中国的风电并网研究与并网导则制订

Study on the grid impact of large scale wind power integration and grid code formulation

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2008-11-18

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1、中国的风电发展及并网情况介绍

Wind power development and grid integration status in China

1.1 中国的风电发展情况介绍
Wind power development status

年份	2002	2003	2004	2005	2006	2007
中国总电源装机容量 Total Power （MW）	356,570	391,410	440,000	500,000	600,000	713,290
中国风电总装机容量 Total wind power （MW）	445.0	568.4	763.8	1260.0	2560.0	6050
中国的风电装机比例 Wind power proportion （%）	0.125	0.145	0.174	0.25	0.43	0.84
世界风电总装机容量 Global Total Wind Power （MW）	31,000	40,300	47,317	59,004	73,904	93,849

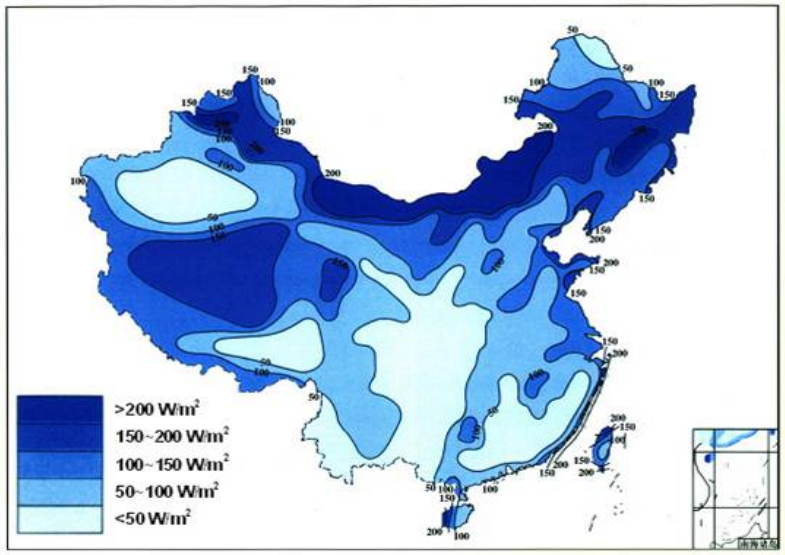
中国的风电装机容量发展情况
Wind power installed capacity in China

1.1 中国的风电发展情况介绍
Wind power development status

- 2007年底，我国风电总装机容量达6050MW.
  - By the end of 2007, the total install capacity of wind power reaches 6050MW.
- 风电场　　158个
  - Wind farms　158
- 风电机组　　6469台
  - Wind turbines　　6469
- 风电机组生产厂商：　50~60余家
  - Wind turbine manufacturers　50 ~ 60

1.1 中国的风电发展情况介绍
Wind power development status

- 风资源　Wind resource
  - 东北地区，西北地区，华北地区及东南沿海风资源较丰富。
  - Northeast, Northwest and North China areas are with rich wind
- 电网情况　Power grid condition
  - 风资源丰富的“三北地区”电网相对薄弱，风电远离负荷中心。
  - Power grid is weak in 3N areas, wind power is far away from load center.



中国风资源分布图
Wind resource distribution

1.2 中国的风电并网情况
Wind power grid integration status

- 越来越多的大容量风电场（≧100MW）接入220kV甚至是更高电压等级的输电网中。
  - More large scale wind farms (≧100MW) are connected into 220kV transmission network even higher voltage level transmission network.
- 百万千瓦风电基地　千万千瓦风电基地
  - 1000MW wind power base， 10 GW wind power base
- 发展特点：建设大基地，融入大电网。
  - Characteristics: Constructing large wind power base, connecting into large power grid with higher voltage level.

1.2 中国的风电并网情况
Wind power grid integration status

风电并网带来的问题

- Issues caused by wind power grid integration

- 小规模风电接入　small scale
  - 电能质量　power quality
  - 电压问题　Voltage issue
- 大规模风电接入　large scale
  - 电压问题　Voltage issue
  - 稳定性问题　Stability issue
  - 系统运行与备用　Power system reserve and operation

1.3 对风电及其接入电网认知的改变
Changes of Perception of wind power grid integration

- 初期： At the very beginning stage
  - 风电机组/风电场不能控制
    - Wind farm/wind turbine uncontrollable
  - 无法调度
    - Un-dispatchable
  - 恶化电网稳定性
    - Deteriorate the power grid stability
  - 对电能质量影响明显
    - Seriously influence the power quality

1.3 对风电及其接入电网认知的改变
Changes of Perception of wind power grid integration

- 当前：Nowadays
  - 风电机组/风电场可以控制
    - Wind farm/wind turbine controllable
  - 对电网稳定性影响降低
    - Improving the stability by active power and reactive power control of wind farm and by wind turbine LVRT capability
  - 电能质量：电压波动和闪变改善；谐波可能存在问题。
    - Improving the voltage variation and flicker, harmonics need more attention
  - 风电功率预测技术进步
    - Wind power forecasting technology benefit for the system operation

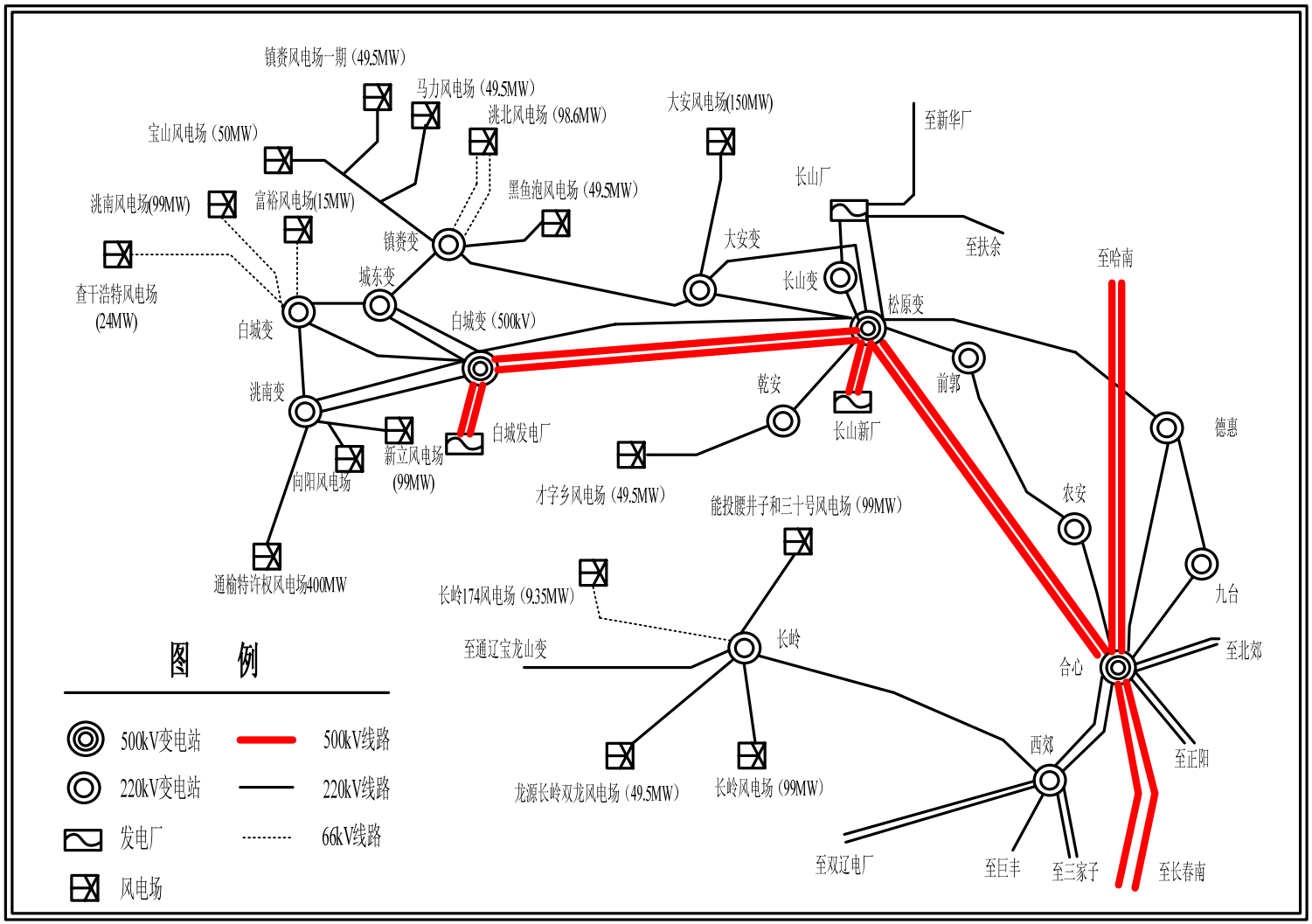
2、大规模风电接入电网带来的技术问题

Technical issues caused by large scale wind power integration

2.1 风电接入电网的电压问题
Voltage issue caused by wind power

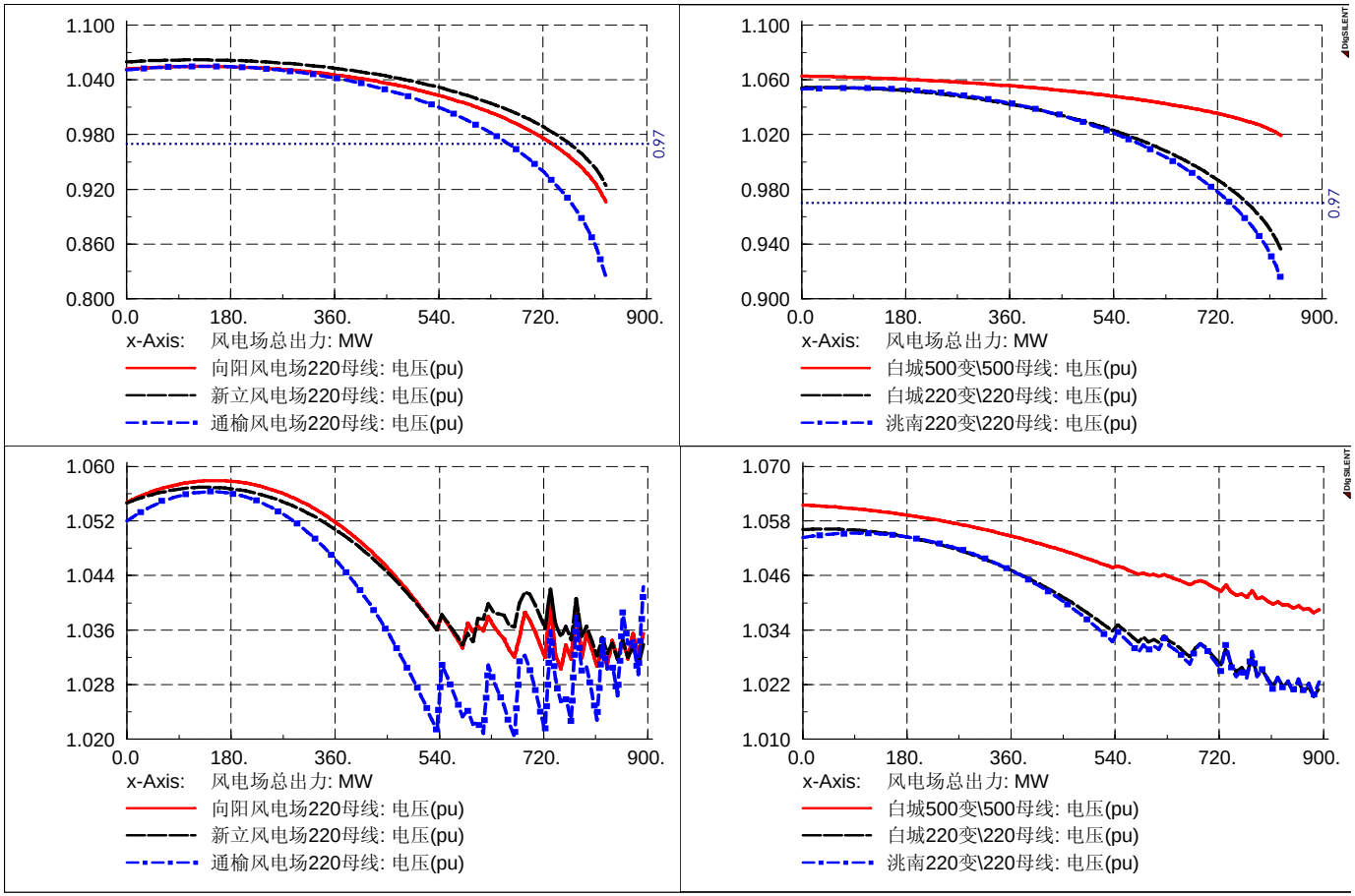
- 由于风电功率变化引起的电压波动必须在可以接受的范围内
  - Voltage variation caused by wind power injection must be in the acceptable zone
- 电压波动取决于 Voltage variation depends on
  - 发电功率 generated power
  - 功率因数 power factor
  - 网络阻抗 network R-X
- 风电引起的无功电压问题主要由风电自身的无功电压特性决定。
  - Voltage issue caused by wind power mainly depends on the voltage-reactive power characteristics of wind power.

风电接入对电网电压影响
Impact on Voltage of wind power integration



Xiangyang Wind Farm Grid Integration scheme

风电接入对电网电压影响
Impact on Voltage of wind power integration



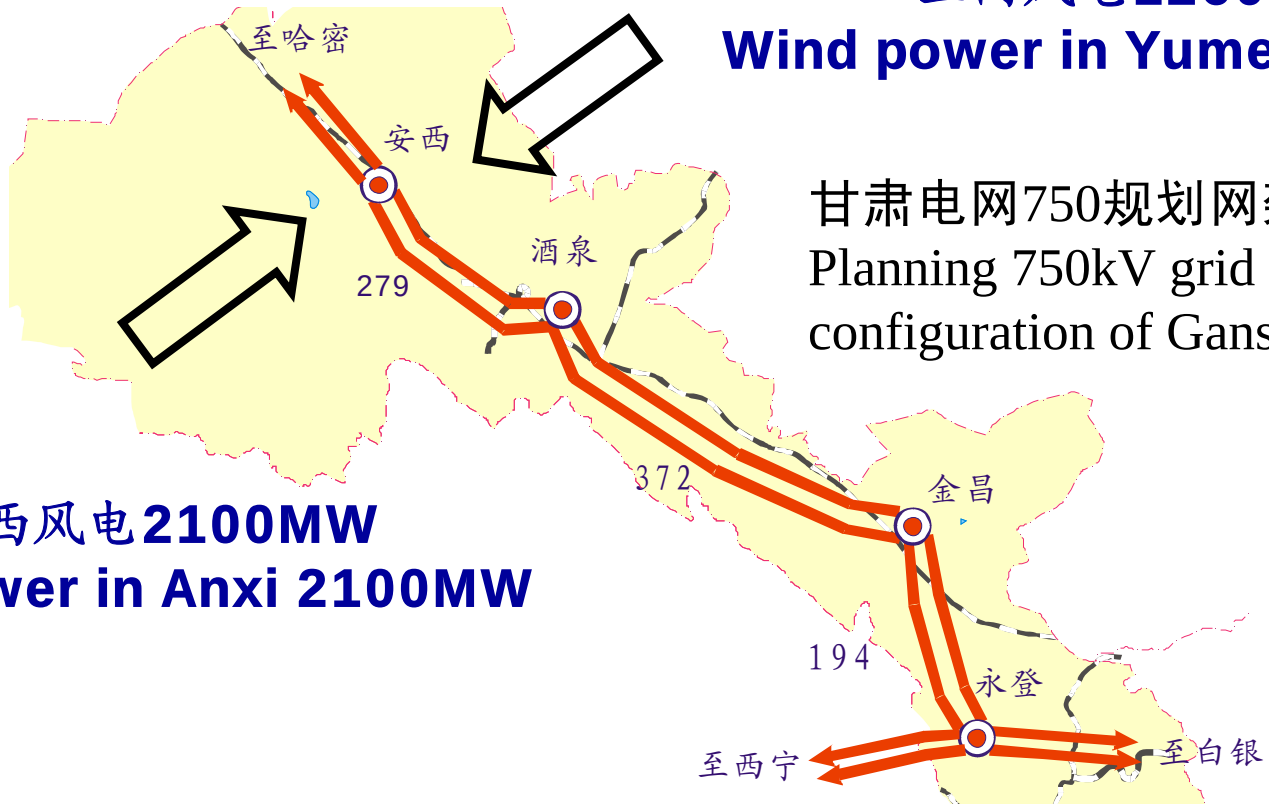
未补偿方案
No Compensation

已补偿方案
With compensation

Voltage Profile caused by wind power injection

大规模风电接入甘肃电网对电压的影响
Large wind power integration impact on voltage in Gansu Province

玉门风电1260MW
Wind power in Yumen 1260MW

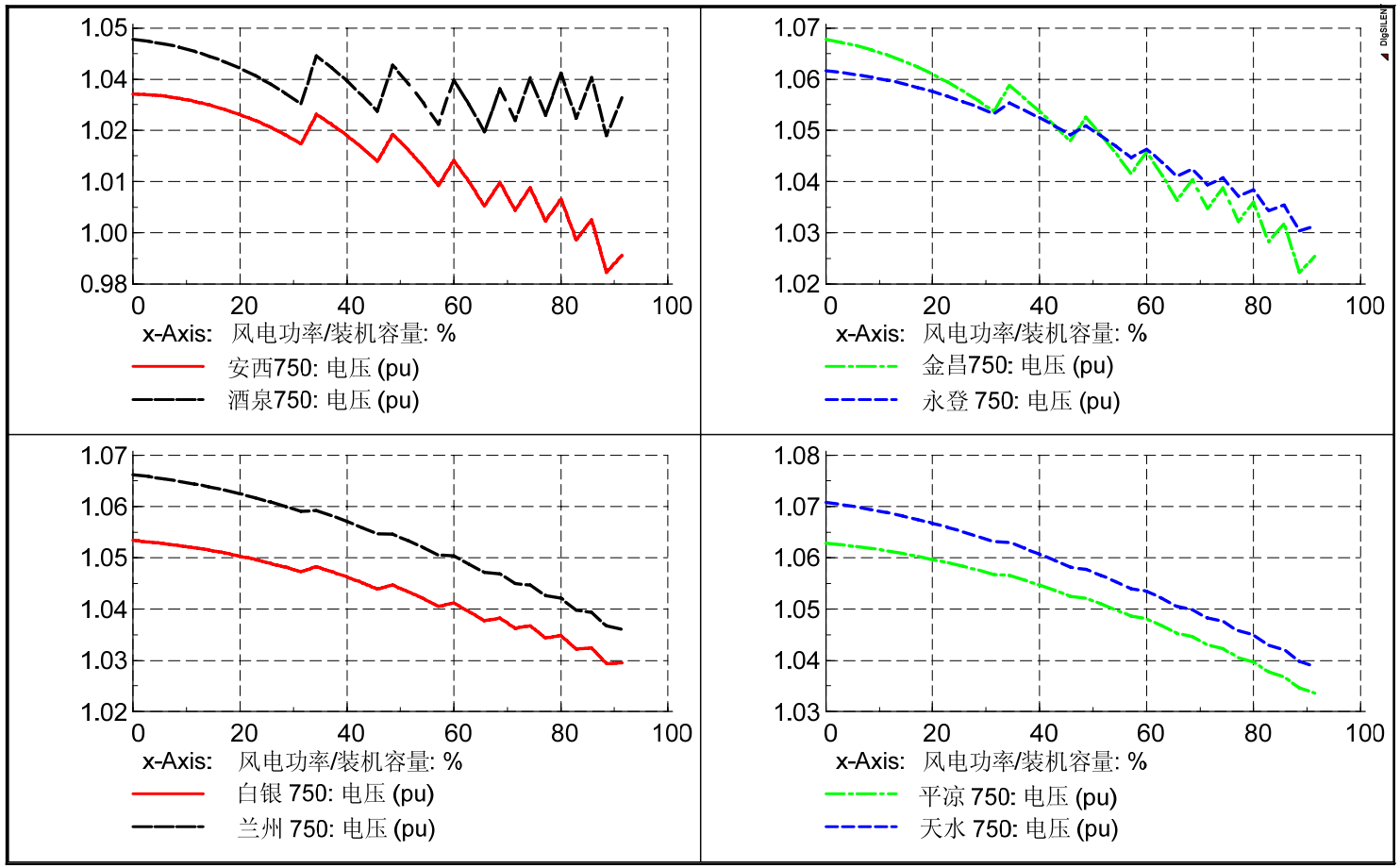


甘肃电网750规划网架结构
Planning 750kV grid configuration of Gansu

安西风电2100MW
Wind power in Anxi 2100MW

3360MW风电接入甘肃电网情况

大规模风电接入甘肃电网对电压的影响
Large wind power integration impact on voltage in Gansu Province



3360MW风电接入甘肃电网对电压的影响

Voltage impact on voltage in Gansu 3360 wind Scenario

大规模风电接入对甘肃电网主网的电压稳定水平影响较大，不采取技术措施无法正常运行！

Severe voltage impact on Gansu power grid by large scale wind power integration, more voltage control measures need to be add.

2.1 风电接入电网的电压问题
Voltage issue caused by wind power

电网可采用的电压控制手段

- Voltage regulation in grid side

- 可控高抗
  - Controllable high voltage reactor
- 串联补偿减少电气距离，增加输电能力
  - TCSC（Thyristor controlled series capacitor）
  - To reduce the electrical distance and increase power the transportation capability.

2.1 风电接入电网的电压问题
Voltage issue caused by wind power

风电场可采用的无功补偿与电压控制手段

- Voltage regulation in wind farm side

- 投切的电容器组
  - Switched shunt capacitor banks
- 静止无功补偿器或静止同步补偿器
  - SVC or STATCOM
- 风电机组采用无功或电压控制策略
  - Wind turbines with Q control

风电机组的低电压穿越能力
LVRT Capability of Wind Turbine

是目前风电接入电网稳定问题中需迫切解决的
is required urgently to solve the instability problem caused by wind power

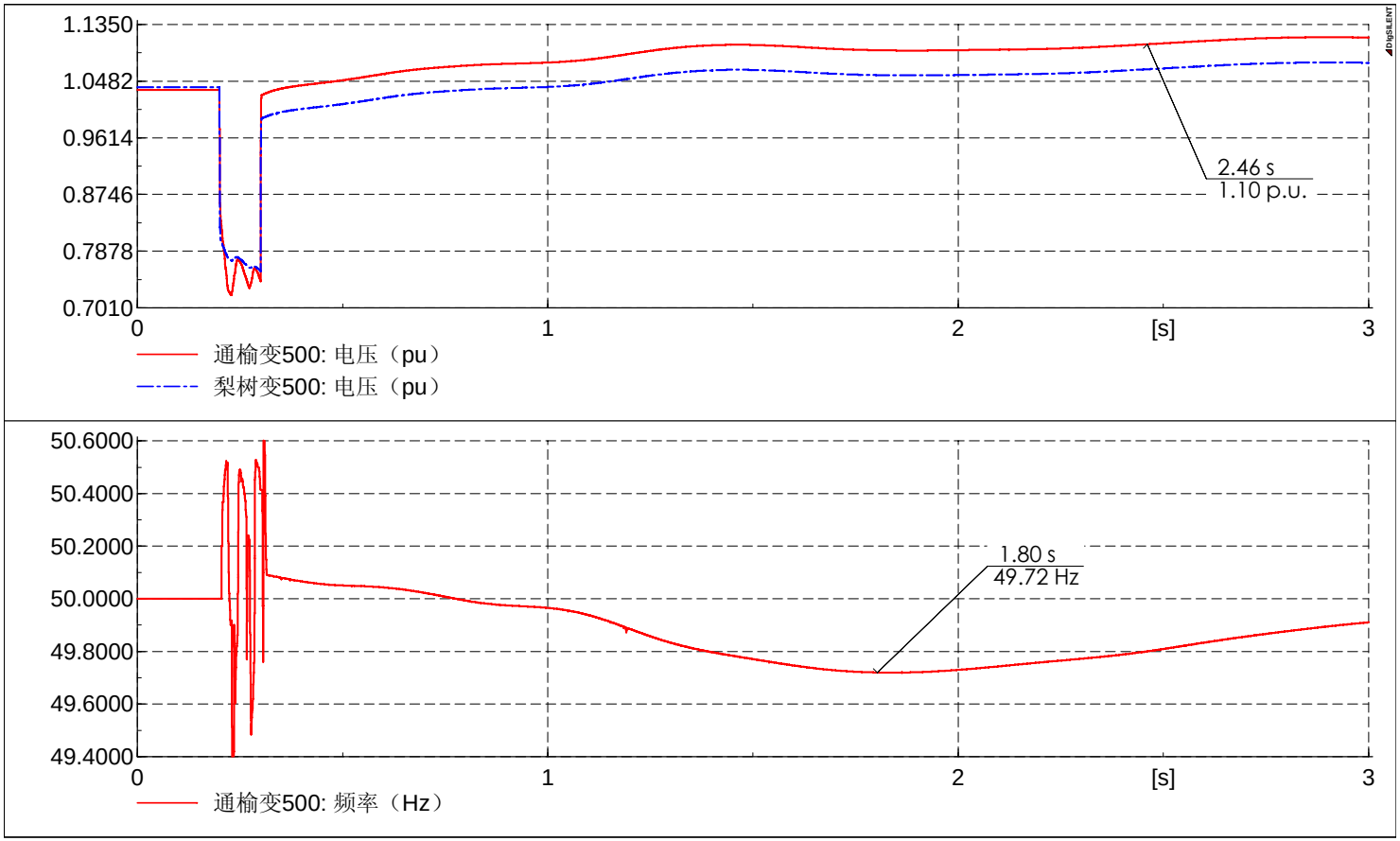
2.2 风电接入引起的稳定问题
Stability issue caused by wind power integration

- 低电压穿越 （LVRT：Low Voltage Ride Through）
  - 电网故障引起电压跌落，风电场在电网发生故障时及故障后，保持不间断并网运行的能力通常称为风电场的低电压穿越能力。
  - The capability of wind turbine to maintain continuous online operation during and after the grid fault which will cause voltage dip.

2.2 风电接入引起的稳定问题
Stability issue caused by wind power integration

- 由于风电机组不具备低电压穿越能力导致的大范围风电切机情况，在东北吉林电网及西北电网的甘肃玉门风电场、甘肃安西中广核大梁子风电场、宁夏贺兰山风电场都发生过。
- When wind turbines don't have LVRT capability, wind farms may trip if grid fault occurs. Such contingency has ever happened in many provincial power grid, such as Jilin, Gansu and Ningxia.
  - 电网扰动，不是非常严重
  - 带有变频器的风电机组切机
  - 大量风电切除导致有功缺额，引起系统频率降低、潮流大范围转移、部分母线电压过高或过低。

2.2 风电接入引起的稳定问题
Stability issue caused by wind power integration



1000MW wind power tripped when wind turbine without LVRT

2.3 应对风电影响的解决方案
Corresponding solutions

- 电网输电能力与电压问题

  Power grid transmission capability and voltage issues

  - ✓ 解决方案：加强电网与风电场电压控制能力

    Solution: Enhance voltage control of power grid and wind farm

- 电网与风电运行的稳定问题

  Stability issue of power grid and wind farms

  - ✓ 解决方案：风电场低电压穿越，增强电网稳定控制手段

    Solution: Require wind farms with LVRT capability to enhance stability control of power grid.

2.3 应对风电影响的解决方案
Corresponding solutions

电能质量问题

Power quality issue

解决方案：加强电能质量监测手段，应用改善措施

Solution: Strengthen monitor measures of power quality.

Use improved technology.

电力系统调度与调峰问题

Dispatching and peak-load regulation issues of power system

解决方案：加强风电功率预测，改善电源结构等

Solution: Strengthen wind power forecasting measures.

Improve power generation mix.

3、风电场接入电力系统技术规定的修订

Grid code upgrading

3、风电场并网技术规定的内容
Content of grid code

- 风电发展较快的几个国家都有较为完善的风电场并网技术规定

  These countries with rapid development of wind power all have relatively perfect grid code.

  - 丹麦Denmark：wind turbine generators connected to network with voltage levels above/below 100kV, 2004.05
  - 德国Germany：Grid Code for High and Extra High voltage, 2003
  - 美国America：AWEA Grid Code, 2004.05
  - 爱尔兰Ireland: Wind Farm Power Station Grid Code Provisions
  - 苏格兰Scotland: Guidance Note for the connection of wind farms

3、风电场并网技术规定的内容
Content of grid code

- 一般都对以下几个方面提出了要求：

  Key items of grid code

  1. 有功功率及其控制要求

     Requirement of active power control

  2. 无功功率容量范围及电压控制要求

     Requirement of reactive power capacity and voltage control

  3. 低电压穿越能力的要求

     Requirement on LVRT capability

  4. 风电机组的电压、频率正常运行范围

     Wind turbine voltage and frequency duration under normal operation

3、风电场并网技术规定的内容
Content of grid code

- 一般都对以下几个方面提出了要求：

  Key items of grid code

  5. SCADA系统与通信信号

     Requirement on SCADA and communication signal

  6. 风电场电能质量指标

     Power quality index of wind farm

  7. 风电场测试的要求

     Requirement on wind farm test

  8. 风电模型及参数要求

     Requirement on wind turbine modeling and parameter

3、风电场并网技术规定的内容
Content of grid code

风电场有功功率 Active power of wind farm

- 在下列特定情况下，风电场应根据电网调度部门的指令来控制其输出的有功功率：

  Wind farm should control active power output according to the order of TSO under the following situations.

  1. 电网故障或特殊运行方式要求降低风电场有功功率，以防止输电线路、变压器发生过载，确保电力系统稳定性；

     Power system meets a fault or operates at special mode, which requires wind farm reduce active power output to prevent transmission lines and transformers from overloading and to ensure the stability of power system.

3、风电场并网技术规定的内容
Content of grid code

- 风电场有功功率 Active power of wind farm

2. 当电网频率过高时，如果常规调频电厂调频能力不足，需要降低风电场有功功率，严重情况下需切除整个风电场。

   When frequency of power system is too high, while the frequency regulation capability of conventional power plants is not sufficient, it's required that wind farm reduce active power output, even cut out the whole wind farm.

3、风电场并网技术规定的内容
Content of grid code

风电场有功功率 Active power of wind farm

- 最大功率变化率包括1min功率变化率和10min功率变化率，具体限值可参照下表。

  Maximum power ramp rates contain 1min maximum power ramp rate and 10 min maximum power ramp rate. The recommendation values are listed in the following table.

风电场装机容量(MW) Installed capacity of wind power in MW	10min最大变化量(MW) 10 min maximum power ramp rate in MW	1min最大变化量(MW) 1 min maximum power ramp rate in MW
<30	20	6
30-150	装机容量/1.5 Installed capacity/1.5	装机容量/5 Installed capacity/5
>150	100	30

3、风电场并网技术规定的内容
Content of grid code

风电场无功功率 Reactive power (Q) of wind farm

1. 当风电机组运行在不同的输出功率时，风电机组的可控功率因数变化范围应在－0.95～＋0.95之间。

   The power factor of wind turbine should be maintained within -0.95 to +0.95.

2. 风电场必须在任何运行方式下，具有在风电场升压变高压侧（并网点）保证整个风电场的功率因数在-0.97～+0.97范围内快速连续可调的能力，以保证风电场具有在系统故障情况下能够调节电压恢复至正常水平的足够无功容量；

   It's required that wind farm power factor of high voltage side of step-up transformer could provide the capability in the range of -0.97 to +0.97, to make sure that wind farm have sufficient reactive power to regulate voltage back to normal value when power system fault occurs.

3、风电场并网技术规定的内容
Content of grid code

风电场无功功率 Reactive power (Q) of wind farm

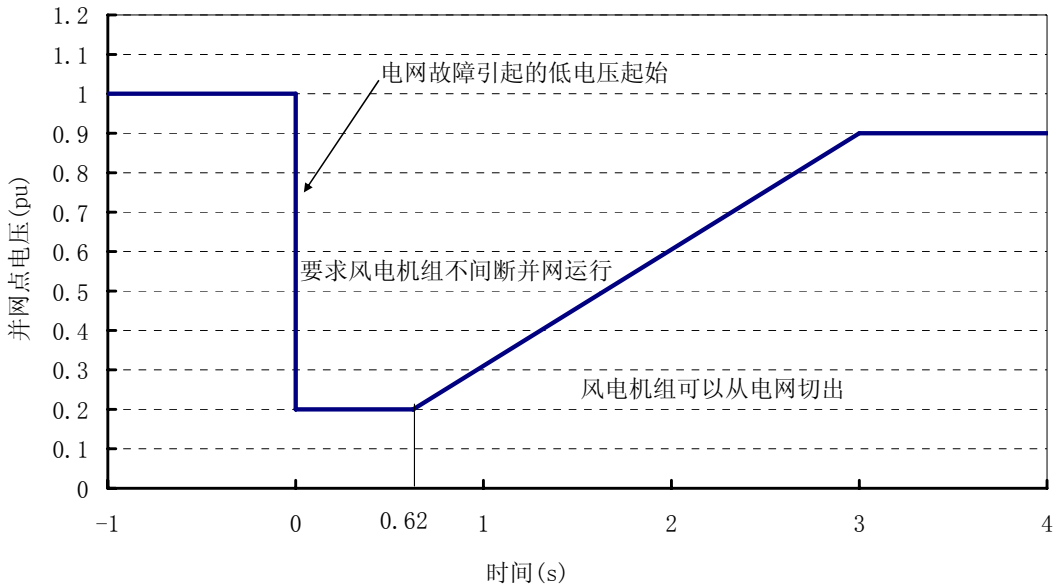
3. 风电场的无功电源包括风力发电机组和风电场的无功补偿装置。首先应当充分利用风力发电机组的无功容量及其调节能力。

   Reactive power compensation devices contain wind turbine and reactive power compensation equipments of wind farm. Reactive power of wind turbine and its regulation capability should be fully used firstly.

3、风电场并网技术规定的内容
Content of grid code

LVRT capability

- 右图为规定的风电机组的低电压穿越要求。当电网发生故障引起风电场并网点的电压跌落时，在一定电压跌落的范围内，风电场必须保证能够不间断的并网连续运行。



注：风电场并网点电压在图中电压轮廓线以上，风电机组必须具有保证不间断并网运行的能力；电压在图中电压轮廓线以下时，风电机组允许从电网切出。

3、风电场并网技术规定的内容
Content of grid code

风电机组/风电场并网的符合性测试
Wind turbine/wind farm grid compliance testing

- 有功控制能力，功率变化率等
  Active power control, power ramp rate, etc.
- 无功范围及控制能力
  Reactive power range and regulation capability
- 低电压穿越能力 LVRT
- 电压变动 Voltage variation
- 闪变 Flicker
- 谐波 Harmonics

3、风电场并网技术规定的内容
Content of grid code

- 虽然不同国家的风电并网导则不完全相同，但都强调风电场必须具备一定的有功控制、无功/电压控制能力及低电压穿越能力，对风电场承受系统电压和频率发生偏差的能力作出了明确的规定，并要求风电场提供模型信息、运行参数和性能测试报告。

  Content of grid code in different countries may be different, but each of them all require that wind farm should have capability in active power control, reactive power/ voltage control and LVRT. The capability of wind farm to endure the tolerance of voltage and frequency is also required, also the model information, operation parameters and performance testing report.

4、 结论

Conclusion

4、 结论
Conclusion

- 大规模风电接入可能对电网电压、稳定性、电能质量及调度运行产生影响；

  The grid integration of large scale wind power may impact power gird voltage, stability, power quality, dispatch and operation.

- 通过采用适当的技术措施可以降低大规模风电接入对电网的不利影响，以保证包含风电电源在内的整个电力系统的安全稳定运行；

  By using appropriate solutions, impact of large scale wind power on power system may be mitigated, maintaining the whole power system including wind farms security and stability.

4、 结论
Conclusion

- 并网技术规定的制定及风电机组/风电场符合性测试是保证风电接入电网安全运行的有效手段；

  Grid code formulation and wind turbine/ wind farms test are effective ways to ensure the security of power system with integration of wind power.

- 加强对风电并网的研究，针对包含大规模风电的电力系统的实际运行问题提出有效的技术措施。

  Increasing emphasis on wind power gird integration research, and put forward more effective solutions to power system operation problems caused by large scale wind power grid integration.


Thank you ！