

Low-Voltage Stacked ESS

The Optimal Architecture for Residential Energy Storage



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Executive Summary

As residential solar and energy storage adoption accelerates worldwide, system architecture has become a critical factor affecting safety, installation efficiency, serviceability, customer experience, and long-term ownership cost.

While high-voltage battery systems have gained popularity in recent years, particularly in higher-power residential and commercial applications, low-voltage stacked energy storage systems continue to offer significant advantages for mainstream residential deployments.

This paper examines the technical characteristics of low-voltage and high-voltage residential ESS architectures and explains why KSTAR has chosen a low-voltage stacked all-in-one (AIO) design for residential applications.

Our analysis demonstrates that for typical residential systems, low-voltage stacked architectures deliver:

- ★ **Industry-leading intrinsic safety**
- ★ **Simplified installation and commissioning**
- ★ **Competitive system efficiency**
- ★ **Reduced service complexity**
- ★ **Lower total cost of ownership (TCO)**
- ★ **Superior homeowner experience**

For these reasons, KSTAR believes that low-voltage stacked ESS represents the optimal balance of performance, safety, and simplicity for residential energy storage.



1. The Evolution of Residential Energy Storage



Residential battery systems have evolved from backup power devices into intelligent energy management platforms capable of:

- ★ Increasing solar self-consumption
- ★ Providing backup power
- ★ Enabling future grid participation
- ★ Reducing electricity costs
- ★ Supporting energy independence

As the market matures, customer priorities are increasingly focused on:

- Safety
- Reliability
- Ease of installation
- Ease of maintenance
- Long-term ownership cost

Rather than battery voltage alone.
The key question is therefore not:

"Which voltage is higher?" but rather:

"Which architecture delivers the greatest value to residential users?"

2. Understanding Residential ESS Architectures

Low-Voltage ESS

Typical characteristics

- ◆ 48V / 51.2V battery architecture
- ◆ Safety Extra-Low Voltage (SELV)
- ◆ Battery protected by BMS
- ◆ DC / DC boost integrated inside the inverter

Benefits

- ◆ Intrinsic electrical safety
- ◆ Simpler battery architecture
- ◆ Easier installation and maintenance

High-Voltage ESS

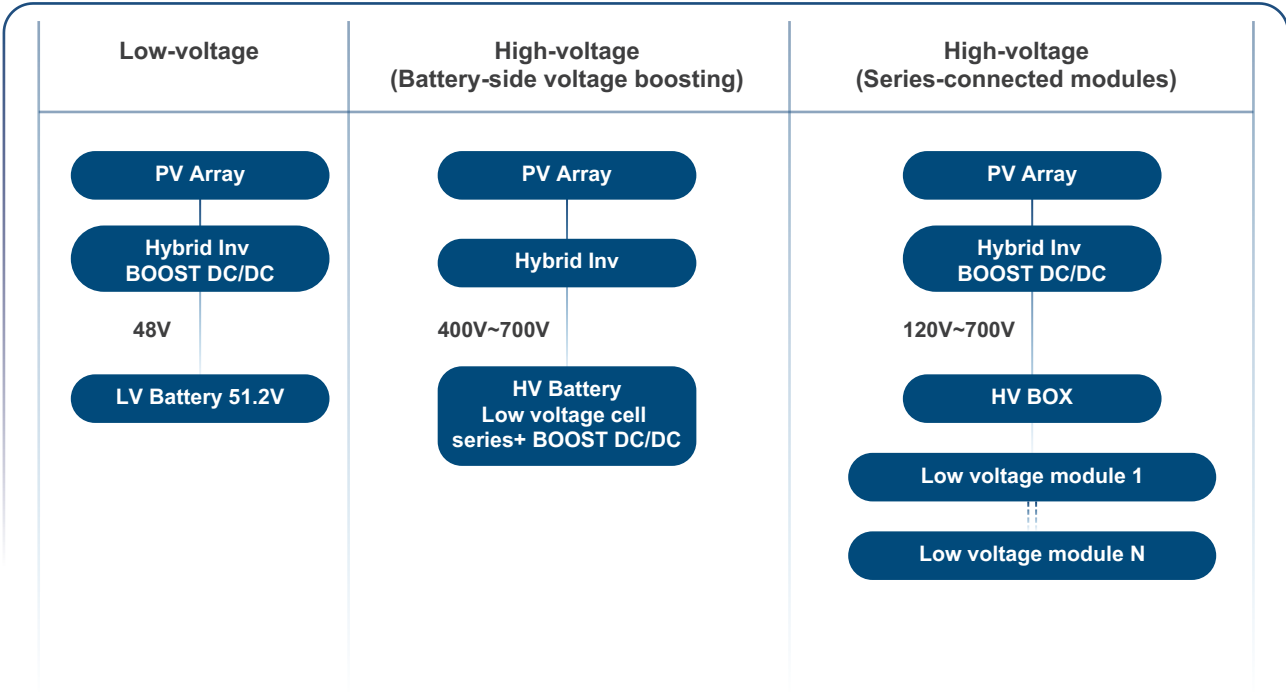
Typical characteristics

- ◆ 120–700V DC battery output
- ◆ Battery-side voltage boosting or series-connected modules
- ◆ Direct connection to high-voltage inverter bus

Benefits

- ◆ Reduced current
- ◆ Lower transmission losses over long cable runs
- ◆ Higher power density

Both architectures can achieve excellent performance when properly engineered. The question is which architecture best matches residential deployment requirements.



Comparison of low-voltage and high-voltage residential ESS architectures

Due to advancements in large-capacity battery cells, which offer advantages in cycle life, cost, and efficiency over smaller cells, the high-voltage(Battery-side voltage boosting) architecture is increasingly becoming the mainstream high-voltage residential storage solution.

3. Safety: The Foundation of Residential Energy Storage

Residential ESS systems are installed in homes, garages, basements, and utility rooms. For these environments, safety must remain the primary design consideration.



Low-voltage systems operate within the SELV range, providing several inherent advantages:

- ★ Reduced electric shock risk
 - ★ Simplified insulation requirements
 - ★ Reduced installation complexity
- ★ Lower arc-flash potential
 - ★ Safer maintenance procedures

Modern high-voltage systems incorporate extensive protection measures and comply with applicable safety standards.

However, higher operating voltages inevitably require:

- ★ Additional protective devices
- ★ More stringent installation practices
- ★ Enhanced safety procedures

For residential applications, intrinsic safety remains a significant advantage of low-voltage architectures.

4. Efficiency: Looking Beyond Battery Voltage

A common assumption is that high-voltage systems are always more efficient.

In reality, efficiency depends on:

- ★ DC / DC converter design
- ★ Control algorithms
- ★ Operating conditions
- ★ Semiconductor performance
- ★ Cable losses

For typical residential systems:

- ★ Power range: 5–10 kW
- ★ Battery current: 100–200 A
- ★ Battery-to-inverter distance: typically <0.1m(stackd AIO design), 2-3m(split design)

Under these conditions:

- ★ Stacked AIO Cable losses become minimal
- ★ Converter efficiency becomes dominant
- ★ Cable losses in the Low Voltage Stacked AIO configuration are lower than those in the Low Voltage Split Design.
- ★ Differences between stacked low-voltage and stacked high-voltage systems become relatively small.
- ★ Consequently, modern low-voltage stacked ESS solutions can achieve round-trip efficiencies comparable to high-voltage residential systems.
- ★ The efficiency advantages of high-voltage systems become increasingly important as power levels and transmission distances increase.

5. Installation Simplicity Creates Real Value

One of the largest challenges facing residential ESS deployment today is installer availability. Reducing installation complexity benefits the entire value chain.

A stacked all-in-one architecture offers:

- ★ Plug-and-play installation
- ★ Reduced wiring
- ★ Faster commissioning
- ★ Fewer installation errors
- ★ Lower training requirements

Benefits include:

- ★ Reduced labor cost
- ★ Faster project completion
- ★ Improved installer productivity
- ★ Better scalability for distribution networks



6. Lower Total Cost of Ownership

Homeowners evaluate systems over their entire service life. Low-voltage stacked architectures contribute to lower lifecycle costs through:



Simplified Hardware

- ◆ Reduced high-voltage protection requirements
- ◆ Simplified electrical architecture
- ◆ Lower installation labor cost



Easier Serviceability

- ♦ Modular replacement
- ♦ Faster troubleshooting
- ♦ Reduced maintenance downtime



Lower Operational Risk

- ♦ Reduced installation complexity
- ♦ Lower likelihood of commissioning issues
- ♦ Simplified field service

The result is a compelling Total Cost of Ownership (TCO) proposition.

7. Industry Myths vs Engineering Reality

High Voltage Always Means Higher Efficiency

Reality

- ♦ In split systems, high-voltage architectures can reduce cable losses.
- ♦ In stacked systems, cable lengths are extremely short and transmission losses become negligible.
- ♦ Overall efficiency is primarily determined by converter design and system integration quality rather than battery voltage alone.

Key takeaway:

- ♦ System design quality matters more than operating voltage.



High Voltage Represents More Advanced Technology Reality

Reality

Voltage level is an architectural choice, not a measure of innovation. Modern low-voltage systems incorporate:

- ♦ Advanced BMS
- ♦ Intelligent EMS
- ♦ Remote monitoring
- ♦ AI-based energy optimization
- ♦ High-efficiency power electronics

Key takeaway:

- ♦ Technology leadership is defined by system capability and customer value—not voltage level.

Low-Voltage Systems Cannot Deliver High Power Reality

Reality

- ♦ Most residential installations require only 5–15 kW.
- ♦ Modern low-voltage architectures can easily support these requirements through optimized battery, busbar, thermal, and inverter designs.

Key takeaway:

- ♦ Low-voltage systems fully satisfy the power requirements of the vast majority of residential installations.



8. Installer and Distribution Partner Perspective

For distributors and installation companies, operational efficiency is often more important than small differences in electrical architecture.

Reduced Training Requirements

High-voltage residential battery systems typically require installers to follow additional safety procedures due to the presence of hazardous DC voltages.

Depending on local regulations and company policies, installers may require:

- ★ Additional high-voltage safety training
- ★ Enhanced lockout/tagout procedures
- ★ Additional PPE requirements
- ★ More stringent commissioning processes

While necessary for safety, these requirements may increase:

- ★ Training costs
- ★ Project preparation time
- ★ Workforce qualification requirements
- ★ Deployment complexity

For rapidly expanding installation networks, reducing training complexity improves scalability and accelerates market adoption.



Reduced Service and After-Sales Risk

Residential ESS systems are expected to operate for more than a decade.

High-voltage architectures typically include additional components such as:

- ★ High-voltage contactors
- ★ High-voltage connectors
- ★ Insulation monitoring systems
- ★ Pre-charge circuits
- ★ Additional protection devices

These components enhance safety but also increase system complexity. From a service perspective, maintenance involving high-voltage equipment may require:

- ★ Additional safety procedures
- ★ Longer troubleshooting time
- ★ More highly qualified personnel
- ★ Increased site intervention costs

Reducing operational complexity can lower lifecycle service costs and improve customer satisfaction.

9. Designed for Real Residential Environments

A modern residential ESS should offer:

- Quiet operation
- Compact footprint
- Attractive appearance
- Minimal maintenance

The low-voltage stacked architecture enables appliance-style product design while maintaining high performance and reliability.

Conclusion

Both low-voltage and high-voltage architectures have important roles in the energy storage market.

High-voltage systems offer advantages in:

- ★ Power density
- ★ Long-distance transmission
- ★ Larger-scale applications

Low-voltage stacked systems offer advantages in:

- ★ Intrinsic safety
 - ★ Ease of maintenance
 - ★ Lower service complexity
 - ★ Lower total cost of ownership
- ★ Installation simplicity
 - ★ Reduced training requirements
 - ★ Competitive efficiency

Dimension	Low Voltage + Split	High Voltage + Split	Low Voltage + Stacked	High Voltage + Stacked
Battery Voltage	≤ 48 / 51.2 V	120 ~ 700 V	≤ 48 / 51.2 V	120 ~ 700 V
System RTE	Lower	Medium	Higher	Higher
Safety	★★★★★	★★★★☆	★★★★★	★★★★☆
Installation Convenience	★★★★☆	★★★★☆	★★★★★	★★★★★
Serviceability	★★★★★	★★★★☆	★★★★☆	★★★★☆

Table 1 Comprehensive Comparison: Low Voltage vs. High Voltage, Split vs. Stacked

For the majority of residential installations, these advantages deliver greater real-world value than voltage specifications alone.

For this reason, KSTAR has chosen the low-voltage stacked all-in-one architecture as its preferred residential ESS platform—providing homeowners, installers, and distribution partners with an optimal balance of safety, performance and simplicity.