Integrated Measures for Low Frequency Oscillation Monitoring and Control

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Outline

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1. Background

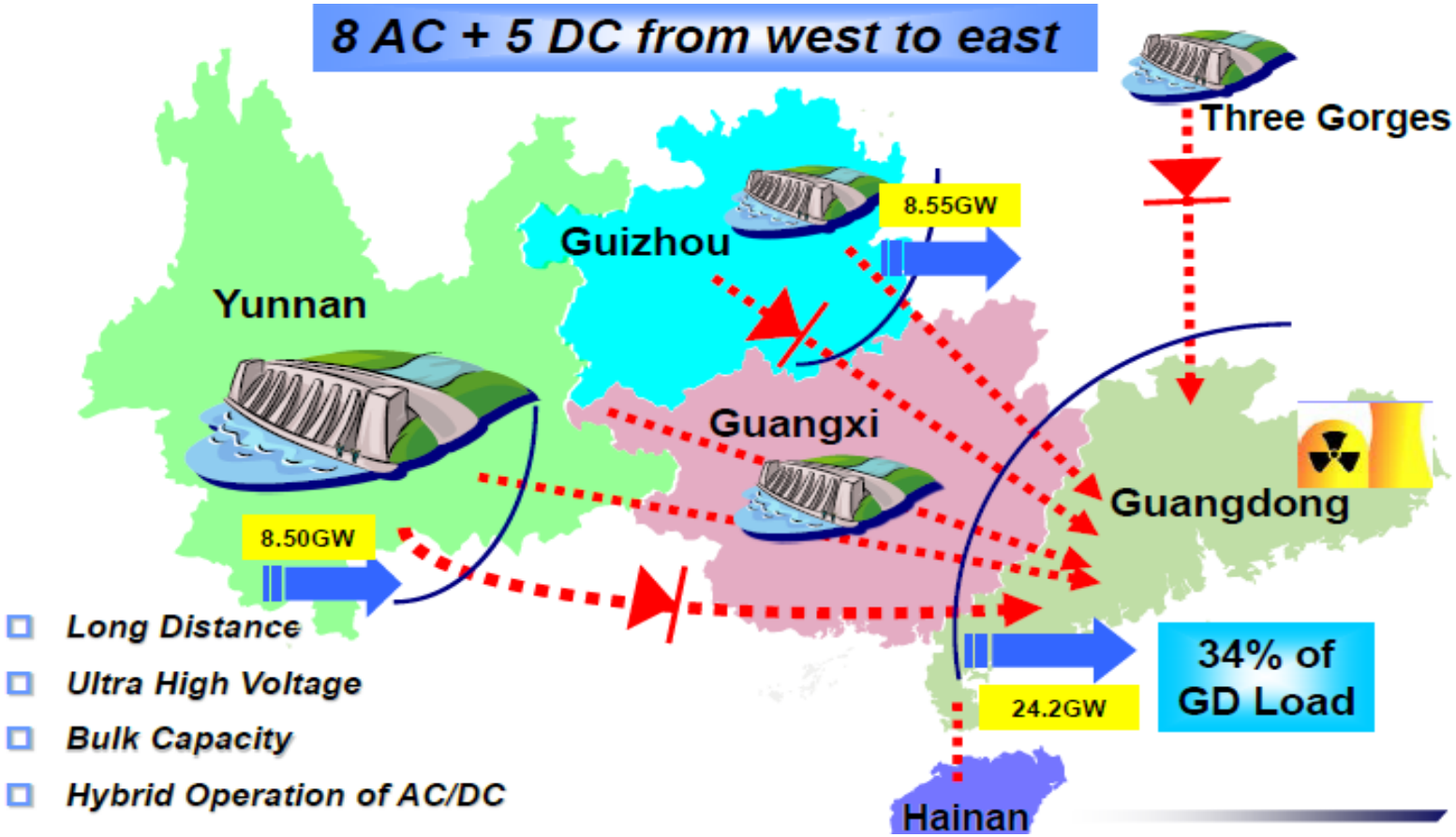
2. Alarming based on Ambient Data Analysis

3. Multiple HVDC Modulation Control

4. Oscillation Energy-based Source Location

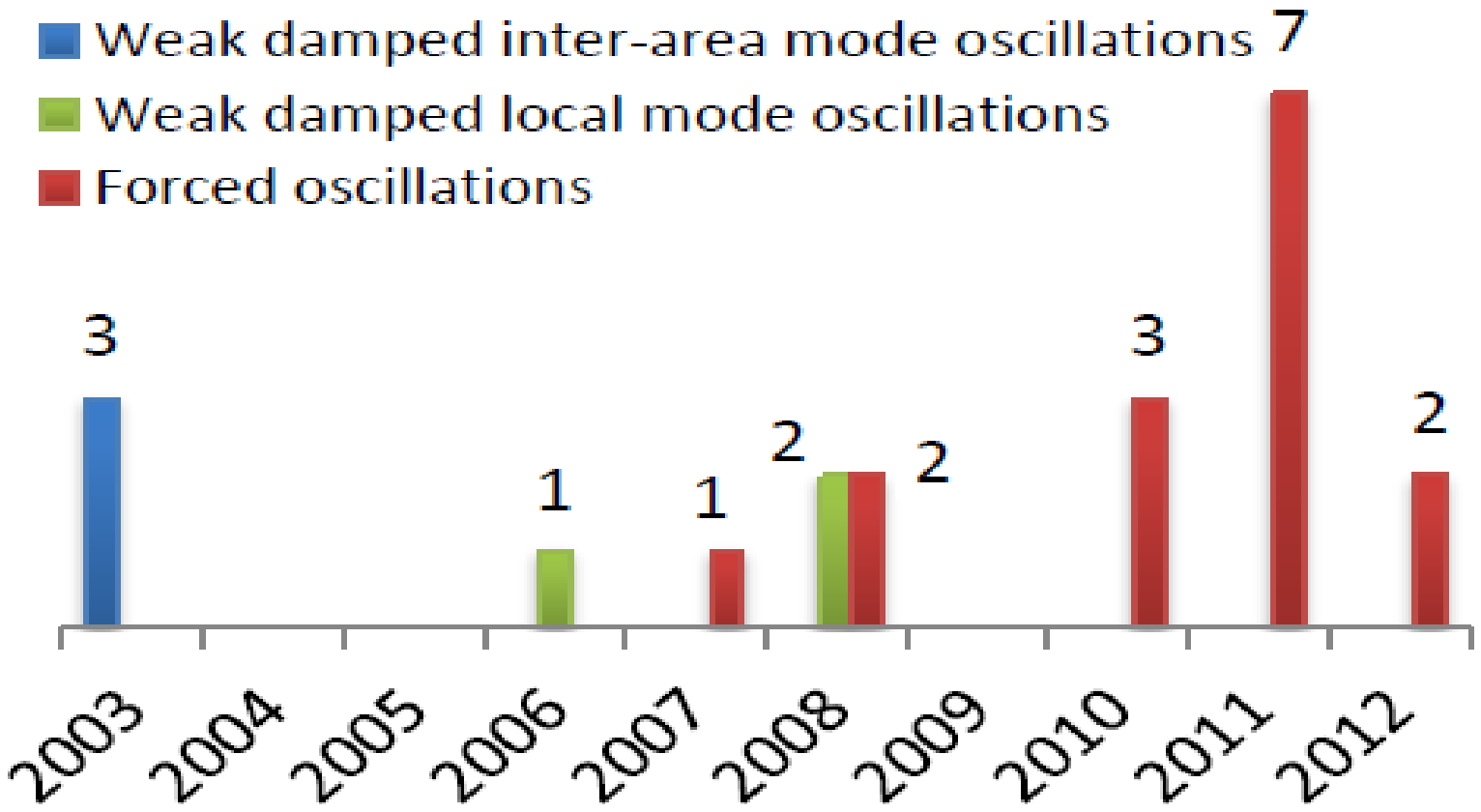
5.Conclusion and Future Work

Background

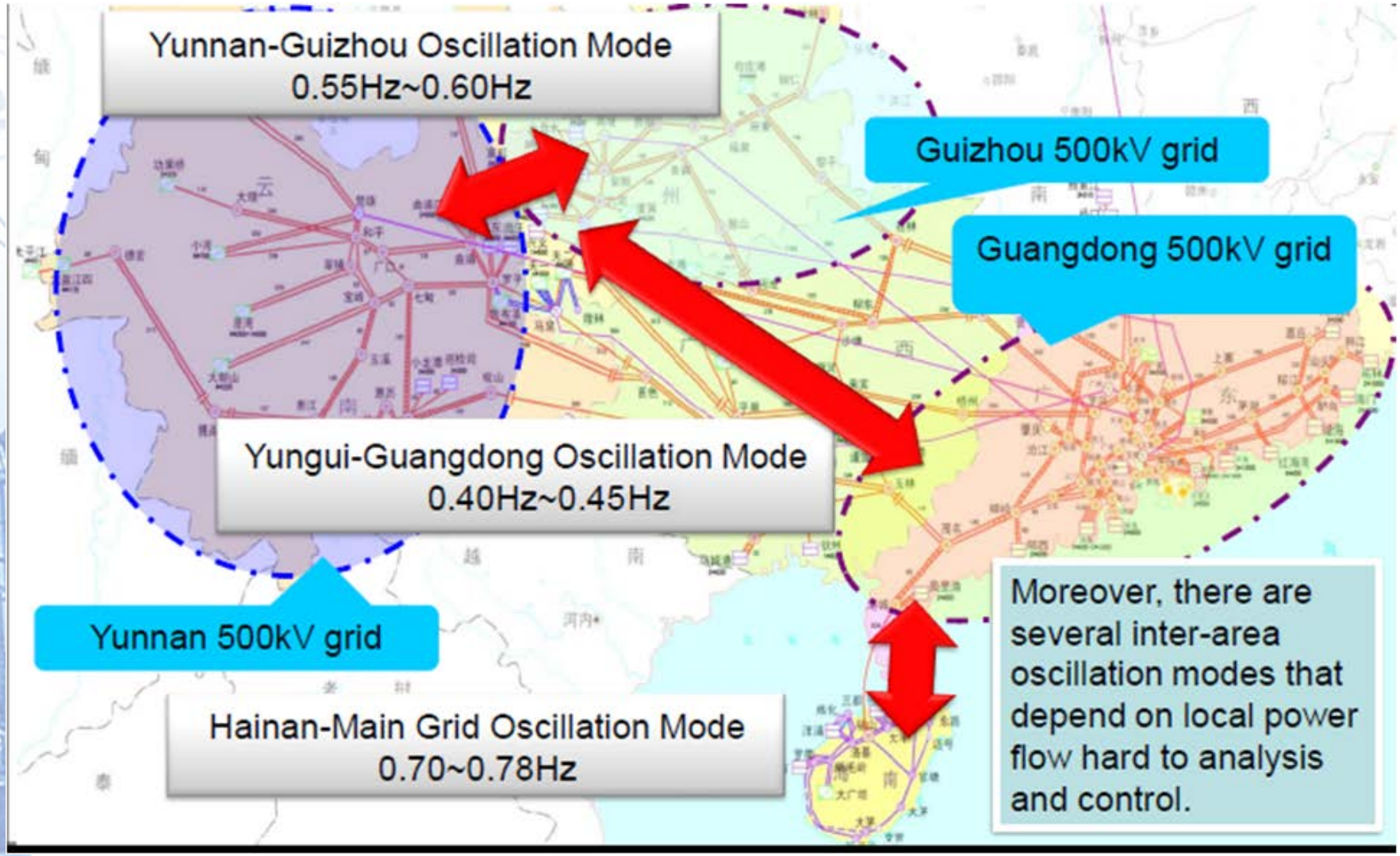


- Span Length >1600km
- Transmission Power > 24GW
- Low Frequency Oscillation (LFO) is inevitable

LFO Events Summary in CSG



Characteristics of LFO in CSG



Measures against LFO

- Conventional measures
  - PSS
  - Manual commands issued by dispatchers
- Novel measures
  - Alarming based on ambient PMU data analysis
  - Multiple HVDC modulation control
  - Generator disconnection or control mode switching based on oscillation source location

Objective of Integrated Measures

- Preventive control **before** LFO occurs
  - By alarming based on ambient PMU data analysis
- Closed loop control **since onset** of LFO
  - By multiple HVDC modulation control
- Remedial control to deal with **sustained** LFO
  - By generator disconnection or control mode switching based on oscillation source location

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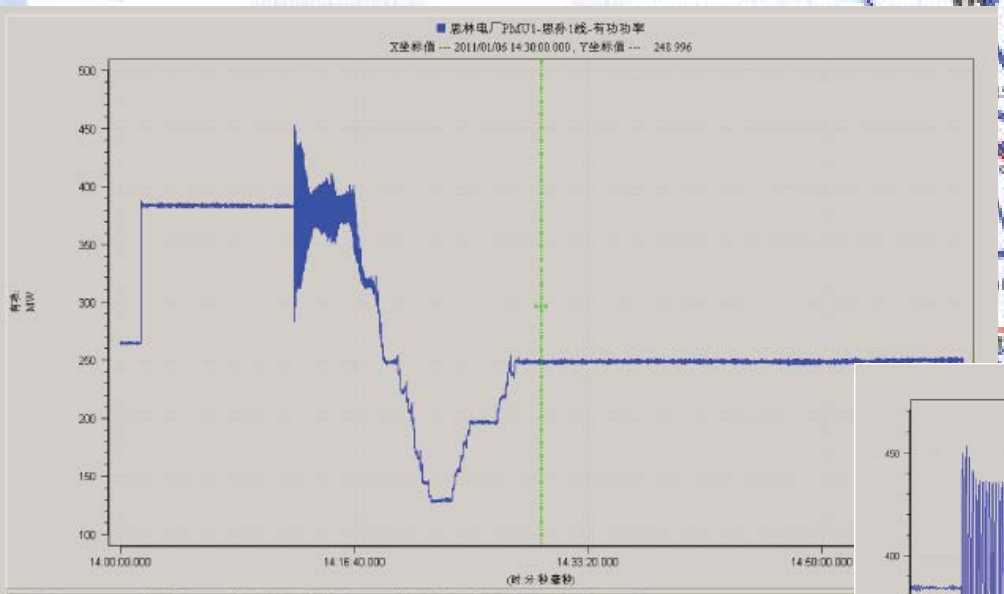
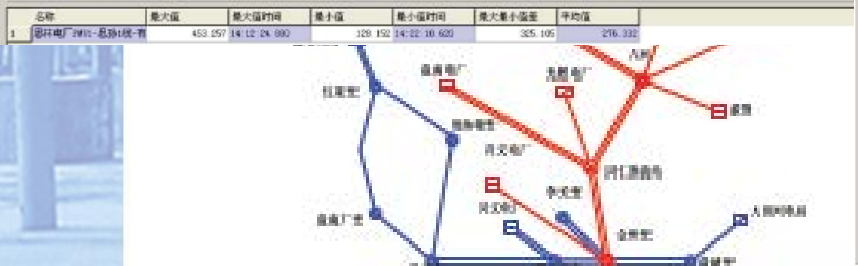
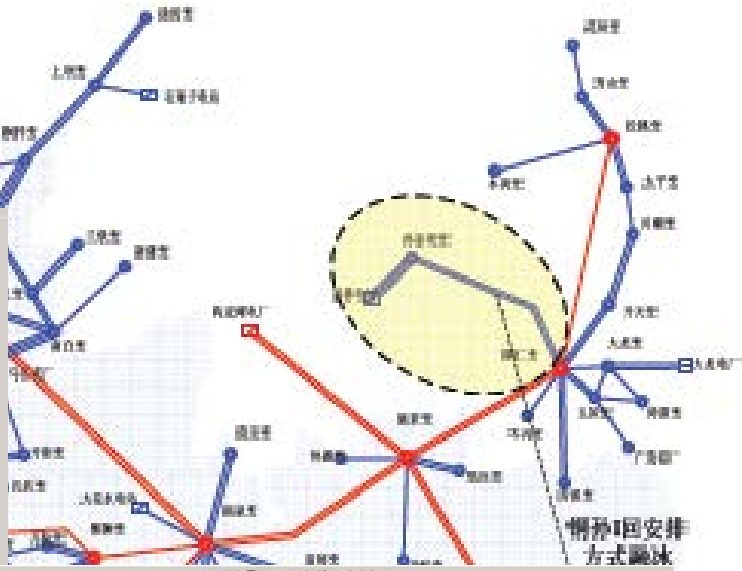
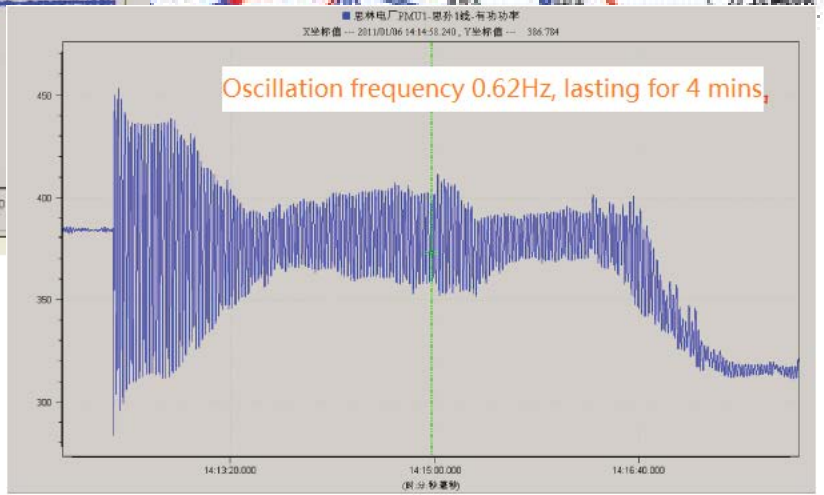
LFO Case 1

- Occurred on Jan.6, 2011
- Due to Bus CB switching

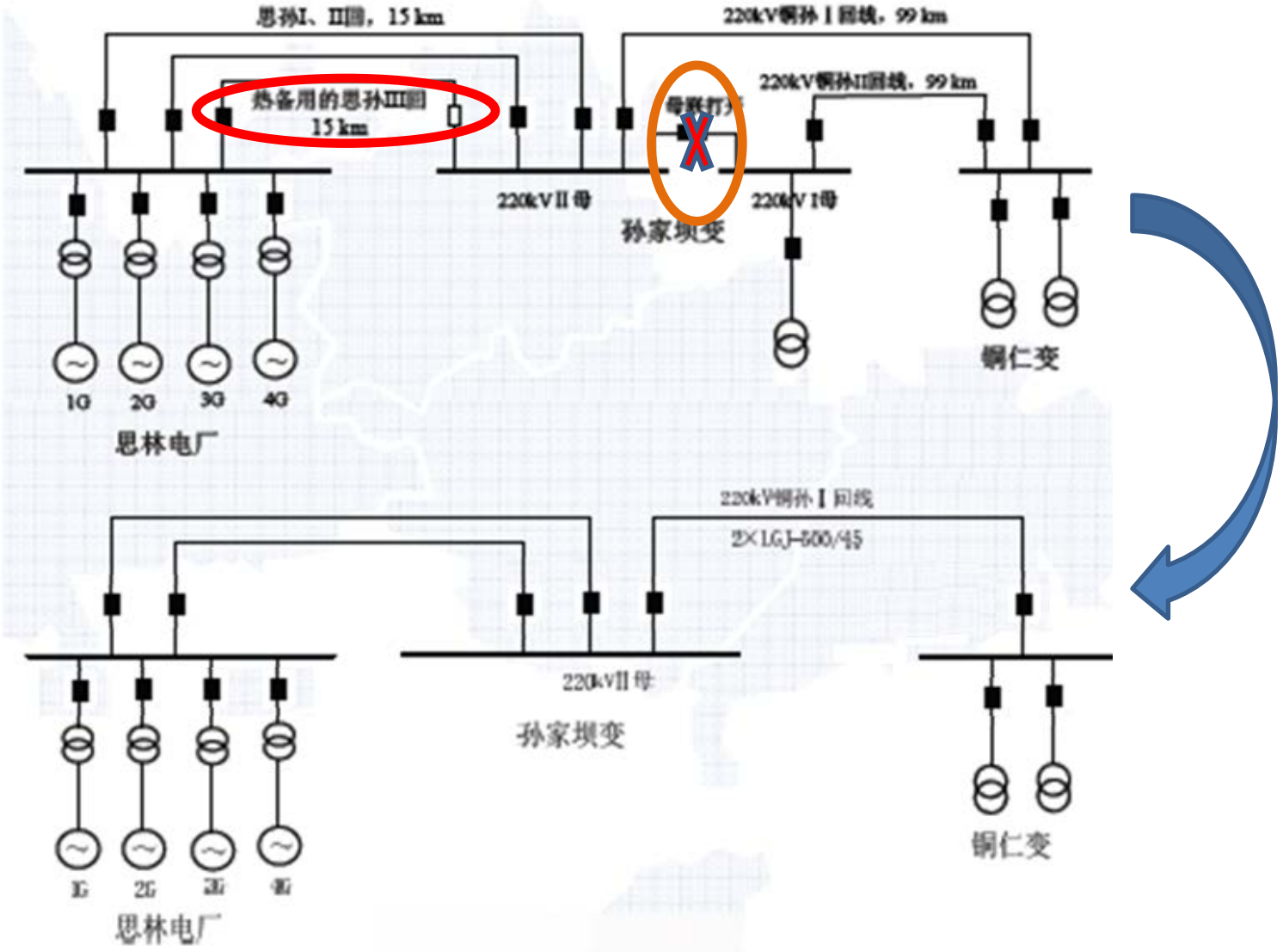




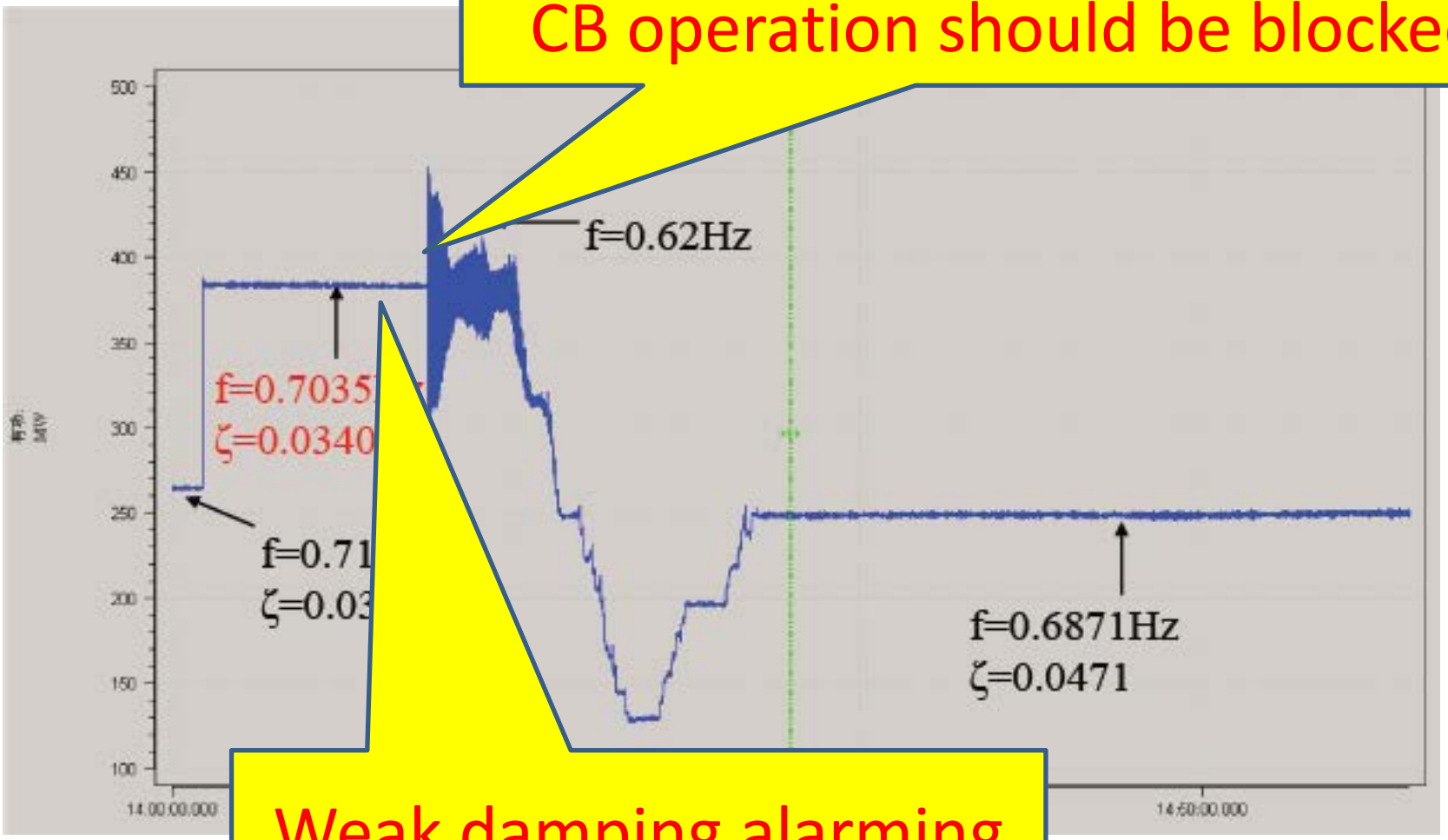




Topology Change of Case 1



Ambient Data Analysis Result

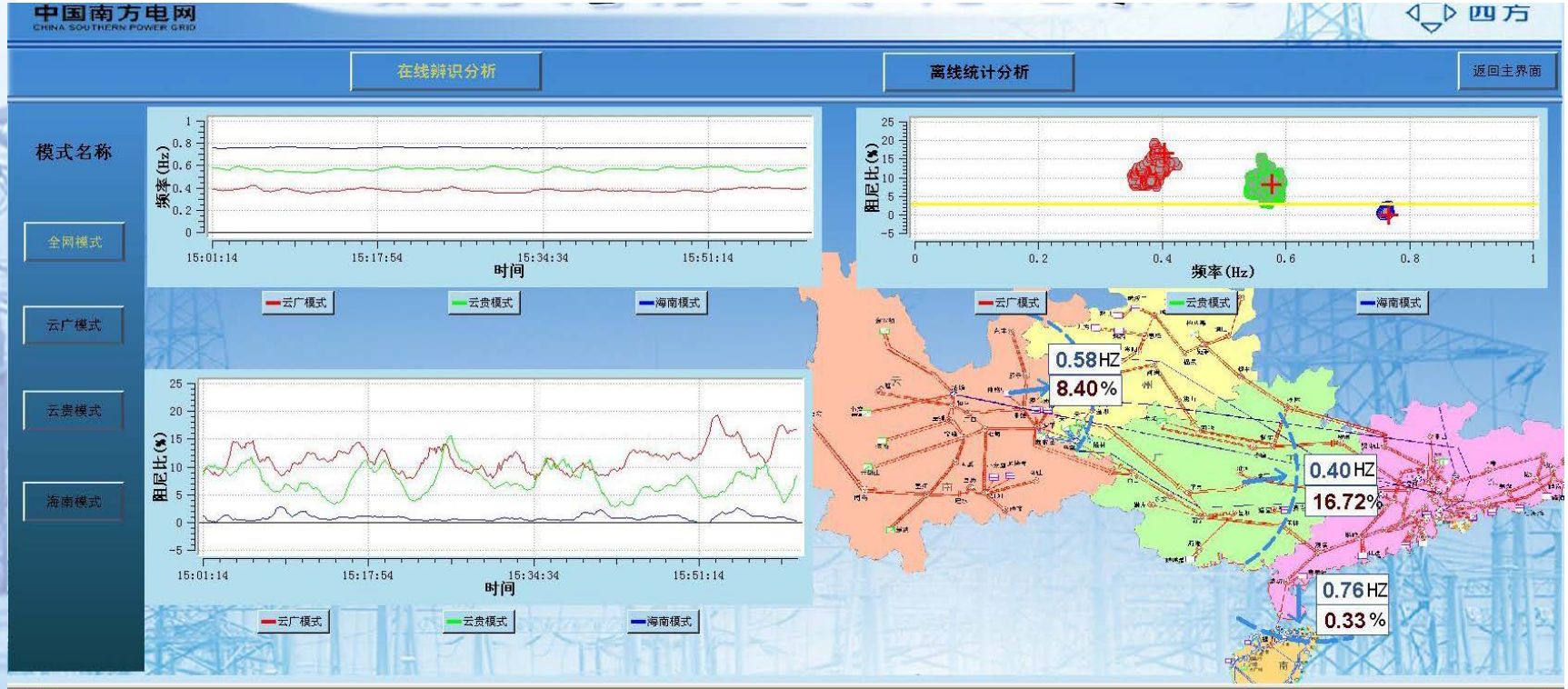


Procedures of Ambient Data based Analysis

- Data preprocessing
- ARMA identification for single measurement
- Clustering of ARMA outputs from multiple measurements

HMI of Ambient Data Analysis

- Commissioned in 2011.
- When damping ratio is lower than the setting threshold, weak or negative damping alarming will be issued.
- YN/GZ-GD mode (0.4Hz, 16.72%) and YN-GZ mode (0.58Hz, 8.4%), are consistent with result from other tools.



Analysis of Abnormal Result

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- HN-GD mode (0.76Hz, 0.33%), where damping is abnormally near zero.
- Restriction of ambient PMU data analysis due to forced oscillation.

$$\Delta\ddot{\delta} + 2\varsigma\omega_n\Delta\dot{\delta} + \omega_n{}^2\Delta\delta = \frac{1}{2*H}(\Delta P_m - \Delta P_e)$$

Normal $\Delta\ddot{\delta} + 2\varsigma\omega_n\Delta\dot{\delta} + \omega_n{}^2\Delta\delta = n(t)$ **White noise input**

Abnormal $\Delta\ddot{\delta} + 2\xi\omega_n\Delta\dot{\delta} + \omega_n{}^2\Delta\delta = R_0\cos(\omega t)$ **Periodic input**

Analysis of Abnormal Result

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$$\Delta\delta(t) = \Delta\delta_1(t) + \Delta\delta_2(t)$$

$$\Delta\delta_1(t) = A_0 e^{-\xi w_n t}\cos(\omega_n\sqrt{1-\varsigma^2}t + \phi_1)$$

$$\Delta\delta_2(t) = \frac{R_0}{\sqrt{(\omega_n^2 - \omega^2)^2 + 4\xi^2\omega_n^2\omega^2}}\cos(\omega t - \varphi_2)$$

- The second item is the dominant component, leading to zero damping ratio.
- Under periodic input, the calculated damping ratio only reflects a pseudo external input oscillation mode.
- As a result, some screening methods are needed to avoid unnecessary alarming.

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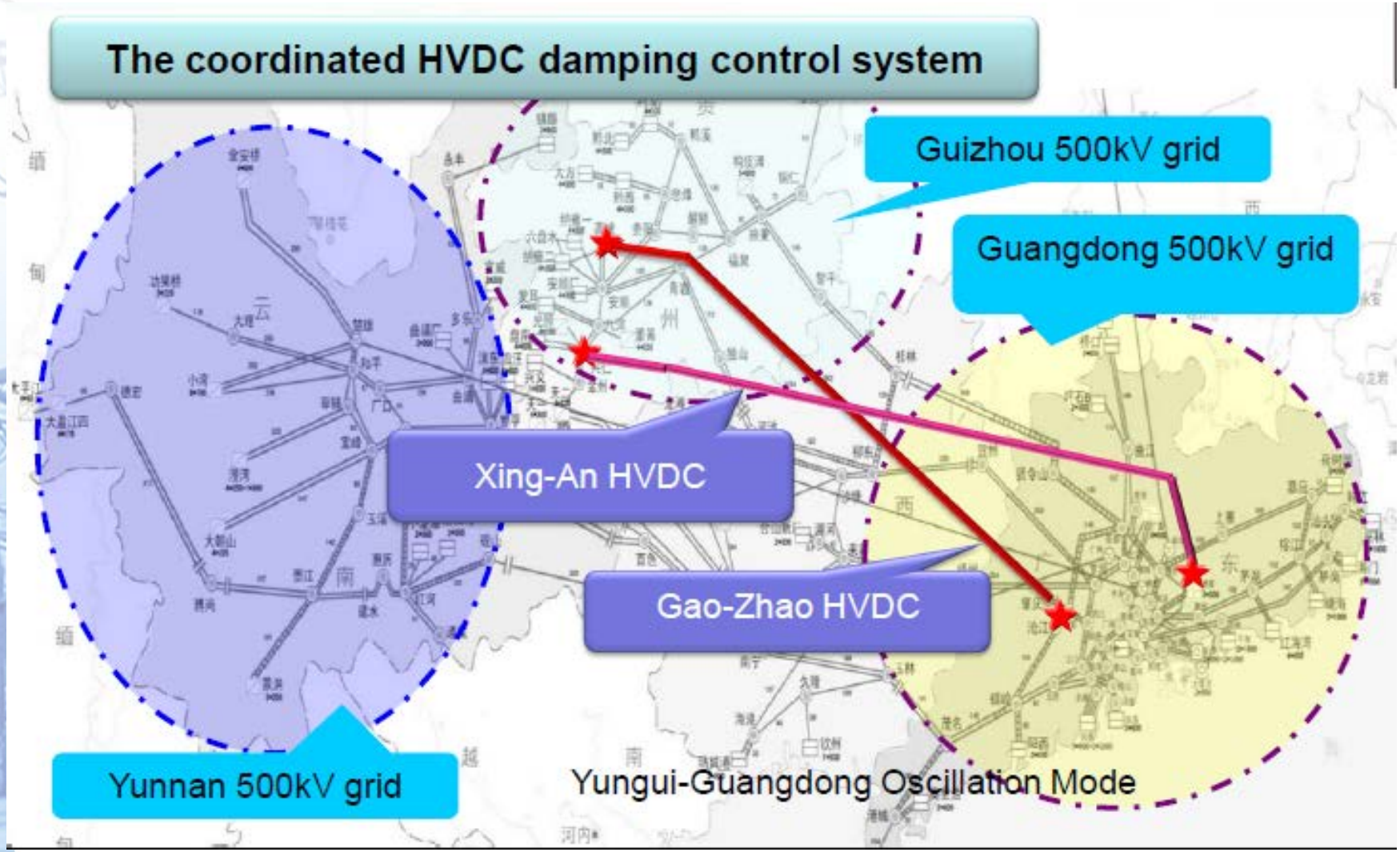
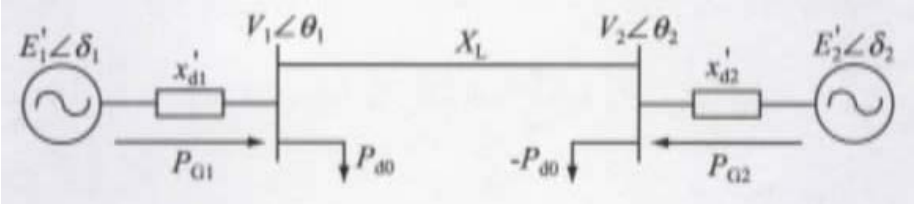
Closed loop control with 2 HVDC lines

- Commissioned in 2009.



Theory on HVDC modulation for LFO damping

- Oscillation between sending-end and receiving-end



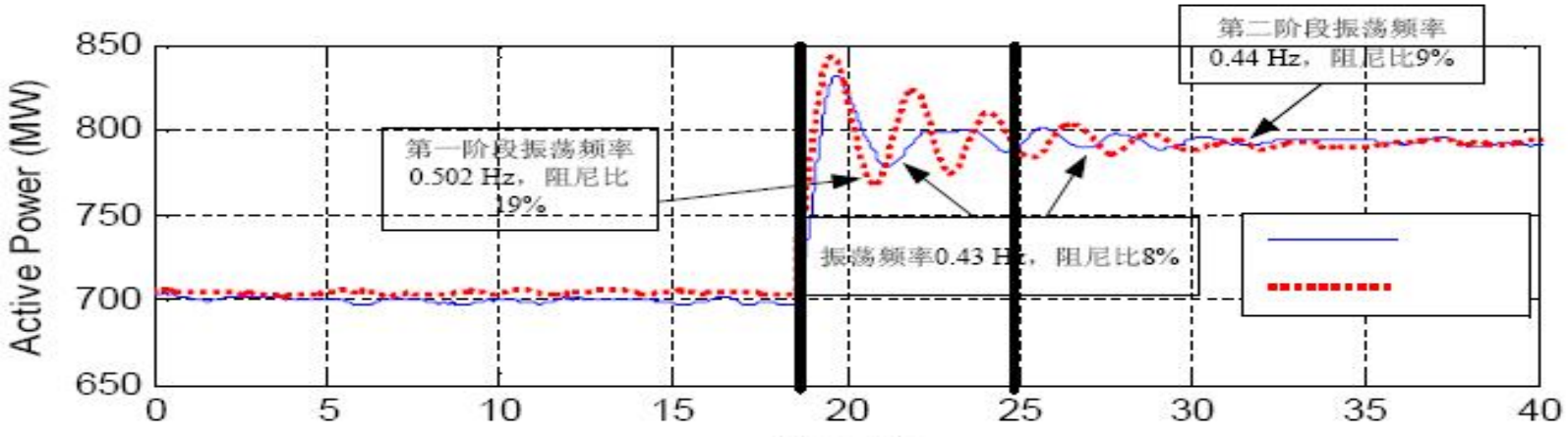
$$V=\sum_{K=1}^{N_G}\left(\frac{1}{2}M_K\,\omega_K^2-P_{mK}\,\delta_K\right)+\sum_{K=1}^{N_L}\left(P_{LK}\,\theta_K+\int\frac{Q_{LK}}{V_{LK}}dV_{LK}\right)+\frac{1}{2}\sum Q_{series}$$

$$P_d=P_{d0}+P_{mod}$$

$$\frac{dv}{dt}=\sum_{i=1}^{2}\left(M_i\frac{d\omega_i}{dt}+P_{Gi}-P_{mi}\right)\frac{d\delta_i}{dt}+\sum_{i=1}^{2}P_i^{inj}\frac{d\theta_i}{dt}+\sum_{i=1}^{2}\frac{Q_i^{inj}}{V_i}\frac{dV_2}{dt}-P_{mod}\left(\frac{d\theta_1}{dt}-\frac{d\theta_2}{dt}\right)$$

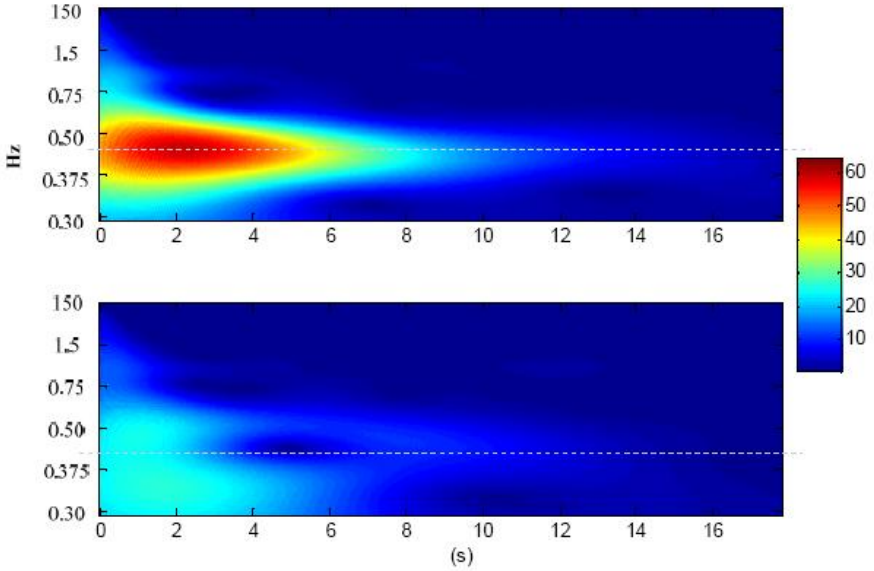
Test on Man-made Disturbance

- Disturbance: TSQ-GD HVDC (carrying 700MW) was blocked



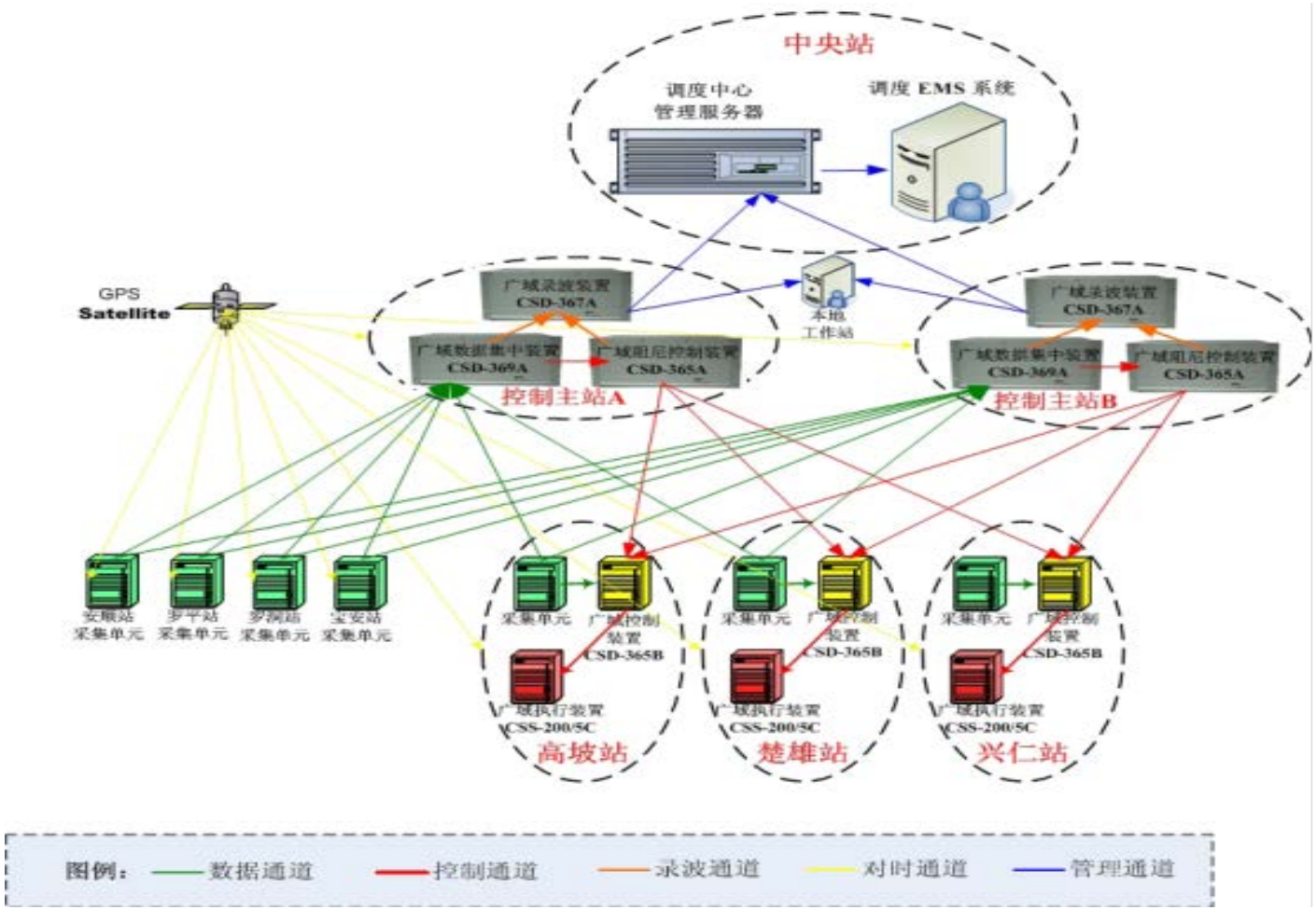
HVDC Modulation Switch Off

HVDC Modulation Switch In



Closed loop control with 3 HVDC lines

- Adding ±800kV Chu-Sui HVDC
- RTDS test finished, commissioning test scheduled



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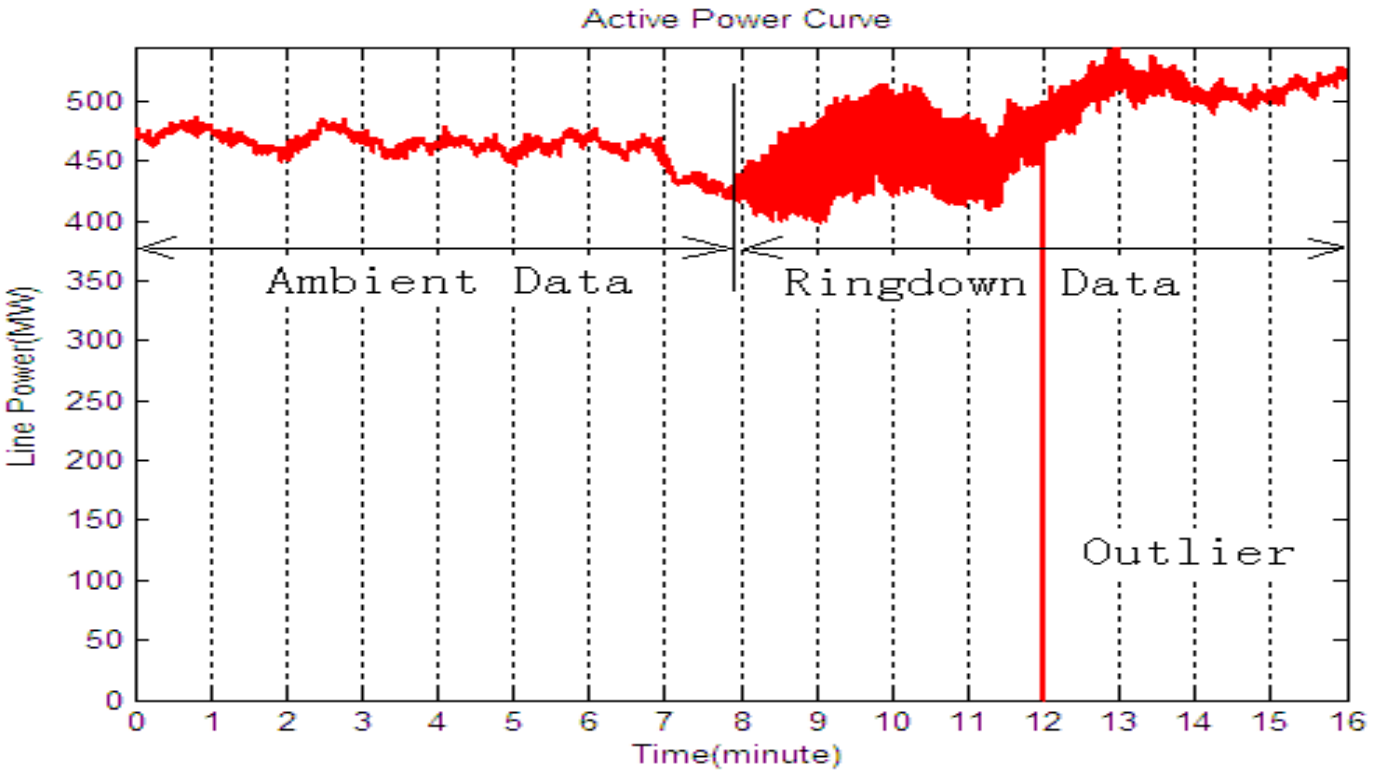
LFO Case 2

- Occurred in 2008, lasting for 6 minutes, peak-to-peak amplitude of oscillation on certain 500 kV tie-line was 91 MW as well as 66 MW at certain generator output.



Event Investigation Result

- Dispatcher issued some control commands, including lowering HVDC transmission power and decreasing generation, but LFO still existed.
- Root cause was found to be faulty turbine control of HH 2# generator.
  - Simulations and field tests prove that, if the main controller of turbine control system with power feedback are out of work, switching the turbine control mode to ‘valve control’ is an effective method to eliminate LFO.
- **Fast automatic** method to locate the oscillation source is needed.

Oscillation Energy Calculation

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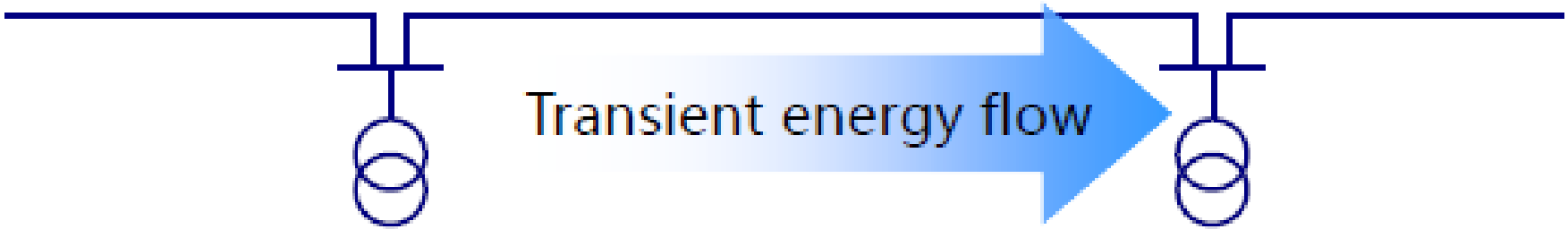
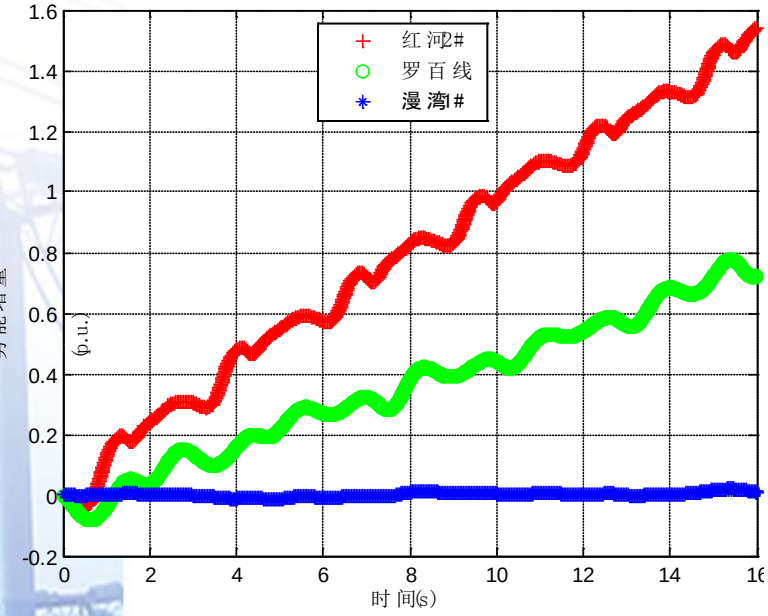
- Basic formula for calculation

$$V_{PEi}(t) = \int_0^t \Delta P_{ij} \Delta \phi_i dt \qquad V_{PEj}(t) = \int_0^t \Delta P_{ji} \Delta \phi_j dt$$

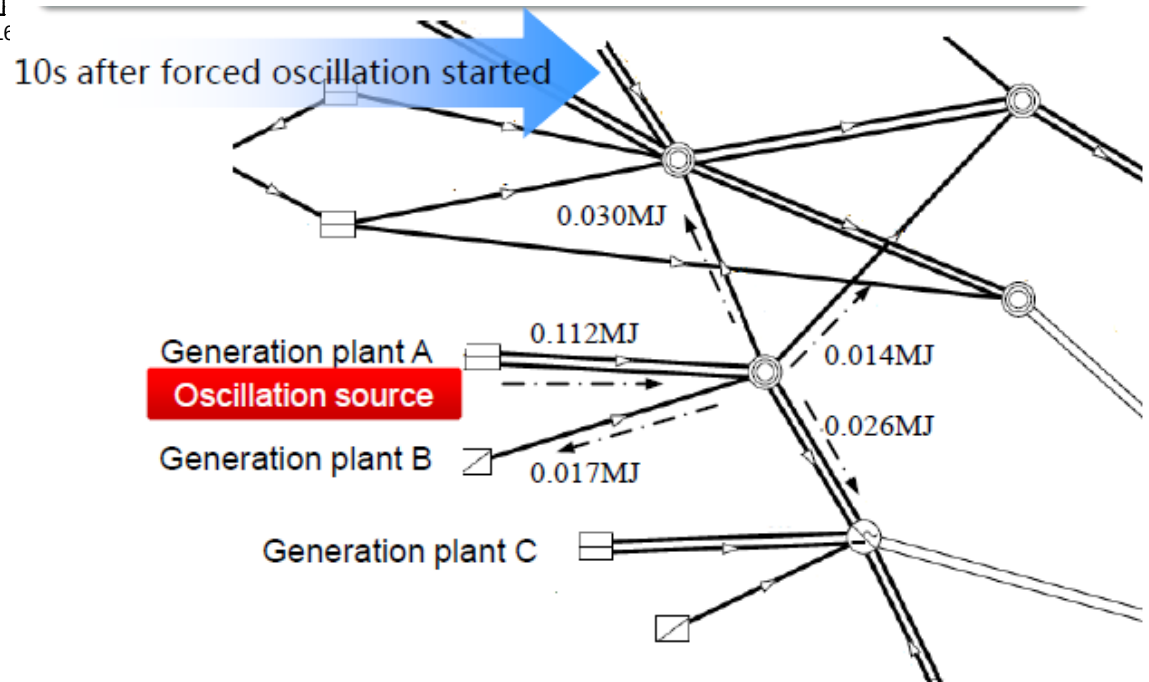


Oscillation source generator

Calculation Result for Case 2

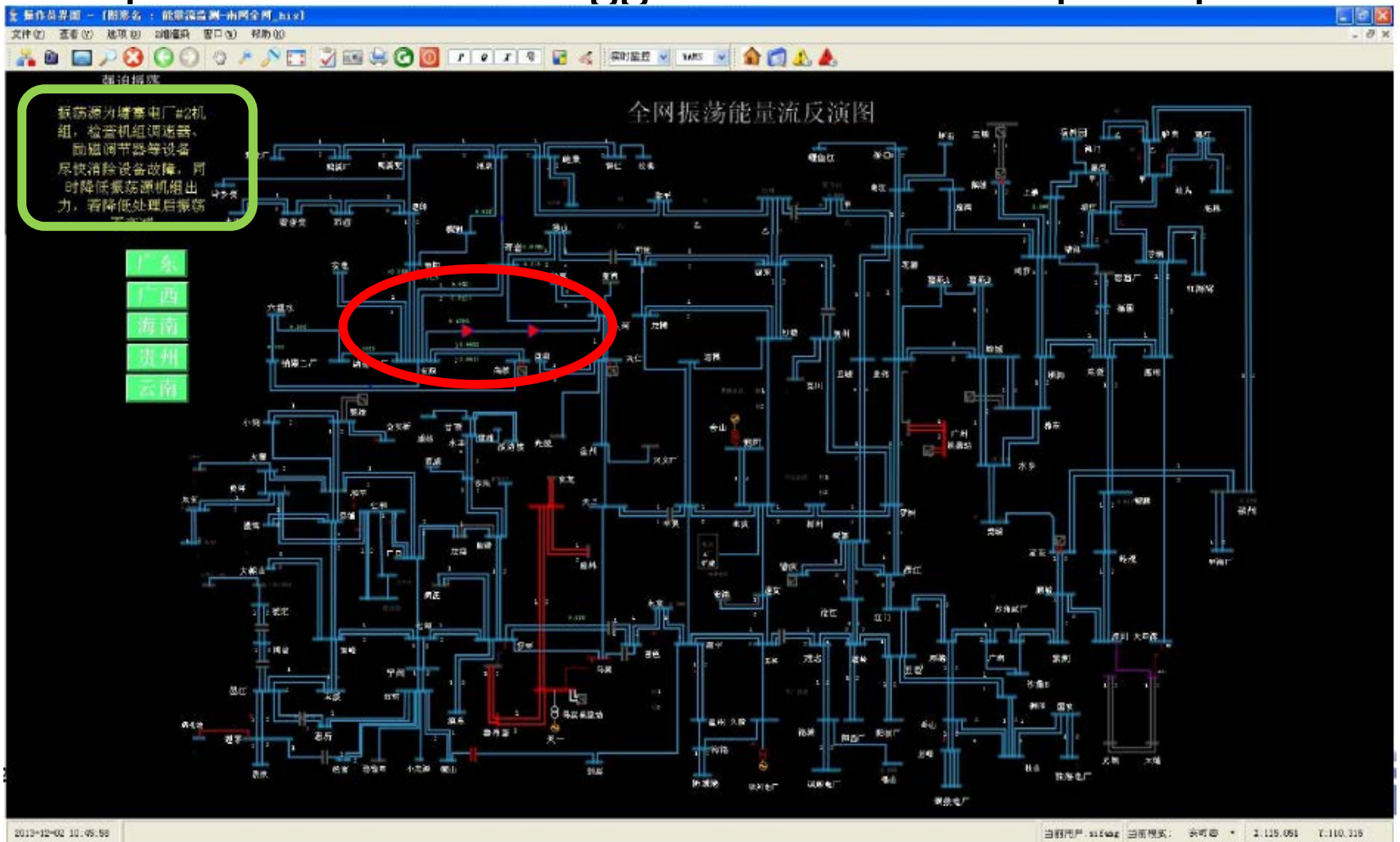


Visualization on geographic diagram



HMI of Oscillation Source Location

- During commissioning test, on Aug.13,2013, forced oscillation caused by turbine controller of TZ power plant was captured. Control suggestion was also prompted.



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Conclusion and Future Work

- Novel measures, together with conventional measures, have constituted an integrated defense system against LFO.
- Further study on mode shape and regulation suggestion with ambient data analysis method should be continued.
- Oscillation energy based source location method should be validated for different kinds of controller fault.
- All these efforts will lead to application in dispatcher's console.

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Thanks!

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