PV Integrated Storage, Connect to Future

SOFAR PowerAll

White Paper
on Intelligent Residential Energy Storage System

2022

Contents

1.

Overview of Residential Energy Storage

The impact of global climate change is posing a major challenge to the survival and development of human race. Carbon neutrality has become a worldwide consensus. More than 130 countries and regions in the world have proposed carbon neutrality goals. Meanwhile, the contradiction between the volatility of renewable energy and the stability of power grid has become increasingly prominent. Based on advanced energy storage technology and utilizing of digital and smart power grid, the top-level designed integration of source, network, power load and storage is able to build a new type of power system which is safe, clean, consolidated and smart and to solve the matching problem of power supply and consumption.

Energy storage has become a key to future energy security and will be the "ballast stone" and "stabilizer" for mankind entering era of carbon neutrality.

In the residential field, energy storage system (ESS) plays an important role in peak shaving and reducing customer's electricity expenditure. There are three main business modes here: for better power generation of PV system, peak-bottom price arbitrage, and isolated off-grid systems.

With introduction of incentive policies for energy storage system in many countries, the market of overseas residential energy storage system continues to rise in pursuit of more self-consumption and better economy. The future with combination of residential solar PV and energy storage is coming. There will be a booming market for energy storage system.

While as a systematic solution, the complexity of the residential energy storage system requires not only the advanced technology and engineering of major components like storage battery and inverter, but also the safety, reliability and cost economy of battery cell, packing technology and etc. Isolated device designing and lacking systematic coordination requires expertise of project integrator / installer which usually not available and, eventually hinders the development of residential energy storage system.

For this reason, Shenzhen SofarSolar Co., Ltd. （hereinafter referred to as SofarSolar）, a leading manufacturer of solar PV inverter and energy storage system, and several professional institutes jointly launched the "2022 White Paper on Intelligent Residential Energy Storage Systems" for the world. With this "One-Stop" residential energy storage system solution, ESS can realize high compatibility with all components, high safety and efficiency of the system and easy installation.

Application of Residential Energy Storage

2.

Presently, there are three main application scenarios of residential energy storage system: better power generation with integration of solar PV and storage; peak-bottom price arbitrage; off-grid standby system for power supply to areas without or with unstable power. As well known by everyone, many countries have issued incentive policies to promote the development of solar PV industry. The grid parity of solar PV realized in most countries of the world due to continuous cost drop in past years encouraged end users to increase self-consumption of their PV generation and reduce energy expenditure with utilization of energy storage. In countries and regions with high electricity prices such as Europe, Japan, Australia, and the United States, one of the main economic drivers for application of residential PV + energy storage is to increase self-consumption of power generated by the solar PV system and to delay and reduce the risk of rising electricity prices.

Along with continuous increasing installation of renewable energy and fast changing of power consumptions, power grid has presented characters of "double peaks" in winter and summer of power load, and significant fluctuations in both directions of power generation and consumption. Some countries and regions have implemented a time-of-use electricity pricing mechanism and believe the energy storage is critical for ensuring of power safety and helping to achieve targets of carbon peaking and carbon neutrality. On the other hand, user of solar PV has to sell power in a low price in day time and purchase in a high price at night in peak time, and cannot optimize the system economy. However, user with energy storage system can time-shift the energy, to store the energy to battery in bottom price period, and to release the energy at night of peak price. This peak-bottom piece arbitrage will optimize the system economy and realize power peak shaving.

Nearly 1.1 billion population around the world are still without access to electricity, and another 1 billion are using unreliable and unstable power grids which are severely hindering the development of productivity in these regions, limiting income-generating opportunities, and impeding the improvement of people's living conditions. Residential energy storage system is widely used in areas without grid connection or with unstable grid connection such as underdeveloped countries and regions which has no electricity, islands, pastoral areas, etc. As an independent renewable energy power supply system, it can provide standby power for key loads when power fails and ensure electricity supply of people's basic production and living requirements.

3.

Difficulty and Challenge of Residential Energy Storage

3.1
Complicated System Installation

The residential energy storage system has complicated architecture and involves multiple equipment including battery, inverter etc. Lacking systematic consideration and design, current industrial device isolates from each other and are often connected by user as a system and causes various problems in applications, mainly including complicated system installation, difficulty of operation and maintenance, inefficiency and low protection of battery pack. Currently there are two major solutions of residential energy storage system (RESS) in the market:

1.Low-voltage RESS (Inverter separated from battery)

Multiple batteries in parallel with voltage ranges 40 to 60 V is connected to inverter. Passing through the internal DC/DC unit, the current couples with DC input from MPPT of PV panel at the bus and eventually is converted into AC for grid. Some inverters are capable with backup output.

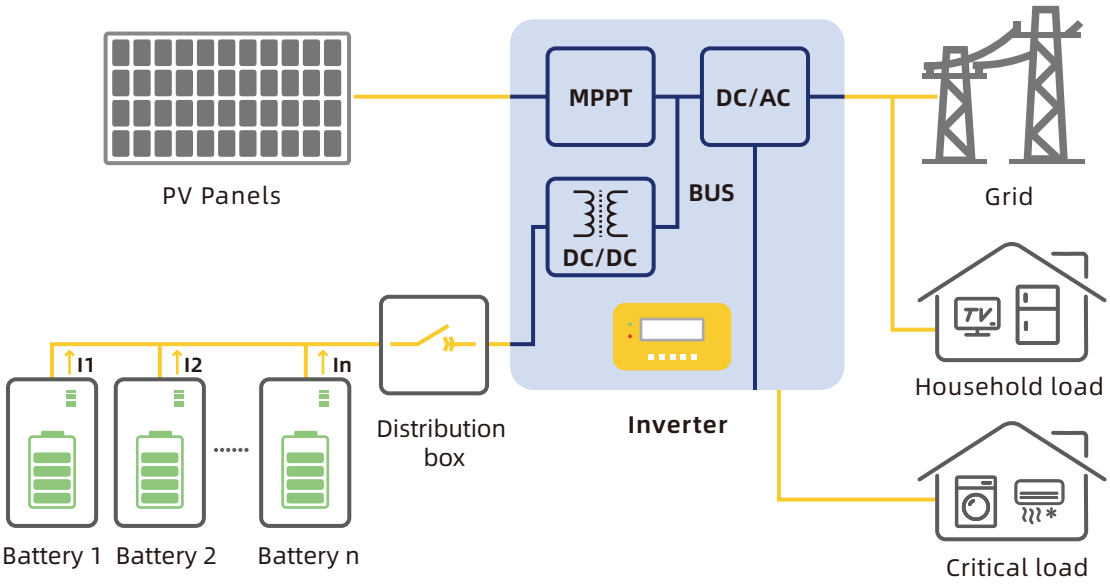


Chart #1 Low-voltage RESS

Problems of Low-voltage RESS:

①Inverters and batteries are installed separately. heavy equipment, difficult to install;

②The cables between the inverter and the battery are not standardized, which requires on-site processing;

As a result, the installation of the entire system takes a long time and increases the cost.

2.High-voltage RESS:

Battery cluster utilizes two-level structure. Multiple batteries in series with output voltage ranges 85 to 600 V is managed by a high-voltage control box and connected to inverter. Passing through the internal DC/DC unit, the current couples with DC input from MPPT of PV panel at the bus and eventually is converted into AC for grid. Some inverters are capable with backup output.

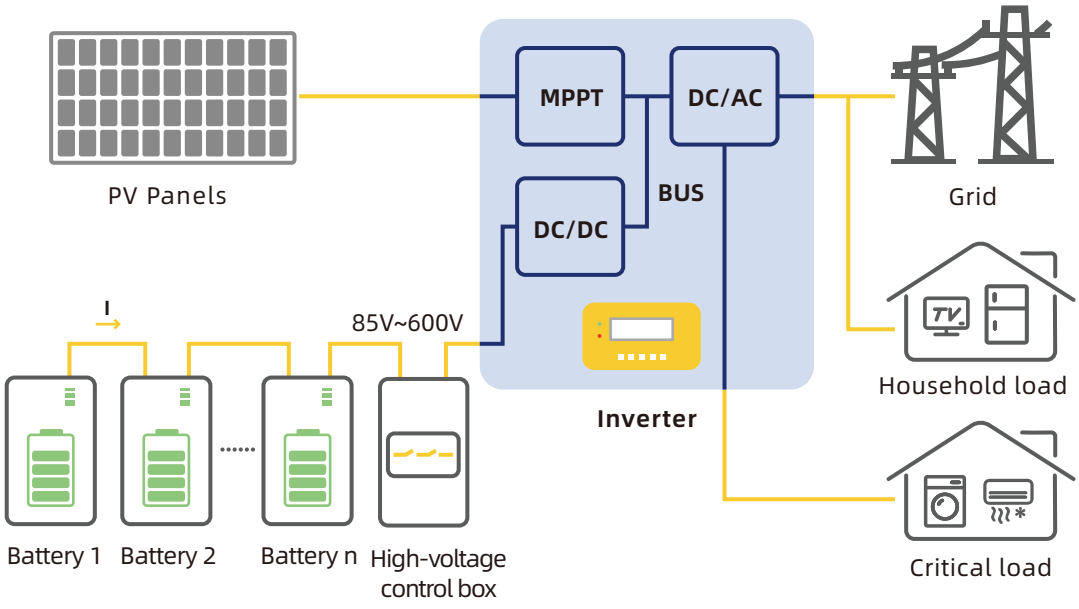


Chart #2 High-voltage RESS

Problems of Low-voltage RESS:

In order to avoid the series connection of battery packs in different batches, strict batch management needs to be applied to all links of production, shipment, warehouse management and installation. The process requires extensive manpower, resources and brings trouble for customer's stock with very complicated procedure. In addition, the self-consumption and capacity attenuation of battery will enlarge the difference between battery packs thus improve possibility of manual

power supplement during the preliminary check before installation, which is usually time consuming and laborious.

3.2 Mismatch of Battery Capacity

1. Parallel mismatch of Low-voltage RESS

Generally, a traditional residential low-voltage energy storage system has a voltage range from 40 to 60 V and expand its capacity with parallel connections of multiple battery packs. Because of the inconsistency of battery cell, pack and cables, the charging / discharging current of battery with high internal resistance is small, and the charging / discharging current of battery with low internal resistance is large. Some batteries in the system cannot get fully charged / discharged for a long time and result in capacity loss of the battery system.

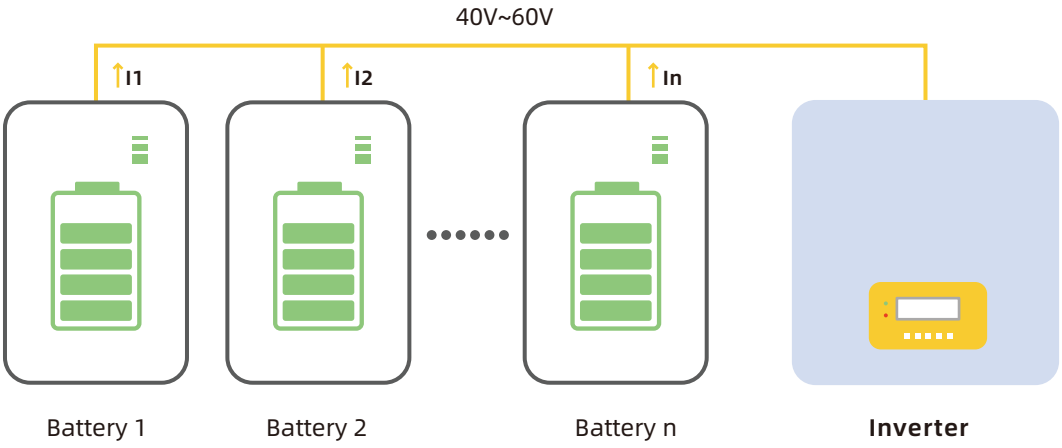


Chart #3 Parallel mismatch of Low-voltage RESS

2. Series mismatch of High-voltage RESS

A traditional residential high-voltage energy storage system has a voltage range from 85 to 600 V and expand its capacity with series connections of multiple battery packs. The series connections align charging and discharging current of each battery pack. But because of capacity inconsistency of battery pack, packs with small capacities finish charging / discharging quicker than

others, and some battery packs cannot get fully charged / discharged for a long time, and some capacity of battery clusters will lose.

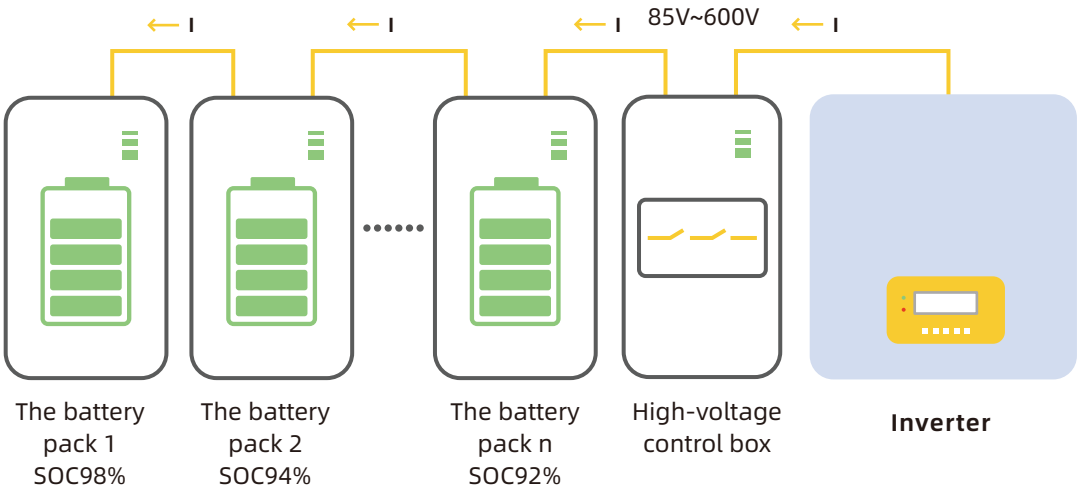


Chart #4 Series mismatch of High-voltage RESS

3.3

Difficulty of operation and maintenance

Good operation and maintenance are one of the effective measures to ensure the reliability and safety of daily operation of residential energy storage system (RESS). However, because of the high requirements for the capability of operation and maintenance personnel due to complicated structure of RESS, time consuming and laborious issue occurred often in actual operation and maintenance and focused on the following two points:

- Regular maintenance, SOC calibration, capacity calibration or main circuit inspection which shall be carried out for the battery pack.
- When the battery pack is abnormal, the conventional lithium battery does not have the automatic equalization function. Maintenance personnel is required to go to site to make the power supplement manually, which is unable to respond to needs of customers quickly.

3.4
Mixed use of new / old battery

For Low-voltage RESS, because of the big difference of internal resistance of batteries, the mixed parallel connection of new and old battery will result in internal circulation and battery temperature increase which will accelerate the aging of batteries. For High-voltage RESS, when in mixed series connection of new and old battery, due to the barrel effect, the new battery pack can only be used with the capacity level of the old battery pack and causes severe capacity mismatch in the battery cluster. For example, the usable capacity of the new pack is 100 Ah and that of the old one is 90 Ah. If they are mixed, the usable capacity of the battery cluster is only 90 Ah. To sum up, it is generally not recommended to mixed use new and old lithium batteries directly in series or parallel.

4.

Intelligent Residential Energy Storage System

4.1

Introduction of the Intelligent Residential Energy Storage System

For years, SofarSolar has deeply engaged in core power electronic technology and focused on key technology innovation and product development in areas of solar PV and storage. With continuous development of storage battery products, self-developed battery management system (BMS), smart lithium battery, remote monitoring and hybrid energy storage system, SofarSolar provides customers with reliable, safe and efficient all-in-one solutions of residential energy storage system.

In view of the problems existed in the industry, SofarSolar innovatively integrated the energy storage battery and power electronics technology and launched solution of intelligent residential energy storage system. Several key technologies such as independent balance management between battery packs, modularization and integrated design are adopted to enhance the balance ability between energy storage battery packs, improve the available capacity of the system and increase the battery cycle life. In the meantime, optimization is carried out in installation, operation and maintenance to improve the reliability and flexibility of the system.

The smart lithium battery is composed of low-voltage battery pack, Battery Management Unit (BMU), and Power Control Unit (PCU). Through the PCU, it can independently adjust the output voltage and current, and automatically balance the capacities between battery packs according to the battery SOC.
In the parallel system of multiple packs of smart lithium batteries, if one battery pack fails, that pack can be isolated automatically without affecting the normal operation of other batteries on the same bus.

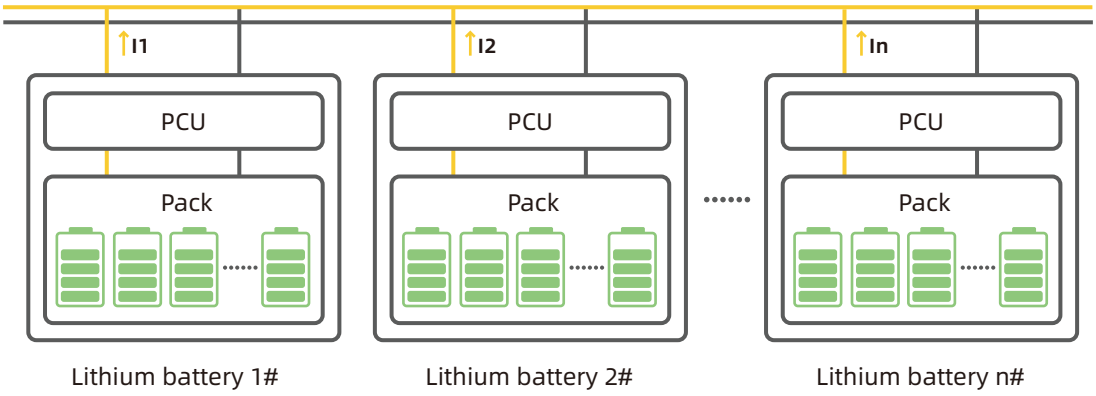


Chart #5 smart lithium battery pack

The smart lithium battery pack has the function of capacity calibration for each pack. The system can set the calibration strategy remotely against real conditions. One battery pack can complete a single charge and discharge so as to realize the accurate calibration of its capacity, while other batteries on the same bus do not charge or discharge and are in an "emergency" state at any time, to prevent sudden power failure in the process and ensure the reliability of the system.

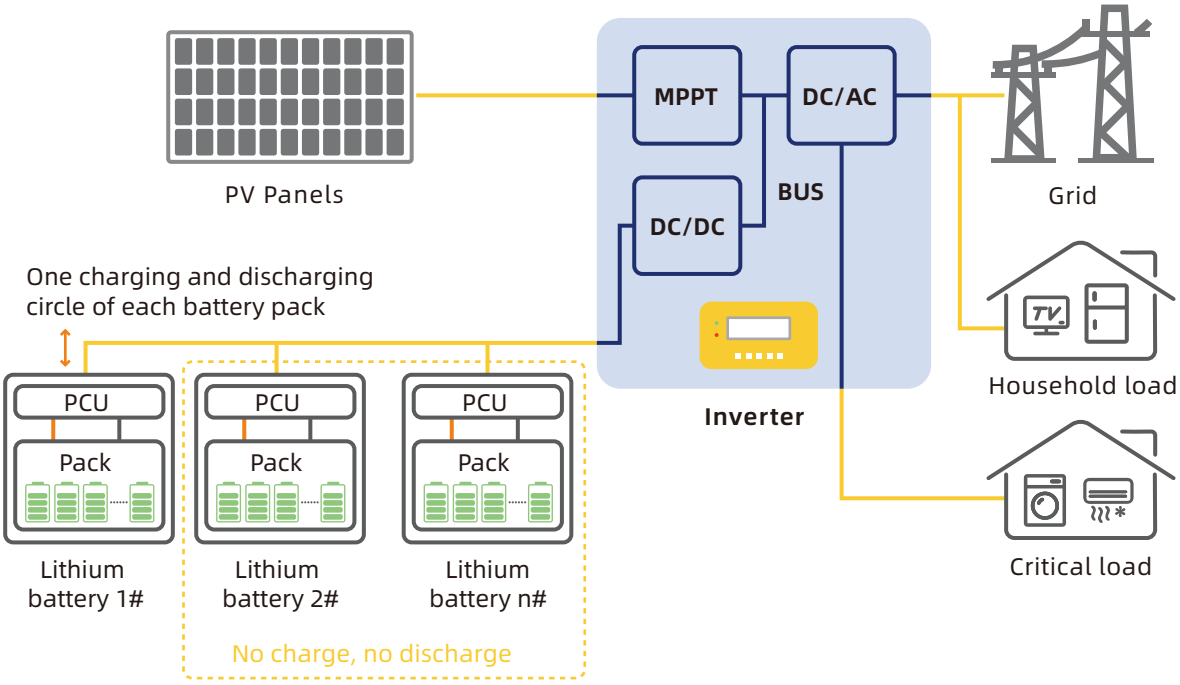


Chart #6 capacity calibration of single pack of smart lithium battery

The solution of intelligent residential energy storage system adopts full modular design and can be stacked in in any combination. With deep integration with lithium battery and inverter, the system can monitor the real-time status of PV panel, lithium battery, grid power and load, and automatically control the power flow direction with a smart energy management strategy to achieve the optimization of system power distribution. Meanwhile, the system can quickly switch between system battery charging and discharging demands and shorten the response time to be less than 100ms.

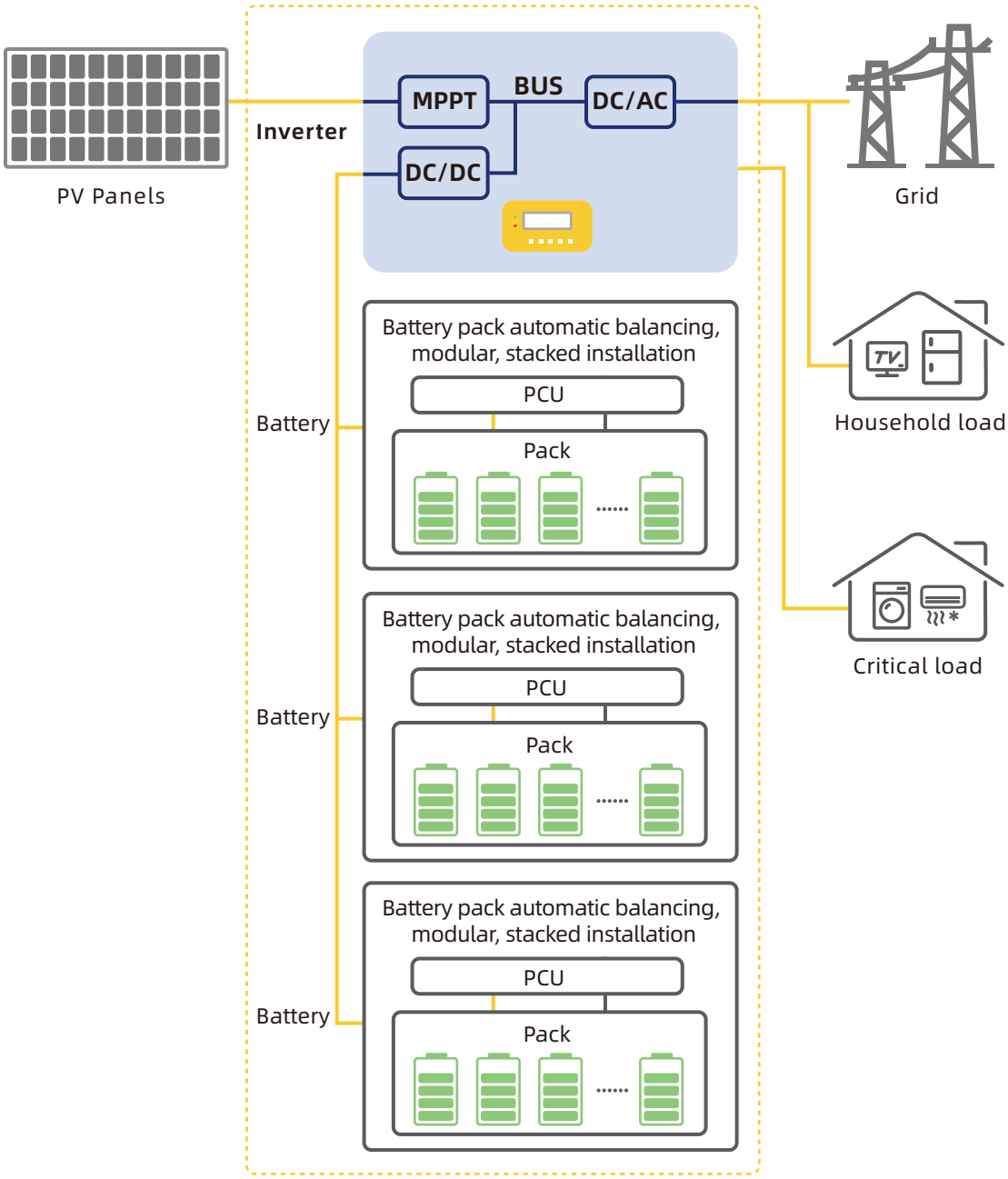


Chart #7 Intelligent Residential Energy Storage System

4.2
Value of Intelligent Residential Energy Storage System

4.2.1Intelligence: lithium battery equips with build-in PCU to improve battery pack capacity mismatch

Because of the differences in internal resistance of battery cells, the unbalanced current between parallel battery packs leads to capacity mismatch after long-term actual use. Intelligent residential energy storage system equips with build-in PCU which will adjust voltage / current of the smart lithium battery according to SOC to ensure batteries on the same bus are simultaneously charged / discharged. This ameliorates the capacity mismatch between battery packs and takes full use of the system capacity.

4.2.2 Full modular design makes transportation and installation easier

The full modular and thin lighter design of the intelligent RESS makes transportation and handling easier with no special tools required. User doesn't need to reserve installation space for future capacity expansion because new module can be stacked and installed directly on the existed ones with flexible configuration. Utilizing with standardized accessories and quick plug connectors, it is no need to make wires on site but with only simple wiring and fixing. The entire installation of the system (inverter and three battery packs) can be completed by two people in 30 minutes.

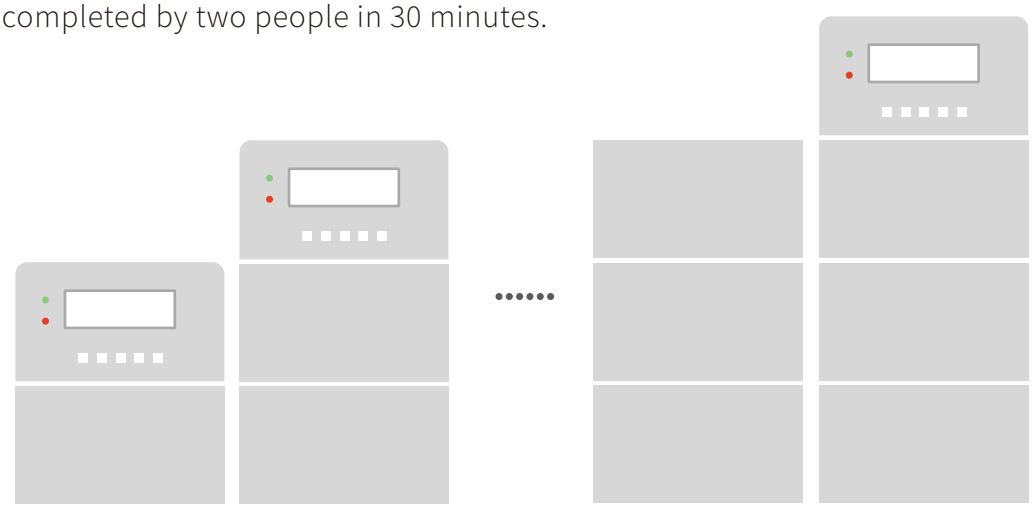


Chart #8 Full modular of intelligent RESS

4.2.3 Direct replacement of battery pack minimizes operation and maintenance

The output voltage / current of the intelligent RESS is controlled independently. Under normal operation, automatic balance and remote cell capacity inspection can be realized between battery packs without on-site maintenance. Meanwhile, the system can realize real-time monitoring and remote system upgrade online which significantly reduces the system's operation and maintenance cost.

The intelligent residential energy storage system supports mixed use of new and old batteries. When abnormal condition occurs to any battery pack, it will automatically exit the operation and can be hot replaced directly with a new battery pack to realize plug and play and quickly responds upon customer's need.

4.2.4 Support phased expansion for better return of investment

The intelligent residential energy storage system equipped with build-in PCU provides automatic balance between battery packs and supports mixed use of new and old batteries. Users can flexibly configure and choose phased expansion of capacity which to deploy with partial capacity in initial stage and texpansion as needed to reduce initial investment cost. In addition, the phased capacity expansion can also allow user to ignore over-provisioning in initial stage and add new battery to expand capacity at any time when installed capacity is short of demand, thus to reduce initial investment cost and optimize customer's investment return.

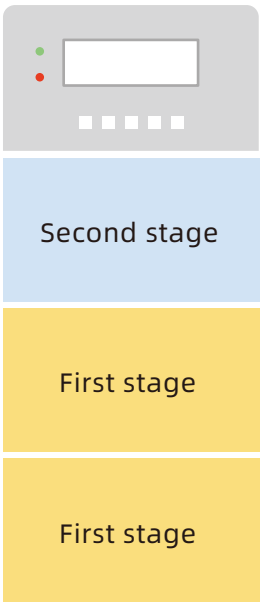


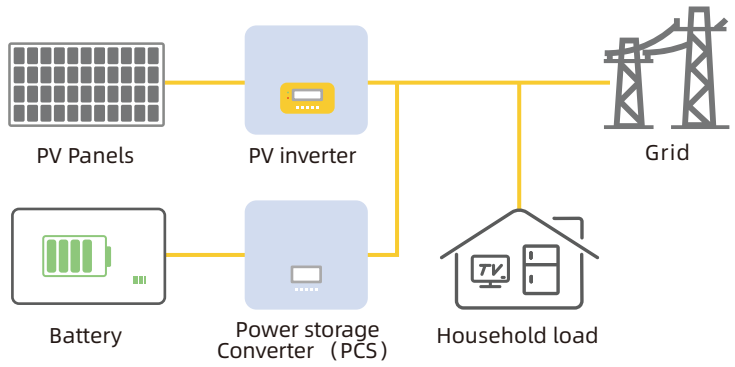
Chart #9 Intelligent RESS expanded by stages

4.2.5 All Scenario Solution: Solar PV, Energy Storage, Off-Grid Integration Design

The intelligent residential energy storage system is designed with concept of "All in one". The system highly integrated with lithium energy storage batteries

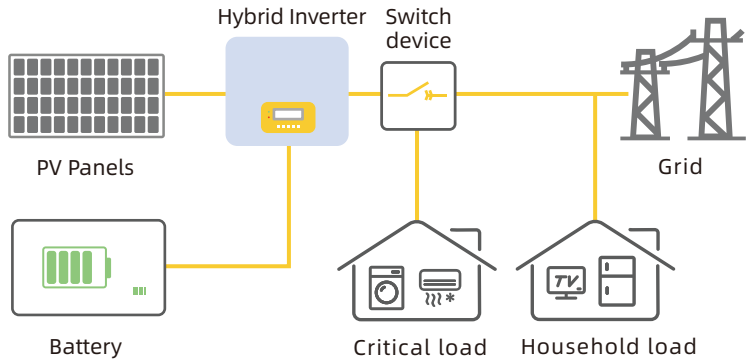
System 1:

Using AC coupling, the system includes photo-voltaic inverters, batteries, power storage converters and other equipment.



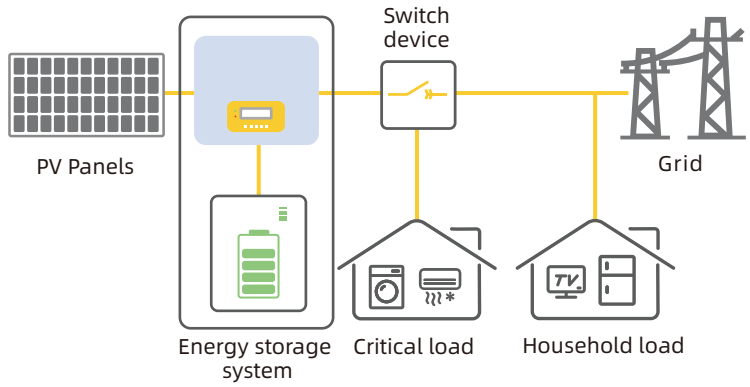
System 2:

The system includes photovoltaic inverters, batteries, energy storage converters and other equipment, which takes longer time for critical load switch.



System 3:

The system highly integrated with lithium energy storage batteries and inverter, which makes the equipment heavy and bulky, inconvenient to transport and install, and requires external switching device, and takes longer for critical load switch.



and inverter Photovoltaic and lithium energy storage batteries adopt DC coupling mode and makes the energy flow link shorter and system efficiency higher. With EPS output port, inverter can achieve seamless switching without external switch. The system has advantages of fewer devices, less space occupation, flexibility, reliability and all scenarios applicability.

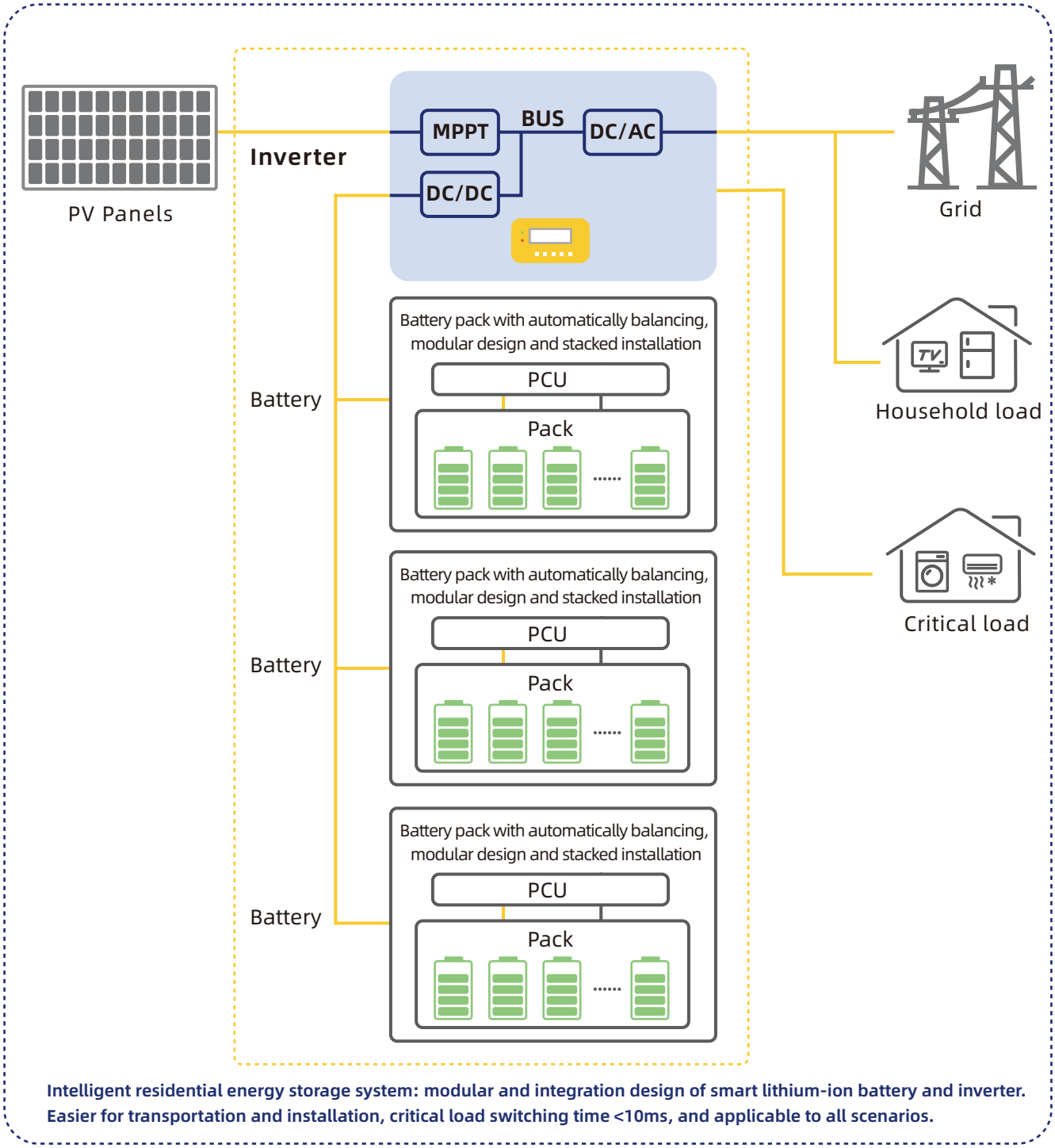


Chart #10 Comparison of intelligent RESS

4.2.6 Safety and reliability: electrical and physical isolation makes personnel and equipment safer

Safety is very special concern by users for residential energy storage system. Adhering to the concept of safety first, SofarSolar has made comprehensive consideration on electrical safety, failure shield and user protection of intelligent residential energy storage system.

The system uses lithium iron phosphate battery which has more stable structure and higher safety based on selected olive crystal structure is selected. A full isolation interface utilized on the pack prevents the battery from being damaged by the electrophoresis impact from power grid. The PCU in vehicle specification level is in an isolated space and physically separated from battery pack. This design would prevent the system from affected by failure of other electrical components such as battery leakage and insulation failure.

When in transportation, installation, operation and maintenance, the battery packs are in a dormant state, the PCU does not work, and the pack's electrical port has a voltage of zero, which effectively guarantee the personal safety of operators.

Flexible Printed Circuit (FPC) technology equipped with fuse in series of each sampling line can effectively avoid potential safety hazard caused by short circuit of sampling line. All-round monitoring in multiple levels including battery cell, battery pack and system, health pre-diagnosis at cell level, and multi-level early warning and protections all contributes the safety and reliability of batteries.

4.3 Comparison of Intelligent RESS with conventional system

	Low-voltage RESS	High-voltage RESS	Intelligent RESS
Energy Utilization	*Low* Parallel mismatch	*Low* Series mismatch	*High* **Automatic balance between battery packs and reduce capacity mismatch**
Safety	*Medium* HIgh frequency isolation, high battery current	*Low* High voltage with output port powered	*High* **High frequency isolation, low battery current, outpot port not powered**
Installation	*Medium* Onsite wiring required	*Complicated* Inspection before installation required, some needs manual power supplement, onsite wire making required	*Simple* **Stand spare parts, plug and play**

	Low-voltage RESS	High-voltage RESS	Intelligent RESS
Operation and Maintenance	*Medium* Requires regular maintenance, line inspections,etc.	*Complicated* Regular calibration, manual power supplement, onsite maintenance	***Simple*** **Automatic balance between battery packs, automatic SOC calibration, online support**
Cycle efficiency	*Low* Large current, long line, high line loss and low efficiency	*High* Less energy change, high efficiency	***Medium*** **Standard wiring, short wiring, low loss, medium efficiency**
Fleixible inventory management	*Medium* Mixed use allowed; performance declined	*Low* Mixed use not allowed; strict batch management	***High*** **Mixed use allowed; Stable performance**
Phased capacity expansion	*Not recommend* Large circulation and low efficiency, fast aging of batteries, Phased capacity expansion not recommended	*Not recommend* New / old battery in series, severe capacity mismatch, Phased capacity expansion not recommended	***Support*** **Phased deployment, reduce initial investment costs, improve investment returns**

5.

Summary and Prospect

Energy is an eternal topic of mankind, and each industrial revolution is accompanied with transformation of energy utilization. A new green power system covering the entire world is under construction with joint promotion of many countries towards to the grand target of carbon neutrality. With support of smart energy storage system, green energy will become more controllable and reliable, and bring better life to more people.

As the development of green power system, green power and energy storage are stepping close to people's daily life. Energy storage system is upgrading to modularized, standardized and smartness due to higher requirements for energy's safety and economy The intelligent residential energy storage system launched by SofarSolar provides residential users with power system which is safer, more convenient and more efficient, and drives the development of a more mature and imaginative market with these values.

ALL IN ONE REPOWER EVERYTHING

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