LAPS State Key Laboratory of Alternate Electrical Power System with Renewable Energy Sources, North China Electric Power University

NASPI North American SynchroPhasor Initiative

ISGAN international smart grid action network

International Synchrophasor Symposium
March 22-24, 2016, Atlanta

Chinese PMU Standard, Dynamic Testing and Future Applications

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Outlines

1. Motivations
2. Chinese PMU standard vs. IEEE C37.118.1a
3. PMU dynamic testing in China
4. Challenges for PMU technology and its applications
5. Conclusions

Advent of PMUs in China

- In 1994, PMUs (ADX3000) from Taiwan was introduced to Chinese Grid;
- From 1995, PMU algorithms were studied in Tsinghua University, North China Electric Power University and Hehai University, etc;
- In 2002, the first PMU (CSS-200) with the independent intellectual property right was invented and implemented in China.

ADX3000

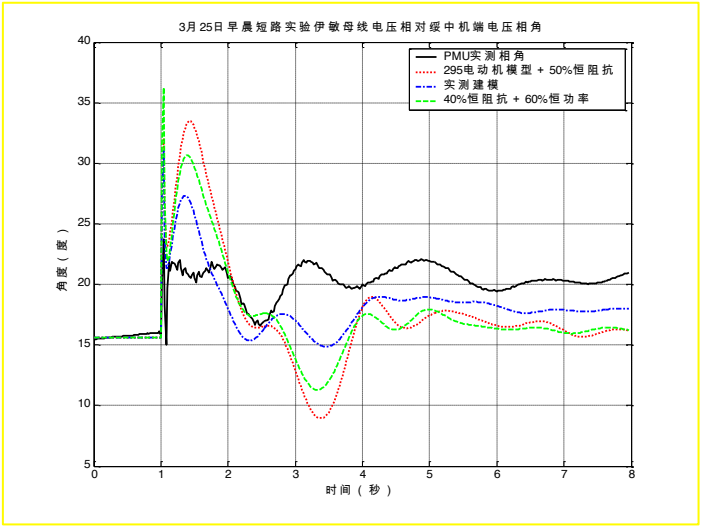
CSS-200

Development of PMUs in China

- In 2004, a man-made short circuit experiment is carried out at 500kV transmission line and PMUs was used for models validation;

- In 2005, PMUs played a major role in the low frequency oscillation monitoring in central China;

- In 2006, PMUs are suggested to be installed at all substations of 500kV and above and the generators of 100MW and above.
- Up to now, about 2500 PMUs have been commissioned in China.



Angle differences between PMU measurements and models

Chinese power system needs PMUs

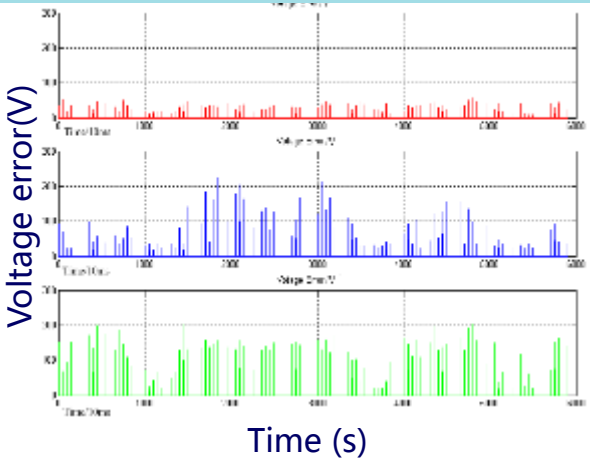
Total installed capacity:1.3 billion kW

- Wind:136 million kW
- Solar:43 million kW
- West-East power transmission :400 million kW
- UHV:1000kV
- HVDC:±800kV
- DC: 20

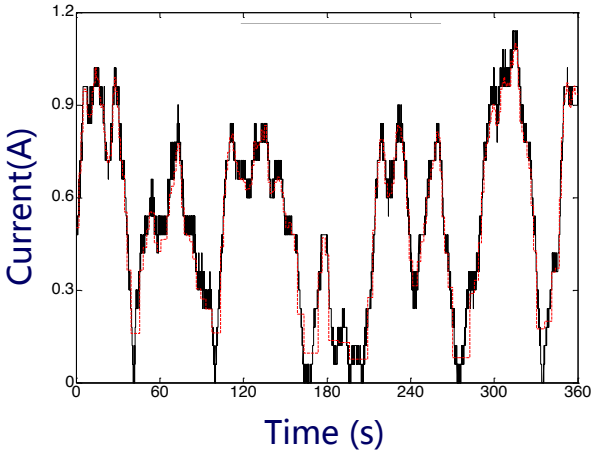
- The dynamic behavior of the power system is much more complicated;
- PMUs and PMU based closed-loop control are crucial for the power system security.

However, the data quality of PMUs ……

In 2006, measurements of different PMU in the same area are different



In 2014, the fake oscillation of PMU measurements in a convertor station



PMU standards under both steady and dynamic states and PMU dynamic testing are essential for its further application in power system.

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Profile of Chinese PMU standards

- **Technical specifications of power system real time dynamic monitoring system, Q/GDW 131-2006**
  - **-Focus on steady states**
- **Test specification for synchrophasor measurement unit for power system, GB/T 26862-2011**
  - **-Scratch the surface of modulation testing**
- **Technical specifications of power system real time dynamic monitoring system, Q/GDW 1131-2014**
  - **-Comprehensive specifications for dynamic states**

How to make PMU standards

Test categories

Summarize the typical testing items according to the static and dynamic states of the power system.

The specifications of the testing items

- The old version of Chinese standards;
- IEEE C37.118.1&IEEE C37.118.1a;
- The PMU testing in China.

Measurement error indices

➢ IEEE

$$\mathrm{TVE}(n)=\sqrt{\frac{(\hat{X}_r(n)-X_r(n))^2+(\hat{X}_i(n)-X_i(n))^2}{(X_r(n))^2+(X_i(n))^2}}$$

➢ China

$$\text{Magnitude measurement error}(ME)=\left|\frac{\text{measurment value}-\text{true value}}{\text{reference value}}\right|\times 100\%$$

$$\text{Phase angle measurement error}(PE)=\left|\text{measurment value}-\text{true value}\right|$$

- **ME and PE do not describe the phasor measurement error directly; and they are relevant to each other;**
- **But the dispatchers in China get used to read the phasor in this way.**

Steady-state compliance

	China			IEEE(M)
	ME(%)	PE(°)	TVE(%)	TVE(%)
Magnitude range test	0.2	0.2-1	0.42-1.76	1
Frequency range test	0.2	0.2-1	0.42-1.76	1
Harmonic distortion	0.4	0.4	0.85	1
Out-of-band test	0.5	1	1.85	1.3

Steady-state compliance

	China		IEEE(M)	
	FE(Hz)	RFE(Hz/s)	FE(Hz)	RFE(Hz/s)
Magnitude range test	0.002	0.01	0.005	0.1
Frequency range test	0.002	0.01	0.005	0.1
Harmonic distortion	0.004	0.02	0.025 /0.005	NA
Out-of-band test	0.025	NA	0.01	NA

The PMU testing results show that the requirements above can be satisfied.

Unique testing in Chinese Steady-state compliance

Power range test

-The active and reactive power measurements are important values for the monitoring and control application of the power system .

Input	$49\text{Hz} \le f \le 51\text{Hz}$, $0 \le \cos\delta \le 1$
Active and reactive power measurement error limits	0.5%

Unbalanced test

-Some algorithms are based on the assumption that the three phases are balanced to eliminate the error caused by the frequency deviation. Therefore, the unbalanced test is necessary.

Unbalanced	$0.0U_n \le U_a \le 0.5U_n$	$0.5U_n \le U_a \le 1.2U_n$	$0.0I_n \le I_a \le 0.5I_n$	$0.5I_n \le I_a \le 1.2I_n$
ME(%)	0.2%	0.2%	0.2%	0.2%
PE(°)	0.5	0.2	1	0.5
FE(Hz)	0.002	0.002	0.002	0.002
RFE(Hz/s)	0.01	0.01	0.01	0.01

Dynamic compliance

	China			IEEE(M)
	ME(%)	PE(°)	TVE(%)	TVE(%)
Magnitude modulation	0.2	0.3	0.58	3
Phase angle modulation	0.2	0.5	0.91	3
Magnitude and phase angle modulation	0.2	0.5	0.91	NA
Ramp of frequency	0.2	0.5	0.91	1

Dynamic compliance

	China				IEEE(M)		
	ME(%)	PE(°)	FE (Hz)	RFE (Hz/s)	TVE (%)	FE (Hz)	RFE (Hz/s)
Magnitude modulation	0.2	0.3	0.025	0.1	3	0.12-0.3	2.3-14
Phase angle modulation	0.2	0.5	0.3	3	3	0.12-0.3	2.3-14
Magnitude and phase angle modulation	0.2	0.5	0.3	3	NA	NA	NA
Ramp of frequency	0.2	0.5	0.01	0.2	1	0.01	0.2
Step	The requirements of the response time and over shoot are the same						

Different

Same

Dynamic compliance

	China				IEEE(M)		
	ME(%)	PE(°)	FE (Hz)	RFE (Hz/s)	TVE (%)	FE (Hz)	RFE (Hz/s)
Magnitude modulation	0.2	0.3	0.025	0.1	3	0.12-0.3	2.3-14

- According to the analysis, the changing magnitude does affect the magnitude measurement a lot; but it does not affect the phase angle, frequency, and ROCOF measurements too much;
- Therefore, the PE, FE, and RFE limits are just extended a little as compared their values under steady state; the ME limit is still 0.2%, because we follow the requirement in the old version of Chinese standard.

Dynamic compliance

	China				IEEE(M)		
	ME(%)	PE(°)	FE (Hz)	RFE (Hz/s)	TVE (%)	FE (Hz)	RFE (Hz/s)
Phase angle modulation	0.2	0.5	0.3	3	3	0.12-0.3	2.3-14

- According to the analysis, the changing phase angle does affect phase angle a lot , and the frequency and ROCOF even more;
- Therefore, the PE, FE, and RFE limits are extended, but not as much as IEEE does.

Test results of a dynamic phasor algorithm

Fs=50Hz	ME	PE	FE	RFE	TVE
Max error	0.014372	0.019916	0.0023972	0.12227	0.036467

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PMU testing platform based on signal generator

The PMU test platform based on the high accurate signal generator take the signal generator as the reference.

The synchronization and signal precisions of the signal generator are crucial. Its performance is tested comprehensively. Based on the test results, the signals synchronizations at different frequencis are compensated.

PMU testing platform based on PMU calibrator

The PMU test platform based on the PMU calibrator take the calibrator as the reference. Therefore, the performance of the PMU calibrator is crucial.

The acquisition and control boards from NI are chosen to established the calibrator. The phasor algorithm with long data window but high accuracy is proposed and implemented.

PMU testing

- In 2010，PMUs from the four main Chinese PMU manufactures are tested under both steady and dynamic states for the first time；
- The test results show the dynamic performance of the PMUs in China at that time cannot meet the requirements of the monitoring and control.

PMU testing

The manufactures were allowed to update their PMU algorithm with our help during the first round test. In the final test, all the PMUs pass the test, which was a big progress for the Chinese PMU technology.

Dynamic testing results

PMU	F_s (Hz)	Magnitude modulation				Phase angle modulation				Magnitude and phase angle modulation				Ramp of frequency				step	
		ME	PE	FE	RFE	ME	PE	FE	RFE	ME	PE	FE	RFE	ME	PE	FE	RFE	RT	OS
A	25	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
	50	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
	100	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
B	25	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
	50	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
	100	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
C	25	S	S	S	S	S	S	S	S	F	S	S	S	S	S	S	S	S	S
	50	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
	100	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
D	25	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
	50	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
	100	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
E	25	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
	50	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
	100	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
F	25	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
	50	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
	100	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
G	25	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
	50	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
	100	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S

S: satisfied the requirements; F: fail to meet the requirements; N: did not do the test

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PMUs for renewable sources

- **In 2015 , the large amount of inter harmonics that appeared near the wind farms of northwest China and three 660MW generator are tripped caused by SSO.**
- **PMUs for the area of renewable energies is of great importance.**

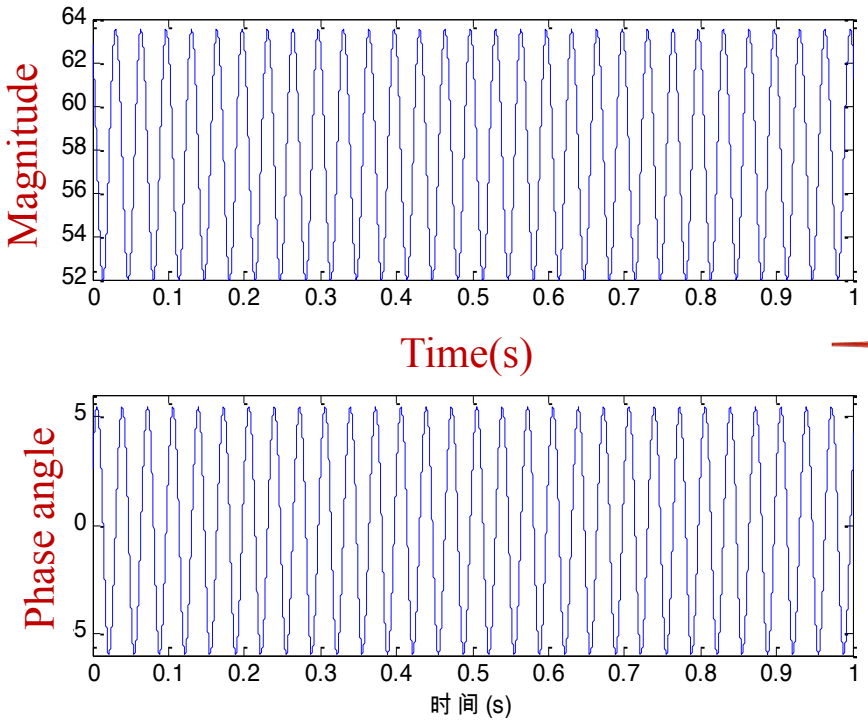
There is no PMUs installed within the wind farm, which makes it hard to find out the exact inter-harmonic source.

The PMUs installed on the high voltage transmission lines can provide the dynamic measurements that are helpful for monitoring and analysis.

PMUs For renewable sources

The inter harmonics make calculating the phasor precisely more difficulty.

Sub-synchronous oscillation of 30Hz = Fundamental frequency + Inter harmonic of 20Hz



The oscillation frequency is high, the frequency aliasing is easy to occur.

The phasor changes in a very fast rate, how to calculate the phasor precisely?

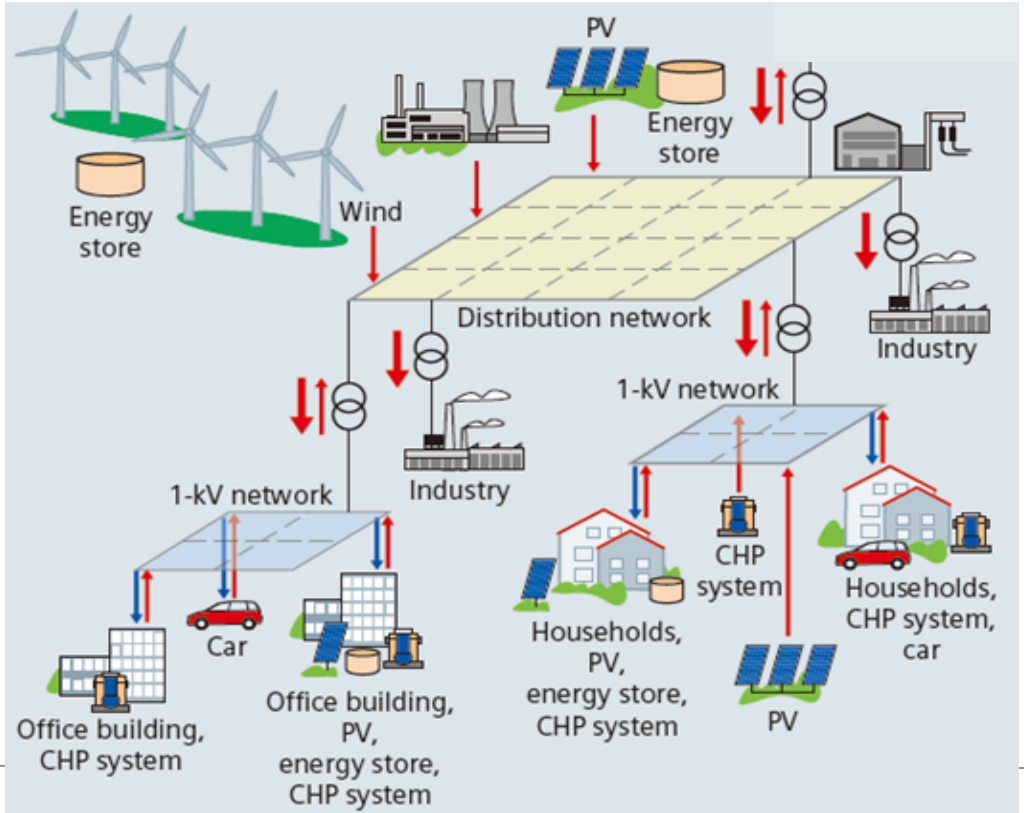
Is the relevant standard needed?

PMUs For distribution

- The coupling of the dynamic behavior of the transmission and distribution lines is much closer;
- The distributed generator, the active loads, and the large amount of the power electronic devices make the dynamic behavior more complicated;
- PMUs for the distribution system are needed.

Challenges:

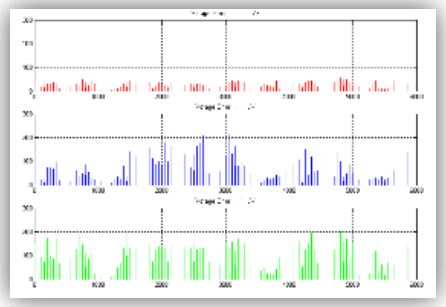
- More harmonics;
- More noises;
- Phase angle difference between the line terminals is small;
- …



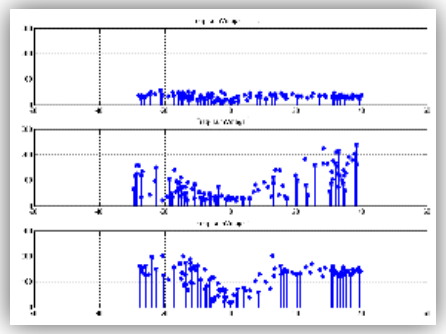
Data quality assessment & dynamic state estimation

Data quality assessment

Use the nature of the power signals to identify the bad measurements of PMU on-line.



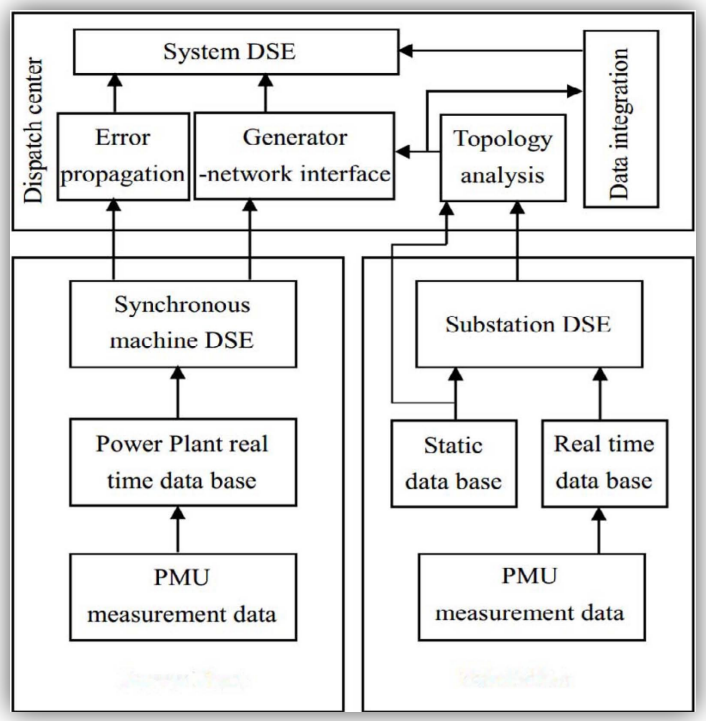
Voltage vibration



Frequency vibration

Dynamic state estimation

The distributed dynamic state estimation based on PMU is proposed to realize the state estimation of the whole power system.



Framework of DSE

Other applications based on PMUs

- **The parameters identification of the transmission lines, generators, and generator excitation based on PMUs**
- **On-line stability assessment based on PMUs**
- **Close-loop control based WAMS**
- **Frequency stability assessment based on PMUs**

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Conclusions

- PMUs play an important role for the monitoring and control of the power system, especially under the dynamic condition;
- The data quality of PMUs is of good concern for the dispatching center, the PMU standards and testing make the PMU technology in China progress dramatically;
- The on-line data quality assessment is essential for PMU-based application;
- The development of power system brings challenges to PMUs, future researches, such as the further standard revision, PMUs for the renewable sources and distribution, filed PMU testing, PMU-based application, are needed.

Questions?