UNIVERSIDAD POLITÉCNICA DE MADRID

# Máster Formación Permanente Energías Renovables y Medio Ambiente

Universidad Politécnica de Madrid

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Máster ERMA

## Módulo 15
## Plantas híbridas y de almacenamiento

# Grid forming, LCOS y KPIs en los sistemas de almacenamiento de Ion-Litio


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*Huawei Spain Digital Power*


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## Learning Objectives

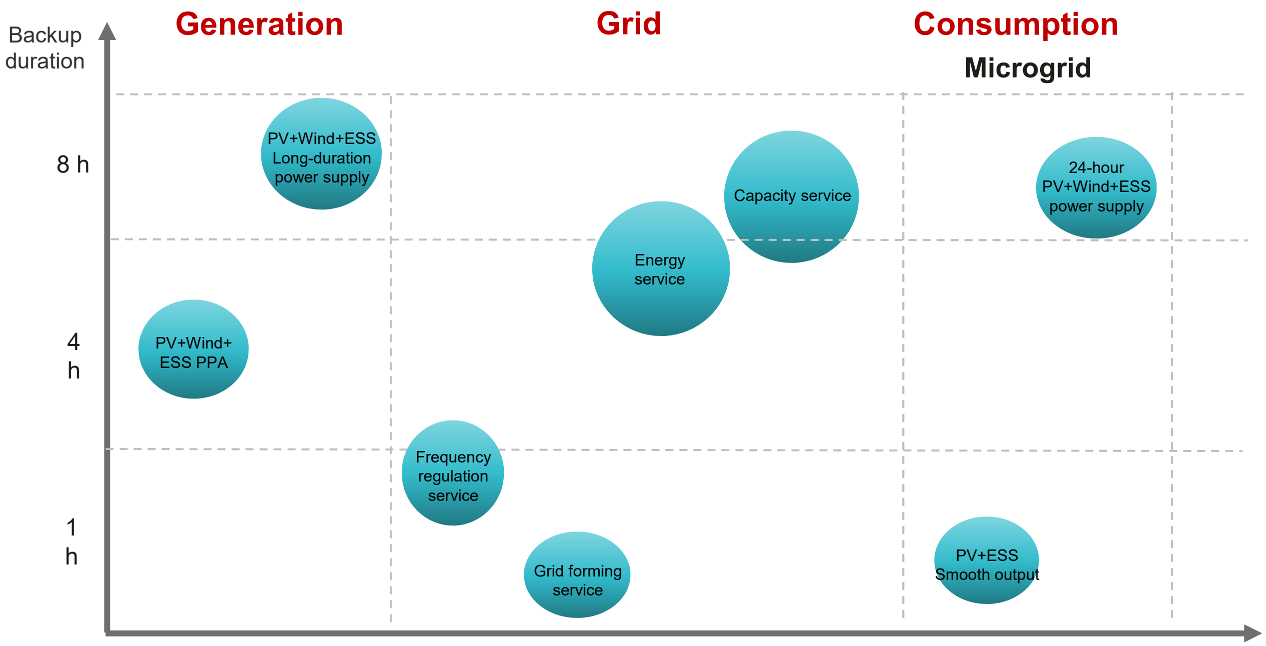
**Grid Forming:**
To explore grid-forming as a key technological requirement and to understand its role in enabling renewable energy to become a primary source of power.
**Understand Industry Trends and Challenges**:
Analyze current trends and emerging challenges in sizing Battery Energy Storage Systems (BESS) and evaluating Levelized Cost of Storage (LCOS).
**Master Fundamental Concepts**:
Gain a solid understanding of key concepts such as Round-Trip Efficiency (RTE), State of Health (SOH), and Usable Capacity in BESS operation.
**Apply Practical Knowledge**:
Conduct a case study covering BESS sizing at different lifecycle stages: Beginning of Life (BOL), End of Life (EOL), and Adaptive Optimization Lifecycle (AOL).
**Explore Network Code Requirements**:
Learn the foundational principles of network codes relevant to BESS integration, with a focus on compliance and certification.
**Assess Warranty and Performance Guarantees**:
Understand the implications of flexible warranty structures and performance guarantees to ensure optimal system reliability and customer satisfaction.

1 Trends & Challenges
2 What is "grid forming"?
3 Why "grid forming"?
4 Smart String ES Solution 2.0
5 Application Cases in Grid forming
6 RTE, SOH and Usuable capacity
7 Case study: Understanding BOL, EOL & AOL and Power, energy and efficiency Diagrams
8 EU RfG (Grid code) and its influence on BESS design
9 Smart String BESS Solution
10 Summary: Smart String BESS Lower LCOS
Mismatch
OPEX
MWh
CAPEX
11 Flexible warranty: SOH degradation curve under variable working conditions

# 1 Trends & Challenges

# Cover Multiple Scenarios Such as Power Generation, Transmission, and Consumption, Improve Wind and PV Power Integration, Stabilize Power Grid Operation, and Reduce Power Consumption Costs

- Generation: Replace the conventional genset power supply with the joint operation of PV+Wind+ESS. Promote PV+Wind+ESS to optimize the PPA electricity prices of PV+wind.
- Grid: Leverage ESSs in power grid services to ensure the stability and balance of power grid operations.
- Consumption: Promote PV+ESS to improve self-consumption, facilitate time-of-use (ToU) arbitrage, and delay power distribution network revamping to reduce power consumption costs.



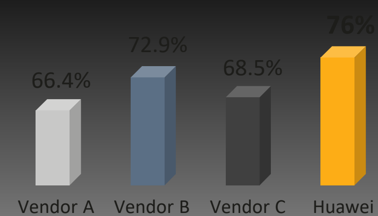
# Smart String ESS: Controllability of power electronics to resolve inconsistencies and uncertainties in lithium batteries

## 115 MW/146 MWh BESS in Singapore


- Rack-level Optimization
- Avoid parallel mismatch

Hourly constant power output


## 2MW/4MWh BESS in Dongguan, Guangdong




- Pack-level Optimization
- Avoid serial mismatch

Comprehensive Energy Efficiency = RTE* × Energy Utilization Rate

Comprehensive energy efficiency improved by up to 3.5%.

*RTE, round trip efficiency



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# Convergence of PV & BESS industries towards string architecture

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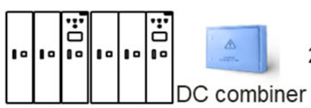
**Solar**

## Central Inverter

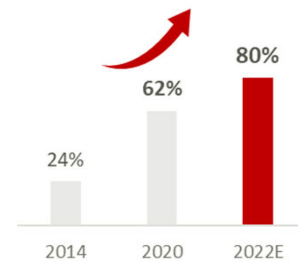



2000+ PV modules / MW

- 1 MPPT centralized Management
- Lower availability around 98%
- single failure recovery cost longer time
- Higher replacement cost
- More Spare parts, hard to find in lifecycle

## Smart PV Controller

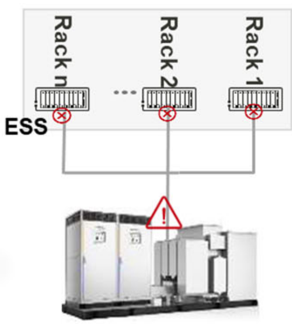
- More MPPT, more yields
- 99.99% availability，more flexibility
- Single failure influence is limited
- Easy O&M and replacement
- Inverter is spare part




Global String Inverter Market Share

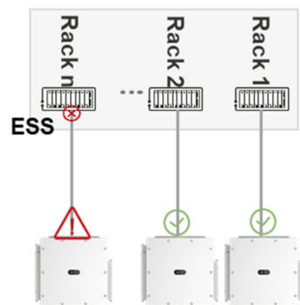
**Energy Storage**

## Central ESS: Centralized rack extensive management




- One central PCS manages 2000 battery cells in series & parallel causes severe mismatch capacity
- Reduced usable capacity, quick degradation & massive O&M costs & poor safety.
- Failure recover take more time
- Lower availability

## Smart String ESS: Distributed and refined rack management




- Independent control of battery packs & racks
- Isolation of faulty pack
- No need of SOC calibration
- Single failure influence is limited
- Higher availability



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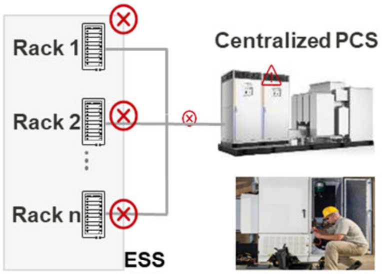
# Short barrel effect impact BESS system availability, output power and O&M complexity, challenge the revenue

## Low availability

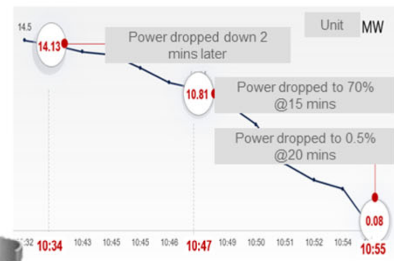



| | |
|---|---|
| location | Singapore |
| Available | **98%** |
| Reason | **Central design**<br>• replace time cost more<br>• have more spare parts<br>• Manual PCS repair on site with risk |
| Loss estimate | 200 times + faults / year |

## Low available capacity

| | |
|---|---|
| location | Qinghai，China |
| Available | **97%** |
| Reason | • **Series & Parallel mismatch** due to inconsistency between battery cells |
| Loss estimate | Loss >+5% yield per cycle |

## Short constant power output




| | |
|---|---|
| location | China |
| Available | **2 mins** |
| Reason | • **Poor thermal mgmt. cost performance worse**<br>• System output power depends on the **worst performing rack** |
| Loss estimate | • The lifecycle power cannot be guaranteed |

## Manual SOC calibration

| | |
|---|---|
| location | China |
| Available | **3 person.days/MWh** |
| Reason | • **Manual site visit for SOC calibration** |
| Loss estimate | • 10MWh cost 10 days 6000 USD/time = 3*200*10 |



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## 2 What is "grid forming"?

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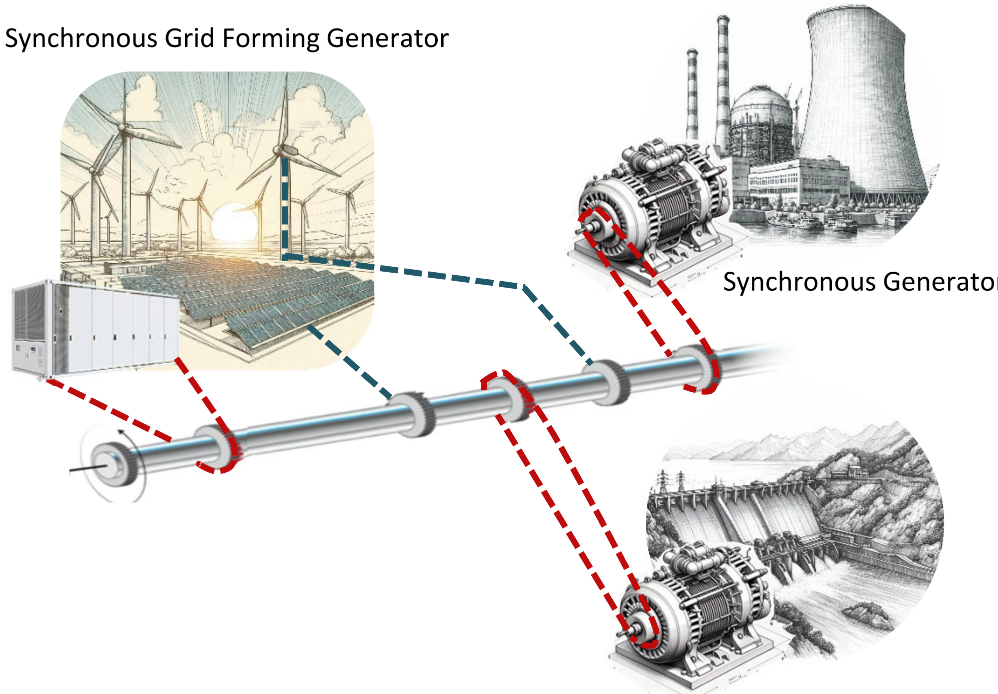
# Key metrics to understand localized power system strength & resiliency

## 1 Short Circuit ratio (SCR)

| | |
|---|---|
| SCR> 3 | Strong grid<br>(~Voltage stability and power reserves) |
| 3 > SCR > 2 | Weak grid<br>(~Voltage instability and control problems) |
| SCR < 2 | Very weak |

## 2 Inertia

- Green H ≥ 4 s Very good contribution
- Yellow 3 s ≤ H < 4 s Good contribution
- Orange 2 s ≤ H < 3 s Marginal contribution
- Red H < 2 s Limited contribution

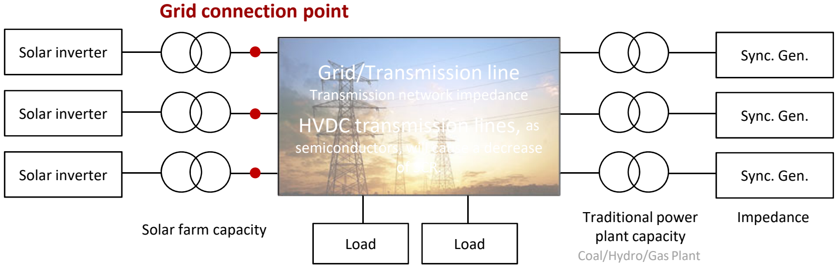


# Increased Renewable Energy Penetration Rate equals to Weakened Grid Strength (SCR)

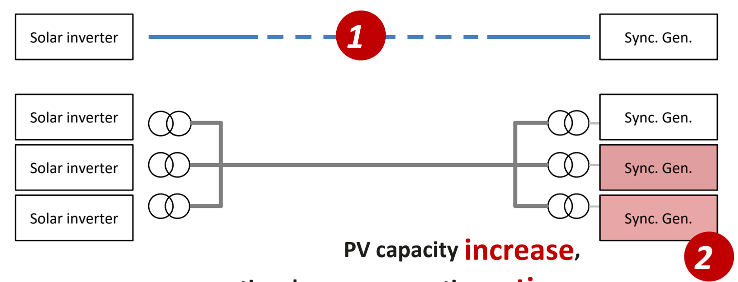
## Short circuit ratio (SCR)

SCR is the ratio of the short-circuit capacity at the grid connection point to the rated capacity of a power plant. It measures the impact of power injection on the voltage quality and stability of local grids, and reflects the grid strength.

**A higher SCR indicates a stronger grid and grid connection ability.**




**PV plants are located remotely.**



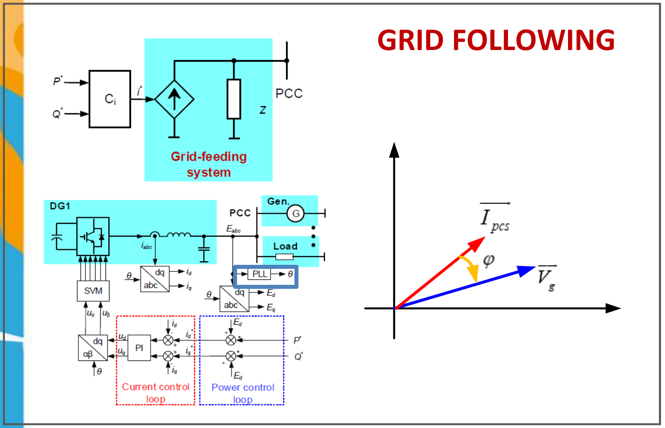

**PV capacity increase, conventional power generation retires.**

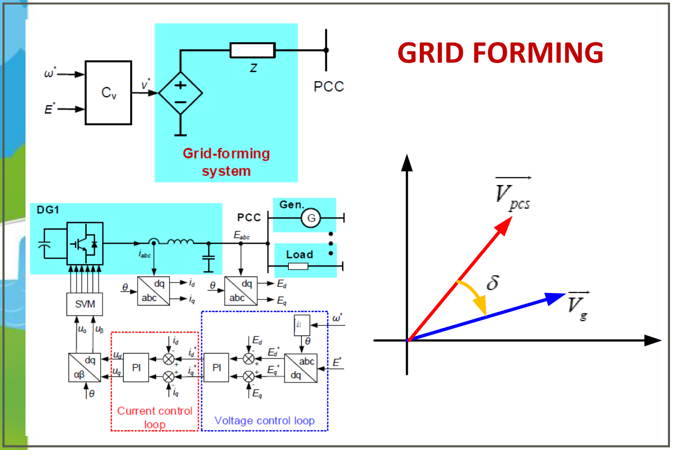
$$SCR = \frac{\dfrac{\text{Square of Voltage at the grid connection point}}{\text{Equivalent impedance at the grid connection point} \nearrow}}{\text{Solar Farm Capacity} \nearrow}$$

1. **Longer** power transmission lines result in **larger equivalent impedance** at the grid connection point.
2. **Less capacity of** traditional power plants result in **larger equivalent impedance** at the grid connection point.

...

# GRID FORMING VS GRID FOLLOWING




| GRID FOLLOWING | GRID FORMING |
|---|---|
| Current source | Voltage Source |
| The power grid can be supported by adjusting the output power. However, the support response speed is limited, | Independent operation without relying on other power generation units |
| Depends on PLL synchronization. | Core controls voltage amplitude and frequency/phase |
| Can't go near at 100% new energy port penetration rate | Only the PLL auxiliary device may be required for mode switching. |
| Depending on the generated voltage reference signal generated by other power generation units to achieve operation | Can be near at 100% new energy port penetration rate |
| The system strength cannot be improved, and the inertia and anti-interference capability (such as phase angle jump) are lacking. | Transient response of output power, supporting voltage and frequency |


## 3 Why “grid forming”?



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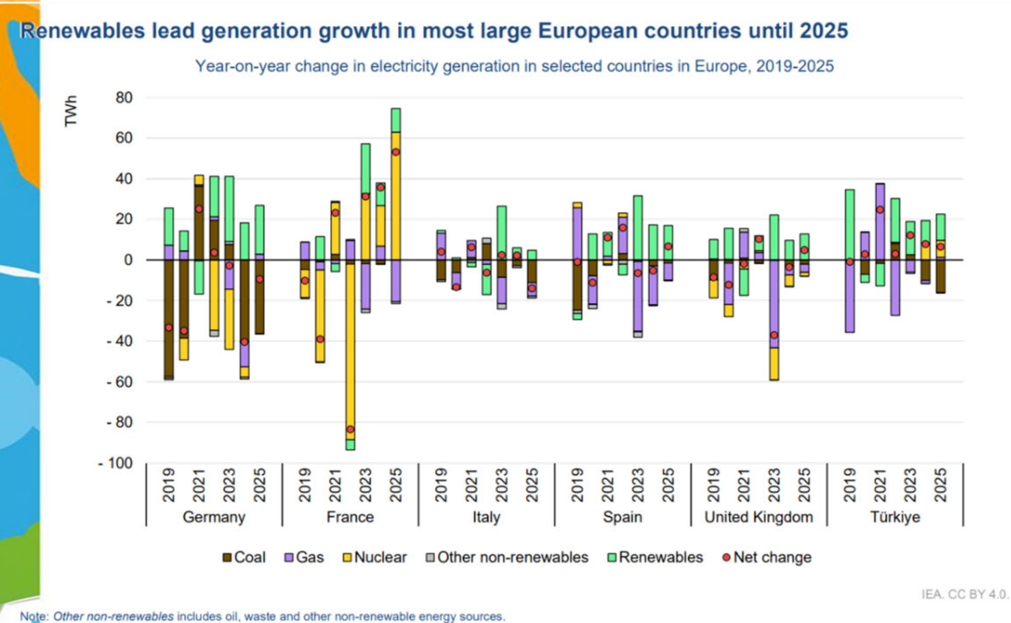
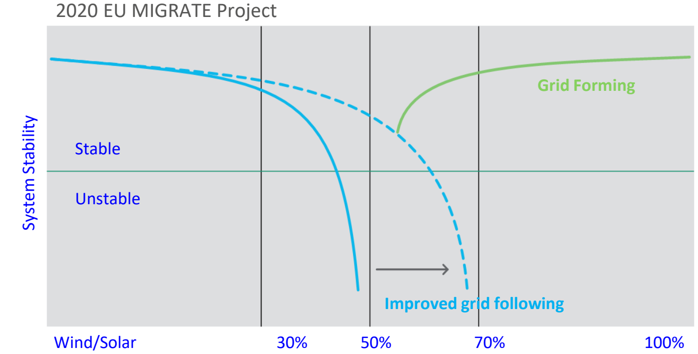
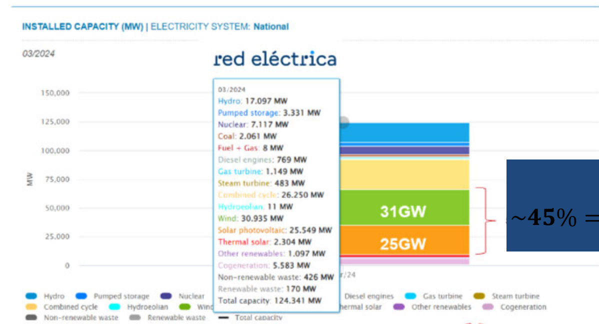
# Renewable industry is booming, while multiple challenges still remain




Source: 2023 Electricity Market Report IEA (International Energy Agency)

**EU considers grid forming as a key to high wind/solar penetration.**



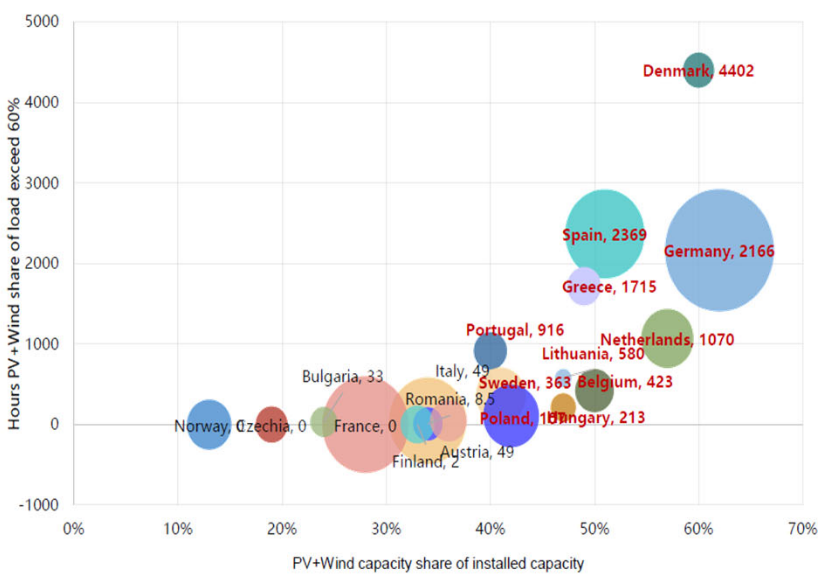

$$\sim 45\% = \frac{56GW}{124GW}\ \%$$

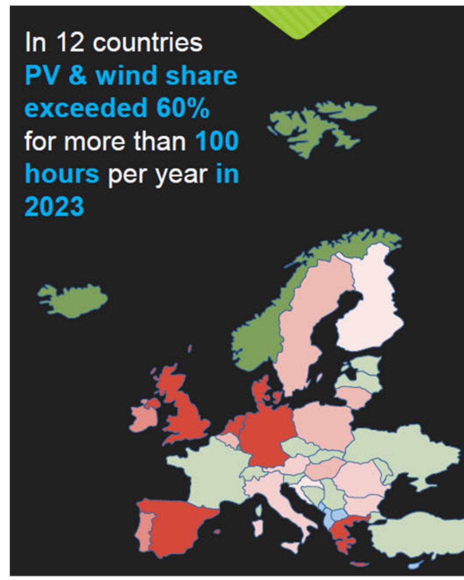
Source: March 2024, Red Eléctrica de España (REE))

# Renewable industry is booming, while multiple challenges still remain

## More wind + solar brings down inertia in 2030

In 2023, hour numbers for solar+wind share of demand exceed 60%



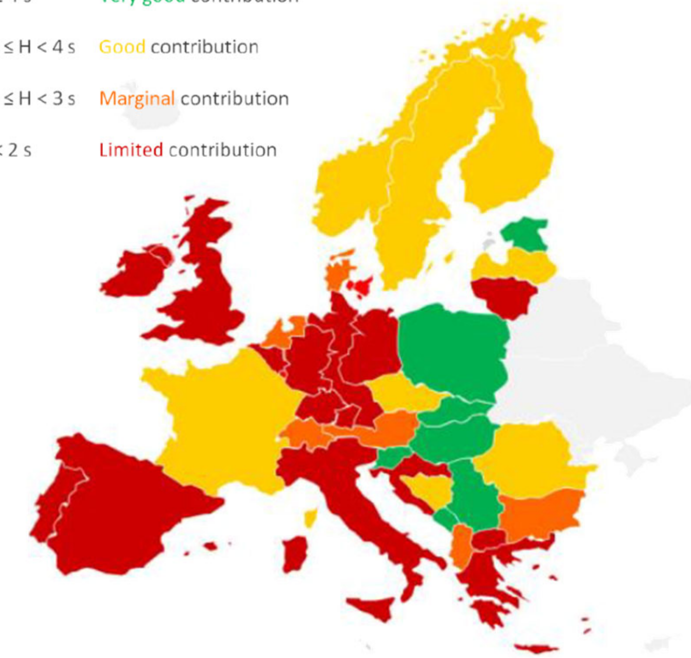




| Country | 60%+ Hours | Power (GW) |
|---|---|---|
| **Denmark** | 4402 | 19.8 |
| **Spain** | 2369 | 128.7 |
| **Germany** | 2166 | 242.2 |
| **Greece** | 1715 | 24.1 |
| **Netherlands** | 1070 | 56.1 |
| Portugal | 916 | 22.3 |
| Lithuania | 580 | 5.3 |
| Estonia | 478 | 3.1 |
| Belgium | 423 | 30.1 |
| Sweden | 363 | 50.6 |
| Hungary | 213 | 12.8 |
| Poland | 107 | 63.3 |
| Italy | 49 | 121.1 |
| Austria | 49 | 27.5 |
| Bulgaria | 33 | 14.7 |
| Romania | 8.5 | 17.6 |
| Luxenberg | 7 | 0.7 |
| Croatia | | 5.2 |
| Finland | | 23.1 |

# Weak power system strength has become an issue

Inertia contribution colouring code:

- Green H ≥ 4 s Very good contribution
- Yellow 3 s ≤ H < 4 s Good contribution
- Orange 2 s ≤ H < 3 s Marginal contribution
- Red H < 2 s Limited contribution

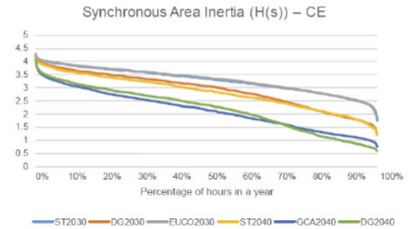


Indicating contribution of each TSO to the TSI constant (source: TYNDP 2016 reflecting 2030 scenario, [7]).

From PNIEC: 81% of the energy in 2030 shall provide from renewable energies

**Grid become 'weaker' with renewable penetrations raising**

**Europe** — Entso-E predicts: The system strength of major EU countries will decline rapidly in the next five years.




Inertia constant in the CE system for given percentage of hours per year under various grid development scenarios. *Source: ENTSOE*

**Spain** — **SRAP (Sistema de reducción automática de potencia)**

**La CNMC aprueba un nuevo procedimiento de operación del sistema eléctrico para la integración masiva de generación renovable**

25 Jan 2022 | Energía Energía, Nota de prensa

- La integración masiva de generación renovable en la red eléctrica prevista en los próximos años exige adaptar los procedimientos de resolución de congestiones en la red.
- Esta adaptación requiere un nuevo procedimiento para la operación del sistema eléctrico, un herramienta para la reducción automática de la potencia de la generación.
- El nuevo sistema permitirá la entrada máxima de generación renovable garantizando la seguridad del suministro y el uso óptimo de las redes.

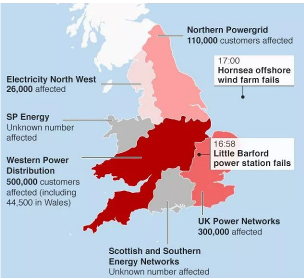
La CNMC ha aprobado un nuevo procedimiento de operación del sistema eléctrico peninsular (P.O.3.11 y modificación del P.O.3.2) para desarrollar un sistema de reducción automática de potencia (**DCOOR/DE/007/21**).

La incorporación de este sistema en el proceso de resolución de restricciones técnicas permitirá incrementar la integración de generación renovable, optimizando el uso de las redes y maximizando la integración de generación renovable.

# New Energy Makes Grid Weaker, Transient Issues Come to The Fore

## 1 Weak inertia support and frequency instability

The Blackout in UK 2019




The failure of Little Barford power plant caused power loss of 730 MW
**System frequency starting to decrease**

Horsea offshore wind farm was largely off the grid, with power fed into the grid reduced by 900 MW.

**System frequency dropped to 48.9Hz**

beyond the allowed range of 49.8–50.2 Hz and triggered mass load shedding

## 2 Fault ride-though failure on weak networks

Australia's power blackout in 2016

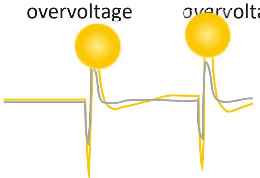
- On Sept. 28th, 2016, Wind farm tripped caused by typhoons and rainstorms.
- Voltage drops occurred for 6 times and caused voltage and frequency collapse. South Australia suffered a 50-hour blackout.

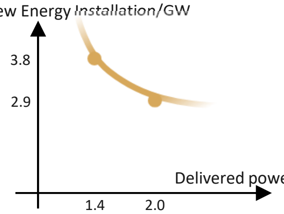
**Voltage collapse**

**Frequency collapse**

## 3 High proportion of renewable difficult to deliver

HVDC transient overvoltage problem (Qinghai-Henan DC transmission)

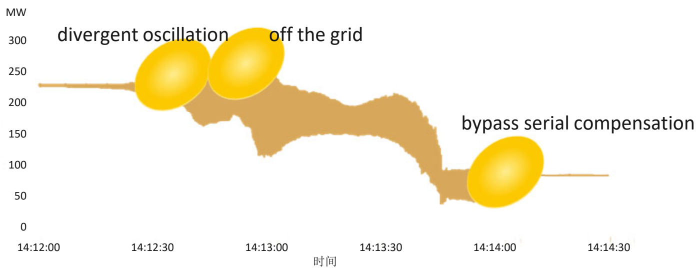



New energy installation and delivery capacity are negatively related!

## 4 Wide-band oscillation

A wind power station in Guyuan, Hebei, China



# The Whole Industry Address Those Challenges Actively, Still with a Number of Restrictions

## Diesel generator

Environmental pollution, high LCOE, and complex maintenance

## Synchronous condenser

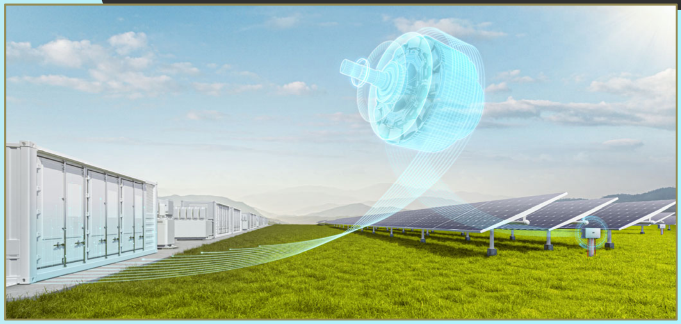
24-hour manual attendance of rotating equipment and regular on-site O&M

## New construction or renovation of thermal generators

Restriction on new construction and environmental pollution

## PV + ESS Generator

**Combine PV and Energy Storage with Intelligence, Accelerating PV to be Primary Energy Source**



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# Smart String ES Solution 2.0

Grid forming capabilities

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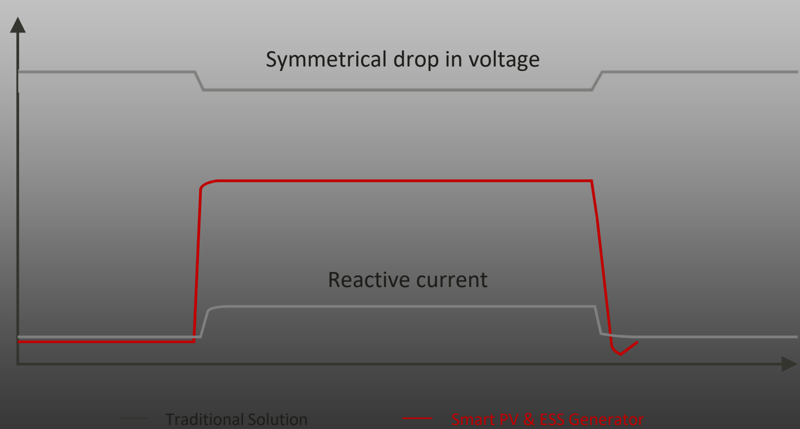
# Redefine Voltage Stability: Upgraded hardware + Grid Forming algorithm , achieving 3 times of reactive current and quickly respond to grid voltage changes

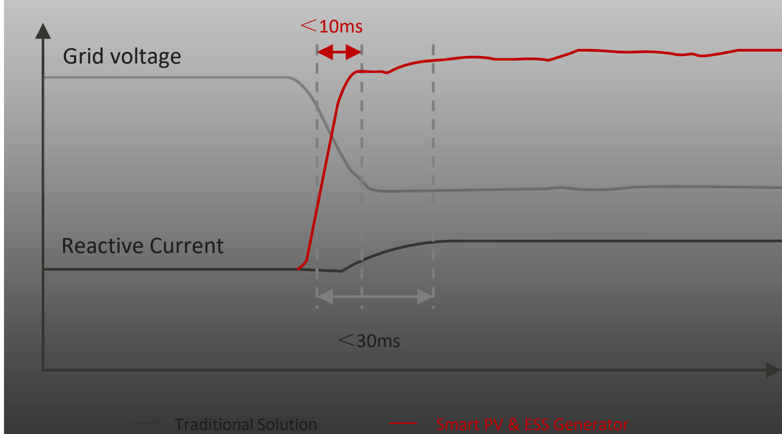
## Reactive current to support voltage

Smart PV & ESS Generator : 3 times VS Traditional solution: 1.04 times




## Dynamic reactive current response

Smart PV & ESS Generator ＜10ms VS Traditional solution ＜30ms



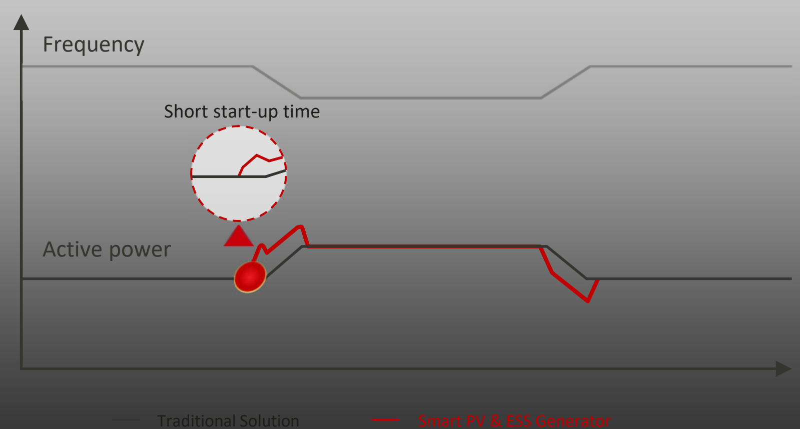
# Redefine Frequency Stability: Grid Forming algorithm to generate equivalent moment of inertia and quickly respond to gird frequency changes

## Virtual inertia

Smart PV & ESS Generator support VS Traditional solution not support


## Frequency adjustment start time (by active power )

Smart PV & ESS Generator ＜5ms VS Traditional solution ＞50ms



# GW level whole grid black start enabling minutes level power recovery

## Traditional Solution

Black start for single array with no loads

Waiting for others started and interconnected

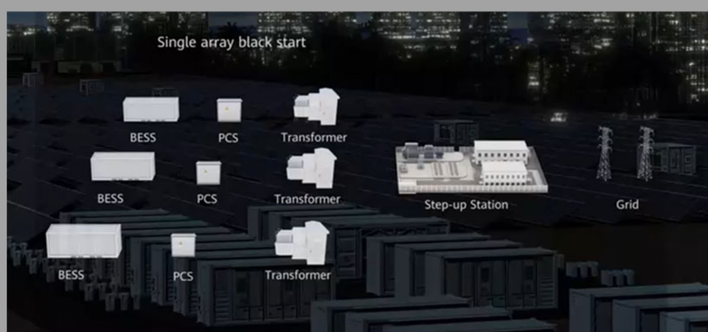
Step-by-step HV switch on for power distribution

Whole microgrid recovery

**Several hours ~ days**

Over-current / voltage impact risks

**Black start single array one by one**

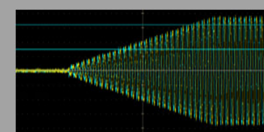



## Huawei Solution

Whole grid recovery, enabling **minutes level recovery**

Multi-PCS parallel soft-start synchronous ramp

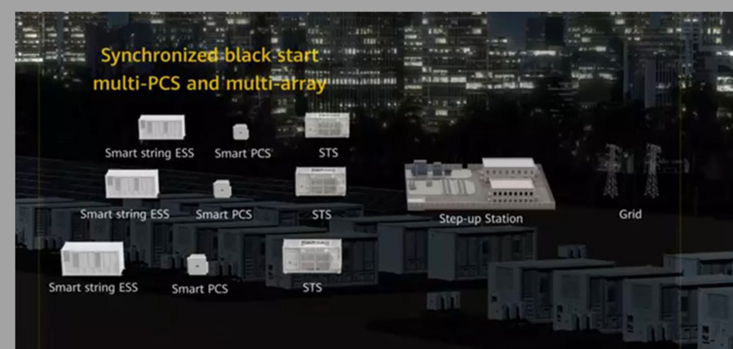
Multi-arrays parallel soft-start synchronous ramp



Quick recovery with more revenue

**$ 0.48 million**

***GW level whole grid black start***



## Saudi Arabia Red Sea Project

### World's Largest 100% PV + ESS Microgrid Project

**400 MW** PV **+ 1.3 GWh** BESS

Serving 100% PV + ESS power supply for 1 million people in Red Sea new city

Grid Forming enabling 100% PV & ESS grid

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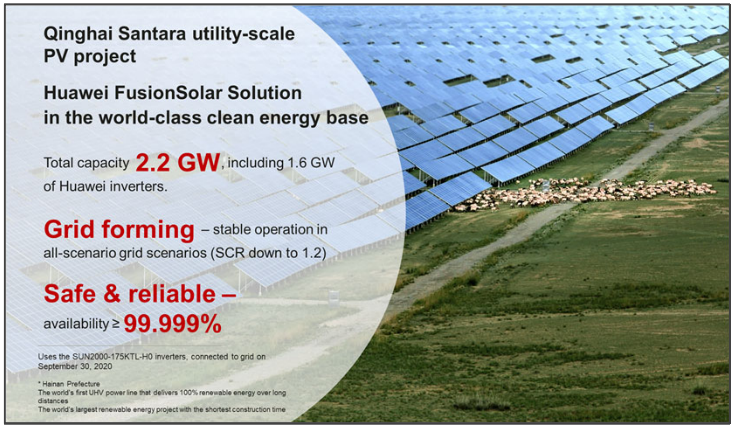
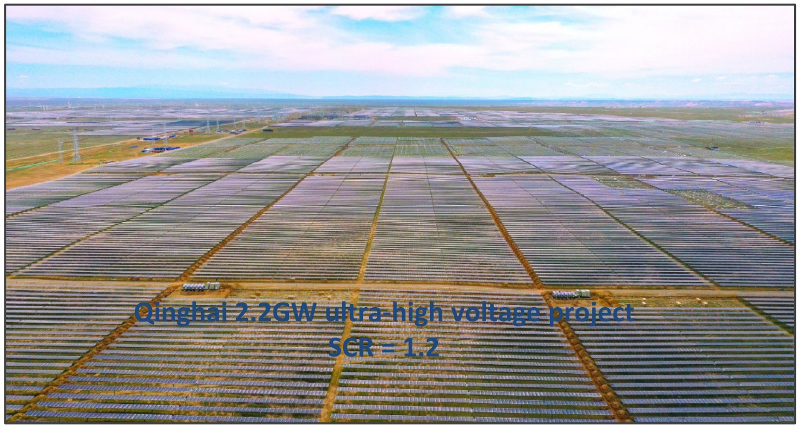
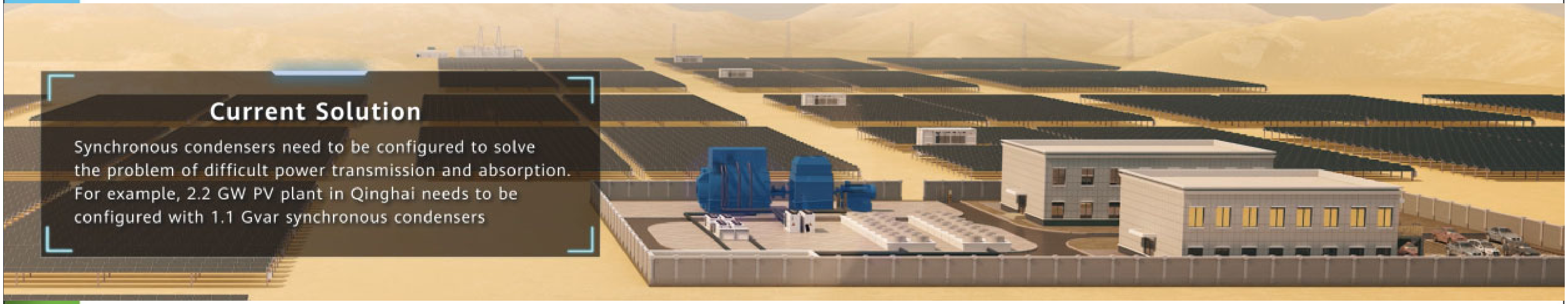
COD: 16MWh ready around Dec. 2022,
others shall be ready around middle of 2023

## 5 Application Cases in Grid forming

# The biggest PV plant with Huawei String inverters 2.2GW





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## 2022, PV plant in Gonghe, Qinghai

**World's first**

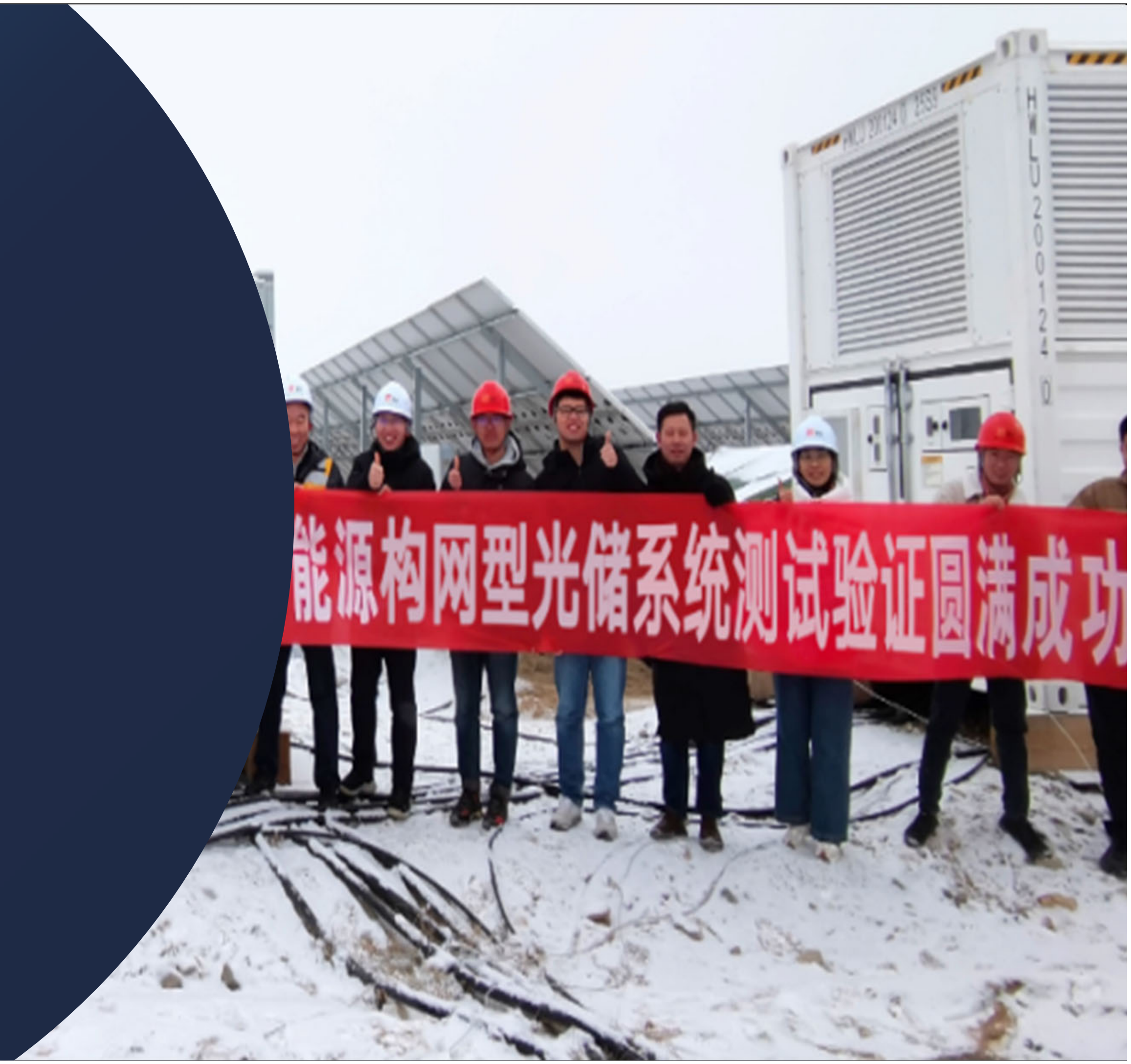
180 tests of the smart grid-forming solution in a **strong grid**

Quick active power adjustment response – **Startup time < 5 ms**

Transient voltage control speed – **Reactive power response < 10 ms**

Short-circuit capacity – **Three-fold overcurrent protection capability**

In 2022, Huawei teamed up with the China Electric Power Research Institute, State Grid Qinghai Electric Power Company, and **CR Power** to test and verify the smart grid-forming solution in the world's first grid-connection performance test.



# 2023, BESS plant in Golmud, Qinghai

# 510 successful tests of the smart grid-forming solution in **weak grid**

**510 Grid-connected tests from SCR 40.0 to SCR 1.0**
to verify how to stabilize the grid in various cases under week grid, such as frequency control, grid steady-state response, transient response, phase-angle jump event, etc.

**300% reactive short-circuit current contribution**

In 2023, Huawei teamed up with the China Electric Power Research Institute, State Grid Qinghai Electric Power Company, and **China Energy Group** to test and verify the smart grid-forming solution in the world's first grid-connection performance test.

# In the Past 10+ Years, Huawei Continuously Invest Heavily in Power Grid Stability Technologies

**Theoretical research on power grid & on-site demonstration**

2014~2020

**Continuous Tech. Innovation and Application Verification**

- Passed the first GB/T 29319-2012 grid-connection certification of China Electric Power Research Institute
- Obtained the first on-site zero voltage ride-through certification
- First Application of Low SCR Adaptation Algorithm
- Obtained the first series compensation adaptability algorithm certification......

**Five core indicators of weak power grids**

2021~

**Full power operation**

Active power not derated when HVRT

SCCR≤0.7

THDi < 1%

DCI < 0.5%

**GFM (ESS)**

2022~2024

**Large-scale commercial use of 100 MWh level GFM ESS**

- Multi-energy Complementation @ Qinghai
- Weak grid + wind storage @ Xinjiang
- Extremely weak power grid + high altitude @ Tibet

**GFM (ESS+PV)**

2025~

- Stronger voltage support capability (stronger reactive overcurrent)
- Stronger frequency support capability (larger inertia)
- Stronger power angle stability (wider oscillation suppression range)



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6 **RTE, SOH and Usuable capacity**

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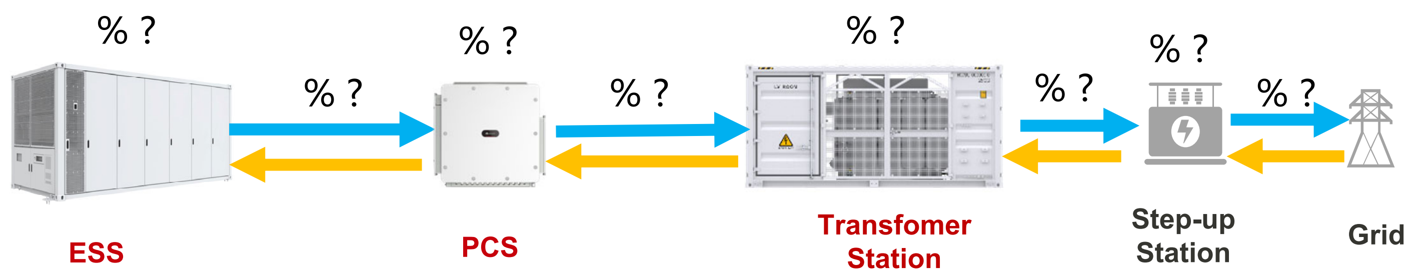
## What is RTE in an energy storage system?

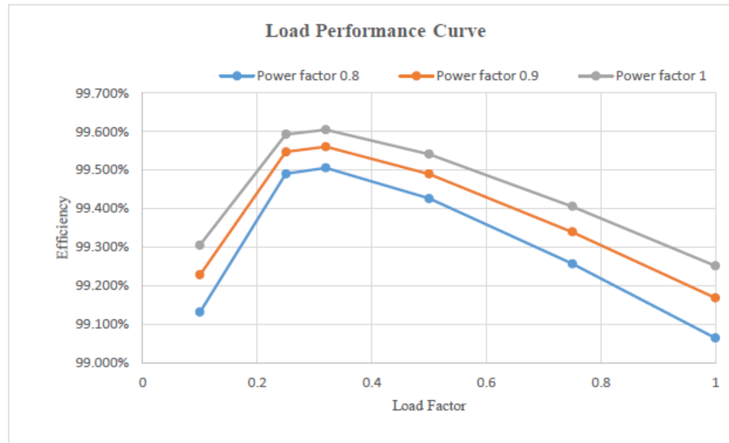



**RTE (Round-Trip Efficiency)** is a measure of the overall efficiency of the system in storing and retrieving energy. It is calculated as the ratio of the amount of energy that can be recovered from the storage system to the amount of energy used to charge the system.

A high RTE value indicates that the system is efficient in storing and retrieving energy, while a low RTE value suggests that a significant amount of energy is lost during the charging and discharging process.

# Key inputs to be considered in RTE

- **Ambient temperature**
- **C-rate**
- **Power output required (POI limitation)**
- **Auxiliary services included?**
- **Capacity utilization ratio:** When 0.25＜C-rate ≤0.5, this value is 0.98; when C-rate ≤0.25, this value is 0.99.

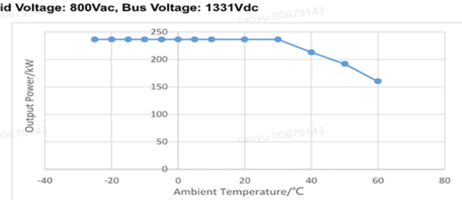



Performance Curve VS. Load Factor of 9MW ecodesign transfomer @40°C

**De-rating Curve VS. Ambient Temperature**

**De-rating Curve VS. Ambient Temperature of LUNA2000-213KTL-H0**

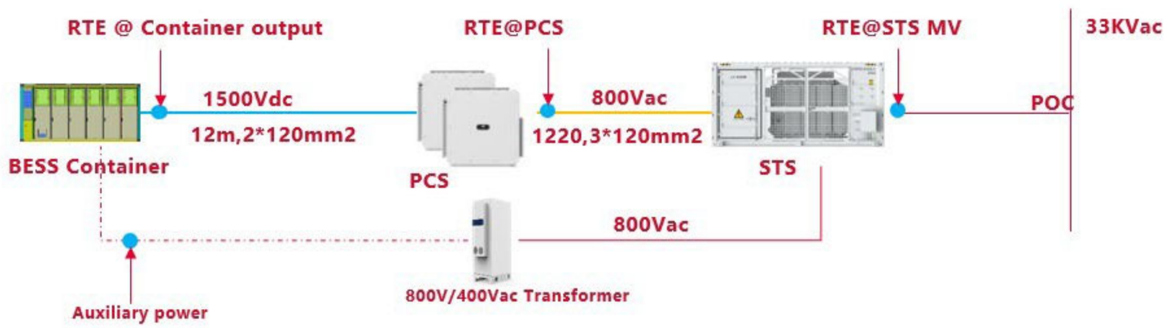
**PF=+-1, Grid Voltage: 800Vac, Bus Voltage: 1331Vdc**




| Model | -25℃ | -20℃ | -15℃ | -10℃ | -5℃ | 0℃ | 5℃ |
|---|---|---|---|---|---|---|---|
| LUNA2000-213KTL-H0 | 236.4 kW | 236.4 kW | 236.4 kW | 236.4 kW | 236.4 kW | 236.4 kW | 236.4 kW |
| | 10℃ | 20℃ | 30℃ | 40℃ | 50℃ | 60℃ | / |
| | 236.4 kW | 236.4 kW | 236.4 kW | 213 kW | 192 kW | 160 kW | / |

| | 25℃ | | 35℃ | |
|---|---|---|---|---|
| Item | 0.5C Efficiency | 0.25C Efficiency | 0.5C Efficiency | 0.25C Efficiency |
| Charge Efficiency | 93.51% | 94.52% | 93.15% | 94.11% |
| Discharge Efficiency | 94.39% | 94.65% | 94.03% | 94.24% |

# RTE calculation




The above data is the specifications under specific test conditions and temperatures.
Huawei does not promise or guarantee the above specifications.
It only can be used to guide customers to understand electrochemical cell performance and facilitate project planning. During the actual operation, the cell is affected by environmental factors.
The specifications do not represent the cell performance in the final product.

| System | | 25°C | |
|---|---|---|---|
| Charge | Item | 0.5C Efficiency | 0.25C Efficiency |
| Single Trip | Charge Efficiency | 93.51% | 94.52% |
| | BESS Aux. Efficiency | 99.43% | 99.19% |
| | STS-POC Efficiency（For reference only，The actual configuration prevails.） | 99.80% | 99.80% |
| | STS Efficiency（For reference only，The actual configuration prevails.） | 99.15% | 99.15% |
| | LV AC cable Efficiency（For reference only，The actual configuration prevails.） | 99.90% | 99.90% |
| | PCS discharge Efficiency（fully loaded） | 98.45% | 98.45% |
| | DC cable Efficiency（For reference only，The actual configuration prevails.） | 99.83% | 99.90% |
| | Rack Efficiency | 99.82% | 99.91% |
| | Pack Efficiency | 96.97% | 98.10% |
| Discharge | Item | 0.5C Efficiency | 0.25C Efficiency |
| Single Trip | Discharge Efficiency | 94.39% | 94.65% |
| | BESS Aux. Efficiency | 99.43% | 99.19% |
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| | STS Efficiency（For reference only，The actual configuration prevails.） | 99.15% | 99.15% |
| | LV AC cable Efficiency（For reference only，The actual configuration prevails.） | 99.90% | 99.90% |
| | PCS discharge Efficiency（fully loaded） | 98.55% | 98.55% |
| | DC cable Efficiency（For reference only，The actual configuration prevails.） | 99.83% | 99.90% |
| | Rack Efficiency | 99.81% | 99.91% |
| | Pack Efficiency | 97.80% | 98.14% |
| **PCS AC side RTE（with auxiliary efficiency）** | | **90.32%** | **91.55%** |
| **POC side RTE (with auxiliary efficiency)** | | **88.26%** | **89.46%** |
| **PCS AC side RTE (without auxiliary efficiency)** | | **91.36%** | **93.05%** |
| **POC side RTE (without auxiliary efficiency)** | | **89.28%** | **90.93%** |



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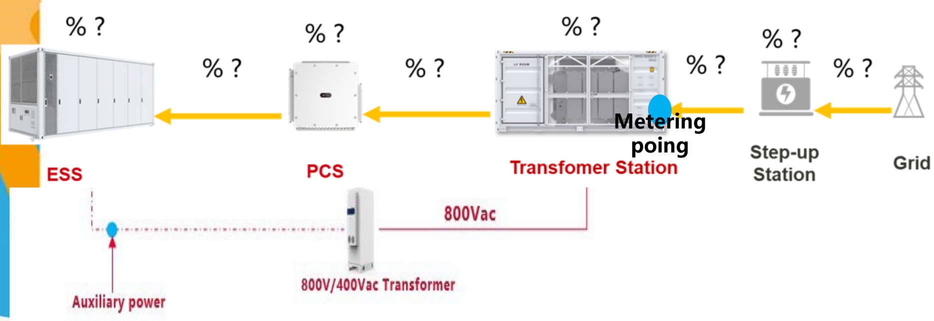
# BESS Energy Charge Efficiency

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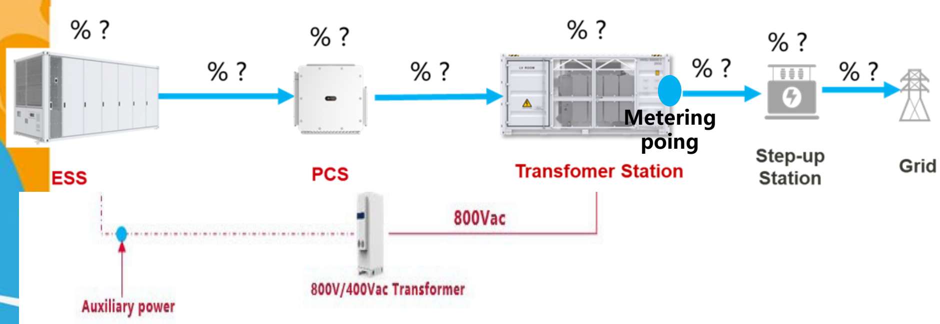
| | Rack Efficiency | 99.82% | 99.91% |
| | Pack Efficiency | 96.97% | 98.10% |

# BESS Energy Discharge Efficiency

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| System | | 25°C | |
|---|---|---|---|
| Discharge | Item | 0.5C Efficiency | 0.25C Efficiency |
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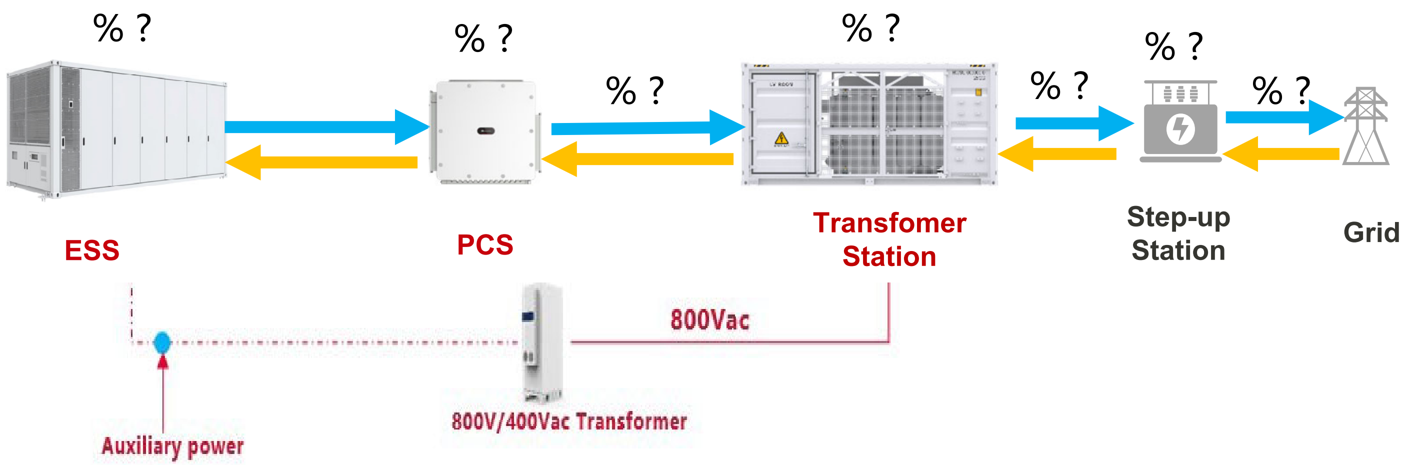
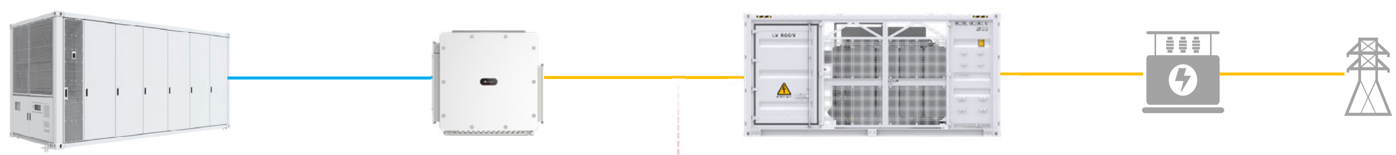
| | Pack Efficiency | 97.80% | 98.14% |

# BESS Energy Round Trip Efficiency




| | | 25°C | |
|---|---|---|---|
| | | 0.5C Efficiency | 0.25C Efficiency |
| PCS AC side RTE（with auxiliary efficiency） | | 90.32% | 91.55% |
| POC side RTE (with auxiliary efficiency) | | 88.26% | 89.46% |
| PCS AC side RTE (without auxiliary efficiency) | | 91.36% | 93.05% |
| POC side RTE (without auxiliary efficiency) | | 89.28% | 90.93% |

# RTE up to 90.3%, Higher revenue, optimized system configuration by 0.5-3%




**Traditional Solution**

**89.5-85%**

@LV AC side Including auxiliary consumption
Single stage PCS, 690Vac output,
Higher efficiency loss

VS

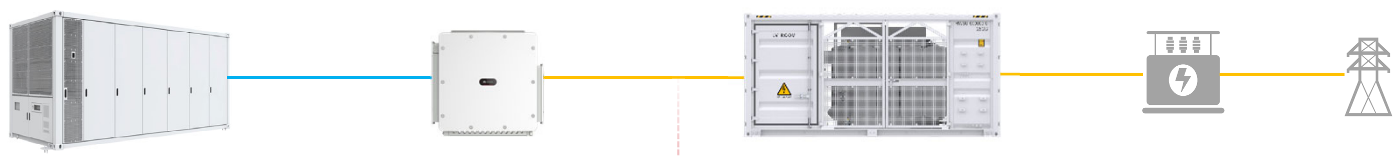
**Smart String ESS 2.0**

**90.3%**

@LV AC side Including auxiliary consumption
Smart liquid cooling control algorithm
800Vac PCS, flexible switchover between single-stage and dual-stage architectures
Less current, differential pressure and loss

Higher RTE
Optimal system configuration by 0.5-3%

# RTE up to 91.5%, Higher revenue, optimized system configuration by 2-6.5%




## Traditional Solution

**89.5-85%**

@LV AC side Including auxiliary consumption
Single stage PCS, 690Vac output,
Higher efficiency loss

VS

## Smart String ESS 2.0

**91.55%**

@0.25C, LV AC side Including auxiliary consumption
Smart liquid cooling control algorithm
800Vac PCS, flexible switchover between single-stage and dual-stage architectures
Less current, differential pressure and loss

Higher RTE
Optimal system configuration by 2-6.5%



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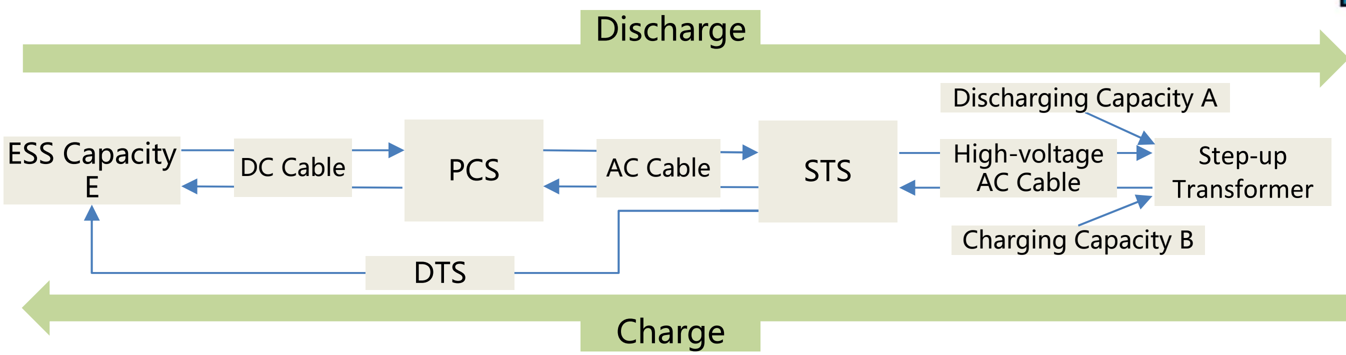
# Subarray Layout Design Principle




The following is the calculation process when the metering point is the input side of the Step-up Transformer.

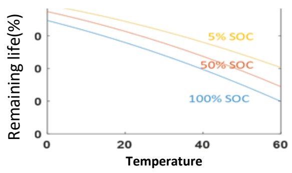
- Discharging Capacity A=( ESS Capacity E× (1- Storage attenuation)× DOD× Capacity utilization ratio× SOH× DC cable efficiency× PCS efficiency× AC cable efficiency—auxiliary power consumption) ×STS efficiency ×High-voltage AC cable efficiency
- Charging Capacity B=( ESS Capacity E× (1- Storage attenuation)× DOD× Capacity utilization ratio× SOH ÷RTE@DC side ÷ DC cable efficiency ÷ PCS efficiency ÷ AC cable efficiency + auxiliary power consumption) ÷ STS efficiency ÷ High-voltage AC cable efficiency
- Auxiliary power consumption= ESS Capacity E× (1- Storage attenuation)× DOD× Capacity utilization ratio× SOH × (1- BESS Aux. efficiency) ÷ DTS efficiency ÷ DTS input cable efficiency÷ DTS output cable efficiency

Notes: ① Capacity utilization ratio: When 0.25 < C-rate ≤0.5, this value is 0.98; when C-rate ≤0.25, this value is 0.99.

②Storage attenuation: It is calculated from the delivery date of Huawei energy storage systems, which is related to deliver and storage time and temperature.

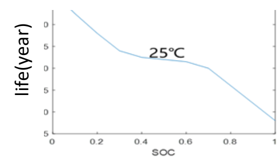
# Storage attenuation

Calendar life degradation vs. temperature




The higher the temperature, the faster the calendar life decays
(described by Arenius formula)

Calendar life vs. SOC




The higher the average SOC, the faster the calendar life decay
(Theoretical calculation can be performed based on negative electrode potential)

| EVE Cell 50% SOC Storage Attenuation | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperature \ Month | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 25 ℃ (Supplier Test Data) | 1.40% | 1.70% | 2.00% | 2.30% | 2.55% | 2.75% | 2.95% | 3.15% | 3.30% | 3.45% | 3.60% |
| 35 ℃ (Interpolation Method) | 1.40% | 2.00% | 2.49% | 2.94% | 3.37% | 3.76% | 4.01% | 4.25% | 4.43% | 4.57% | 4.71% |
| 45 ℃ (Supplier Test Data) | 1.40% | 2.25% | 2.94% | 3.54% | 4.10% | 4.62% | 4.92% | 5.20% | 5.36% | 5.49% | 5.62% |

1. The preceding storage attenuation data is calculated from the delivery date of Huawei energy storage systems. For example, Huawei energy storage systems are commissioned 4 months after delivery. Assume that the average storage temperature is 35°C. Therefore, the attenuation of transportation and storage is 3.37%, and the remaining SOH is 96.63%.

2. Recharging batteries please according to the recharging guide. Otherwise, batteries may be overdischarged.

| Storage Temperature Requirement | Storage Temperature | Recharge Period | Remark |
|---|---|---|---|
| 0℃~40℃ | 0℃≤T≤30℃ | 12 months | During the recharge period, no process is required and the battery is consumed as soon as possible.<br>Recharge the battery when the recharge time is reached.<br>Stop charging when the battery SOC reaches 50% |
| | 30℃≤T≤40℃ | 8 months | |



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SOH Guarantee

# Huawei considers 19 factors to simulate the attenuation curve

| Fitting Model | | Industry | Huawei | Impact |
|---|---|---|---|---|
| Two Main Factors | | **3 to 5** factors | **19** factors | more factors considered, more accurate result |
| **Cyclic degradation** | **Cell Degradation** | Cell cycle: 300-500 cycles | Cell cycle: **1250** cycles | More the number of times, the more the working conditions, the more accurate. |
| | | Test conditions/Quantity: 1 working condition | Test conditions/quantity: **2 to 3** working conditions, 3 PCS for each type | |
| | **Pack Degradation** | Temperature rise: The temperature rise of the cell in the pack **is not considered.** | Temperature rise: The temperature rise of the cell in the pack must be considered. | Temperature is one of the top factors. |
| | | Consistency: Generally, consistency differences are **not considered** and there is no design to prevent. | Consistency: Package Optimization and rack management avoid differences | Consistency is one of the top factors. |
| **Storage degradation** | | Cell storage: degradation **is not usually considered** | Cell storage: test for 6 months + fitting, with degradation considered | Storage degradation accounts for about **33%** of the lifetime degradation. |


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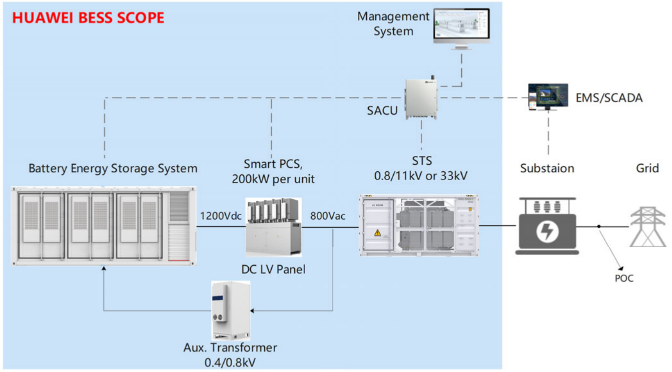
# BESS Energy Discharge Procedure—0,6MW/2.032MWh

- **Assumed condition：**
  - Test after delivery factory 3 month;
  - From STS to POC eff 99.5%;
  - Ambient temperature 25℃.
  - SOH = 100% @ year 0




•Aux loss 1.92% @25° C

BESS Energy → Battery max discharge energy → DC part discharge energy → PCS DC side energy → PCS AC side energy → STS LV energy → POC usable energy

**BESS Energy: 2.032MWh**
- Storage retention 97.70%
- DOD 98%
- Capacity utilisation ratio: 99%
- Battery efficiency 97.97%

**Battery max discharge energy: 1.93MWh**
- DC/DC eff 99.46%
- Rack eff: 100%

**DC part discharge energy: 1.92MWh**
- DC cable eff 99.5%

**PCS DC side energy: 1.88MWh**
- PCS discharge eff 98.65%

**PCS AC side energy: 1.88Wh**
- LV AC cable eff 99.73%

**STS LV energy: 1.88 MWh**
- STS eff 99.01%
- STS to POC eff 99.5%

**POC usable energy: 1.85 MWh**



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# BESS Energy Charge Procedure—0,6MW/2.032MWh

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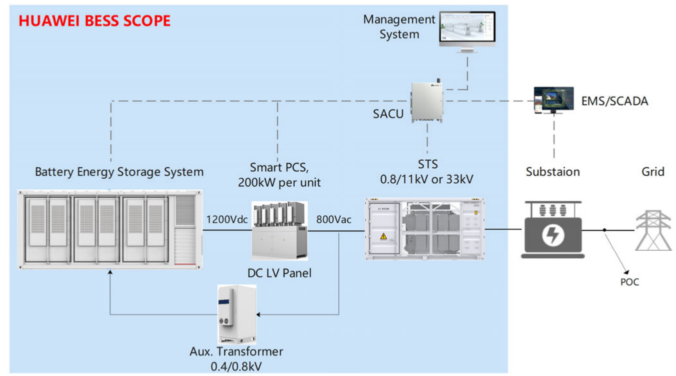
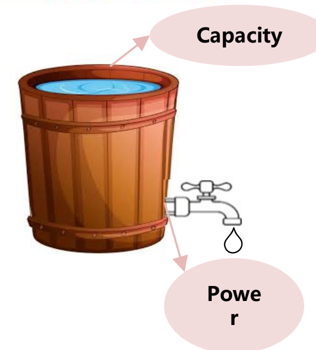



- •Aux loss 1.92%@25 °C

| BESS Energy | Battery max charge energy | DC part charge energy | PCS DC side energy | PCS AC side energy | STS LV energy | POC input energy |
|---|---|---|---|---|---|---|
| 2.032MWh | 1.97MWh | 2.02MWh | 2.03MWh | 2.06MWh | 2.09MWh | 2.10MWh |
| | Capacity utilisation ratio: 99%<br>•Battery efficiency 97.97%<br>•DOD 98%<br>•Storage retention rate 97.70% | •DC/Dc eff 99.46%<br>•Rack eff: 100% | •DC Cable loss 99.50% | •PCS charge eff 98.41% | •LV AC Cable eff 99.73% | •STS eff 99.01%<br>•STS-POC eff . 99.5% |

# BESS Power Discharge Procedure—0,6MW/2.032MWh




- The discharge power of the BESS is determined by the discharge capacity and PCS
- 0.25C system. At a certain moment, the output power of the battery side is 508kW (discharge power do not effect by DOD and SOH)。

- **Assumed condition：**
  - From STS to POC eff 99.5%;
  - Ambient temperature 25℃.

Battery discharge power: 508kW
- •DC/Dc eff 99.46%
- •Rack eff: 100%

DC side power: 505kW
- •DC cable eff 99.50%

PCS DC side power: 502kW
- •PCS discharge eff 98.65%

PCS AC side power: 495kW
- •LV AC cable eff 99.73%

•Aux loss 1.92% @25° C

STS LV power: 493.8kW
- •STS eff 99.01%
- •STS to POC eff 99.5%

POC power at a certain moment: **487kW**



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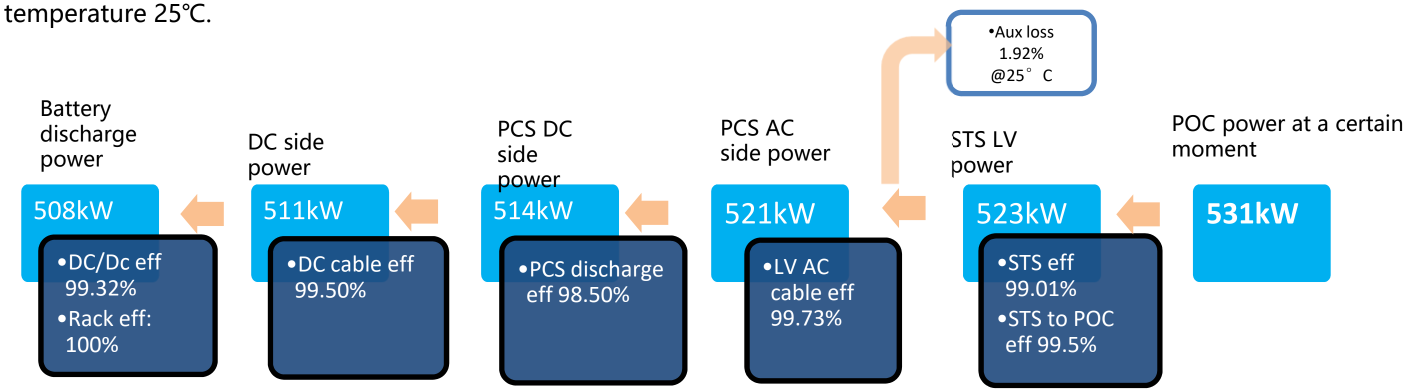
# BESS Power Charge Procedure—0,6MW/2.032MWh

- The discharge power of the BESS is determined by the discharge capacity and PCS
- 0.25C system， At a certain moment, the output power of the battery side is 508kW (discharge power do not effect by DOD and SOH)。

- **Assumed condition：**
  - From STS to POC eff 99.5%;
  - Ambient temperature 25℃.



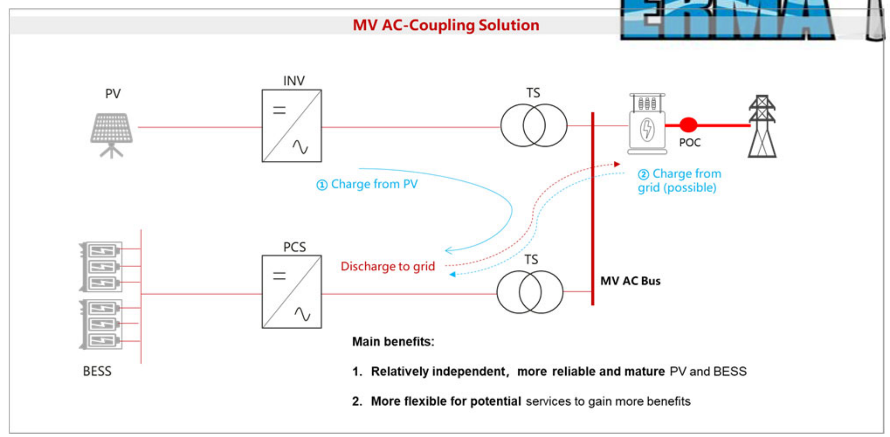
# General Overview of DC Coupling & AC Coupling

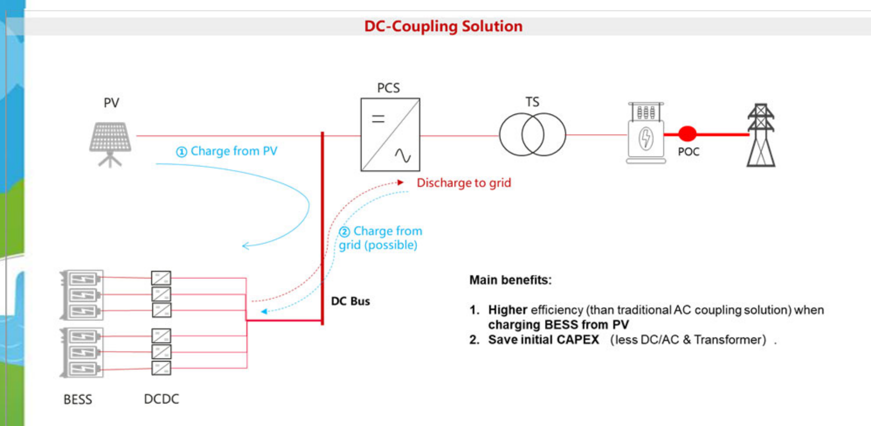
| | Capex | Efficiency | Affect PV | Safety | Grid Forming | Ancillary service | Availability | OPEX |
|---|---|---|---|---|---|---|---|---|
| **DC Coupling** | ★★★ | ★★½ | Y | ★★ | ★★★ | ★ | ★★ | High |
| **MV AC Coupling** | ★★ | ★★ | N | ★★★ | ★★★ | ★★★ | ★★★ | Low |
| **LV AC Coupling** | ★★★ | ★★★ | N | ★★★ | ★★★ | ★★★ | ★★★ | Low |

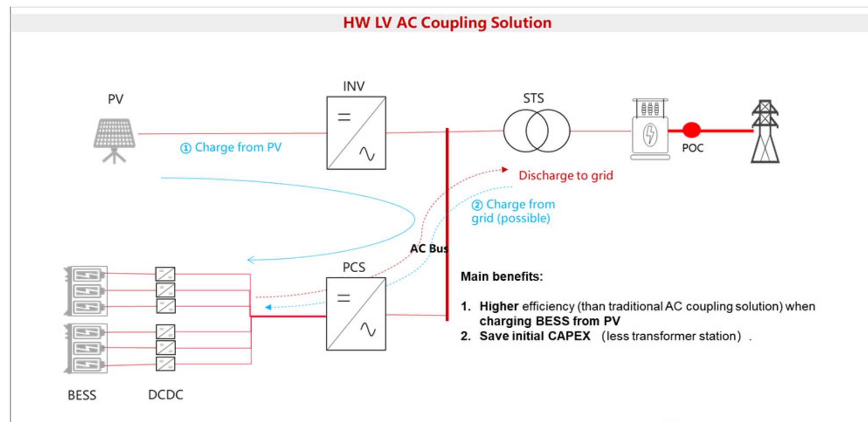
# System Overview of Different PV+BESS Solution

1.All three technologies can both be charged from grid and discharge to grid

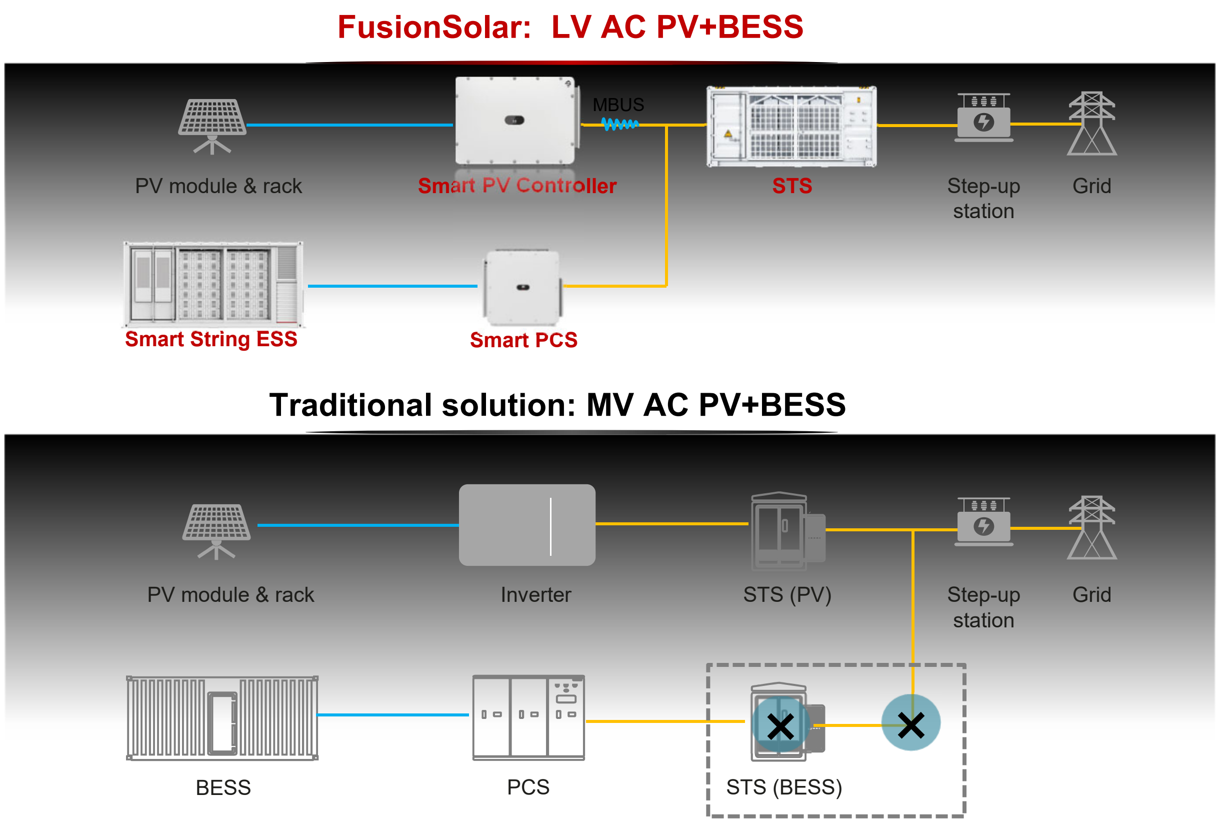
2.Based on the connection point , both DC coupling and LV AC coupling are part of PV System .

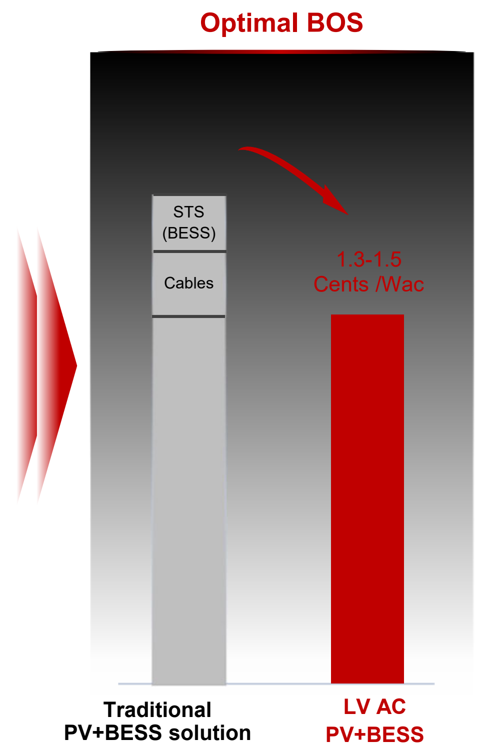


# FusionSolar LV AC PV+BESS Solution： Optimal CAPEX



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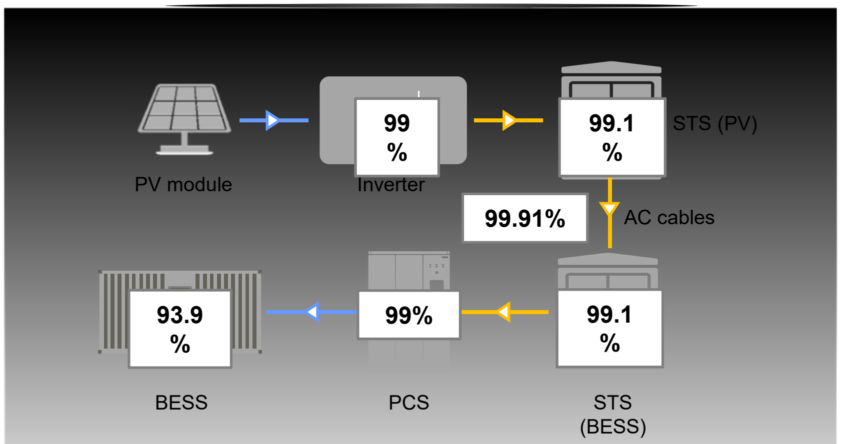
# FusionSolar LV AC PV+BESS Solution： Improving RTE about 1.5~2%

## Traditional solution: PV+ESS MVAC

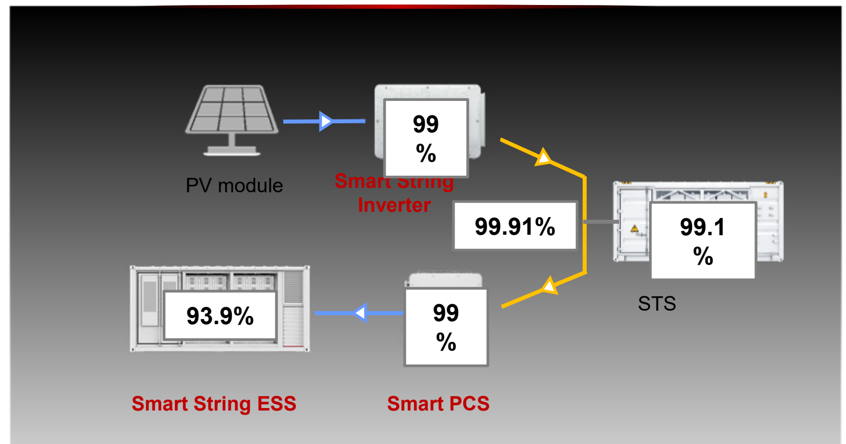



**Charging** efficiency

= 99% × **99.5%** × 99.91% × **99.5%** × 99% × 93.9%

**= 90.03%**

## Huawei solution: PV+ESS LVAC




**Charging** efficiency

= 99% × 99% × 93.9% x 99.91%

**= 91.95%**

Note: considering BESS to charge from PV.





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# RTE degradation scenarios cases

| 0.5C 1cycle/day DOD100% 25°C | | | | | |
|---|---|---|---|---|---|
| Year | Pack RTE @ Container output without Auxiliary consumption | RTE @ PCS output without Auxiliary consumption | RTE @ POC output without Auxiliary consumption | RTE @ PCS output with Auxiliary consumption | RTE @ POC output with Auxiliary consumption |
| 0 | 94.48% | 91.49% | 89.41% | 90.31% | 88.25% |
| 1 | 94.30% | 91.32% | 89.24% | 90.14% | 88.08% |
| 2 | 94.10% | 91.13% | 89.05% | 89.95% | 87.89% |
| 3 | 93.95% | 90.98% | 88.91% | 89.80% | [illegible] |
| 4 | 93.80% | 90.84% | 88.76% | 89.66% | [illegible] |
| 5 | 93.70% | 90.74% | 88.67% | 89.56% | [illegible] |
| 6 | 93.60% | 90.64% | 88.57% | 89.47% | [illegible] |
| 7 | 93.50% | 90.55% | 88.48% | 89.37% | [illegible] |
| 8 | 93.40% | 90.45% | 88.39% | 89.28% | [illegible] |
| 9 | 93.30% | 90.35% | 88.29% | 89.18% | [illegible] |
| 10 | 93.20% | 90.25% | 88.20% | 89.09% | 87.05% |
| 11 | 93.10% | 90.16% | 88.10% | 88.99% | [illegible] |
| 12 | 92.95% | 90.01% | 87.96% | 88.85% | [illegible] |
| 13 | 92.80% | 89.87% | 87.82% | 88.70% | [illegible] |
| 14 | 92.60% | 89.67% | 87.63% | 88.51% | [illegible] |
| 15 | 92.40% | 89.48% | 87.44% | 88.32% | [illegible] |
| 16 | 92.20% | 89.29% | 87.25% | 88.13% | [illegible] |
| 17 | 92.00% | 89.09% | 87.06% | 87.94% | [illegible] |
| 18 | 91.80% | 88.90% | 86.87% | 87.75% | 85.75% |
| 19 | 91.60% | 88.71% | 86.68% | 87.56% | [illegible] |
| 20 | 91.30% | 88.41% | 86.40% | 87.27% | [illegible] |

| | |
|---|---|
| 0.5C 1cycle/day DOD100% | 0.25C 1cycle/day DOD100% |
| 25°C | 25°C |
| 35°C | 35°C |
| 40°C | 40°C |
| 45°C | 45°C |
| 0.5C 1.5cycle/day DOD100% | 0.25C 1.5cycle/day DOD100% |
| 25°C | 25°C |
| 35°C | 35°C |
| 40°C | 40°C |
| 45°C | 45°C |
| 0.5C 2cycle/day DOD100% | 0.25C 1cycle/day DOD100% |
| 25°C | 25°C |
| 35°C | 35°C |
| 40°C | 40°C |
| 45°C | 45°C |

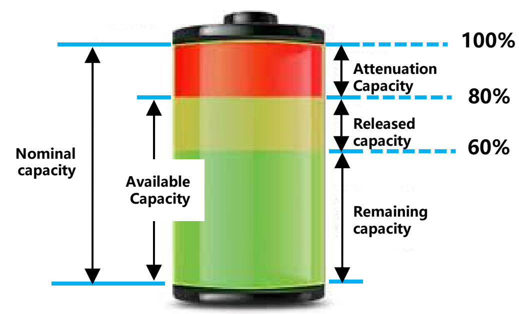
# Key specifications of Lithium-ion battery status

## SOH

- The State of Health (SOH) indicates the ability of the current battery to store energy relative to the new battery. Currently, the SOH is not defined in a unified manner. The most common SOH is the percentage of the current available battery capacity to the nominal battery capacity.
- Accurately measuring the SOH of lithium batteries helps you know the battery health status in time.
- **The ambient temperature,charge/discharge ratio and depth of charge/discharge are the main factors affecting SOH.** When the battery temperature is too high or too low, the charge/discharge ratio is too large, and the charge/discharge ratio is too high, the SOH of lithium battery will be rapidly reduced.

## SOC

- The State of Charge (SOC) indicates the current energy storage state of the battery, that is, the percentage of the remaining battery capacity to the total available battery capacity.
- SOC is the most important parameter of lithium-ion battery management. It not only reflects the remaining power of the battery, but also the estimation input of other parameters of the battery status, but also the important criterion of BMS (battery management system) control strategy.
- The SOC of lithium batteries cannot be measured directly. It can only be estimated by using the estimation model, such as battery cell voltage, charging and discharging current, temperature, and internal resistance.

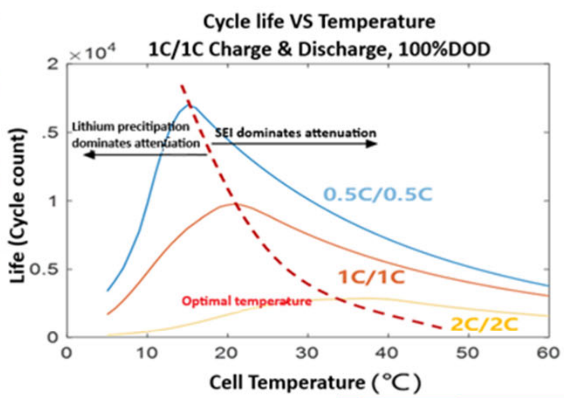



In the preceding example:

$$\text{SOH}=\frac{Abalibale\ capacity}{Normianl\ capacity}\text{x}100\% = 80\%$$

$$\text{SOC}=\frac{Remaining\ Capacity}{Abalibale\ capacity}\text{x}100\% = 75\%$$

# Cycle life (SOH)

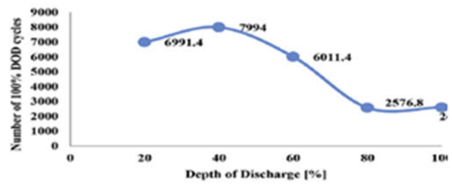



**Temperature**

The higher the temperature, the faster the cycle decay under the condition of lithium.

**charge/discharge ratio**

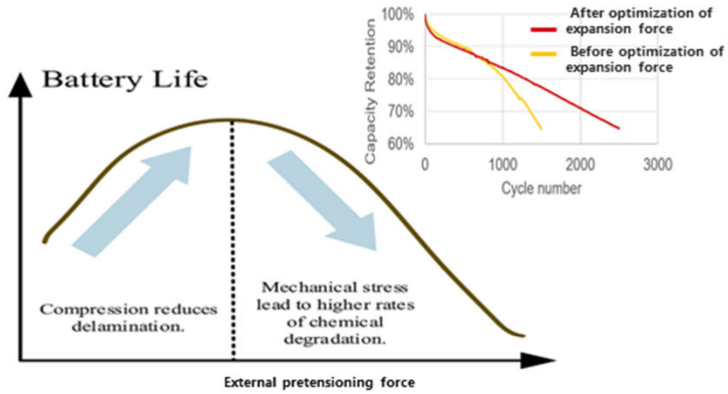
1. For the traditional charging mode, the higher the magnification, the faster the attenuation.
2. The cycle life can be increased by improving the charging and discharging modes (under research).




**charge/discharge interval**

Charge/discharge interval = Average SOC + Charge/discharge depth (in research)

1. The greater the depth of charge and discharge, the faster the attenuation
2. The higher the average SOC, the faster the attenuation.




**External binding force (expansion force**

The external binding force significantly affects the cell life, and there is an optimal initial binding force condition, but it is not possible to accurately and quantitatively judge the cell life (in research).

# SOH Guarantee

| | Category | | warranty model | Data volume/time limit requirements | Note 1 | Note 2 |
|---|---|---|---|---|---|---|
| 1 | Cell data | Storage Degradation Data | SOH storage degradation data in 100% SOC at 25°C. | ≥ 6 months data (at least 6 data records) | Provide data + fit curve | Data storage volume ≥ 6 months, at least two temperature points (temperature difference ≥ 10°C) |
| 2 | | | SOH storage degradation data in 100% SOC at 45°C. | ≥ 6 months data (at least 6 data records) | Provide data + fit curve | |
| 3 | | | SOH storage degradation data in 50% SOC at 25°C. | ≥ 6 months data (at least 6 data records) | Provide data + fit curve | |
| 4 | | | SOH storage degradation data in 50% SOC at 45°C | ≥ 6 months data (at least 6 data records) | Provide data + fit curve | |
| 5 | | Cycle data | SOH cycle degradation data at 25°C (1/2 max rate) | ≥ 1 / 8 cycle specification + 50 turns | Provide data + fit curve | The number of cycles is greater than or equal to 1/8 + 50, and at least three temperature points (temperature difference is greater than or equal to 5°C). The maximum rate and 1/2 maximum rate data are required. |
| 6 | | | SOH cycle degradation data at 35°C (1/2 max rate) | ≥ 1 / 8 cycle specification + 50 turns | Provide data + fit curve | |
| 7 | | | SOH cycle degradation data at 45°C (1/2 max rate) | ≥ 1 / 8 cycle specification + 50 turns | Provide data + fit curve | |
| 8 | | | SOH cycle degradation data at 25°C (max rate) | ≥ 1 / 8 cycle specification + 50 turns | Provide data + fit curve | |
| 9 | | | SOH cycle degradation data at 35°C (max rate) | ≥ 1 / 8 cycle specification + 50 turns | Provide data + fit curve | |
| 10 | | | SOH cycle degradation data at 45°C (max rate) | ≥ 1 / 8 cycle specification + 50 turns | Provide data + fit curve | |
| 11 | Pack data | Consistency | Consistency of cells in the same container, including capacity and internal resistance | Data of each electrochemical cell during shipment. Cell → pack → container corresponds to each other. | | By apply pack optimization & Rack management can avoided this degradation. Competitors do not consider this function |
| 12 | | | Temperature difference consistency of the PACK in different positions | | | |
| 13 | | Temperature rise | Temperature rise curve of the cell in the pack at an ambient temperature of 25°C and 0.5CP charge and discharge | | | Some competitors do not consider this part. |
| | | | Temperature rise curve of the cell in the pack at an ambient temperature of 25°C and 0.33CP charge and discharge | | | |
| 14 | | | Temperature rise curve of the cell in the pack at an ambient temperature of 25°C and 0.25CP charge and discharge | | | |
| 15 | Operating condition data | Working condition data (provided by the customer) | Operating ambient temperature | | Calculated by Huawei based on the average dimension and temperature rise. | |
| | | | Daily cycle times | | Calculated by Huawei based on the customer's working conditions | |
| 16 | | | Charge/discharge ratio | | Huawei calculated based on the customer's working conditions | |
| 17 | | | Storage SOC | | Huawei uses 50% SOC storage. | |
| 18<br>19 | | | DOD | | Huawei calculates the DOD based on 100%. | |

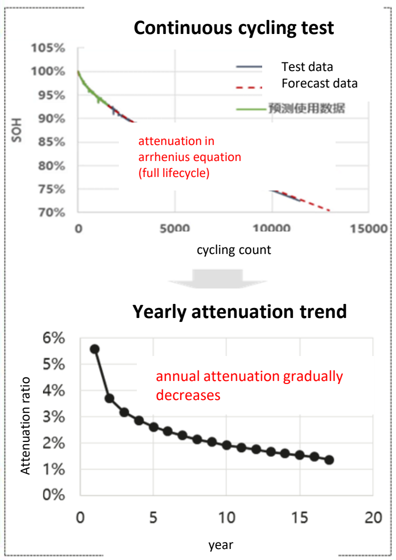
# SOH degradation scenarios cases

| | (0.25CP Constant power charge/discharge) | | | (0.33CP Constant power charge/discharge) | | | (0.5CP Constant power charge/discharge) | | |
|---|---|---|---|---|---|---|---|---|---|
| SOC | 50% | 50% | 50% | 50% | 50% | 50% | 50% | 50% | 50% |
| DOD | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| ℃ (Ambient temperature) | (below 40℃) | (below 40℃) | (below 40℃) | (below 40℃) | (below 40℃) | (below 40℃) | (below 40℃) | (below 40℃) | (below 40℃) |
| (Number of cycles/day) | 1 | 1.5 | 2 | 1 | 1.5 | 2 | 1 | 1.5 | 2 |
| (Interval between charge & discharge/hour) | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 |
| (Number of cycles/year) | 365 | 548 | 730 | 365 | 548 | 730 | 365 | 548 | 730 |
| Year | SOH | SOH | SOH | SOH | SOH | SOH | SOH | SOH | SOH |
| 0 | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% |
| 1 | 94.89% | 94.34% | 93.90% | 94.69% | 94.07% | 93.55% | 94.27% | 93.52% | 92.89% |
| 2 | 92.71% | 91.83% | 91.01% | 92.45% | 91.50% | 90.60% | 91.86% | 90.74% | 89.68% |
| 3 | 90.96% | 89.68% | 88.47% | 90.68% | 89.31% | 88.00% | 89.97% | 88.39% | 86.85% |
| 4 | 89.38% | 87.70% | 86.11% | 89.09% | 87.31% | 85.58% | 88.28% | 86.22% | 84.21% |
| 5 | 87.91% | 85.84% | 83.86% | 87.61% | 85.41% | 83.28% | 86.69% | 84.16% | 81.69% |
| 6 | 86.52% | 84.05% | 81.71% | 86.19% | 83.59% | 81.07% | 85.17% | 82.17% | 79.25% |
| 7 | 85.18% | 82.33% | 79.62% | 84.84% | 81.83% | 78.92% | 83.71% | 80.25% | 76.87% |
| 8 | 83.88% | 80.66% | 77.58% | 83.52% | 80.12% | 76.82% | 82.29% | 78.38% | 74.55% |
| 9 | 82.63% | 79.03% | 75.59% | 82.25% | 78.45% | 74.77% | 80.92% | 76.54% | 72.28% |
| 10 | 81.40% | 77.43% | 73.64% | 81.01% | 76.81% | 72.76% | 79.57% | 74.75% | 70.04% |
| 11 | 80.21% | 75.87% | 71.72% | 79.79% | 75.21% | 70.78% | 78.24% | 72.98% | 67.83% |
| 12 | 79.03% | 74.33% | 69.83% | 78.60% | 73.63% | 68.82% | 76.95% | 71.23% | 65.66% |
| 13 | 77.88% | 72.82% | 67.97% | 77.42% | 72.07% | 66.90% | 75.67% | 69.51% | 63.51% |
| 14 | 76.75% | 71.33% | 66.14% | 76.27% | 70.54% | 65.00% | 74.41% | 67.82% | 61.38% |
| 15 | 75.64% | 69.86% | 64.32% | 75.13% | 69.03% | 63.12% | 73.16% | 66.13% | |
| 16 | 74.54% | 68.40% | 62.53% | 74.01% | 67.53% | 61.26% | 71.93% | 64.47% | |
| 17 | 73.45% | 66.97% | 60.75% | 72.90% | 66.05% | | 70.72% | 62.82% | |
| 18 | 72.38% | 65.54% | | 71.80% | 64.58% | | 69.52% | 61.19% | |
| 19 | 71.32% | 64.14% | | 70.72% | 63.13% | | 68.33% | | |
| 20 | 70.28% | 62.74% | | 69.65% | 61.68% | | 67.14% | | |

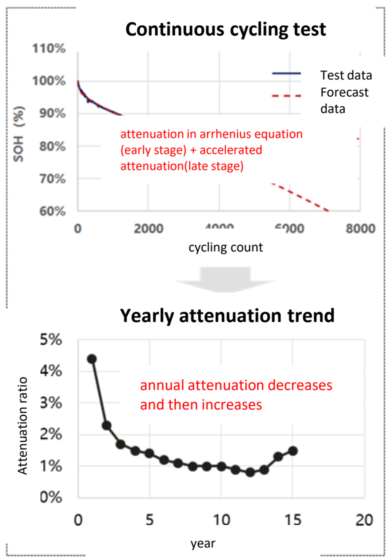
# Lifespan of energy storage systems

Live test shows life aging curve meets either rule 1 or rule 2

life aging rule 1 [1]




life aging rule 2 [2]





1. Maik Naumann et., al. Analysis and modeling of cycle aging of a commercial LiFePO4/graphite cell. Journal of Power Sources 451 (2020) 227666.
2. Damian Burzyński', Leszek Kasprzyk,et,al. A novel method for the modeling of the state of health of lithium-ion cells using machine learning for practical applications. Knowledge-Based Systems 219 (2021) 106900.


CAPEX
1. Cost of equipment (ESS, PCS)
2. Installation cost
3. Other cost
3. 其他成本

OPEX
preventative maintenance & fault maintenance cost
O&M labor cost
Warranty Expenses and the power generation loss during fault

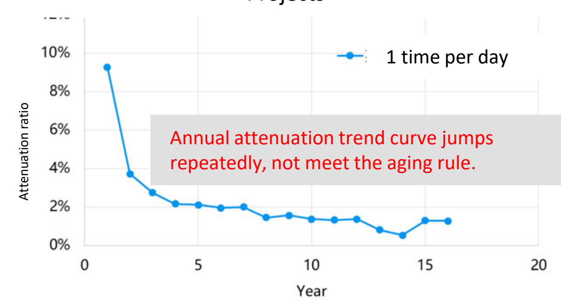
Total electricity charge fee in life cycle

$$LCoS = \frac{\sum_{n=1}^{N} NPV\ (CAPEXt\ ) + \sum_{n=1}^{N} NPV\ (OPEX_t\ ) + \sum_{n=1}^{N} NPV\ (FUEL_t)}{\sum_{n=1}^{N} NPV\ (放电量_t\ )}$$

Total electricity discharged in life cycle

| XX | United Kingdom energy storage project, 1C | |
|---|---|---|
| Year | 1 time per day | annual attenuation SOH (n years)-SOH (n+1 years) |
| 0 | 100.00% | |
| 1 | 90.73% | 9.27% |
| 2 | 87.01% | 3.72% |
| 3 | 84.26% | 2.75% |
| 4 | 82.10% | 2.16% |
| 5 | 79.98% | 2.12% |
| 6 | 78.02% | 1.96% |
| 7 | 76.02% | 2.00% |
| 8 | 74.56% | 1.46% |
| 9 | 73.00% | 1.56% |
| 10 | 71.62% | 1.38% |
| 11 | 70.29% | 1.33% |
| 12 | 68.91% | 1.38% |
| 13 | 68.11% | 0.80% |
| 14 | 67.57% | 0.54% |
| 15 | 66.28% | 1.29% |
| 16 | 65.01% | 1.27% |

Comparison of Annual Degradation Trends Curve for XX Projects




**Conclusion: It can be concluded that some integrators provide a manually changed degradation curve**



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7

# Case study: Understanding BOL, EOL & AOL and Power, energy and efficiency Diagrams

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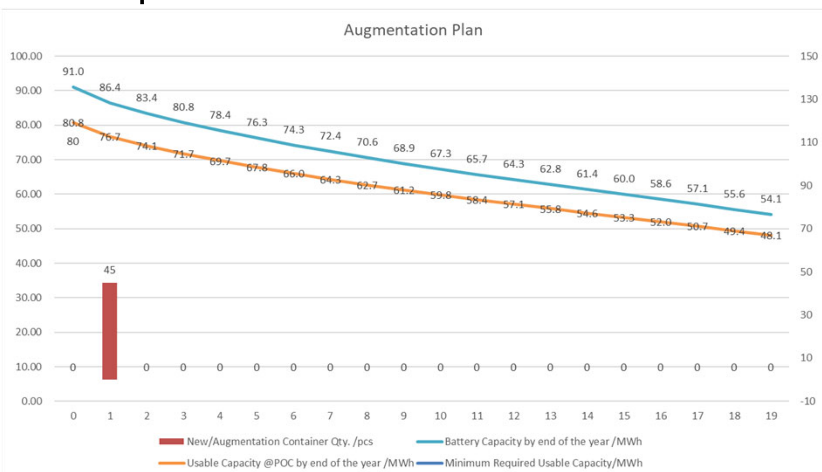
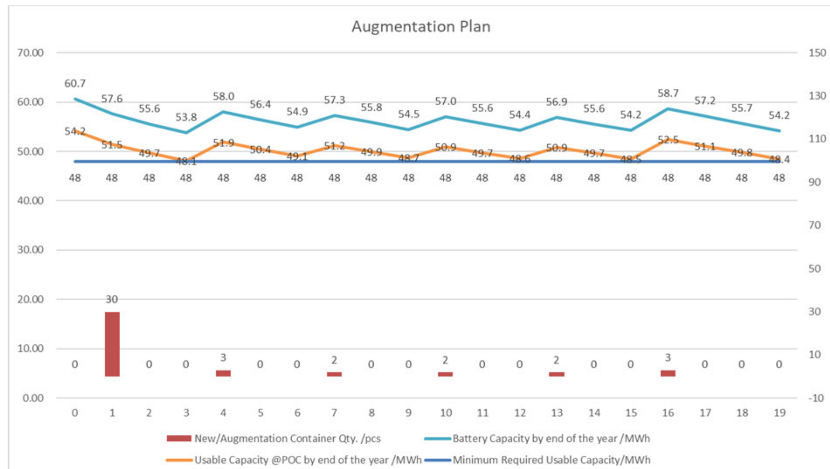
# BOL, EOL & AOL

- BOL = Beginning of Life
- EOL = End of Life
- AOL = Augmentation of Life

## Example 1: *BOL 80MWh = EOL 48MWh*




## Example 2: *AOL 48MWh*



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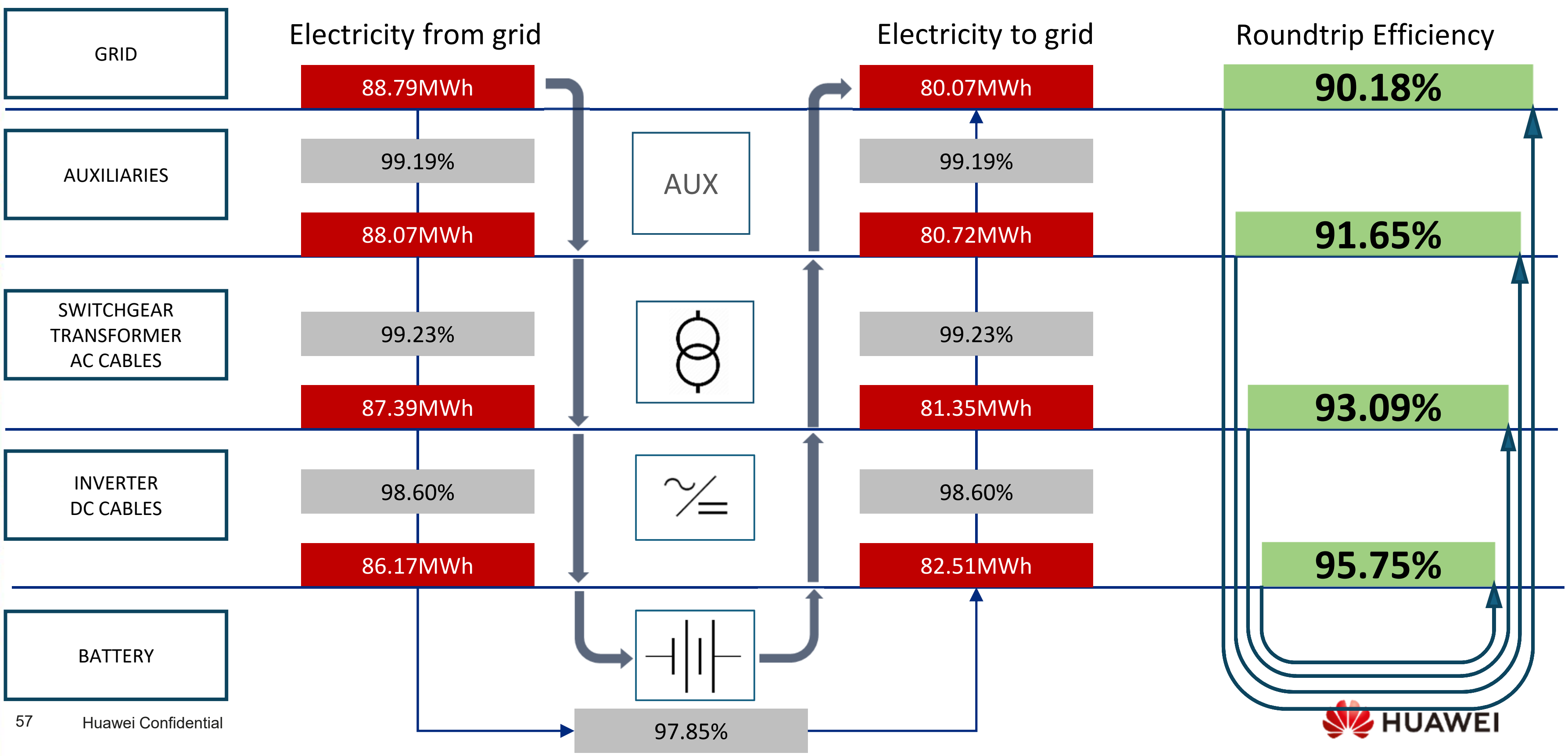
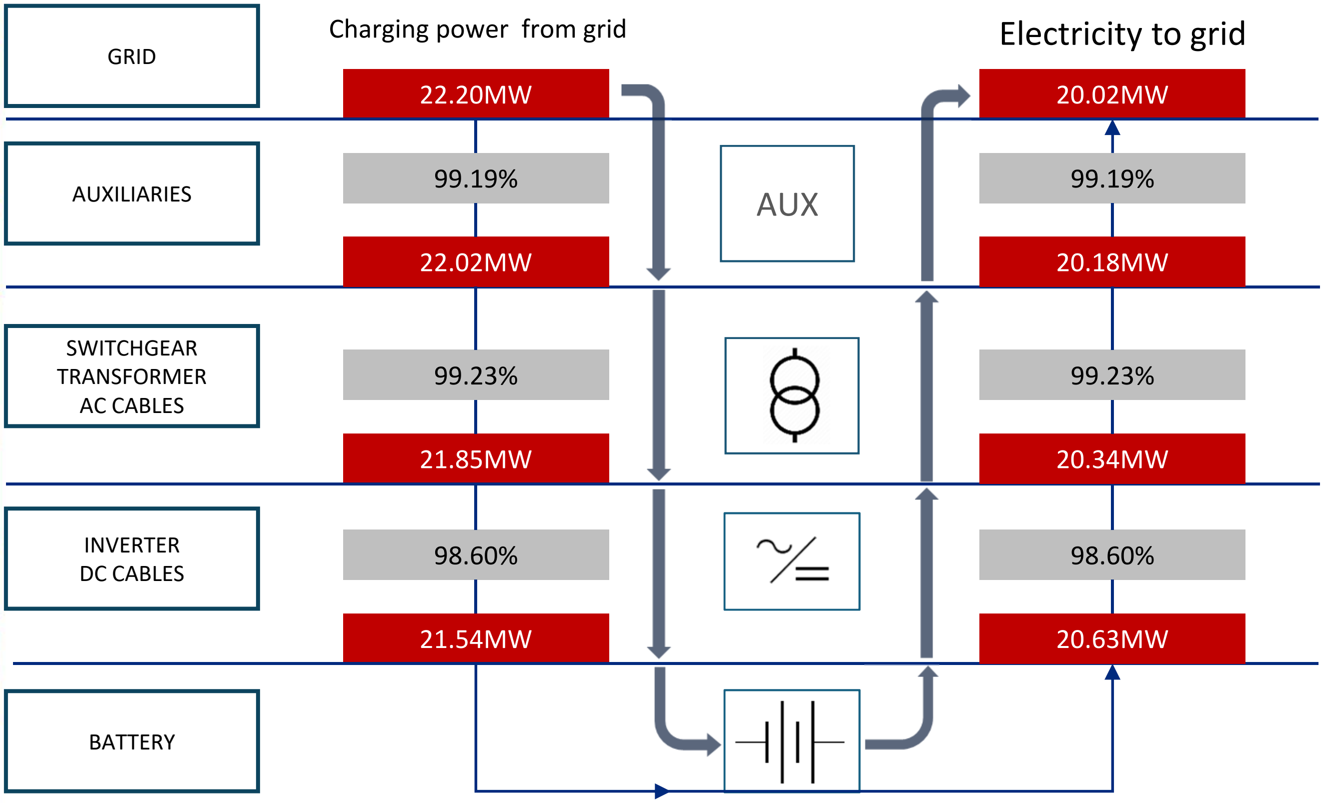
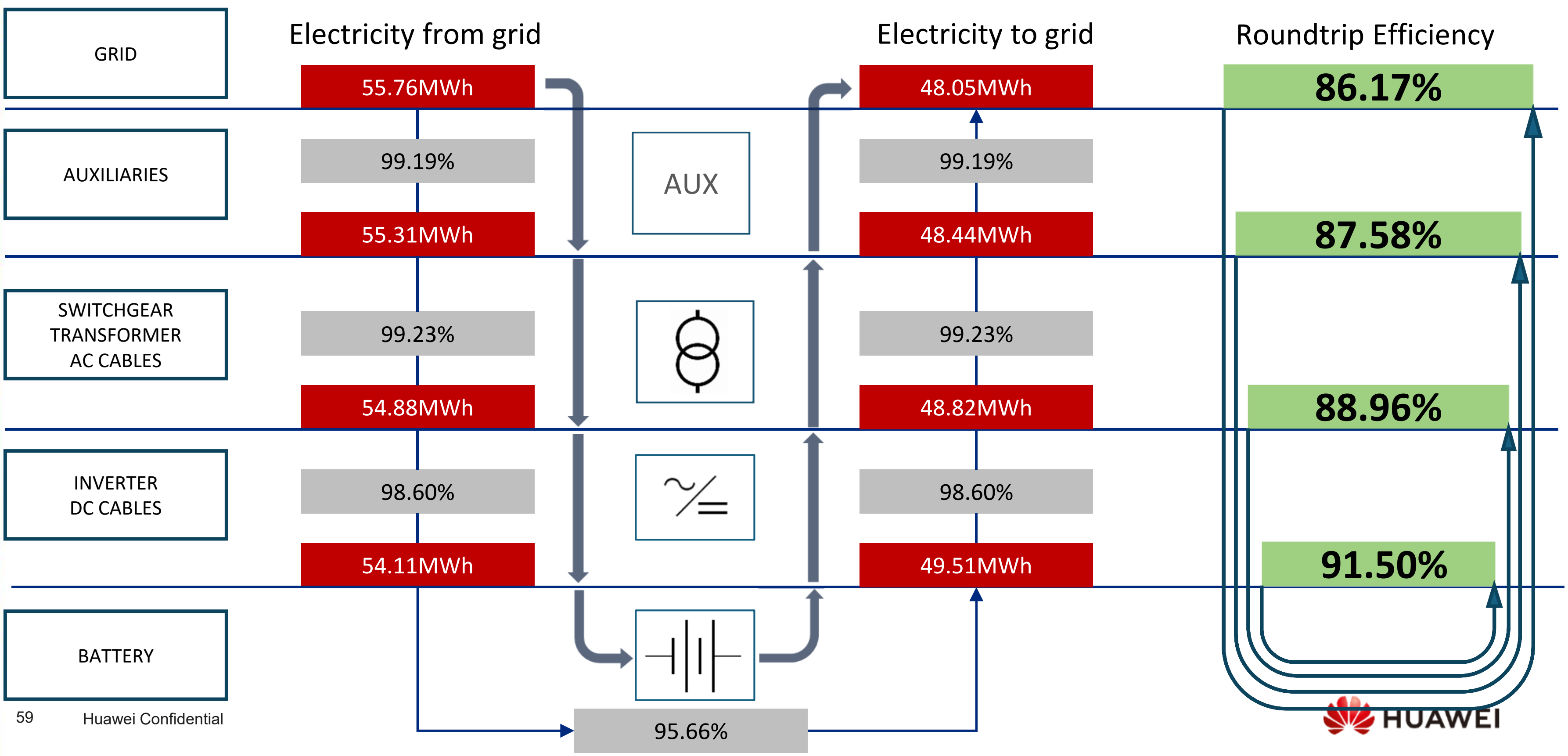
# Energy at BoL



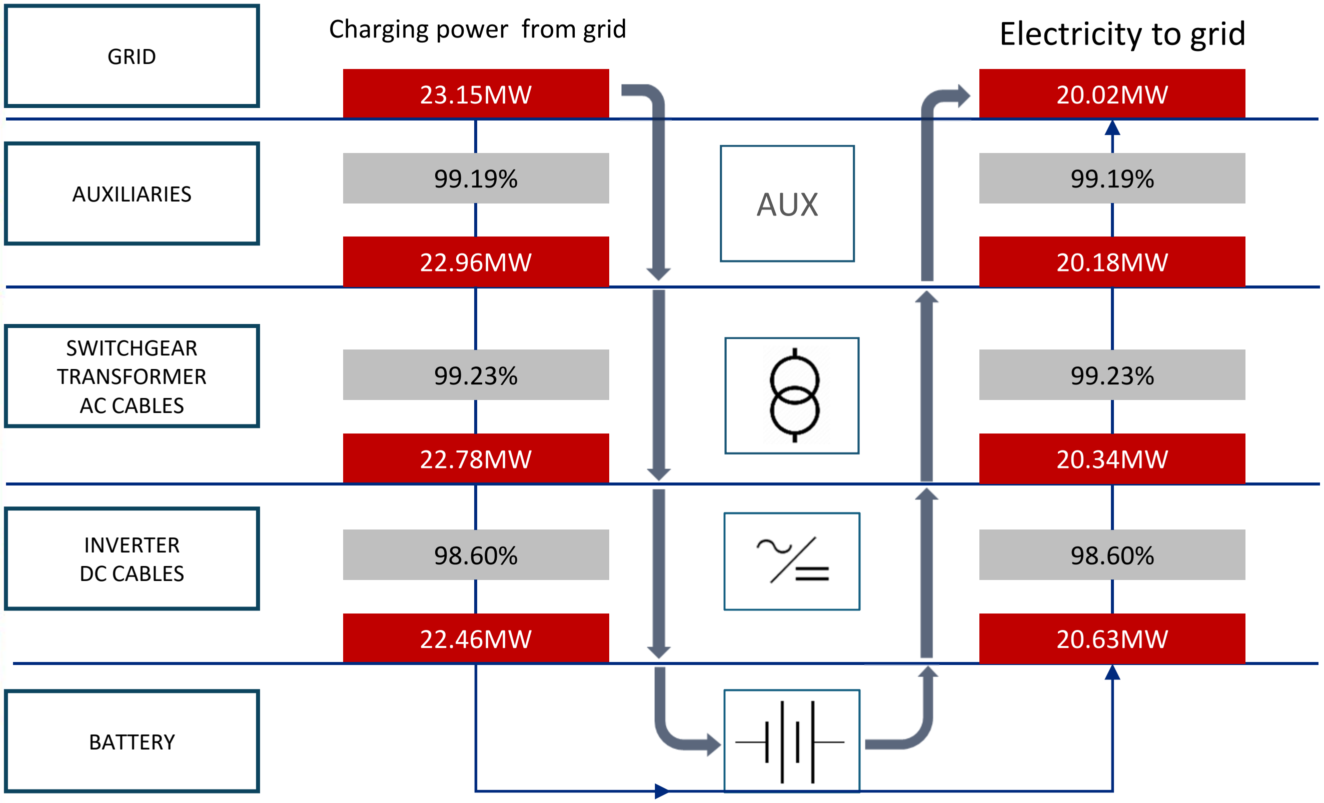
# Power at BoL


GRID
AUXILIARIES
SWITCHGEAR
TRANSFORMER
AC CABLES
INVERTER
DC CABLES
BATTERY
Charging power from grid
22.20MW
99.19%
22.02MW
99.23%
21.85MW
98.60%
21.54MW
AUX
Electricity to grid
20.02MW
99.19%
20.18MW
99.23%
20.34MW
98.60%
20.63MW

# Energy at 60% State of Health



# Power at 60% State of Health



8

# EU RfG (Grid code) and its influence on BESS design

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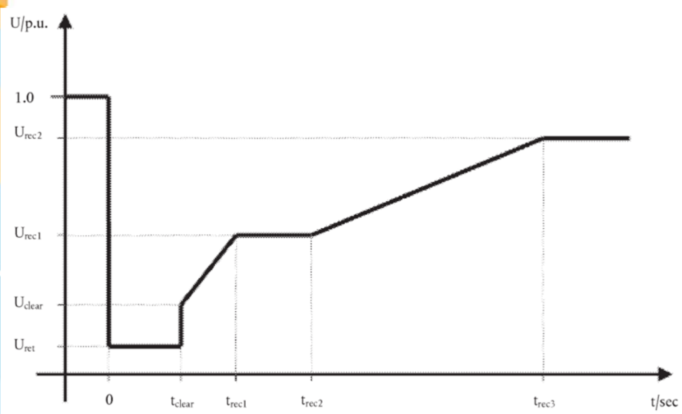
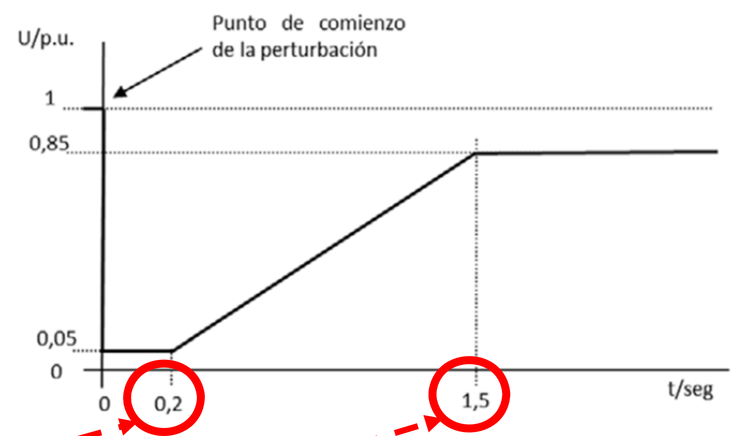
# RfG NC structure and implementation

## Requirements validation procedures:




From RfG into Grid Code



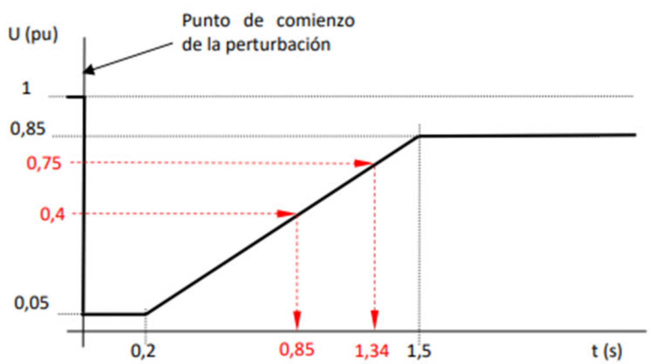

**Parameters for Figure 3 for fault-ride-through capability of power park modules**

| Voltage parameters (pu) | | Time parameters (seconds) | |
|---|---|---|---|
| $U_{ret}$: | 0 | $t_{clear}$: | 0,14-0,15 (or 0,14-0,25 if system protection and secure operation so require) |
| $U_{clear}$: | $U_{ret}$ | $t_{rec1}$: | $t_{clear}$ |
| $U_{rec1}$: | $U_{clear}$ | $t_{rec2}$: | $t_{rec1}$ |
| $U_{rec2}$: | 0,85 | $t_{rec3}$: | 1,5-3,0 |

**Remember: this is NOT voltage control**

# RfG NC structure and implementation

## Requirements validation procedures:



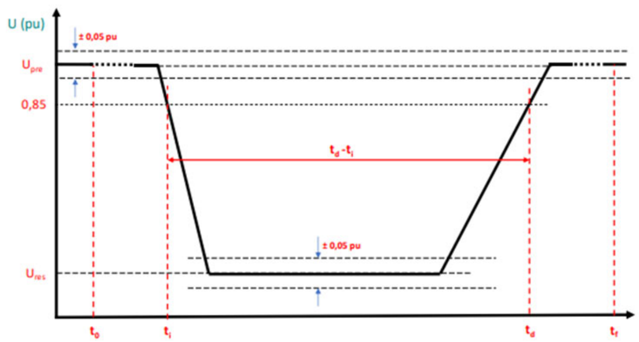




Figura 25. Ensayo de hueco. Tensiones y tiempos. Tolerancias.

| Tipo de Ensayo | $U_{res}$(p.u.) | $T_f$(ms) | Tipo de falta | Carga | $Q/P_{max}$ | K |
|---|---|---|---|---|---|---|
| $U0TP_{max}$ | 0%Un (±5%) | ≥150 | Trifásico | Plena | 0 ± 10% | K=3,5 |
| $U0TP_{med}$ | | | | Parcial | 0 ± 10% | K=3,5 |
| $U0BP_{max}$ | | | Bifásico | Plena | 0 ± 10% | K=3,5 |
| $U0BP_{med}$ | | | | Parcial | 0 ± 10% | K=3,5 |
| $U40TP_{max}$ | 40%Un (±5%) | ≥830 | Trifásico | Plena | 0 ± 10% | K=3,5 |
| $U40TP_{med}$ | | | | Parcial | 0 ± 10% | K=3,5 |
| $U40BP_{max}$ | | | Bifásico | Plena | 0 ± 10% | K=3,5 |
| $U40BP_{med}$ | | | | Parcial | 0 ± 10% | K=3,5 |
| $U75TP_{max}$ | 75%Un (±5%) | ≥1340 | Trifásico | Plena | 0 ± 10% | K=3,5 |
| $U75TP_{med}$ | | | | Parcial | 0 ± 10% | K=3,5 |
| $U75TP_{med}Q_{max}$ | | | | | $Q_{max}/P_{max}$ | K=3,5 |
| $U75TP_{med}Q_{min}$ | | | | | $Q_{min}/P_{max}$ | K=3,5 |
| $U75TP_{min}$ | | | | $P_{min}$* | 0 ± 10% | K=6 |
| $U75BP_{max}$ | | | Bifásico | Plena | 0 ± 10% | K=3,5 |
| $U75BP_{med}$ | | | | Parcial | 0 ± 10% | K=3,5 |
| $U75BP_{min}$ | | | | $P_{min}$* | 0 ± 10% | K=6 |

**Tabla 50. Ensayos de huecos de tensión a realizar para MPE ≥ 110 kV**

# RfG NC structure and implementation

## Requirements validation procedures:

Spanish NTS

RED ELÉCTRICA DE ESPAÑA
Grupo Red Eléctrica
aeléc
ufd
Grupo Naturgy
cide
aniversario ASEME

**Technical standard for monitoring the compliance of power generating modules according to EU Regulation 2016/631**

| Review | Reason | Date | Comments |
|---|---|---|---|
| 1.0 | Publication | 18/7/2019 | |
| 2.0 | Publication version 2 | 3/11/2020 | Adoption of Order TED/749/2020 and Royal Decree 647/2020. English version contains Corrigendum to Spanish version 2 published on 13/4/2021. |
| 2.1 | Publication version 2.1 | 9/7/2021 | Relevant modifications to version 2 |

| REQUIREMENT | | | | TYPE OF ASSESSMENT | |
|---|---|---|---|---|---|
| Article [1] | Definition of Requirement | PGM Type | Subsection of the Technical Standard | PPM | SPGM |
| 13.2 | Limited Frequency Sensitive Mode - Overfrequency (LFSM-O) | ≥A | 5.1 | (S and T) or C** | (S and T) or C** |
| 15.2.(a) and (b) | Remote power control capability and range | ≥C | 5.5 | T or C | N/A |
| 15.2.e | Power-frequency control | ≥C | 5.4 | T | T |
| 15.2.d | Frequency Sensitive Mode (FSM) | ≥C | 5.3 | (S and T) or C** | (S and T) or C** |
| 15.2.c | Limited Frequency Sensitive Mode-Underfrequency (LFSM-U) | ≥C | 5.2 | (S and T) or C** | (S and T) or C** |
| 21.2 | Synthetic inertia during very fast frequency variations* | ≥C | 5.6 | S | N/A |
| 17.3 | Recovery of active power after a fault | ≥B | 5.11 | N/A | T (S***) or C** |
| 14.3 | Fault-ride-through capability of synchronous generators connected below 110 kV | ≥B | 5.11 | N/A | T (S***) or C** |
| 16.3 | Fault-ride-through capability of synchronous generators connected above 110 kV | D | 5.11 | N/A | T (S***) or C** |
| 20.3 | Recovery of active power after a fault | ≥B | 5.11 | T (S***) or C** | N/A |
| 14.3 | Fault-ride-through capability of PPMs connected below 110 kV | ≥B | 5.11 | T (S***) or C** | N/A |
| 16.3 | Fault-ride-through capability of PPMs connected above 110 kV | D | 5.11 | T (S***) or C** | N/A |
| 15.5.a | Black start* | ≥C | 5.12 | N/A | T or C |
| 15.5.b | Capability to take part in island operation* | ≥C | 5.13 | S or C | S or C |
| 15.5.c | Fast re-synchronisation capability | ≥C | 5.14 | N/A | T or C |
| 18.2.b | Reactive power capability at maximum capacity | ≥B | 5.7 | N/A | (P) or C** |
| 18.2.c | Reactive power capability below maximum capacity | ≥B | 5.7 | N/A | (T) or C** |
| 19.2 | Power oscillation damping control | D**** | 5.9 | N/A | S or C |
| 20.2.b and 20.2.c | Fast fault current injection at the connection point in case of symmetrical (3-phase) faults | ≥B | 5.11 | T (S***) or C** | N/A |
| 21.3. b | Reactive power capability at maximum capacity | ≥B | 5.7 | (T) or C** | N/A |
| 21.3.c | Reactive power capability below maximum capacity | ≥B | 5.7 | (T) or C** | N/A |
| 21.3.d | Reactive power control modes | ≥B | 5.8 | T or C** | N/A |
| 21.3.f | Oscillation damping control | ≥C | 5.10 | S | N/A |

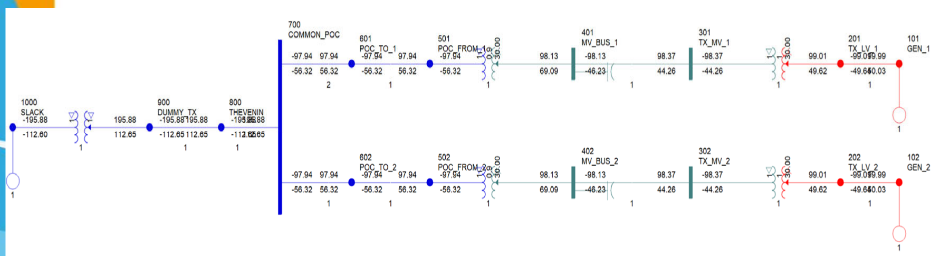
Validation test documents allow three procedures to prove the grid code compliance:

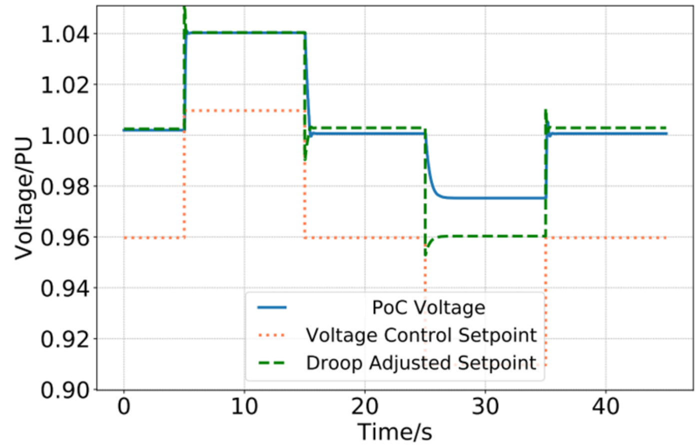
- Simulation
- On-site test
- Certification

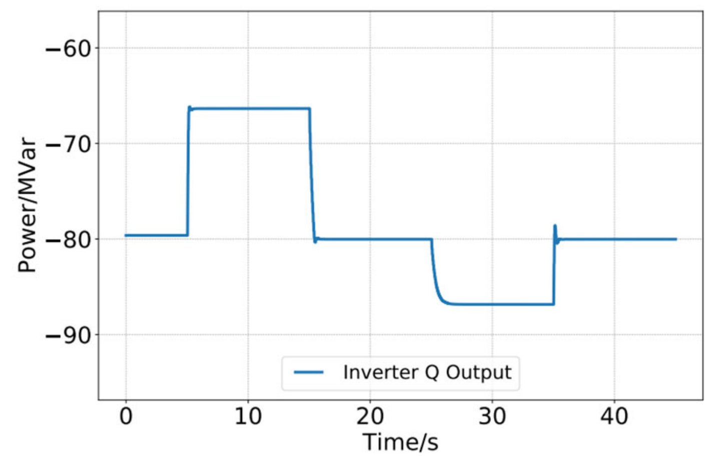
# RfG NC structure and implementation

## Requirements validation (simulation):

Example: Voltage control modelled in PSSE / DigSilent PowerFactory





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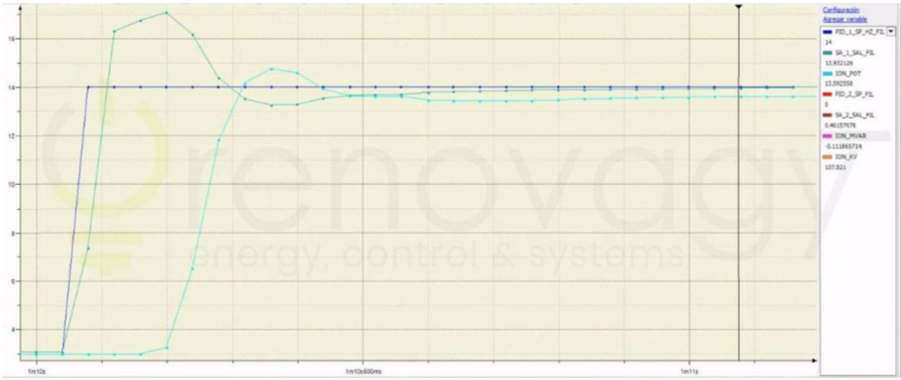
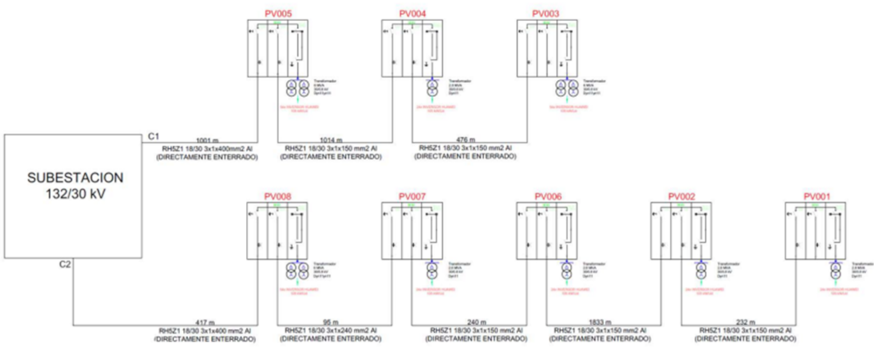
# RfG NC structure and implementation

## Requirements validation (On-site test):

Typical test done by PPC manufacturer in field:

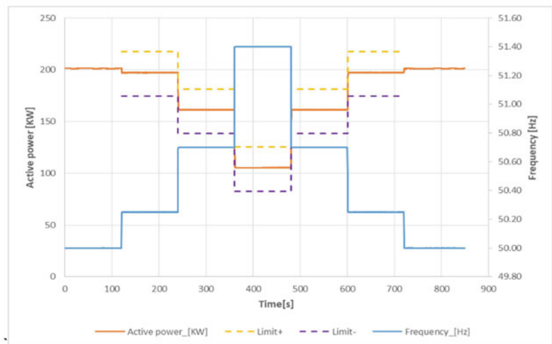
- P control
- Q control
- PF control
- Voltage control

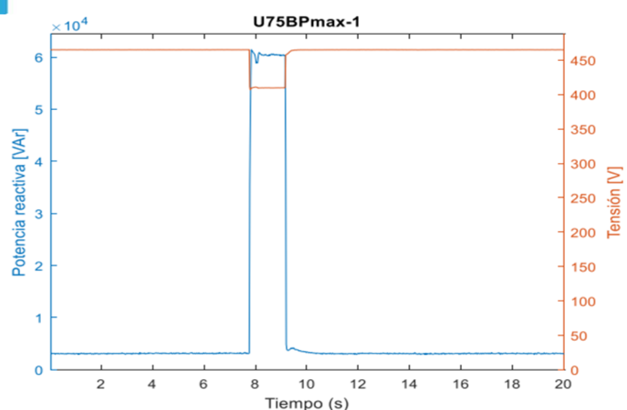




# RfG NC structure and implementation

## Requirements validation (certification):




20329-4-[redacted]

NTS_P[redacted]

**CERTIFICADO DE CONFORMIDAD "20329-4[redacted]" DE INVERSOR FOTOVOLTAICO CONFORME A LOS REQUISITOS TÉCNICOS ESTABLECIDOS EN:**

**Norma Técnica de Supervisión** de la conformidad de los módulos de generación de electricidad según el Reglamento UE 2016/631. Versión 2.0 del 03 de noviembre de 2020 + Corrección de errores de la versión 2.0 (del 3/11/2020) de la Norma Técnica de Supervisión de la Conformidad de los Módulos de Generación de Electricidad según el Reglamento UE 2016/631 del 13/04/2021.

La entidad de certificación Certification Entity for Renewable Energies S.L. (CERE) certifica que el inversor fotovoltaico siguiente:

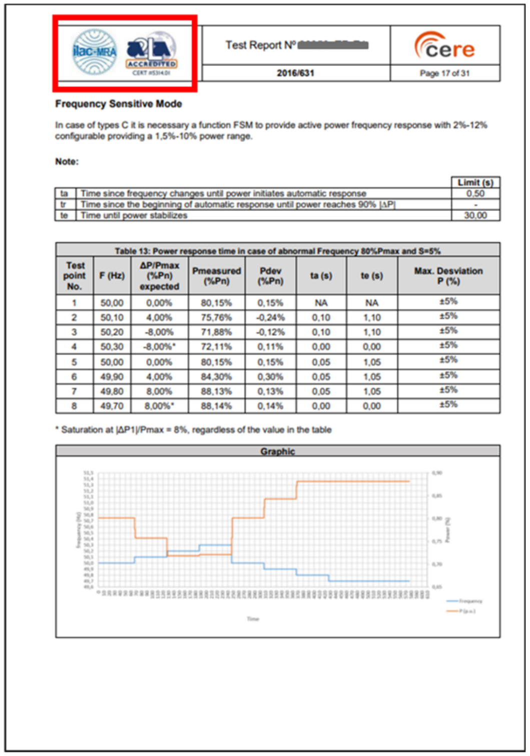
| | | | |
|---|---|---|---|
| Fabricante / Solicitante | | Huawei Technologies Co. Ltd. | |
| Características del inversor fotovoltaico | Serie | S[redacted] | |
| | Modelos | S[redacted] | |
| | Tipo de MPE donde se instalará | [redacted] de tipo A, B, C o D | |
| | Datos técnicos | Ver anexo I | |
| | Versión de firmware | Para modelos [redacted] | |
| | | Para modelos [redacted] | |
| | Modelo dinámico de la UGE validado (certificado nº 20329-4-CER-VM) | Nombre del modelo | [redacted] |
| | | Checksum MD5 | [redacted] |
| | | Formato (software utilizado) | DIgSilent PowerFactory (2020) |
| Es conforme con los capítulos indicados en la tabla de la página 2 de la norma: | | **Norma Técnica de Supervisión** de la conformidad de los módulos de generación de electricidad según el Reglamento UE 2016/631. Versión 2.0 del 03 de noviembre de 2020. Tipo A, B C y D + Corrección de errores de la versión 2.0 (del 3/11/2020) de la Norma Técnica de Supervisión de la Conformidad de los Módulos de Generación de Electricidad según el Reglamento UE 2016/631 del 13/04/2021. | |

Habiendo analizado el informe de ensayos número 203[redacted] y el informe de simulación 20[redacted] realizados por CERE (Laboratorio acreditado por ENAC con Nº 1376/LE2560) basándose en los requisitos de EN ISO/IEC 17025: 2017.

La unidad generadora mencionada anteriormente cumple con los requisitos de PET-CERE-24 Rev. 4 basándose en los requisitos de EN ISO/IEC 17065:2012.

Para este proceso de conformidad las actividades del análisis de conformidad han sido basadas en ensayos y simulaciones.

Este certificado cancela y sustituye al certificado número 20[redacted], emitido el 26 de marzo [redacted]



| | | |
|---|---|---|
| | Test Report Nº [redacted] | |
| | 2016/631 | Page 17 of 31 |

**Frequency Sensitive Mode**

In case of types C it is necessary a function FSM to provide active power frequency response with 2%-12% configurable providing a 1,5%-10% power range.

**Note:**

| | | Limit (s) |
|---|---|---|
| ta | Time since frequency changes until power initiates automatic response | 0,50 |
| tr | Time since the beginning of automatic response until power reaches 90% \|ΔP\| | - |
| te | Time until power stabilizes | 30,00 |

Table 13: Power response time in case of abnormal Frequency 80%Pmax and S=5%

| Test point No. | F (Hz) | ΔP/Pmax (%Pn) expected | Pmeasured (%Pn) | Pdev (%Pn) | ta (s) | te (s) | Max. Desviation P (%) |
|---|---|---|---|---|---|---|---|
| 1 | 50,00 | 0,00% | 80,15% | 0,15% | NA | NA | ±5% |
| 2 | 50,10 | 4,00% | 75,76% | -0,24% | 0,10 | 1,10 | ±5% |
| 3 | 50,20 | -8,00% | 71,88% | -0,12% | 0,10 | 1,10 | ±5% |
| 4 | 50,30 | -8,00%* | 72,11% | 0,11% | 0,00 | 0,00 | ±5% |
| 5 | 50,00 | 0,00% | 80,15% | 0,15% | 0,05 | 1,05 | ±5% |
| 6 | 49,90 | 4,00% | 84,30% | 0,30% | 0,05 | 1,05 | ±5% |
| 7 | 49,80 | 8,00% | 88,13% | 0,13% | 0,05 | 1,05 | ±5% |
| 8 | 49,70 | 8,00%* | 88,14% | 0,14% | 0,00 | 0,00 | ±5% |

* Saturation at |ΔP1|/Pmax = 8%, regardless of the value in the table

Graphic

# RfG NC structure and implementation

## Accreditation for test report and certification:

| Entidad | Pais |
|---|---|
| Pakistan National Accreditation Council – PNAC | Pakistan |
| National Standardization Council of Thailand – NSC | Thailand |
| Comite Francais d'Accreditation – COFRAC | France |
| ENAC | Spain |
| Czech Accreditation Institute – CAI | Czech Republic |
| DANAK | Denmark |
| Bundesministerium f. Digitalisierung u. Wirtschaftsstandort | Austria |
| Belgian Organisation for Accreditation – BELAC | Belgium |
| Deutsche Akkreditierungsstelle GmbH – DAkkS | Germany |
| Hellenic Accreditation System S.A. – ESYD | Greece |
| Irish National Accreditation Board – INAB | Ireland |
| Sistema Nazionale Accreditamento – ACCREDIA | Italy |
| Dutch Accreditation Council – RvA | Netherlands |
| Norwegian Accreditation – NA | Norway |
| IPAC | Portugal |
| Swedish Board for Accred.& Conformity Assessment – SWEDAC | Sweden |

Full list: https://www.gometrics.net/que-es-la-acreditacion-enac/

- Accreditation entities authorizes laboratories to do specific tests for specific normative.

ENAC Entidad Nacional de Acreditación

DAkkS

CNAS

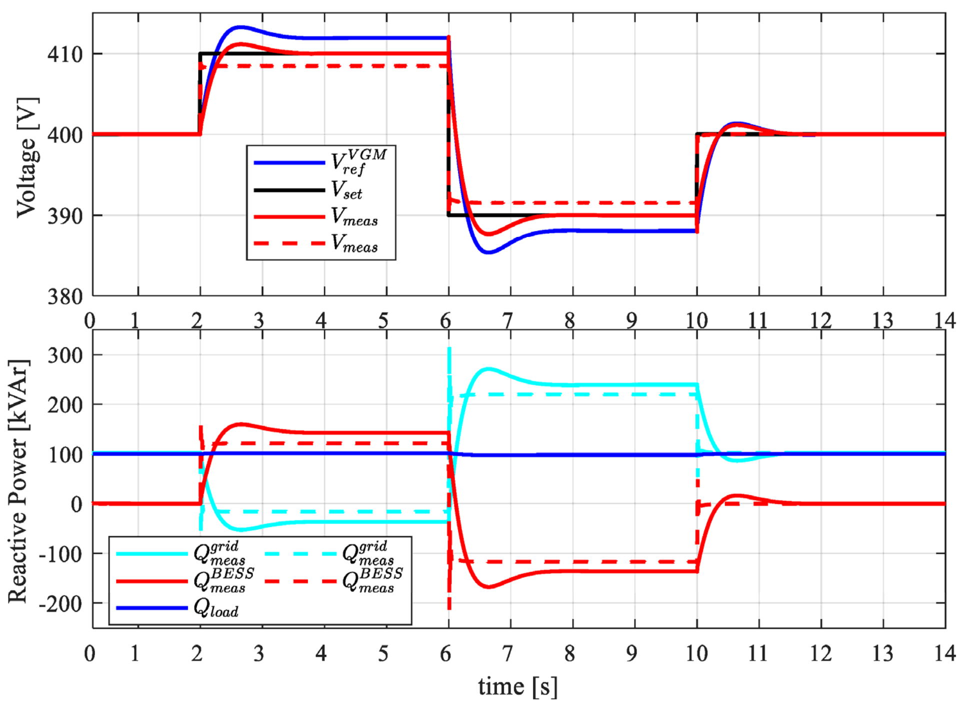
- ILAC: facilitating trade by promotion of the acceptance of accredited test and calibration results

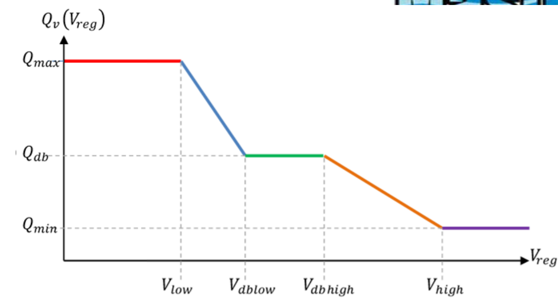
ilac

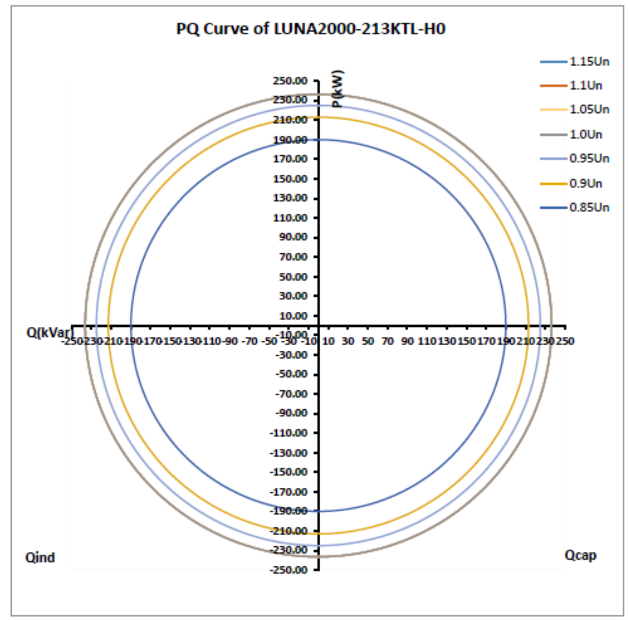
https://iaf.nu/en/recognised-abs/

# RfG NC impact on BESS sizing

Grid code compliance for reactive power/voltage regulation:



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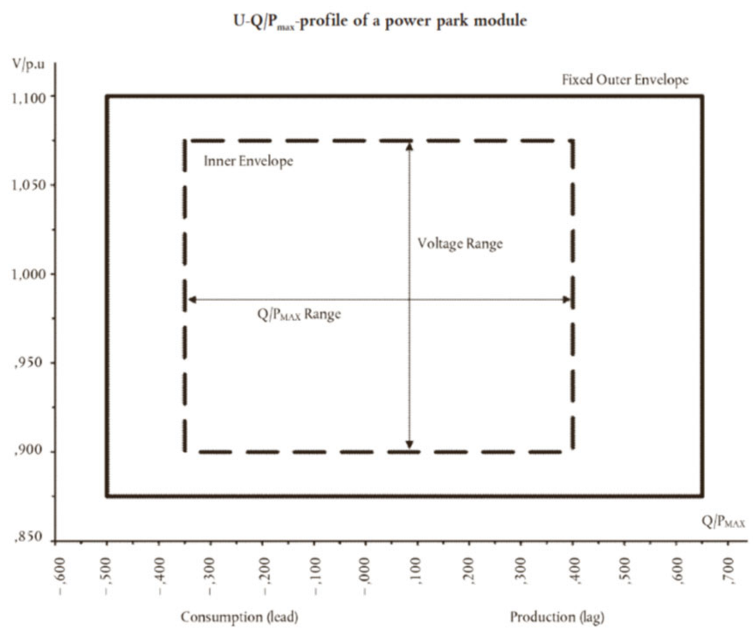
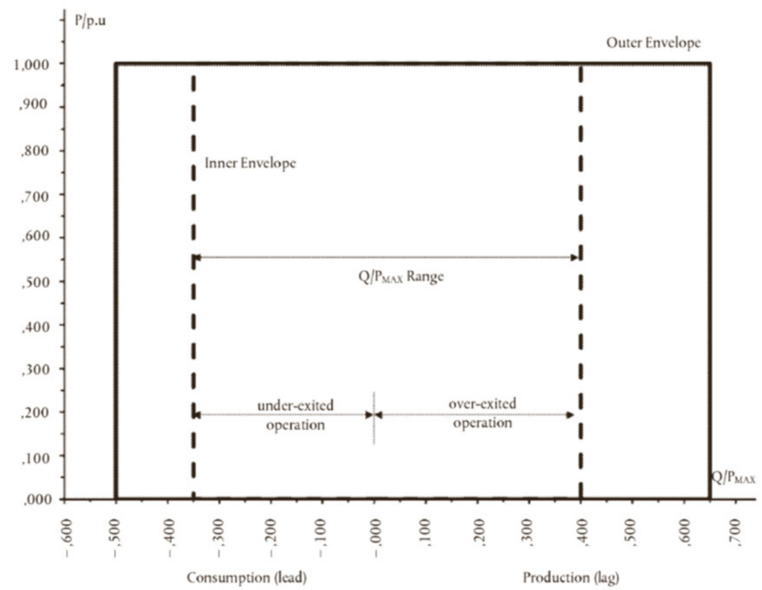
# RfG NC impact on PV sizing

Grid code compliance for reactive power/voltage regulation:

<u>NC RfG requirement boundaries</u>

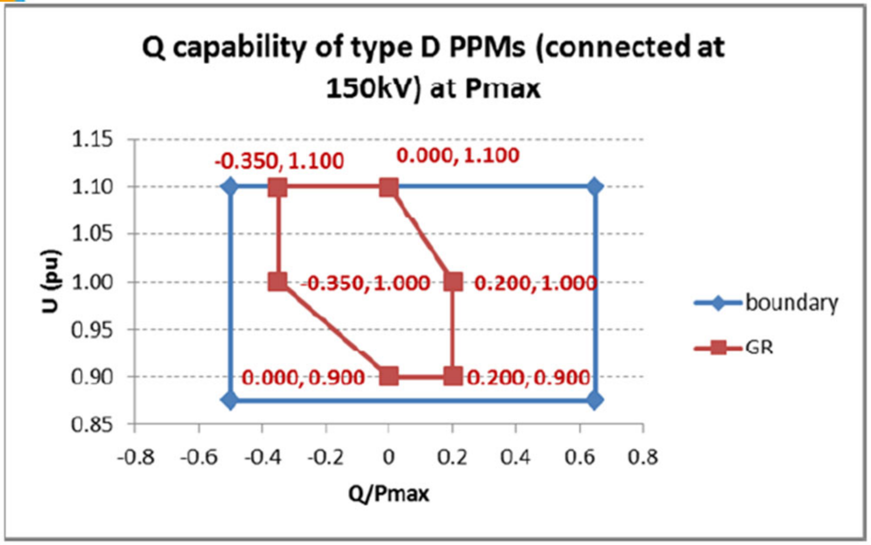


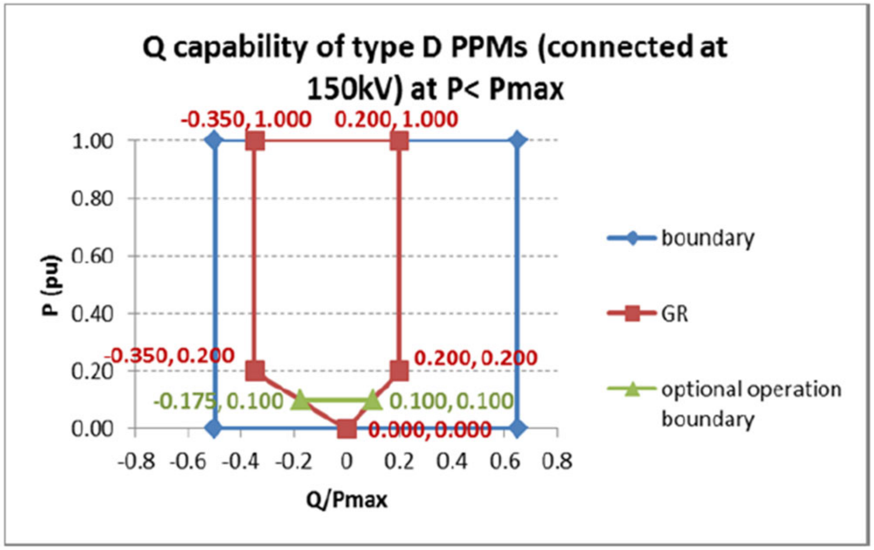



# RfG NC impact on PV sizing

Grid code compliance for reactive power/voltage regulation:

Implementation of the requirements into Greek GCs

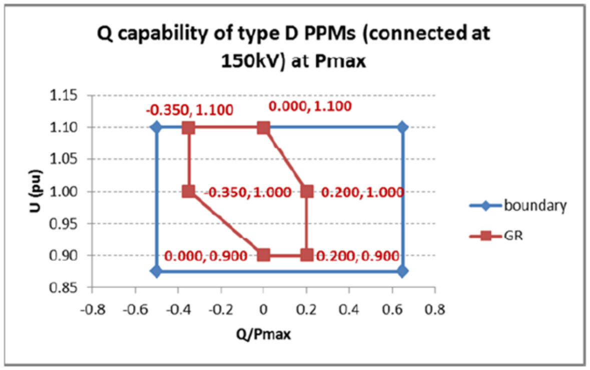


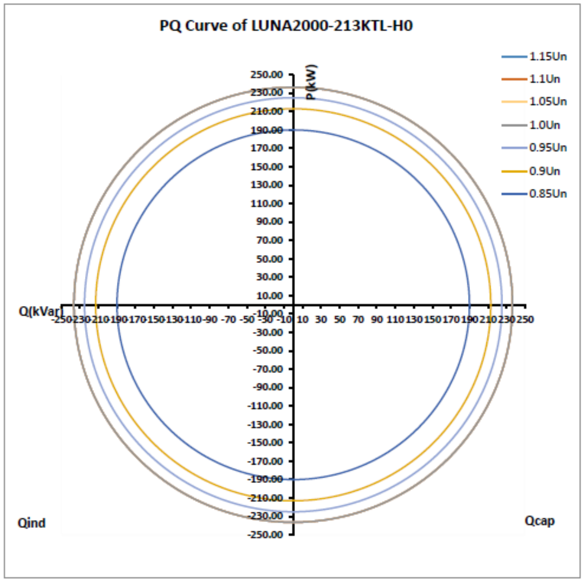



# RfG NC impact on BESS sizing

Example simulation for a generic BESS sizing with PowerFactory:

| BESS sizing requirements | |
|---|---|
| Requirement | Value |
| Rated Active power at POI | 50 MW |
| Voltage range at POI (pu) | 0.9-1.1 pu |
| Rated HV | 135 kV |
| Rated MV | 30 kV |
| Rated LV | 800 V |
| DC voltage | 1080 V |
| Frequency | 50 Hz |
| Power factor at POI | 0,9438 ind / 0,9805 cap |
| Temperature | 25 |
| Altitude | 800 m |
| HV/MV transformer data | |
| Rated power | 60/75 MVA |
| Short-circuit impedance | 13 % |
| No-load losses | 0.05 % / KW |
| Copper losses | 0.3% / KW |

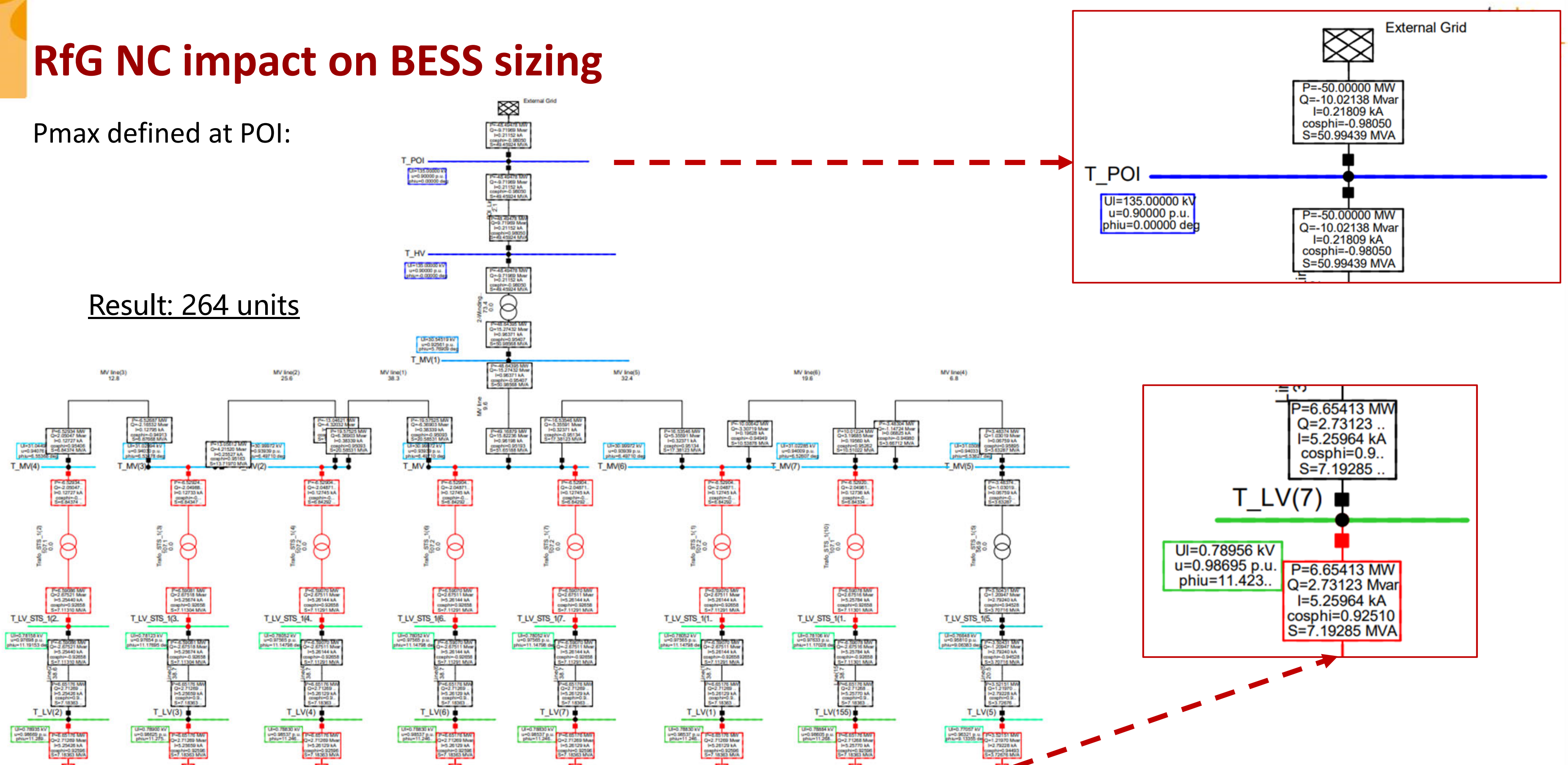


# RfG NC impact on BESS sizing

Pmax defined at POI:

Result: 264 units





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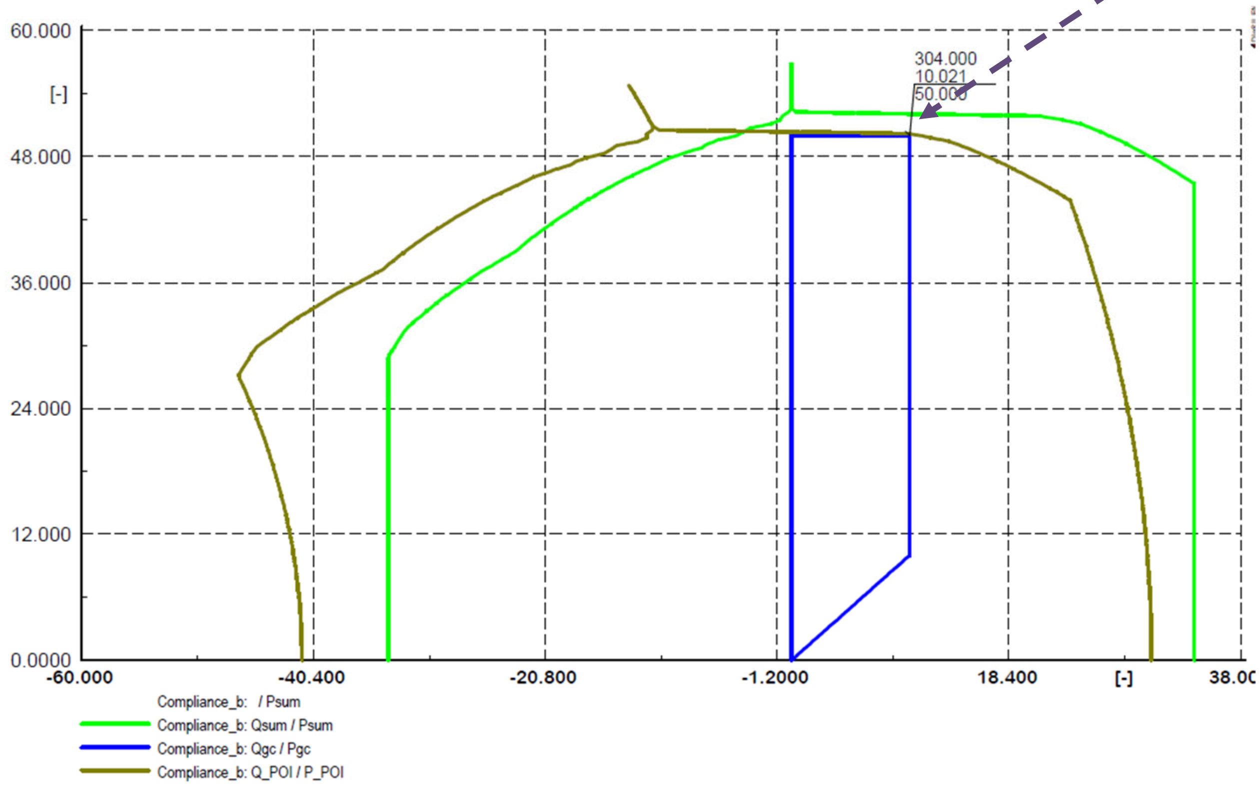
# RfG NC impact on PV sizing

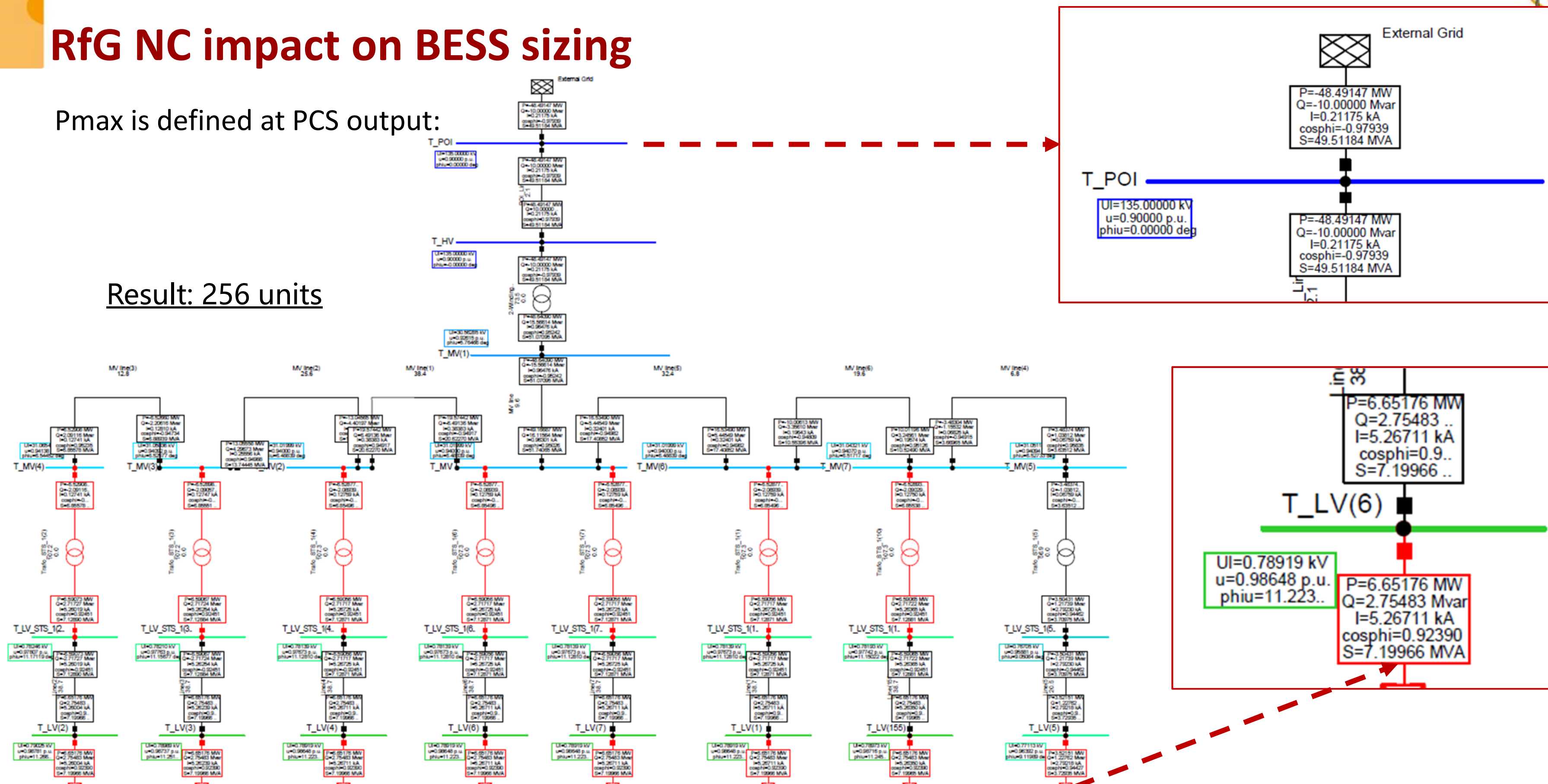
Pmax is defined at POI:



# RfG NC impact on BESS sizing

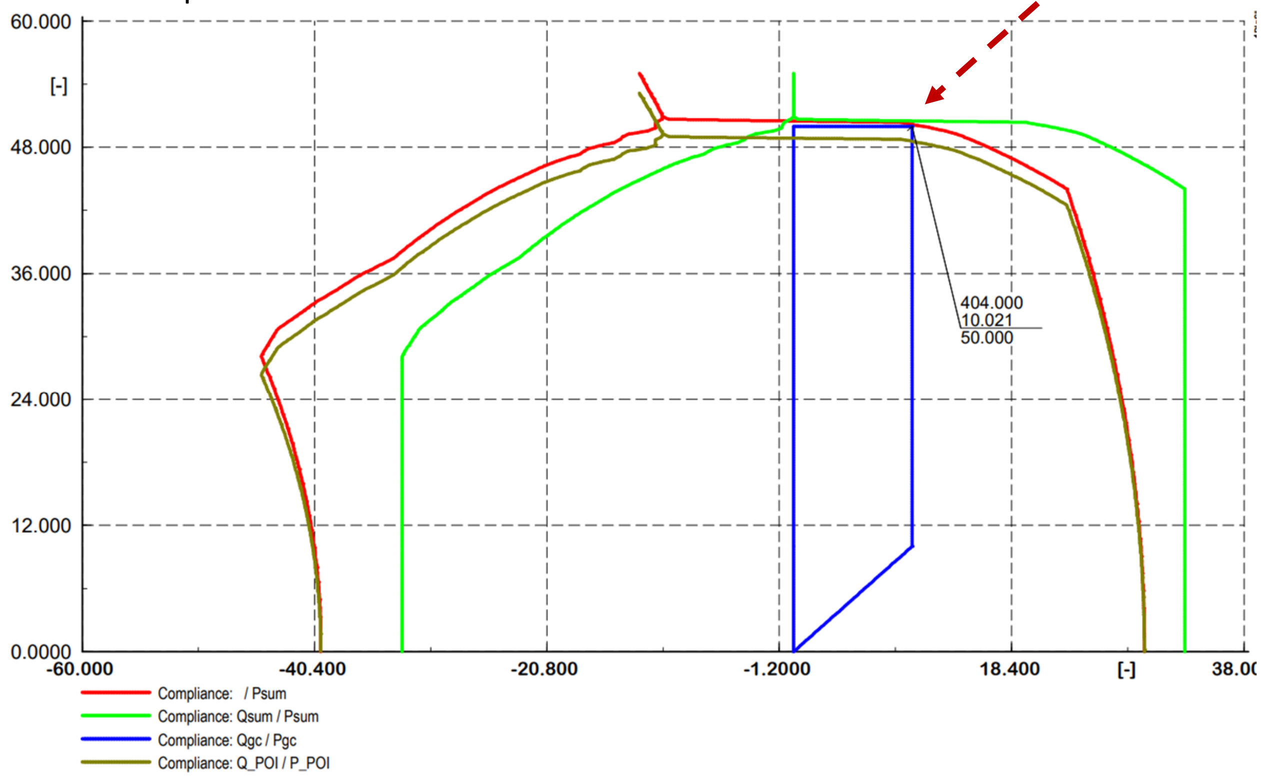
Pmax is defined at PCS output:

<u>Result: 256 units</u>



# RfG NC impact on BESS sizing

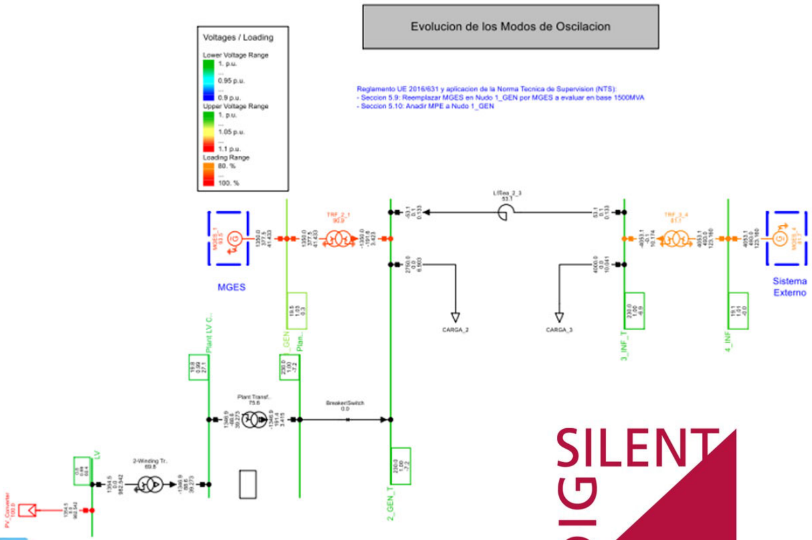
Pmax is defined at PCS output:

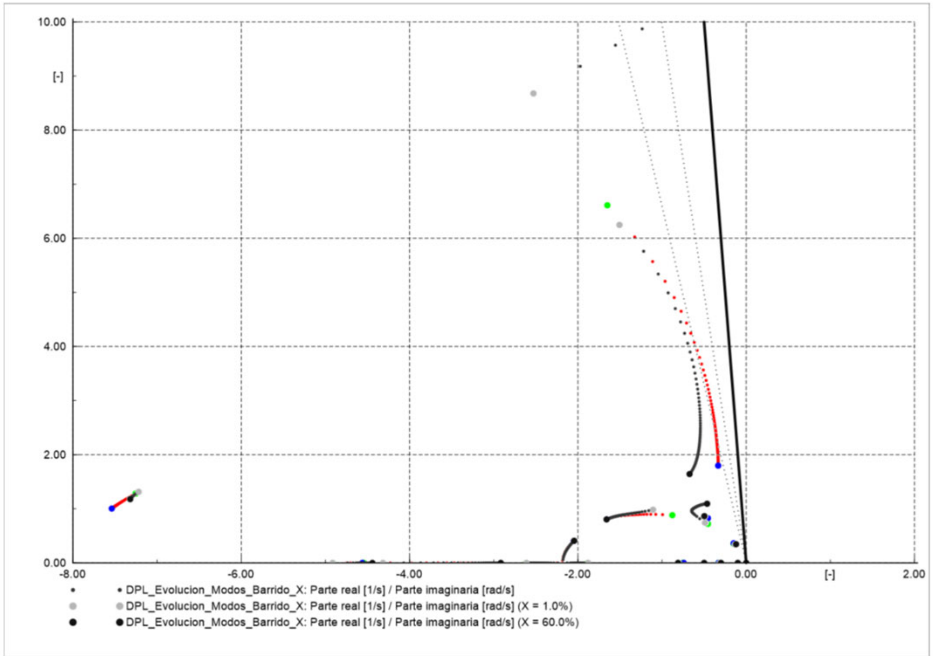


# RfG NC structure and implementation

## Requirements validation (simulation):

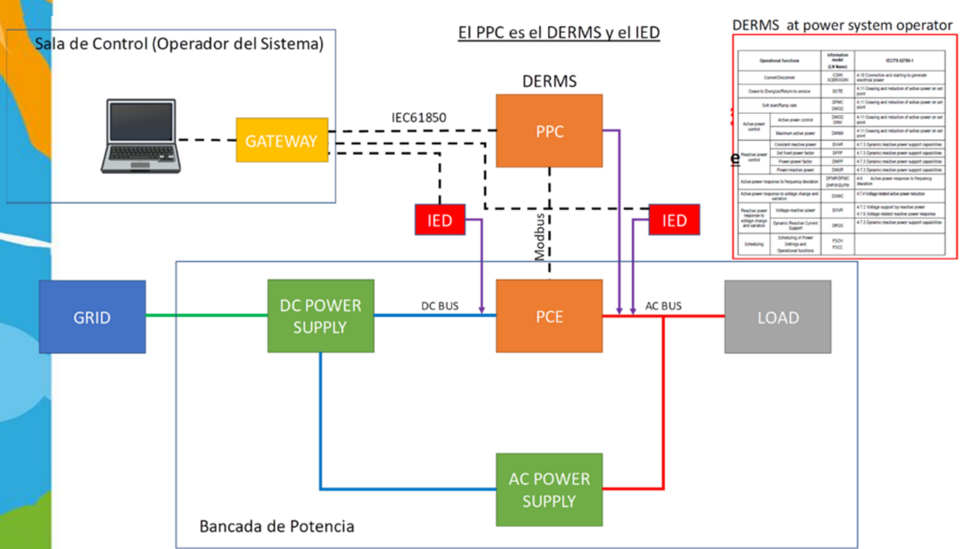
Power Oscillation damping modelled in PowerFactory



# RfG NC structure and implementation

## Requirements validation (certification):




*IEC 63409-7

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# 9 Smart String BESS Solution

Higher Revenue

# Full-lifecycle equivalent performance, optimal system configuration by 4.6-12%

## Four Core Indicators for BESS Configuration

**91.55% Higher RTE***

**Reduce the ↓ 0.5-3% configuration**

*Smart liquid cooling system*
*PCS 800 Vac*
*higher voltage level, lower loss*

**0-100% Constant Power Range**

**Reduce the ↓ 2-6% configuration**

*Pack-level Optimization*
*Rack-level Optimization*
*Intelligent power control algorithm*

**99.9% Availability**

**Reduce the ↓ 1-3% configuration**

Refined management
*Modular design*
*Fewer vulnerable parts*

**3% SOC Accuracy**

**Reduce the ↓ 4% configuration***

*High precision voltage sampling,*
*Battery management Integrated chip*
*and Self-learning algorithm*

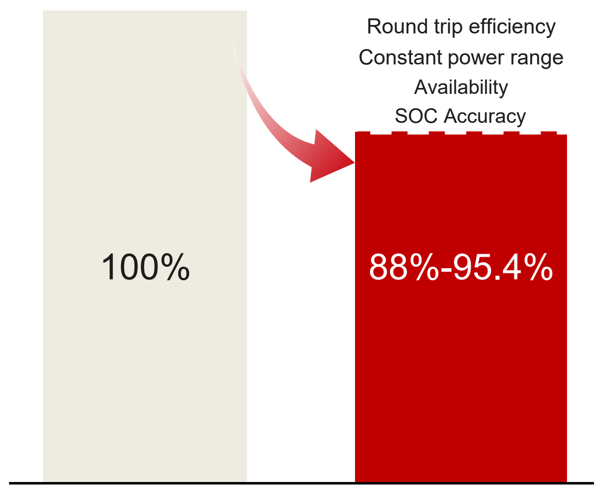
**Performance Guarantee**

**Guarantee 20 years* discharge capacity**

*Make sure the every year capacity is enough for using.*

*Note： 91.55%RTE @0.25C, LV AC side Including auxiliary consumption*
*3% SOC reduces the 4% configuration @ Micro-grid scenario*
*Warranty for a shorter period of 20 years or SOH ≥ 60%*

## Equivalent performance, optimal configuration




**Traditional Solution** **Smart String ESS 2.0**

*Note: Configuration Comparison with Other Vendors in Grid-tied scenario*



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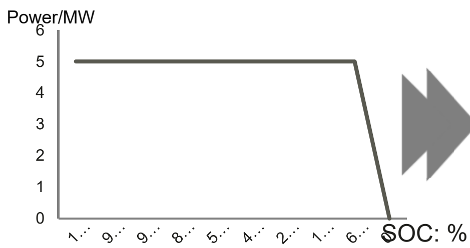
Constant Power

# Constant Power Output @100 ~ 0% SOC, optimized system configuration by 2-6%
# Supports Higher Revenue in the FM and Capacity Markets

## Traditional Solution

Constant output power: **100% ~ 6% SOC**



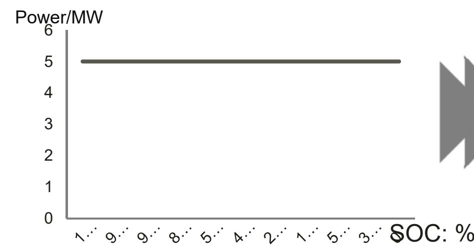

**6%** more ESS configuration when constant output needed

- Batteries are not managed in a refined manner
  Output capability depends on the worst performing battery
- Insufficient overload capacity of electrical equipment

*Conditions: ambient temperature 25°C, 0.5C

## Smart String ESS 2.0

Constant output power: **100~ 0% SOC**




**No need for extra** ESS
Reducing CAPEX by **6%**

- Pack-level and Rack-level optimization avoiding current bias and series-parallel SOC mistmatch
- Intelligent power control algorithm



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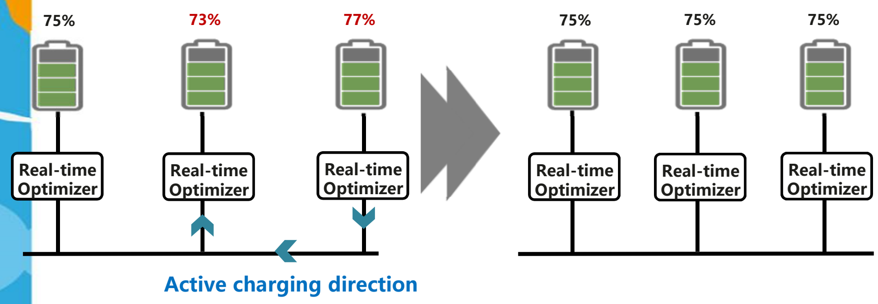
Constant Power

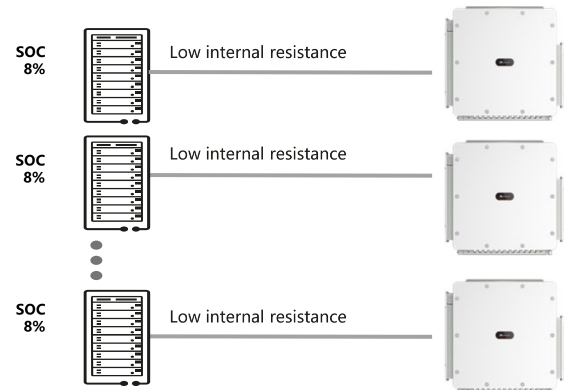
# Pack and Rack Level Optimization to Achieve Constant Power with 100% DOD

## Pack level optimization 2.0, achieving 100% constant power discharge within one rack




- **A pack optimizer is integrated in each Battery pack**, and the BMIC in the pack monitors the voltage and temperature of each battery in real time. **When the voltage of a battery pack is higher than that of other battery packs, the other battery pack will be charged with low current.** This eliminates the inconsistency problem caused by battery series connection. Avoid the "Buckets Effect ". Improves available capacity by 2% in the first year.
- **Real-time balancing between battery packs** ensures consistent battery pack capacities and **constant power with 100% DOD**

## Rack level management, achieving 100% constant power discharge between racks




- String PCS design, **each rack is controlled independently**. This eliminates battery rack inconsistency and prevents inter-rack "Buckets Effect ", battery pack overcharging & over discharging caused by inter-rack circulation.
- **Monitor battery rack capacity in real time**, adjust the output power, balance the capacity between racks, and discharge at constant power with 100% DOD.
- Improves available capacity by 4% in the first year.

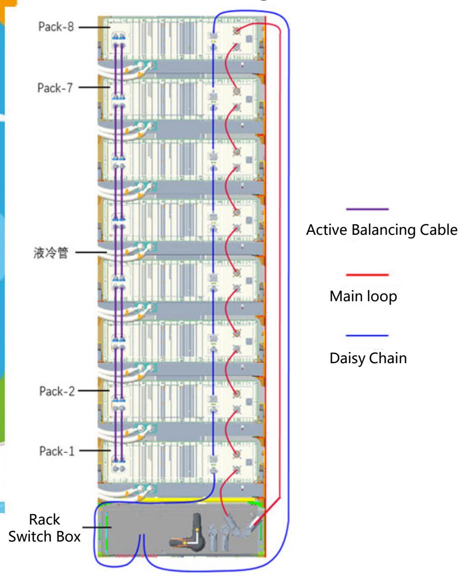
# Active Balance Description

One DC-DC converter is configured for each battery pack for pack-level active balancing.

The active equalization module **balances the power between different packs by balancing the DC-DC bus, which enables packs with high SOC to charge or discharge more power**, preventing the packs with short capacity from cutting off in advance and affecting the power of the entire Rack.

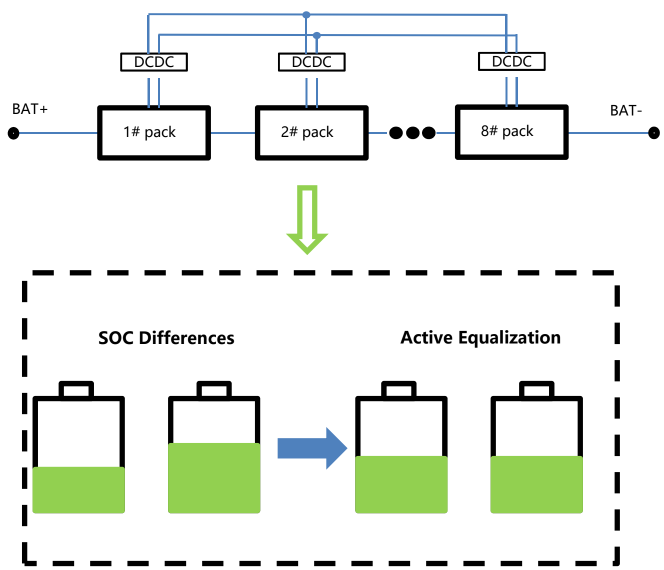
Finally, the ESS can discharge more capacity in the entire life cycle and actively improve the SOC consistency between packs.

**Rack Active Balancing Connection:**




The active equalization module is connected to the DC bus (power supply by the battery pack) and runs separately from the main loop.

**Schematic diagram of rack active balancing**




**Description of active balancing:**

**1. Active equalization can be enabled during charging, discharging, or stationary status.**

Condition: When there is electrochemical cell pressure difference between the packs, which is greater than the threshold during charging, discharging, or stationary.

**2. Active balancing exit**

2.1 Trigger electrochemical cell protection or equalization pressure below threshold or component abnormality.

**Note:**

1. A maximum of two pairs (battery packs) are enabled.
2. Balance Capability: 1.1 kW DC-DC can transmit a maximum of 1.1 kW.

Constant Power

# ESS 100% DOD- Full Scope Constant Power Output Challenge

## Traditional solution: battery packs and racks are connected in series and parallel.

**Battery Packs in Series:**

- **Battery pack available capacities are different** due to **battery inconsistency and temperature differences.** When a pack with small capacity is fully charged or discharged, other packs will stop charging or discharging.
- **The differentiation of pack capacity become more and more severe with the increase of operating time** without effective balanced management, which further accelerates the decline of available capacity of battery system.

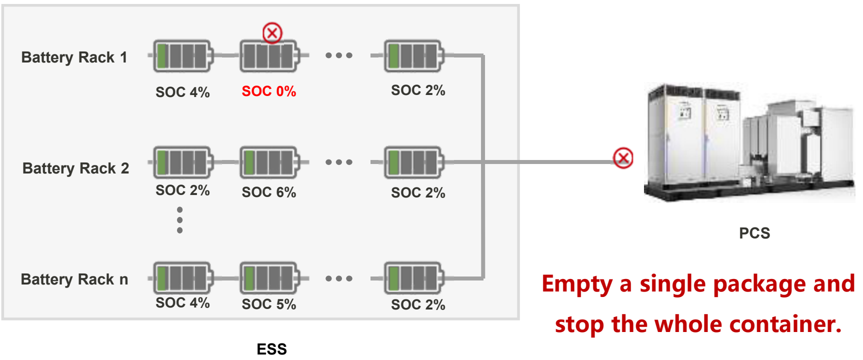
**Battery Racks in Parallel:**

- **When the battery rack with low capacity is fully charged or discharged, other racks stop charging or discharging.** As a result, the battery rack is not fully charged or discharged, resulting in capacity loss and reducing the available capacity of the battery system.
- In addition, due to small internal battery resistance, **even if the voltage difference between racks is only a few volts, the uneven current between racks will be very large.** The deviation current will cause overcharge/discharge phenomenon in some battery racks, resulting lower efficiency, battery life, and even serious safety accidents.

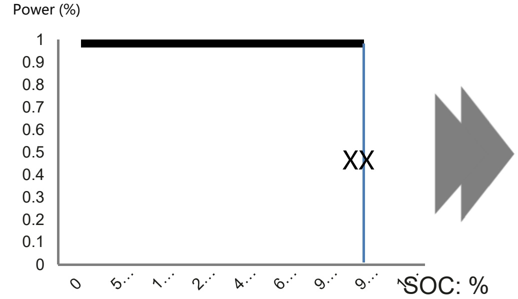
**Impact on the constant power:**

- **After a single battery pack is put out, all the other batteries in the container stop discharging. As a result, the constant power discharge range is less than 100%, reducing the available capacity.**

## Traditional Solution: Centralized PCS manages ESS




**Empty a single package and stop the whole container.**



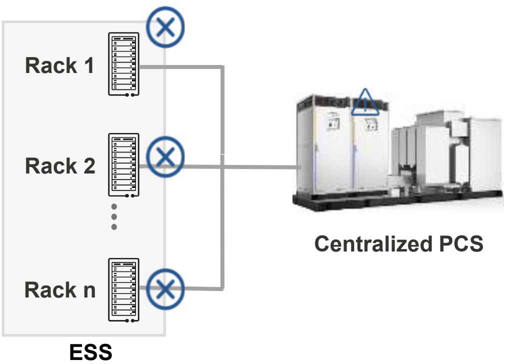

**Capacity over-configuration is needed. If the constant power duration is the same**

Higher Availability

# Modular design, fewer vulnerable parts, 99.9% system availability

## Traditional centralized ESS

A single PCS manages the entire ESS



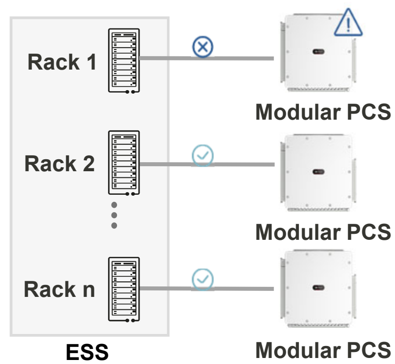

- **A PCS** is faulty which **affecting X MW**

- The entire ESS stops working, **the maintenance of PCS is complicated and time-consuming**

Part spare parts


## Smart String ESS 2.0

A single PCS manages the one battery rack




- **A string PCS** is faulty which **only affecting 186.5 kW**.

PCS is spare parts

- Other units work normally and the impact is **minimized**
- Faulty PCS **is easy and quick to replace**



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Smart O&M

# Built-in Liquid-Cooled PCSs: Complex Liquid Cooling Pipe and Cable Routing, O&M Longer than 8 Hours (16 Times Longer than That of External PCSs)

## All-in-one ESS with built-in PCSs

VS

## ESS with external PCSs

### Diagram

**Maintenance**: The PCS AC/DC power cables and liquid cooling pipes are complexly routed, making installation and maintenance difficult. **The replacement takes more than 8 hours.**

1. **Shut down the ESS, open the door**, and remove the liquid cooling ports and AC and DC power cables.
2. Use **tooling** to pull out the switch box and two PCSs (> 250 kg).
3. Remove all the cables and liquid cooling pipes from the switch box and PCSs.
4. Replace the PCS, and reinstall the cables and liquid cooling pipes.
5. Use tooling to insert the switch box and two PCSs into the container.
6. Install AC power cables and liquid cooling pipes.
7. **Remove condensate water, dehumidify, and add coolant (about 1 L)**

**High risks across the entire process, lower IP rating, and O&M personnel directly dealing with the ESS**

### External air-cooled PCSs

**Maintenance:** The PCS is easy to maintain. No complex cable connection is involved and no dedicated tooling is required. **The replacement takes 0.5 hour.**

1. **Disconnect the AC and DC power supplies of only the faulty PCS** and remove the AC and DC power cables.
2. Manually replace the PCS.
3. Reconnect the AC and DC power cables.

**Low risks across the entire process, no need to open the ESS**



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Higher SOC Precision

# Pack-level automatic SOC calibration, higher SOC precision, charging and discharging accurately, optimized system configuration by 4% @ *Microgrid scenario*

**High precision voltage sampling**

Extremely high-precision voltage sampling

**Battery management Integrated chip**

Dedicated battery management chip, higher computing power
Cell-level automatic equalization

**Self-learning algorithm**

High-precision battery model modeling, parameter identification, feature extraction

**Traditional Solution**

**≥5%**

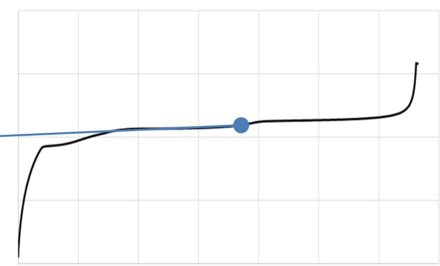
**Manual SOC calibration by experts on Site**

**VS**

**Smart String ESS 2.0**

**3%**

**High-precision automatic SOC calibration**





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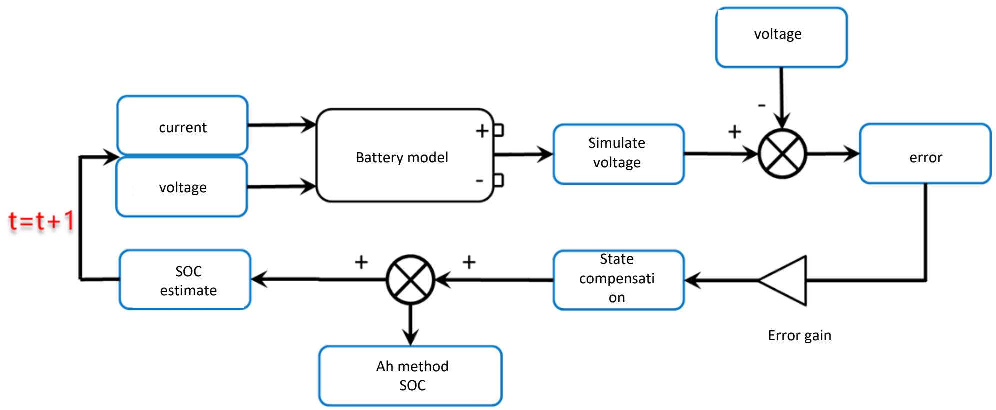
## Huawei SoC Calibration Solution:
## Ampere-hour integral + Full charge/deep discharge calibration + Power-on lookup table

① Huawei's SOC solution mainly uses ampere-hour integral, and the remaining SOC is calculated based on the accumulated discharge capacity. Calibration of the SOC at full charge and deep discharge；

$$SOC_k = SOC_0 - \frac{\sum I\Delta t}{rated\ capacity * SOH}$$

② During full charge and deep discharge, the SOC is calibrated according to the battery voltage conditions based on the observer principle.




③ To identify the SOC decrease caused by self-discharge during initial startup and long-term unused use, the system obtains the initial SOC value based on the current open-circuit voltage.

The open-circuit voltage is the terminal voltage of the battery after the battery is fully static, and is directly mapped to the SOC.

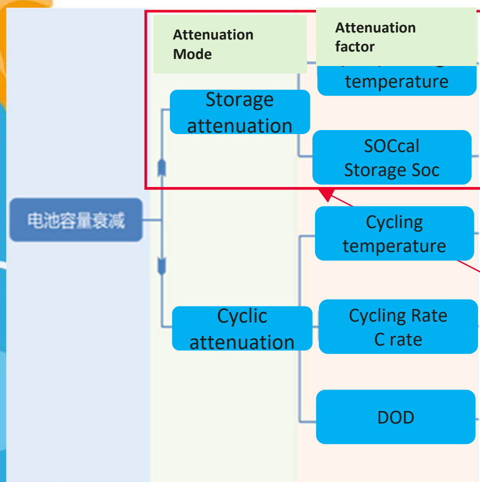
**SOH Guarantee**

# The basic logic of each vendor's model is the same.

The general difference lies in whether temperature rise and storage attenuation are considered.

**Other vendors usually do not consider storage attenuation and temperature rise in packs.**

## Degradation Coefficient Decomposition




## Degradation coefficient calculation logic

$Qloss = Qloss_{cal} + Qloss_{cycle}$

**Storage Decay: Arrhenius Decay Law**

$$Qloss_{cal} = kTStorage * kSOC * t^{z1}$$

① kT storage. T storage is the average storage temperature.

$$k_T = kref_{cal} * e^{-\frac{Ea\_cal}{R}(\frac{1}{T_{Storage}} - \frac{1}{Tref})}$$

② kSOC. SOC is the average SOC.

③ t is the running time, including storage and cycle time, i.e. the calendar decay when both storage and cycle are considered

④ z1 is the storage degradation coefficient, which is related to the storage specifications under different SOHs.

**Cyclic Decay: Arrhenius Decay Law**

$$Qloss_{cycle} = kTcycle * kcrate * kDOD * Q^{z2}$$

① kT cycle, T cycle takes the average temperature of the cycle

$$k_{TCycle} = kref_{cycle} * e^{-\frac{Ea\_cycle}{R}(\frac{1}{TCycle} - \frac{1}{Tref})}$$

② kcrate, affected by the charge rate

According to the empirical formula, kcrate and charging rate are logarithmic functions. The specific values are related to the cycling performance at different rates.

③ kDOD, affected by the charge and discharge depth, fluctuates around 50% SOC

The empirical formula in the reference literature, kDOD and the depth of discharge are cubic functions.

$$kDOD = 3.57 * (DOD - 0.6)^3 + 0.77$$

④ Q is the discharge amount, which reflects the growth of SEI film.

5 z2 is the cyclic degradation coefficient, which is mainly related to the cyclic specifications under different SOHs.

Other Venders: The temperature rise of electrochemical cells in the pack is not considered.

$$Qloss_{cal} = kref_{cal} * e^{-\frac{Ea\_cal}{R}(\frac{1}{Storage} - \frac{1}{Tref})} * kSOC * t^{z1}$$ ---- 1 Storage degradation

$$Qloss_{cycle} = kref_{cycle} * e^{-\frac{Ea\_cycle}{R}(\frac{1}{Cycle} - \frac{1}{Tref})} * kcrate * kDOD * Q^{z2}$$ ---- 2 Cycle degradation

Other vendors: The storage degradation is not considered.

- Input: operating temperature, charge/discharge temperature rise, charge/discharge ratio, depth of discharge, EOL, average SOH, and daily cycles
- Output: cycle degradation curve from the specified working condition to the specified SOH, including the number of cycles and service life

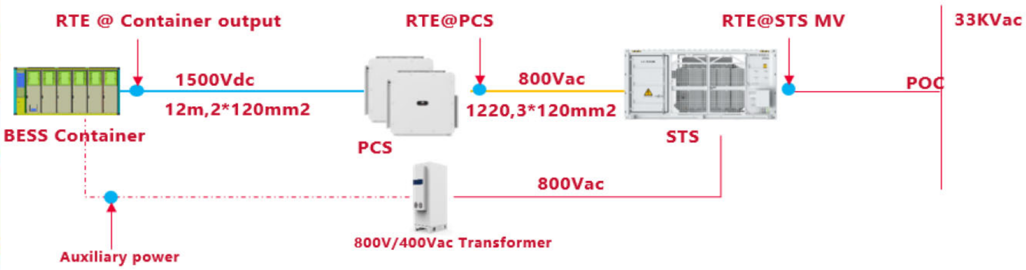
SOH Guarantee

# Huawei considers 19 factors to simulate the attenuation curve

| Fitting Model | | Industry | Huawei | Impact |
|---|---|---|---|---|
| Two Main Factors | | **3 to 5** factors | **19** factors | more factors considered, more accurate result |
| **Cyclic degradation** | **Cell Degradation** | Cell cycle: 300-500 cycles | Cell cycle: **1250** cycles | More the number of times, the more the working conditions, the more accurate. |
| | | Test conditions/Quantity: 1 working condition | Test conditions/quantity: **2 to 3** working conditions, 3 PCS for each type | |
| | **Pack Degradation** | Temperature rise: The temperature rise of the cell in the pack **is not considered.** | Temperature rise: The temperature rise of the cell in the pack must be considered. | Temperature is one of the top factors. |
| | | Consistency: Generally, consistency differences are **not considered** and there is no design to prevent. | Consistency: Package Optimization and rack management avoid differences | Consistency is one of the top factors. |
| **Storage degradation** | | Cell storage: degradation **is not usually considered** | Cell storage: test for 6 months + fitting, with degradation considered | Storage degradation accounts for about **33%** of the lifetime degradation. |

*SOH Guarantee*

# SOH, RTE, & CUE Guarantee




| 0.5C 1cycle/day DOD100% | | | | | |
|---|---|---|---|---|---|
| 25℃ | | | | | |
| Year | Pack RTE @ Container output without Auxiliary consumption | RTE @ PCS output without Auxiliary consumption | RTE @ POC output without Auxiliary consumption | RTE @ PCS output with Auxiliary consumption | RTE @ POC output with Auxiliary consumption |
| 0 | 94,48% | 91,49% | 89,41% | 90,31% | 88,25% |
| 1 | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| 2 | | | | | |
| 3 | | | | | |
| 4 | | | | | |
| 5 | | | | | |
| 6 | | | | | |
| 7 | | | | | |
| 8 | | | | | |
| 9 | | | | | |
| 10 | | | | | |
| 11 | | | | | |
| 12 | | | | | |
| 13 | | | | | |
| 14 | | | | | |
| 15 | | | | | |
| 16 | | | | | |
| 17 | | | | | |
| 18 | | | | | |
| 19 | | | | | |
| 20 | 91,30% | 88,41% | 86,40% | 87,27% | 85,28% |

| C rate | 0.25Cp | | |
|---|---|---|---|
| Average SOC | ≤50% | ≤50% | ≤50% |
| DOD | 100% | 100% | 100% |
| Ambient Temperature | ≤40℃ | ≤40℃ | ≤40℃ |
| Cycle per day | 1 | 1.5 | 2 |
| Cycle per year | 365 | 548 | 730 |
| Year | SOH (%) | SOH (%) | SOH (%) |
| 0 | 100.00% | 100.00% | 100.00% |
| 1 | [redacted] | [redacted] | [redacted] |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |
| 10 | | | |
| 11 | | | |
| 12 | | | |
| 13 | | | |
| 14 | | | |
| 15 | | | |
| 16 | | | |
| 17 | | | 60.75% |
| 18 | | | |
| 19 | | | |
| 20 | 70.28% | 62.74% | |



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# SOH Guarantee

SOH Guarantee

| | Category | | warranty model | Data volume/time limit requirements | Note 1 | Note 2 |
|---|---|---|---|---|---|---|
| 1 | **Cell data** | Storage Degradation Data | SOH storage degradation data in 100% SOC at 25°C. | ≥ 6 months data (at least 6 data records) | Provide data + fit curve | Data storage volume ≥ 6 months, at least two temperature points (temperature difference ≥ 10°C) |
| 2 | | | SOH storage degradation data in 100% SOC at 45°C. | ≥ 6 months data (at least 6 data records) | Provide data + fit curve | |
| 3 | | | SOH storage degradation data in 50% SOC at 25°C. | ≥ 6 months data (at least 6 data records) | Provide data + fit curve | |
| 4 | | | SOH storage degradation data in 50% SOC at 45°C | ≥ 6 months data (at least 6 data records) | Provide data + fit curve | |
| 5 | | Cycle data | SOH cycle degradation data at 25°C (1/2 max rate) | ≥ 1 / 8 cycle specification + 50 turns | Provide data + fit curve | The number of cycles is greater than or equal to 1/8 + 50, and at least three temperature points (temperature difference is greater than or equal to 5°C). The maximum rate and 1/2 maximum rate data are required. |
| 6 | | | SOH cycle degradation data at 35°C (1/2 max rate) | ≥ 1 / 8 cycle specification + 50 turns | Provide data + fit curve | |
| 7 | | | SOH cycle degradation data at 45°C (1/2 max rate) | ≥ 1 / 8 cycle specification + 50 turns | Provide data + fit curve | |
| 8 | | | SOH cycle degradation data at 25°C (max rate) | ≥ 1 / 8 cycle specification + 50 turns | Provide data + fit curve | |
| 9 | | | SOH cycle degradation data at 35°C (max rate) | ≥ 1 / 8 cycle specification + 50 turns | Provide data + fit curve | |
| 10 | | | SOH cycle degradation data at 45°C (max rate) | ≥ 1 / 8 cycle specification + 50 turns | Provide data + fit curve | |
| 11 | **Pack data** | Consistency | Consistency of cells in the same container, including capacity and internal resistance | Data of each electrochemical cell during shipment. Cell → pack → container corresponds to each other. | | By apply pack optimization & Rack management can avoided this degradation. Competitors do not consider this function |
| 12 | | | Temperature difference consistency of the PACK in different positions | | | |
| 13 | | Temperature rise | Temperature rise curve of the cell in the pack at an ambient temperature of 25°C and 0.5CP charge and discharge | | | Some competitors do not consider this part. |
| | | | Temperature rise curve of the cell in the pack at an ambient temperature of 25°C and 0.33CP charge and discharge | | | |
| 14 | | | Temperature rise curve of the cell in the pack at an ambient temperature of 25°C and 0.25CP charge and discharge | | | |
| 15 | **Operating condition data** | Working condition data (provided by the customer) | Operating ambient temperature | | Calculated by Huawei based on the average dimension and temperature rise. | |
| | | | Daily cycle times | | Calculated by Huawei based on the customer's working conditions | |
| 16 | | | Charge/discharge ratio | | Huawei calculated based on the customer's working conditions | |
| 17 | | | Storage SOC | | Huawei uses 50% SOC storage. | |
| 18<br>19 | | | DOD | | Huawei calculates the DOD based on 100%. | |



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Higher Revenue

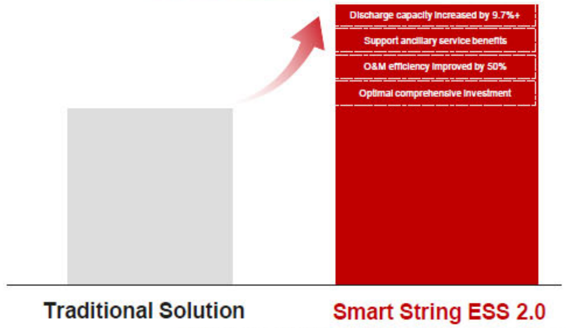
# All-lifecycle cost-effectiveness: Optimal comprehensive investment, increasing ROI by 3%- 8%and discharge capacity by over 9.7% throughout the life cycle

## Eight Core Indicators for BESS Configuration

- Rack-level Optimization improving available capacity by 7.23% @ 12 racks
- Pack-level Optimization 2.0 improving available capacity by 1.7%
- 91.5% Higher RTE*
- 95.7% Higher discharge eff.
- 3% SOC Accuracy
- 0-100% Constant Power Range
- 99.9% Availability
- Guarantee 15-20 years* SOH

Note： 91.5%RTE @0.25C, LV AC side Including auxiliary consumption
Warranty for a shorter period of 20 years or SOH ≥ 60%

## 3~8% increase in ROI




$$ROI = \frac{\text{Total power generation revenue in 20 years + Power grid auxiliary service revenue in 20 years}}{\text{Initial investment – Residual value of fixed assets + 20-year O\&M cost}}$$

## One platform, compatible with all business models, and higher benefits in the lifecycle

Energy Market | Capacity Market | FM Market | GFM Market | PV/Wind & ESS PPA | Power supply | Microgrid

| Short-circuit capacity | Inertia | Black Start | Oscillation suppression | FCR,aFRR,mFRR | Reactive overload capacity | Constant power capability | SOC Accuracy | Availability | On-/off grid |
|---|---|---|---|---|---|---|---|---|---|
| 1.5/3/6times VS 3 time | 3-20s VS 20s | Minute Level VS Day level | 0.1~100HZ VS 0.2~2.5HZ | < 100ms VS >200ms | 1.5 times VS 1.2 times | 0~100% VS 0~94% | 3% VS 5% | 99.9% VS 98% | One Platform |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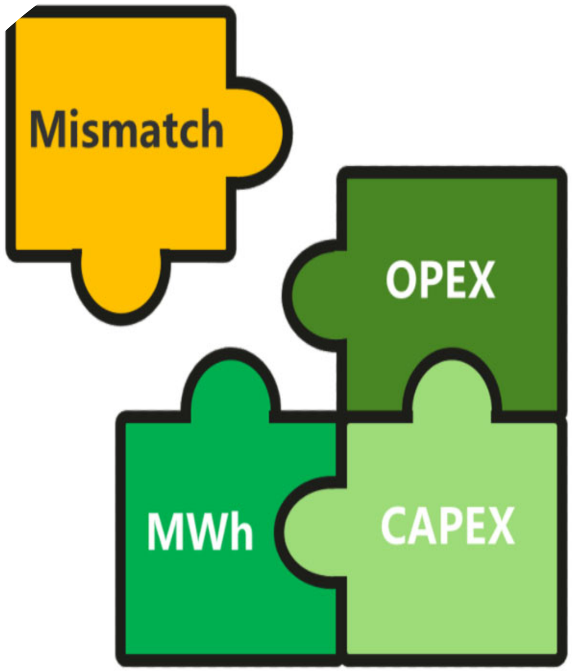
# Central Solution: Comparison in Discharge Performance, Availability, Maintenance Efficiency, and Configuration Flexibility

| Item | Central Architecture | Huawei's String Architecture |
|---|---|---|
| ESS architecture | **Multiple battery racks are connected in parallel and then connected to the central high-power PCS.** | **Each battery rack is managed by the DCDC, combined, and then connected to string PCSs, no power derating or backfeed during HVRT** |
| **Discharge performance** | Low. Mismatch between parallel-connected racks, lack of inter-rack balancing, affecting the charge and discharge capacity | High. **No mismatch between racks connected in parallel**, discharge capacity increased by **7%+ (at the end of the 10th year)** compared with the central solution |
| **Availability** | Low,. Bulky central equipment, large scope of fault impact | High. DCDC rack-level management, modular PCS, high availability<br>Faulty PCS replaced within 30 min, narrow scope of fault impact, high availability |
| **Maintainability** | Low. Bulky central equipment needs to be maintained by experts onsite, resulting in complex maintenance or replacement process and high costs. | High. Modular, easy maintenance, high replacement efficiency |
| **Calibration** | Manual calibration, ESS power-off required, high equipment and labor costs | Automatic calibration, no need for power-off or site visit |
| **Configuration flexibility** | Low. Old and new batteries cannot be used together. To expand capacity, both batteries and PCSs need to be added, affecting the AC capacity. | High. Racks can have difficulty configurations. Old and new racks can be used together. Capacity expansion does not affect the AC capacity. |
| **Safety and reliability** | Rack-level management unavailable, circulating current between racks, high safety risks | Intelligent rack-level management, **no circulating current between racks**, no thermal safety risk due to circulating current |
| | Passive shutdown, fuse | 4-level active + 2-level passive, intelligent active/passive protection<br>Automatic alarm reporting for rack-level faults, local fault isolation (overcurrent protection and short-circuit protection for the rack controller), passive shutdown and isolation (battery side) |
| | IP55 rating, C3 to C5 corrosion resistance | Higher structure protection, **IP66 rating, and C5 corrosion resistance**, ensuring stable and reliable operation in extreme environments |
| **On-grid performance** | SCR > 1.2, THDi ≤ 3%, weak energy in weak power grids, weak power quality | Adapting to weak power grids; stable operation in weak power grids with **SCR = 1.1, THDi ≤ 1.5%, good power quality** |
| | Active power derating and backfeed during 1.3 Un HVRT, SOC < 10%, PCS failure risk | Active power not derated during HVRT in the SOC range of 0% to 100% |
| | No use case of grid forming | 100 MWh-level POC test by China Electric Power Research Institute, the world's only vendor that has completed manual short-circuit tests at the 35/110 kV voltage level |
| | Weak simulation capability | Providing global modeling and simulation capabilities; adapting to global grid codes; stable grid connection in various complex power grid environments |




10 Summary:
Smart String BESS
Lower LCOS

# LCoS – Levelized Cost of Storage (Compare apples to apples)

$$LCoS = \frac{Investment}{Output}$$

Goal is to lower the numerator and increase the denominator.

$$= \frac{CAPEX + O\&M \times \sum_{n=1}^{N} \frac{1}{(1+r)^{n}}}{System\ lifetime\ cycles \times (Dis)charge\ efficiency\ [\%]} \left[\frac{€}{kWh}\right]$$

**Rules of LCoS**

- Energy based not power based
- Only compare same use case
- Understand where the numbers are coming from
- Use realistic numbers
- Don’t try and over complicate

**RAMS**

# Challenges in Battery Energy Storage System Industry

## Low Available Capacity

- Series & Parallel mismatch due to inconsistency between battery cells, which leads to lower available capacity according to Cannikin Law

**Pack & Rack Optimizer**


## Complex O&M

- On-site battery installation wiring & commissioning
- Regular SOC calibration by professional staff

**No need for periodic balancing**
**No need for experts to visit sites**

## Fire Risks

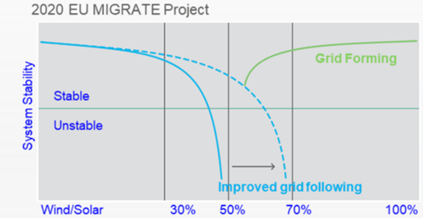
- Battery cell over-charge, over-discharge ,or other faults
- Key components(circuit boards, contactors, etc.) failure cause sparking and arcing

**Cell to system safety protection**
**Avoid thermal runaway**


## Grid Forming

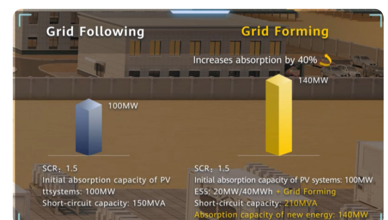
**EU considers grid forming as a key to high wind/solar penetration**

2020 EU MIGRATE Project




The European Power Grid Code (RfG) raised requirements of Grid Forming for Type A-D power generating modules

**Grid forming increase absorption of PV capacity by 40%**



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## LCOS - Simple

$$\text{LCoS [€/kWh]} = \frac{\textit{Investment costs per kWh}\ [\frac{€}{kWh}]}{\textit{System lifetime}\ [\textit{cycles}] * (\textit{Dis})\textit{charge efficiency}\ [\%]}$$

## LCOS - Complex

$$LCOS = \frac{CAPEX}{\#cycles * DOD * C_{\text{rated}} * \sum_{n=1}^{N} \frac{(1-DEG*n)}{(1+r)^n}}$$
$$+ \frac{O\&M * \sum_{n=1}^{N} \frac{1}{(1+r)^n}}{\#cycles * DOD * C_{\text{rated}} * \sum_{n=1}^{N} \frac{(1-DEG*n)}{(1+r)^n}}$$
$$- \frac{\frac{V_{\text{residual}}}{(1+r)^{N+1}}}{\#cycles * DOD * C_{\text{rated}} * \sum_{n=1}^{N} \frac{(1-DEG*n)}{(1+r)^n}}$$
$$+ \frac{P_{\text{elec-in}}}{\eta(DOD)}$$

With:

- $\#cycles$ = full charging/discharging cycles per year
- $DOD$ = depth of discharge
- $C_{\text{rated}}$ = rated capacity
- $DEG$ = annual degradation rate of capacity[1]
- $N$ = project lifetime in years
- $r$ = discount rate (e.g., weighted average cost of capital)
- $O\&M$ = O&M cost (assumed to be constant)
- $V_{\text{residual}}$ = residual value (after project lifetime)
- $P_{\text{elec-in}}$ = charging electricity tariff (assumed to be constant)
- $\eta(DOD)$ = round-trip efficiency at *DOD* (assumed to be constant)

1) Assuming linear degradation

# RTE & Usable Capacity

**Inputs:** Life time, Min. usable Energy Capacity & Min. Active Power @Metering point, charge/discharge cycle per day…

**Outputs:** OPEX, RTE, Usable Capacity @Metering Point…

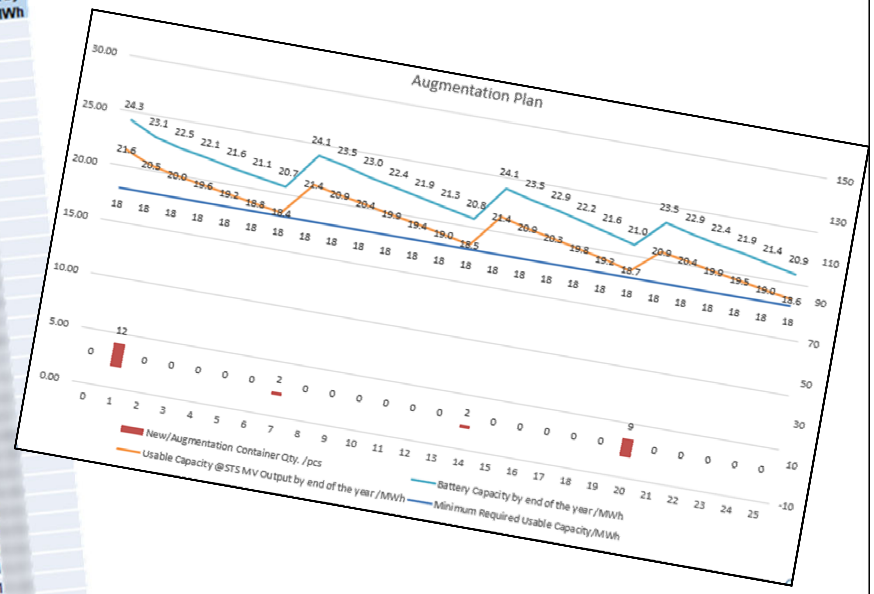
RTE – **Round Trip Efficiency / Usable Capacity**

SOH – State of Health

| | End of Year | Average of Year |
|---|---|---|
| Year | SOH(%) | SOH(%) |
| 0 | 100.00 | 100.00 |
| 1 | 9 | 9 |
| 2 | 9 | 9 |
| 3 | 9 | 9 |
| 4 | 8 | 9 |
| 5 | 8 | 8 |
| 6 | 8 | 8 |
| 7 | 8 | 8 |
| 8 | 8 | 8 |
| 9 | 7 | 8 |
| 10 | 7 | 7 |
| 11 | 7 | 7 |
| 12 | 7 | 7 |
| 13 | 7 | 7 |
| 14 | 7 | 7 |
| 15 | 6 | 6 |
| 16 | 6 | 6 |
| 17 | 6 | 6 |
| 18 | 6 | 6 |
| 19 | 6 | 6 |

| Year | RTE @ POC without Aux. | RTE @ POC with Aux. |
|---|---|---|
| BOL | 87.43% | 82.85% |
| 1 | 8 | 8 |
| 2 | 8 | 8 |
| 3 | 8 | 8 |
| 4 | 8 | 8 |
| 5 | 8 | 8 |
| 6 | 8 | 8 |
| 7 | 8 | 8 |
| 8 | 8 | 8 |
| 9 | 8 | 8 |
| 10 | 8 | 8 |
| 11 | 8 | 8 |
| 12 | 8 | 8 |
| 13 | 8 | 8 |
| 14 | 8 | 7 |
| 15 | 8 | 7 |
| 16 | 8 | 7 |
| 17 | 8 | 7 |
| 18 | 8 | 7 |
| 19 | 8 | 7 |

| Year | New/Augmentation Container Qty. /pcs | Usable Capacity @STS MV Output by end of the year /MWh |
|---|---|---|
| 0 | BOL | 21.55 |
| 1 | 12 | 2 |
| 2 | 0 | 2 |
| 3 | 0 | 1 |
| 4 | 0 | 1 |
| 5 | 0 | 1 |
| 6 | 0 | 1 |
| 7 | 2 | 2 |
| 8 | 0 | 2 |
| 9 | 0 | 2 |
| 10 | 0 | 1 |
| 11 | 0 | 1 |
| 12 | 0 | 1 |
| 13 | 0 | 1 |
| 14 | 2 | 2 |
| 15 | 0 | 2 |
| 16 | 0 | 2 |
| 17 | 0 | 1 |
| 18 | 0 | 1 |
| 19 | 0 | 1 |
| 20 | 9 | 2 |
| 21 | 0 | 2 |
| 22 | 0 | 1 |
| 23 | 0 | 1 |
| 24 | 0 | 1 |
| 25 | 0 | 1 |
| 26 | 0 | 1 |
| 27 | 0 | 1 |
| 28 | 0 | 1 |
| 29 | 0 | 1 |
| 30 | 0 | 1 |
| Aug Total | 13 | |



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# LCOS Calculator Basis

## Mid Complexity LCOS

$$LCOS = \frac{\sum (Capital_t + O\&M_t + Fuel_t) \cdot (1+r)^{-t}}{\sum MWh_t \cdot (1+r)^{-t}}$$

Where:
- $Capital_t$ = Total capital expenditures in year t
- $O\&M_t$ = Fixed operation and maintenance costs in year t
- $Fuel_t$ = Charging cost in year t
- $MWh_t$ = The amount of electricity discharged in MWh in year t, measure for the capacity factor
- $(1+r)^{-t}$ = The discount factor for year t

| | | |
|---|---|---|
| f | f = (a + e) / c | LCOS |

| | | |
|---|---|---|
| a | CAPEX + OPEX | "Capital + O&M" |

| | | |
|---|---|---|
| e | Electricity purchase costs<br>e = b x d | "Fuel"<br>Electricicty required to charge x Avg. Purchase Price |

| | | |
|---|---|---|
| c | Electricity output<br>Electricity output<br>Electricity required<br>"Efficiency" | "MWh"<br>Electricity Required x "Efficiency"<br>Capacity x Cycles x DOD<br>RTE x (1- mismatch%) |

| | 20.00 MW | 80 MWh | @POI |
|---|---|---|---|
| | **BESS LCOS Calculator** | **HUAWEI** | **Description** |
| BESS SPECIFICATIONS | ESS Model | LUNA2000-4472-2S | |
| | ESS rated capacity (MWh / unit) | 4.472 | |
| | ESS quoted quantity | 20 | |
| | **Installed rated capacity (MWh)** | 89.44 | **Total Energy** |
| | Installed Power (MW) | 22.36 | **Total Power** |
| | C-Rate | 0.25 | **C/D Duration BOL; 0.25C=4h; 0.5C=2h** |
| | **Economic Investment Horizon (years), lifespan** | **20** | **System Lifetime** |
| CAPEX | **Capital Intensity (ratio, k€/MWh storage capacity)** | **150 €** | |
| | **Upfront Cost - CAPEX (€) (Commercial offer)** | **13,416,000 €** | |
| | CAPEX gap (%), respect HUAWEI | 0% | **Hardware, Software, service, warranties…** |
| | **IRR Target, pre-tax (% p.a.)** | **7%** | **Internal Rate of Return** |
| | Annuitised build cost (€/year) | 1,266,375 € | **Annual cost inc interest** |
| | BOS (€/installed capacity) | 10,389 € | |
| OPEX | **O&M + Sust. Capex (% of Upfront Costs p.a.)** | **3.0%** | **Cost of O&M as a percentage of Capex** |
| | O&M + Sust. Capex (EUR per year) | 402,480 € | **Opex cost** |
| BESS CONFIGURATION SPECIFICATIONS | **Is SOH degradation curve considered?** | **No** | |
| | **Depth of discharge (% of total storage that can be cycled)** | **100%** | **DOD** |
| | **Cycles per day (CPD)** | **1** | **Full equivalent cycles per day** |
| | **Roundtrip efficiency (%) [@POC RTE (with auxiliary efficiency)]** | **90.0%** | **Round trip efficiency of overall system** |
| | **Battery Pack Mismatch (1st year)** | **0.0%** | |
| | **Battery Rack Mismatch (1st year)** | **0.0%** | |
| | **BESS Availability** | **98.4%** | **Huawei Optimizer** |
| | **Charge efficiency @PCS output [%]** | **94.87%** | **Huawei Smart Rack Controller** |
| | **Overall available capacity ratio, over ESS rated capacity @POC [%]** | 93.31% | |
| a | **Total economic cost before charge costs (€/year)** | **1,668,855 €** | |
| b | **Electricity required to charge (MWh pa/year)** | **34,411** | |
| c | **Electricity output from discharge (MWh pa)** | **599,507** | **Storaged energy** |
| c = a / c | **Levelised cost per MWh discharged, before power purchase costs (€/MWh)** | **57 €** | |
| d | **Average purchase price when charging (€/MWh)** | **60** | **Cost of electricity per MWh to charge the battery** |
| **e = b x d** | **Electricity purchase costs (€/year)** | **2,064,653 €** | |
| f = (a + e) / c | **LCOS, per discharged MWh (€/MWh)** | **126.10 €** | |

*Please note that figures on this presentation are indicative, and are advertised as a guide only.*

# LCOS Sensitivity

## Multiple benefits from Huawei system

| | BESS LCOS Calculator | HUAWEI | VENDOR B |
|---|---|---|---|
| | 20 MW / 80 MWh / @POI | | |
| BESS SPECIFICATIONS | ESS Model | LUNA2000-4472-2S | XXXX |
| | ESS rated capacity (MWh / unit) | 4.472 | 5.016 |
| | ESS quoted quantity | 20 | 17 |
| | **Installed rated capacity (MWh)** | 89.44 | 85.27 |
| | Installed Power (MW) | 22.36 | 18.89 |
| | C-Rate | 0.25 | 0.22 |
| | **Economic Investment Horizon (years), lifespan** | **20** | **20** |
| CAPEX | **Capital Intensity (ratio, k€/MWh storage capacity)** | **150 €** | **126 €** |
| | **Upfront Cost - CAPEX (€) (Commercial offer)** | **13,416,000 €** | **10,737,918 €** |
| | CAPEX gap (%), respect HUAWEI | 0% | **-19.96%** |
| | **IRR Target, pre-tax (% p.a.)** | **7%** | |
| | Annuitised build cost (€/year) | 1,266,375 € | 1,013,583 € |
| | BOS (€/installed capacity) | 10,389 € | 7,632 € |
| OPEX | **O&M + Sust. Capex (% of Upfront Costs p.a.)** | **0.0%** | **0.3%** |
| | O&M + Sust. Capex (EUR per year) | 0 € | 32,214 € |
| BESS CONFIGURATION SPECIFICATIONS | **Is SOH degradation curve considered?** | **No** | |
| | **Depth of discharge (% of total storage that can be cycled)** | **100%** | **100%** |
| | **Cycles per day (CPD)** | **1** | **1** |
| | **Roundtrip efficiency (%) [@POC RTE (with auxiliary efficiency)]** | **90.0%** | **90.0%** |
| | **Battery Pack Mismatch (1st year)** | **0.0%** | **-2.0%** |
| | **Battery Rack Mismatch (1st year)** | **0.0%** | **0.0%** |
| | **BESS Availability** | **98.4%** | **98.0%** |
| | **Charge efficiency @PCS output [%]** | **94.87%** | **94.87%** |
| | **Overall available capacity ratio, over ESS rated capacity @POC [%]** | 93.31% | 93.31% |
| a | **Total economic cost before charge costs (€/year)** | **1,266,375 €** | **1,045,797 €** |
| b | **Electricity required to charge (MWh pa/year)** | **34,411** | **34,411** |
| c | **Electricity output from discharge (MWh pa)** | **599,507** | **557,861** |
| c = a / c | **Levelised cost per MWh discharged, before power purchase costs (€/MWh)** | **44 €** | **39 €** |
| d | **Average purchase price when charging (€/MWh)** | **60** | |
| e = b x d | **Electricity purchase costs (€/year)** | **2,064,653 €** | **2,064,653 €** |
| f = (a + e) / c | **LCOS, per discharged MWh (€/MWh)** | **112.68 €** | **112.68 €** |

***Please note that figures on this presentation are indicative, and are advertised as a guide only.***

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The logic behind the sensitivity analysis is to quantify the impact of pack level optimizer by:

1) Assuming exactly the same specifications of all Technical parameters.
2) Modify the capital intensity ratio (€/MWh) to aim for the same LCOS.

**Means around 20% CAPEX "gap" to have same LCOS**

Without additional OPEX due to calibration

Same RTE

+2% extra discharged energy increase with pack optimizers

Same Discharge efficiency

Same LCOS

HUAWEI

# Pack Level Optimization to Achieve higher discharged energy

Series & Parallel mismatch due to inconsistency between SOC of battery cells leads to lower available capacity according to Cannikin Law


### 3 Conclusion and Summary

Through detailed test and data comparison, and combining the test results of the evious three runs with the test results of the current run for two years and ten months, e report results are as follows:

1、After three months of operation, the charging capacity and discharging capaci of the pack optimizer enabled state are increased by 1.82% and 2.23% respectively compared with the pack optimizer disabled ;

2、When the ESS runs for two years and 10 months, the charging capacity and discharging capacity increase by 8.41% and 8.96% respectively compared with the pack optimizer disabled.

This test verifies that the cell difference and cell attenuation inconsistency affect the iarging and discharging capability and system revenue of the whole system when the ick optimizer is disabled. As time goes by, the cell inconsistency will become more an ore serious, resulting in more serious mismatch, which poses challenges to the chargi id discharging capabilities of the energy storage system and seriously affects the ›erating revenue.

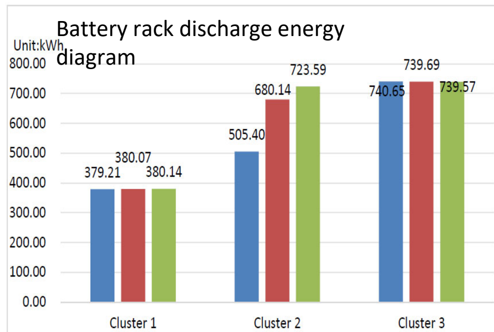
When the pack optimizer is enabled, the function verification of the pack optimizer ıder the same test conditions shows that the charge and discharge capacity is effective ıproved.

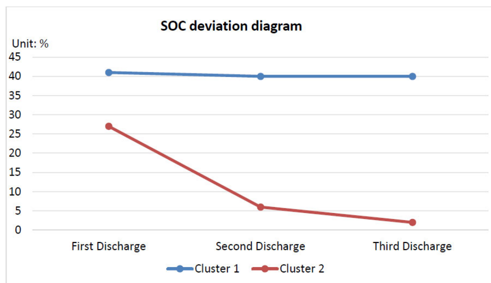
From the comparison of the tracking test results of nearly 3 years operation, it can l ›en that the pack optimizer can solve the cell inconsistency problem effectively, ›pecially with the operation of time, the value of the pack optimizer further increases, hich confirms the necessity of pack optimizer.

End

**BESS POC Testing resulting in +2.23% extra discharged energy within 3 months and +8.96% in only 2 years and 10 months of operation**

**Huawei LUNA2000-4472-2S Smart String Energy Storage System Battery Pack Active Equalization Function Test Report**




Innitial conditions

Rack 1: optimizer OFF, SOC 50%

Rack 2: optimizer is ON, SOC 50%

Rack 3: optimizer is ON, SOC 100%

After three full cycles **Rack 1** has not recovered of the series mistmatch and the energy output is heavily limited,

while, **the SOC deviation in the Rack 2 is reduced to less than 2%, reaching a discharge of 723,59kWh, +90% higher available output capacity than Rack 1.**

**Active balancing with optimizer at pack level, considerably increases the available capacity automatically, without manual interaction**

**No cost**

**0**

Automatic calibration
No site visit

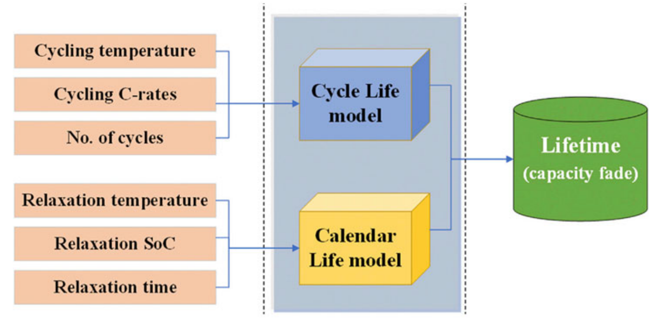
ESS Technical Due Diligence Report by TÜV, ID-Number: SMN_GCN_F_37.00CS

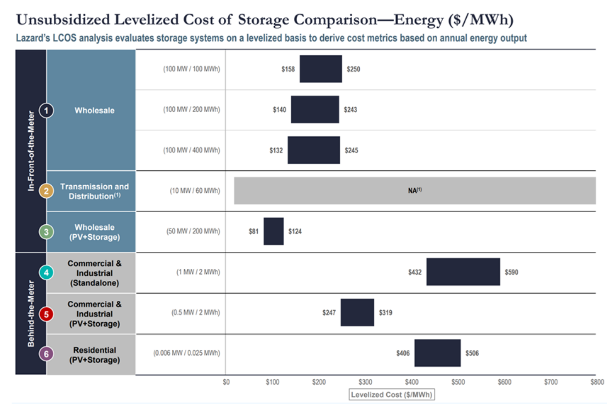


HUAWEI

# LCOS: Overall levelized cost per MWh

| BESS LCOS Calculator | HUAWEI | HUAWEI | HUAWEI |
|---|---|---|---|
| ESS Model | LUNA2000-4472-2S | LUNA2000-4472-2S | LUNA2000-4472-2S |
| ESS rated capacity (MWh / unit) | 4.472 | 4.472 | 4.472 |
| ESS quoted quantity | 20 | 20 | 20 |
| **Installed rated capacity (MWh)** | 89.44 | 89.44 | 89.44 |
| Installed Power (MW) | 22.36 | 22.36 | 22.36 |
| C-Rate | 0.25 | 0.25 | 0.25 |
| **Economic Investment Horizon (years), lifespan** | **20** | **20** | **17** |
| **Capital Intensity (ratio, k€/MWh storage capacity)** | **111 €** | **111 €** | **111 €** |
| **Upfront Cost - CAPEX (€) (Commercial offer)** | **9,972,110 €** | **9,972,110 €** | **9,972,110 €** |
| CAPEX gap (%), respect HUAWEI | 0% | 0% | 0% |
| **IRR Target, pre-tax (% p.a.)** | **7%** | **7%** | **7%** |
| Annuitised build cost (€/year) | 941,297 € | 941,297 € | 1,021,395 € |
| BOS (€/installed capacity) | 10,389 € | 10,389 € | 10,389 € |
| **O&M + Sust. Capex (% of Upfront Costs p.a.)** | **3.0%** | **3.0%** | **3.0%** |
| O&M + Sust. Capex (EUR per year) | 299,163 € | 299,163 € | 299,163 € |
| **Is SOH degradation curve considered?** | **No** | **No** | **No** |
| **Depth of discharge (% of total storage that can be cycled)** | **100%** | **100%** | **100%** |
| **Cycles per day (CPD)** | **1** | **1.5** | **2** |
| **Roundtrip efficiency (%) [@POC RTE (with auxiliary efficiency)]** | **90.0%** | **90.0%** | **90.0%** |
| **Battery Pack Mismatch (1st year)** | **0.0%** | **0.0%** | **0.0%** |
| **Battery Rack Mismatch (1st year)** | **0.0%** | **0.0%** | **0.0%** |
| **BESS Availability** | **98.4%** | **98.4%** | **98.4%** |
| **Charge efficiency @PCS output [%]** | **94.87%** | **94.87%** | **94.87%** |
| **Overall available capacity ratio, over ESS rated capacity @POC [%]** | 93.31% | 93.31% | 93.31% |
| **Total economic cost before charge costs (€/year)** | **1,240,460 €** | **1,240,460 €** | **1,320,559 €** |
| **Electricity required to charge (MWh pa/year)** | **34,411** | **51,616** | **68,822** |
| **Electricity output from discharge (MWh pa)** | **599,507** | **899,261** | **1,019,163** |
| **Levelised cost per MWh discharged, before power purchase costs (€/MWh)** | **43 €** | **29 €** | **27 €** |
| **Average purchase price when charging (€/MWh)** | **60** | **60** | **60** |
| **Electricity purchase costs (€/year)** | **2,064,653 €** | **3,096,979 €** | **4,129,305 €** |
| **LCOS, per discharged MWh (€/MWh)** | **111.81 €** | **97.50 €** | **91.82 €** |




*Source: Lazards LCOS analysis*

***Please note that figures on this presentation are indicative, and are advertised as a guide only.***

# Minimum Installed Capacity Calculation

## In-depth understanding of the seven key elements of energy storage project solution configuration to help maximize customer benefits.

### "Apple to apple "

**Project requirement:**

- BOL
- POC 40MW/80MWh
- 1cycle per day

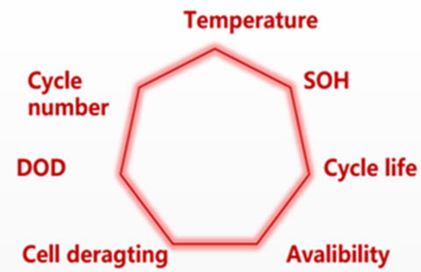
**Capcity from client:**

| Name | Nominal MWh | RTE@PCS | DOD | Storage | Avalibility |
|---|---|---|---|---|---|
| HW(2MWh) | 97.5 | 86% | 93% | 2.5% | 98% |
| **HW(4.5MWh)** | **89.44** | **90.3%** | **100%** | **2.5%** | **98%** |
| BX | 95.2 | 87% | NA | NA | NA |
| SX | **88.06** | 89.5% | NA | NA | NA |
| CT | **90.27** | 88.5% | NA | NA | NA |
| TX | **84.79** | 89.8% | NA | NA | NA |

**Caculation at same level:**

| Name | Nominal MWh | RTE@PCS | DOD | Storage | Avalibility |
|---|---|---|---|---|---|
| BX | 95.2 | 87% | 95% | 2.5% | 98% |
| SX | **93.5** | 89.5% | 98% | 2.5% | 98% |
| CT | **95.3** | 88.5% | 95% | 2.5% | 98% |
| TX | **92.5** | 90% | 98% | 2.5% | 98% |

### Output solution configuration around seven key elements




① **Temperature: Whether the project design temperature and the actual temperature of the equipment location are clear**;

② **Cycle number**: make cycler number clearly followe business modle ;

③ **SOH**: average SOC working condition;

④ **EFF**: the Eff should be a reasonable erange. Confirm the right situation ;

⑤ **DOD**: if constantly power ;

⑥ **Storage** : delivery plan is most important

**Minimum Installed capacity should follow all calculation parameters, other company tend to overpromise**

# LCOS Comparison Results

| | BESS LCOS Calculator | HUAWEI | VENDOR B | Description |
|---|---|---|---|---|
| | | 20.00 MW | 80 MWh | @POI |
| BESS SPECIFICATIONS | ESS Model | LUNA2000-4472-2S | XXXX | |
| | ESS rated capacity (MWh / unit) | 4.472 | 5.016 | |
| | ESS quoted quantity | 20 | 17 | |
| | **Installed rated capacity (MWh)** | 89.44 | 85.27 | **Total Energy** |
| | Installed Power (MW) | 22.36 | 19.30 | **Total Power** |
| | C-Rate | 0.25 | 0.23 | **C/D Duration BOL; 0.25C=4h; 0.5C=2h** |
| | **Economic Investment Horizon (years), lifespan** | **20** | **20** | **System Lifetime** |
| CAPEX | **Capital Intensity (ratio, k€/MWh storage capacity)** | **130 €** | **110 €** | |
| | **Upfront Cost - CAPEX (€) (Commercial offer)** | **11,627,200 €** | **9,379,920 €** | |
| | CAPEX gap (%), respect HUAWEI | 0% | **-19.33%** | **Hardware, Software, service, warranties…** |
| | **IRR Target, pre-tax (% p.a.)** | **7%** | | **Internal Rate of Return** |
| | Annuitised build cost (€/year) | 1,097,525 € | 885,398 € | **Annual cost inc interest** |
| | BOS (€/installed capacity) | 10,389 € | 7,632 € | |
| OPEX | **O&M + Sust. Capex (% of Upfront Costs p.a.)** | **3.0%** | **3.3%** | **Cost of O&M as a percentage of Capex** |
| | O&M + Sust. Capex (EUR per year) | 348,816 € | 314,040 € | **Opex cost** |
| BESS CONFIGURATION SPECIFICATIONS | **Is SOH degradation curve considered?** | **No** | | |
| | **Depth of discharge (% of total storage that can be cycled)** | **100%** | **100%** | **DOD** |
| | **Cycles per day (CPD)** | **1** | **1** | **Full equivalent cycles per day** |
| | **Roundtrip efficiency (%) [@POC RTE (with auxiliary efficiency)]** | **90.0%** | **88.1%** | **Round trip efficiency of overall system** |
| | **Battery Pack Mismatch (1st year)** | **0.0%** | **-2.0%** | |
| | **Battery Rack Mismatch (1st year)** | **0.0%** | **-4.0%** | |
| | **BESS Availability** | **98.4%** | **98.0%** | **Huawei Optimizer** |
| | **Charge efficiency @PCS output [%]** | **94.87%** | **94.64%** | **Huawei Smart Rack Controller** |
| | **Overall available capacity ratio, over ESS rated capacity @POC [%]** | 93.31% | 92.22% | |
| a | **Total economic cost before charge costs (€/year)** | **1,446,341 €** | **1,199,438 €** | |
| b | **Electricity required to charge (MWh pa/year)** | **34,411** | **34,494** | |
| c | **Electricity output from discharge (MWh pa)** | **599,507** | **528,797** | **Storaged energy** |
| c = a / c | **Levelised cost per MWh discharged, before power purchase costs (€/MWh)** | **50 €** | **47 €** | |
| d | **Average purchase price when charging (€/MWh)** | **60** | | **Cost of electricity per MWh to charge the battery** |
| e = b x d | **Electricity purchase costs (€/year)** | **2,064,653 €** | **2,069,645 €** | |
| f = (a + e) / c | **LCOS, per discharged MWh (€/MWh)** | **118.68 €** | **124.87 €** | **Lower CAPEX, but equal or higher LCOS** |

***Please note that figures on this presentation are indicative, and are advertised as a guide only.***

# Smart String ESS: Optimal LCOS , Active and Ultra Safety

Lower LCOS

## LCOS decreased by 15%

Based on 100MW/200MWh projects

| Lower CAPEX | More Energy | Easy O&M | Safe & Reliable |
|---|---|---|---|
| Save **21.2 million USD** by augmentation plan<br>Prefabricated & Pre-installed Battery Container | Improve utilization by **13%**<br>Increase service life by **50%** | Save 25-year O&M cost<br>~**7.7 MUSD** | Intelligent internal short circuit detection<br>Fire risk warning |

**CAPEX**

1. Battery containers, PCSs, and power distribution cabinets
2. Power station compensation cost
3. Other Costs

**OPEX**

1. Scheme design, construction, and delivery expenses
2. PMI and fault O&M expenses
3. Warranty expense and power generation loss due to failure

$$LCOS = \frac{\sum_{n=1}^{N} NPV\,(CAPEXt) + \sum_{n=1}^{N} NPV\,(OPEXt)}{\sum_{n=1}^{N} NPV\,(Discharget)} * \text{Safety Factor} \propto \text{System availability}$$

(RTE/DoD/Optimizer, etc.)

(Auto SOC calibration/Less O&M, etc.)

(Higher RTE/Constant power/Optimizer, etc.)

Total discharge energy in the life cycle

**Safety Factor**
(C2G safety)

**System availability**
(module/string design)


11 **Flexible warranty: SOH degradation curve under variable working conditions**

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Warranty policy

# Flexible warranty and performance warranty promotion strategies

- **Key challenge:** As customer scenarios may vary, quantitative analysis of the impact of SOH and failure rate is required under different working conditions.
- **Overall strategy**: Obtain the SOH degradation curve under variable working conditions (enter the working condition, rate, number of cycles, DOD, and storage SOC).

| | | |
|---|---|---|
| SOH | RTE | Capacity |
| Power | Availability | DOD |

Example:

| | |
|---|---|
| C rate | 0.25C @constant power |
| SOC | 0.5 |
| DOD | 1 |
| Ambient temperature | below 40℃ |
| Number of cycles/day | 1 |
| Interval between charge & discharge/hour | 2 |

# Energy throughput

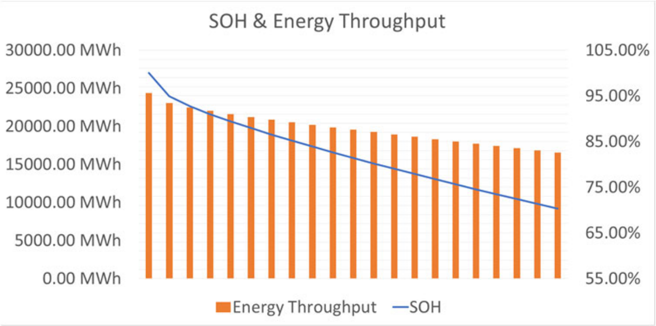
Cycles x DC Useable Capacity x RTE x Availability = **Energy Throughput**

| Number of cycles/year | Year | SOH | DC cap. - retention | RTE with aux. consumption | Avaliability | Energy Throughput |
|---|---|---|---|---|---|---|
| 365 | 0 | 100.00% | 76.80 MWh | 88.25% | 98.40% | 24342.43 MWh |
| 365 | 1 | 94.89% | 76.80 MWh | 88.08% | 98.40% | 23054.92 MWh |
| 365 | 2 | 92.71% | 76.80 MWh | 87.89% | 98.40% | 22474.75 MWh |
| 365 | 3 | 90.96% | 76.80 MWh | 87.75% | 98.40% | 22015.72 MWh |
| 365 | 4 | 89.38% | 76.80 MWh | 87.61% | 98.40% | 21600.02 MWh |
| 365 | 5 | 87.91% | 76.80 MWh | 87.52% | 98.40% | 21222.86 MWh |
| 365 | 6 | 86.52% | 76.80 MWh | 87.43% | 98.40% | 20864.33 MWh |
| 365 | 7 | 85.18% | 76.80 MWh | 87.33% | 98.40% | 20517.86 MWh |
| 365 | 8 | 83.88% | 76.80 MWh | 87.24% | 98.40% | 20185.43 MWh |
| 365 | 9 | 82.63% | 76.80 MWh | 87.12% | 98.40% | 19855.89 MWh |
| 365 | 10 | 81.40% | 76.80 MWh | 87.05% | 98.40% | 19546.07 MWh |
| 365 | 11 | 80.21% | 76.80 MWh | 86.96% | 98.40% | 19238.92 MWh |
| 365 | 12 | 79.03% | 76.80 MWh | 86.82% | 98.40% | 18927.24 MWh |
| 365 | 13 | 77.88% | 76.80 MWh | 86.68% | 98.40% | 18621.57 MWh |
| 365 | 14 | 76.75% | 76.80 MWh | 86.49% | 98.40% | 18310.77 MWh |
| 365 | 15 | 75.64% | 76.80 MWh | 86.31% | 98.40% | 18007.35 MWh |
| 365 | 16 | 74.54% | 76.80 MWh | 86.12% | 98.40% | 17706.70 MWh |
| 365 | 17 | 73.45% | 76.80 MWh | 85.93% | 98.40% | 17410.61 MWh |
| 365 | 18 | 72.38% | 76.80 MWh | 85.75% | 98.40% | 17120.76 MWh |
| 365 | 19 | 71.32% | 76.80 MWh | 85.56% | 98.40% | 16832.89 MWh |
| 365 | 20 | 70.28% | 76.80 MWh | 85.28% | 98.40% | 16531.35 MWh |

**EVE Cell 50% SOC Storage Attenuation**

| Temperature \ Month | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 25 ℃ (Supplier Test Data) | 1.40% | 1.70% | 2.00% | 2.30% | 2.55% | 2.75% | 2.95% | 3.15% | 3.30% | 3.45% | 3.60% |
| 35 ℃ (Interpolation Method) | 1.40% | 2.00% | 2.49% | 2.94% | 3.37% | 3.76% | 4.01% | 4.25% | 4.43% | 4.57% | 4.71% |
| 45 ℃ (Supplier Test Data) | 1.40% | 2.25% | 2.94% | 3.54% | 4.10% | 4.62% | 4.92% | 5.20% | 5.36% | 5.49% | 5.62% |

DC Useable Capacity =
SOH x (DC capacity – storage retention)
Example: Year 0: 100% x (80MWh – 4%) = 76.8 MWh



# Flexible SOH warranty scheme

## Calculation Description

1. **Specify the operating conditions of the ESS, including C-rate, DOD, average SOC, numbers of cycle per day and so on.**
2. **Base on <Huawei BESS SOH Degradation Curves based>, find the SOH curve corresponding to the initial operating condition, and find the SOH value (X) corresponding to the last year of this condition.**
3. **Find the SOH curve corresponding to the second operating condition and the SOH value (Y) closest to the SOH value (X) in the first working condition.**
4. **Base on the SOH curve corresponding to the second operating condition, calculate the differential value (Δ) between the current SOH value (Y) and SOH values each subsequent year.**
5. **Subtract the differential value (Δ) from the SOH value (X) of the first operating condition to obtain the SOH list for the duration of the second operating condition.**
6. **If more operating conditions are involved, refer to the above steps until the SOH is less than 60%.**

## Example Description

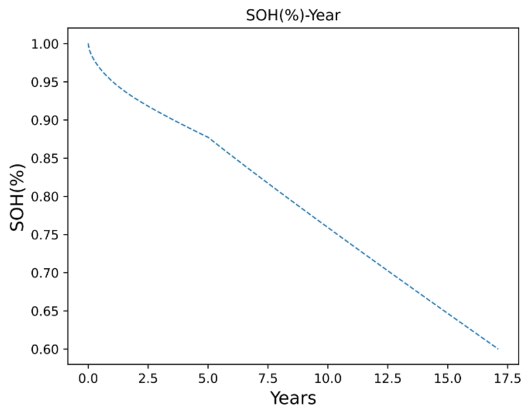
*Project Conditions:*

| | First Operating Condition | Second Operating Condition |
|---|---|---|
| Type of ESS | LUNA2000-4.5MWH-2H1 | LUNA2000-4.5MWH-2H1 |
| C-rate | 0.5C | 0.5C |
| Max. Temperature | ＜40℃ | ＜40℃ |
| Altitude | ＜4000m | ＜4000m |
| DOD | 100% | 100% |
| Average SOC | ≤50% | ≤50% |
| Cycle per day | 1 | 1.5 |
| Term of Year | 0-5 | 6-EOL |

# Flexible SOH warranty scheme

***Calculation:***

1. **According to first operating condition, find the SOH rack @ 1cycle/day and the SOH value (X) at the end of 5 year is 87 %;**
2. **According to second operating condition, find the SOH rack @ 1.5cycle/day and the SOH value (Y) closest to the SOH value (X) in first operating condition is 87 %;**
3. **The differential SOH value ($\Delta_1$) between Y and the SOH value next year ($Y_1$)= 87% - 85%=2%. So the SOH value at the end of six year = 87% – 2% = 85%;**
4. **The differential SOH value ($\Delta_2$) between $Y_1$ and the SOH value next year ($Y_2$)= 85% - 83%=2 %. So the SOH value at the end of seven year = 85% – 2 % = 83%;**
5. **According to this method, the SOH of the 8th, 9th, and end of year is calculated.**



SOH simulation tool for combined working conditions

*<Huawei BESS SOH Degradation Curves based @ 0.5C>*

| End of Year | SOH @1 cycle/day | SOH @ 1.5 cycle/day | SOH @ 2 cycle/day |
|---|---|---|---|
| 0 | 100% | 100% | 100% |
| 1 | 95% | 94% | 93% |
| 2 | 92% | 91% | 90% |
| 3 | 90% | 89% | 87% |
| 4 | 89% | 87% | 85% |
| 5 | 87% | 85% | 82% |
| 6 | 86% | 83% | 80% |
| 7 | 84% | 81% | 77% |
| 8 | 83% | 79% | 75% |
| 9 | 81% | 77% | 72% |
| 10 | 80% | 75% | 70% |
| 11 | 79% | 73% | 68% |
| 12 | 77% | 71% | 65% |
| 13 | 76% | 70% | 63% |
| 14 | 75% | 68% | 61% |
| 15 | 74% | 66% | |
| 16 | 72% | 64% | |
| 17 | 71% | 62% | |
| 18 | 70% | 61% | |
| 19 | 68% | | |
| 20 | 67% | | |



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# Flexible warranty: According to SOH, adjust the conditions to meet long time requirement

**Strategy:**

- Solution team **provides the SOH curve;**
- Before EOL, customer uses **at different conditions and equerry the remaining SOH** at the end of each year.
- Inform customer **the remaining SOH, calculate the yearly price based on new conditions.**

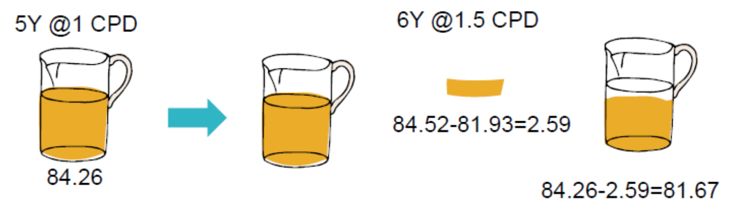
## Project conditions

| Working conditions | Condition A | B Conditions |
|---|---|---|
| BESS Solution | LUNA2000-4.5MWH-2H1 | LUNA2000-4.5MWH-2H1 |
| C/D-rate | **0.5C** | **0.5C** |
| CPD | **1** | **1.5** |
| DOD | 100% | 100% |
| SOC | 50% | 50% |
| Maximum Warranty Period | 20 years | 15 years |

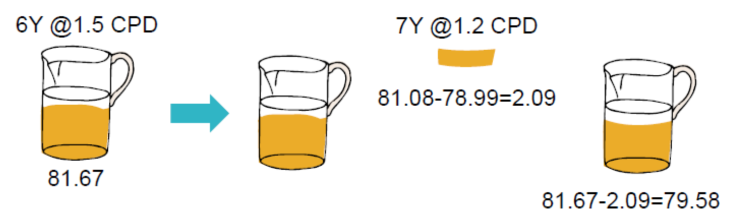
## SOH degradation curve

| End of Year | SOH (%) @0.9cycle/day | SOH (%) @ 1 cycle/day | SOH (%) @ 1.2 cycle/day | SOH (%) @ 1.5 cycle/day | SOH (%) @ 1.8 cycle/day |
|---|---|---|---|---|---|
| 0 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| 1 | 95.02 | 94.88 | 94.61 | 94.23 | 93.85 |
| 2 | 91.92 | 91.68 | 91.21 | 90.52 | 89.86 |
| 3 | 89.29 | 88.95 | 88.30 | 87.36 | 86.45 |
| 4 | 86.92 | 86.51 | 85.69 | 84.52 | 83.40 |
| 5 | 84.76 | 84.26 | 83.30 | 81.93 | 80.62 |
| 6 | 82.73 | 82.17 | 81.08 | 79.52 | 78.04 |
| 7 | 80.83 | 80.20 | 78.99 | 77.27 | 75.64 |
| 8 | 79.03 | 78.34 | 77.02 | 75.14 | 73.39 |
| 9 | 77.31 | 76.57 | 75.14 | 73.14 | 71.26 |
| 10 | 75.67 | 74.88 | 73.36 | 71.23 | 69.23 |

## SOH & Flexible Warranty




End of 6th Year : SOH =81.67%




End of 7th Year : SOH =79.58%



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# Thank you