



China practices :

Interconnecting variable RE to Weak AC Networks

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Qualification and Screening

Overview of Weak AC Networks Connection

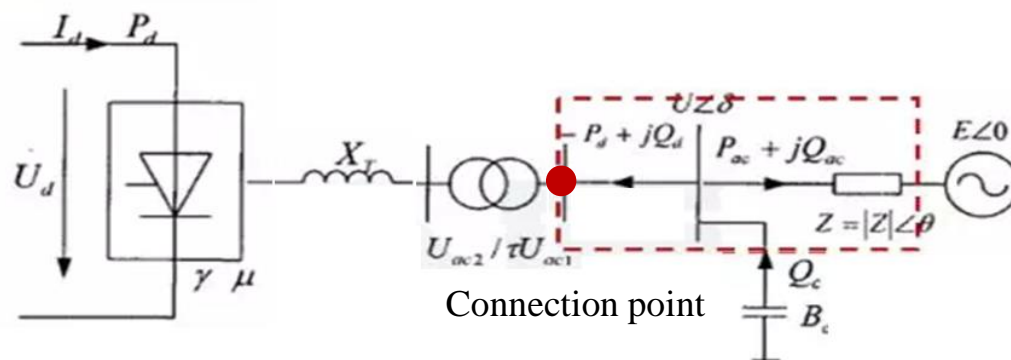
- ❑ The “strength” of a power system is a metric used to describe the ability of a power system to maintain the core characteristics through which it interacts with a connection, namely voltage and frequency, as steadily as possible, under all operating conditions.^[1]
- ❑ The “strength” of a weak AC grid or “weakness” of a power system is a relative concept and needs to be addressed in two meanings:
 - ✓ A larger impedance of power system (normally means long transmission line) from a given connection point
 - ✓ The capacity of Inverter-Based Resources is larger, comparing to the power system short circuit capacity.
- ❑ **Two problems need to be solved**
 - ✓ Understanding the characteristics of weak AC networks.
 - ✓ Qualification and screening.

Overview of Weak AC Networks Connection

□ SCR was used for describing the “strength” of a power system

The short circuit ratio (**SCR**) is defined in the case of connection of HVDC transmission firstly as the ratio of the short circuit capacity S_{sc} at the AC bus to the rated DC capacity P_{dN} of the inverter station.

$$SCR = S_{sc} / P_{dN}$$

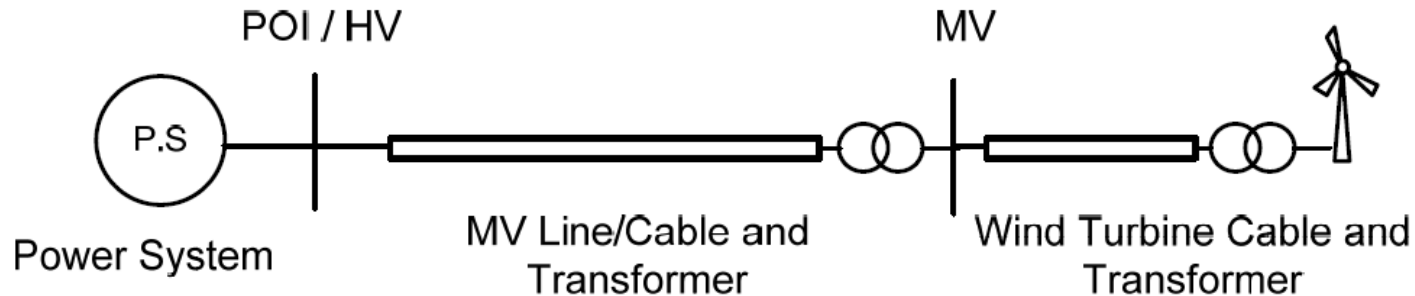


□ Concept in IEEE Std 1204-1997^[2]

- ✓ A high SCR SCR value greater than 3.
- ✓ A low SCR SCR value between 2 and 3.
- ✓ A very low SCR SCR value lower than 2.

[2] IEEE 1204-1997 Guide for Planning Dc Links Terminating At Ac Locations Having Low Short-circuit Capacities

Overview of Weak AC Networks Connection



❑ Concept in CIGRE Working Group B4.62 TB 671 2016

- ✓ Weaker Wind Power Plant applications (e.g. $3 < SCR < 5$)
- ✓ Very weak Wind Power Plant applications (e.g. $SCR < 3$)

❑ Potential issues

- ✓ Voltage issue, failure to ride through disturbances, electro-mechanical instability, control interaction and instability, etc.

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Overview of Weak AC Networks Connection



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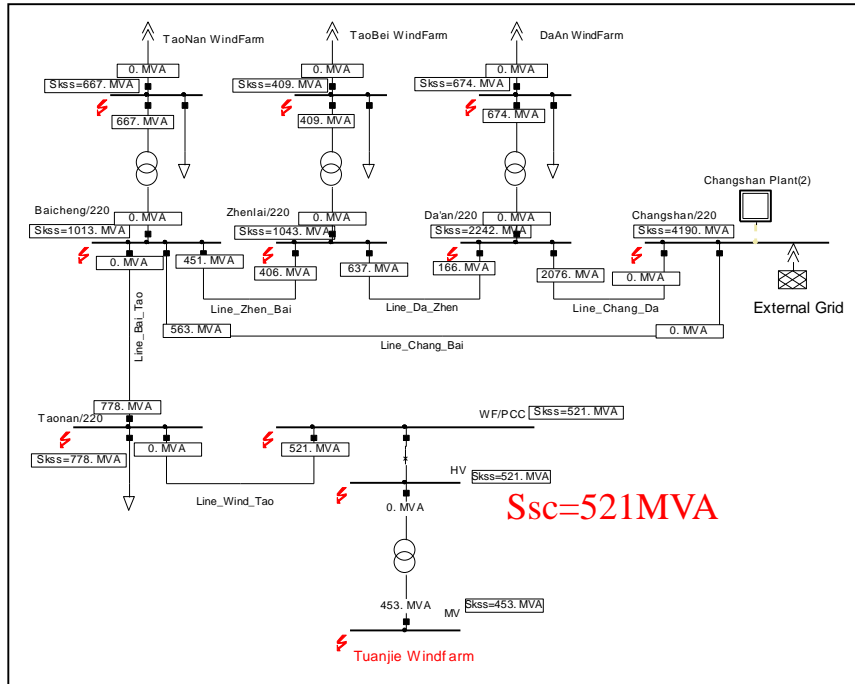
Case study in China

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Qualification and Screening

2.1 Cases of steady-state voltage issue

□ Jilin Tongyu, Baicheng China



The short circuit capacity of Baicheng Network

The SCR of Tuanjie wind farm equals to 2.08, and that could be deemed as the case of wind farm connected into a weak AC network.

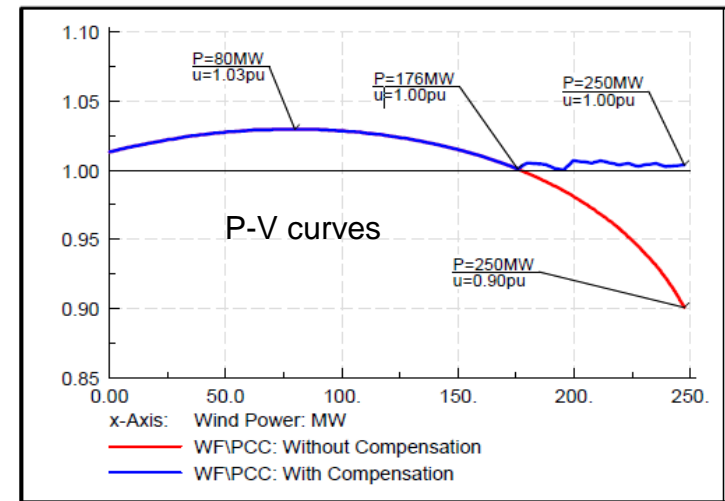
The installed capacity of Tuanjie wind farm, located in Tongyu County, Jilin Province is 250MW, equipped with DFIG based wind turbines. The wind farm is connected into 220kV Taonan substation with a 100 km long AC transmission line. The network structure of Baicheng is shown in figure, with the backbone mesh grid of 220kV system.

2.1 Cases of steady-state voltage issue

□ Jilin Tongyu, Baicheng China

Wind power variation leads to more severe grid voltage fluctuation, especially at the busbars very close to the wind farm.

| Condition | SCC at PCC point of the wind farm (MVA) | Maximum power generation of the wind farm (MW) |
|-------------------------------|---|--|
| Normal condition | 521 | 260 |
| Baicheng-Zhenlai,N-1 | 398 | 205 |
| Zhenlai-Da'an, N-1 | 398 | 190 |
| Changshan Plant-Da'an, N-1 | 398 | 170 |
| Changshan Plant-Baicheng, N-1 | 350 | 155 |

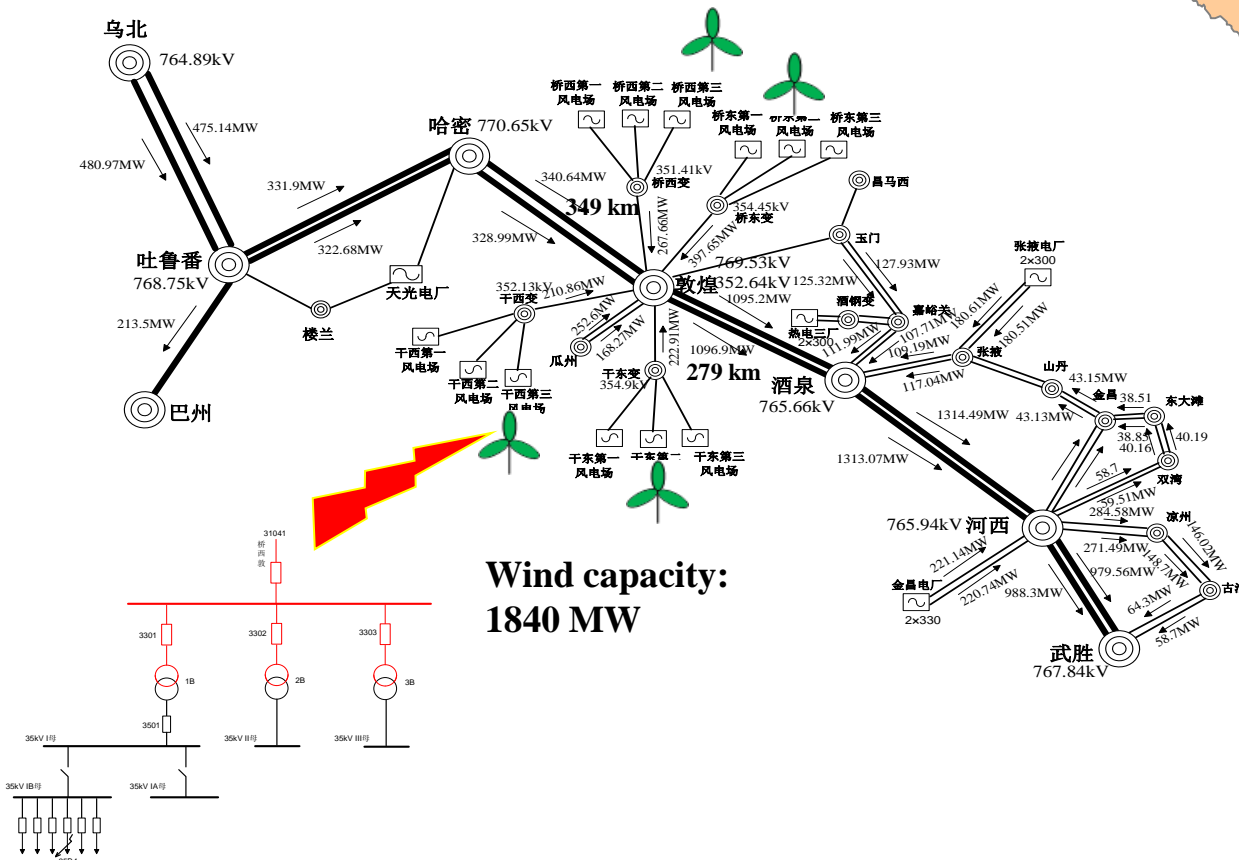


The AC network looks more and more weak with the installed capacity of renewable energy increased. The voltage sensitivity $\frac{dV}{dP}$ or $\frac{dV}{dQ}$ is becoming high at the connection point in weak AC network, and the voltage stability margin becoming low.

2.2. Cases of fault ride through

□ Gansu Jiuquan wind farms, China, 2011.02.24

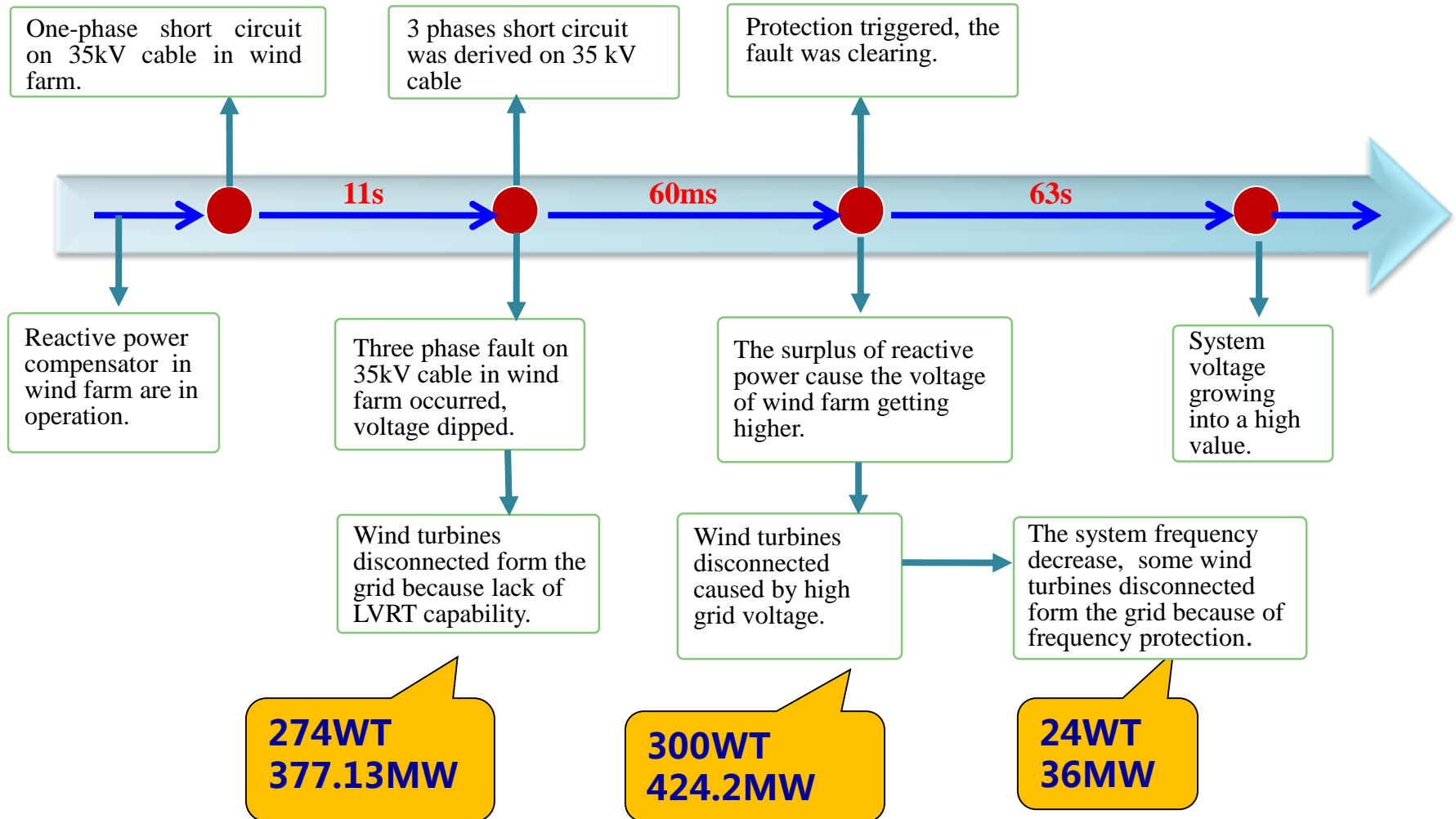
- **Fault Location : Jiuquan Wind Farm in Gansu**
- **Fault type : Single Phase Short Circuit of 35kV Cable**



| | | |
|-------------------|----------------|---------------|
| Pro-fault | 1226 WT | 1545MW |
| ↓ | | |
| Post-fault | 628 WT | 705MW |

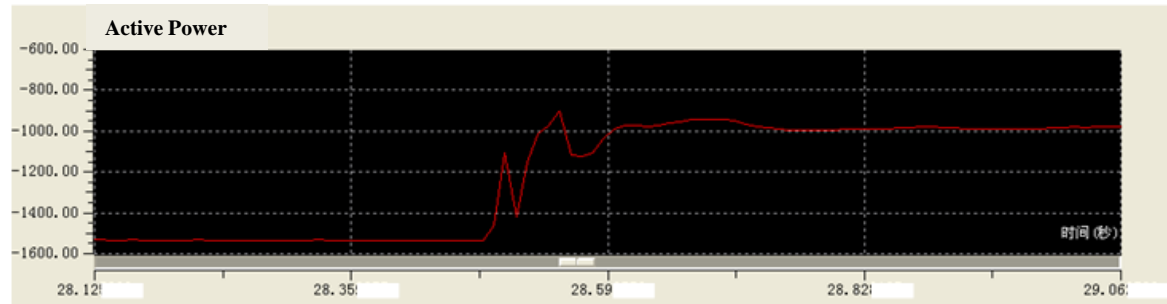
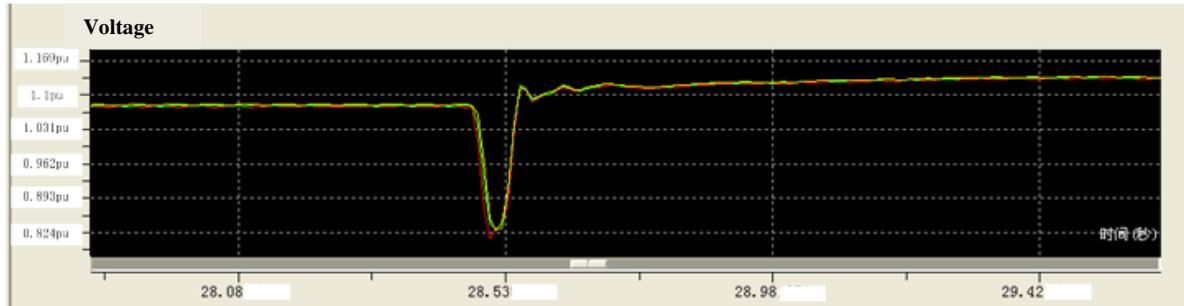
2.2. Cases of fault ride through

Time sequence of the cascading failure of Jiuquan wind power^[3]



[3] Report on large-scale cascading trip-off of wind turbine generators in China

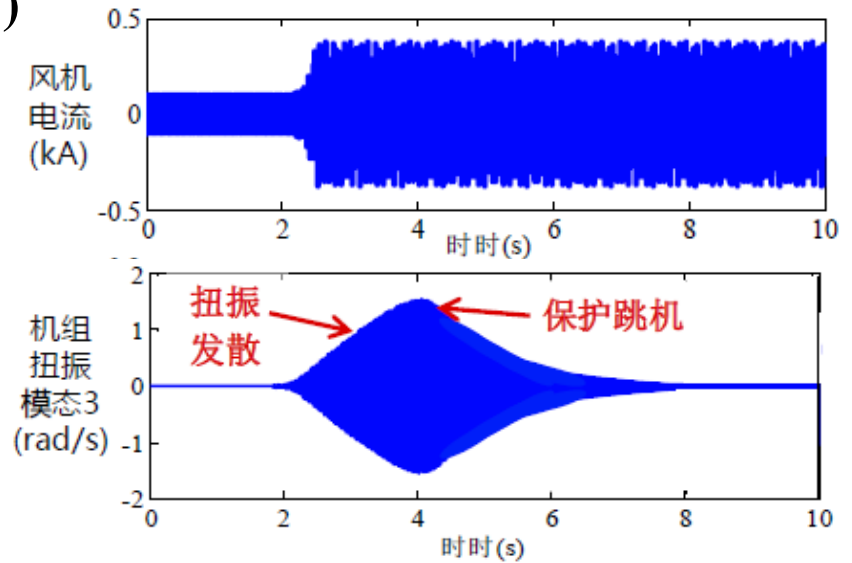
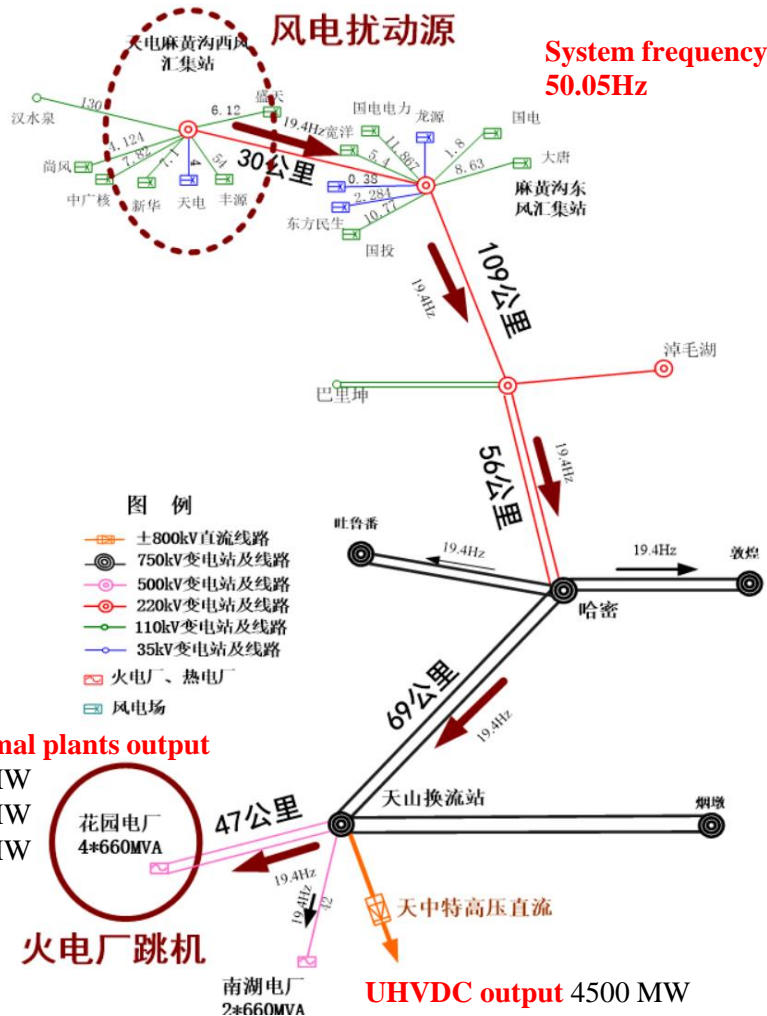
2.2. Cases of fault ride through



- ✓ Lack of fault ride through capability could lead to wind turbine disconnection, and cascading voltage rise during grid fault, much more severe in the case of weak AC system situation or large wind penetration.
- ✓ The voltage is becoming difficult to control after clearance of grid fault, more coordination are also needed for the wind turbines and Q compensation facilities.

2.3. Cases of sub-synchronous oscillation

SSO case in Hami China (July 1, 2015)

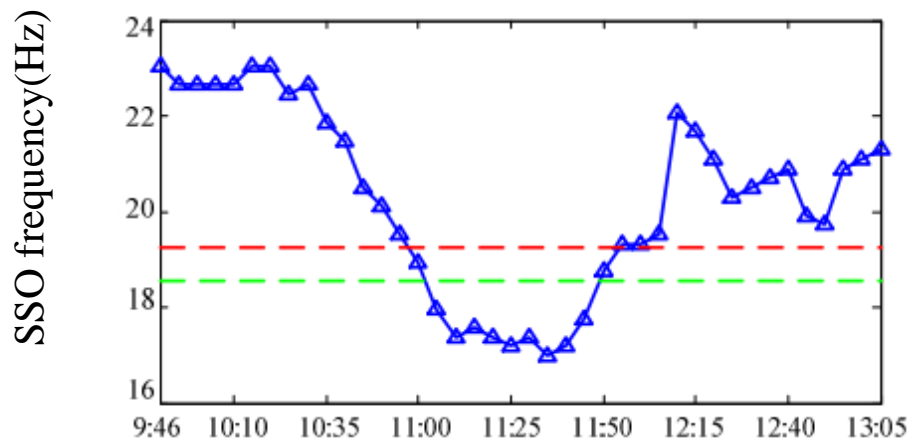


- ✓ There are several full-converter based wind farms (1500MW) in the north, wind power is connected into grid via 110 kV lines.
- ✓ There are 2 thermal power plants with 6 units (each 660MW) and a $\pm 800\text{kV}$ UHVDC converter station. The distance between wind farms and thermal power plants is around 300 km (length of lines).

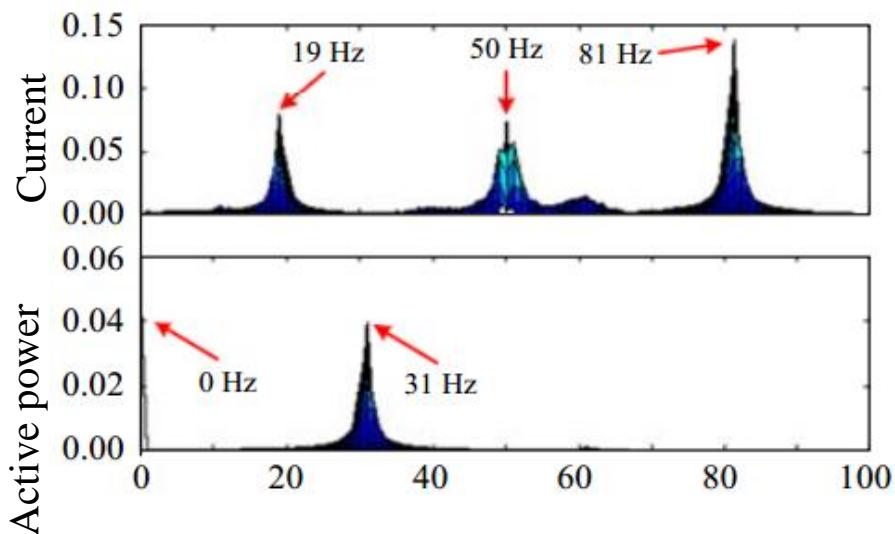
TSR: Torsional Stress Relay

2.3. Cases of sub-synchronous oscillation

□ SSO case in Hami China (July 1, 2015)



- ✓ SSO frequency is from 17 to 23 Hz time-varying, based on the PMU data analysis.
- ✓ The red line is the complementary frequency of shaft torsional mode. During 11:50-11:55, SSO frequency is coupled with plant shaft torsional frequency, resulting in the shaft torsional vibration and tripped the thermal power unit.
- ✓ Current contains sub-synchronous(19Hz) and super-synchronous ((81Hz) components, active power contains 31 Hz components.



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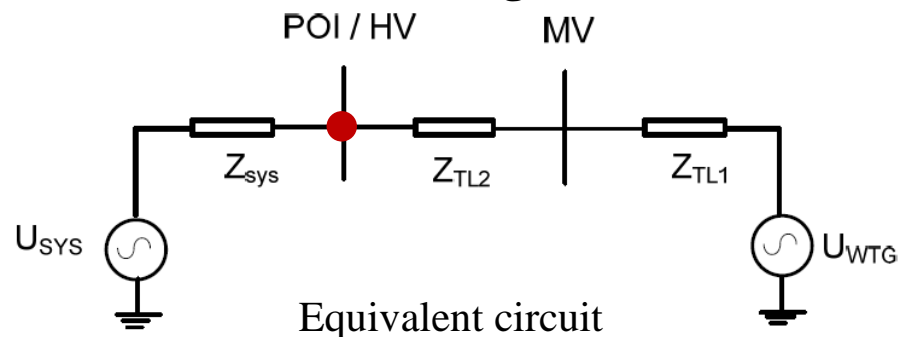
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Qualification and Screening



Qualification and Screening

- **SCR(short circuit ratio) used for describing the AC networks**



- ✓ The basic definition of the short circuit ratio, SCR at the point of interconnection (POI) can be written as:

$$SCR_{POI} = \frac{S_{POI}}{P_{WF}}$$

- ✓ The SCR at the POI can be calculated as the inverse of the per-unit impedance seen at the POI

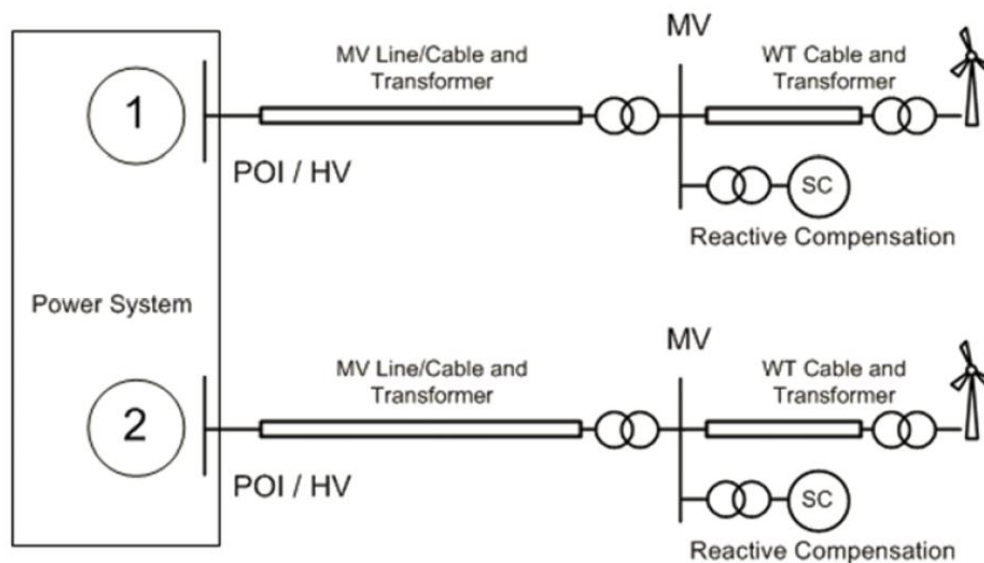
$$SCR_{POI} = \frac{1}{Z_{pu,POI}}$$

Qualification and Screening

Weighted short circuit ratio (WSCR):

The weighted short circuit ratio (WSCR) are described for assessment of the likely power system integration issues with multiple WPPs in service, which is defined by:

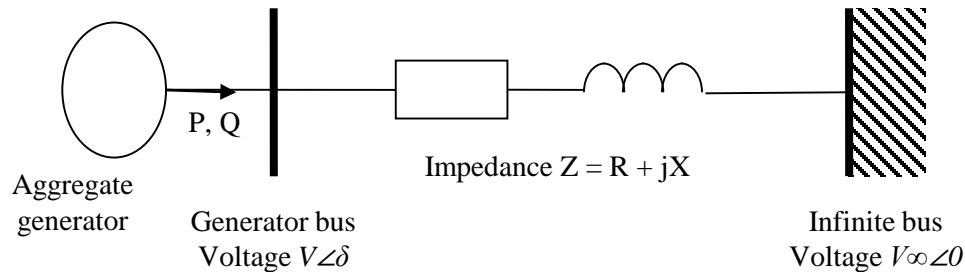
$$\begin{aligned}
 \text{WSCR} &= \frac{\text{Weighted } S_{\text{SCMVA}}}{\sum_i P_{\text{RMWi}}} \\
 &= \frac{(\sum_i S_{\text{SCMVA}i} * P_{\text{RMWi}}) / \sum_i P_{\text{RMWi}}}{\sum_i P_{\text{RMWi}}} \\
 &= \frac{\sum_i S_{\text{SCMVA}i} * P_{\text{RMWi}}}{(\sum_i P_{\text{RMWi}})^2}
 \end{aligned}$$



Where $S_{\text{SCMVA}i}$ is the short circuit capacity at bus i before the connection of WPP i and P_{RMWi} is the MW rating of WPP i to be connected. N is the number of WPPs fully interacting with each other and i is the WPP index.

Qualification and Screening

□ Voltage sensitivity

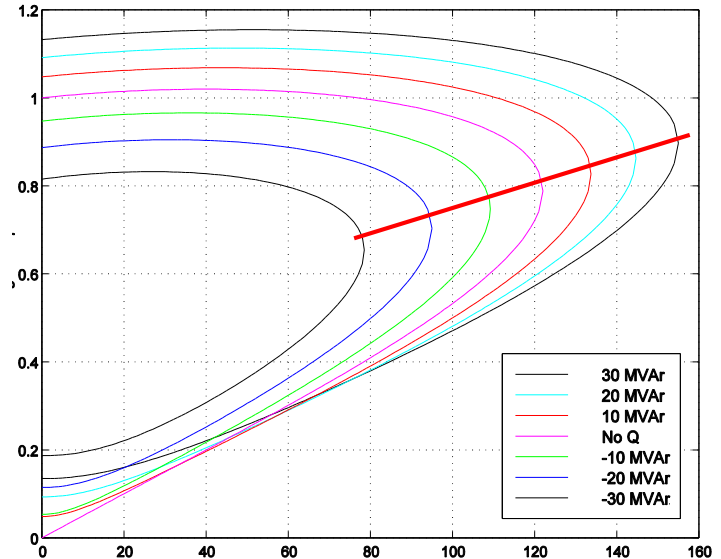


Single generator connected to infinite bus via grid impedance

$$P + jQ = \frac{VV_\infty \sin \delta}{X} + j\left(\frac{V^2 - VV_\infty \cos \delta}{X} - V^2 B\right)$$

$$P_{\max} = \frac{V_\infty^2}{2X} \left(\frac{|Z|}{X} \sqrt{1 + \frac{4XQ}{V_\infty^2}} + \frac{R}{X} \left(1 + \frac{2XQ}{V_\infty^2}\right) \right)$$

As is evident from both this formula and Figure, increasing the reactive power export Q increases P_{\max} and thus boosts the power export capacity of the connection, while reducing Q has the opposite effect.

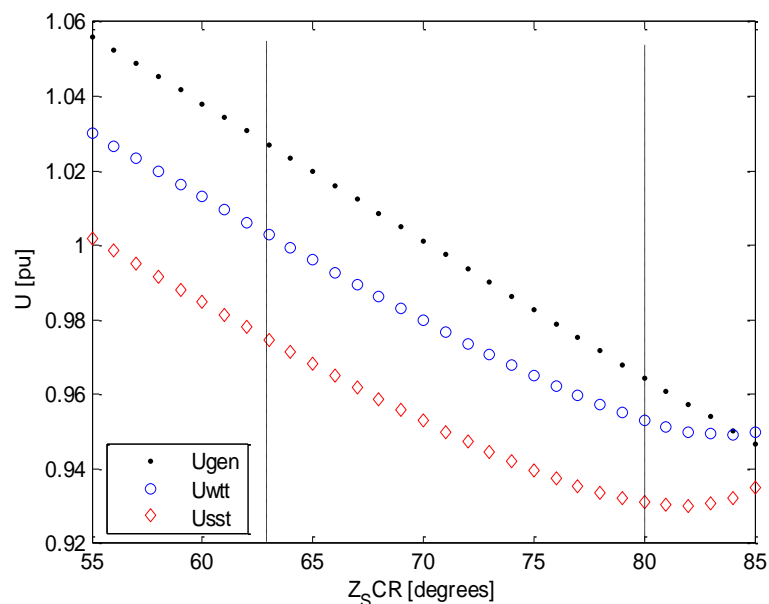


Qualification and Screening

□ X/R ratio

✓ X/R ratio is another factor which can provide insight into the strength of the WPP connection point. In general as the transmission voltage increases, X/R ratio of the transmission lines increases. Therefore, similar to the SCR, a high X/R ratio generally indicates a stronger connection point.

✓ The grid X/R is sometimes represented at the equivalent grid impedance angle. In practical WPPs the grid impedance angle is in the range of 60-85 degrees. Typically, an X/R ratio of below 3 indicates a weak network. Alternatively, a phase angle of below 70 degrees can be used.

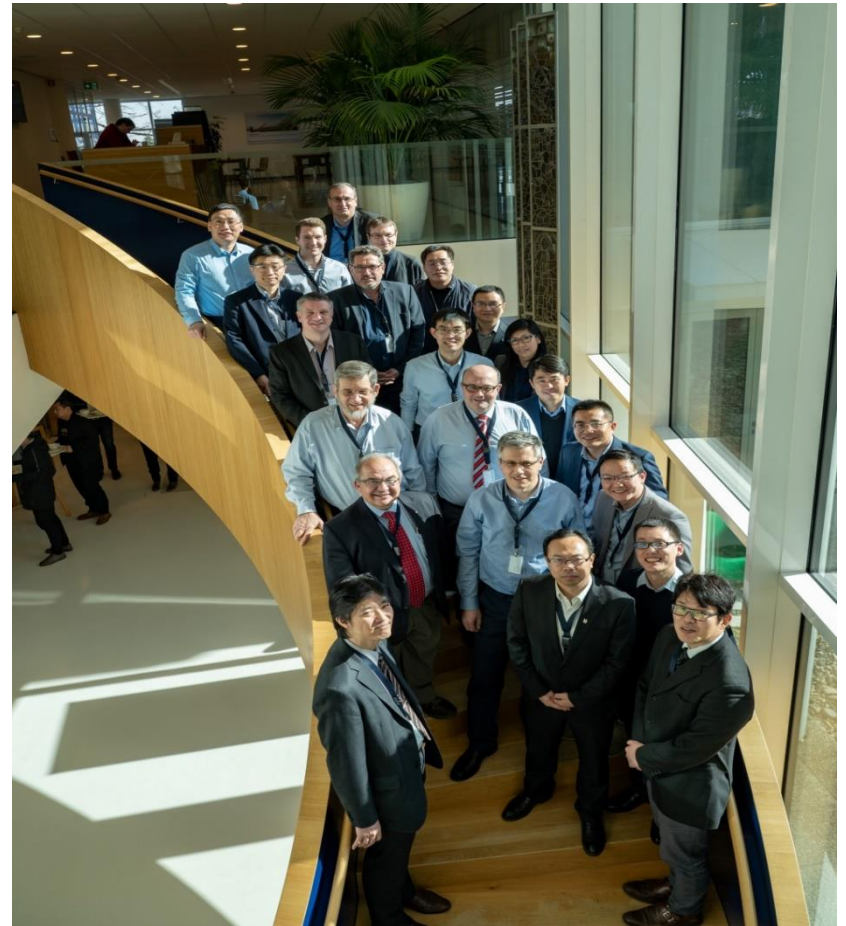


IEC activities on system issues

- ❑ **IEC TC 8/SC 8A/JWG 5 - System issues regarding integration of wind and PV generation into bulk electrical grid**

Four projects:

- ✓ Project 1: Interconnecting Inverter-Based Resources to Weak AC Networks
- ✓ Project 2: Sub- and Super-synchronous Control Interactions
- ✓ Project 3: Fast Frequency Response and Frequency Ride-Through from Inverter-Based Resources during Severe Frequency Disturbances
- ✓ Project 4: Behavior of Inverter-Based Resources in Response to Bulk Grid Faults



Thanks !

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