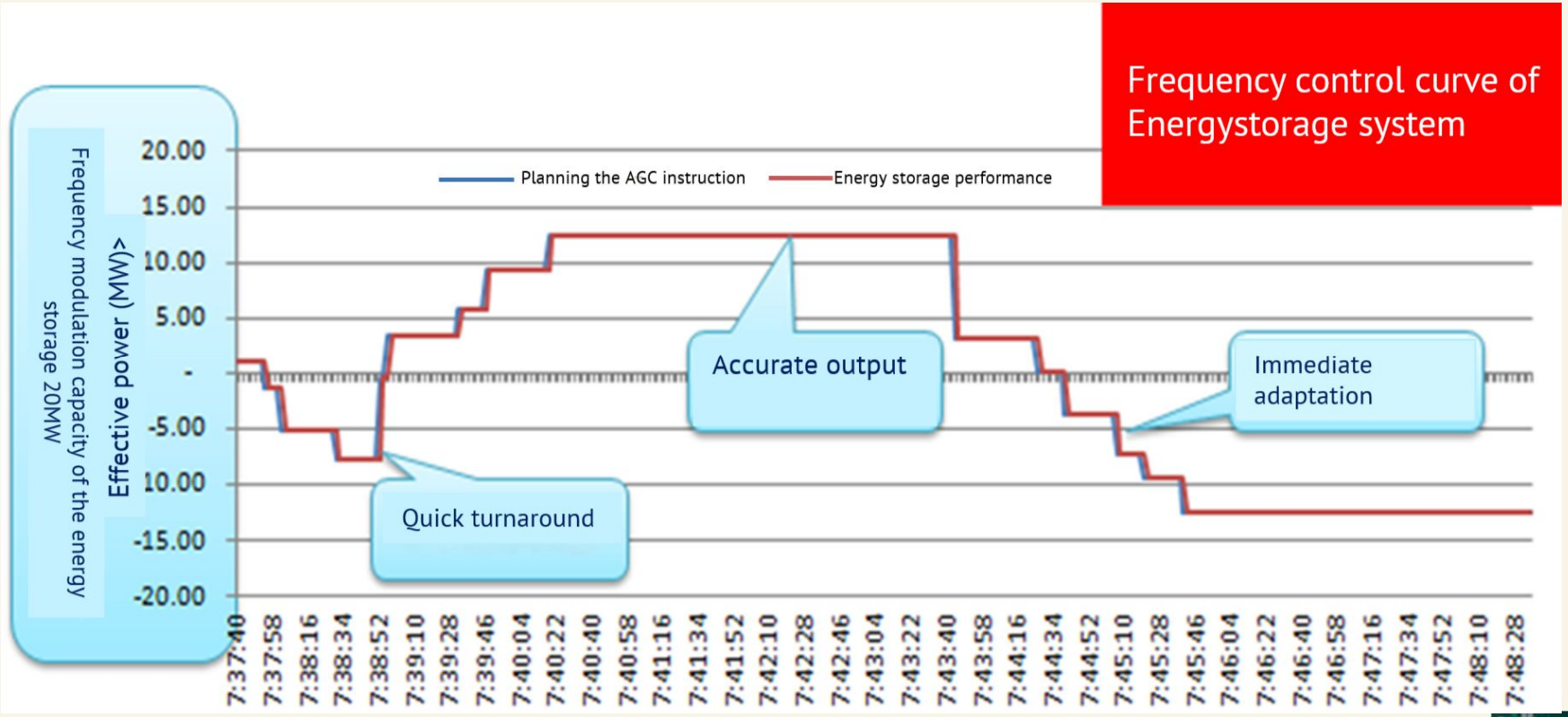
5. SOLUTION: ENERGY STORAGE SYSTEMS

Frequency control system for coupled energy storage units

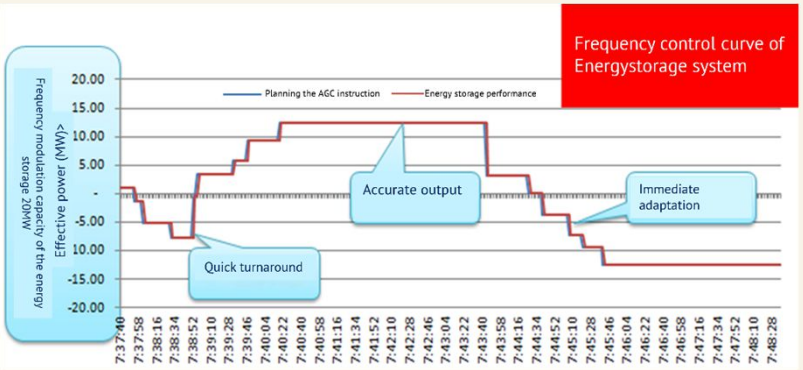


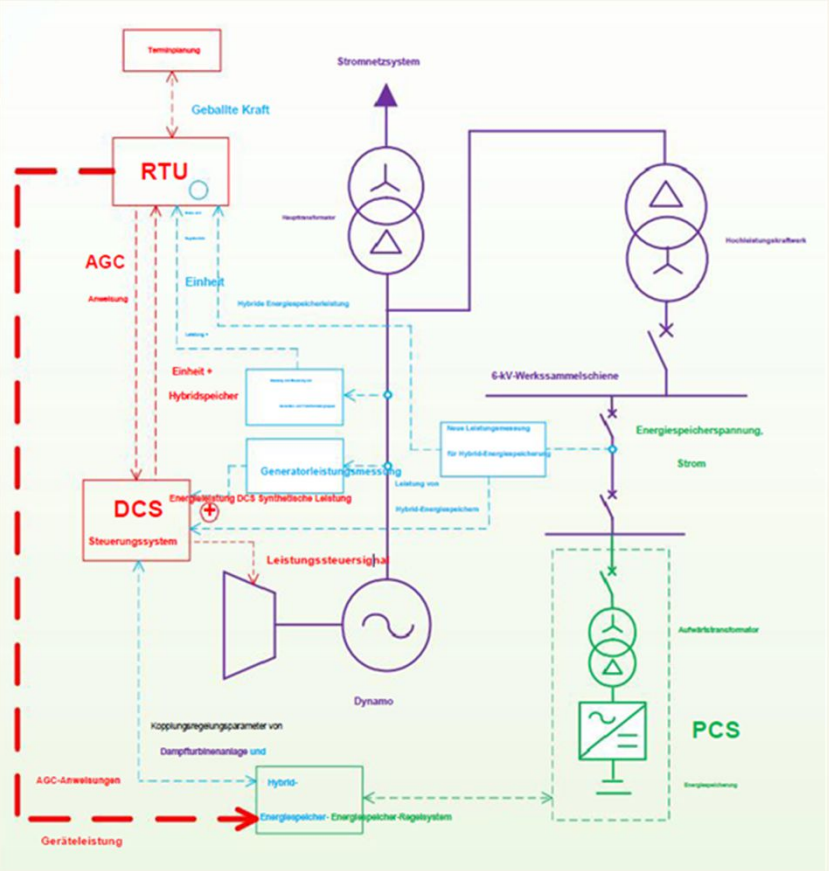
5. SOLUTION: ENERGY STORAGE SYSTEMS

Frequency control system for coupled energy storage units

- The energy storage frequency modulation system mainly includes: energy storage unit, energy storage converter
  - (PCS), energy management system (EMS) and power distribution devices.

- Energy storage uses the deviation between AGC and generator output as a control target
  - Instruction, RTU sends the sum of the energy storage and generator power to the dispatcher



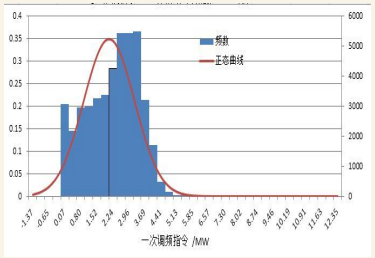


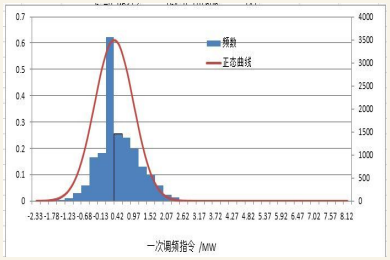
5. SOLUTION: ENERGY STORAGE SYSTEMS

Frequency control system for coupled energy storage units

Frequency regulation characteristics of energy storage devices:

- High frequency: more than a thousand to several thousand times a day
- Short time: most of them are at S level, hundreds of times more than 5 s , more than ten times to dozens of times about 100 s
- Bidirectional





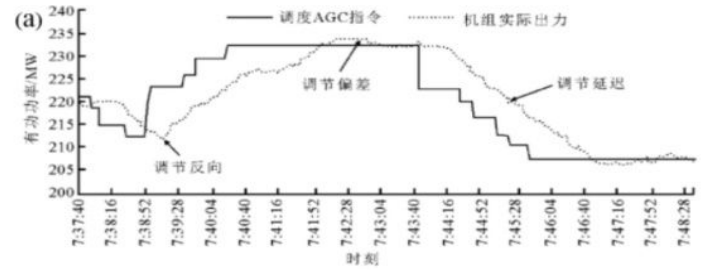
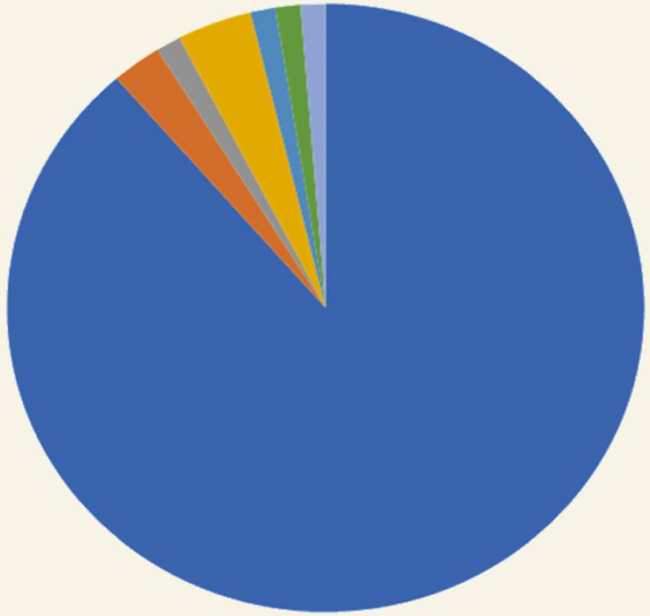


图 1(a)火电机组跟踪 AGV 指令响应过程(机组调频容量 40MW)；图 1(b)锂离子电容器储能系统跟踪 AGV 指令响应过程(储能调频容量 20MW)

5. SOLUTION: ENERGY STORAGE SYSTEMS

Energy storage technologies and their share of the market for frequency control of thermal power plants



- Lithium iron phosphate
- Flywheel
- Flow batteries
- EDLC
- Heat storage with molten salt
- Sodium batteries
- Lithium titanate

There is no absolutely good energy storage technology.
The best engineering achievement is to apply the most suitable energy storage method to the most suitable scenario!

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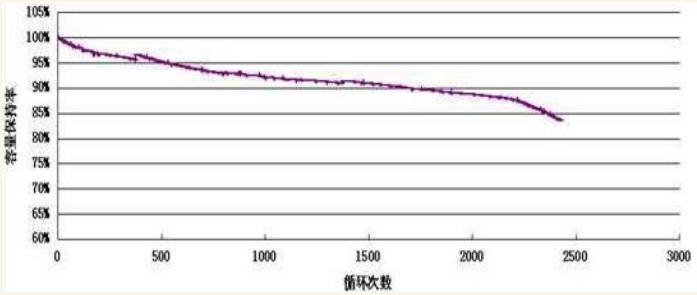
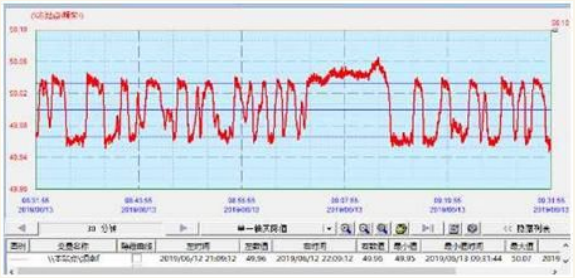
6. PROBLEMS WITH CURRENT ENERGY STORAGE SYSTEMS

AGC FM commands about 200-400 times/day, 60,000-120,000 times/year



Lithium iron phosphate battery life 3000-5000 times



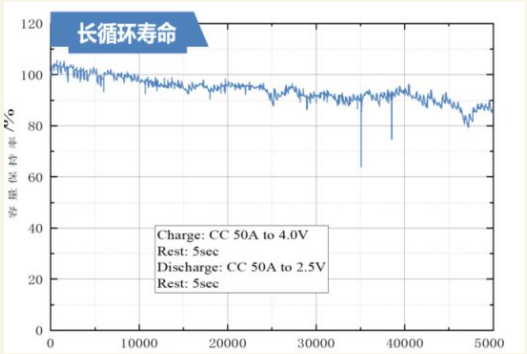
One FM overrun 2000-5000 times/day (unit action effective action dozens to hundreds of times), millions of times per year.

6. PROBLEMS WITH CURRENT ENERGY STORAGE SYSTEMS

Characteristics of supercapacitors:

- cycle life of 500,000 times, more than 10 years
- strong high current discharge capability,
- good temperature range (from plus to minus degrees)
- high safety
- fast charging and discharging speed

The characteristics are suitable for frequency modulation conditions.



UL 810A certified


CERTIFICATE OF COMPLIANCE

Certificate Number MH61501
Report Reference MH61501-20160812
Date 2020-December-21

Issued to: Nantong Jianghai New Energy Co Ltd
No. 998 Xiwang Road
South of Economy Technology Development Zone
Tongzhou District
NantongJiangsu 226000 CN

This is to certify that representative samples of: CAPACITORS, ELECTROCHEMICAL - COMPONENT
See Addendum Page for Product Designation(s).

Have been investigated by UL in accordance with the component requirements in the Standard(s) indicated on this Certificate. UL Recognized components are incomplete in certain constructional features or restricted in performance capabilities and are intended for installation in complete equipment submitted for investigation to UL LLC.

Standard(s) for Safety: Standard for Electrochemical Capacitors, UL 810A

Additional Information: See the UL Online Certifications Directory at https://iq.ulprospector.com for additional information

This *Certificate of Compliance* does not provide authorization to apply the UL Recognized Component Mark. Only the UL Follow-Up Services Procedure provides authorization to apply the UL Mark.

Only those products bearing the UL Recognized Component Mark should be considered as being UL Certified and covered under UL's Follow-Up Services.

Look for the UL Recognized Component Mark on the product.

Bruce Mahrenholz, Director North American Certification Program
UL LLC


CERTIFICATE OF COMPLIANCE

Certificate Number MH61501
Report Reference MH61501-20160812
Date 2020-December-21

This is to certify that representative samples of the product as specified on this certificate were tested according to the current UL requirements

Models / Product:

USR Component- Electrochemical Capacitors, Series HAA, HBR, SRP and SSP

Model Number
HAA Series

HBR Series

SRP Series

SSP Series

HBX Series

Note: X may be R, RL or E in HBX series model number.

#: following by model number, which can be Blank or J, representing special purpose for different customers.


CERTIFICATE OF COMPLIANCE

Certificate Number MH61501
Report Reference MH61501-20160812
Date 2020-December-21

HAX Series

Note: X may be A, L, H or E in HAX series model number.

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SRX_2.7V Series

Note: X may be E, Q or P in SRX_2.7V Series model number.

#: following by model number, which can be Blank or J, representing special purpose for different customers.

SRX_3.0V Series


CERTIFICATE OF COMPLIANCE

Certificate Number MH61501
Report Reference MH61501-20160812
Date 2020-December-21

Note: X may be E, Q or P in SRX_3.0V Series model number.

#: following by model number, which can be Blank or J, representing special purpose for different customers.

SSX_2.7V Series

Note: X may be E, L or P in SSX_2.7V Series model number.

#: following by model number, which can be Blank or J, representing special purpose for different customers.


CERTIFICATE OF COMPLIANCE

Certificate Number MH61501
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SSX_3.0V Series

Note: X may be E, L or P in SSX_3.0V Series model number.

#: following by model number, which can be Blank or J, representing special purpose for different customers.

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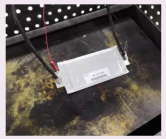
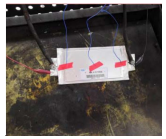
7. ALTERNATIVE SOLUTION: ENERGY-C

Test		Safety	Test		Safety
Overdischarge		✓	Heating		✓
Overcharge		✓	Drop-test		✓
Short circuit		✓	Crush		✓
Penetration		✓	Temperature cycle		✓
Seawater immersion		✓			

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7. ALTERNATIVE SOLUTION: ENERGY-C

Test	Test conditions	Test result
Over discharge	Charging capacitor to the rated voltage with constant current I, discharge them to 0V and continue to discharge until overdischarge capacitance reaches 50% of the nominal capacitance, then observe for 1 h	No explosion, No fire, No electrolyte leakage
Overcharge	No explosion, No fire, No electrolyte leakage	No explosion, No fire, No electrolyte leakage
Short circuit	Charging capacitor to the rated voltage with constant current I, short-circuit between the positive and negative terminal for 10min by external wire (R <5mOhm)	No explosion, No fire
Penetration	Charging capacitor to the rated voltage with constant current I, observe them for 1 h after penetration	No explosion, No fire
Seawater immersion	Charging capacitors to the rated voltage with constant current I, Immerse them into a water container of 3.5% NaCl solution for 2h	No explosion, No fire
Heating	Charging capacitors to the rated voltage with constant current I, put them into a temperature chamber to 130°C + - 2°C at a rate of 5°C/min and hold for 30min, then observe for 1h	No explosion, No fire
Drop-test	Charging capacitors to the rated voltage with constant current I, make cells fall the concrete floor from 1.5m height with terminal facing down, then observe for 1h	No explosion, No fire, No electrolyte leakage
Crush	Charging capacitors to the rated voltage with constant current I, crush them and observe for 1h	No explosion, No fire
Temperature cycle	Charging capacitors to the rated voltage with constant current I, and observe for 1h after five temperature cycles	No explosion, No fire, No electrolyte leakage

7. ALTERNATIVE SOLUTION: ENERGY-C

- Significantly less Lithium than in a lithium-battery
    - *<3% with the same volume*
- Lithium ions doped in graphite-grid-structure
- Internal short circuit not a problem
    - Potential difference of the cathode too low for the extraction of doped ions
- No oxygen present for exothermal reactions
- Regression of Lithium not possible

8. PROJECT: NENGLUOYUAN POWER STATION

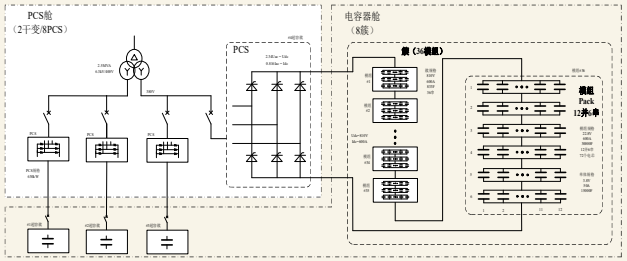
- May 12, 2022, subject contract signed
- June 25, 2022, equipment procurement initiated
- September 28, 2022, demonstration project commenced
- December 5, 2022, commissioning commenced
- January 7, 2023, first grid connection of the energy storage system
- February 28, 2023, 168 hours of operation completed
- April 17, 2023, grid interconnections completed and put into operation

9. PROJECT: HYBRID-SOLUTION IN HUANENG LUOYUAN

Huaneng Luoyuan Power Plant Super Capacitor Energy Storage and Frequency Regulation Demonstration Project

In April 2023, the world's largest capacity supercapacitor FM system was built at Huaneng Luoyuan Power Plant, which was the first time that lithium-ion capacitor technology was applied in thermal power FM field, creating a new technology route and application market.

Top view of the demonstration project for frequency modulation of the supercapacitor hybrid energy storage system of the Huaneng Luoyuan power plant



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9. PROJECT: HYBRID-SOLUTION IN HUANENG LUOYUAN

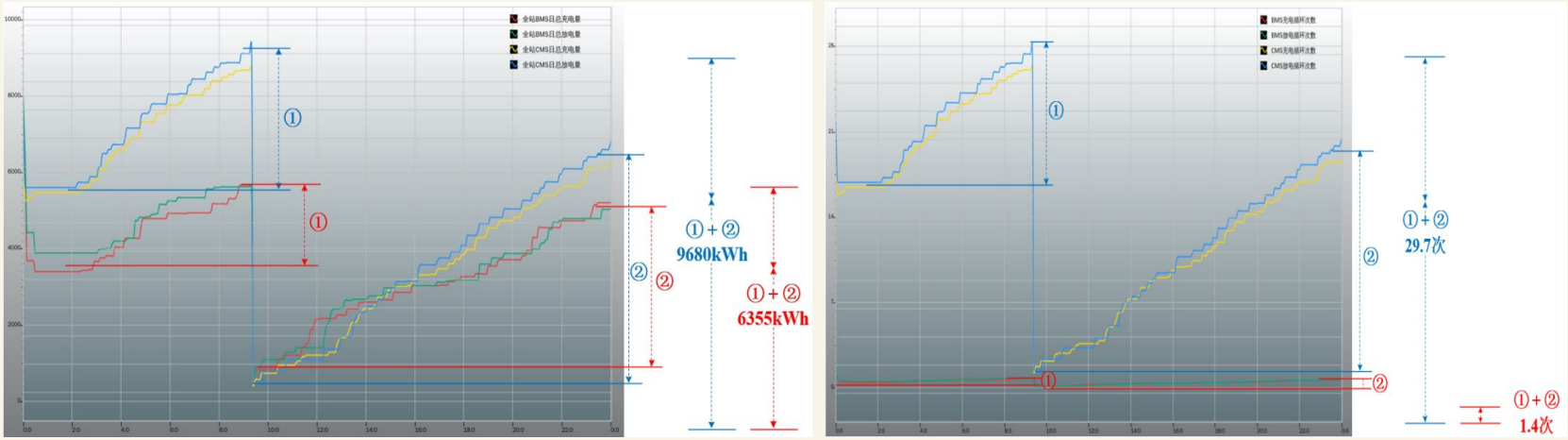
Super capacitor + lithium iron phosphate hybrid energy storage and frequency regulation performance

Modulation curve **before** installing the hybrid solution

Modulation curve **after** installing the hybrid solution

10. TECHNOLOGY COMPARISON

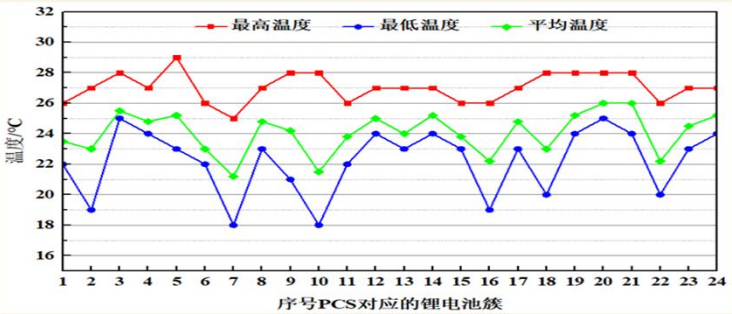
Comparison of the operation of supercapacitor and lithium iron phosphate battery

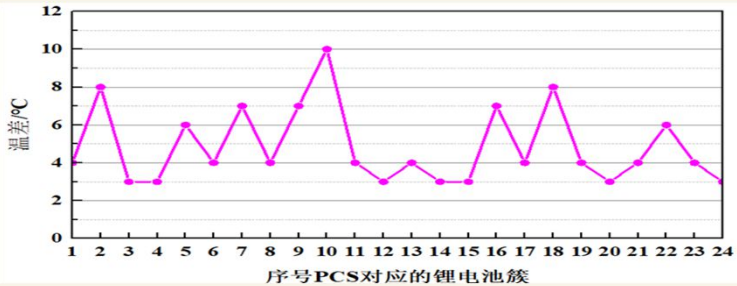


- Taking full advantage of the super capacitor's life expectancy, the ‘capacitor first’ strategy is adopted
- The super capacitor takes up about 60% of the FM power with 25% of the power and 4.3% of the capacity.
- The charge/discharge cycle of supercapacitor is 29.7 times/D, which is nearly 20 times more than that of lithium-ion battery (1.4 times/D).

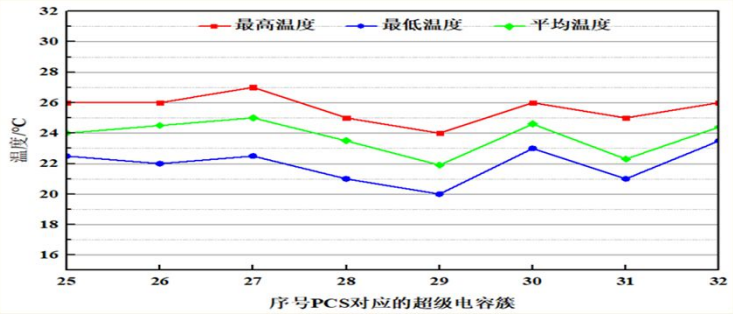
10. TECHNOLOGY COMPARISON

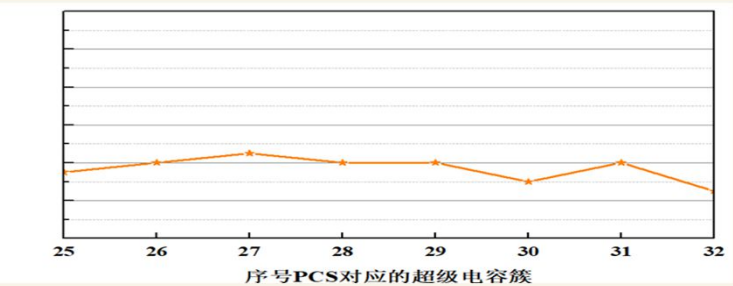
Lithium-ion batteries





Supercapacitors





- In terms of temperature difference between clusters of cells, the maximum temperature difference between lithium batteries is 10°C, and the maximum temperature difference between supercapacitors is 5°C.
- The consistency of supercapacitors is better than that of lithium batteries, and they have higher safety and operational stability.

Economic analysis of the frequency control of energy storage coupling units based on pure supercapacitors

Comparison of frequency control technologies for thermal storage systems (using the example of a 600,000 kW system in the north)

Energy storage technology	Supercapacitor energy storage	Lithium Battery Storage
Safety	Higher	normal
Lifetime	10 years	3-5 years
Functionality	Primary FM AGC FM	Primary FM AGC FM
Static amortisation period	2.76 years	4.13 years

11. SUMMARY

- Initial investment is basically the same with consideration of fire protection
- Frequency regulation can be realised with both supercapacitor energy storage and lithium-ion battery storage power and is comparable in its function
- A major difference is the service life of more than 3 times as the results were determined in the Huaneng Luoyuan power plant demonstration

1. The integrated MW-class supercapacitor energy storage system is technically feasible
   The technical results of this project have been demonstrated in Huaneng Huaneng Luoyuan Power Plant

2. The MW-class supercapacitor energy storage system operates safely, stably, and reliably
   In the operation of supercapacitor, the temperature and voltage consistency between clusters is good, and the safety is higher

3. Supercapacitor energy storage is more economical in the whole life cycle
   Supercapacitor does not need to be replaced in 10 years, which is more economical in the whole life cycle

To summaries,
it can be said that in the course of the switch to new fluctuating energy sources, grid stability is increasingly becoming the focus of attention.

New technologies are also finding their place here and enabling stable operation

THANK YOU FOR YOUR ATTENTION

Alexander Schedlock

on behalf of heynen

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