山东大学
SHANDONG UNIVERSITY

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WAMS Light and Its Applications

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Outlines

1. **Why measure from LV side?**
2. **Brief introduction to WAMS Light**
3. **Applications of WAMS Light**
4. **Disturbance location with WAMS Light**
5. **Summary**

PMU and WAMS

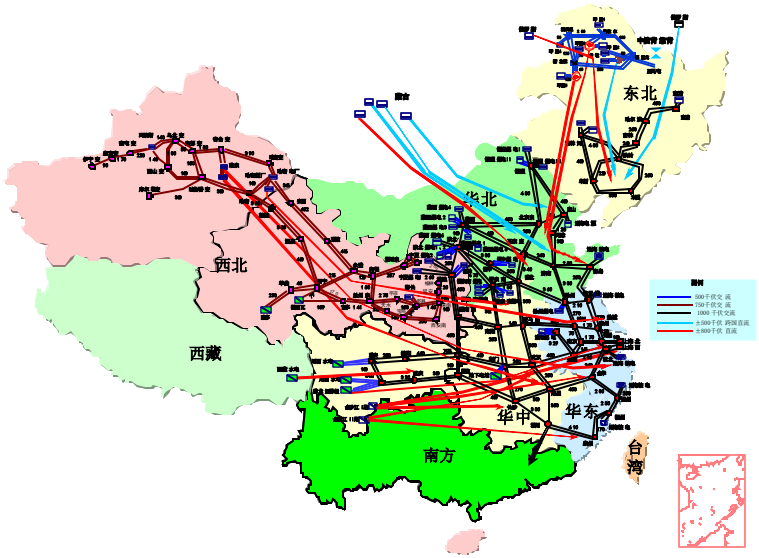
- In 1893, Charles Proteus Steinmetz presented a paper on simplified mathematical description of the waveforms of alternating current electricity. Steinmetz called his representation a phasor.

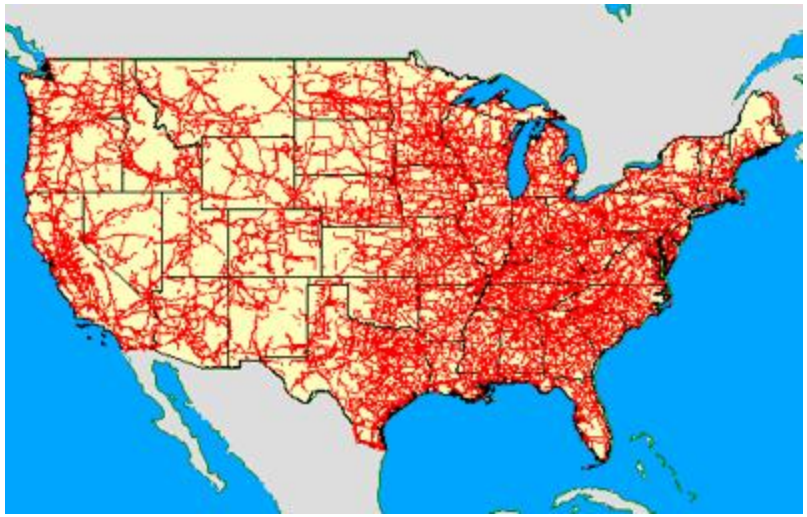
- With the great contributions of Dr. Arun G. Phadke and Dr. James S. Thorp, the first PMU was invented in 1988 at Virginia Tech.

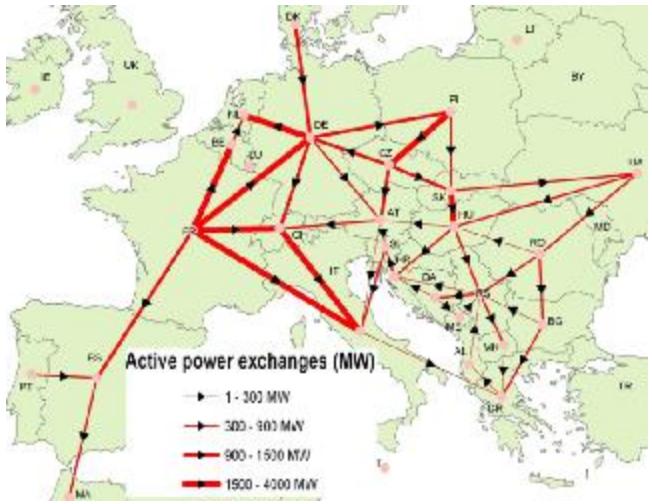
- WAMSs are playing a very important role in power systems operation.

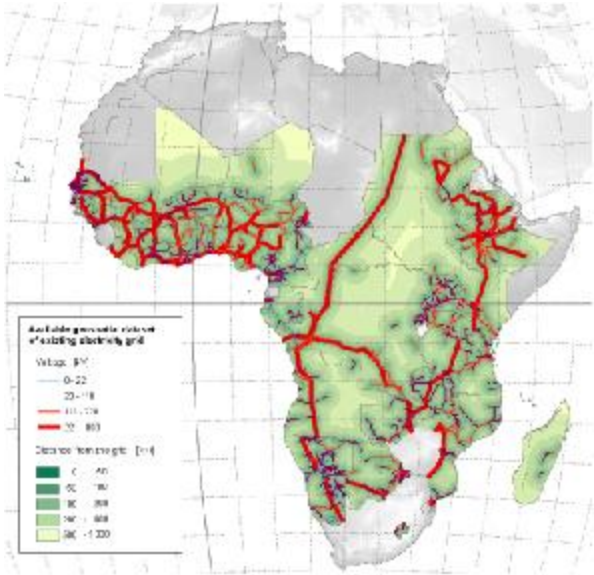
Configuration of power systems

- High voltage (HV) and large-scale power system is still playing the most important role in energy supply



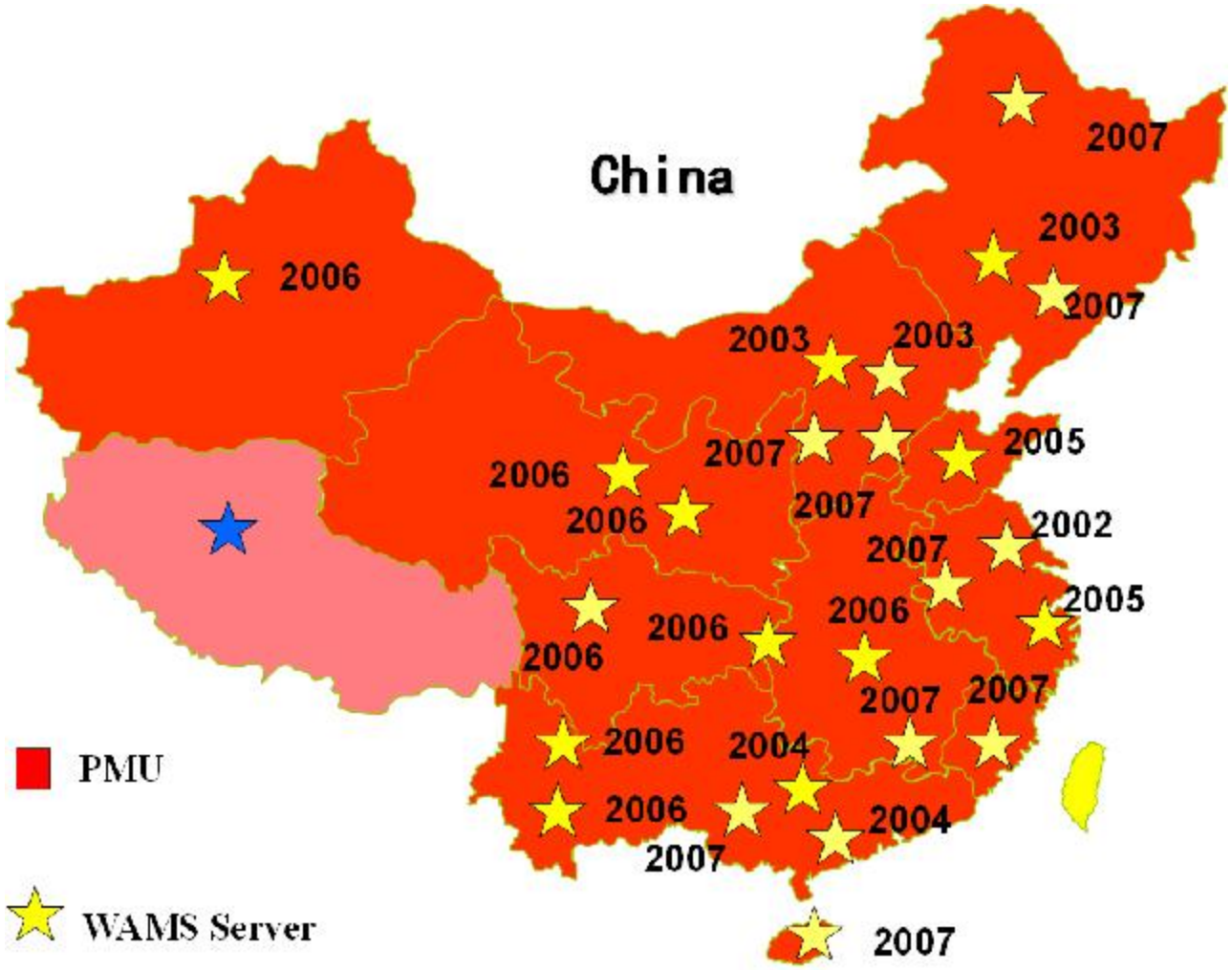






WAMS deployment in China

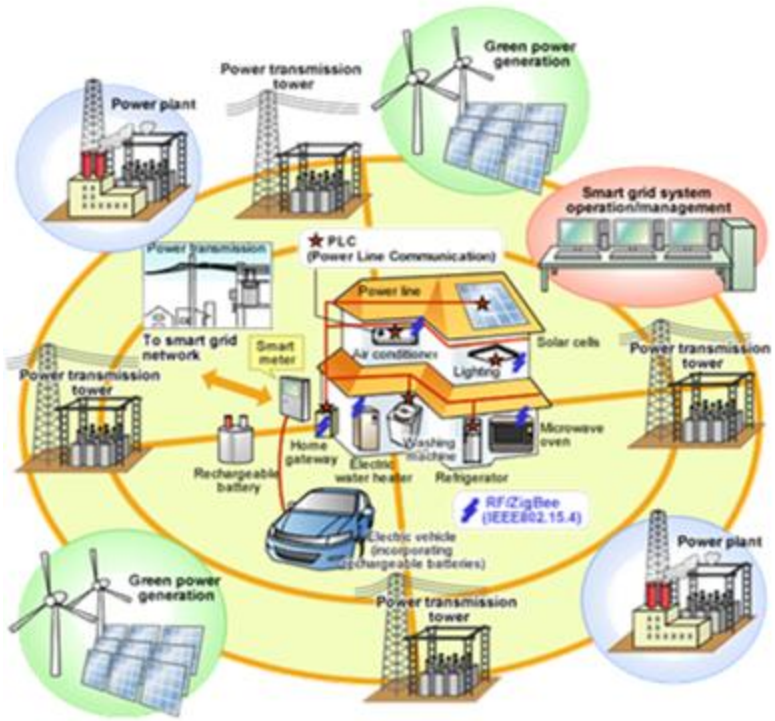
More than 2500 PMUs installed



All installed at 500kV, 1000kV substations and power plants

Driven force of monitoring at LV side

- Measurement of LV network is required for smart grid operation and control
  - Distributed generation
    - Wind, PV
  - Storage
  - Electric vehicles (EV)
  - Demand response (DR) under market enviroment
  - ...

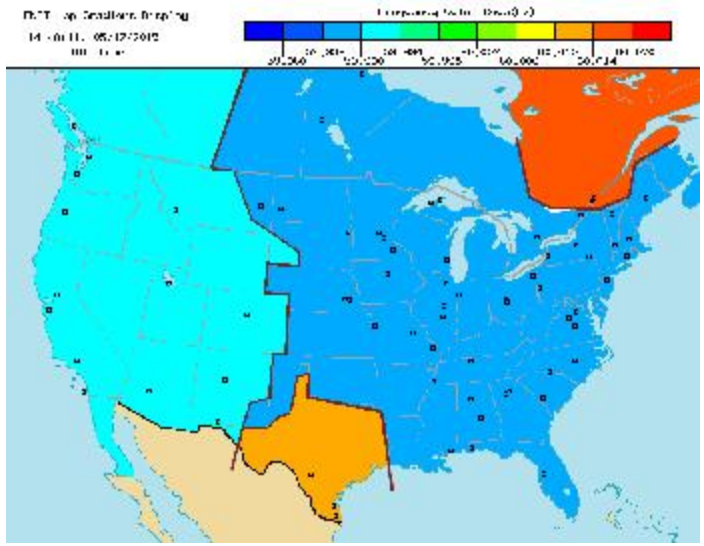


Distributed renewable generations are driving the dynamics of the LV networks to become more complex

LV monitoring in the world

Frequency monitoring NETwork(FNET)

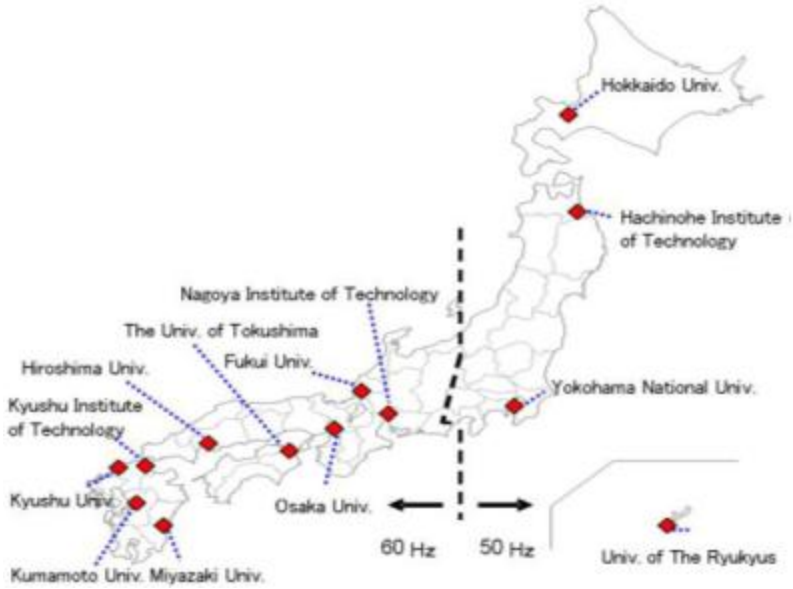
- Frequency disturbance recorder (FDR) (120V)
- installed in Korea, Japan, China, ...
- *http://fnetpublic.utk.edu/*



Other LV monitoring network

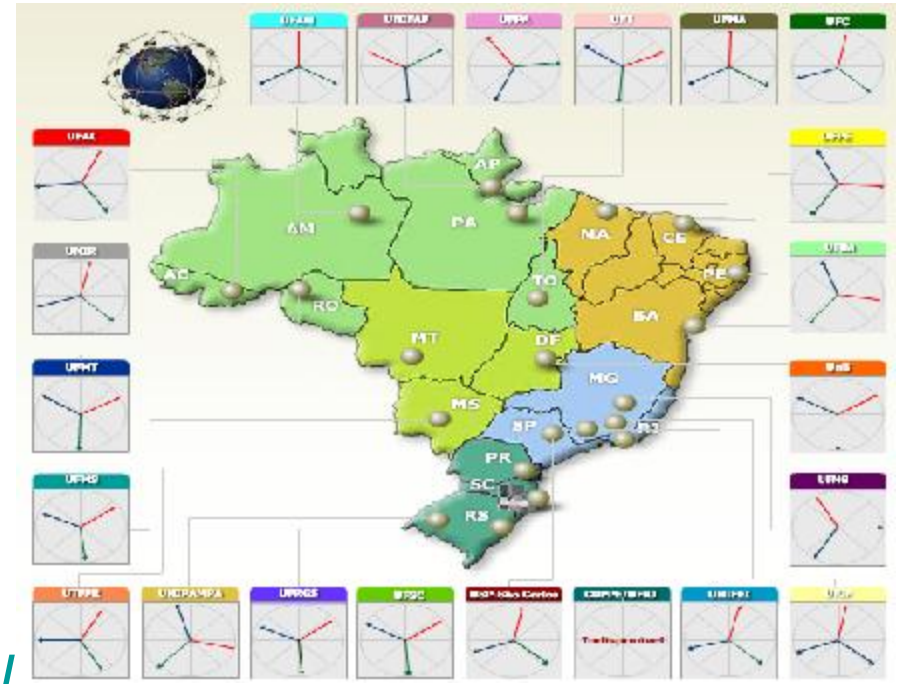
Japan: Campus WAMS

- 12 universities (2014)
- commercial PMUs at 100V outlets
- Server
  - Kyushu Institute of Technology



Brazil: LVPMS

- 22 universities (2015)
- Simplified DFR with PMU function
- Server
  - Federal Univ. of Santa Catarina
  - *www.medfasee.ufsc.br/temporeal*



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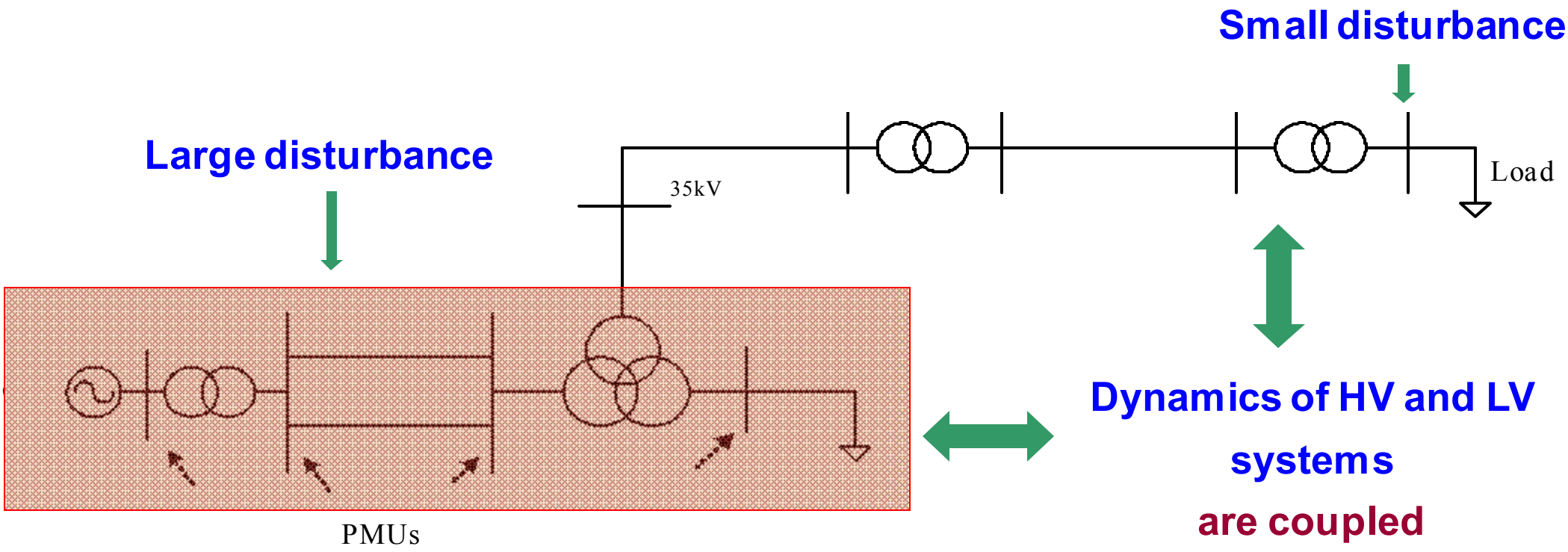
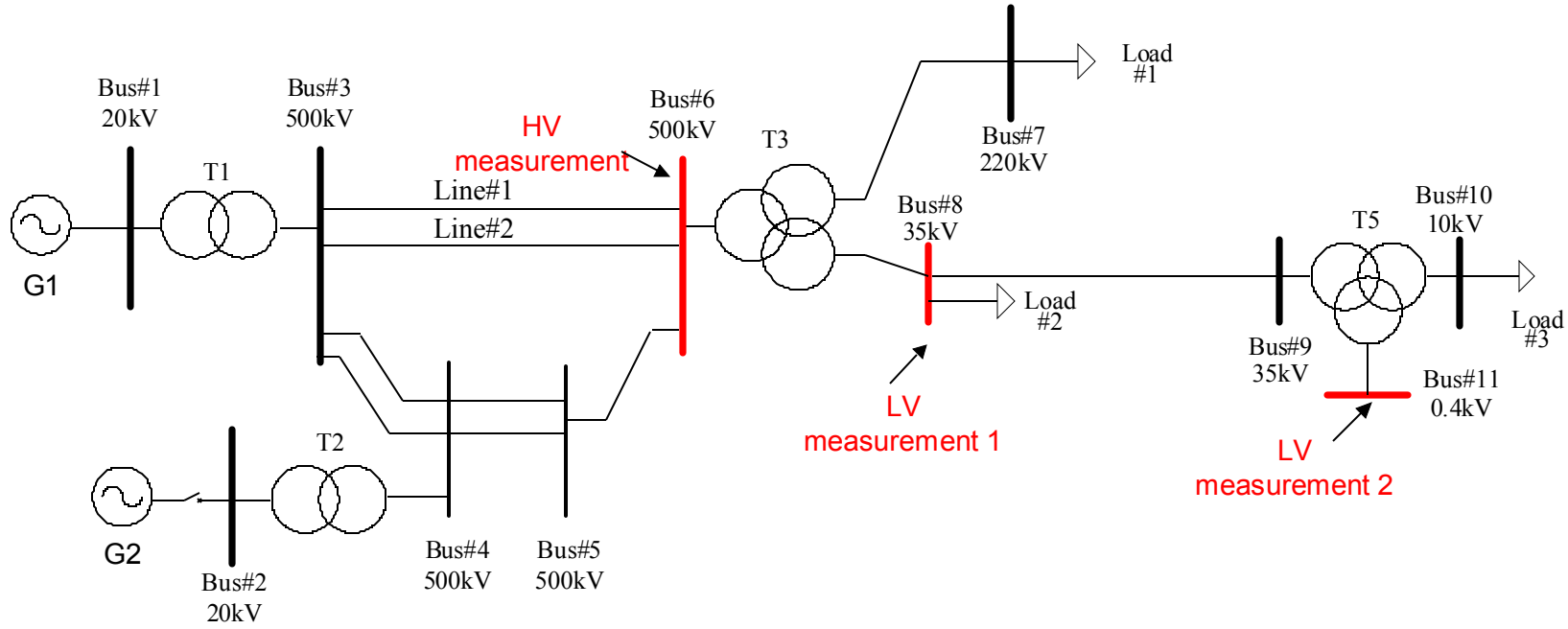
Our ponderings on LV monitoring

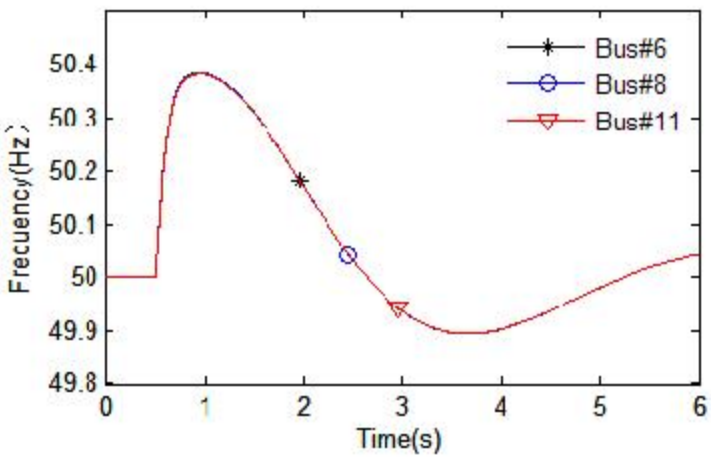
Coupling of HV and LV dynamics

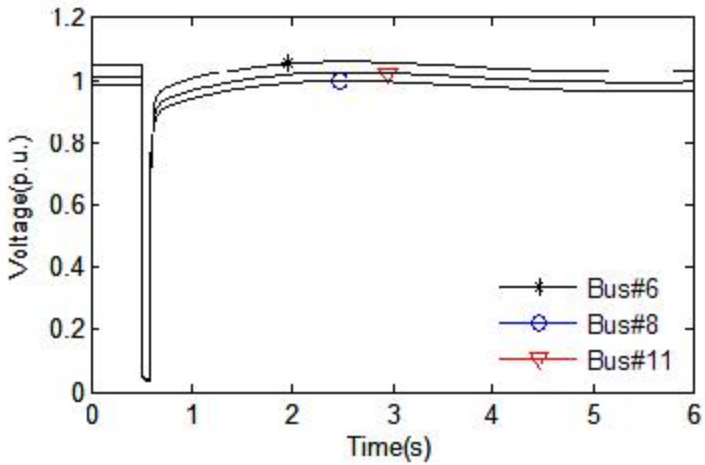


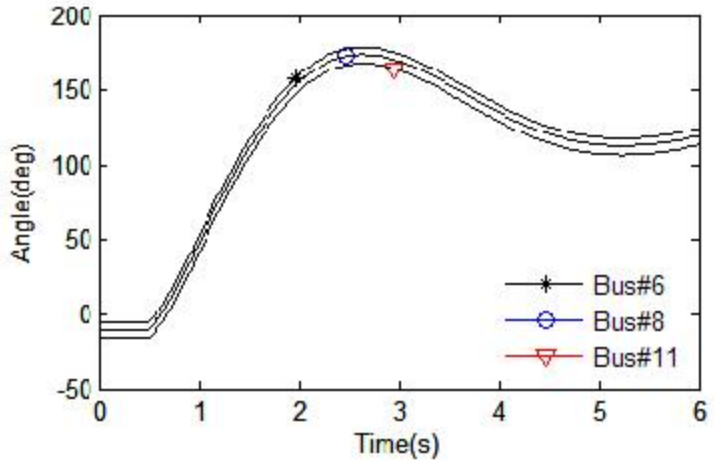
- Dynamics of HV system reflects the overall behavior of the synchronized system, and affects the LV dynamics
- Dynamics of LV system is determined by both HV system and local events

Dynamics of HV and LV sides (Simulation)

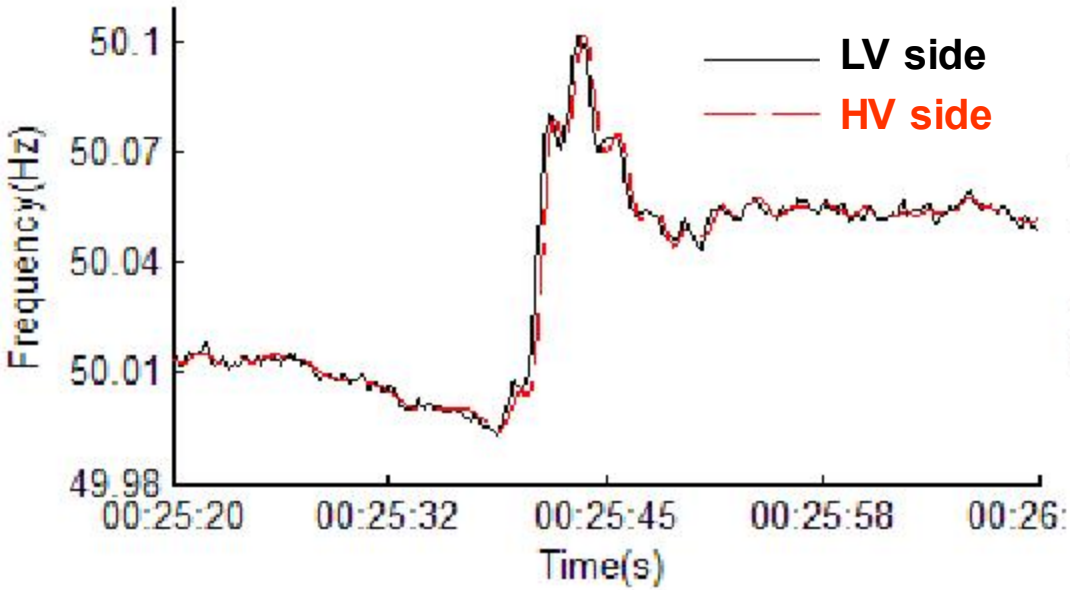


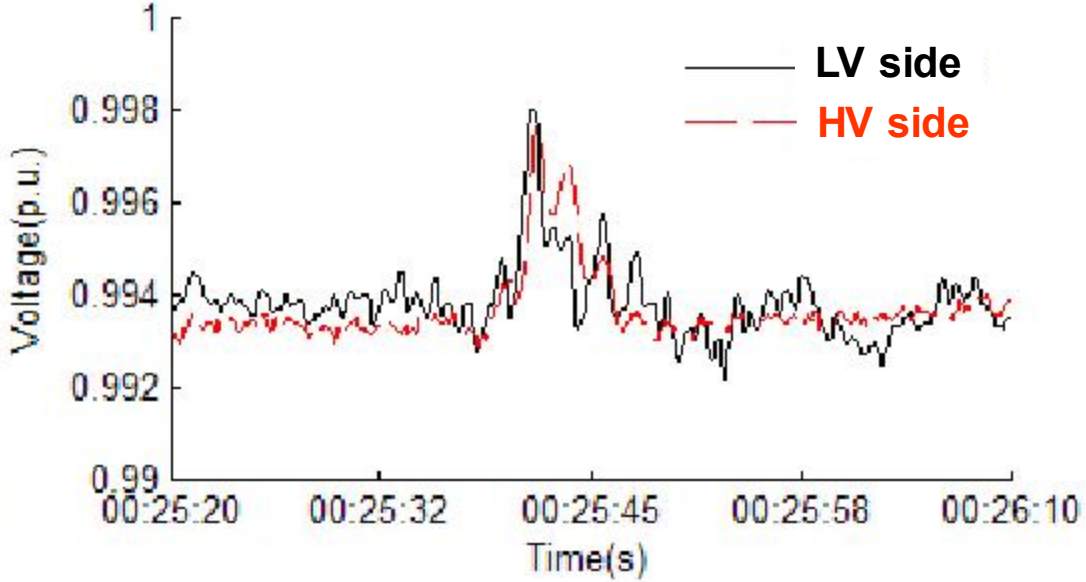


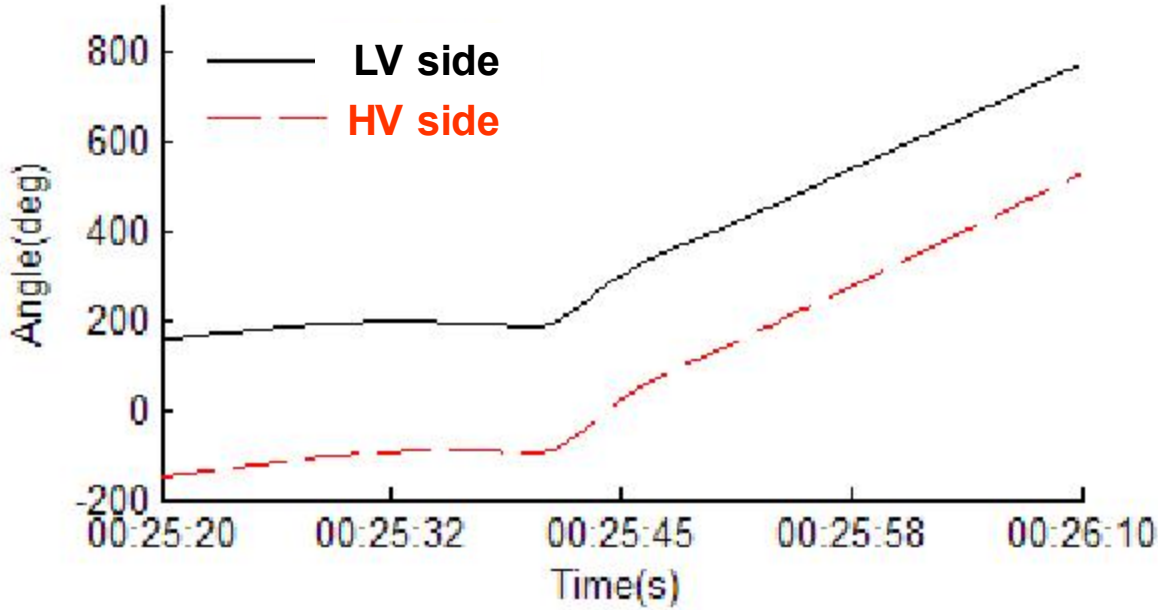




Dynamics of HV and LV sides (Measurement)







Difference between HV and LV sides

	HV	LV
Concerns	Angle, voltage, frequency stability. Oscillation	Angle stability is not a key problem, but angle trajectory can give lots information. Voltage is of concern. Frequency monitored for grid operation in isolated mode
Signals	**clean** with little harmonics; not affected by local events at LV side	**polluted** with harmonics, noise; composite of HV dynamics and local events
Number of nodes	**limited** (34 500kV substations for SD)	**numerous**
Device	**PMU** (Costly) (world-widely deployed)	**FDR, PMU Light** **1/20-1/30**
System	**WAMS**	**FNET, WAMS Light**

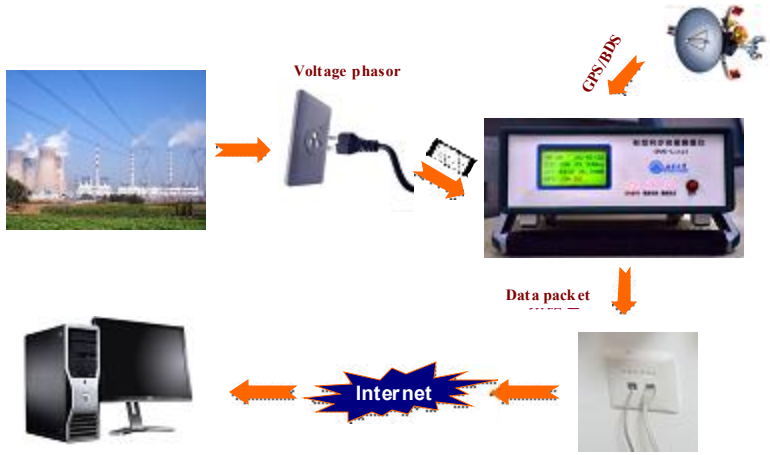
What's our focus?

- Idea
  - Measure voltage phasor from LV grid
  - De-noising and decoupling the dynamics of HV and LV grid
  - Get system behaviors and local behaviors at the same time

- Solution
  - Device: PMU Light (simplified PMU)
    - Measured: voltage magnitude, angle, and frequency
    - Unmeasured: rotor angle, transformer tap
  - System: WAMS Light
    - for data acquisition, processing, and advanced applications based on PMU Light

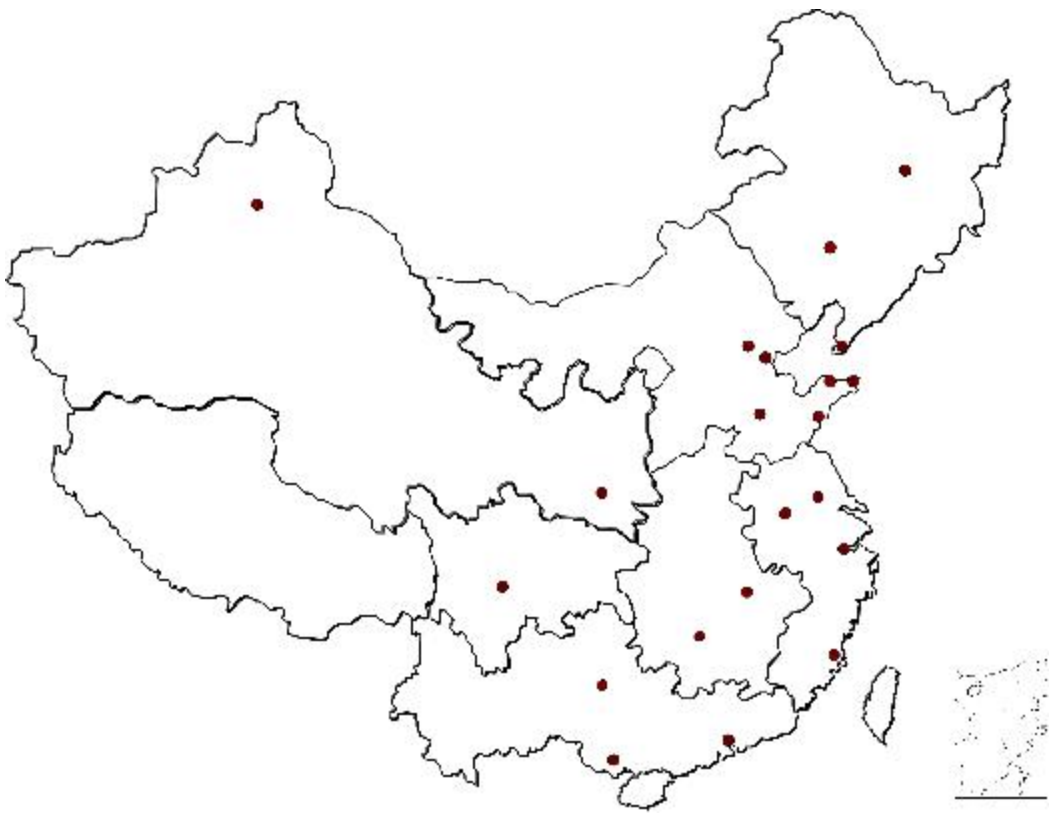
Dual-mode PMU Light

- Measure from 220V customer side
- Dual-mode communication：
  - Public internet cable and wireless (3G)
- Dual-mode timing
  - GPS and BDS
- Accurate time keeping when timing signal is unavailable
- High accuracy of frequency measurement



Ongoing Deployment of WAMS Light in China

http://wamslight.sdu.edu.cn/



- More PMU Light will be deployed to monitor the grid dynamics
- Demonstration with some smart grid projects

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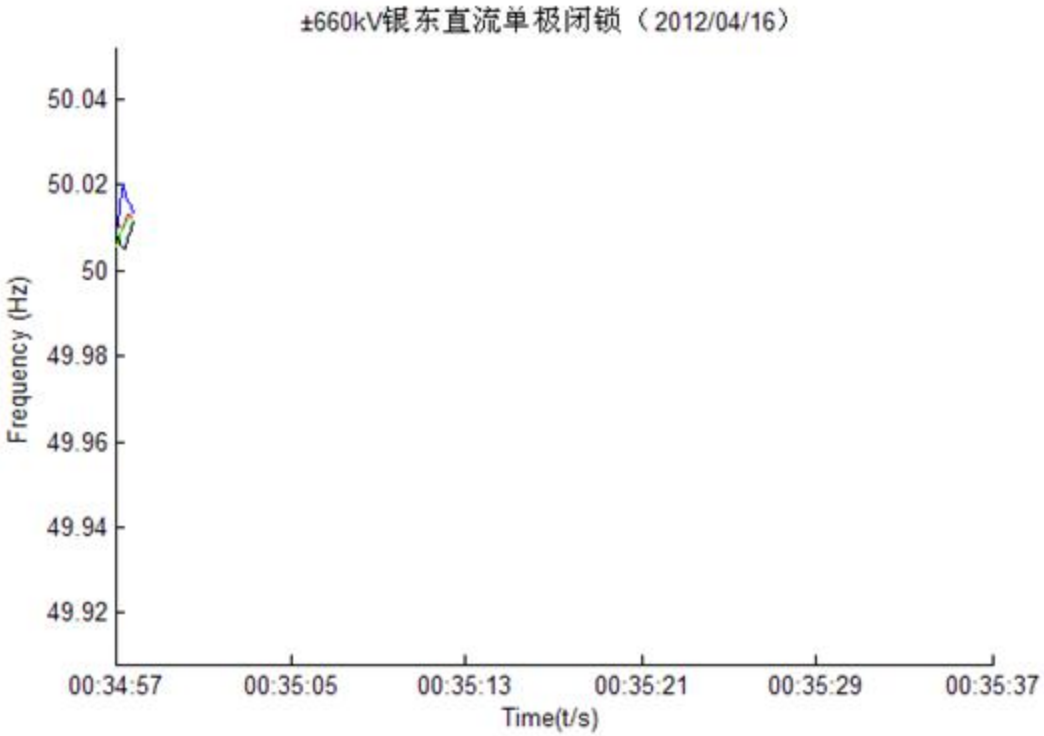
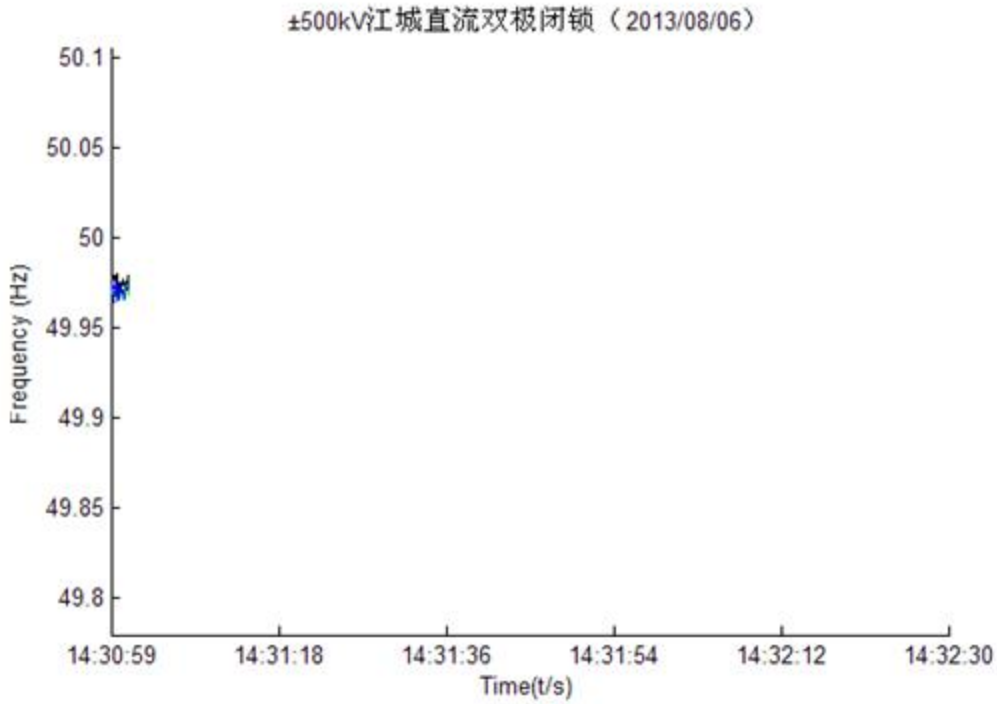
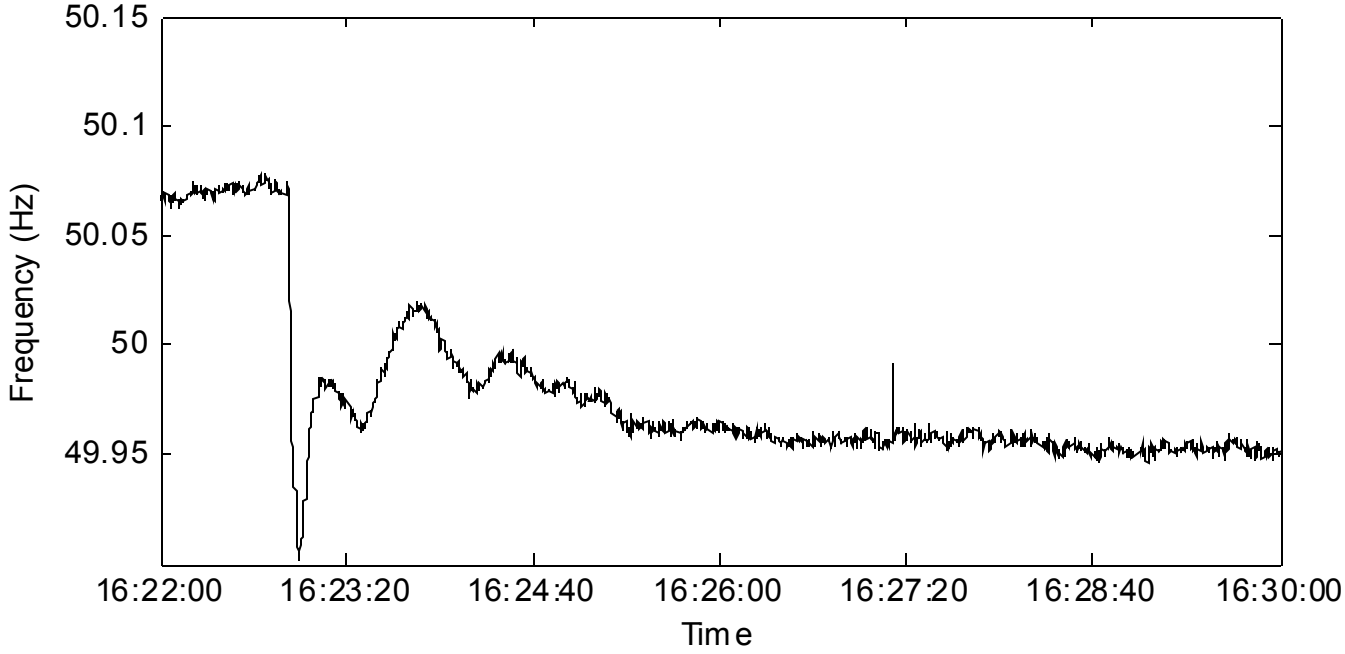
Applications of WAMS Light

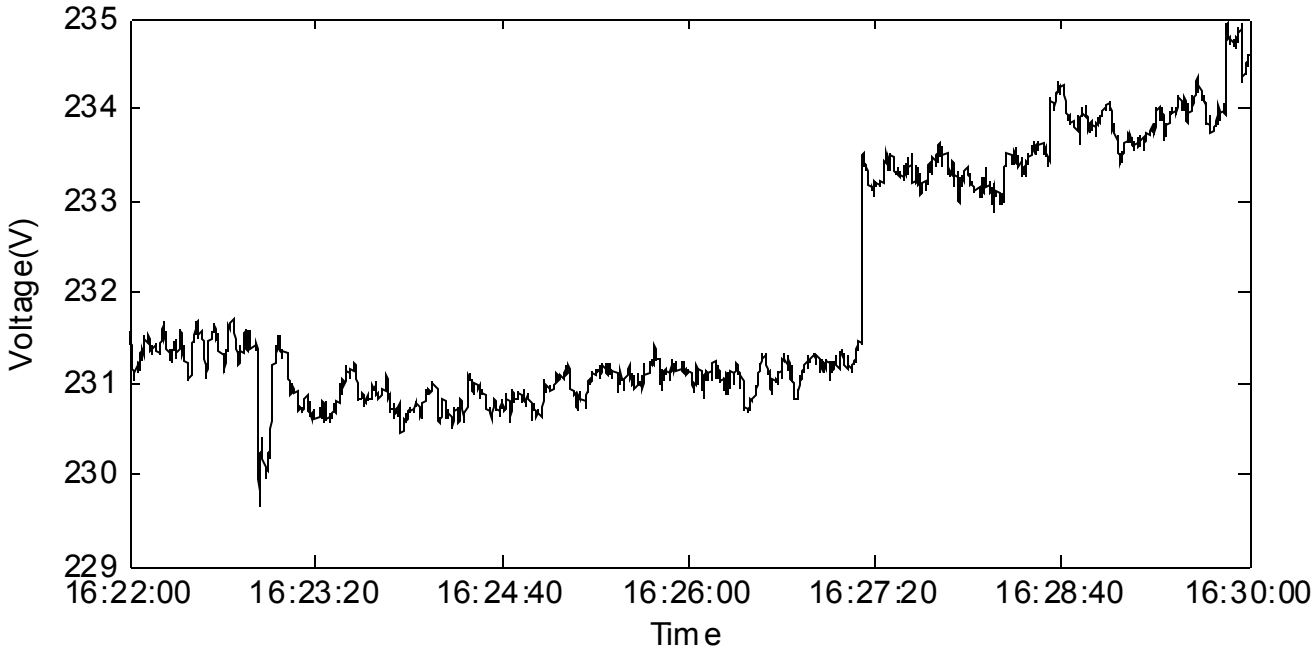
- Monitor dynamics with major disturbances





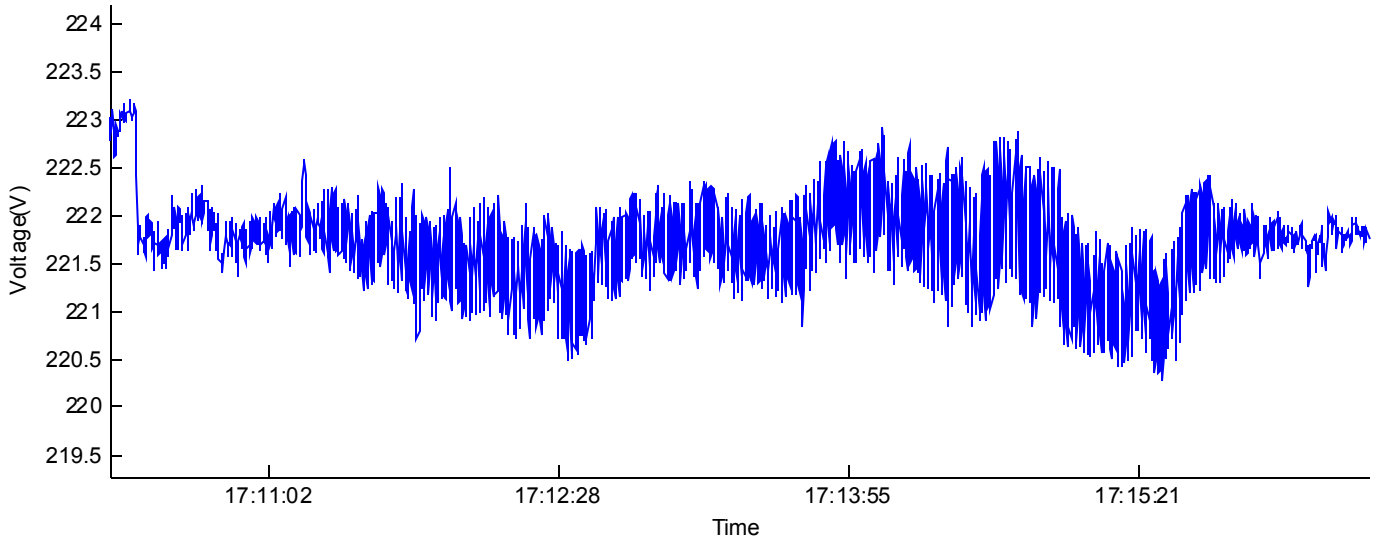
±800 Chuxiong-Guanzhou Ultra-HVDC monopole blocking

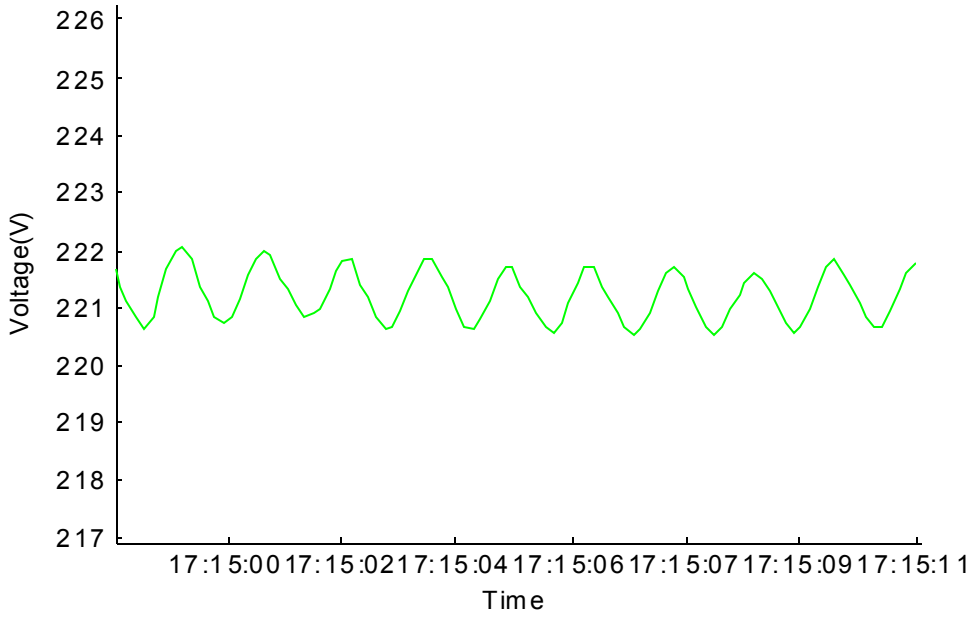


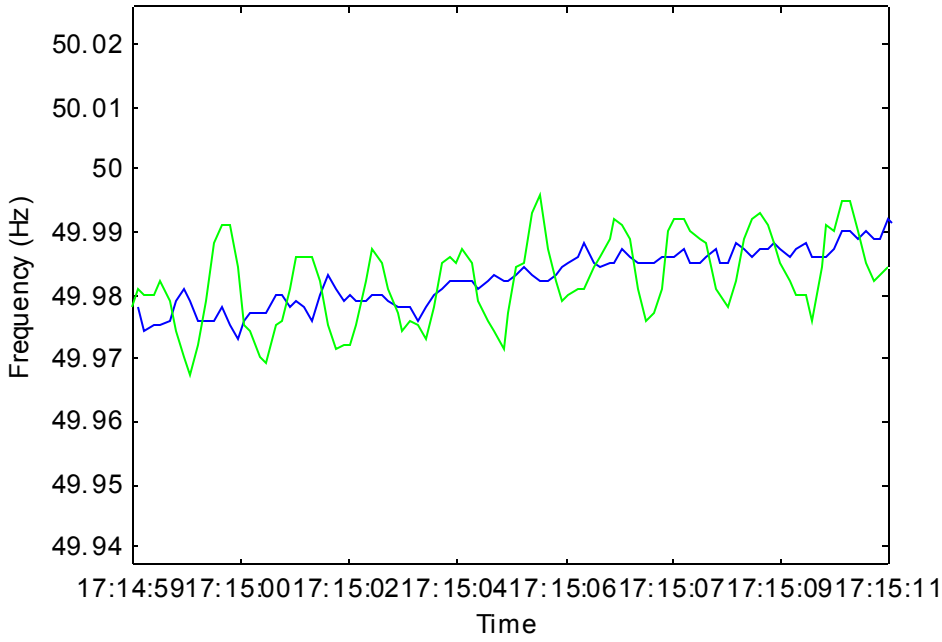


Recorded by PMU Light in Nanning

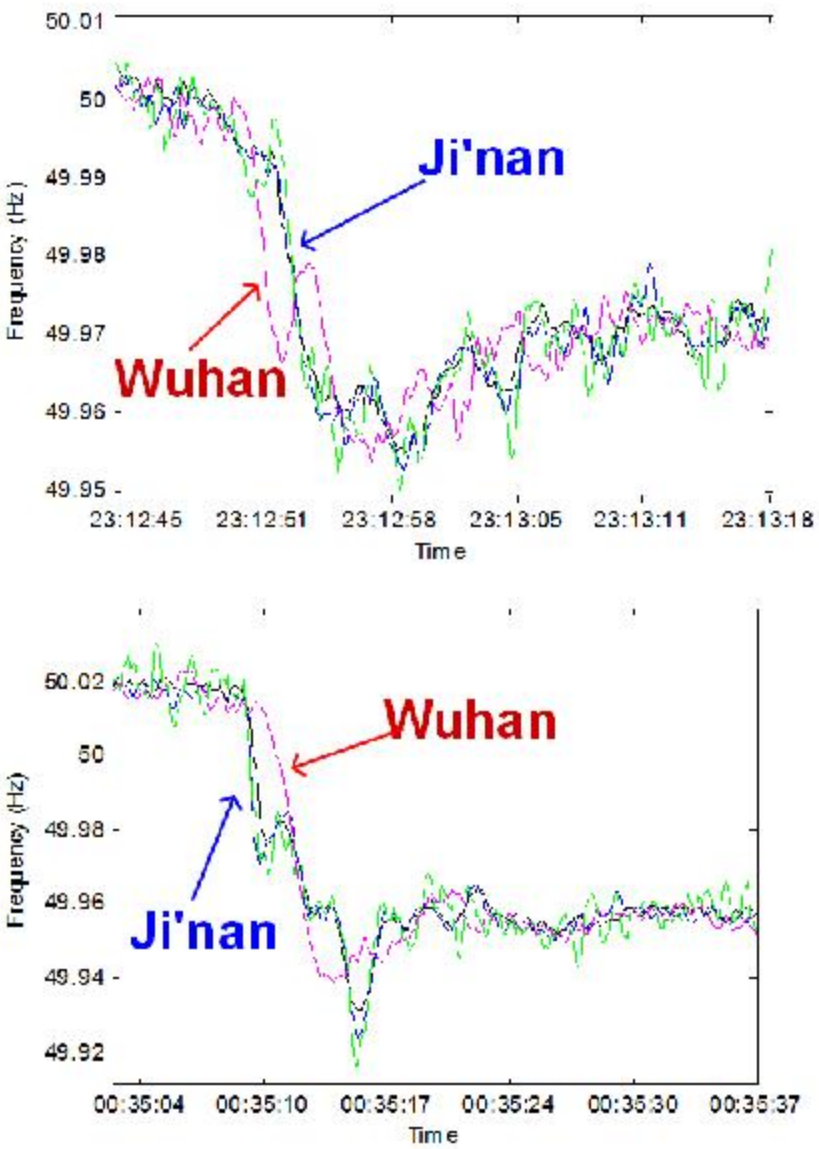
Oscillation detection





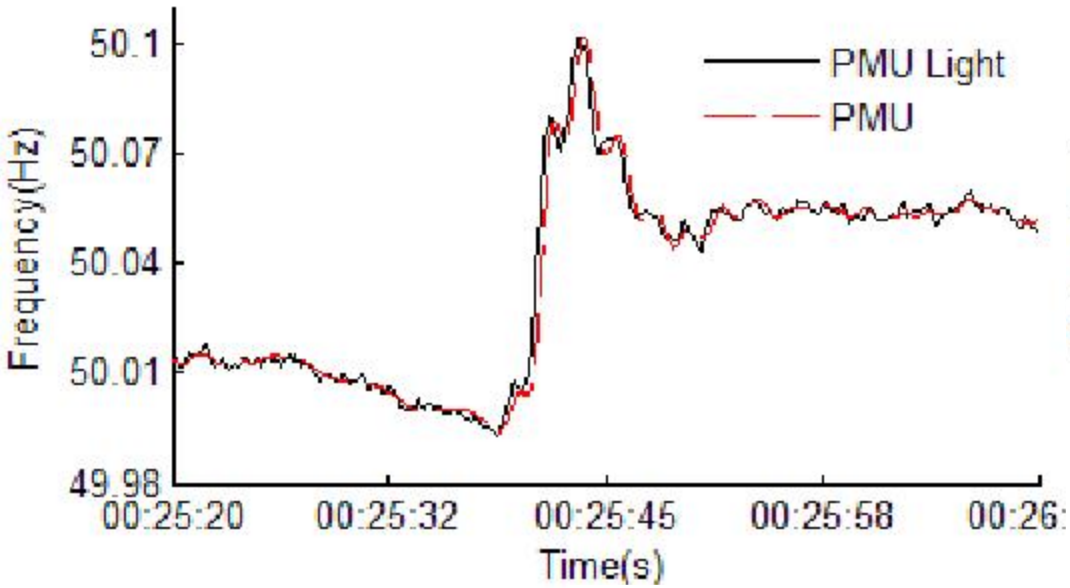


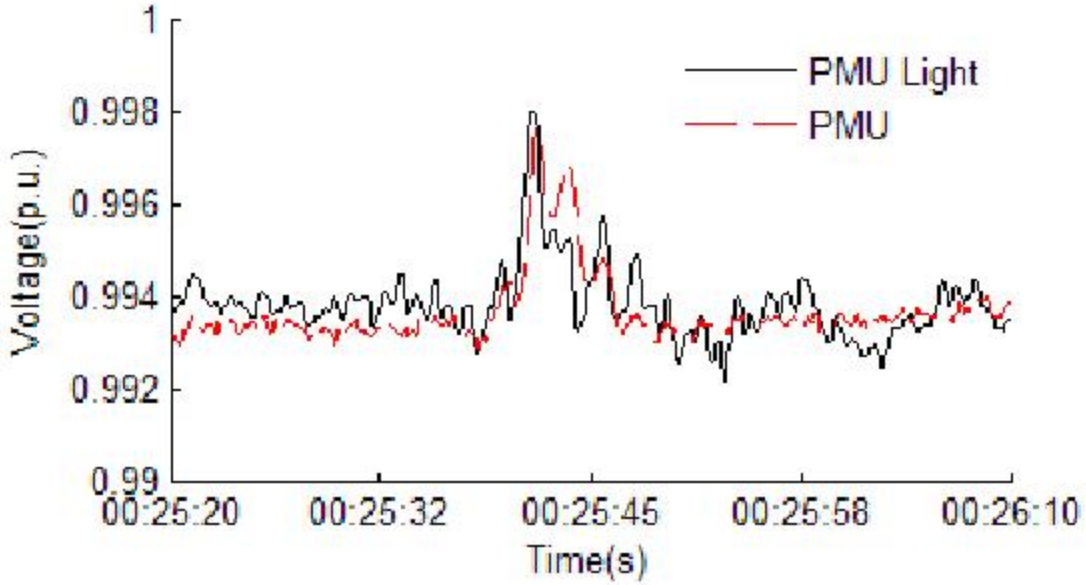
Space-time distribution of frequency dynamics

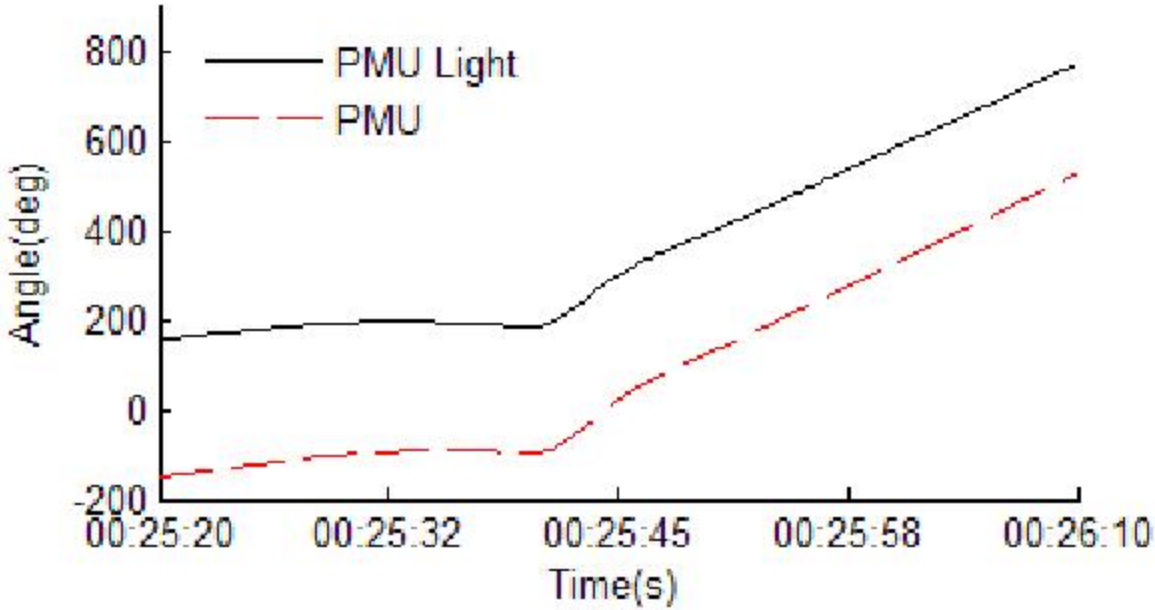


Frequency response pattern

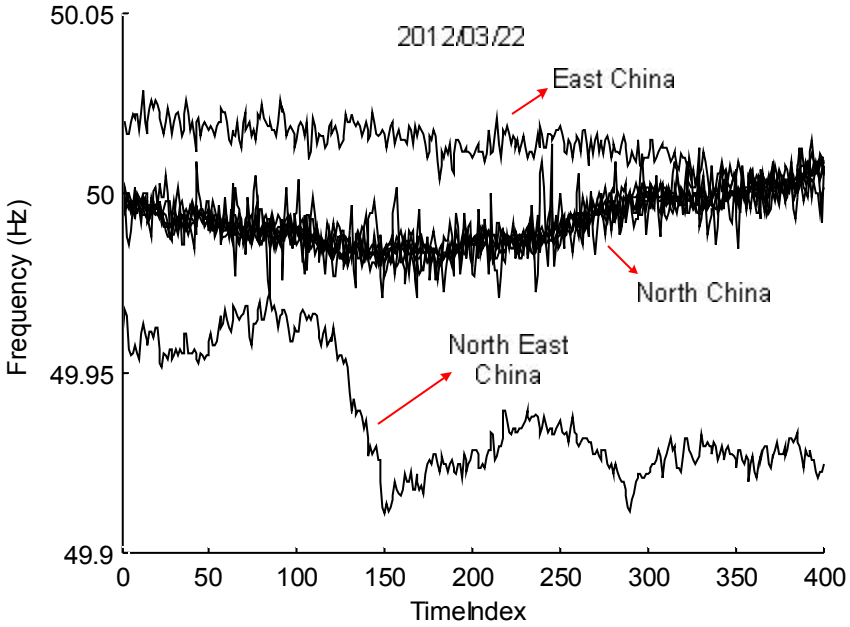
Line trip event can be detected by PMU Light even 1000km away

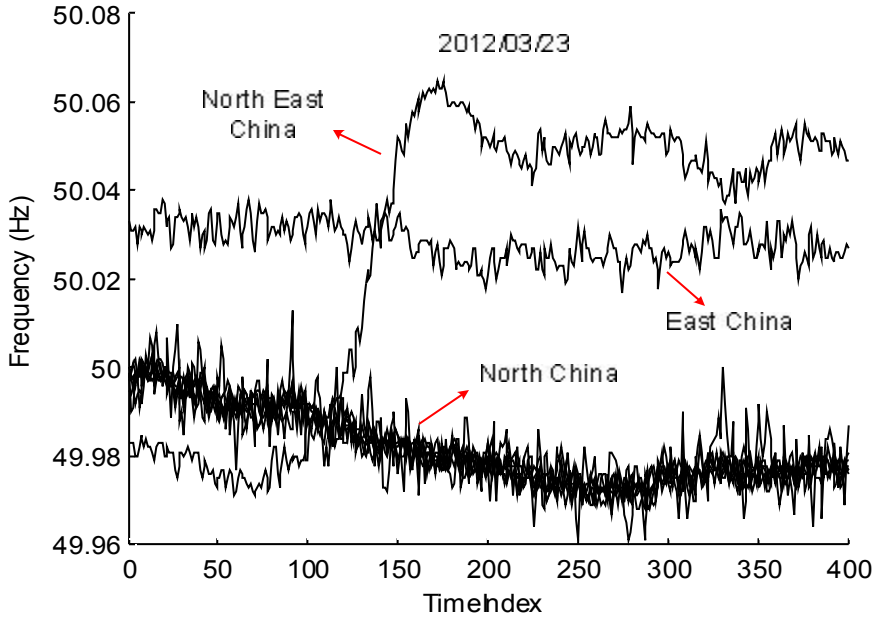


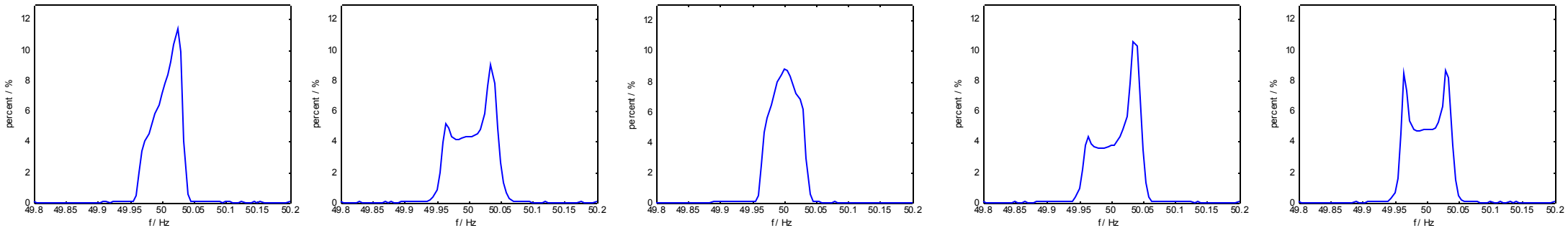




Statistical analysis of frequency regulation





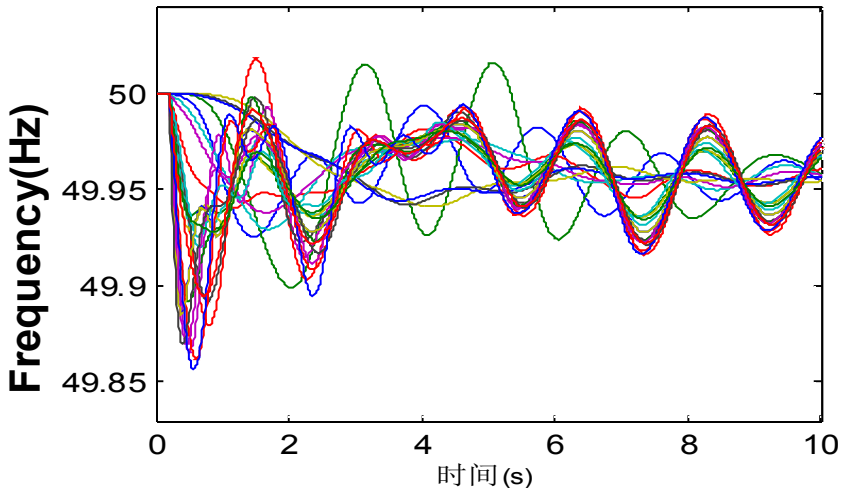


Model validition

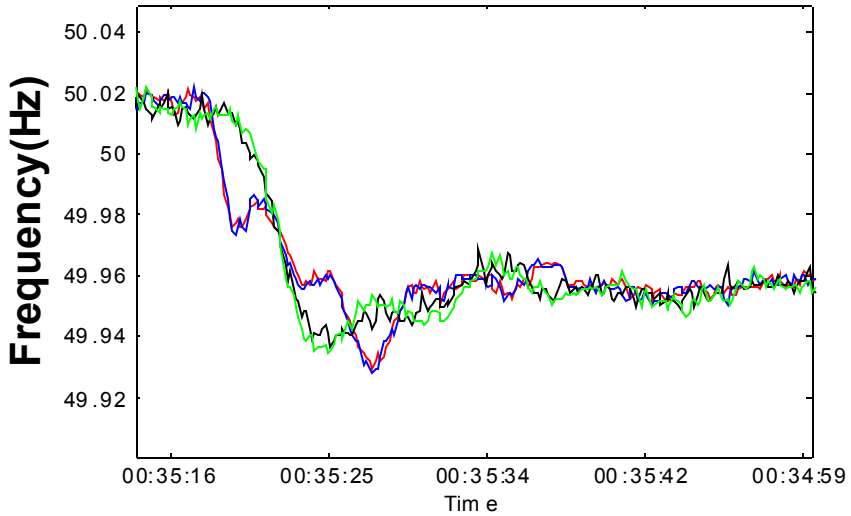
Numerical simulation

Model Validiton

Measured dynamics



Simulation of monopole blocking



Measurement of monopole blocking

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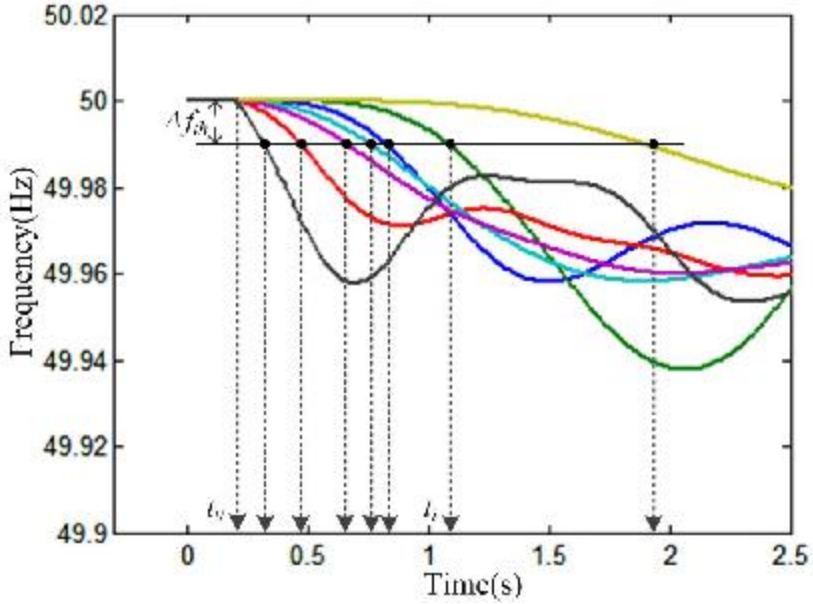
Disturbance location problem

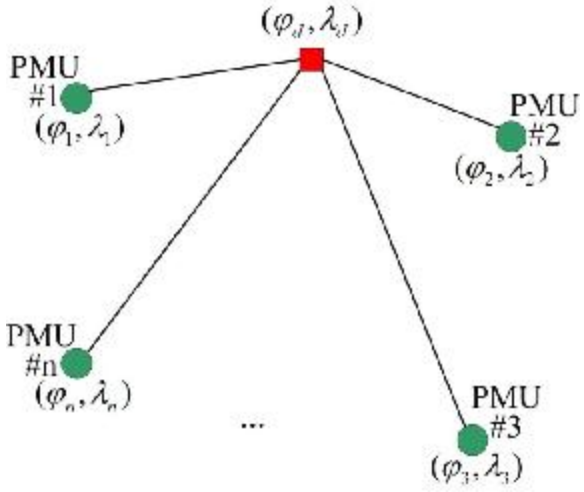
- Large disturbance in a power system can be observed system-widely, e.g., with frequency at different locations



Problem: How to estimate the disturbance location with measured frequency?

Disturbance location estimation model (Reference)

- Assumption: uniform frequency propagation speed



$$\begin{cases} (x_1 - x_d)^2 + (y_1 - y_d)^2 - v^2(t_1 - t_d)^2 = 0 \\ (x_2 - x_d)^2 + (y_2 - y_d)^2 - v^2(t_2 - t_d)^2 = 0 \\ \cdots \\ (x_n - x_d)^2 + (y_n - y_d)^2 - v^2(t_n - t_d)^2 = 0 \end{cases}$$

$$F = \sum_{i=1}^{n} ((x_i - x_d)^2 + (y_i - y_d)^2 - v^2(t_i - t_d)^2)^2$$

$$s.t. \quad x_{\min} < x_d < x_{\max}$$

$$y_{\min} < y_d < y_{\max}$$

$$0 < t_d < t_i, \quad \forall i \in \{1, 2, ..., n\}$$

- Essentially, frequency deviation propagates to different locations at different speeds.
- Problem: How to improve the disturbance location with the anisotropy of FPS?

Improved disturbance location estimation model

$$\begin{cases} (x_1 - x_d)^2 + (y_1 - y_d)^2 - v^2 (t_1 - t_d)^2 = 0 \\ (x_2 - x_d)^2 + (y_2 - y_d)^2 - v^2 (t_2 - t_d)^2 = 0 \\ \cdots \\ (x_n - x_d)^2 + (y_n - y_d)^2 - v^2 (t_n - t_d)^2 = 0 \end{cases}$$

$$\begin{cases} (x_1 - x_d)^2 + (y_1 - y_d)^2 - v_1^2 (t_1 - t_d)^2 = 0 \\ (x_2 - x_d)^2 + (y_2 - y_d)^2 - v_2^2 (t_2 - t_d)^2 = 0 \\ \cdots \\ (x_n - x_d)^2 + (y_n - y_d)^2 - v_n^2 (t_n - t_d)^2 = 0 \end{cases}$$

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$$s.t. \qquad x_{\min} < x_d < x_{\max}$$

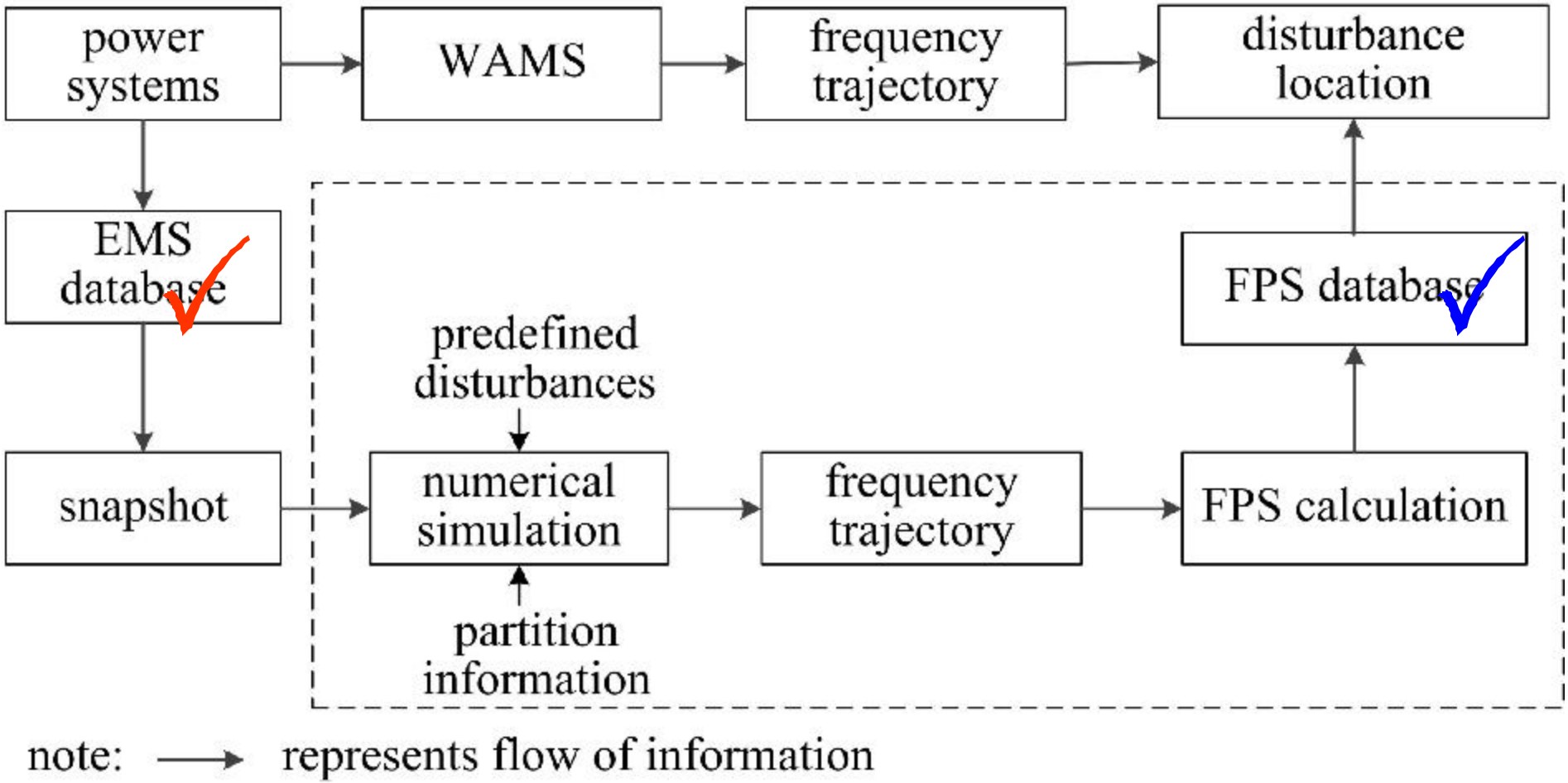
$$y_{\min} < y_d < y_{\max}$$

$$0 < t_d < t_i, \qquad \forall i \in \{1, 2, \ldots n\}$$

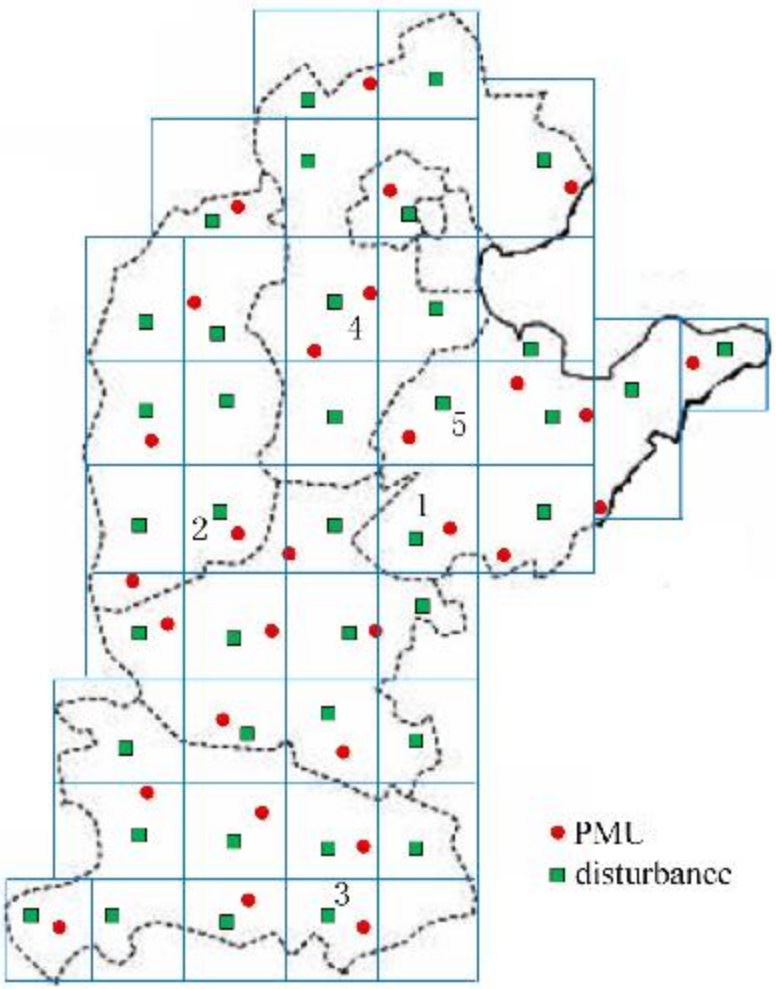
under-determined equations

Adaptive online disturbance location

The key issue is the FPS database is changing.

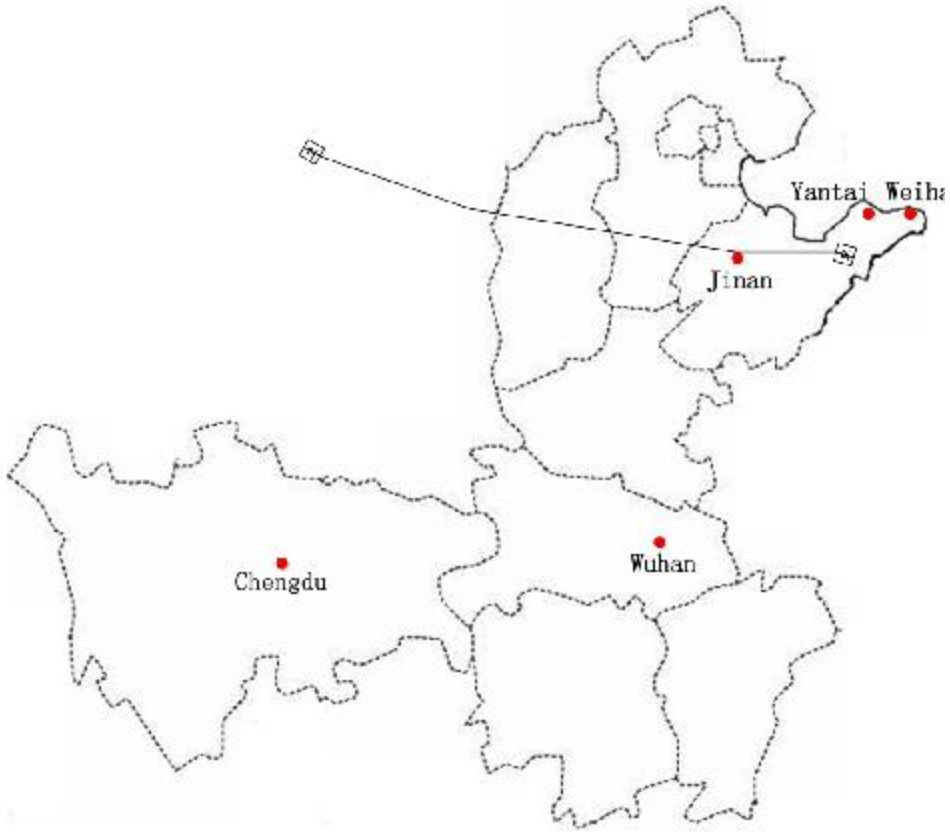


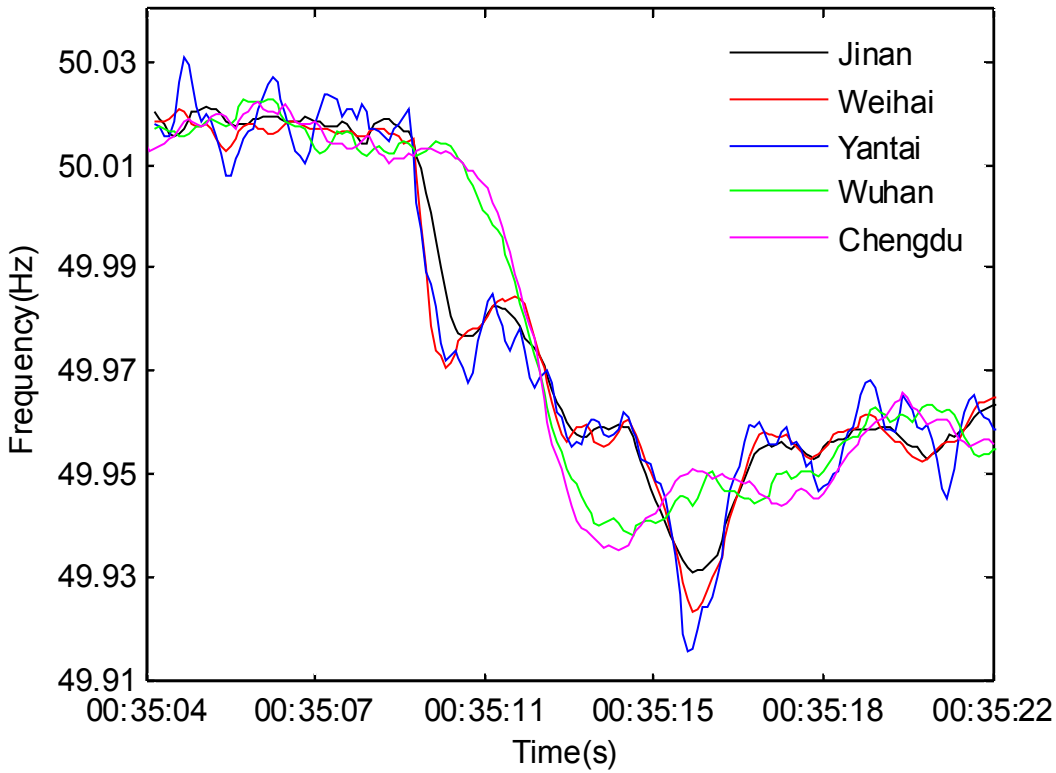
Simulation of North and Central China Power Grid



Case Index	Improved model		Old model	
	Location error (km)	Relative error (%)	Location error (km)	Relative error (%)
1	27.9	1.74	66.4	4.15
2	30.3	1.89	89.1	5.57
3	35.6	2.23	81.7	5.11
4	21.5	1.34	65.8	4.11
5	29.6	1.85	73.5	4.59

Measuremend data of HVDC monopole blocking





Improved model		Old model	
Location error (km)	Relative error (%)	Location error (km)	Relative error (%)
45.3	2.27	131.2	6.56

For more information: Adaptive Online Disturbance Location Considering Anisotropy of Frequency Propagation Speeds.
Newly published online by IEEE Trans. on Power Systems

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Summary

- With the development of smart grids, measurement from LV side is badly needed
- It is an interesting and tough task to monitor power systems from low voltage grid, lots of works need to be done.

And it can be done!

Thanks for your attention!
Questions?