Workshop on Promoting Renewable Energy and Sustainable Development in Myanmar

Development, technologies and policies for photovoltaic generation and micro-grid in China

HUANG Lei, huanglei@ms.giec.ac.cn

Laboratory of distributed generation and microgrid

GIEC, CAS

June 7, 2018

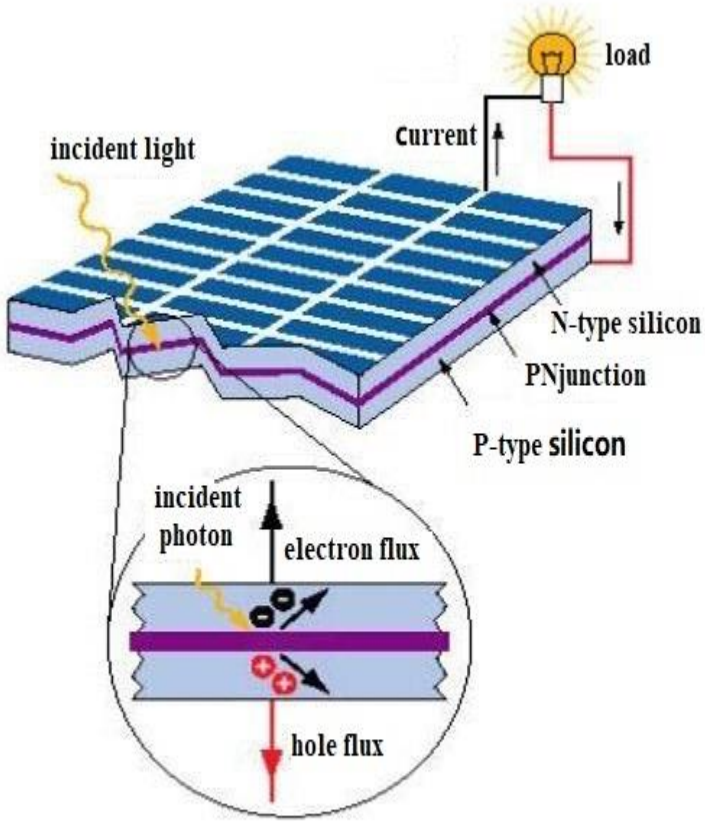
Outline

- 1. Brief introduction of PV generation
- 2. Development of PV generation in China
- 3.PV generation technology
- 4.PV Microgrid technology
- 5.PV generation policies in China

1. Brief introduction of PV generation

- **Introduction**

- Solar energy utilization technology: photo-thermal, PV generation and photochemical technology.
- The principle of PV generation technology: using the principle of photovoltaic effect of semiconductor devices to carry out photoelectric conversion, the conversion device (solar cell) to convert solar radiation energy into electric energy.
- From space to the ground: It took nearly 40 years.
- The characteristics of PV generation: safety, no noise, no pollution, short construction period, arbitrary installation, simple maintenance, and unattended operation.



Principle diagram of solar power generation

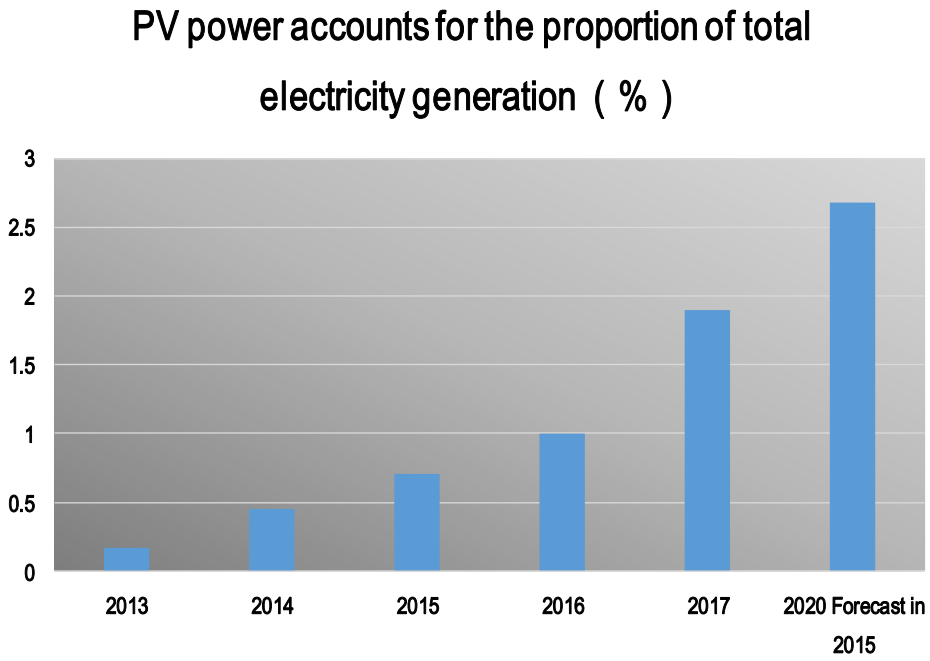
2. Development of PV generation in China

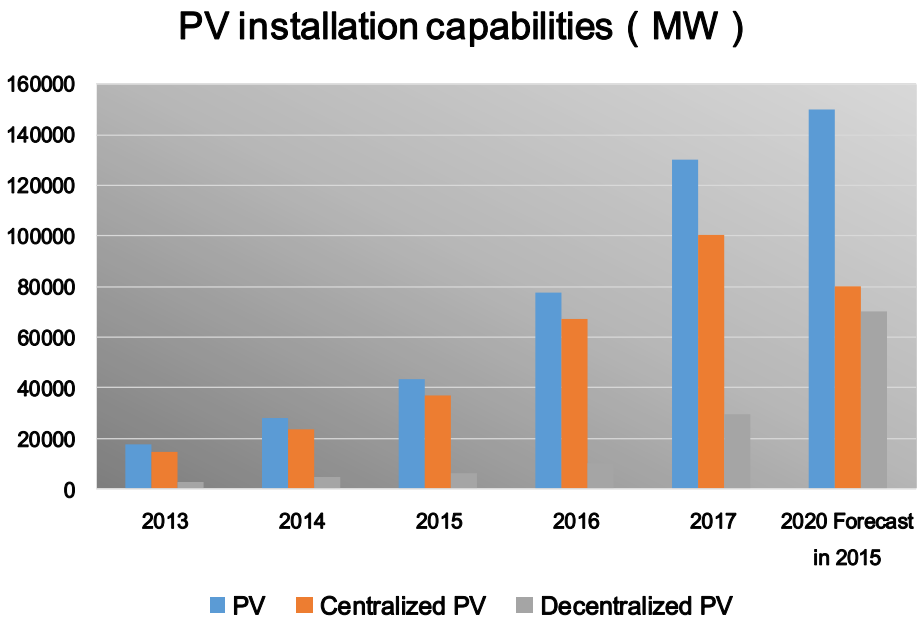
- **Brief history of PV generation application**

Years	Short description	Details
Before 2000	Exploratory	1) 1958, first mono-silicon PV cell in CN 2) 1975, first solar PV cell factory 3) 1998, first 3MW Poly-silicon PV cell and application system pilot
2000 ~2008	Start	2001, 10MWp PV cell production line is founded
2009 ~2011	"Gold sun projects"	1) 2009, China became the world's largest solar cell producer 2) Since 2009 , "golden sun project", "BIPV demonstration" 3) large scale PV station concession tendering and 50% initial investment subsidy for distributed PV
2012	Setback	2012 ，the United State started "double reverse"
2013 ~2015	Warmer	1) The State Council issued some favorable policies. It was clear that by 2015, the total installed capacity will be more than 35GW 2) By the end of 2015, China became the world's largest PV installation country with 43 GW PV installation
2016 to present	Boost	1) China's PV installation boost in the 13th Five-year plan 2) 2017, 52.8GW additional PV installation

2.Development of PV generation in China

- Installation capacities and generation ratio in the last five years

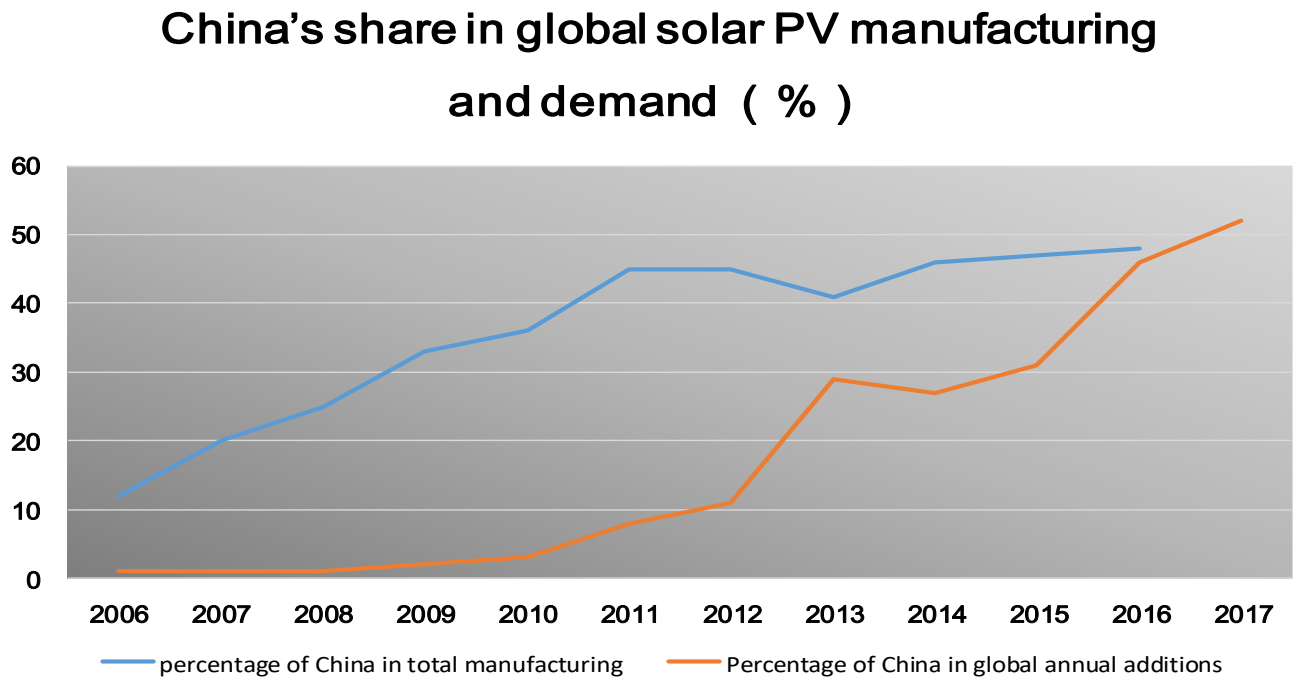




Source: National Energy Administration

2.Development of PV generation in China

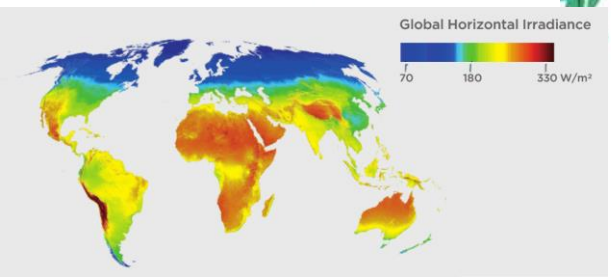
- China's share in global solar PV manufacturing and demand



Source：Renewables 2017, IEA

2.Development of PV generation in China

- Global renewable auctions overview



Asia-Pacific

Countries with auctions programmes or renewable energy tenders

Onshore wind bids

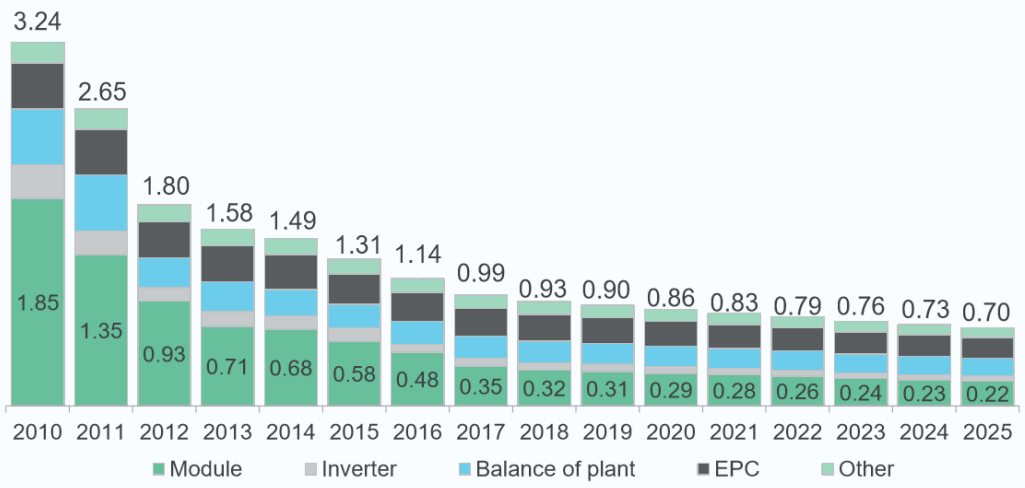
Solar PV bids

Source：Bloomberg New Energy Finance; Future Energy & Finance ASIA Risks and Returns in Solar Investments (Conergy)

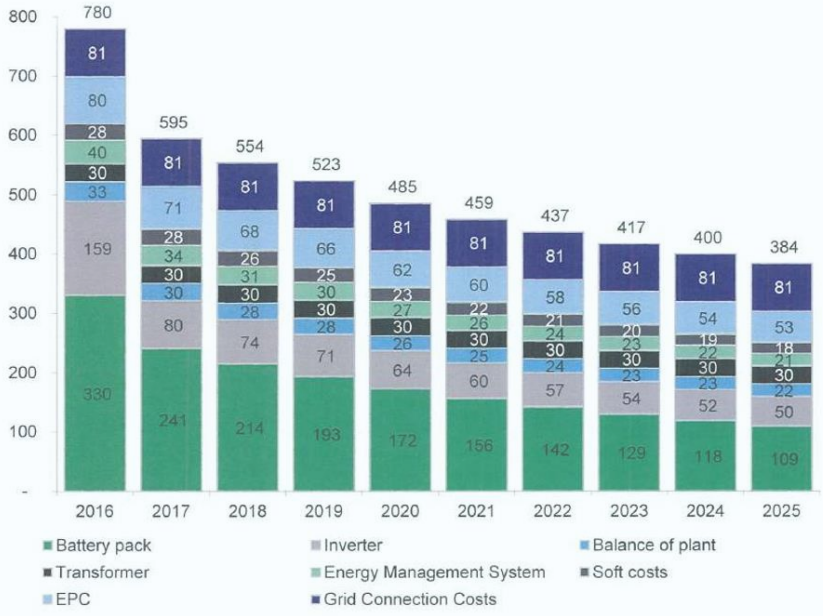
2.Development of PV generation in China

- **Prediction**

Price benchmark for fixed-axis utility-scale PV systems, 2016 $/W(DC)



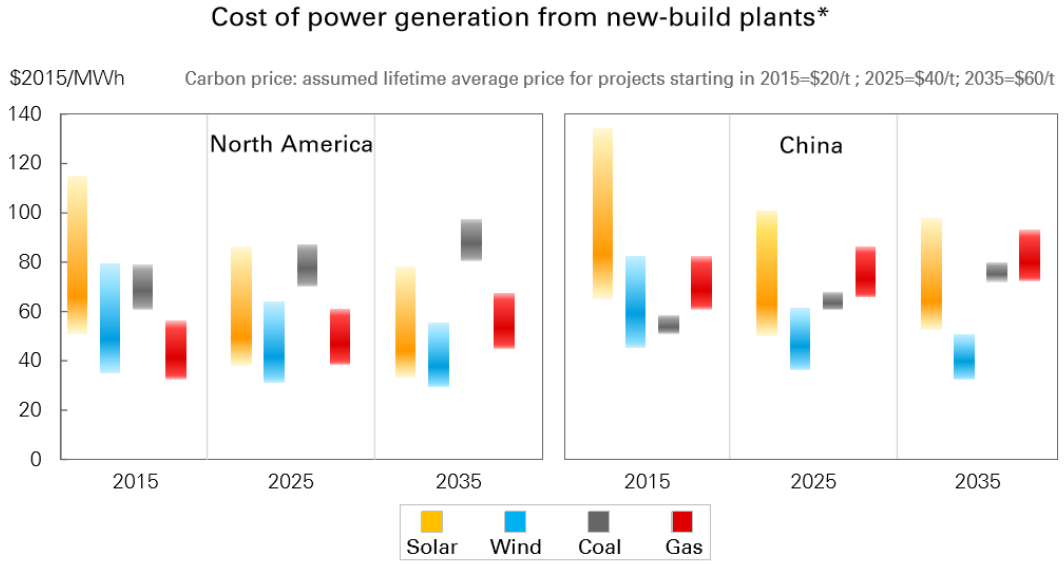
Utility scale lithium-ion battery system costs (2016 USD / kWh)



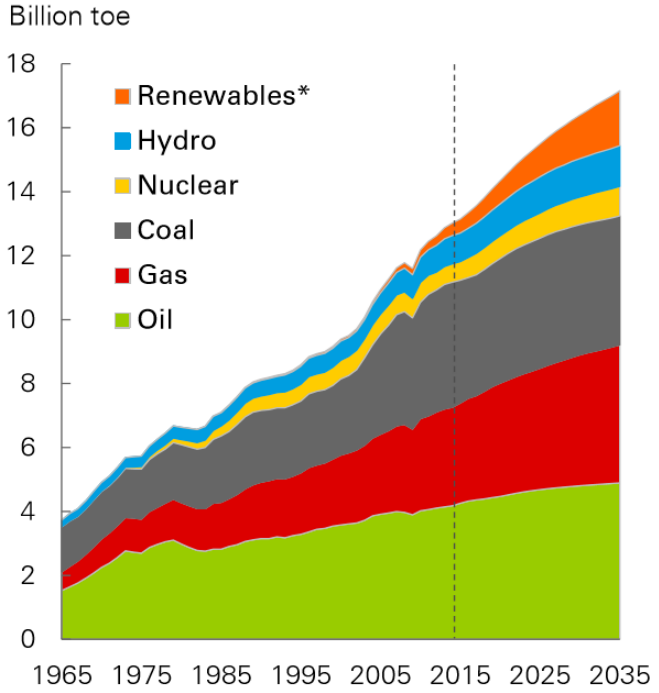
Source:Bloomberg New Energy Finance, 2016
; Bloomberg New Energy Finance – Grid-Scale batteries in Australia, 2017; Future Energy & Finance ASIA Risks and Returns in Solar Investments(Conergy)

2.Development of PV generation in China

- **Prediction**



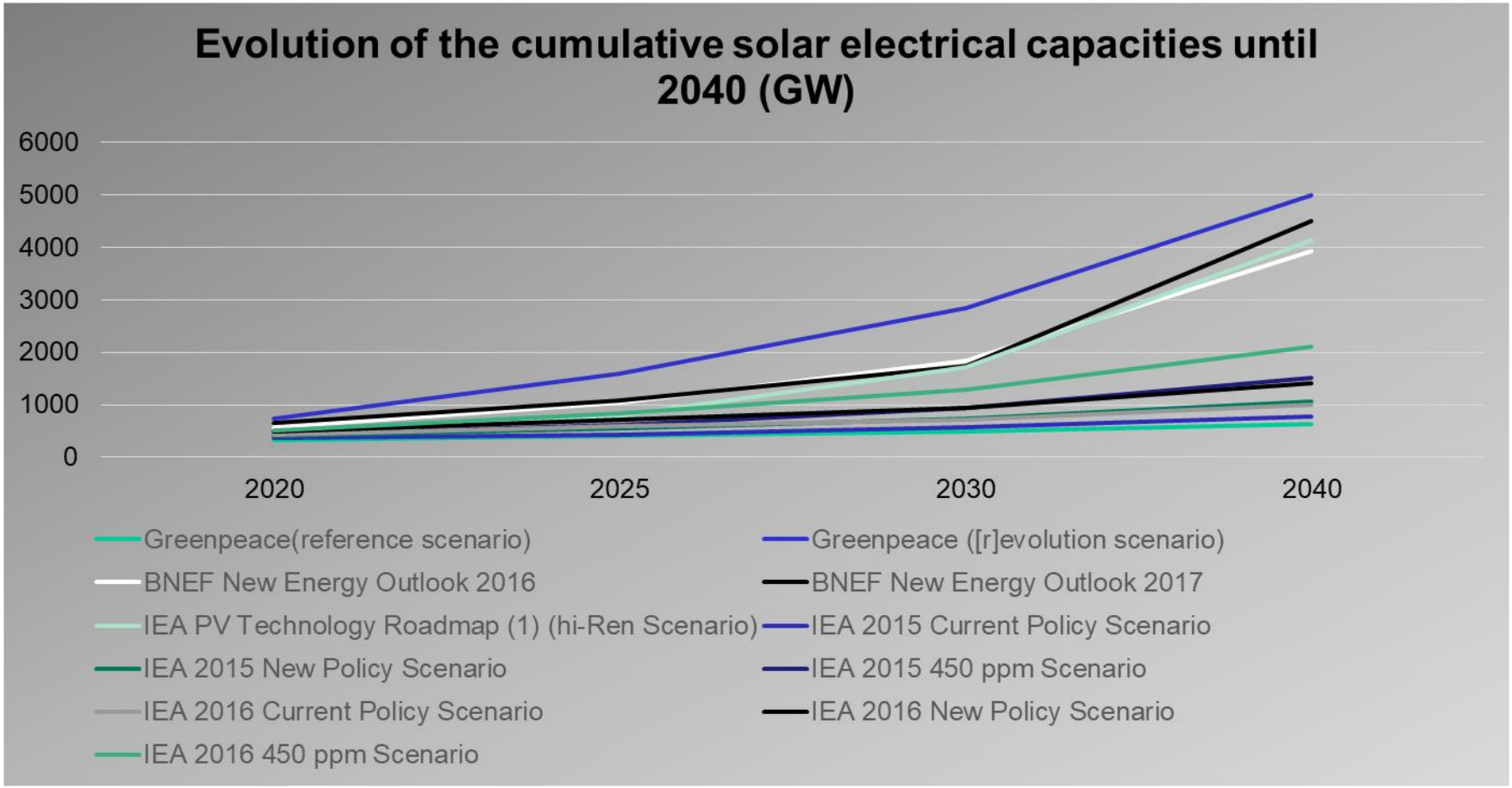
*Levelized cost of power over the lifetime of a plant. Ranges reflect the impact of low/high estimates for: cost of capital; load factors for solar and wind; fuel prices for gas and coal. Solar and wind include estimates of system integration costs



Source：BP Energy Outlook 2017 edition; Bloomberg New Energy Finance

2.Development of PV generation in China

- Prediction



Source：PV Status Report 2017

3.PV generation technology

- Solar cell types

	Types	Efficiency	Features
The first generation solar cells (crystalline)	Mono-silicon	Avg. 20.5	Commercialize, high efficiency, medium cost
	Poly-silicon	Avg. 18.8	Commercialize, diversify
The second generation solar cells (thin-film)	Amorphous silicon	Avg. 13%	Low cost, efficiency decay
	Dye-sensitized (DSSC)	Avg. 12%	Low cost, unstable
	Copper indium selenium (CIS)	8~12%	Indium is rare metal
	Organic	Avg. 6.5%	Flexibility, unstable
	Gallium arsenide (GaAs)	Above 30%	High efficiency, high cost
The third generation solar cells	Quantum Dots	concept	Theoretical limit efficiency up to 68%
	Hot-carrier	concept	

3.PV generation technology

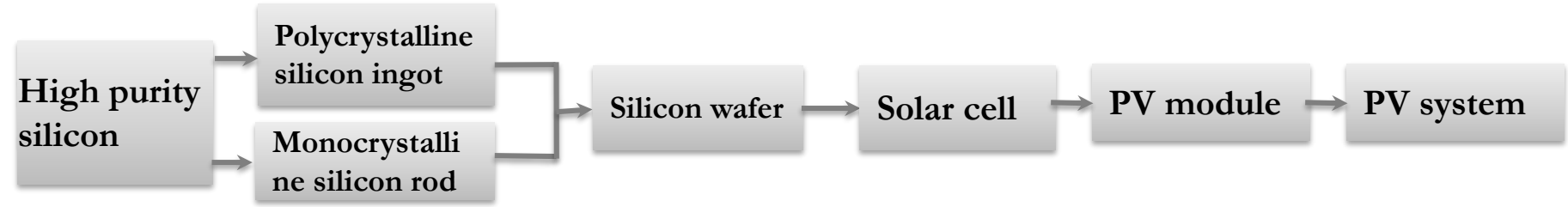
- **Solar cell market**

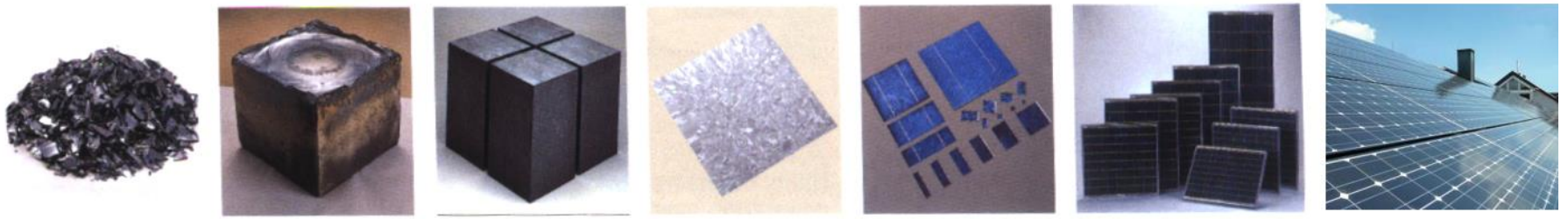
  - Silicon occupies the largest market share .
  - Silicon PV cell development: thinner, larger size, higher efficiency.
  - Thin film PV cell (CIGS, a-si, CdTe) has a small market share

	Silicon	Amorphous silicon	CIS /CIGS	GaAs
Highest efficiency	24%	13%	21%	20%
Commercial efficiency	18~20%	6~8%	11~12%	13~15%
Market share	About 95% Mono- 49% Multi-Si 46%	<1%	2%	3%

3.PV generation technology

- Silicon PV industry chain





Upstream

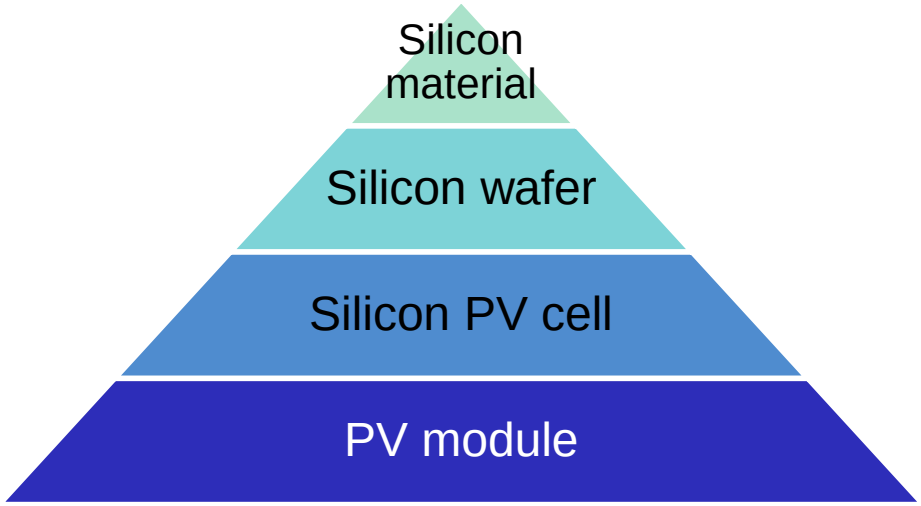
Mid-stream

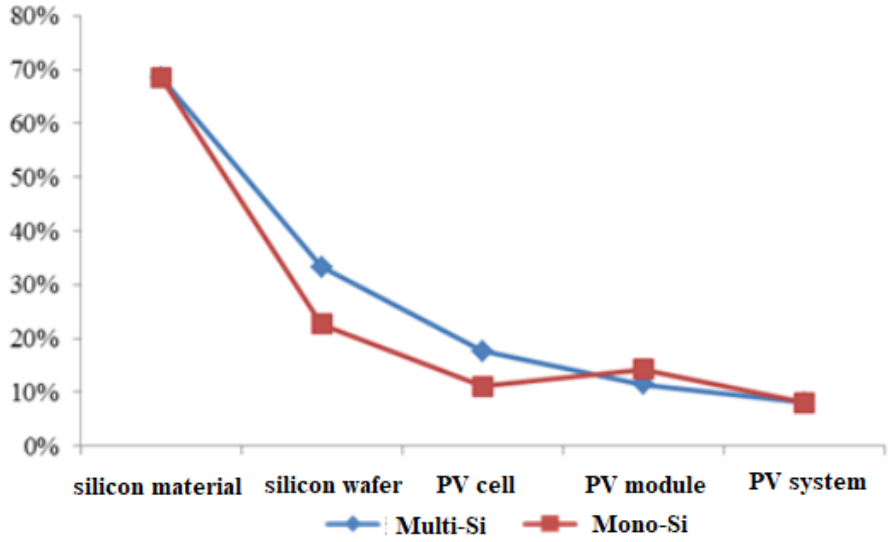
Downstream

3.PV generation technology

Silicon PV industry chain

- Silicon material technology is the key link of the PV industry with the highest profit.
- In 2017, China's production of polysilicon : 242 thousand tons, silicon wafer: 87GW, PV cell: 68GW, PV module: 76GW.
- China is the world's top producer accounted for more than 50% of the total scale of production .

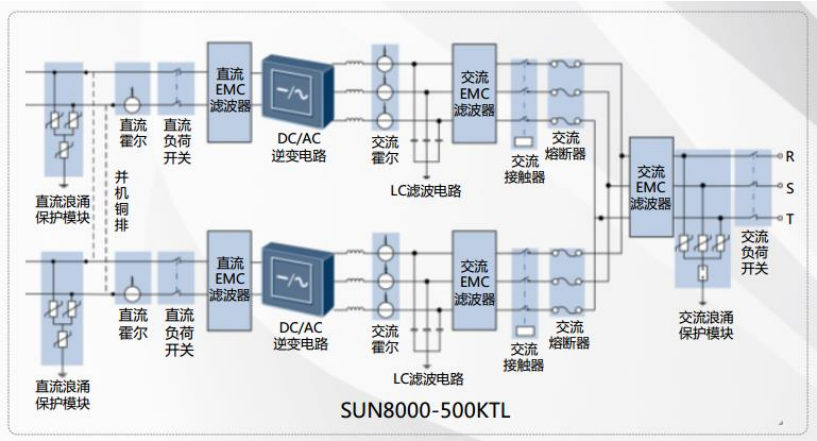




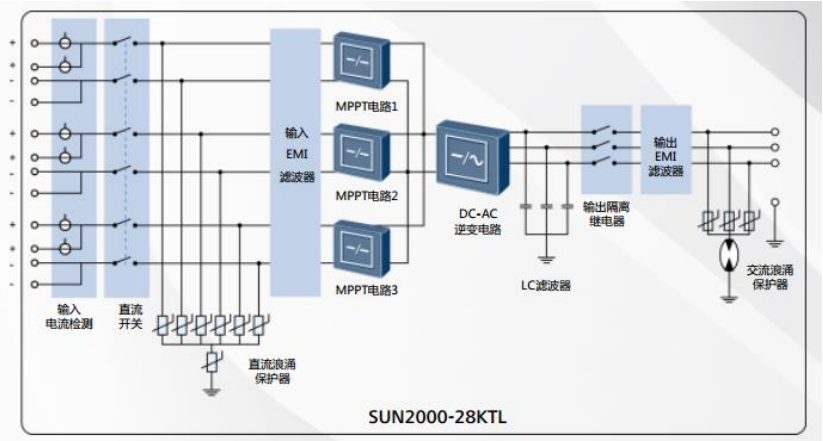
3.PV generation technology

- **PV inverter types**

Attribute	Central Inverter	String Inverter
Capacity	Up to 4 MW-AC	25 to 125 kW-AC
Installation	Concrete pad or steel skid, crane lift	Rack mountable, 2 person lift
Design	Isolation Transformer, typically grounded, air or liquid cooled	Transformer-less, typically floating ground, air or convection cooled
Cable losses	Shorter AC cable runs	Shorter DC cable runs
Grid Interaction	Advanced Inverter Functions (e.g. frequency/voltage control, reactive power compensation, etc.)	
Unplanned Maintenance	Service failed component in the field	Remove failed component, send to factory for possible refurbishment
Design Life	10 to 25 yr with refurbishment	+20 yr, limited (or no) field service
Maximum Power Point Tracker (MPPT)	Single or Multiple	Multiple
Warranty	~5-10 year	~10 year



Central inverter



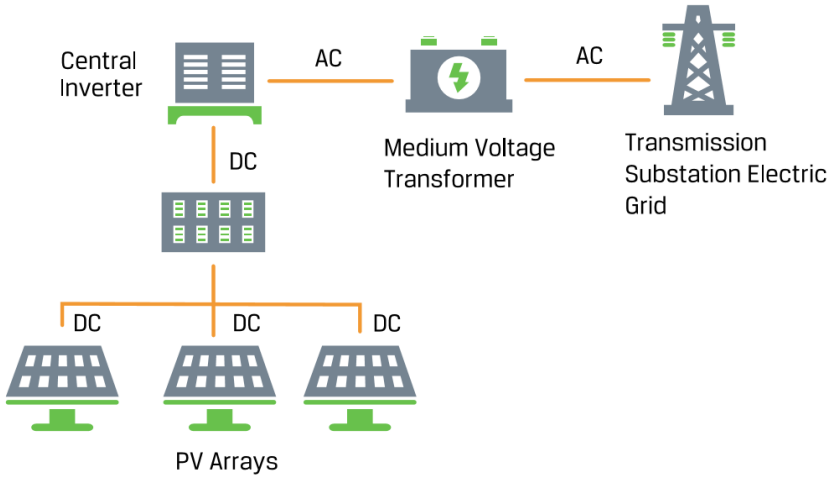
String inverter

Source：ICF.com, A Guide to Choosing Central Versus String Inverters

3.PV generation technology

- **PV inverter application scheme**

Central inverter is generally used in large power plants with uniform sunshine, desert power stations, ground PV stations and other large power generation systems.
The total power of these system is usually in the megawatt scale.

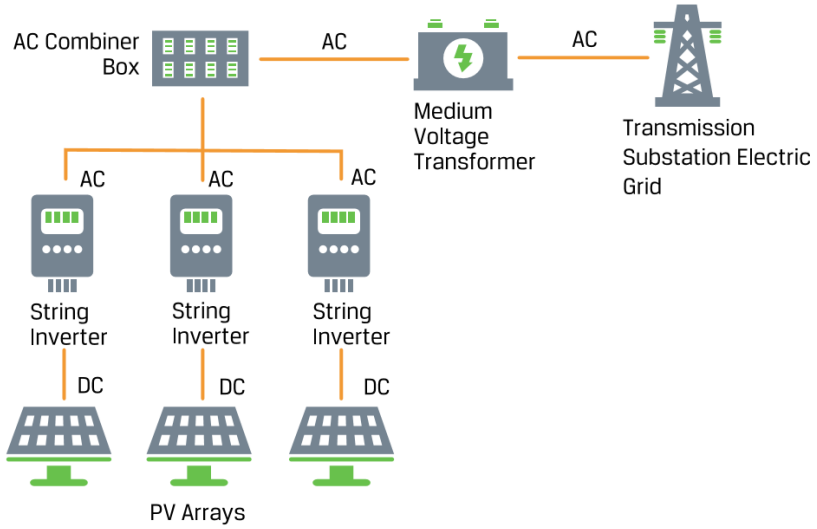


Main features	Main drawbacks
Easy management of inverters	High failure rate of combiner box
High reliability	Narrow MPPT range, short generation time in cloudy day
Low harmonic	Inverter room requirement
Low inverter price	Complex system maintenance
High security	Low efficiency under partial shaded condition
Good regulate ability	No redundant ability

3.PV generation technology

- PV inverter application scheme

String inverter is generally used in medium and small scale BIPV system and small ground PV station.



Main features	Main drawbacks
Increased generation	Lower reliably
Wide MPPT range	Lower security
Small size and light	Higher harmonic
Easy transport and install	High difficulty in monitoring
Small fault impact and Low power consumption	Difficult to achieve functions such as power regulation when multiple machines run in parallel
Easy maintenance	

3.PV generation technology

- **PV inverter application scheme**

Simple recommend configuration

System capacity	Recommended inverters	Instructions
<400kW	String inverter	Similar investment cost, string inverters have a higher efficiency
400kW~2MW	String inverter	String-inverter system cost is higher then central-inverter system. But String-inverter system generation is higher. The total income of string-inverter system is higher.
2MW~6MW	Uniform irradiation area: centralized inverter non-uniformity irradiation area: string inverter	Chosen according to application areas
>6MW	centralized inverter	Centralized inverter meet the grid requirement

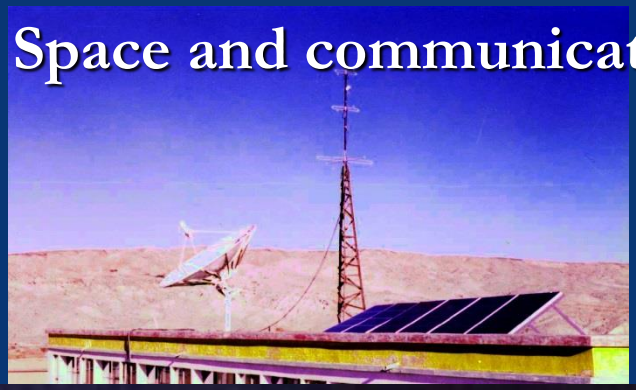
3.PV generation technology

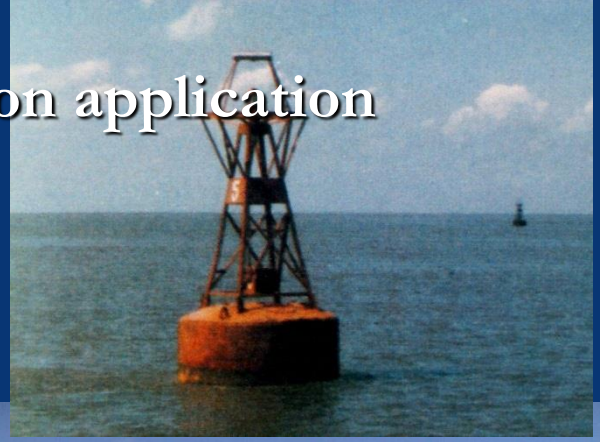
- **PV system classification**

  - **PV system Classified by operation mode**

Stand-alone PV system	Grid-connected PV system	Distributed multi-energy system
PV emergency power supply	Household PV system	Wind/PV hybrid system
Island PV system	Large-scale grid connected system	Wind/PV/diesel/storage
Remote area PV station	BIPV grid-connected system	PV/biomass CCHP
PV lighting system	Farm and PV system	PV/storage AC/DC hybrid system
Space and communication application PV system	PV shed	……

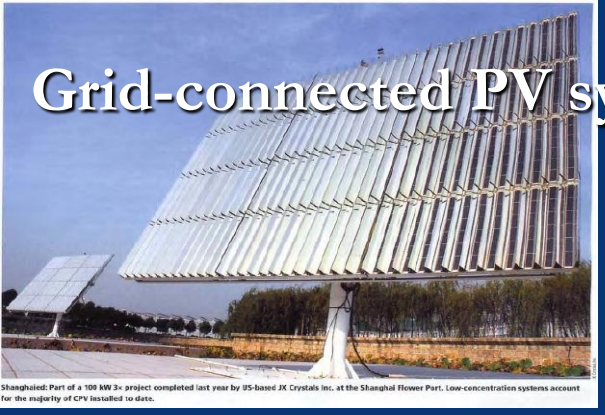
Space and communication application



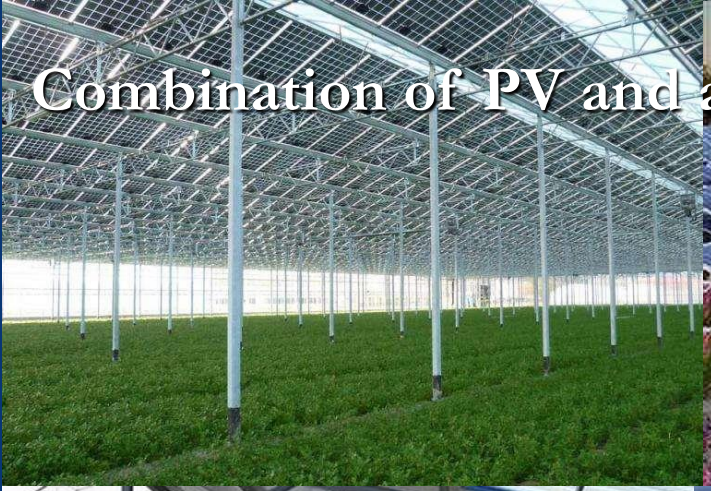
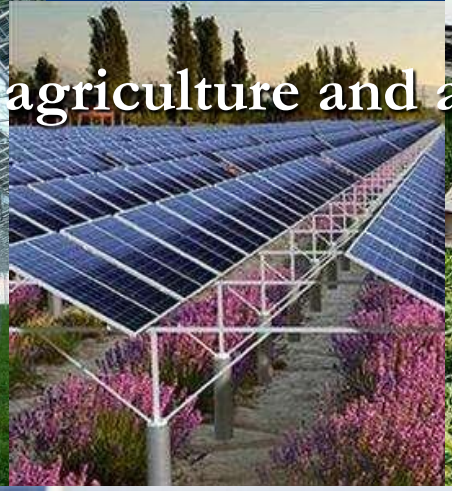


Stand-alone PV system

Grid-connected PV system


Shanghaied: Part of a 100 kW 3× project completed last year by US-based JX Crystals Inc. at the Shanghai Flower Port. Low-concentration systems account for the majority of CPV installed to date.

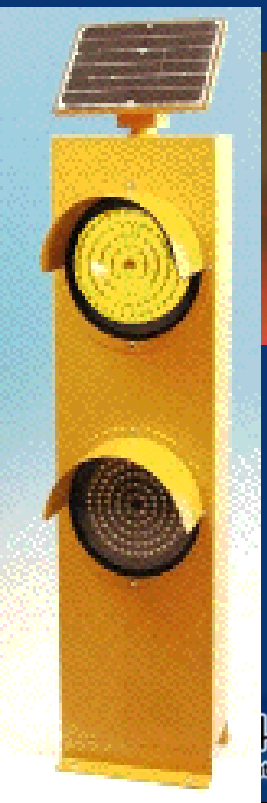
Combination of PV and agriculture and animal husbandry

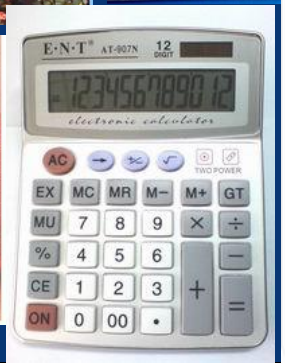








PV electronic and lighting products





3.PV generation technology

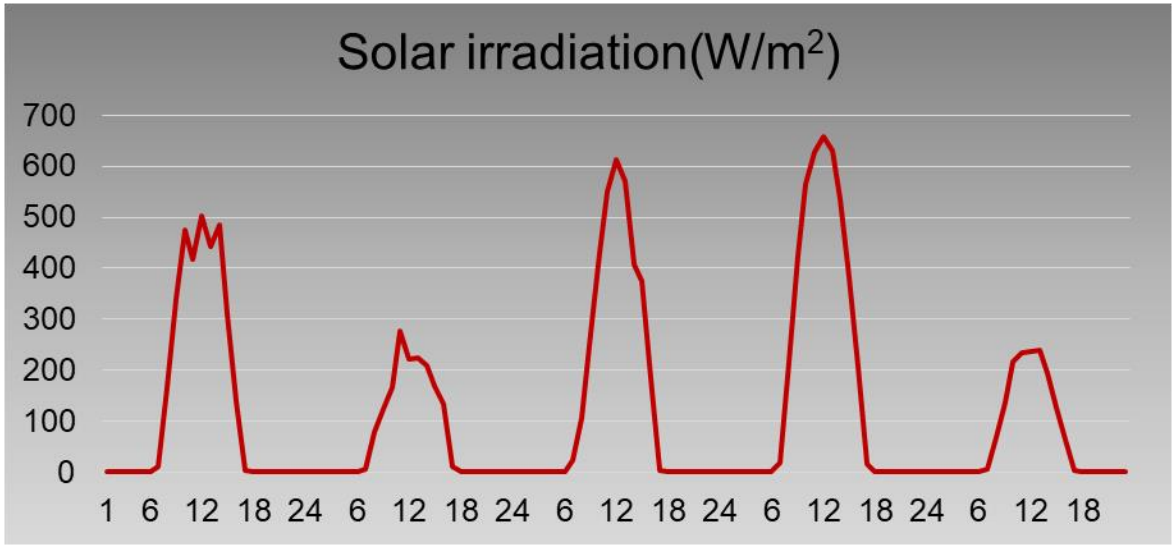
- **Grid-connected PV system investment（>1MW）**
  - ➢Investment＜7000RMB/kWp
  - ➢Annual maintenance cost≈ Investment×（0.1~0.3）%
  - ➢system efficiency>80%

Category	Investment/RMB	Ratio（%）
PV cell(including racket)	0.35	62.00
Inverters (above 10kW)	0.1	10.00
Distribution box and cable	0.1	10.00
Installation and debugging	0.1	10.00
Tax and others	0.05	8.00
Total	0.7	100

4.PV Microgrid technology

- **The necessity of implementing PV by Microgrid technology**

- **PV generation characteristic：stochastic and intermittent RE**
- **Influence to the utility grid**
  - Increase scheduling difficulty and reserve capacity
  - Change the demand side characteristic and Causes voltage rise
  - Power harmonic pollution due PV inverters
  - Affect operation schedule, safety and relay protection of the utility grid

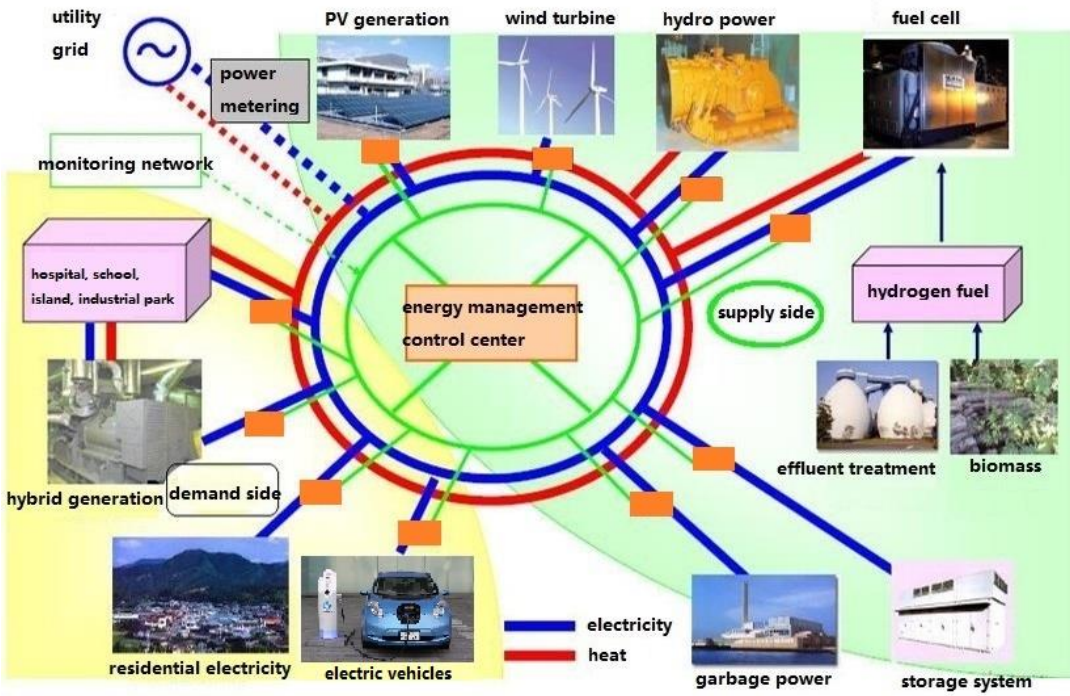


4.PV Microgrid technology

- **Generation**
  - ➢ Controllable generation sources

    combustion engine, micro gas turbine, micro-turbine, fuel cell, etc.
  - ➢ Uncontrollable generation sources

    PV generation, wind turbine, tidal power generation, etc.
- **Inverters and bi-directional converters**
- **Energy storage**
  - ➢ Battery, super capacitor, fly wheel, etc.
  - ➢ Plug-in electric vehicles
- **Software**
  - ➢ Energy management and integration with building automation
  - ➢ Grid aggregation and dispatch
- **Project finance and execution**
- **Operation and maintenance**



Anatomy of a Microgrid

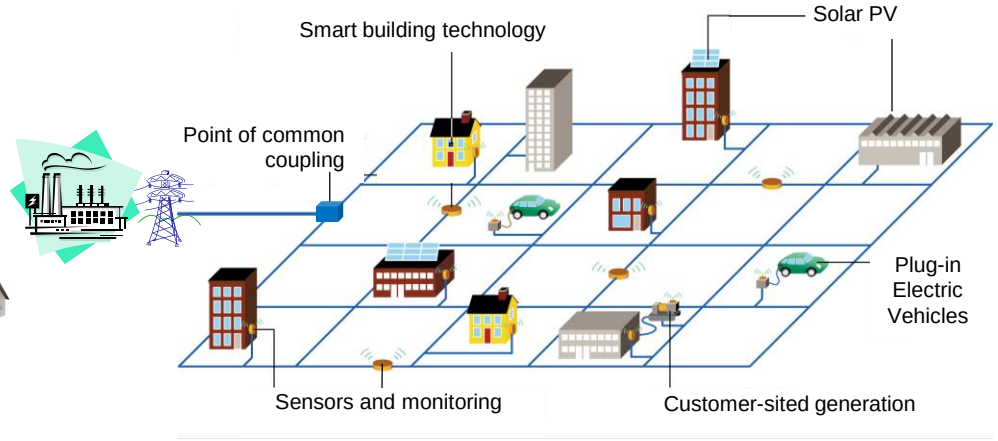
4.PV Microgrid technology

- **Differences between microgrid and utility grid**

Traditional grid structure

- High voltage and transmission line
- Customers receive electricity
- Dedicated networks with limited resources
- Grid as a sole source
- Real-time data/control

Microgrid structure



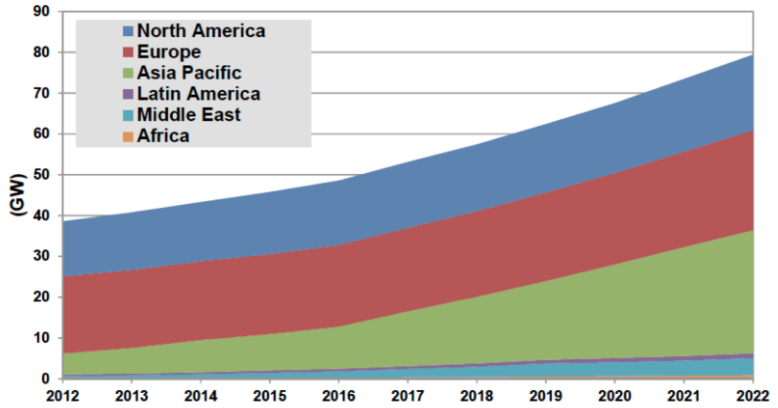
- Low voltage and near demand side
- Customers receive/feed electricity
- Networks with shared assets and layered customer resources
- Grid as a back-up source and two-way flow
- Increased real-time data/control
- Including renewable resource

4.PV Microgrid technology

- **Trends & Outlook**

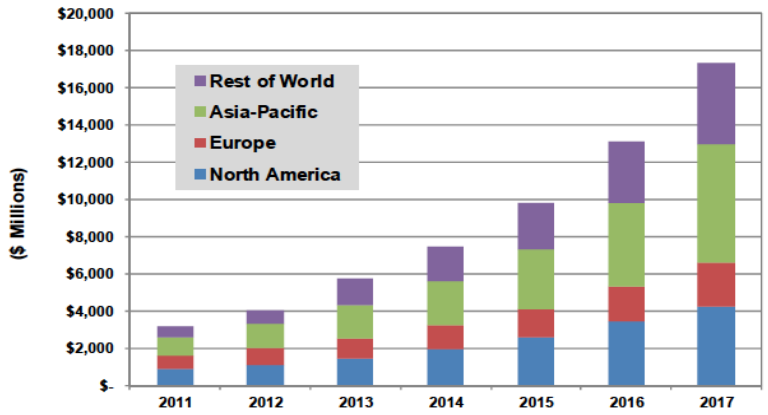
  - **According to Pike Research**
    - ➢ CHP installed capacity is projected to double by 2022 to 80 GW
    - ➢ North America is currently the largest region for microgrids
    - ➢ The Asia Pacific region will likely emerge as the global leader for microgrid deployments by 2030 or 2035
    - ➢ the Most Numerous Category of Microgrid Projects：Remote Microgrids
    - ➢ Energy Storage will become a Key Part of Microgrid Deployments in the Decade Ahead

Chart 1.1 comCHP Installed Capacity by Region, World Markets: 2012-2022



(Source: Pike Research)

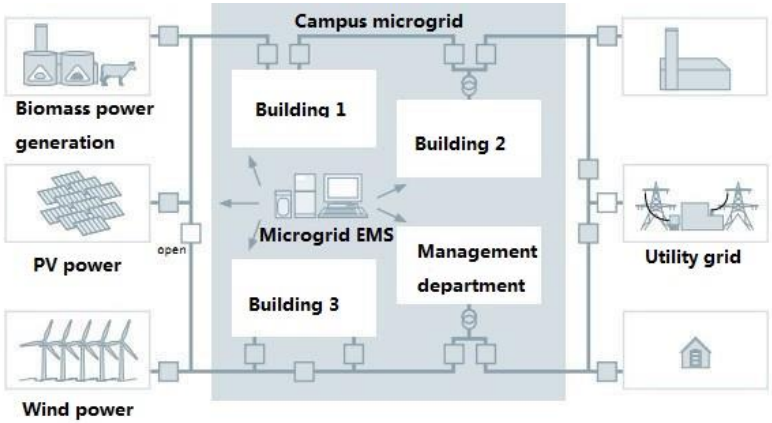
Annual Microgrid Revenue by Region, Average Scenario, World Markets: 2011-2017



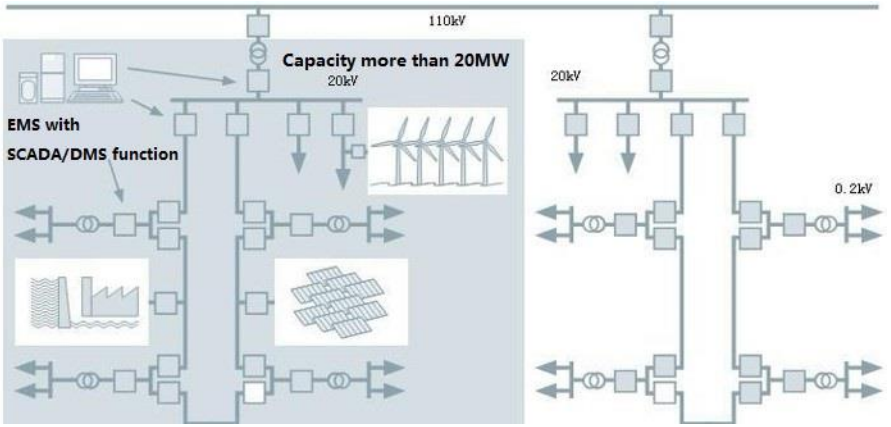
(Source: Pike Research)

4.PV Microgrid technology

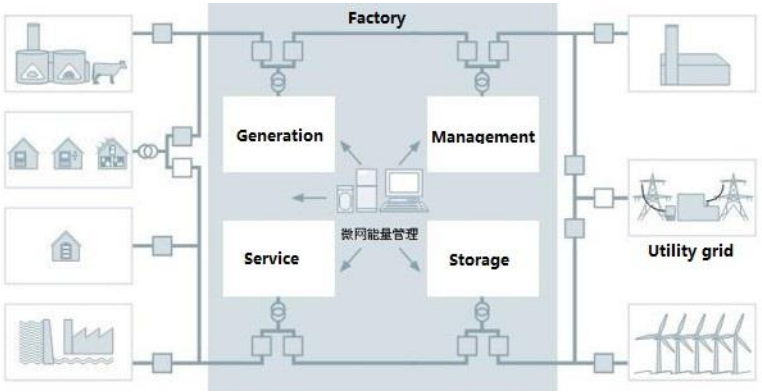
- Microgrid application forms
  - Public institution and campus microgrids



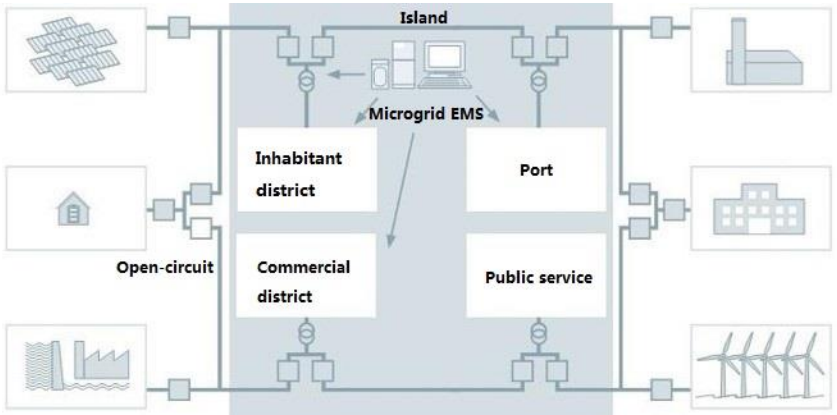
  - Regional and integrated microgrids



  - Commercial and industrial microgrids



  - Island and remote microgrid



4.PV Microgrid technology

- Storage configuration-a key role in PV large scale development

Contribution

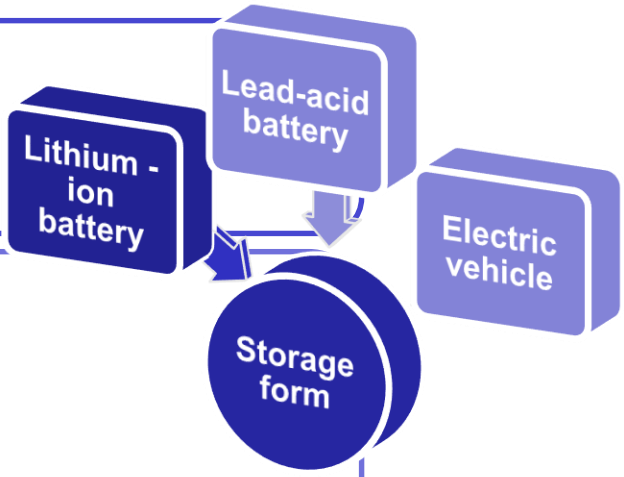
- Improve PV penetration rate
- Improve power quality
- Decrease the life cycle cost of PV system

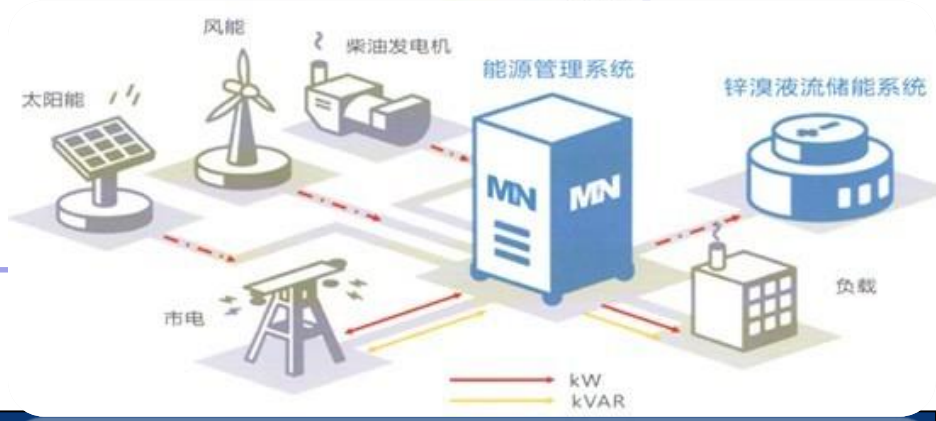
Influence factors

- Loads characteristic
- intermittent RE
- RE generation forecast accuracy
- Demand side requirement

Objective

- Support critical loads
- Maximize RE utilization
- Stabilize fluctuation
- Load shifting





4.PV Microgrid technology

- **Combined heat and power co-generation**

•Generation

- Micro-turbine
- Internal-combustion engine
- PV system

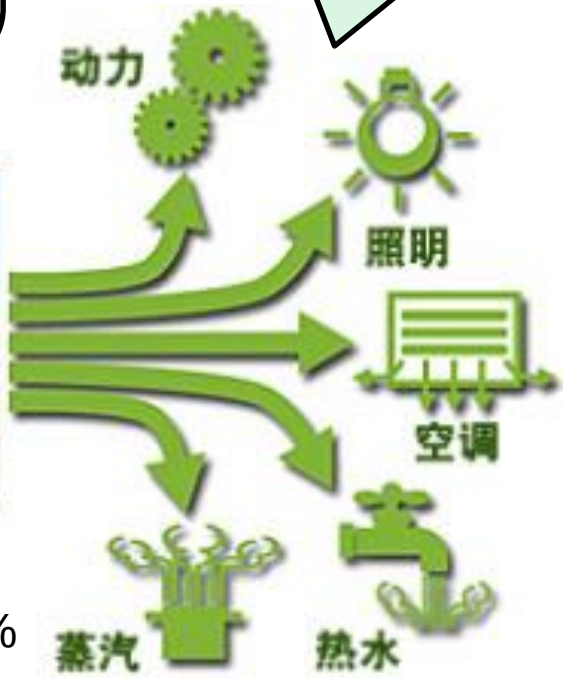
•CCHP

➢Electricity is easy to transmit, hard to store

➢Thermal power is easy to store, hard to transmit

•Thermal storage

Water, ice, gravel, phase-change material



•Thermal utilization

➢Heating, Cooling, hot water, dehumidification

- **Efficiency**

➢ Thermal load 40-45%

➢ Electric load 38-40%

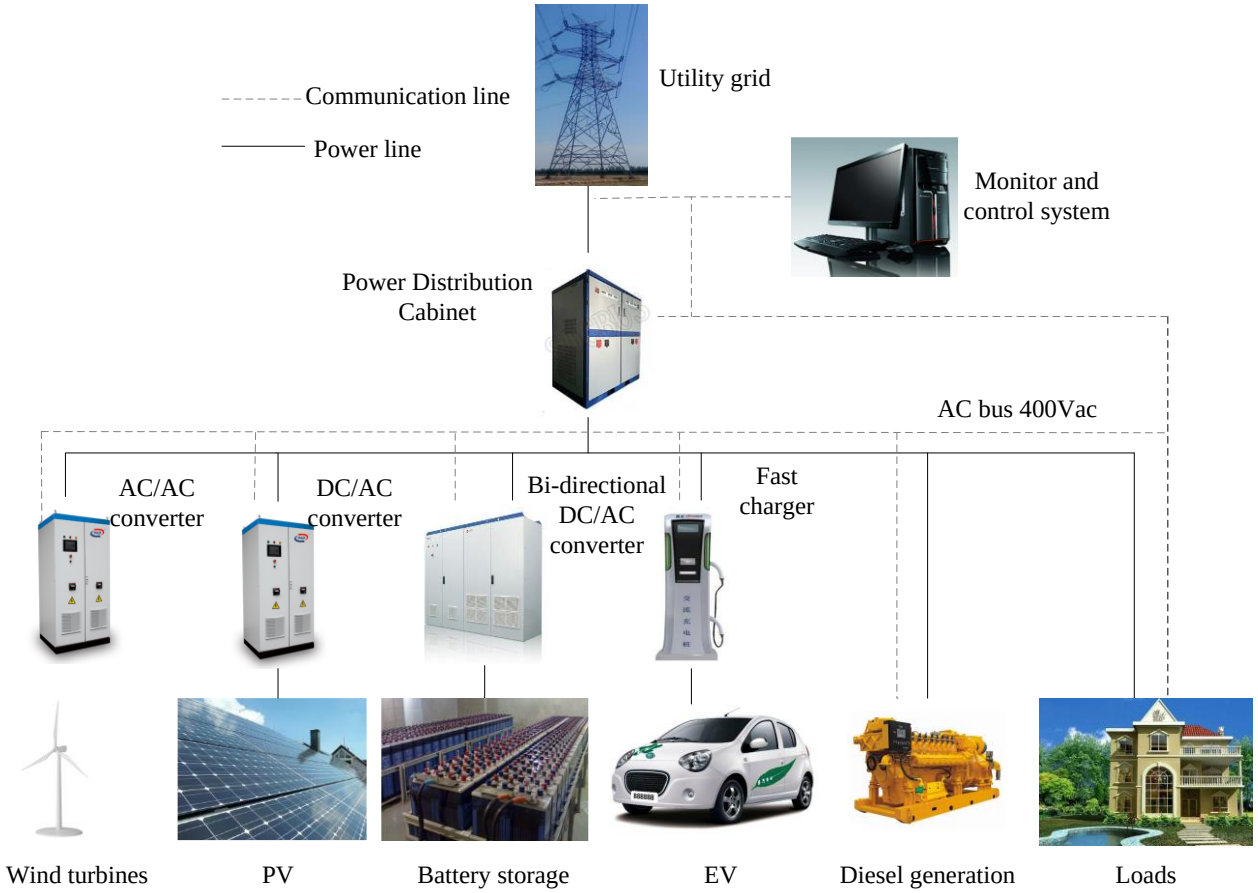
•Advantages

➢Improve energy efficiency

➢Reduce cost

4.PV Microgrid technology

- Electric vehicle microgrid



Applications

Large-scale RE station
Islands
Large-scale villages
Back-up source
Non-electricity area
Load shifting

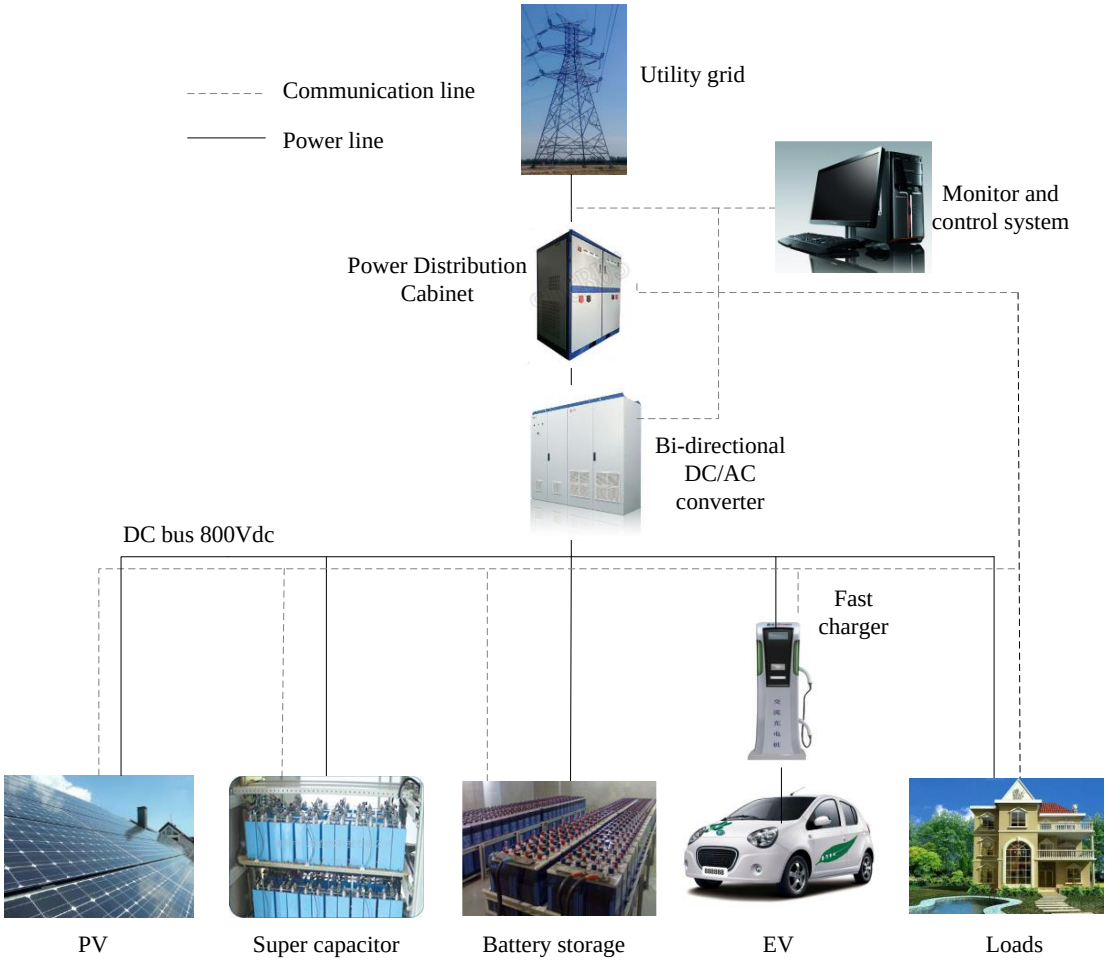
Control strategy

Grid-connected mode
PV, other sources and utility grid supply power
Extra power stored in battery
Off grid mode
PV and other sources supply power coordinately

Combine PV and EV to increase PV utilization and reduce EV effect

4.PV Microgrid technology

- Electric vehicle microgrid



Applications

Small-scale RE station
Off grid villages
Non-electricity area
MG demonstration

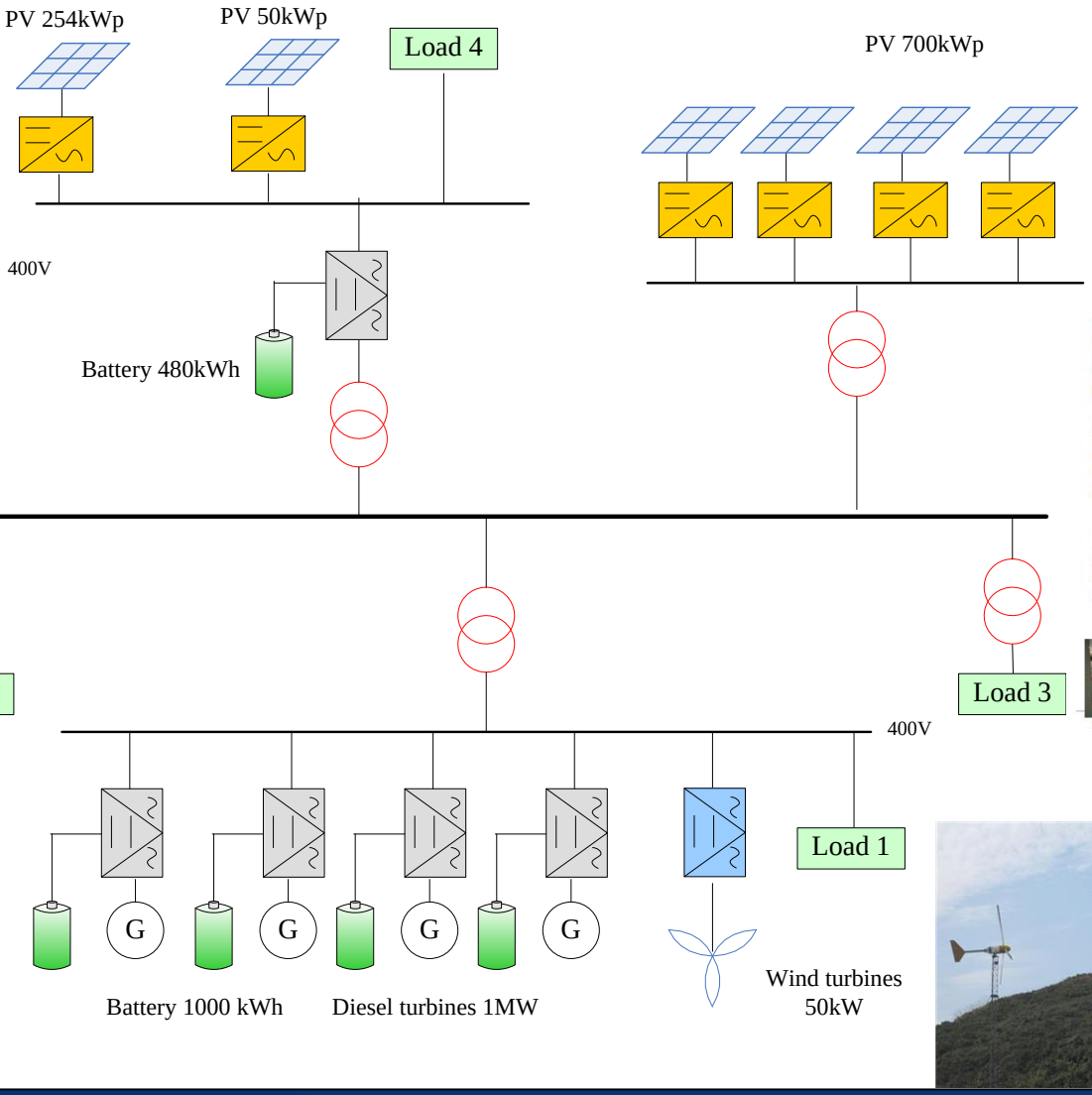
Control strategy

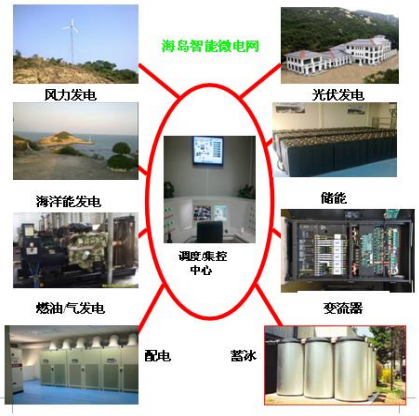
Grid-connected mode
PV, other sources and utility grid supply power
Extra power stored in battery
Off grid mode
PV and other sources supply power coordinately

Combine RE and EV to increase RE utilization and reduce EV effect

4.PV Microgrid technology

- Island microgrid





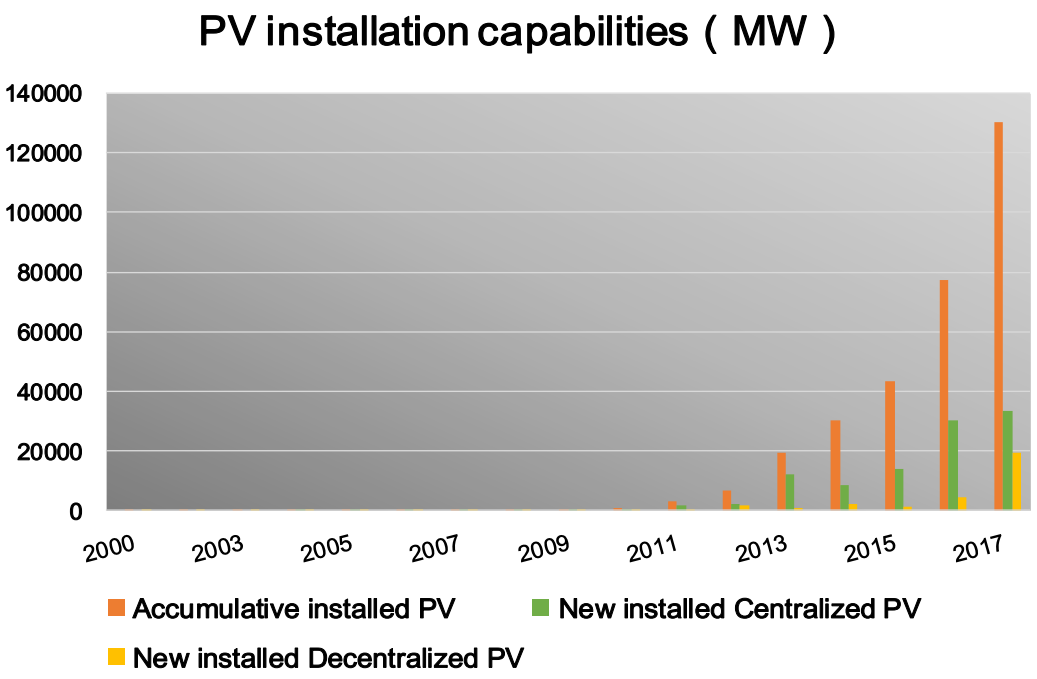
4.PV Microgrid technology

- Selected microgrid projects in China

5.PV generation policies in China

- **Before 2007**, China's early stage of photovoltaic power generation was mainly to solve electricity shortage in the western region. By the end of 2007, accumulative stand-alone PV project is 17.8MW and grid-connected project is 2.2MW.
- **After 2009**, as the implement of "golden sun project" and "photoelectric building application demonstration", the distributed PV market was greatly stimulated.

- **For distributed PV project**, the initial investment subsidy was made since 2009 to 2013, and the electricity subsidy was implemented after 2013 (0.42 RMB->0.37RMB). And the distributed PV installed capacity increased significantly in the 13th Five-Year plan.
- **For large scale ground PV stations**, the subsidy form of benchmarking is adopted since 2008, and the amount of subsidies is divided according to regional resources and varies from different periods.



5.PV generation policies in China

- PV generation price and subsidy since 2018

Solar irradiation resource zone	Centralized PV station Feed-in Tariff prices (RMB)/kWh	Distributed PV system PV prices (RMB)/kWh	
		Local consumption	the redundant power back to grid
Ⅰ	0.55	Electricity price + 0.37 （subsidy）	The benchmark electricity price of desulphurized coal combustion + 0.37 （subsidy）
Ⅱ	0.65		
Ⅲ	0.75		

- Key points：
- Centralized PV station and distributed PV system both have FIT prices, and the scales are control by annual planned scale.
- The scale of BIPV and local-consumption PV system project is not limited.

5.PV generation policies in China

- Distributed PV generation project regulation since 2018

	Distributed PV generation project regulation policies
Categories	**1) Household PV system < 50kW** 2) Single point grid-connected < 6MW 3) Local consumption PV system: 6MW~20MW
Regulation and subsidies	1) All DPV is under scale regulation except household PV system 2) Household PV system must be invested by house owner **3) Household PV systems are allowed to all operation mode** 4) Other DPV are not allowed to feedback all PV electricity 5) All three categories are guaranteed of timely payment of subsidies
Influence	**1) Household PV systems are not under scale control** 2) All three categories are guaranteed of timely payment of subsidies
	3) DPV systems without local consumption except for household PV are not included in DPV regulation without guaranteed timely payment 4) DPV systems except for household PV are under scale regulation and reduce market shares
Suggestions	All three categories should have no scale regulation

5.PV generation policies in China

- Distributed generation marketized transaction

	Distributed generation pilot marketized transaction policies
Transaction modes	1) **Direct transaction （recommend）** 2) Commissioned transaction 3) Benchmark price based transaction
Description	1) PV system in pilot transaction areas are automatically incorporated into the scope of subsidies after the construction of the project 2) Grid enterprises are responsible for metering and subsidies transfer 3) National energy administration determined the annual quotas to the end of 2020
Some details	1) All PV projects included in pilot marketized transaction implement fixed electricity price subsidy 2) For direct transaction projects, local consumption > 75% 3) When direct transaction and commissioned transaction fail, the project‘s transaction mode is automatically changed to benchmark price based transaction mode

5.PV generation policies in China

- **Forecast of the PV generation market in the next three years**

	Forecast of the PV generation market in the next three years
1	1) Limit target for ordinary PV 2) PV poverty alleviation is development focus
2	1) Top runner project's annual installation of PV station is 8GW in 2017~2020 2) BIPV and local consumption PV projects is the main develop area in 2018~2020 3) China's PV capacity is huge(>100GW)，and above 50% capacity need to be consumed in China
3	PV market priority: electricity reform project, poverty alleviation project, unlimited-scale distributed PV, top runner project, PV+(hydro, farm, forestry, livestock farming), ordinary PV station

5.PV generation policies in China

	Analysis of the priority in PV generation market
Electricity reform project	1) Has quota 2) No limit on electricity 3) Fix and guarantee subsidy
Poverty alleviation project	1) State key management projects 2) Subsidies are not in arrears.
Unlimited-scale distributed PV	1) Unlimited scale 2) Timely subsidy 3) All electricity feed back to grid or self consumption
Top runner project	1) No problem in land, grid connection and consumption 2) Low transaction cost and fierce competition
PV+(hydro, farm, forestry, livestock)	1) Need quota 2) Subsidy need to be queued 3) No need to bid and no discarding PV generation
Ordinary PV station	1) Large scale and high income 2) Need quota and subsidy need to be queued 3) Discarding PV generation and high transaction cost

THANK YOU VERY MUCH FOR YOUR ATTENTION!

HUANG Lei

huanglei@ms.giec.ac.cn