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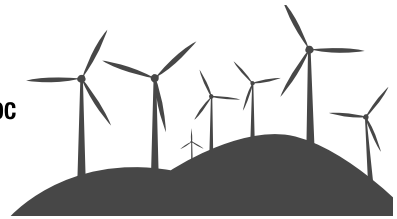
7-10 сентября 2015 года - Куала-Лумпур, Малайзия



# Off-Grid Solar Power System and Mongolia

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**School of Applied Science and Engineering**

# Sustainable Energy for All (SE4All)

Sustainable Energy for All (SE4All) is aimed at catalyzing a transformation in the world's energy systems toward an equitable and sustainable future. Launched in September 2011 by UN Secretary-General Ban Ki-moon, the three objectives of SE4All are to, by 2030:

1. Ensure universal access to modern energy services
2. Double the global rate of improvement in energy efficiency
3. Double the share of renewable energy in the global energy mix

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- Statistics of the PV Systems applications
- Standards for Off-grid PV Systems
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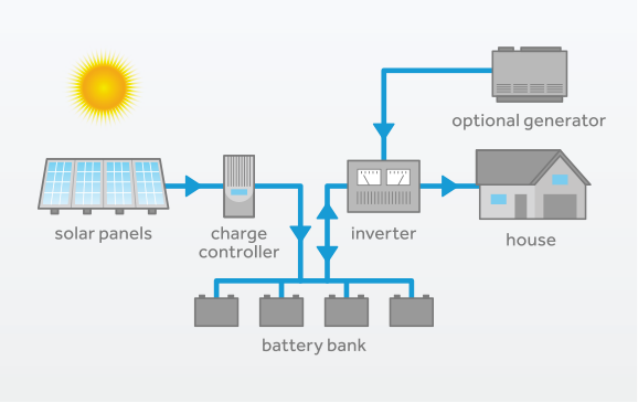
- Why are costs so much higher for off-grid
- Cost reductions Off-grid PV Systems
- Benefits of Solar PV for off-grid solutions
- Barriers for solar PV off-grid (Barriers for developers)
- Sustainability of the off-grid system
- Importance of Energy efficiency for off-grid PV applications
- Trends for off-grid PV System development
- Development of Plug-and-play Off-grid PV System based on Lithium battery technology and Super high efficiency electrical appliances
- Concluding remarks

# Solar PV Systems-Types of Systems

## Stand Alone - Off grid

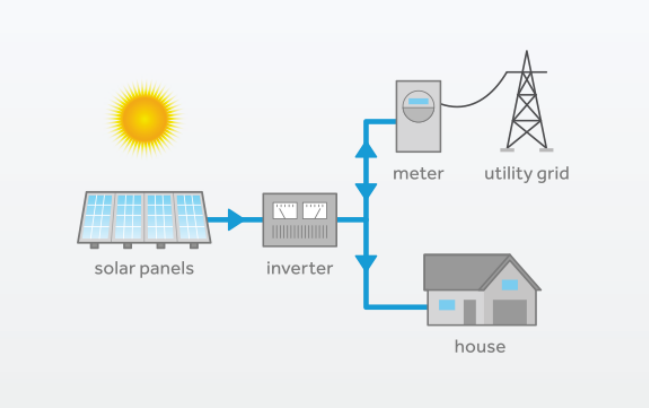
An off-grid energy supply is autonomous and independent of the public grid:

- Non-renewable off-grid systems
- Renewable energy off-grid systems.



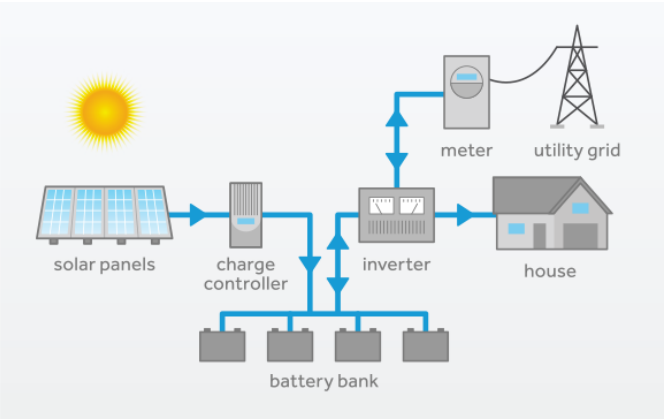

## Grid Tie - Grid connected (On-grid)

PV Modules, and inverter connected to the power grid (utility)



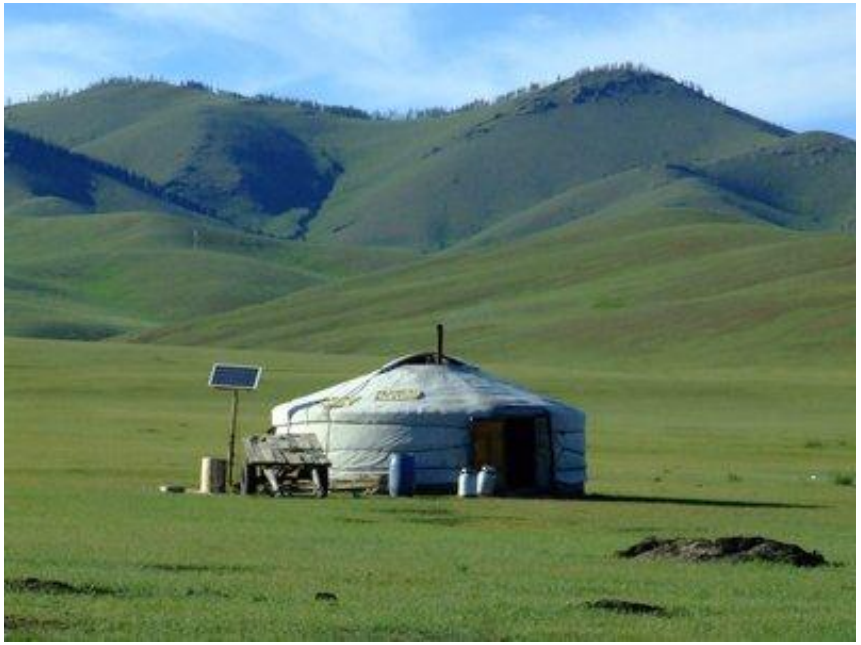

## Hybrid - Grid connected with batteries

PV Modules, grid-tie inverter, and batteries for backup storage when the grid is unavailable. Systems with Battery Backup can supply power 100% of the time: At night, on cloudy days and when the utility power is down



# Types of Solar PV Systems

## Off-Grid



- Battery = Energy Reservoir
- Days of autonomy
- Moderate cycling
- Used in low voltage electricity generation 12/24/48V
- Typically provide DC and AC power to smaller systems

## On-Grid

- Battery = Buffer
- Minutes to hours
- Intensive cycling
- Used in high voltage electricity generation
- Typically provide AC power to grid

# Statistics of the PV Systems applications

Solar home systems (SHSs) have enjoyed sustained growth in many developing countries, with installations now surpassing more than six million:

| | | |
|---|---|---|
| Bangladesh | 2014 (July) | > 3 200 000 |
| India | 2012 (March) | > 861 654 |
| China | 2008 | >400 000 |
| Kenya | 2010 | > 320 000 |
| Indonesia | 2010 | > 264 000 |
| Nepal | 2012 | > 229 000 |
| South Africa | Est. | > 150 000 |
| Sri Lanka | 2011 | > 132 000 |
| Morocco | Est. | > 128 000 |
| Mongolia | 2014 | > 120 000 |
| Zimbabwe | Est. | > 113 000 |
| Mexico | Est. | > 80 000 |
| Tanzania | Est. | > 65 000 |
| **Total** | | **> 6 million** |

In Bangladesh, the government has played an important leadership role in off-grid RE, having deployed more than three million SHSs.

Unfortunately, other Asian nations have yet to replicate this success.

According IFC (2012), total sales in Asia in 2011 reached 2.2-2.4 million, nearly half of which was located in India .

Kenya - Africa's leader in solar home systems with 320 000 units market growth of around 10% per year

Source: Off-grid renewable energy systems: Status and Methodological issues, Working paper, Ruud Kempener, Olivier Lavagne d'Ortigue, Deger Saygin, Jeffrey Skeer, Salvatore Vinci, and Dolf Gielen (IRENA),2015

# Standards for Off-grid PV Systems

The main standards required for Off-grid PV systems are:

- Standards PV Array quality
- Standards for Electronic system quality (Inverter, Controller)
- Standards for Batteries for Off-grid system
- Standards for Wiring performance and Electrical installations
- Standards for Lightning Protection
- Standards for Energy management programs
- Standards for Noise level limits

It is intended to develop standards for Off-grid DC system for CAREC countries!

# Main requirement for Off-grid PV Systems

**Off-grid PV System is used mainly in remote areas, and popular in developing countries. It must be**

1. High quality, reliable, longlife
2. User-friendly, simple to use –Plug in/plug out design
3. Reasonable low cost and affordable for poor users

**Therefore, Off-grid PV System must have quality which governs product safety.**

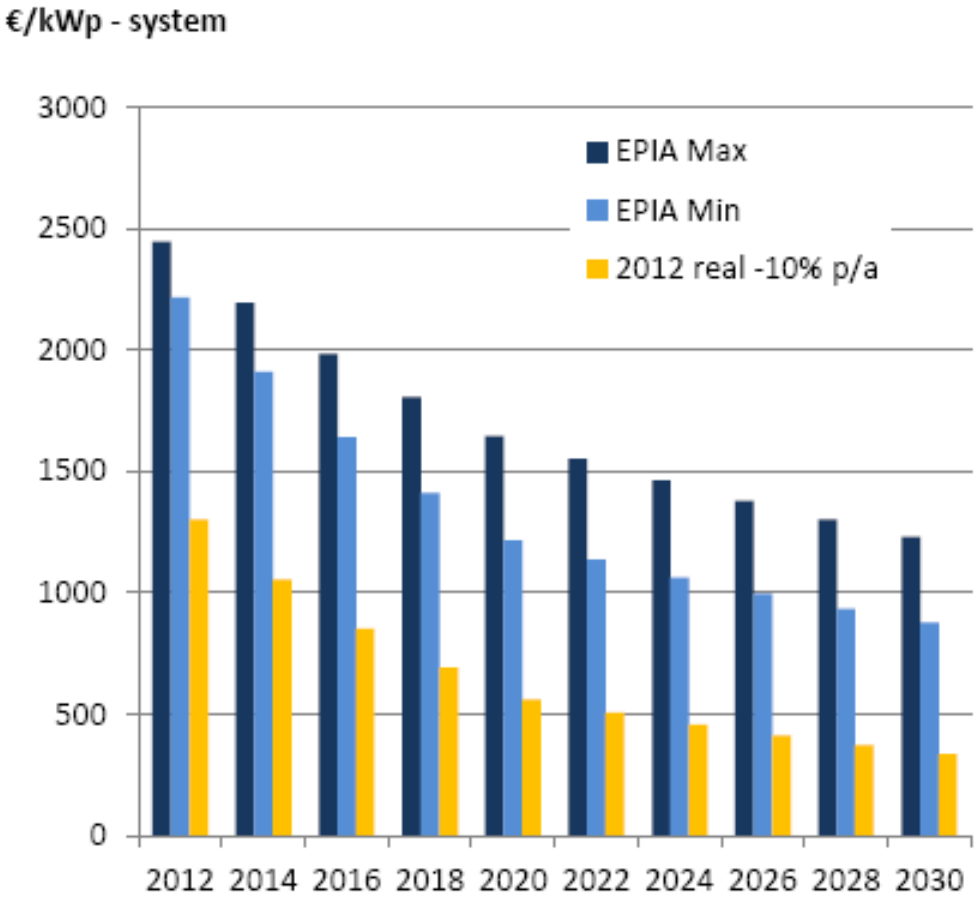
- PV modules must meet international standards such as IEC 61215 for Si PV and IEC 61646 for thin film modules) and the IEC 61730 (or the equivalent UL 1703)
- Inverters must meet international standards and also have to meet the quality standard to allow their interconnection to the grid.
- The majority of the other electronic components, such as charge controls must meet international standards (last ten or more years)
- Batteries typically need replacement every five to ten years.

Need to establish after-sales service, including where the products need to be sent for warranty service, and who pays for shipping & warranty services.

# The reasons of high cost of the off-grid system

- The need for storage of electricity
- Off-grid PV solutions require a battery bank for energy (for evening use and as a back-up for cloudy days). The batteries are usually the largest cost component for off-grid installations, making up typically between 20-30% of total installation cost
- Off-grid market is very mature markets and many pilot projects
- Remote locations makes transportation a large cost component
- Small system sizes and lack of scale leads to higher equipment costs (i.e. not possible to obtain lowest module prices when sourcing small quantities) and higher project management costs, as each system has to be designed individually

# Cost reductions Off-grid PV have by far surpassed even the most optimistic projections




One example:

- EPIA (European Photovoltaic Industry Association) report from 2011*
  - Blue columns represent EPIA`s price projections for two scenarios
  - EPIA Min (light blue) represents EPIA`s most optimistic price projections
  - Yellow columns represent actual system cost for 2012, and projecting a 10% annual price reduction between 2012-2020 (Photon projections), and then a 5% annual price reduction 2020-2030
- Lowest reported system price in Germany in 2012 is 1 100 €/kWp
  - This is equivalent to year 2024 in EPIA`s most optimistic price projections (EPIA Min)

*Sources: EPIA, 2011. Unlocking the Sunbelt Potential of Photovoltaics. Norplan database and analysis*

# Benefits of Solar PV for Off-grid solutions

- Solar energy is abundant and locally available
- Sustainable – clean and renewable with no emissions
- Decentralized – no need for long transmission lines
- Free and predictable energy source – no need to worry about increasing/fluctuating fuel prices
- No moving parts – reliable and easy to operate
- Modular and scalable – easy to add-on more capacity if needed
- Short installation time

**Solar PV is ideal for off-grid solutions and it can make a big change in developing countries !**

# Barriers for off-grid PV applications (Barriers for developers)

**Financial barriers**

- Overcoming the high upfront investment
- Application of off-grid systems are costly and requires public and/or donor money
- The *availability* of funds is in many cases less of a barrier than *accessibility* and *attractiveness* of financing schemes
- Commercial banks are very reluctant to provide debt financing (at affordable rate)

**Business model**

- How to make a profit? (Revenues from villagers are minimal, unstable, and challenging and costly to collect)
- Who is the customer? (Individual consumer? Community? Utility? Local govt? Development organization?)

**Policy barriers**

- Subsidies on alternatives (diesel and electricity tariffs)
- Lack of functional incentive schemes
- Lack of policy framework allowing for solar PV off-grid development (license to build and operate, tax and VAT regime, agreement securing developers revenue if grid is extended to the village etc)

# Energy efficiency for off-grid PV applications

All appliances should be chosen for the lowest possible energy consumption for each application, such as:

- High efficiency DC LED lighting
- Energy efficient DC LED TV
- Energy efficient PC and Laptop
- Energy efficient DC Refrigerator & Freezer
- Energy efficient DC Washing machine

*Note: Energy efficiency of the loads and conservation are important measures that should be considered in conjunction with PV systems. It is far cheaper to save a kilowatt-hour than to produce one.*

# Trends for Off-grid PV System development

1. **Development of plug-and-play Off-grid PV System,** simple to install and operate and more reliable

2. **Development of Lithium battery based Off-grid PV System**
   Lithium batteries offer significant advantages over lead acid batteries. It is expected that lithium batteries will begin to replace lead acid batteries in significant numbers over the coming years. Emerging battery technologies such as lithium iron phosphate (LiFePO4) batteries are approaching price parity with lead-acid batteries.

3. **Super-high efficient appliances** offer perhaps the best upcoming opportunity to reduce PV system initial purchase prices, but other trends in the off-grid energy market offer avenues for improving durability and longevity, further reducing life cycle costs.

*The transition to new type may not allow to reduce quickly for some period off-grid system price, as Lithium batteries and Super-high efficient home appliances more expensive than traditional system based on lead acid batteries and. However, it will result in improved system durability and a lower system life cycle.*

| End use | Efficiency technologies | Description | Power reduction and other benefits |
|---|---|---|---|
| **Lighting** | · LEDs | LEDs are on the order of 1000 times, 6 times, and 1.3 times more efficient than kerosene-based lights, incandescent, and CFLs, respectively (US–DOE, 2014; Mills, 2005) | A 10 W LED lamp can replace a 60 W incandescent or a 13 W CFL, and has 30 and 2.5 times the rated life, respectively. |
| **TV** | · LED backlight<br>· Efficient optical films<br>· Dimming technology<br>· DC powered system | In general, LED backlit LCD TVs are 50%+ more efficient than CRT TVs. Efficient backlight sources, optical films, local dimming technology, and DC powered systems can further improve the typical LED-LCD TV efficiency by more than 40% (Park et al., 2011, 2013a & 2013b) | A 19 in, 10 W DC-powered LED-LCD TV can replace a 60 W CRT TV of similar screen size. DC LED-LCD TVs provide better picture quality, require less space, and do not need an AC to DC converter in the TV set. |
| **Fans** | · Brushless DC motors<br>· Efficient blades | Brushless DC motors are 50% more efficient than the typical induction motors used in ceiling fans. Better blade design can improve the efficiency of a ceiling fan by 15% (Sathaye et al., 2013)<br>Similar efficiency gains are expected from table fans. | A 6 W DC motor powered table fan can replace a 10 W standard table fan and provide the same service (air delivery). Further, these DC fans do not require an AC to DC convertor. |

# Lithium Ion Battery for Off-grid Systems



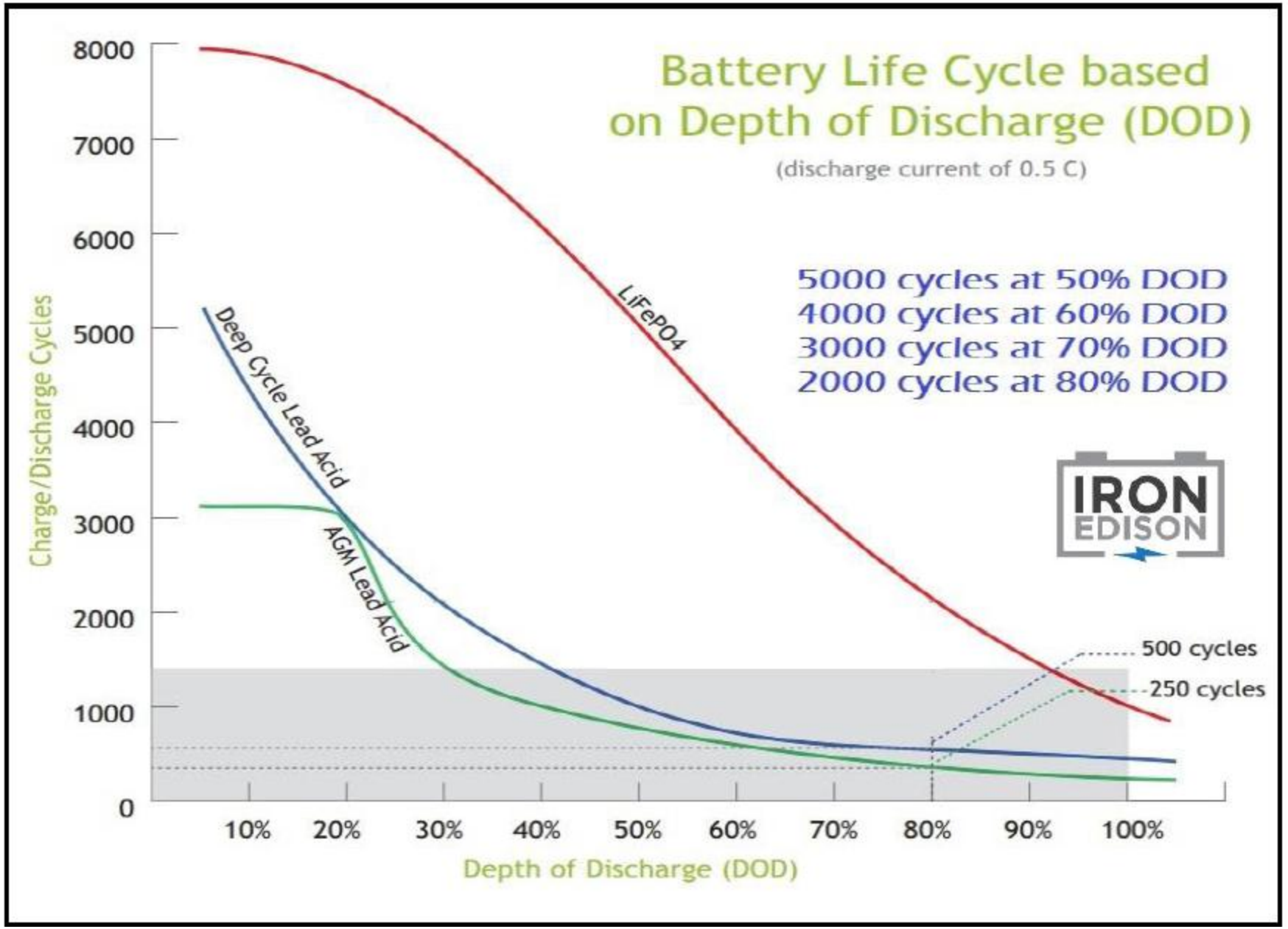

# Lithium Ion Battery- The cutting edge of battery technology

- No maintenance, no gas
- High power, light weight
- 10-15 year cycle life
- Low cost over time

**Retail Price Lithium Battery**

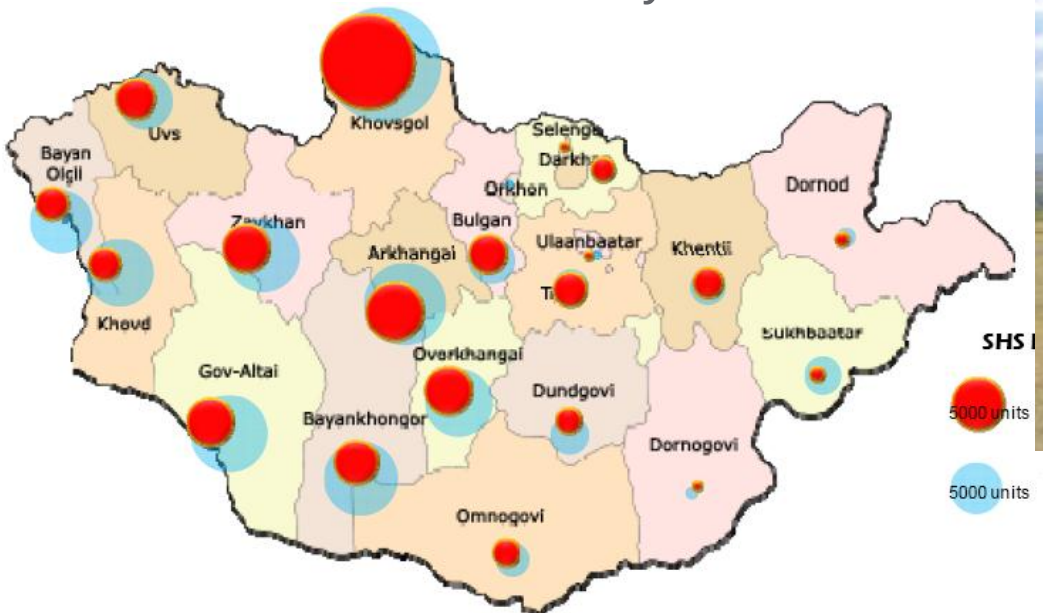
- Deka AGM $320 per kWh
- Trojan AGM $350 per kWh
- Flooded Lead Acid: $390 per kWh
- Lithium Iron Edison: $680 per kWh
- Tesla Power Wall $350 per kWh

*Tesla's selling price to installers is $3500 for 10kWh*

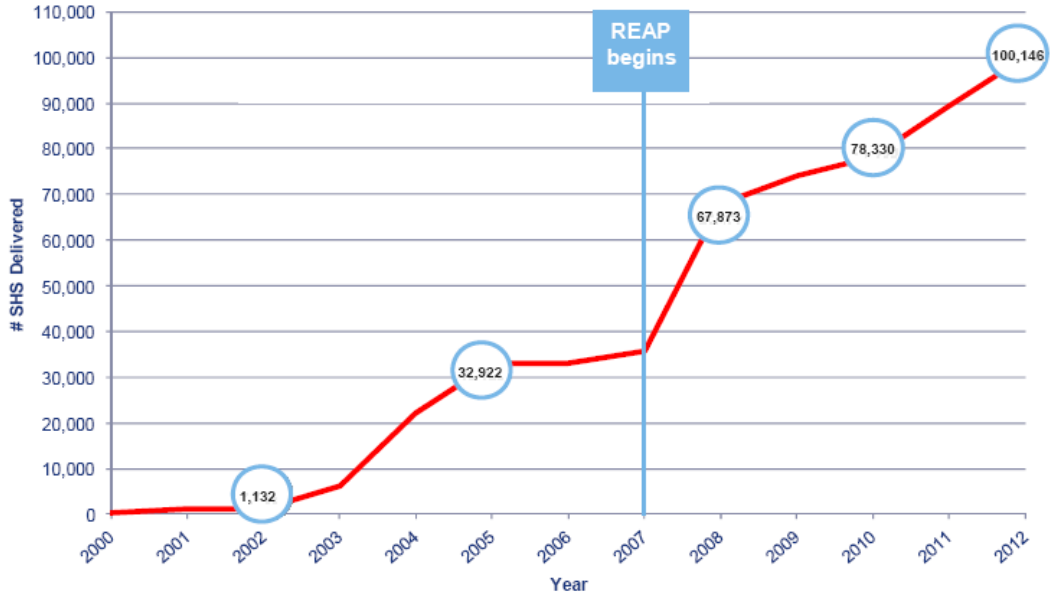

Battery Life Cycle based on Depth of Discharge (DOD)
(discharge current of 0.5 C)
5000 cycles at 50% DOD
4000 cycles at 60% DOD
3000 cycles at 70% DOD
2000 cycles at 80% DOD
IRON EDISON
LiFePO4
Deep Cycle Lead Acid
AGM Lead Acid
500 cycles
250 cycles
Charge/Discharge Cycles
8000
7000
6000
5000
4000
3000
2000
1000
0
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Depth of Discharge (DOD)

# The National 100,000 Solar Ger Program

## Distribution of SHSs by Province



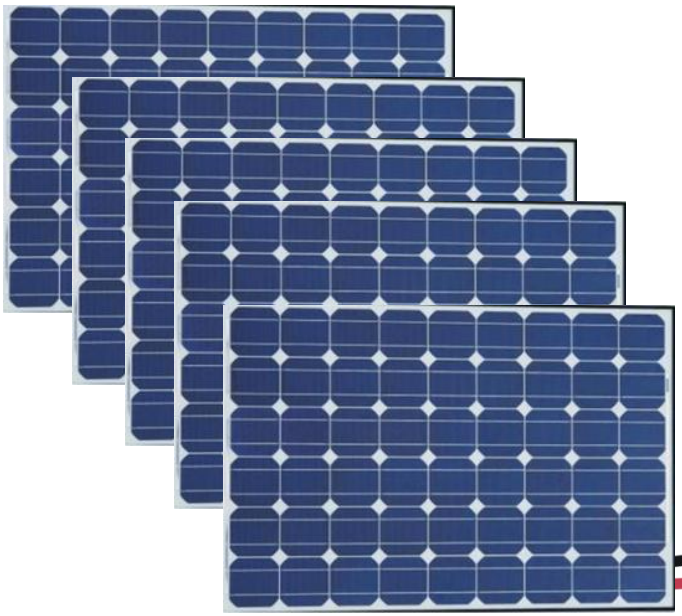

As part of 100,000 Solar Ger Electrification Program *(including REAP)*

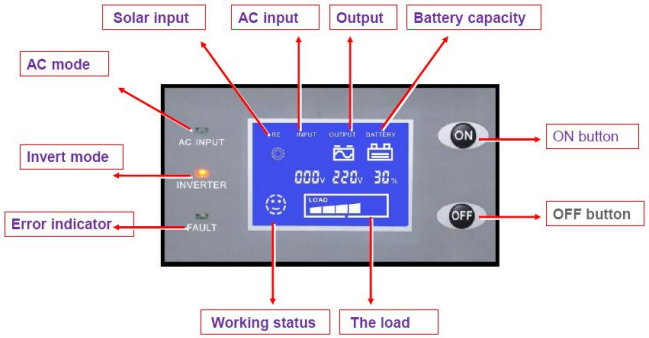



Within 100000 SHS national program the Distribution network of private dealers, Sales and Service Centers (SSC) was formed. SSCs are fully trained and certified to perform after sales maintenance and repair services.

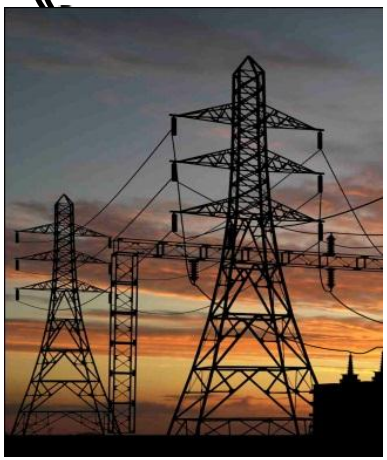
# Development of Plug-and-play off-grid PV System based on Lithium battery technology and Super high efficiency electrical appliances

# WORKING PRINCIPLE OF THE OFF-GRID PV SYSTEM FOR HOMES







# OFF-GRID DC PV SYSTEM


Front side


Back Side

**DC Power Control System;**

- **Solar PV module 200W, 12V, 1ps**
- **Charge Controller 12V/24V, 30A, 1pc**
- **Battery 12V, 150A.цаг 1pc**
- **Battery management system**

# Off-grid AC PV System

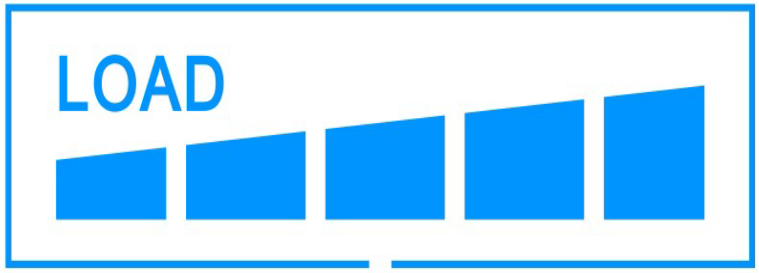

Front side

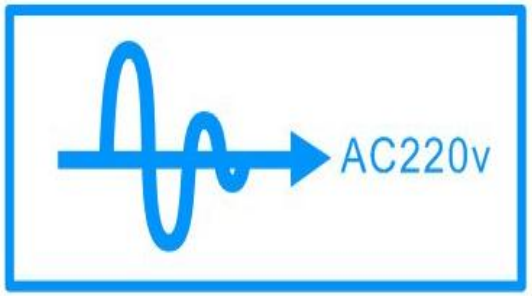
- **Power Control System**
  - **Solar PV module 4kW**
  - **Inverter 6000W, 96V**
  - **Charge Controller 60A**
  - **Battery 12V, 200A.цаг 8pcs.**
  - **20A Charger**
- **Dimension: 926x620x1230mm**

Back Side

# The Functions & Features of the proposed Plug-and Play off-gird PV system

# Full Power, Standard & Stable Pure Sine Wave

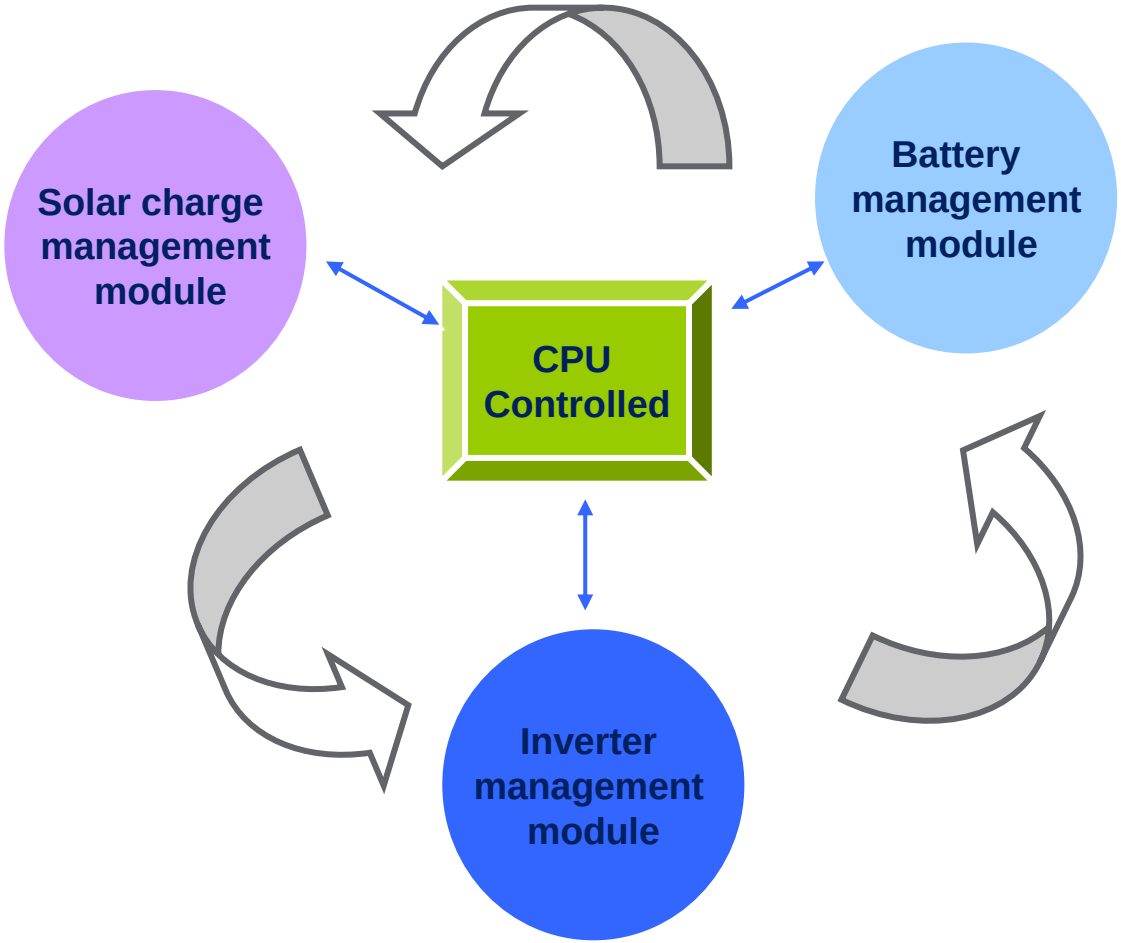


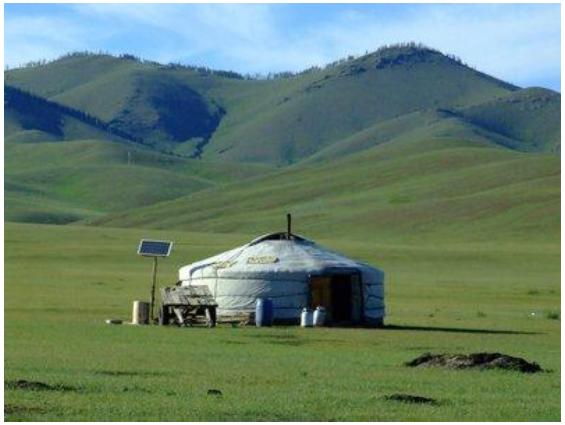

**All items:**
**1. Full power ;**
**2. The peak power is 3 times of rated power**

**1.The output is standard pure sine wave, the same as the grid AC output.**
**2. Wide application and suitable for any electrical equipments.**
**3. High efficinecy with low no-load loss**

# CPU Controlled and Achives Free Communication with Protocol



# Off-grid DC PV System



Solar PV Module

DC Power Controller System


DC loads

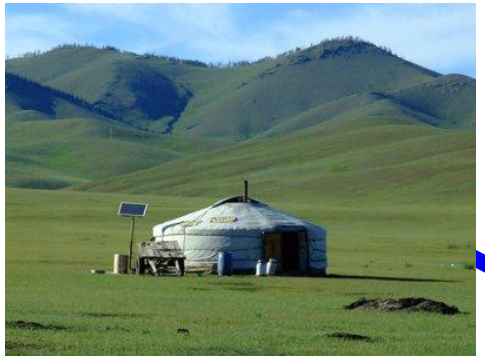




Lithium Ion Battery

# Automatically Identify and Select the PV Mode or AC Mode

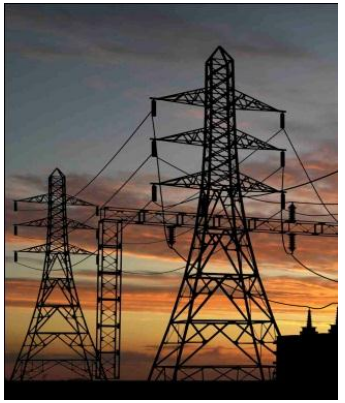
## Three Working Modes



Solar PV Module


Inverter & Controller System

AC load

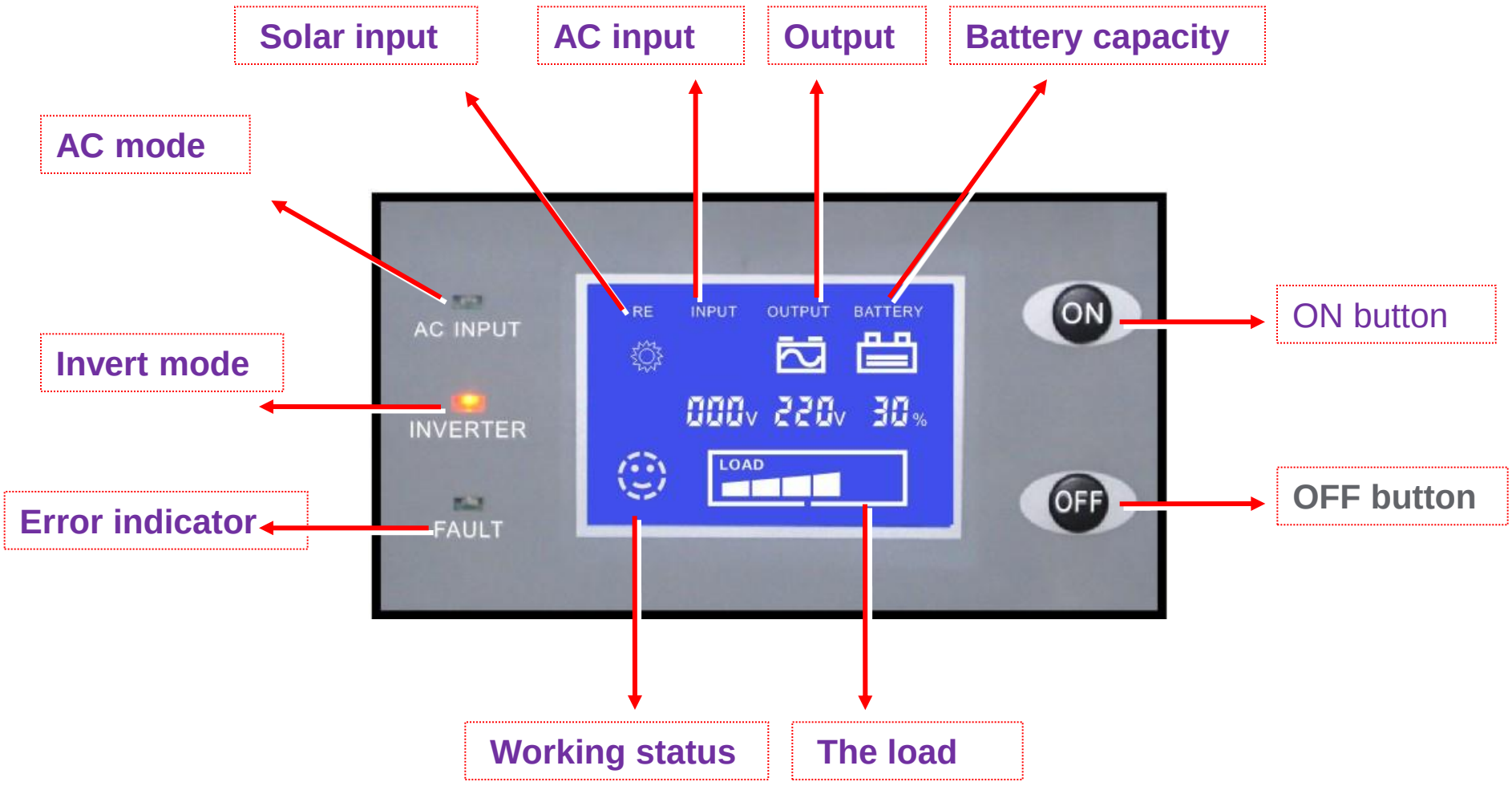



Grid AC

① PV mode ;

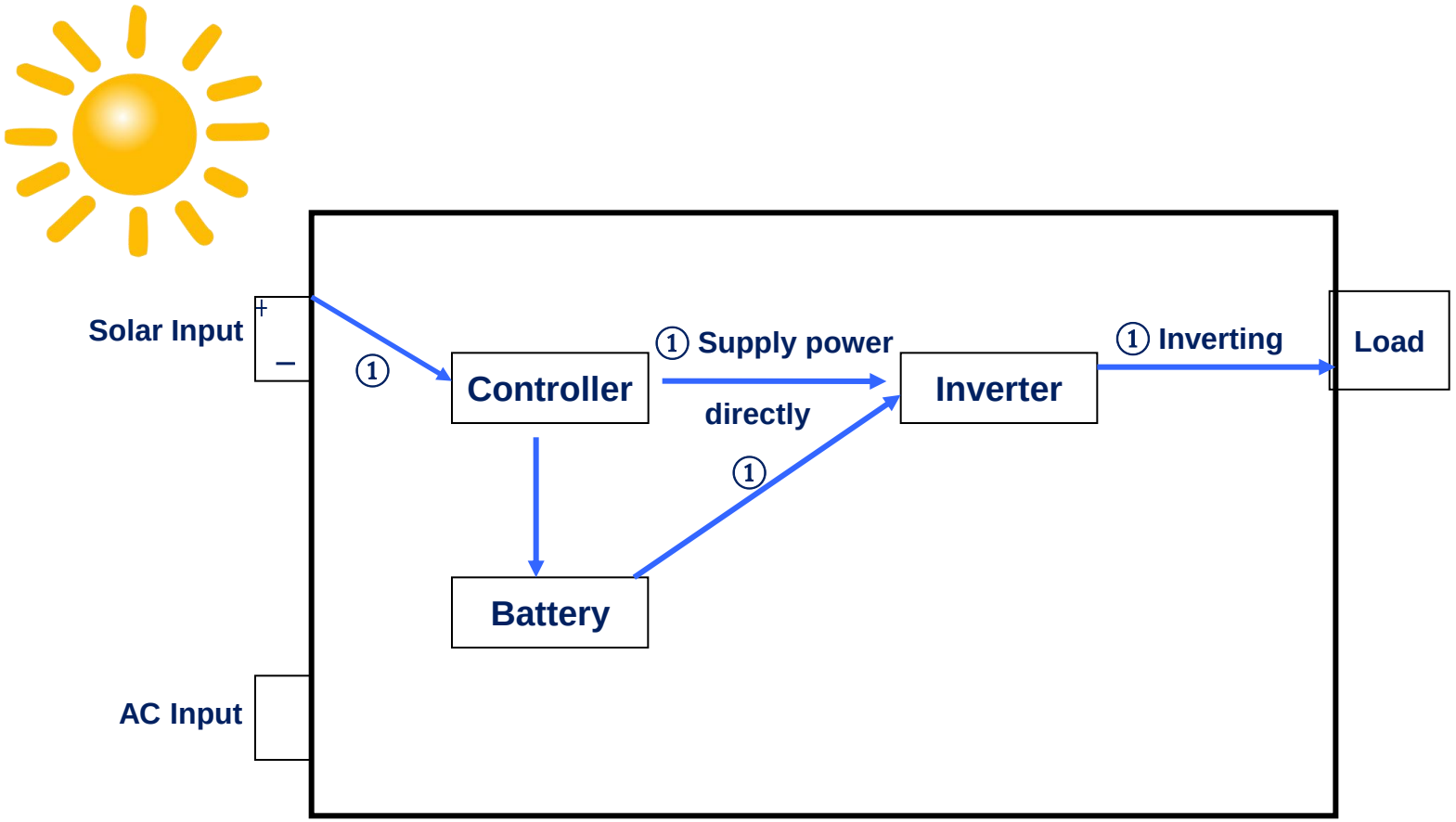
② AC mode

# LCD DISPLAY


Solar input
AC input
Output
Battery capacity
AC mode
AC INPUT
RE
INPUT
OUTPUT
BATTERY
ON
ON button
Invert mode
INVERTER
000V 220V 30%
LOAD
Error indicator
FAULT
OFF
OFF button
Working status
The load

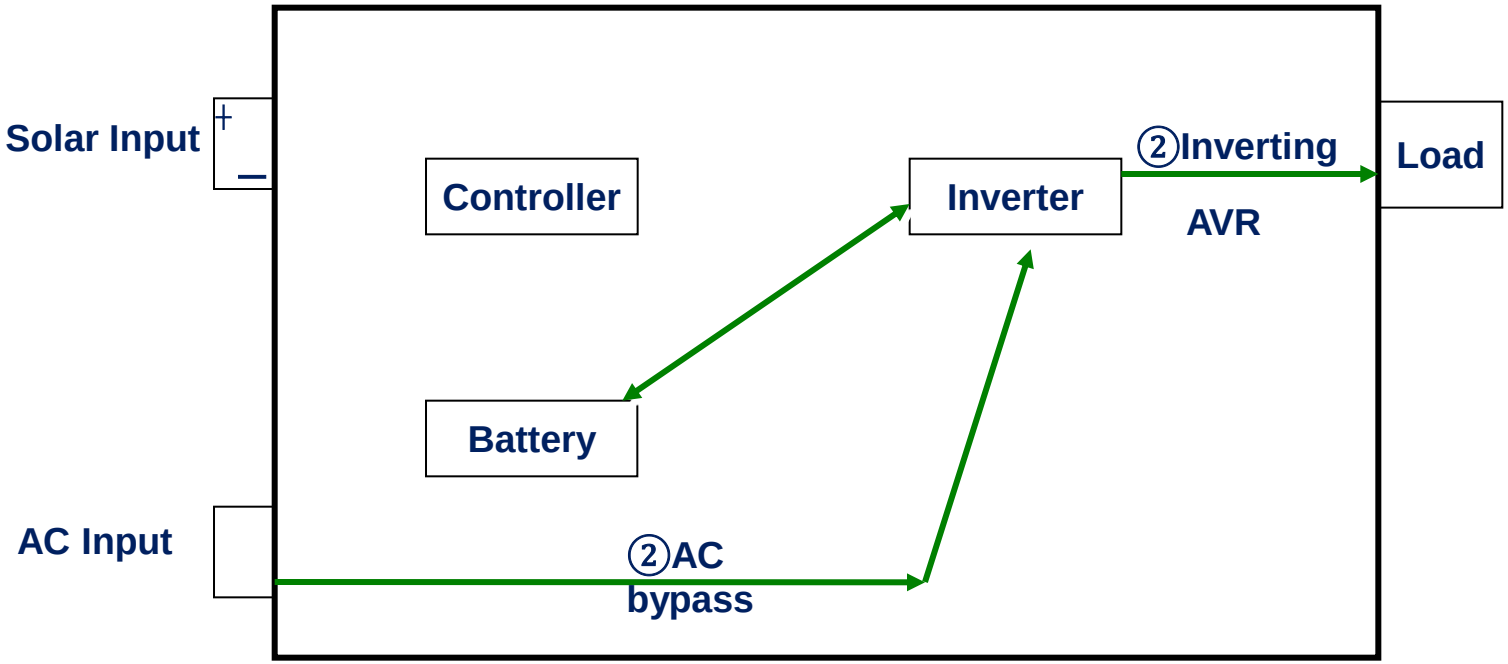
# Automatically Identify and Select the PV Mode or AC Mode

**PV Priority working mode is auto selected during the day**



# Automatically Identify and Select the PV Mode or AC Mode

## AC Priority working mode is auto selected at night



# Solar Energy Provides Power for Loads Directly

**When there is sufficient sunshine**

PV Module 3500W

3500W


3000W loads

**Loads**

500W for battery


Battery

# Solar Energy Provide Power for Loads Directly

**When there is no sufficient sunshine**

2500W


3000W for loads

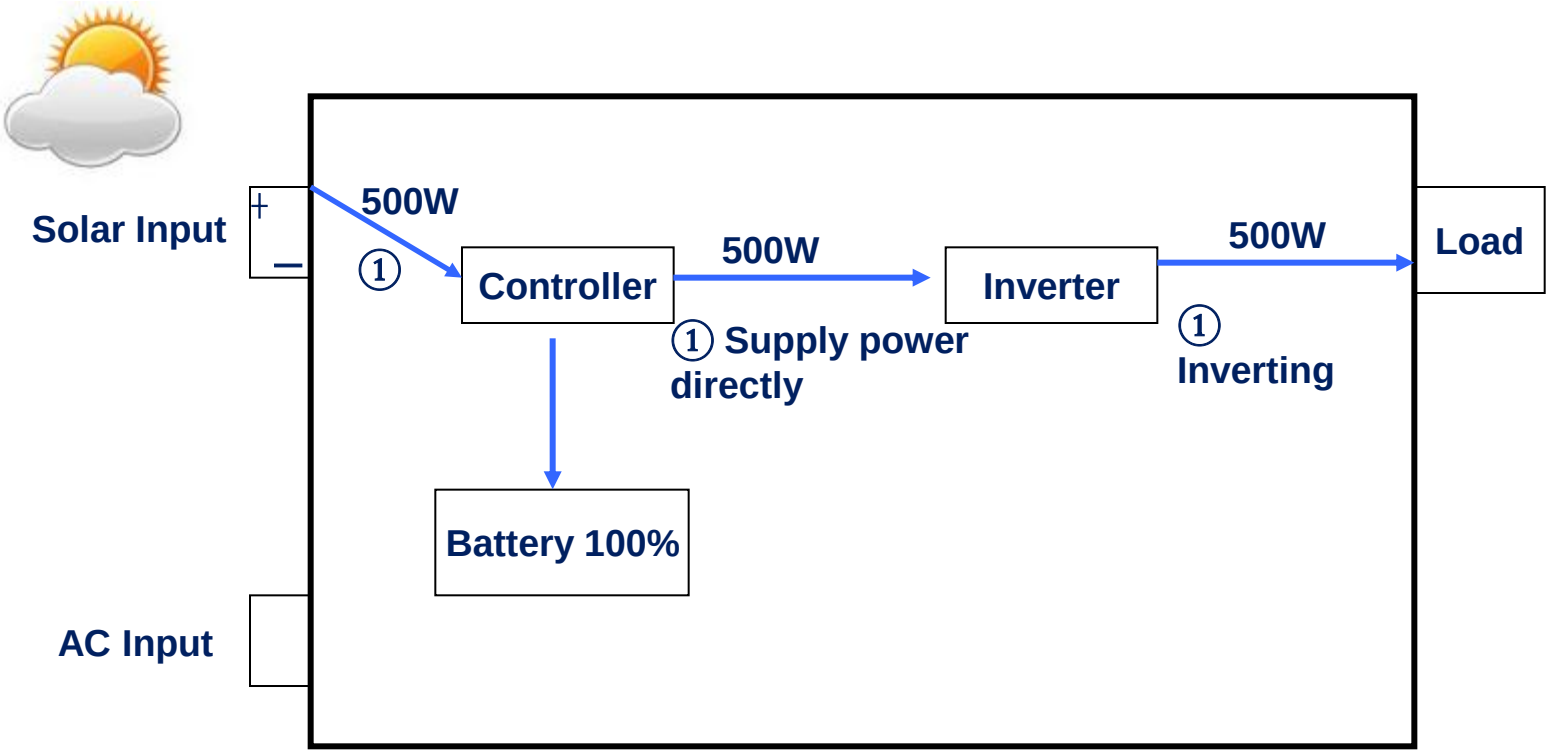
**Loads**

**Battery**

500W

# Solar/Grid AC Complementary Functions

**When there is solar energy and the battery voltage is relatively high (to the appointed point)**

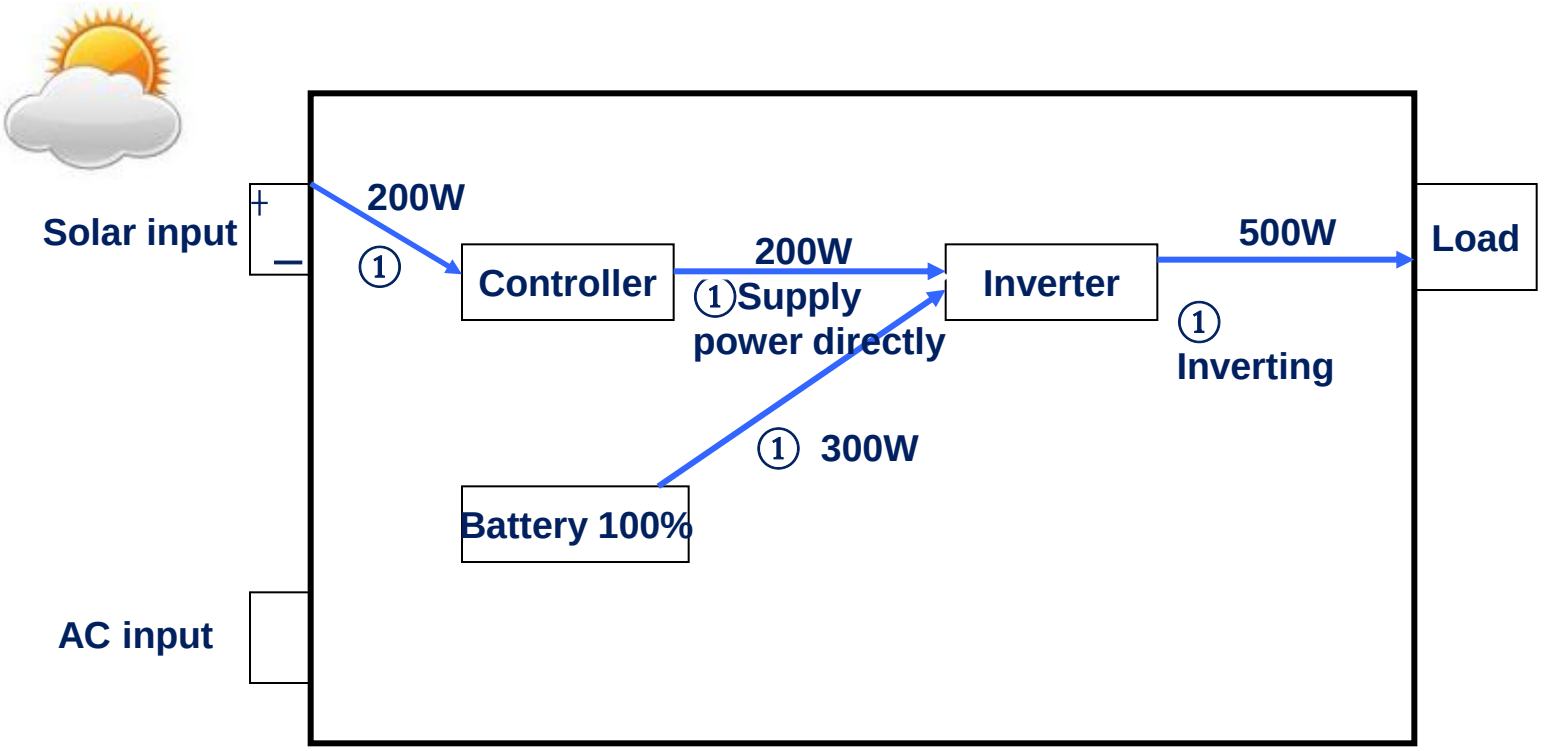



① PV mode ;

② AC bypass mode

# Solar/Grid AC Complementary Functions

**When there is solar energy, and the battery voltage is relatively high (to the appointed point), but the solar is insufficient**

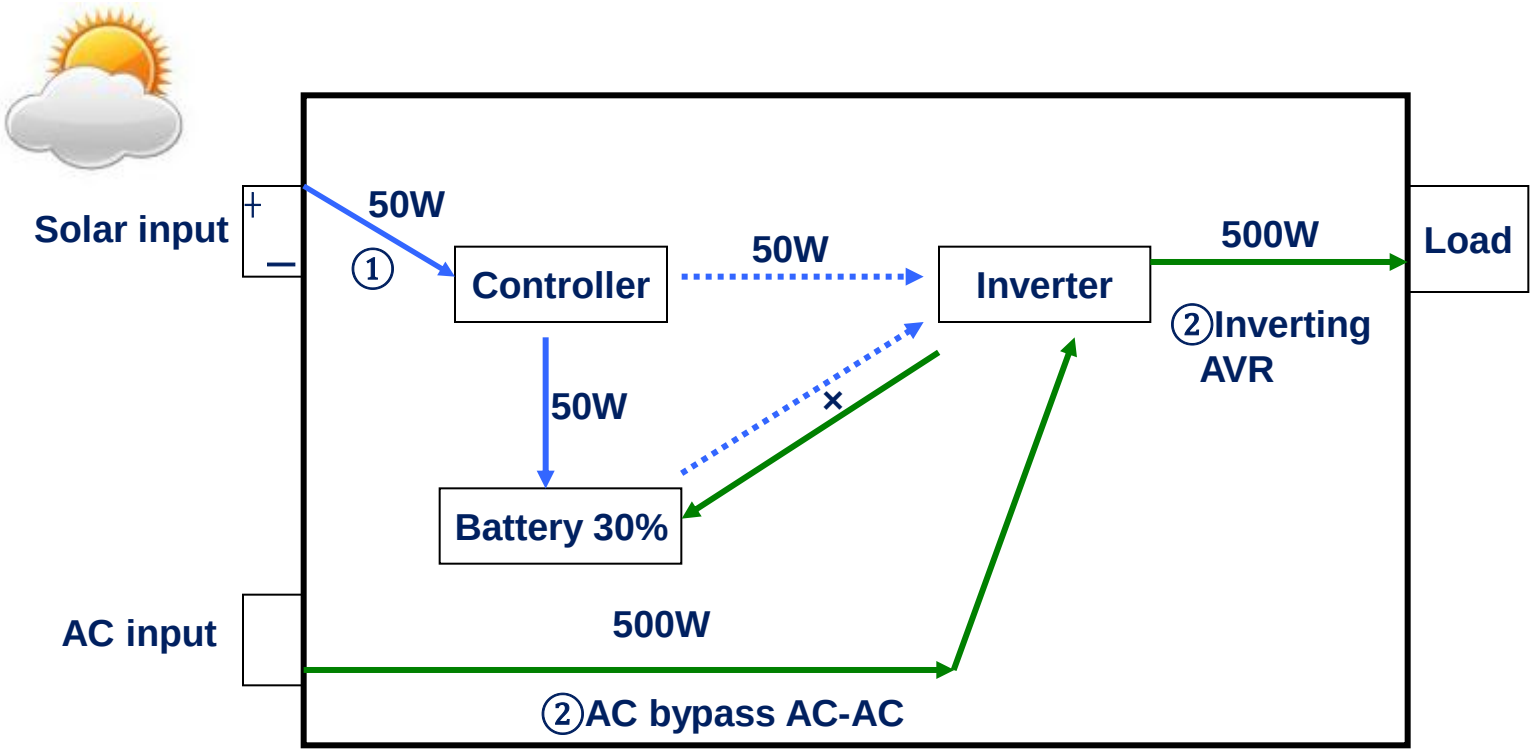



① PV mode ;

② AC bypass mode

# Solar/Grid AC Complementary Functions

**When there is solar energy, but the solar is insufficient and the battery voltage drops to the protection voltage**

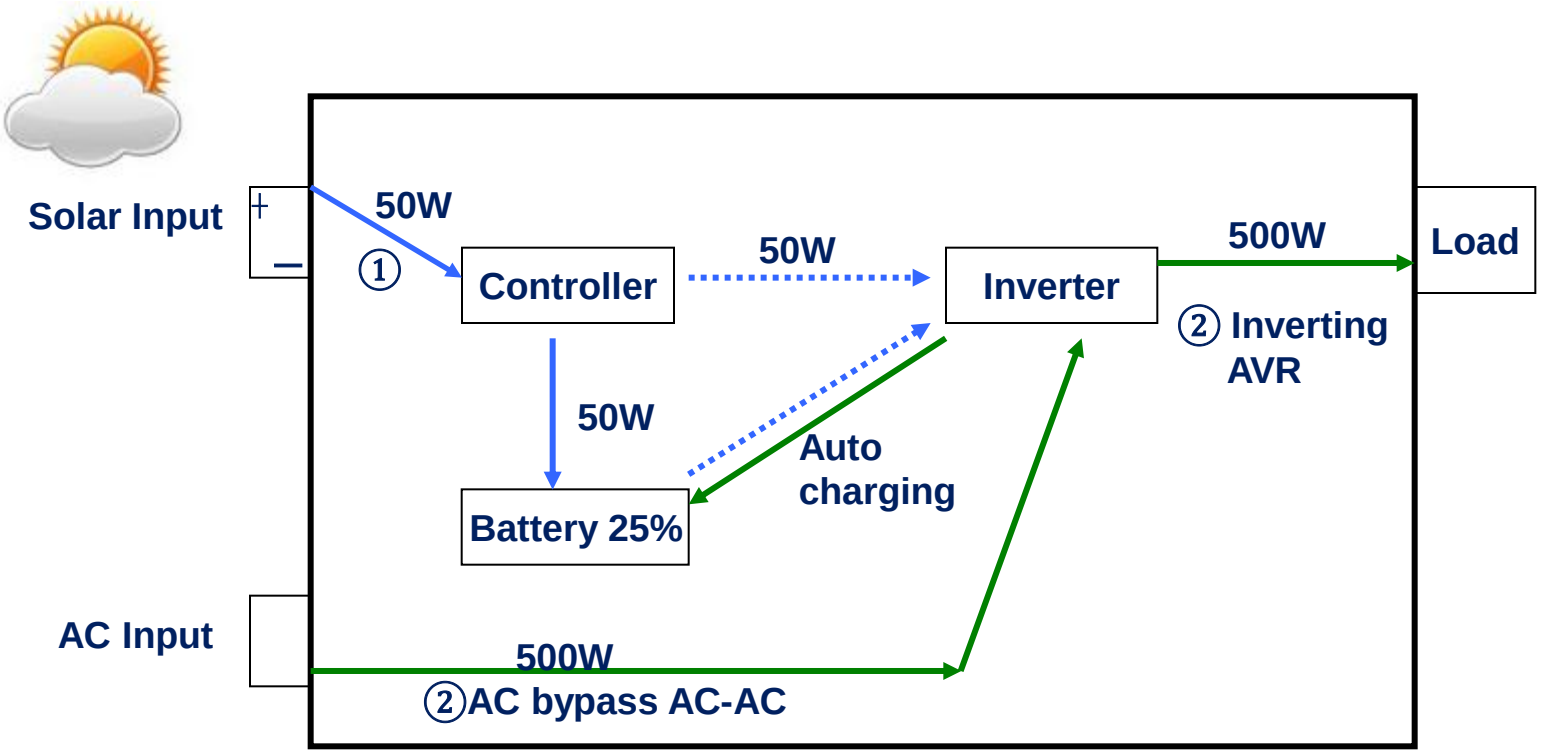



① PV mode ;

② AC bypass mode

# Solar/Grid AC Complementary Functions

**When there is solar energy, but the solar is insufficient and the battery voltage is lower than the protection voltage**

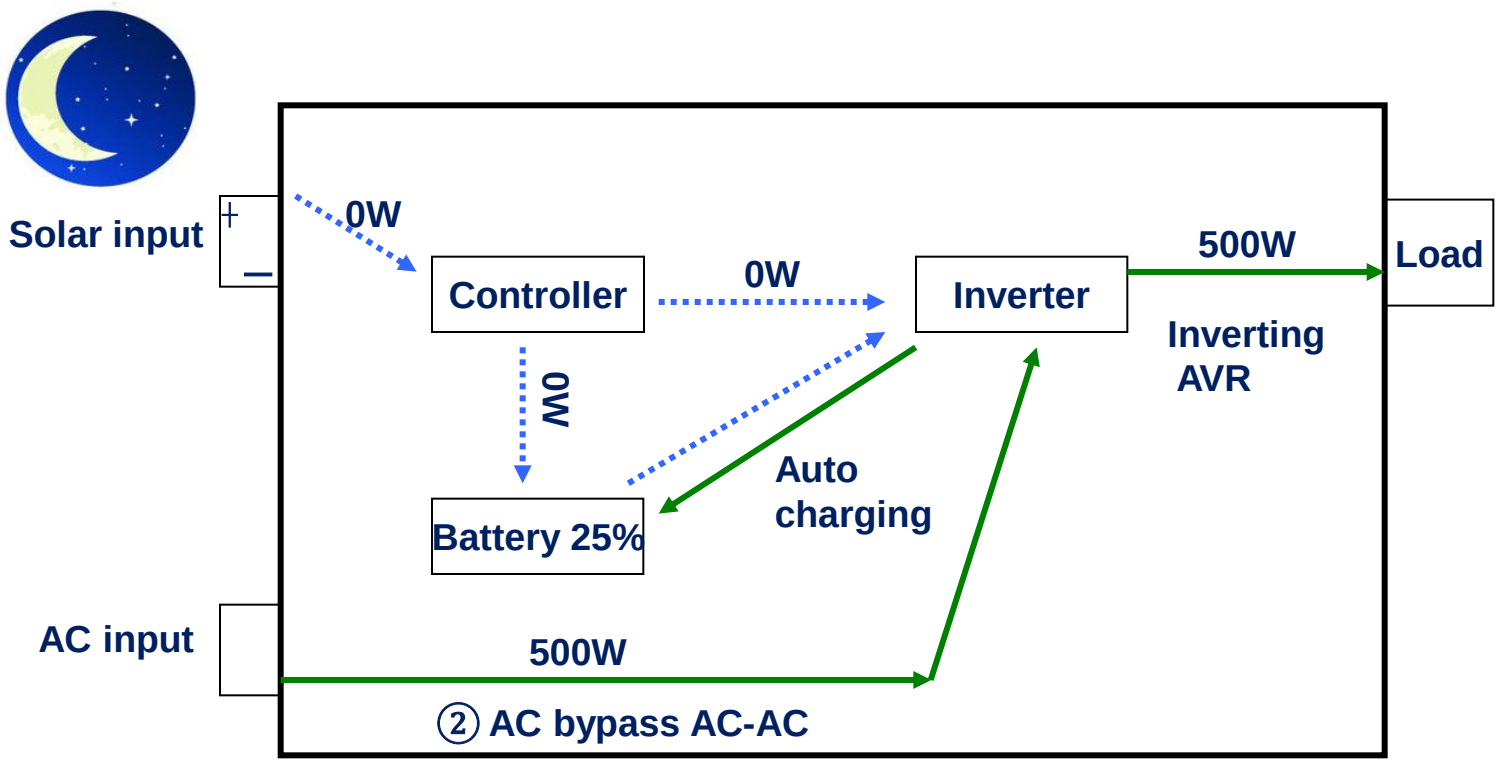



①PV mode ;

②AC bypass mode

# Solar/Grid AC Complementary Functions

**When there is no solar, and the the battery voltage is lower than the protection voltage**




① PV mode ;

② AC bypass mode

# AVR Function

AC140V

AC280V


220V

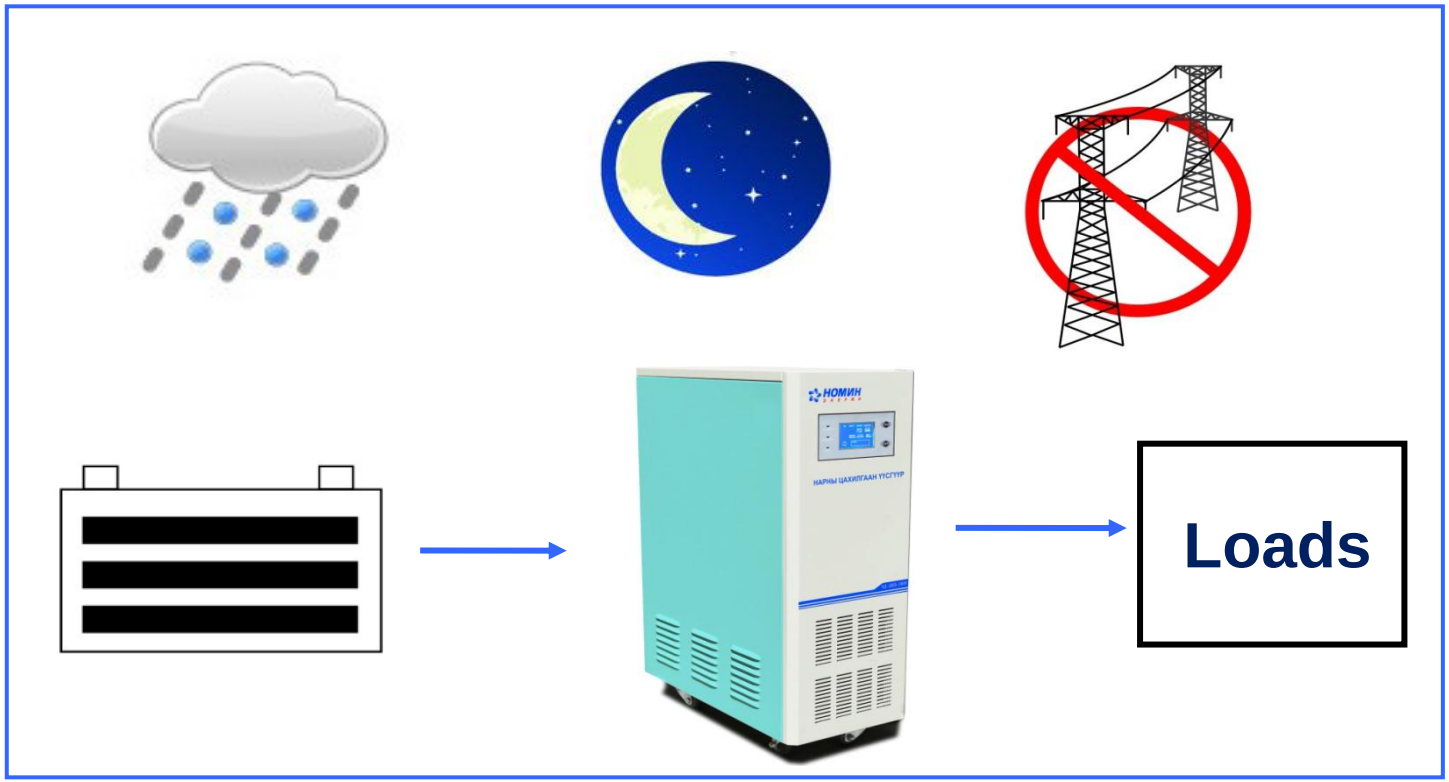
AVR function
(better AC output)

AC load

AC input: AC145±5V-AC275±5V,
AC output:AC220±5%V, with better and stable AC output

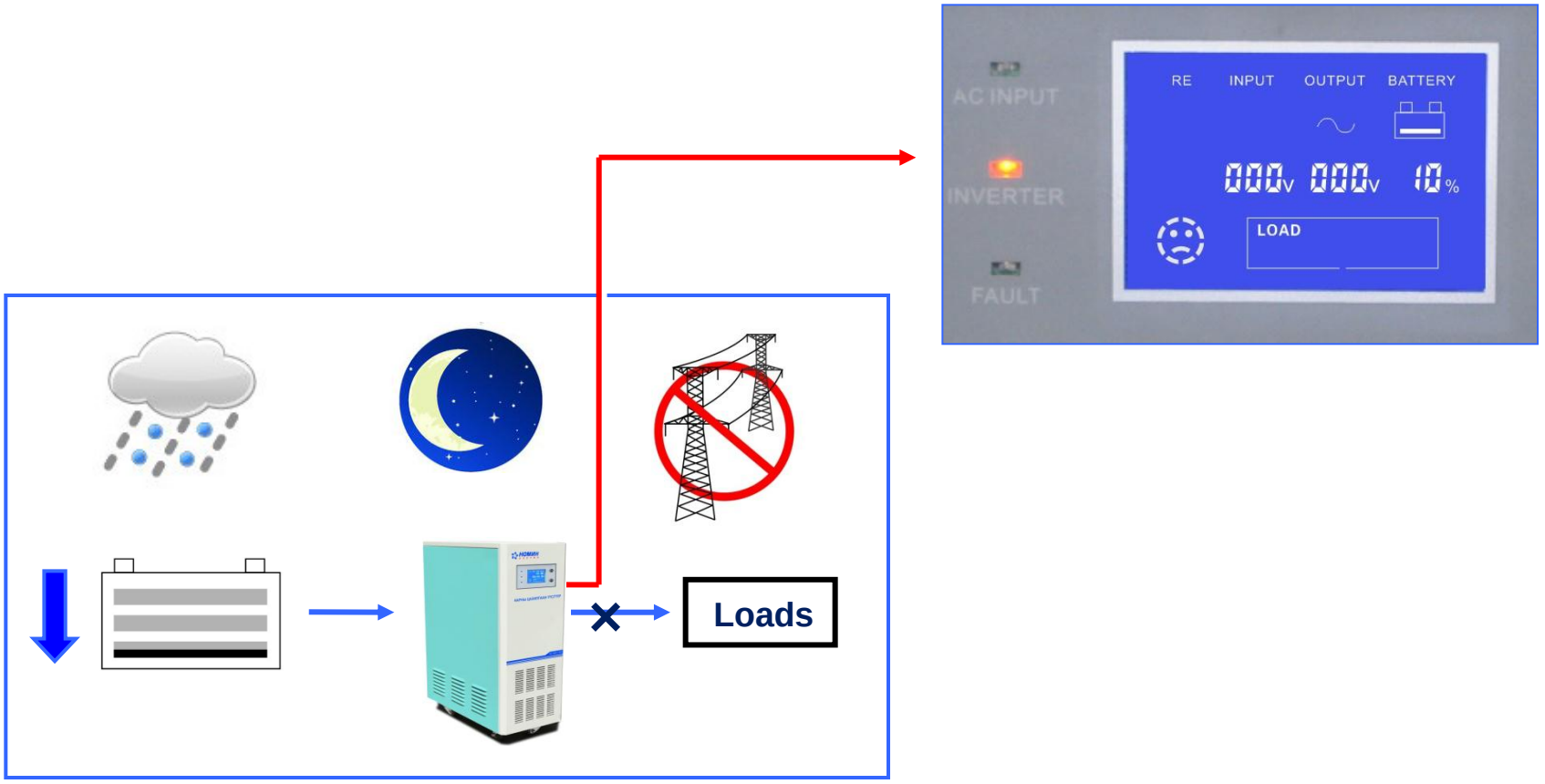
# Self-recovery and Unattended Operation

## Low-voltage protection and self-recovery



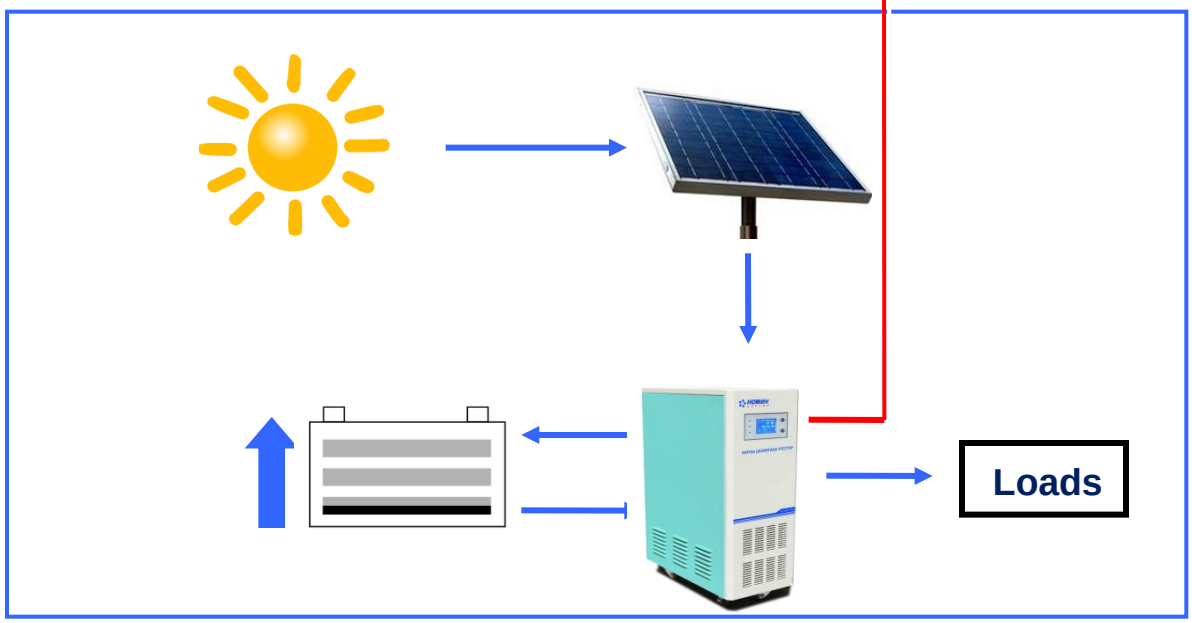

**In overcast/rainy days or at night, and there is no grid AC, the battery will supply power to loads through inverter**

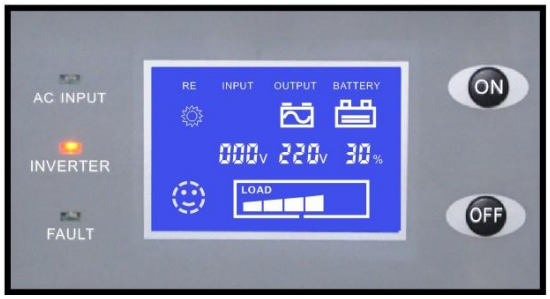
# Low-voltage protection and self-recovery




**If the battery keeps supplying power for loads, its voltage gets lower and lower. When the battery voltage drops to low-voltage protection, the system will be protected automatically , no AC output, and the system will not be shut down but on standby status.**

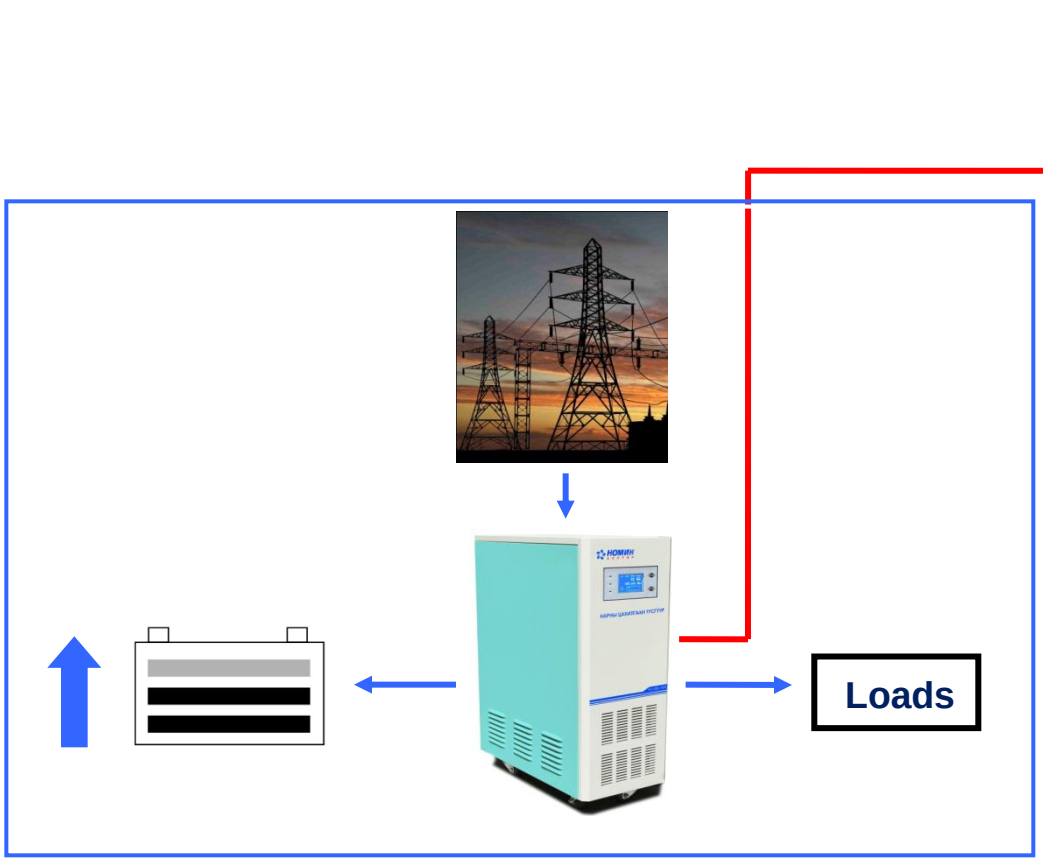
# Low-voltage protection and self-recovery

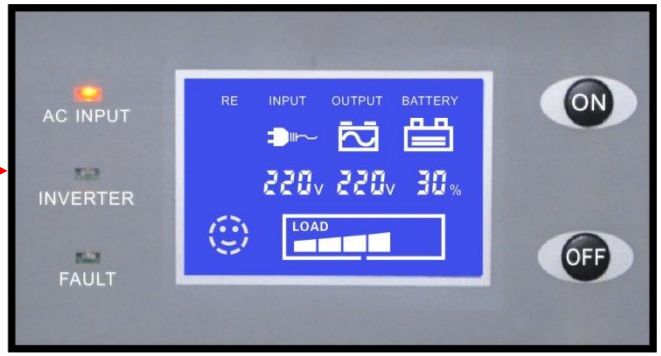



**When the system detects there is solar input, it will charge for the battery automatically. If the battery voltage is higher than the appointed point, the solar and battery will supply power for loads together.**

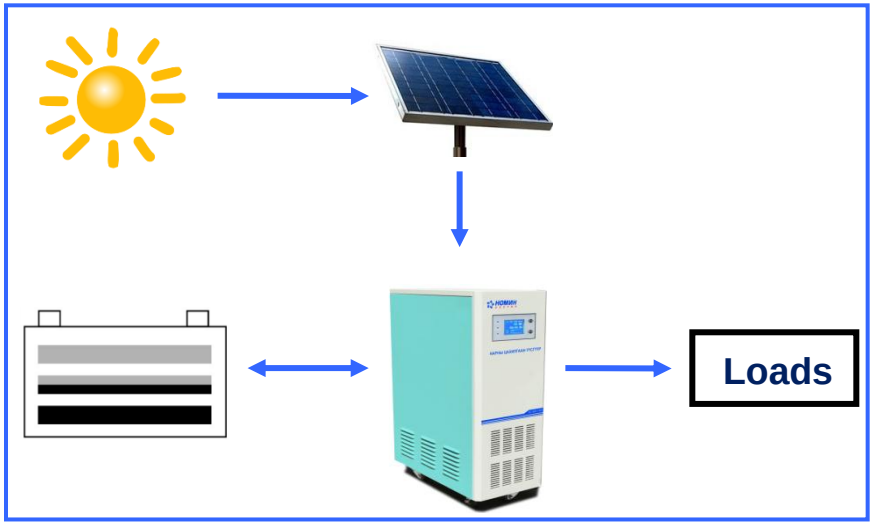
# Low-voltage protection and self-recovery



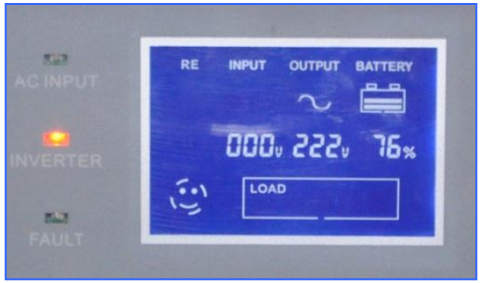



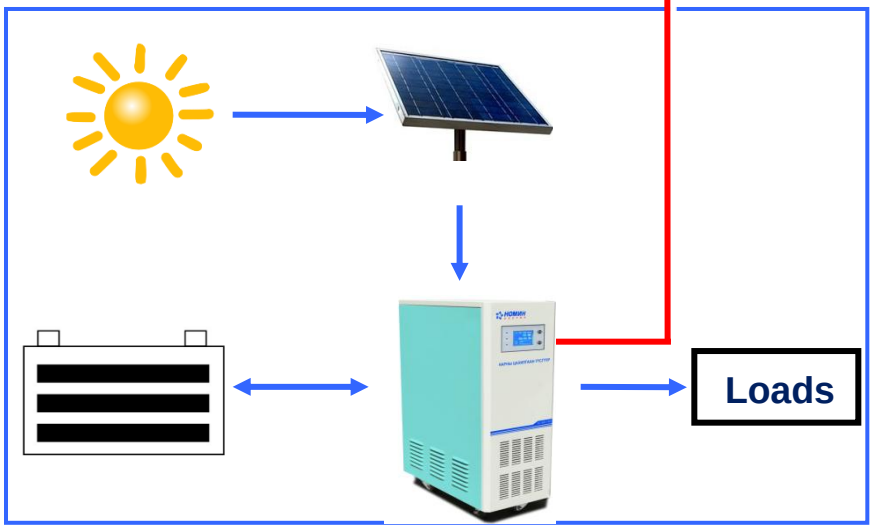

**When the system detects there is grid AC input, it will start working automatically: Gird AC will supply power for load with AC bypass, and charge for the battery at the same time**

# Over-voltage protection and self-recovery

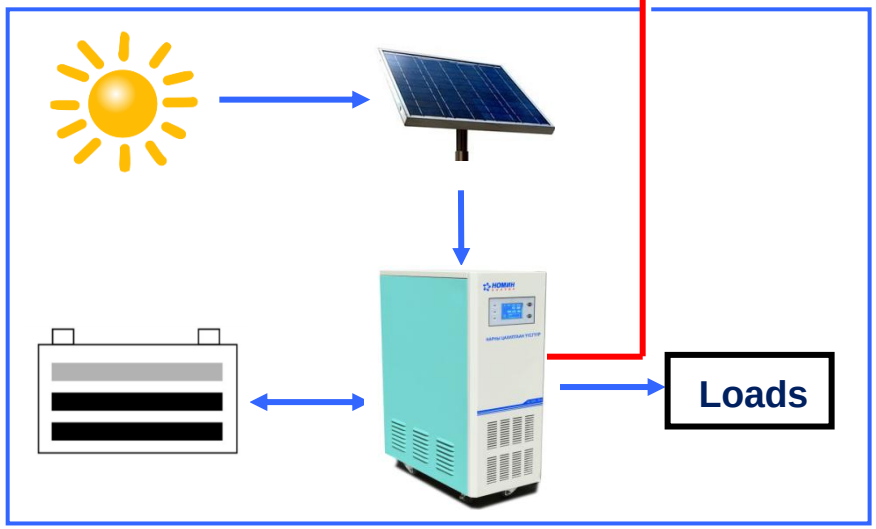




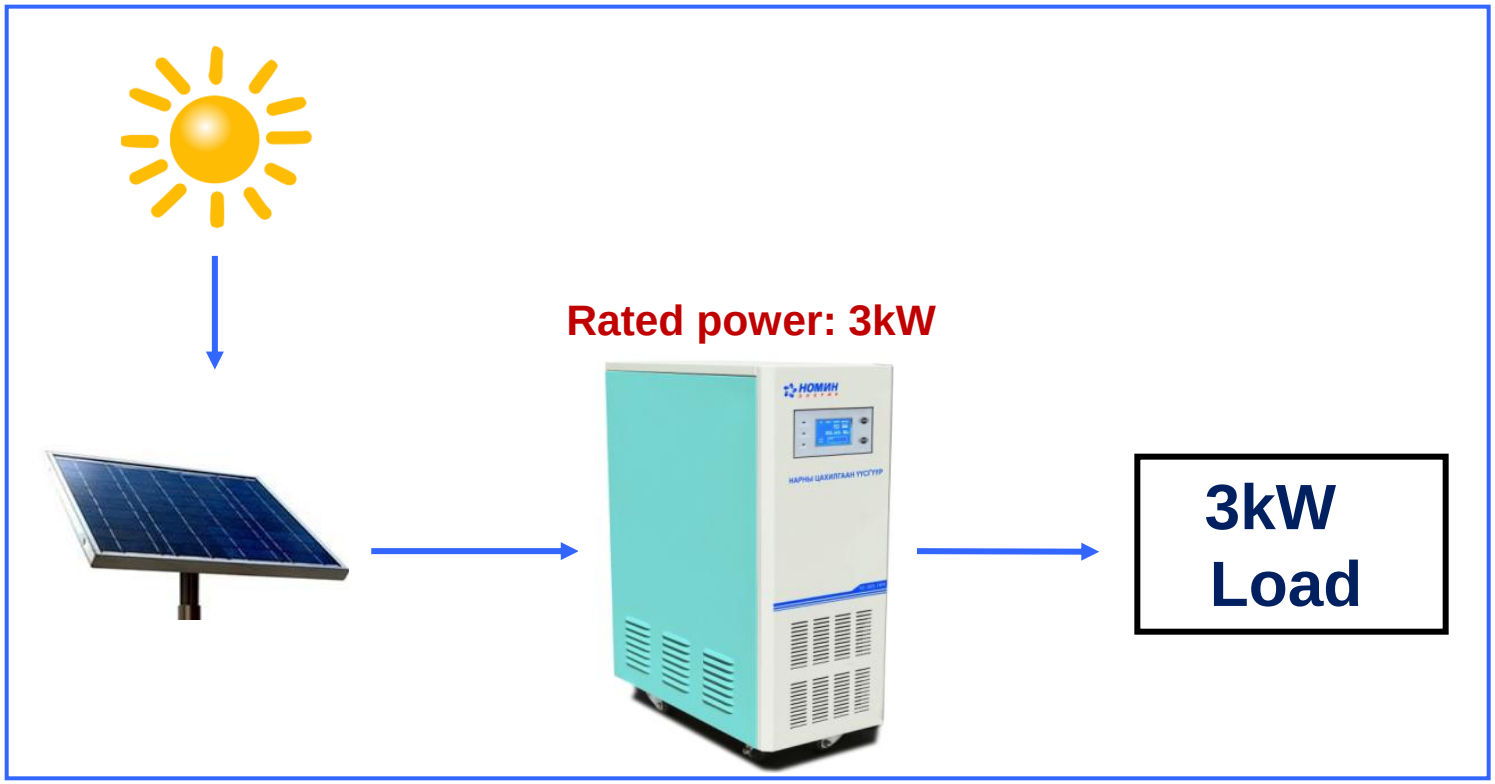



Discharge

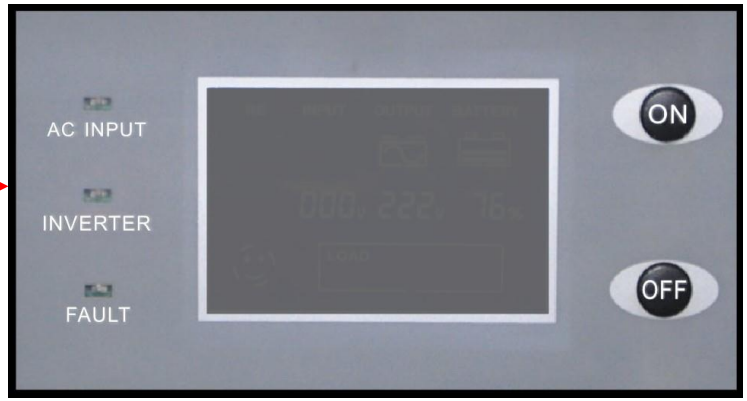


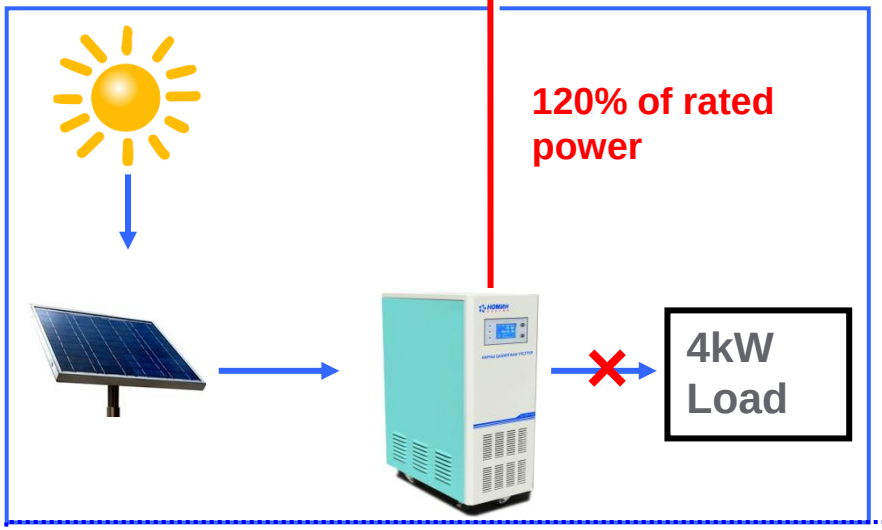
# Overload Protection




If the rated power of the system is 3000W，it can work properly with loads ≤3000W

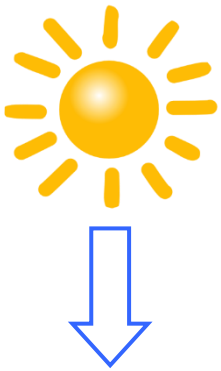
# Overload Protection

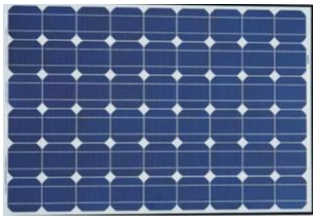



**2、Over-load protection:**
**120% of rated power,shut down automatically after 30S and restart after reducing the load by hands.**
**150% of rated power,shut down after 10S**
**200% of rated power,shut down after 1S**

# EXPERIENCE OF USING THE PV SYSTEM IN MONGOLIA





PV MODULE 5000W

*(09:00-18:00)*
*PV Charging*

**5000Вт**


*(09:00-18:00)*
*цэнэглэнэ*

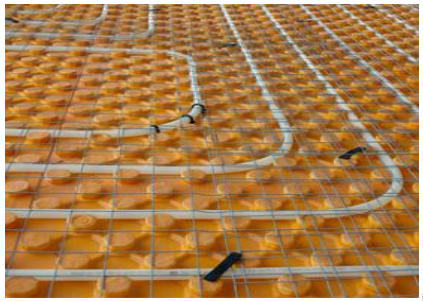
**4750Вт**

BATTERY

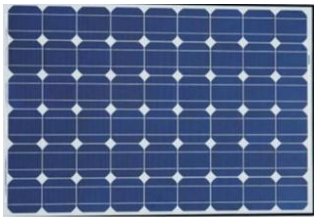
*(17:00-22:00)*
*Peak hour use*

**4200Вт**



# NIGHT TIME CHARGING MODE OF PV SYSTEM



PV MODULE 5000W

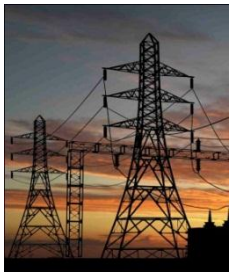

4200Вт

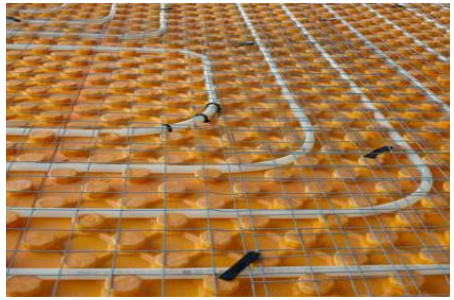
(06:00-10:00)




4750Вт

(18:00-22:00)
Night time charging
from Grid





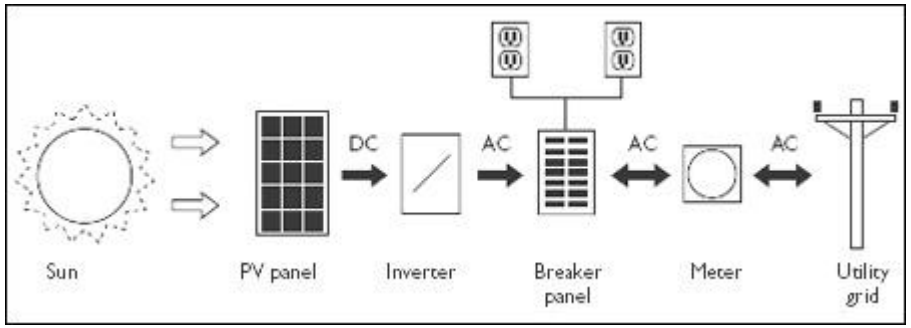
# On-grid AC PV System with Battery Backup


**Front side**

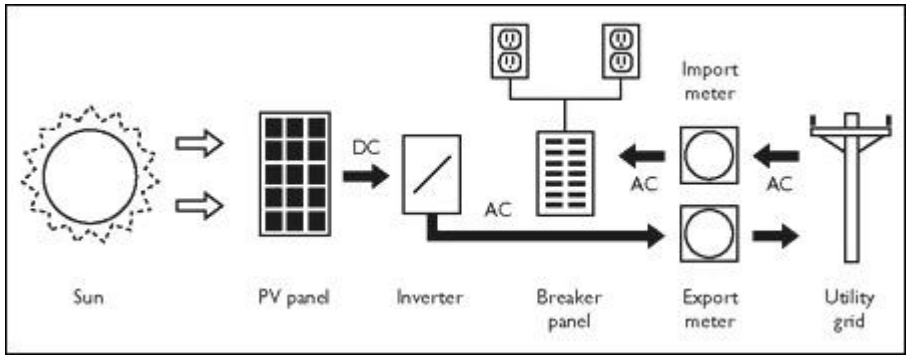
- **Power Control System**
  - **Solar PV module 4kW**
  - **Inverter 6000W, 96V**
  - **Charge Controller 60A**
  - **Battery 12V, 200A.цаг 8pcs.**
  - **20A Charger**
- **Dimension: 926x620x1230mm**

**Back Side**

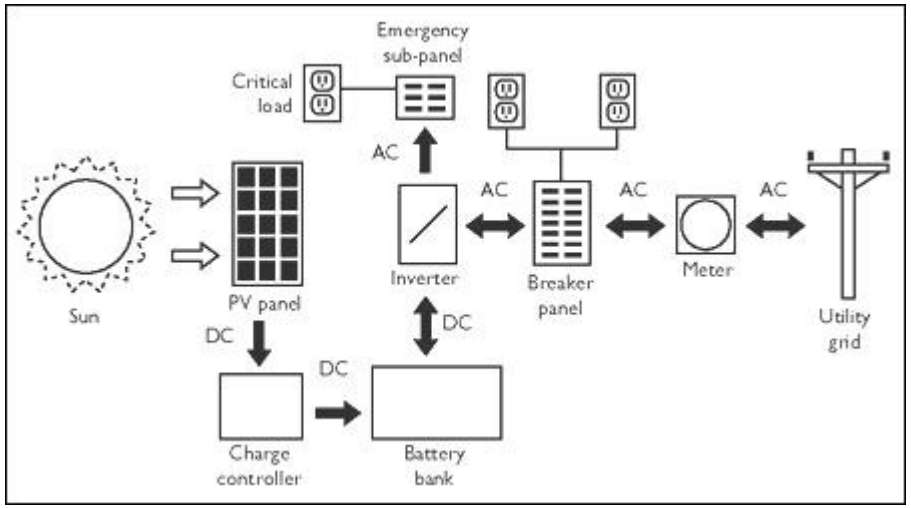
# Operation modes of the AC PV Systems




**Net-metering PV system configuration**

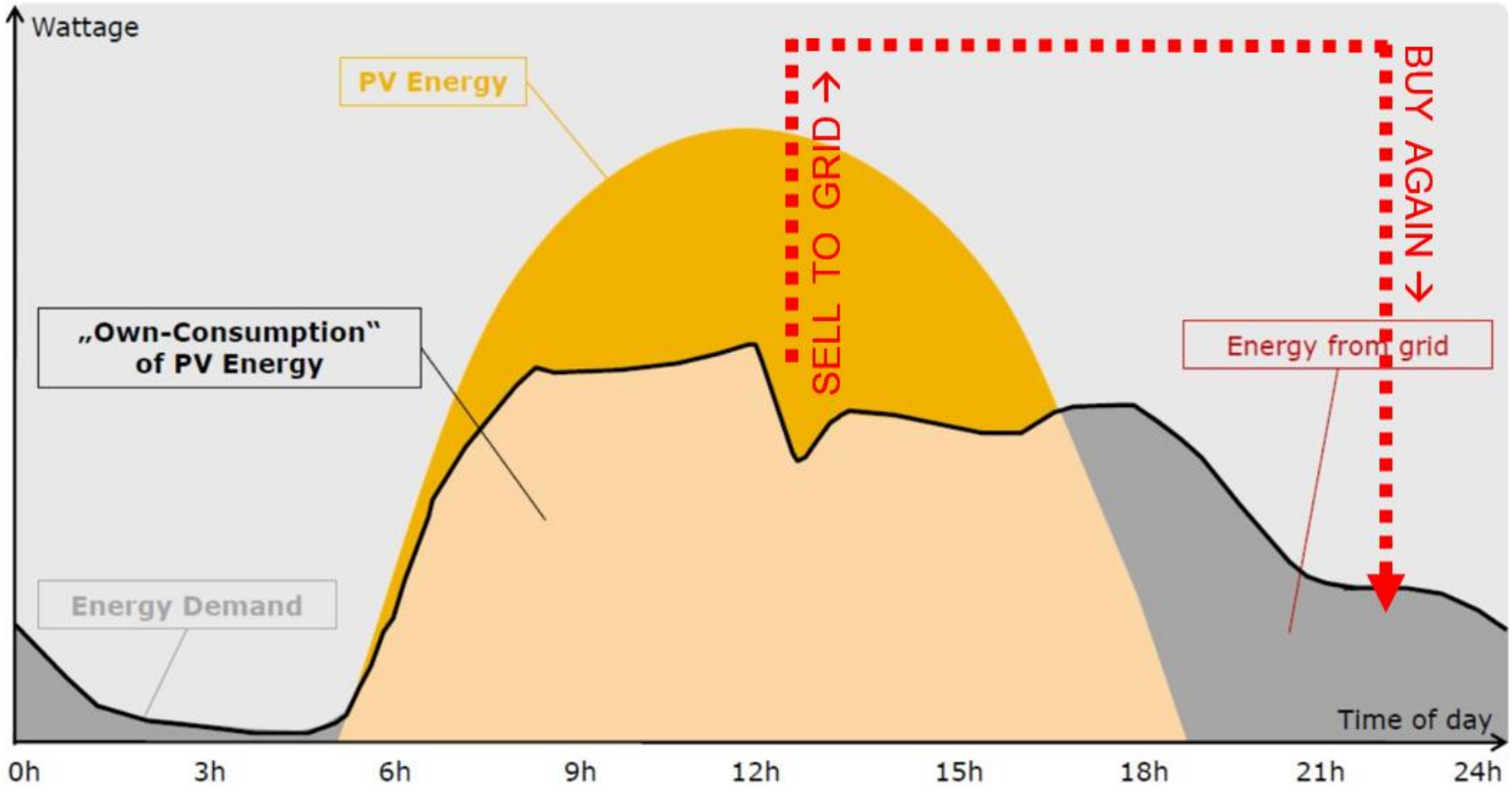



**PV generated electricity is individually measured**



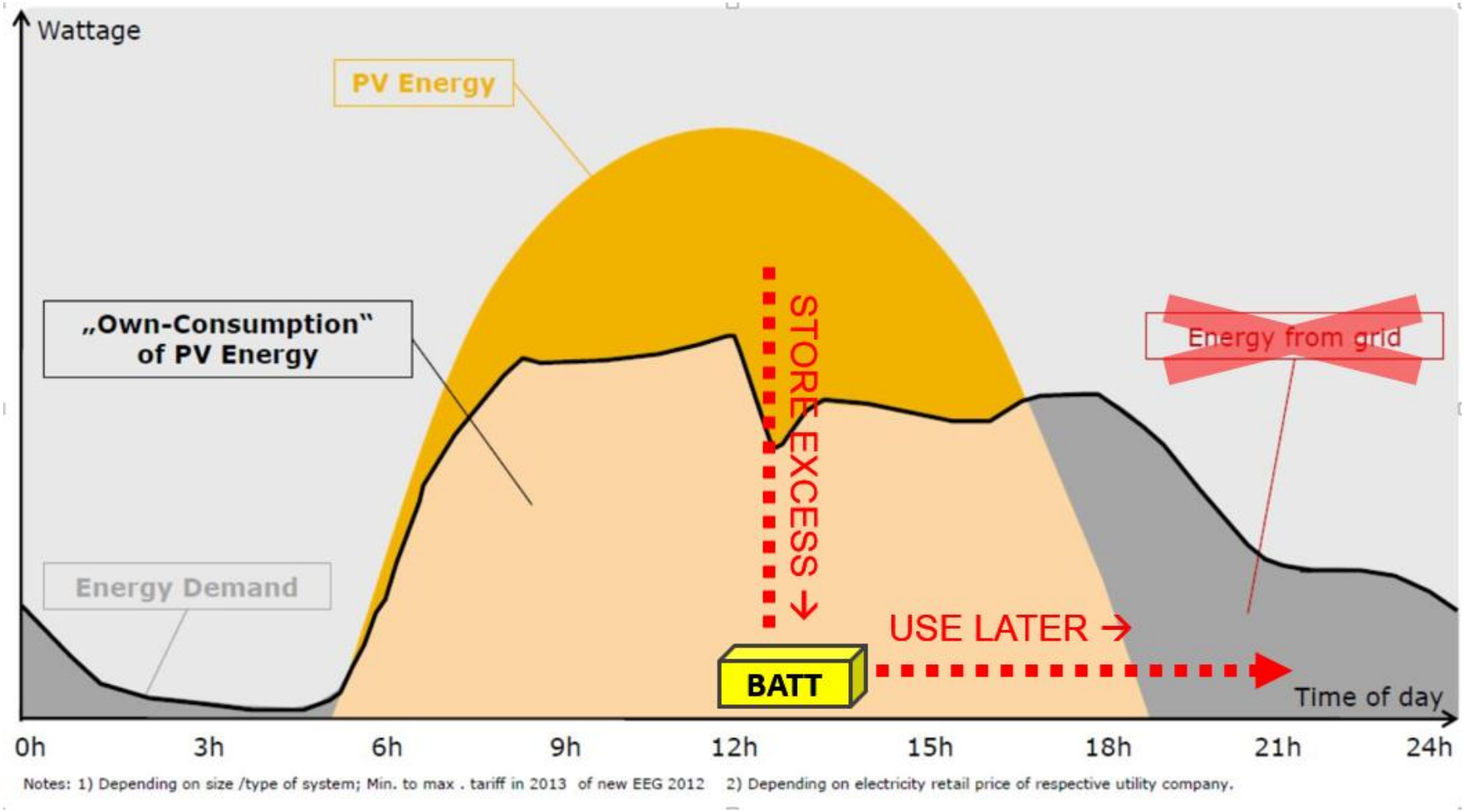

**Net-metering PV system with emergency backup**

# PEAK SHAVING MODE OF PV SYSTEM




Notes: 1) Depending on size /type of system; Min. to max . tariff in 2013 of new EEG 2012 2) Depending on electricity retail price of respective utility company.

# PEAK SHAVING MODE OF PV SYSTEM




Notes: 1) Depending on size /type of system; Min. to max . tariff in 2013 of new EEG 2012 2) Depending on electricity retail price of respective utility company.

# Concluding remarks

1. Highly efficient DC appliances have the potential to dramatically increase the affordability of off-grid PV systems by reducing the size of the systems required. For example, the combined power requirement of a highly efficient color TV (28-45W) , DC Freezer (60-80W) and DC LED lamps, a Mobile phone charger, and Radio (approximately 10W) can be supported by a small solar power system 200-250W.
2. Price declines and efficiency advances in LED technology are already enabling rapidly increased use of small off-grid lighting systems
3. Similar progress is also possible for larger household-scale solar home systems that power appliances such as lights, TVs, Fans, Freezer, Radios, and mobile phones all together.
4. When super-efficient appliances are used, the total cost of PV systems and their associated appliances can be reduced by as much as 50% by now.

These findings have critical relevance for efforts to provide modern energy services to the 1.2 billion people worldwide without access to the electrical grid and one billion more with unreliable access. However, policy and market support are needed to realize rapid adoption of Lithium battery technology and Super-efficient appliances.

# Concluding remarks (continued…)

The impact of off-grid renewable energy systems will not only be measured in terms of their usage or reduced costs for electricity consumption in remote areas and developing countries

Off-grid renewable energy systems are not only urgently needed to connect this vast number of people with a source of electricity, but are also most appropriate for many applications due to geographical constraints and costs for grid extension.

Off-grid systems could become an important vehicle to support the development of renewables-based mini-grids, which are increasingly considered an option to improve energy security, power quality and reliability, as well as to avoid power blackouts due to natural disasters

# Thank you for your attention

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