FRANKLINWH

Breakthroughs in North American Residential Energy Storage **Power Quality**

Foreword

Aging power grids and an increasing frequency of extreme weather in North America are causing increasingly common household power outages, leading more homeowners to choose residential energy management and storage systems as backup power sources to ensure normal daily life. However, power outages are just the tip of the iceberg when it comes to household electricity crises. A hidden but equally critical threat—off-grid power quality issues—is often overlooked by households. Off-grid power quality is crucial for maintaining essential activities such as everyday home functions and remote work. A key issue is that quality varies widely among available products in the market, with many systems suffering from unstable output during critical moments or experiencing frequent collapse, which only adds to consumer anxiety about electricity supply.

This white paper examines residential off-grid situations from a power quality perspective. It is intended to provide practical solutions and actionable recommendations that serve as both a theoretical framework and reference for real-world implementation.

The Popularization of Residential Energy Storage Presents New Challenges to Off-Grid Power Quality Technology

In most people's impression, off-grid power quality has been perceived as relevant only to "premium applications" such as manufacturing facilities, healthcare institutions, and data centers, which are seemingly far away from everyday residential settings. However, the reality is that it impacts far more. As household electrification continues to advance, more critical devices depend on stable electrical supply. When power quality suffers, everything from smart home systems and routers to electric vehicle (EV) charging stations is affected, with immediate consequences for both life quality and electrical safety.

Off-Grid Power Quality Issues Cause Significant Disruption to Users

Based on field research and user feedback, it is shown that off-grid energy storage systems encounter significant power quality issues during actual operation, which creates multiple issues for homeowners:

- Residential energy systems frequently trigger overload protection when air conditioners or water heaters are started.
- Residential energy systems shut down unexpectedly when coffee makers, hair dryers, pool pumps, or smart toilets are operating, resulting in whole-home power outages.

- Residential energy systems can't be easily scaled up to support the full energy needs of an entire home.
- Smart home gateways frequently disconnect, causing devices to go offline.
- Lights flicker during home office work.
- Security equipment malfunction without apparent cause.
- Most OEMs do not provide or support a warranty for off-grid installations.

What appear to be separate problems actually stem from one fundamental issue: poor power quality in off-grid systems. It not only affects home electrical safety, but also reduces the operational efficiency of electrical appliances and even shortens their service life.

Common Issues with Off-Grid Power Quality

Off-grid power quality issues mainly manifest in two aspects:

- Unstable power output: When high-power appliances are in operation, they can distort the sinusoidal waveform of the output voltage, resulting in diminished voltage regulation and frequency stability.

- Poor compatibility with household appliances: Unable to support the startup of some household appliances (such as water heaters, water pumps, air conditioners), and fail to be compatible with everyday small appliances such as coffee makers and hair dryers, frequently resulting in protective shutdowns or malfunctions.

Industry Challenges Due to Standardization Gaps

The absence of industry standards and regulations has led to significant inconsistencies in terms of off-grid power quality and whole-home backup experience. Many residential energy management and storage systems have fundamental technical limitations. Manufacturers often prioritize power output, capacity and cost reduction over power quality while power quality remains the most critical factor for customers. These technical shortcomings substantially compromise the user experience. The resulting "quasi off-grid" performance not only creates potential electrical safety concerns but also fails to deliver the energy independence that consumers expect from these systems.

To address these challenges, FranklinWH looked beyond the residential sector—adopting the rigorous power quality standards of data center UPS systems.

"Gold Standard" in Data Center Establishes a Critical Benchmark for the Residential Energy Storage Industry

Under this trend, driving off-grid power quality technology toward data center-level power supply standards has become a new frontier in modern residential energy storage development.

IEC 62040, a globally recognized standard, establishes rigorous performance requirements for Uninterruptible Power Systems (UPS), particularly for critical power applications such as those for data centers. The standard explicitly mandates that UPS systems deliver exceptional power quality and versatile load compatibility. By quantifying essential UPS performance parameters, IEC 62040 aims to ensure zero-interruption and disturbance-free power supply to data centers, underpinning the high reliability demands of global digital infrastructure.

High-Standard, Comprehensive Power Quality Requirements

IEC 62040-3 primarily specifies requirements for UPS output voltage accuracy, frequency precision, harmonics, and other key parameters.

Off-grid parameters	Value
THDu	<1%
Voltage Regulation Accuracy	±1%
Frequency Accuracy	±0.5Hz
Load Imbalance Rate	100%
Dynamic Voltage Range	Maintains stable output between 192V and 264V

Table 1: IEC 62040-3 Off-Grid Power Quality Specifications

Core Requirements for Load Adaptability: Load Compatibility and Dynamic Curve Compliance

IEC62040-3 stipulates fundamental requirements for load capacity: UPS systems must adapt to various load types throughout their operational cycle—startup, operation, and shutdown—without causing damage to connected equipment during fault conditions. Safety must be maintained under all circumstances. The critical evaluation metric in this context is adherence to tertiary dynamic curve specifications during load startup and shutdown phases. The curve requires that UPS voltage fluctuations do not exceed the specified range during transient load changes (see Figure 1).

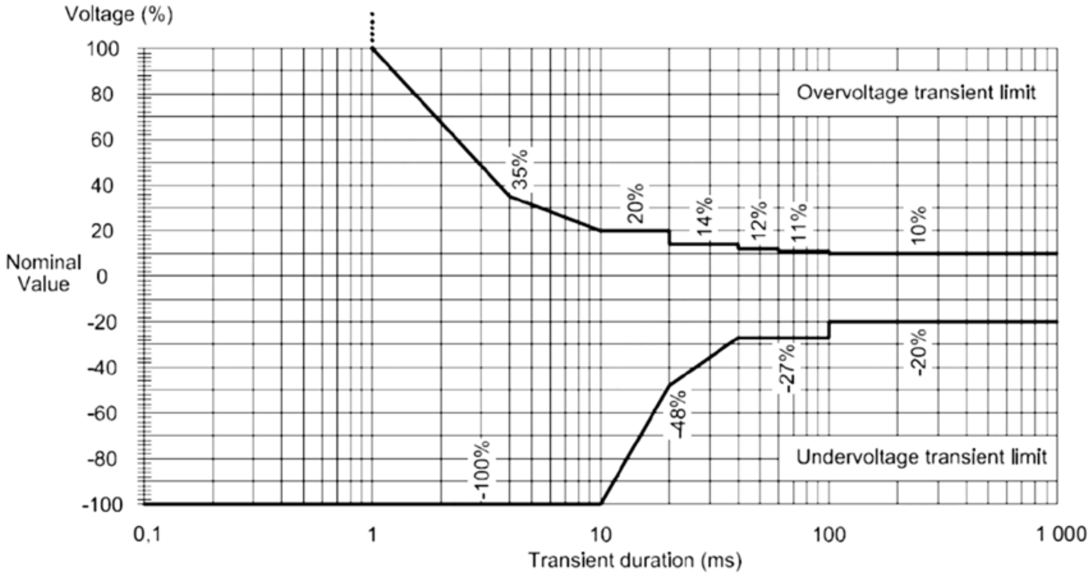

Figure 1: UPS Class III Dynamic Output Performance Specifications

These two major characteristics establish the "Gold Standard" for UPS systems in data centers. Simultaneously, their stringent requirements for power quality and multi-load adaptability provide important reference and insights for residential energy storage systems in off-grid scenarios.

FranklinWH Off-Grid Power Quality Technology Solution

Overview of Off-Grid Power Quality Technology Solution

Based on the principle of "Green Electricity and Energy Freedom," FranklinWH has drawn upon its extensive expertise in UPS sectors for data centers to innovatively adapt 100% uptime assurance technology for residential energy storage. This solution maintains the same design standards, manufacturing processes, and verification systems used in data centers, providing households with equally reliable off-grid power.

FranklinWH's off-grid power quality technology represents a comprehensive solution that integrates quality algorithms, superior startup capabilities, complete load compatibility, and an efficient parallel control architecture. Equipped with this technology, energy systems operate reliably and stably even in complex environments with diverse load combinations. This solution not only provides power output but also guarantees power quality through real-time monitoring and compensation. By adhering to design principles used for high-performance UPS systems, FranklinWH helps establish a stable and reliable power experience for customers.

Quality Algorithms, Superior Power Output

When non-linear loads operate in residential settings, harmonic current distortion can easily lead to output voltage distortion in AC power sources, affecting power quality and potentially causing equipment malfunctions and reduced efficiency, and other issues. This solution employs a power quality algorithm that incorporates technologies such as high-precision digital filtering, instantaneous power control, predictive control, and dynamic compensation. It precisely regulates inverter output to ensure the continuous delivery of clean power even in complex electrical environments.

Core Technical Advantages

- **High-Precision Harmonic Detection:** High-resolution sampling and multi-channel signal monitoring precisely identify harmonic components as low as 0.1%. This provides accurate input for our control strategies, ensuring efficient and stable response from compensation algorithms.

- **Integration of Predictive and Dynamic Control:** Integrates predictive control models and dynamic load tracking mechanisms that anticipate changes of loads in advance, enabling proactive adjustments to inverter strategies to significantly reduce voltage fluctuations and frequency deviations.

- **Real-Time Dynamic Compensation:** Calculates and outputs compensation commands in real-time during each control cycle, adaptively reducing 2~40 characteristic harmonics, maintaining pure voltage waveforms and ensuring stable performance of critical loads under dynamic operating conditions.

FranklinWH has verified the technology through multiple working conditions. In extreme scenarios, such as transient load increases, it can keep the Total Harmonic Distortion in Voltage (THDu) at less than 1% (for resistive loads) and at less than 5% (for non-linear loads), improving harmonic suppression capability by more than 40% compared to conventional solutions.

Off-grid parameters	FranklinWH Solution	Conventional Solution
THDu	<1% (@resistive loads)	<3%
	<5% (@non-linear loads)	<10%

Table 2: THDu Performance Comparison

Predictive Control Technology: Enhancing Instantaneous Start-up Capability

When high-power loads start instantaneously, traditional energy storage systems often face issues such as voltage sags and waveform distortion, which directly affects the normal operation of other household appliances. This solution uses predictive load control with millisecond-level load identification and dynamic energy pre-allocation mechanisms to ensure zero impact on other electrical loads during shock load start-up.

Core Technical Advantages

- **Zero-Perception Start-up:** Employs patented pre-charging control strategies that constrain voltage fluctuations to within ±8% when high-power loads such as air conditioners and water pumps start up, ensuring no disruption to other devices.
- **Intelligent Power Buffering:** The innovative input-output dynamic tracking architecture provides up to five times peak current support instantaneously, avoiding the insufficient load capacity problems caused by response delays in traditional systems.

Extensive testing in off-grid residential environments confirms this technology’s reliability, maintaining stable output voltage even under **250% rated load with 1 second** response, completely complying with the third characteristic curve requirements of IEC62040-3. The performance substantially exceeds industry standards, providing users with truly seamless power delivery.

Off-grid parameters	FranklinWH Solution (aPower 2)		Conventional Solution
Peak output power	15 kW @ 10 s	Voltage fluctuation < 1%	Voltage fluctuation < 5%
Transient load capacity	25 kW @ 1 s	Voltage fluctuation < 8%	Voltage fluctuation < 30%
LRA	185 A	Voltage fluctuation < 8%	Voltage fluctuation < 30%

Table 3: Starting Shock Load Performance Comparison

Self-adaptive Load Technology: Universal Compatibility with All Load Types

The FranklinWH System tackles the complexities of diverse load types through an integrated approach combining a real-time algorithm for scanning load characteristics, innovative power electronics architecture and load-adaptive control strategies. This achieves universal compatibility with all types of loads, inductive, capacitive, non-linear, and impact loads, significantly enhancing system robustness and power supply continuity.

Core Technical Advantages

- **Automatic Load Characteristic Scanning:** Using real-time load characteristic scanning algorithms, the adaptive range of power factor is extended to -1 to +1. The system dynamically detects and adapts to all load types—linear, capacitive, inductive, and non-linear—ensuring stable operation. Even under 100% unbalanced load conditions, voltage fluctuation still remains < ±2%.
- **Innovative Power Electronics Architecture:** Our patented buffer design delivers half-wave load handling capacity at twice the level of conventional solutions. When operating with 100% unbalanced half-wave loads, THDu is <5%, far superior to the industry average.

This solution not only significantly improves system compatibility with various household appliances but also provides more stable and reliable energy support for complex residential electricity usage scenarios such as simultaneous operation of multiple appliances and high instantaneous load impacts.

Off-grid parameters	FranklinWH Solution	Conventional Solution
Load adaptability	THDu <5% (half-wave load 5 kW)	THDu <10% (half-wave load 1.5 kW)
Load imbalance ratio	100%	<50%

Table 4 Half-wave Load Performance Comparison

Efficient Parallel Control Architecture: Enhanced Load Capacity with Preserved Power Quality

To establish highly reliable parallel operation of multiple modules, a dual high-speed isolated CAN bus architecture is used. Combined with distributed digital current-sharing algorithms and active voltage regulation mechanisms, this achieves real-time power coordination and self-balancing output at the module level, significantly enhancing the system's load expansion capability and output consistency.

Core Technical Advantages

- **Fault-Tolerant Dual CAN Communications:** Engineered with a primary/backup dual-channel redundant design, where the primary channel is responsible for broadcasting of power status and module coordination, while the backup channel is used for takeover of abnormal communications and real-time synchronization. The design significantly enhances system stability, and ensures uninterrupted power supply to critical household loads.

- **Self-adaptive Current-sharing Mechanism:** Leverage an inter-module current sharing mechanism that integrates average current tracking with dynamic voltage self-adjustment strategies to achieve intelligent load distribution across multiple modules. The current deviation is maintained within ±3%. A single intelligent controller can support parallel connection of up to 15 BESS modules, accommodating the scalable capacity requirements of residential energy management and storage applications across diverse scenarios. While load capacity increases proportionally, voltage deviation is maintained within ±1%, with voltage total harmonic distortion (THDu) below 5% under non-linear load conditions without compromising power quality regardless of capacity expansion.

This architecture offers homeowners flexible scalability and robust load adaptability, meeting various power needs from everyday usage to high-demand applications.

Value of the Technical Solution

FranklinWH's off-grid power quality solution is based on a flexible and expandable multi-module parallel architecture, allowing for capacity expansion, plug-and-play convenience, and self-adaptive current-sharing mechanism. This ensures pure power output even in scenarios with multiple load combinations, high-power impacts, and non-linear loads.

The FranklinWH System safeguards the operation of your various household devices and creates a truly reliable and anxiety-free off-grid power experience you can count on.

Application Cases

Off-grid energy storage solutions are transforming how we live and work. The following two representative cases showcase how FranklinWH's off-grid power quality technology addresses real-world challenges.

Case 1: Green Transformation at an Island Youth Camp

A non-profit youth camp situated on an island in eastern North America had long grappled with the limitations of diesel generators—high noise levels, inefficiencies, substantial costs, and contradiction against the environmental principles advocated by the camp. After implementing the FranklinWH off-grid system, the camp has achieved:

- **High Compatibility and Synergy:** The solution supports battery operation alongside high-harmonic diesel generators and solar panels, overcoming the power quality sensitivities that typically restrict conventional energy management and storage systems. This integration greatly improves power reliability in challenging off-grid environments.

- **Reduced Noise Pollution:** When solar isn't producing sufficient energy, the diesel generator consistently operates within its optimal efficiency range to charge batteries. Combined with a battery power supply strategy, this achieves near-zero noise operation, ensuring daytime classes, office work, or outdoor activities proceed without disturbance.

- **Increased Green Energy Usage:** The solution prioritizes solar power generation while supplementing with generator capacity when needed. This can significantly increase renewable energy usage rates and reduces the camp's carbon footprint.

Figure 2: FranklinWH System at Off-grid Youth Camp in North Carolina

Case 2: Energy Independence Revolution at a North American Ranch

A 500-acre ranch located in central California, situated beyond the reach of power grid infrastructure, had historically relied on diesel generators for its basic electricity needs. FranklinWH implemented a customized off-grid system (a 22 kW photovoltaic array + 70 kWh energy storage). It achieves:

- **Comprehensive Protection for Critical Equipment:** The system ensures reliable 24/7 operation of essential loads including electric fencing, lighting, HVAC equipment, water pumps, feeding systems, milking machines, and refrigeration units.

- **Year-Round Energy Self-Sufficiency:** Even during the winter and rainy seasons, the energy storage capacity can support critical loads for more than seven consecutive days.

- **Intelligent Load Prioritization:** Algorithm-driven prioritization guarantees power supply during crucial milking periods while automatically reducing non-essential loads.

Figure 3: FranklinWH System at Off-grid Farm in California

Conclusion and Outlook

The residential energy management and storage industry currently faces significant challenges in off-grid storage scenarios due to the absence of standards and insufficient verification mechanisms. The absence of a unified evaluation system and clearly-defined performance parameters has resulted in inconsistent product quality across the market, making it hard for consumers to make decisions based on reliable metrics. More significantly, this standardization gap has evolved into a systemic issue that impacts the reliability, safety, and user experience of household off-grid storage systems.

In response to the industry challenge, FranklinWH has taken a pioneering approach by adopting data center power quality standards as a benchmark—systematically improving the power quality of residential storage products in off-grid environments. We aim to provide the industry with a quantifiable and verifiable reference model that not only addresses critical technological gaps in residential off-grid storage sectors but also establishes foundational practices for future off-grid power quality standards development. To accelerate industry-wide improvements, FranklinWH recommends: establishing residential off-grid power quality standards based on IEC 62040; encouraging third-party validation to build consumer trust; and promoting policy incentives for high-performance energy storage products. These measures will promote the widespread adoption of advanced technologies and support sustainable, high-quality industry growth.

Moving forward, FranklinWH remains committed to driving innovation based on high standards and validating performance claims with empirical data.

As the core of home microgrids, the FranklinWH System offers flexible compatibility with multiple energy sources—including diesel generators, EVs, and photovoltaic systems—creating an open and interconnected energy ecosystem. Through intelligent coordination and energy allocation, our solution achieves higher levels of electricity self-sufficiency and system resilience, comprehensively enhancing the quality of life and power usage experience for modern households.

www.franklinwh.com info@franklinwh.com +1 888-851-3188
1731 Technology Dr., Suite 530, San Jose, CA 95110