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Energy Storage Technologies and Applications in Power Systems - Challenges and Experiences

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1 Requirements for Energy Storage

2 Energy Storage Technologies

3 A Demonstration Project Integrated with Large Wind /Solar/Storage and Transmission System

4 Conclusions

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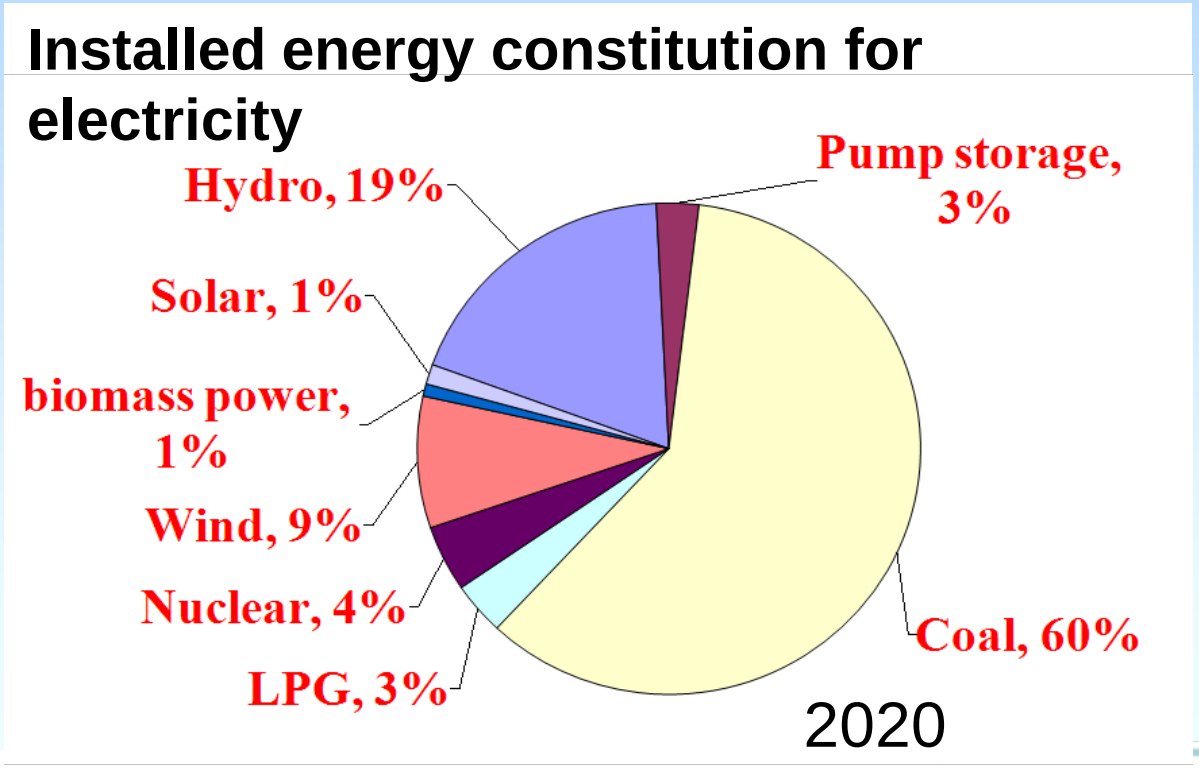
1 Requirements for Energy Storage – Energy Resource Structure

Energy group - Coal and hydro-energy are main energy resources available at present and in the foreseeable future.



1 Requirements for Energy Storage – Energy Resource Structure

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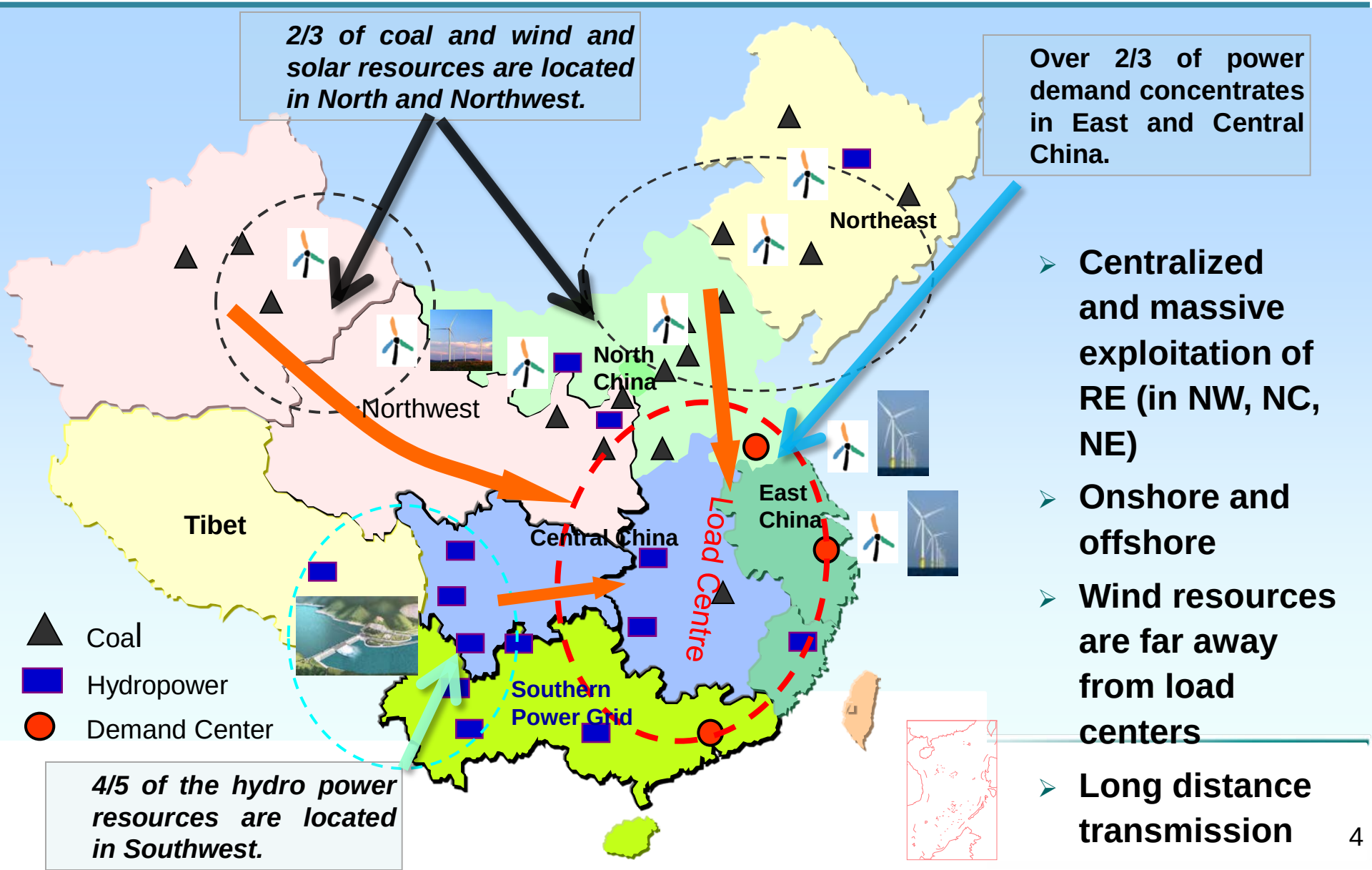

- Centralized and massive exploitation of RE (in NW, NC, NE)
- Onshore and offshore
- Wind resources are far away from load centers
- Long distance transmission

1 Requirements for Energy Storage – Renewable Energy plan

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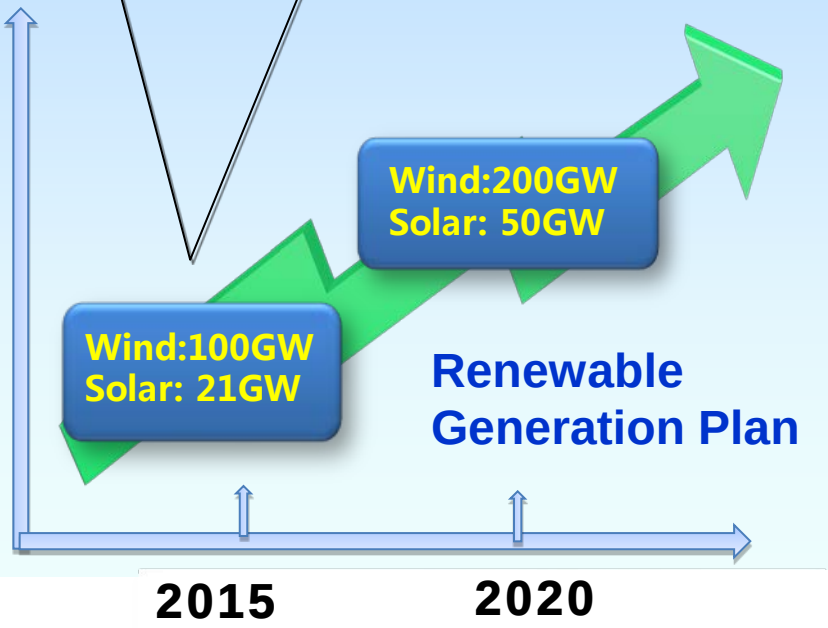
- 80%的风电/太阳能资源集中在我国的三北地区

  80% of wind/solar resources, is located in North, Northeast and Northwest

- Installed Wind Power Capacities in 2015 129 GW
- Installed Solar Power Capacities in 2015 43GW



1 Requirements for Energy Storage – Challenges

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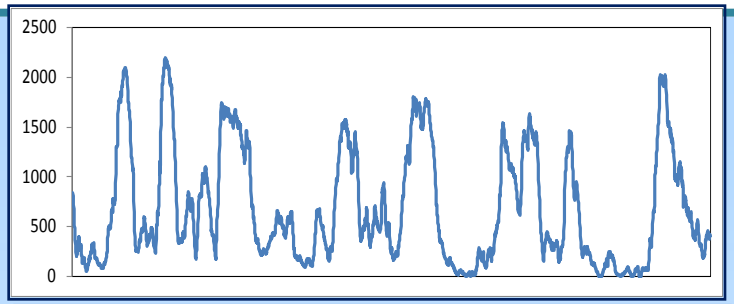
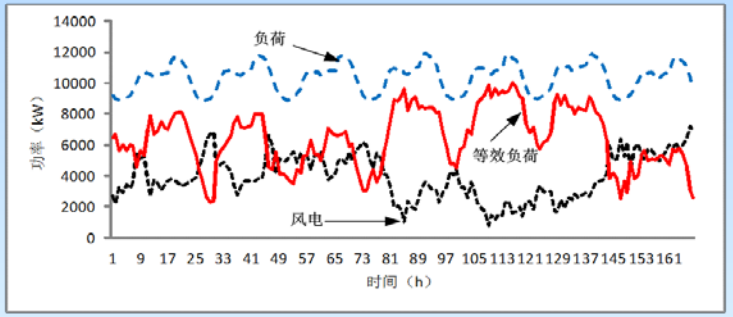
风力/光伏发电特征 Main characteristics of wind power/PV：

- **出力波动性 Generation fluctuation**
- **发电技术 Different generation technology used**
- **分布特性 Distributed characteristics/locations**



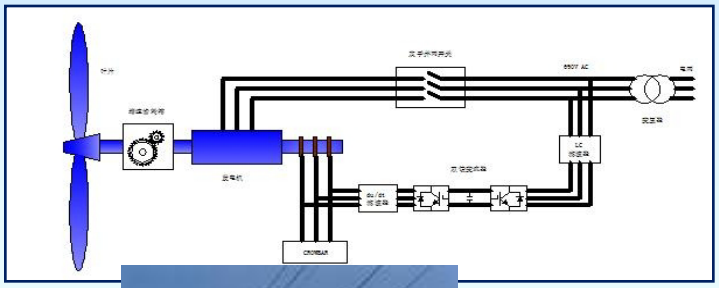


Impacts on Grids

大量风力/光伏发电的并网接入，给电力系统安全稳定运

带来很大挑战 Grid integrations of large wind /solar power bring challenges to operation and stability of grids

- **弱抗扰性 Weak adaptability to disturbances**
- **弱支撑性 Weak support to power grid**
- **储能需求 Large storage requirement**



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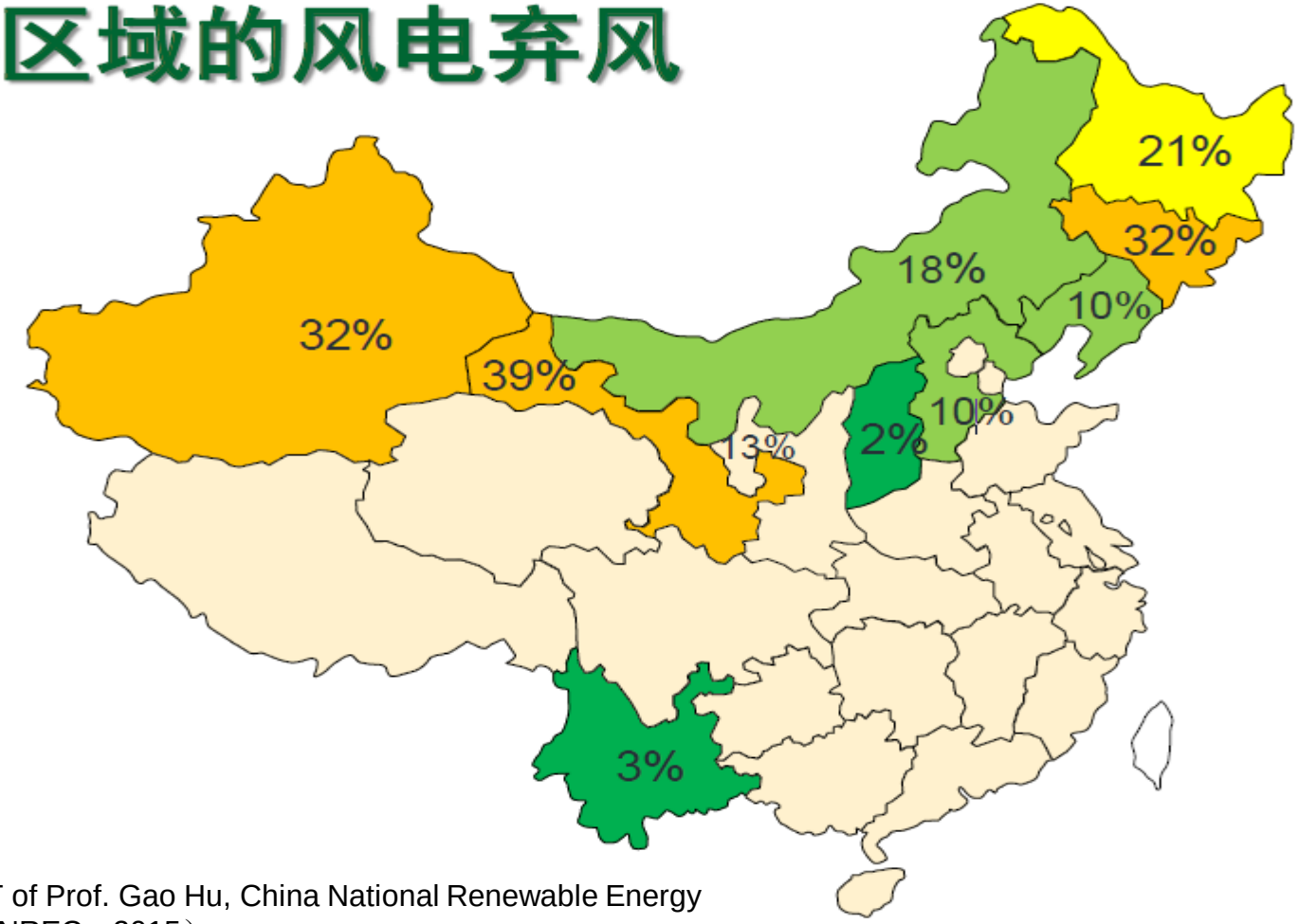
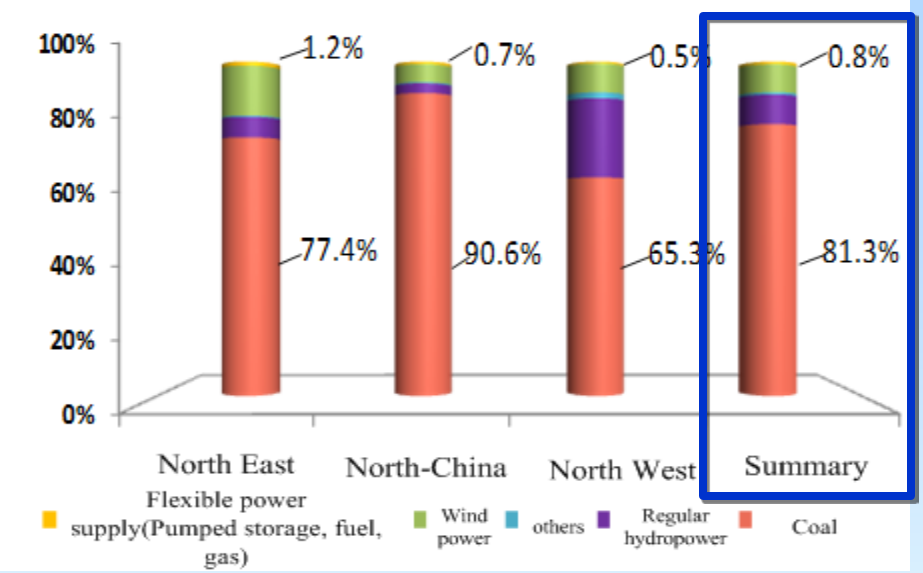
1 Requirements for Energy Storage – Challenges

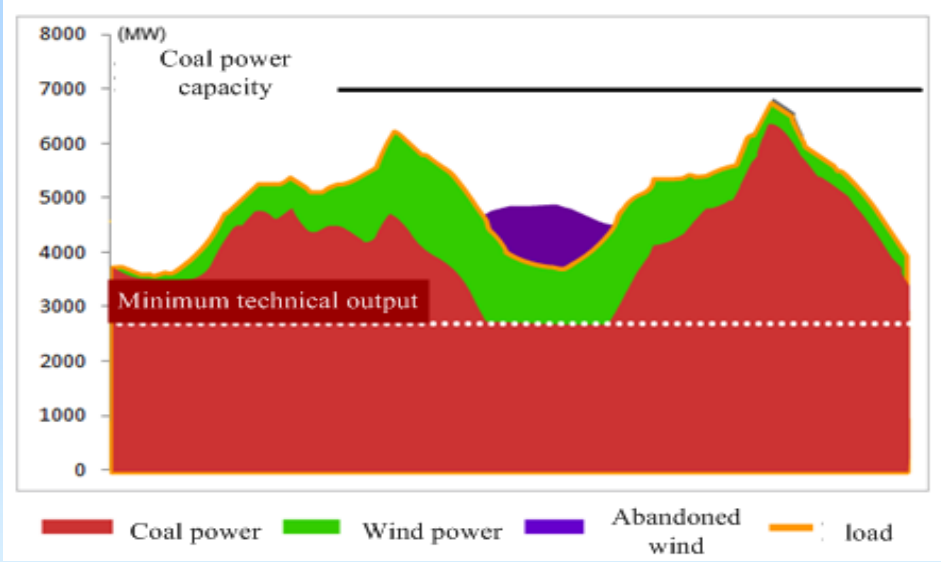
Key area's wind curtailment
主要区域的风电弃风



From PPT of Prof. Gao Hu, China National Renewable Energy Centre (CNREC，2015）

1 Requirements for Energy Storage – Challenges





Main Reasons

- Lack of **flexible generation sources and energy storages** to accommodate the stochastic **uncertainty** features of renewables
- Improving renewable power **forecasting accuracy**
- Strengthen **electricity transmission channels**
- Promote multi-type **local consumption** for renewable energy
- Adopt multiple time-space **dispatching optimization**

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Energy Storage Functions

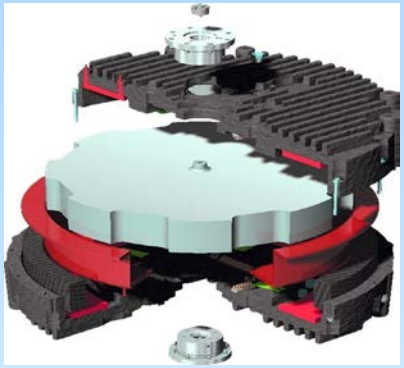
Applications of different energy storage technologies can resolve the issues caused by wind/solar power uncertainties, particularly

- **Provide energy reserve for emergency**
- **Peak shaving**
- **Smooth power output as scheduled**
- **Frequency Regulation**
- **Reduce the renewable power curtailments**
- **Improve the power quality**
- **Others**

2 Energy Storage Technologies
储能技术

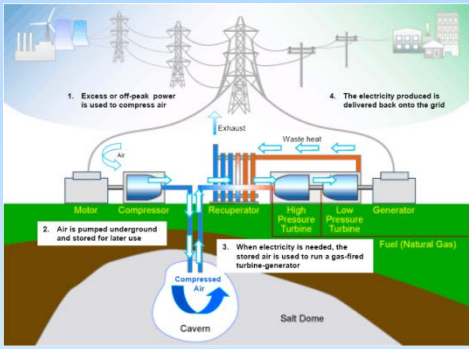
Types of energy storage technologies

抽蓄Pumped Hydro

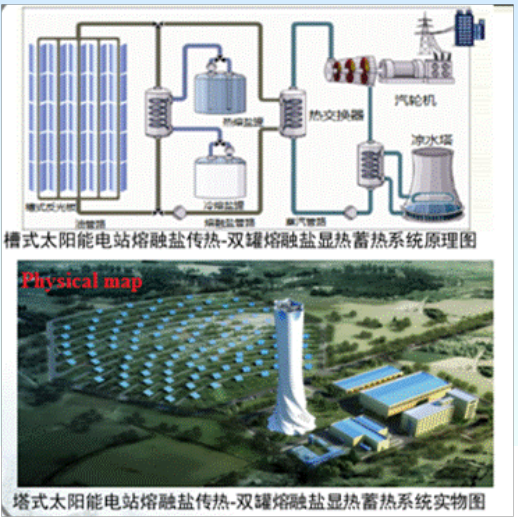


飞轮储能Fly Wheels

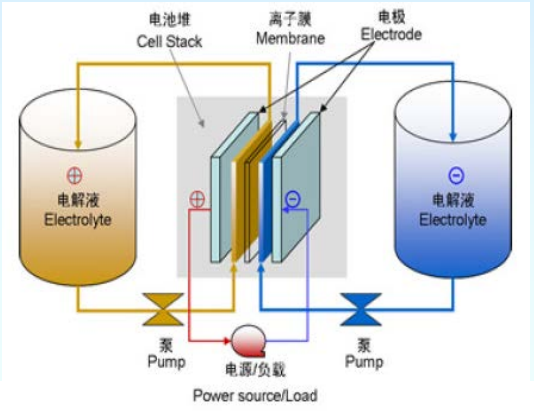
电池储能Battery



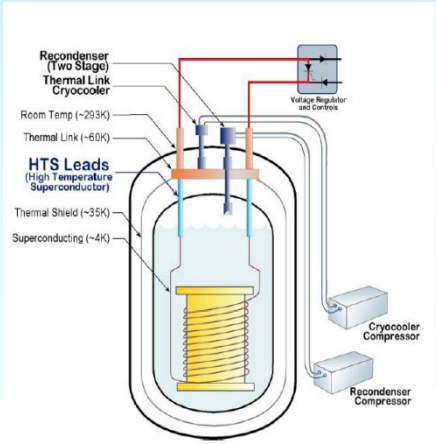
Compressed Air ES



Heat ES from Solar
- Molten salt



Electrochemical ES
-Various batteries



SuperCon MES
(low temperature)

Hydrogen ES
from Wind

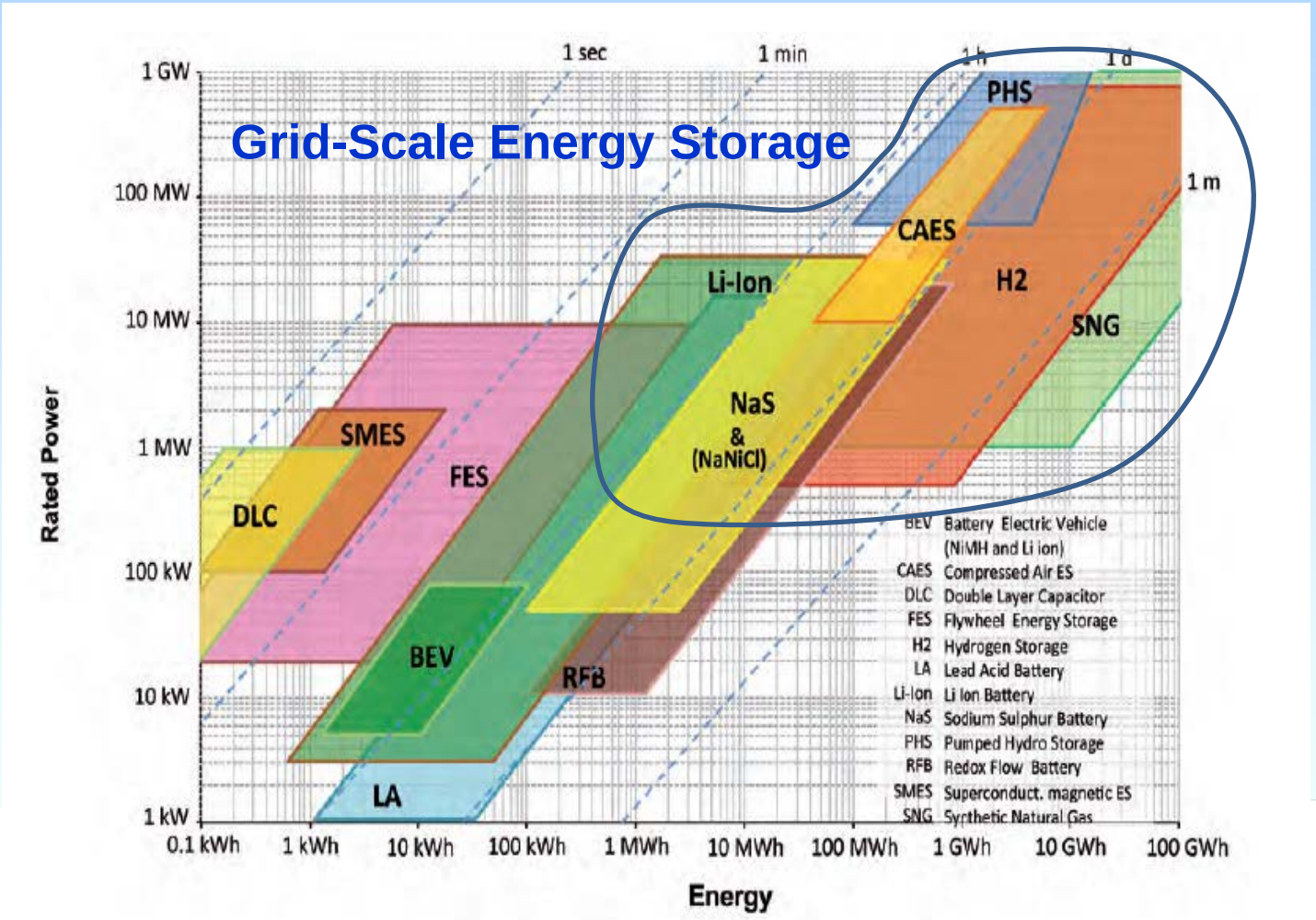
2 Energy Storage Technologies
储能技术

◆**According to the form of ES medium, electricity ES can be divided into:**

- **Mechanical ES** 机械储能
  - Pumped Storage
  - Compressed Air ES
  - Flywheel ES
- **Heat / Cold ES** 热/冷储能
  - Thermochemical ES
  - Phase Change ES
  - Thermal material ES
- **Electrochemical ES** 电化学储能
  - Sodium-sulfur Battery
  - Lithium Ion Battery
  - Lead-acid (carbon) Battery
  - Flow Battery
  - Sodium-ion Battery
  - Other new technologies
- **Electromagnetic ES** 电磁储能
  - SMES
  - Super Cap
- **Chemical ES** 化学储能
  - Hydrogen Storage
  - Synthetic fuels

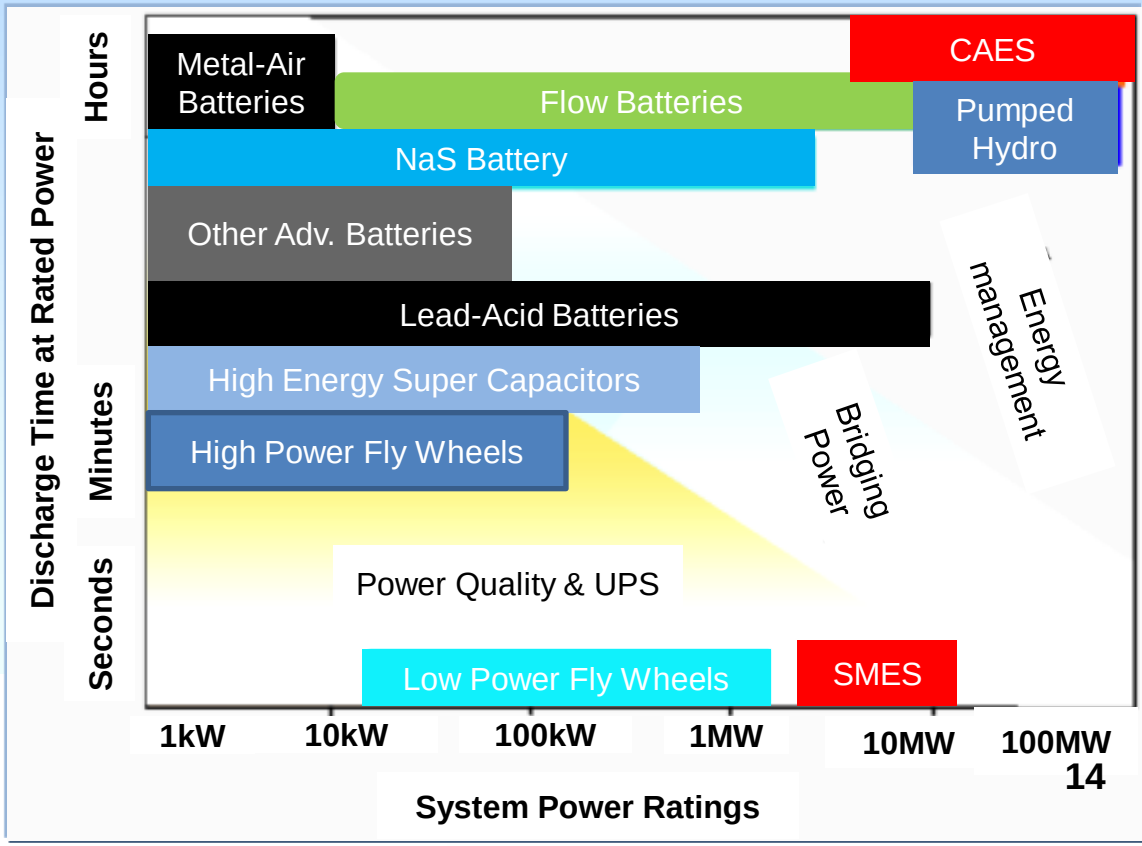
2 Energy Storage Technologies
储能技术

◆Scales/Capacities of various energy storage technologies



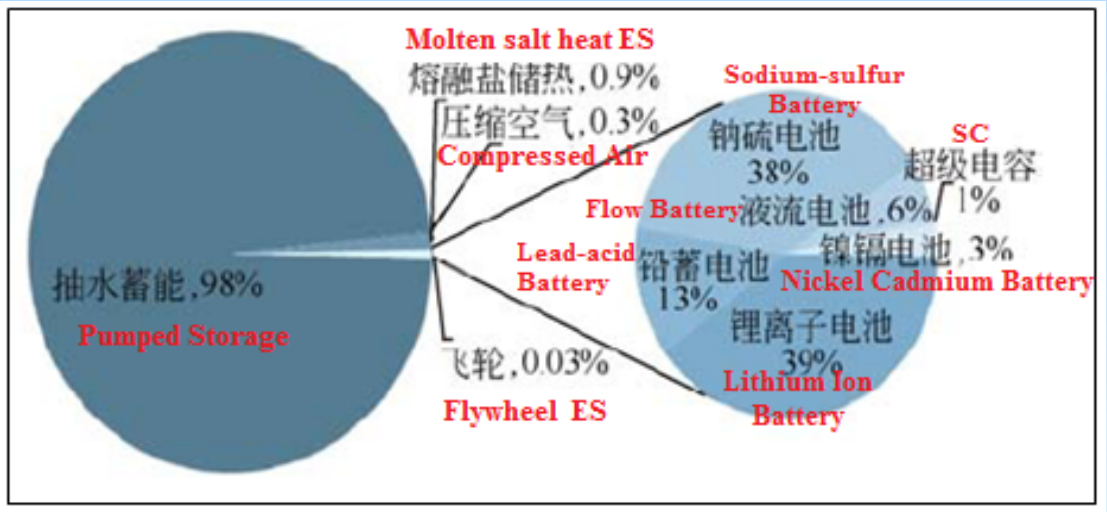
2 Energy Storage Technologies
储能技术

- **Expected characteristics of various energy storage technologies for T&D applications**
  - **Capacity: From small to large in capacity**
  - **Response time: ms/s/minutes**
  - **High efficient**
  - **Cost: affordable**



2 Energy Storage Technologies
储能技术

◆ Installed ES in the world

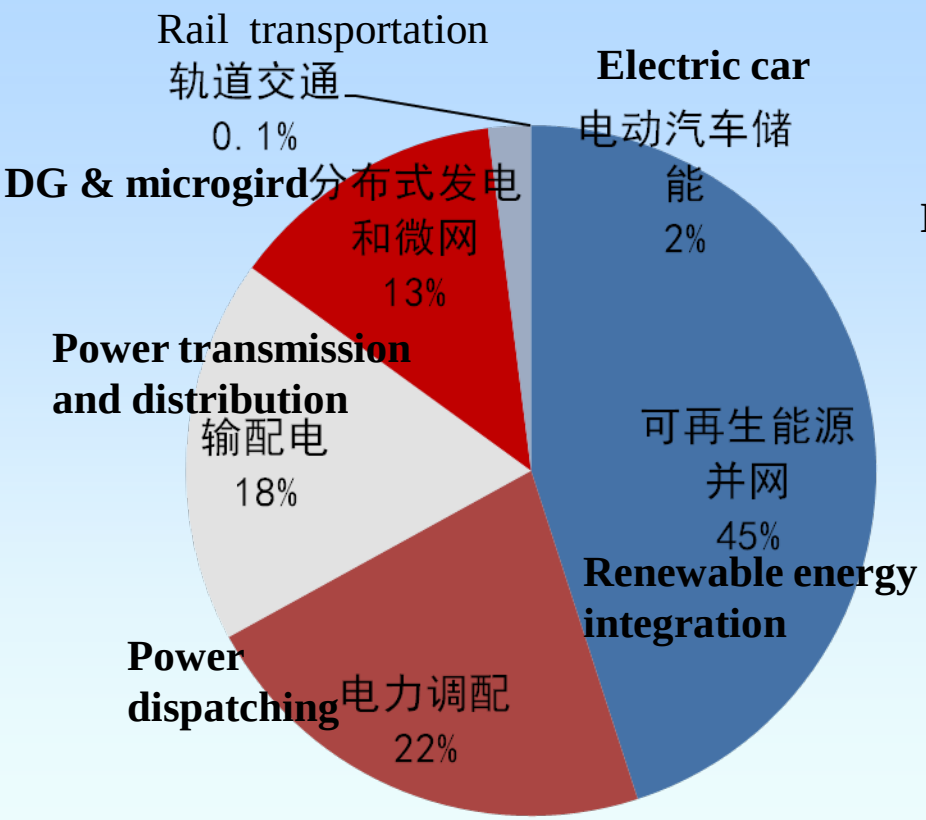


Total installed capacity of global ES （2000 - 2015）

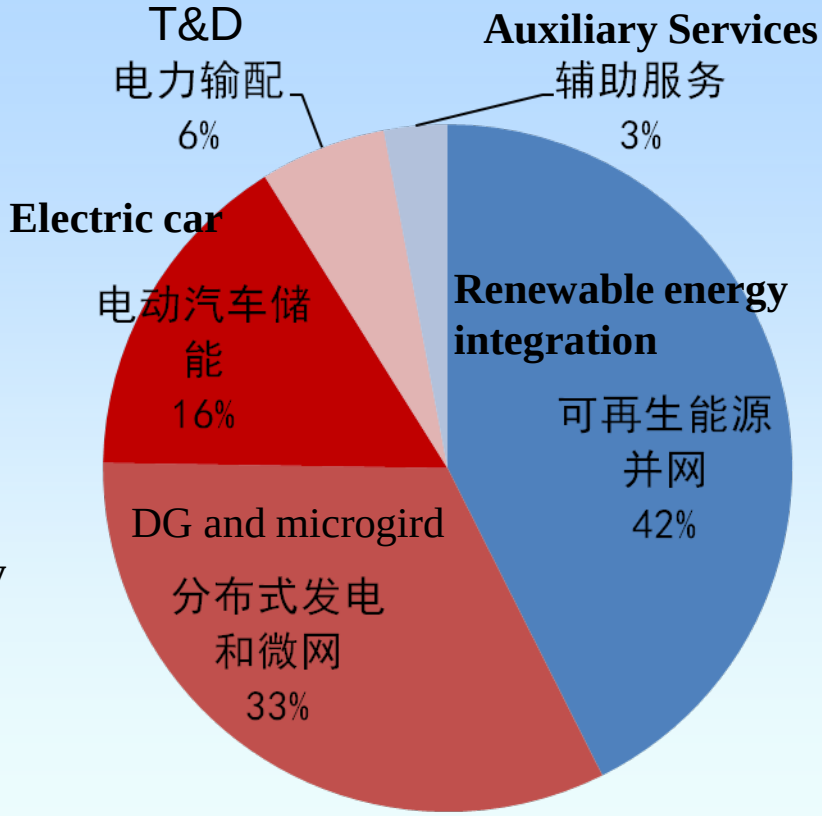
	Total Installed （GW）	Pumped Storage （GW）	Electrochemical ES （MW）
Global	144.8	142.1	891（318 projects）
China	21.9	21.8	106

2 Energy Storage Technologies
储能技术

◆ ES Application Situations



Global ES Application Category (2010-2015, excluding pumped storage, compressed air and heat storage)



China ES Application Category (2010-2014, excluding pumped storage, compressed air and heat storage)

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3 Demonstration Project - General Information

- **Capacity plan of project**: wind power **500MW**, solar power **100MW**, energy storage capacity **110MW.**
- **The first phase** of project construction: wind power **100MW** , solar power **40MW** , energy storage capacity **20MW,** had been completed and operated since **Dec 2011**

规划情况：风电500MW，光伏发电100MW，储能装置110MW。一期工程建设风电100MW、光伏发电40MW和储能装置20MW，于2011年12月31日建成投产。

3 Demonstration Project - Location

示范工程位于风、光资源丰富的河北张家口地区，但当地负荷量较小，必须通过高电压、远距离输电送至京津唐电网负荷中心，具备我国新能源开发利用的基本特征，在破解电网接纳大规模新能源技术难题上具有典型性和代表性。

- The demonstration project is located in Zhangjiakou, where wind and solar resources are rich. And it is also far away from the load center of local Jingjintangpower grid.
- The wind and solar power must be transmitted to the load center by high voltage and long distance transmission network.
- This project represents the basic characteristics for developing renewable generation in China, and is a typical case for accommodating large scale renewable generation in local grid.

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3 Demonstration Project - Objectives

Key Objectives

- Develop high precise prediction technologies for renewable generation
- Develop smart coordination and control strategies for renewable generation operation
- Develop large storage application technologies in dealing with renewable generation fluctuation and uncertainty
- Develop smart technologies for renewable generation transmission over long distance
- Demonstrate grid code compliance of renewable generation integration
- Cost assessment for renewable energy generation、transmission and operation

3 Demonstration Project
- System Configuration

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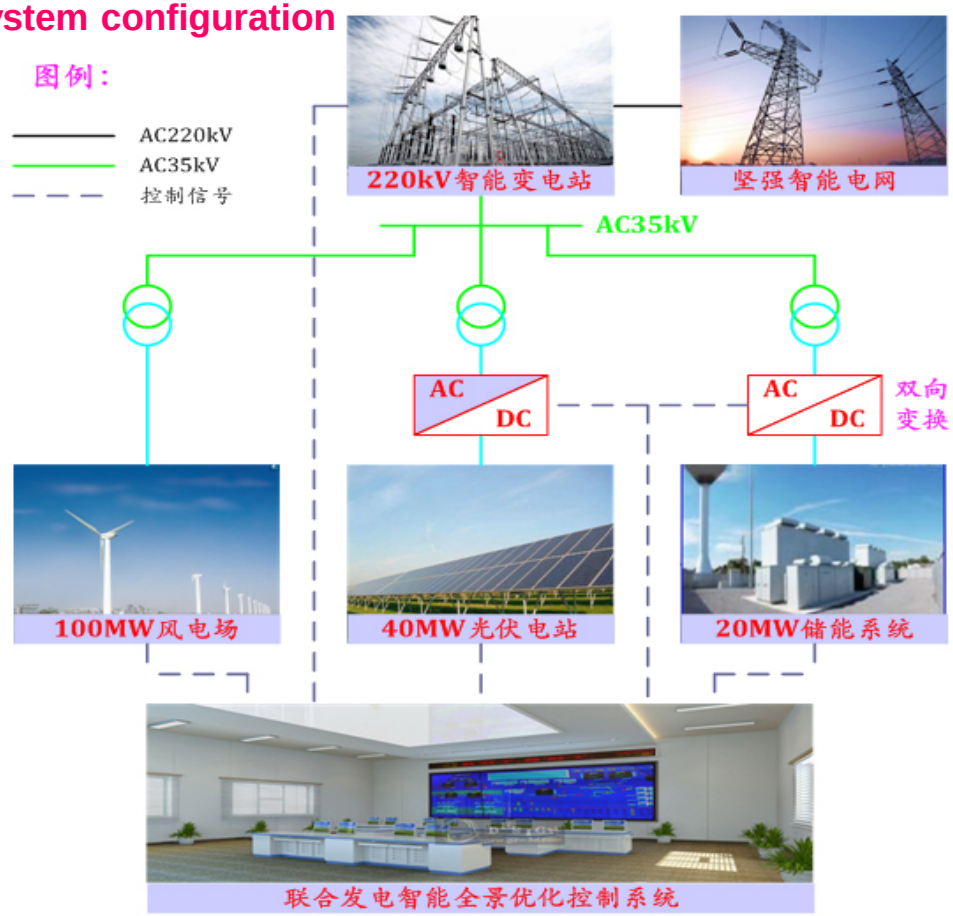
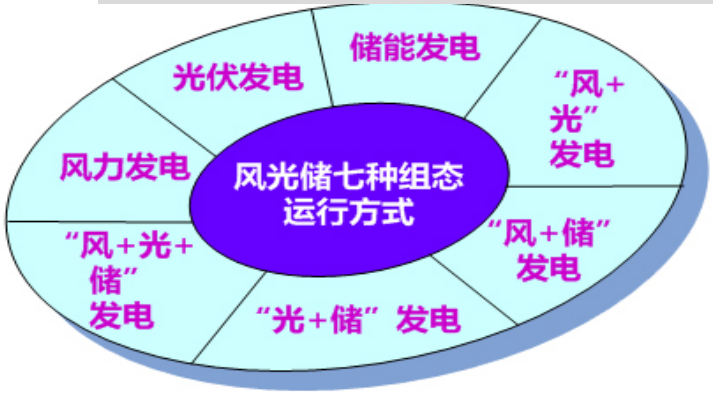
- **General configuration of the integrated wind, solar, storage energy and transmission system 风光储输系统总构架**

System configuration



■ Consider Intelligent optimization and control system for cogeneration and operation based on schedule and forecasting.

■ Is able to automatic configure and change from each operation mode to others.



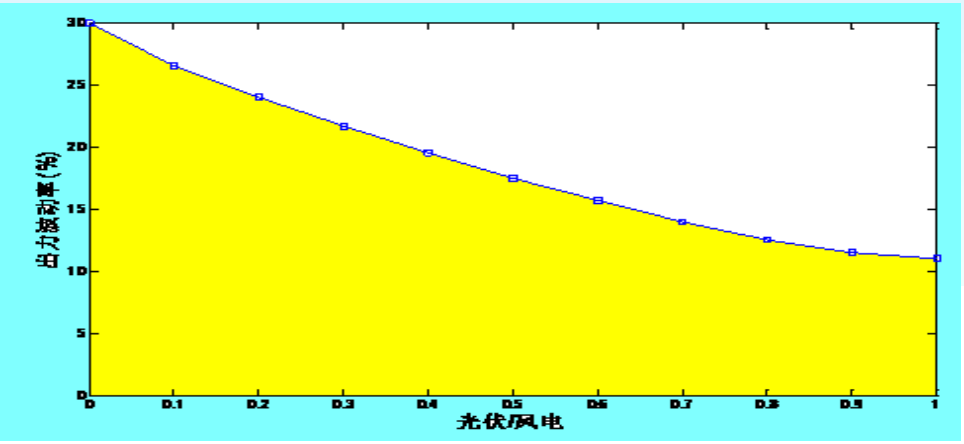
■ **7 operation modes are considered**
- Wind
- Wind + storage
- Solar
- Solar + storage
- Storage
- Wind + solar
- Wind +solar +storage

3 Demonstration Project
- Key Technology Characteristics

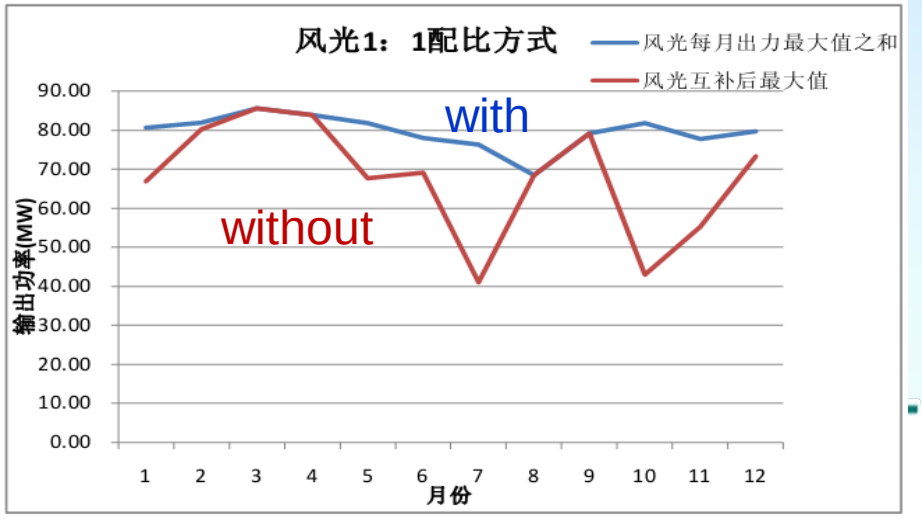
风光互补特性 Wind and PV generation complementary characteristics

- By analyzing the characteristics of wind and solar resources, it is found that the power output of wind and solar cogeneration operation varies between 30% and 12% when the ratio in power capacity between wind and solar changes form 10:0 to 10:10. Therefore, the wind and solar cogeneration can be used to mitigate the power output variation /fluctuation.通过对张北地区风光资源的分析，风光比例从10:0 - 10:10时，联合出力波动在30% - 12%之间。因此，可利用风光互补特性改善输出功率波动。

风光配比 W/S	10:0	10:3	10:4	10:5	10:10
出力波动 Power Variation	30%	22%	20%	18%	12%



风光互补模态分析表



风光叠加出力最大值曲线（风光容量比为 1:1）

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3 Demonstration Project
- Key Technology Characteristics

- **Energy storage can improve the grid integration capability of the cogeneration system from four aspects** 储能系统从四个方面提高风光联合发电的接入能力

1、平滑联合发电的波动性，增强可控性，减少电力系统的备用容量
Mitigate the fluctuation of the cogeneration, enhance controllability, reduce reserve capacity of power system

2、跟踪发电计划出力，提高联合发电的预测性，减小出力偏差
Follow the planned generation output, improve the predictability of cogeneration, reduce the output deviation

3、参与电网削峰填谷，提升系统可调度性
Participate in peak shaving (power load shifting), improve system scheduleability

4、全天候参与系统调频，为电网提供优质调频服务
Participate in the system frequency regulation to provide qualified services for the grid at any time

采用磷酸铁锂电池、钠硫电池、液流电池三种不同技术类型的化学储能方式，储能总功率约20MW，总容量95MWh

lithium iron phosphate batteries, sodium sulfur batteries, flow batteries which are three different types of chemical energy storage technologies, have been used. Total storage power rating is 20MW (95MWh in capacity)

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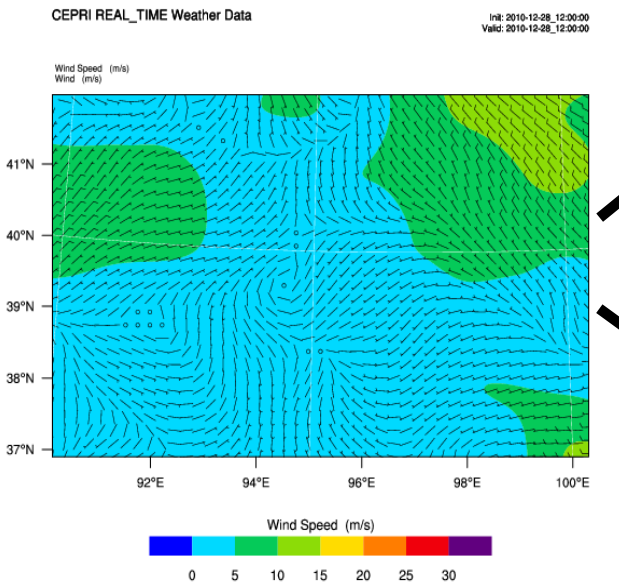
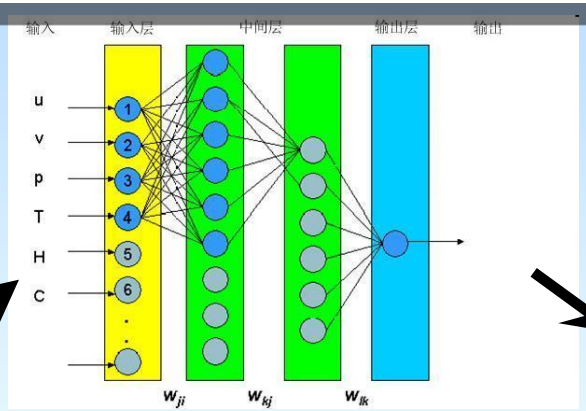
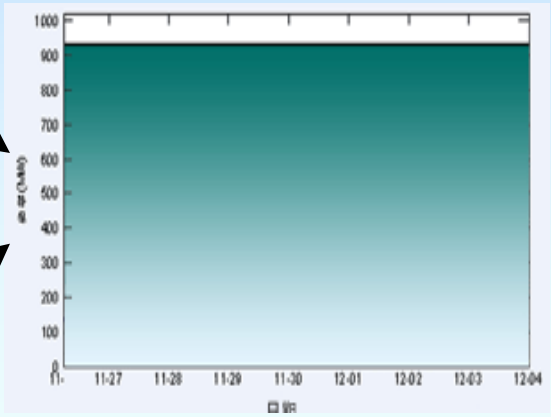
3 Demonstration Project
- Key Technology Characteristics

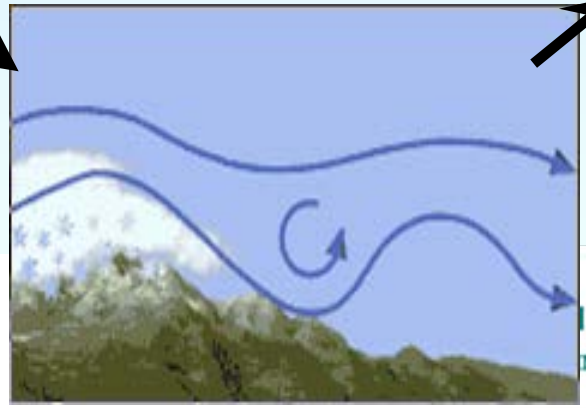
- **For wind and solar power forecasting, hybrid method (physical + statistical) is used to account the uncertainty caused the data and the local conditions of wind farm** 采用了物理和统计混合方法，全面地考虑了由于数据和风电场局部条件引起的不确定性带来的影响，开展风电/光伏功率预测。

Statistical Method









Physical Method

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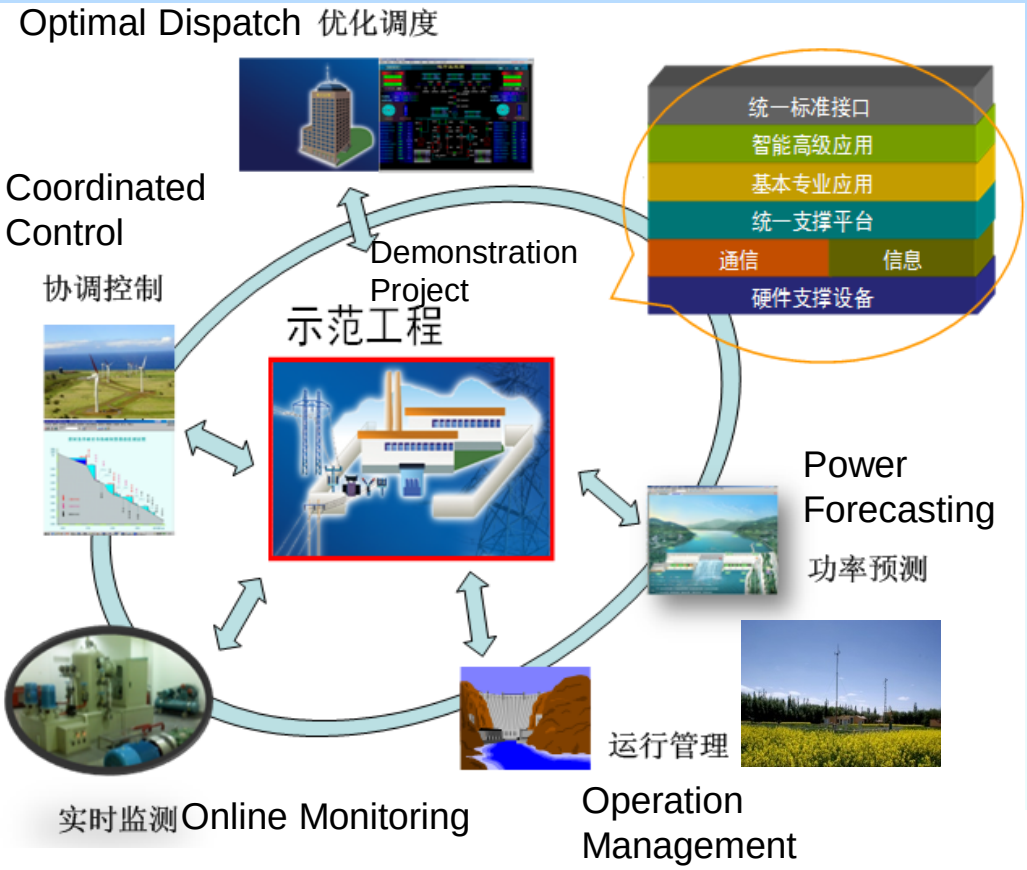
3 Demonstration Project
- Key Technology Characteristics

Intelligent optimal control system is used for cogeneration
联合发电智能全景优化控制系统方案



■该一体化系统采用集中决策、分布执行的控制理念，实现不同组合(风、光、储、风+光、风+储、光+储、风+光+储七种方式)、不同时间尺度（稳态、动态、暂态）下的多控制目标（平滑出力、跟踪计划、支持AGC、削峰填谷等）协调的联合运行

The system uses a particular controlling method with centralized decisions and distributed implementations. Therefore, it can implement the coordinated operation with different combinations (wind, light, storage, light wind + wind + storage, light + storage, light + wind + storage seven ways), different time scales (steady state, dynamic, transient), in multi-control targets (smooth output, track plan, support AGC, load shifting,etc)

3 Demonstration Project
- Key Technology Characteristics

Main functions of Intelligent Optimal Control System
联合发电智能全景优化控制系统的功能

1. Data acquisition and joint monitoring of wind-solar storage energy风光储数据采集和联合监视
2. Generation prediction of wind-solar -storage energy风光储发电预测
3. Control of the combined wind-solar- storage energy风光储联合控制
4. Analysis and evaluation of wind-solar- storage energy.风光储数据分析与评估
5. Coordinated dispatch and optimization of wind-solar -storage energy风光储联合优化调度
6. Communication with grid dispatching system实现与电网调度系统通信
7. Communication within station systems实现与场站系统通信

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3 Demonstration Project - Operation Experience

The combined wind & solar power and storage cogeneration operation mode (active control mode) 风-光-储-输组合发电模式

- **Output smoothing mode** 功率平滑输出模式
- **Tracking scheduling mode** 跟踪调度计划模式
- **Peak load shifting/peak shaving mode** 削峰填谷模式
- **Frequency response/regulation mode** 调频模式

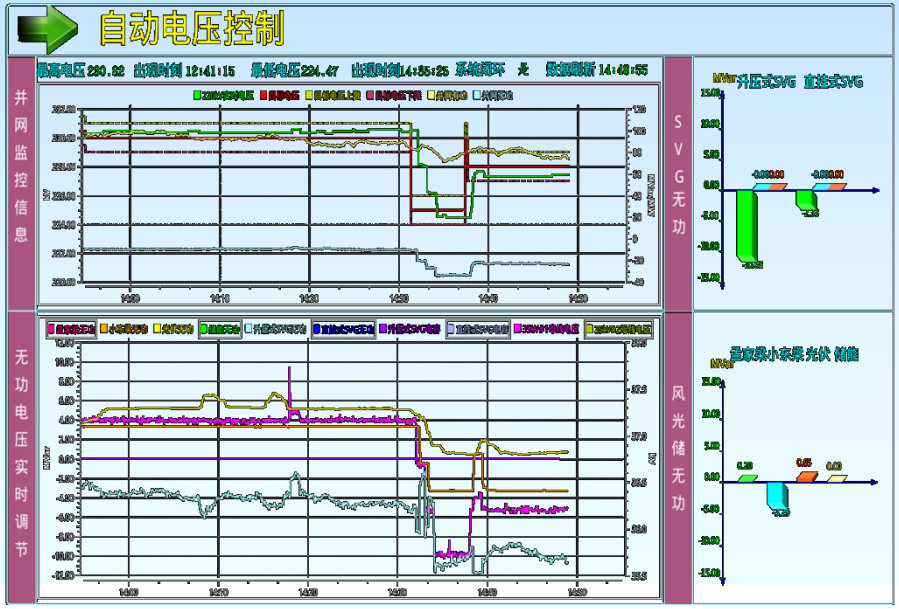
■ **In 2012, demonstration project accumulated generating 248million kWh, including 192million kWh wind power and 56million kWh solar power. Until May 2014, the total generation capacity is over 700million kWh**

2012年示范工程累计发电2.48亿kWh，其中风电1.92亿kWh，光伏发电0.56亿kWh. 至2014年5月，总发电量超7亿kWh

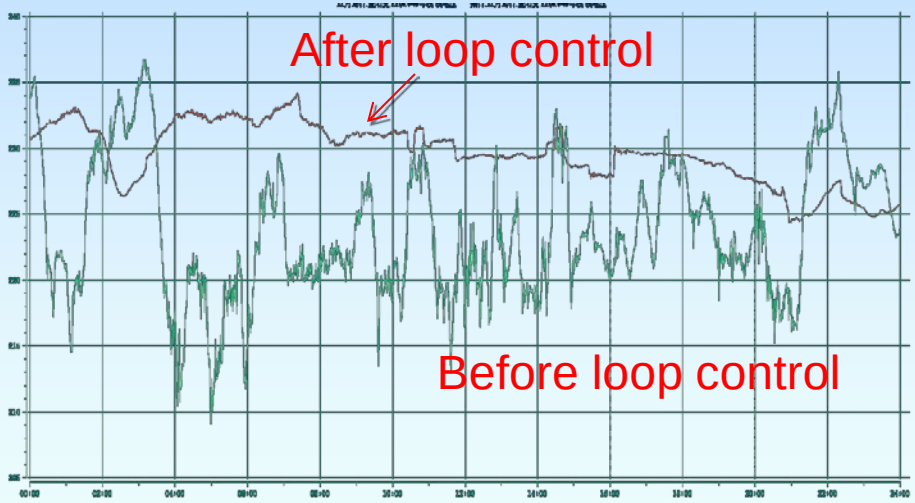
3 Demonstration Project - Operation Experience

AVC control mode (reactive control mode) AVC控制模式

- **Voltage tracking control mode** 电压跟踪控制模式
- **Dynamic reactive power exchange mode** 动态无功置换模式
- **Control mode considering large step transient voltage change** 暂态电压大幅变化控制模式



风光储稳态电压AVC协调控制曲线图



风光储电站220kV闭环控制前后电压曲线

Substation Voltage Curve

Voltage Curve

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3 Demonstration Project - Operation Experience

Technological Innovation 技术创新

■**Propose the optimization approach for renewable cogeneration - the combined renewable generation system optimization configuration is suitable for the north area , and a renewable generation system with the wind/solar/storage 5:2:1 configuration scheme is used.**

提出了适用于我国三北地区的新能源联合发电系统优化配置方法，制定了风光储**5:2:1**的配置方案

■**Develop the combined power monitoring and control system for the 100MW scenery storage project**

研制出百兆瓦级的风光储联合发电监视、控制系统。

■**Propose the intensive control for multi-type energy storage devices, realize operation targets of large capacity, fast response, precise output regulation**

对多类型储能装置进行集约化控制，实现了容量大、响应快、调节准的输出目标

■**Accurately predict the short-term and super-short term power for wind and solar power, the accuracy rate reaches the levels of 90% for short-term and 92% for super short term**

可以准确预测日前短期和实时超短期风光发电功率曲线，准确率达到短期**90%**、超短期**92%**的水平

3 Demonstration Project - Operation Experience

The project has demonstrated 示范工程将成为:

- The biggest and controllable solar power , which can be controlled 国内容量最大的功率调节型光伏电站；
- The first grid-friendly wind farm 国内首个电网友好型风电场；
- The largest chemical energy storage power station with different types of betteries 世界上规模最大的多类型化学储能电站；
- The most intelligent renewable demonstration project with multi operation modes 智能化运行水平最高、运行方式多样的新能源示范工程。

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中国电力科学研究院
CHINA ELECTRIC POWER RESEARCH INSTITUTE

4 Conclusions

- ES technologies play a very important role in the safe and stable operation of power grid, and its application prospect is broad.
- ES technologies integrating with electricity, heat, gas and other energies are the future trend for large-scale energy storage applications.
- Large-scale ES applications are still facing the issues and challenges associated with cost, lifetime, safety, etc. The policy supports are needed.
- Government, power companies, energy storage suppliers and end users working together to promote the ES technology applications and form standards, are effective measures to accelerate the development and applications of grid-scale ES technologies

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Thank you for your attention!

谢谢!

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