Development of Metrology for Digital Measurement Technology in SGCC

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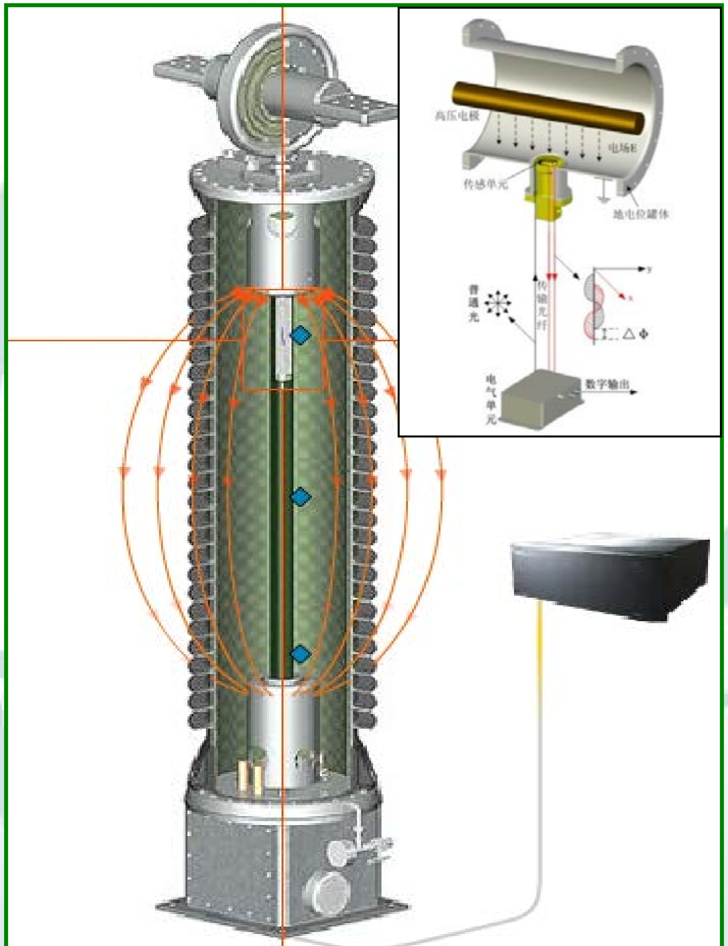
1. Development of DES in SGCC
2. Traceability, Calibration R&D Plan
3. R&D Highlights
4. Further Research

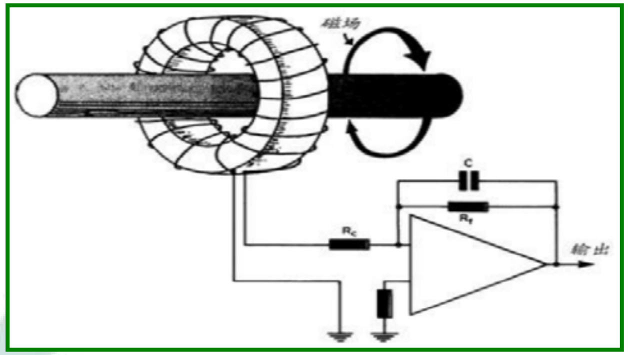
Advantage of Electronic Instrument Transformer
More Safety & Reliability



Optical Voltage Transformer

ECT(Rogowski Coil)

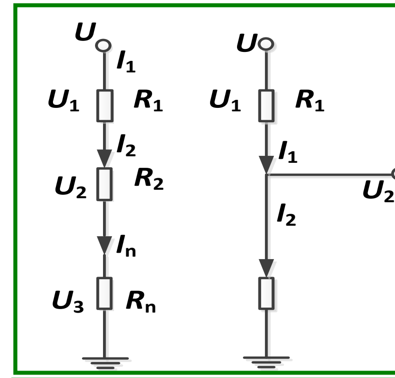
Sensor Principle



$$e(t) = -\frac{d\Phi}{dt} = -\frac{\mu_0 Nh}{2\pi} \bullet \ln\frac{r2}{r1} \bullet \frac{di(t)}{dt} = -\frac{\mu_0 Nh}{2\pi} \ln\frac{r2}{r1} \bullet \omega I_0 \cos(\omega t + \theta)$$

EVT(Voltage Divider)

Resistive Voltage Divider



$$U_2 = \frac{R_2}{R_1 + R_2} \cdot U_1$$

advantages：

1) **Make the Grid More Safety** - No Ferromagnetic Resonance, Simple wiring.

2) **Energy Saving and Environmental Friendly** - Lighter, Less Energy Consumption.

Advantage of Electronic Instrument Transformer More Accuracy

Traditional Energy System – Used Nowadays

TV
Error: 0.2%

TA
Error: 0.2%

Secondary circuit
Error: 0.1%

Electronic Energy Meter
Error: 0.2%

System Error: **0.7%**

Digital Energy System – Next Generation

EVT(OVT)
Error: 0.2%

ECT(OCT)
Error: 0.2%

MU
Error: ≈0%

Digital energy metering
Error: ≈0%

System Error: **0.4%**

Advantage of Electronic Instrument Transformer
More Data & Information

Traditional Energy System – Used Nowadays

Instrument Transformer

Analog signal

Electronic Energy Meter

DL/T 645

Acquisition terminal

Data Sapling Rate

96S/d

Digital Energy System – Next Generation

Electronic instrument transformer

Analog Signal

IEC 60044-8

FT3

Merge Unit

IEC 61850-9-2

Digital energy meter

Data Sapling Rate

4kS/s

Digital Energy Equipment Used in China

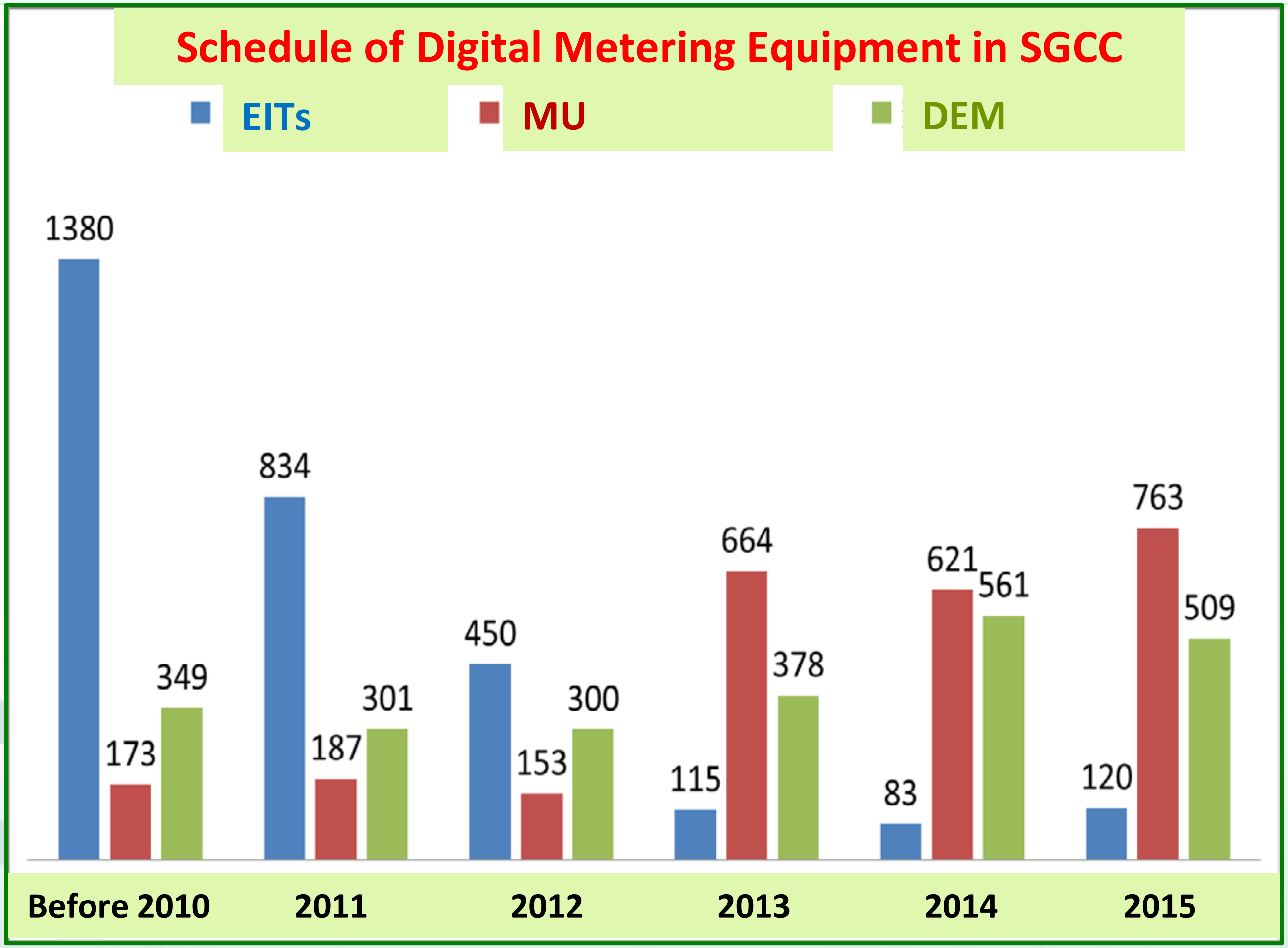
Survey info:

Time: Jan 2016; **Object**: 27 Province; **Rated Voltage**: 10kV & 35kV
Equipment: EIT, MU & DEM

Voltage level	Electronic transformer	Merging Unit	Digital Energy Meter
10kV	2503	1725	1682
35kV	479	836	716
Total	2982	2561	2398

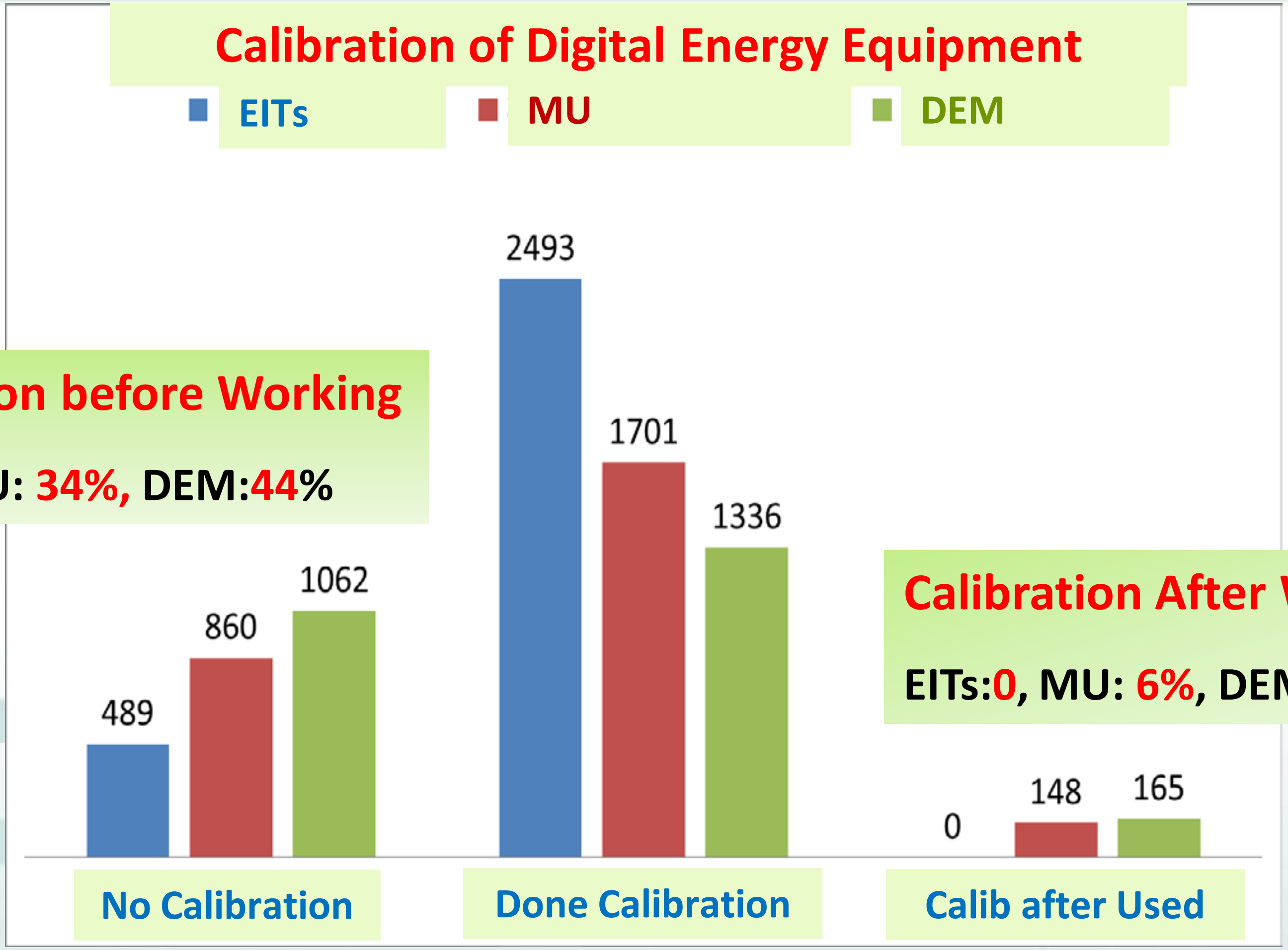
1. Widely Used in SGCC; 2. 10kV More than 35kV;

Operation Time of Digital Energy Equipment



Started: 2007; **Experiment Stage**: 2010~2013; **Widely Used**: After 2013

Calibration of Digital Energy Equipment in SGCC



No Calibration before Working

EITs: 16%, MU: 34%, DEM:44%

Calibration After Working

EITs:0, MU: 6%, DEM: 7%

Problem Still Not Solved in Traceability

1. Test Methods 2. Condition Evaluation

1 Development of DES in SGCC

2 Traceability, Calibration R&D Plan

3 R&D Highlights

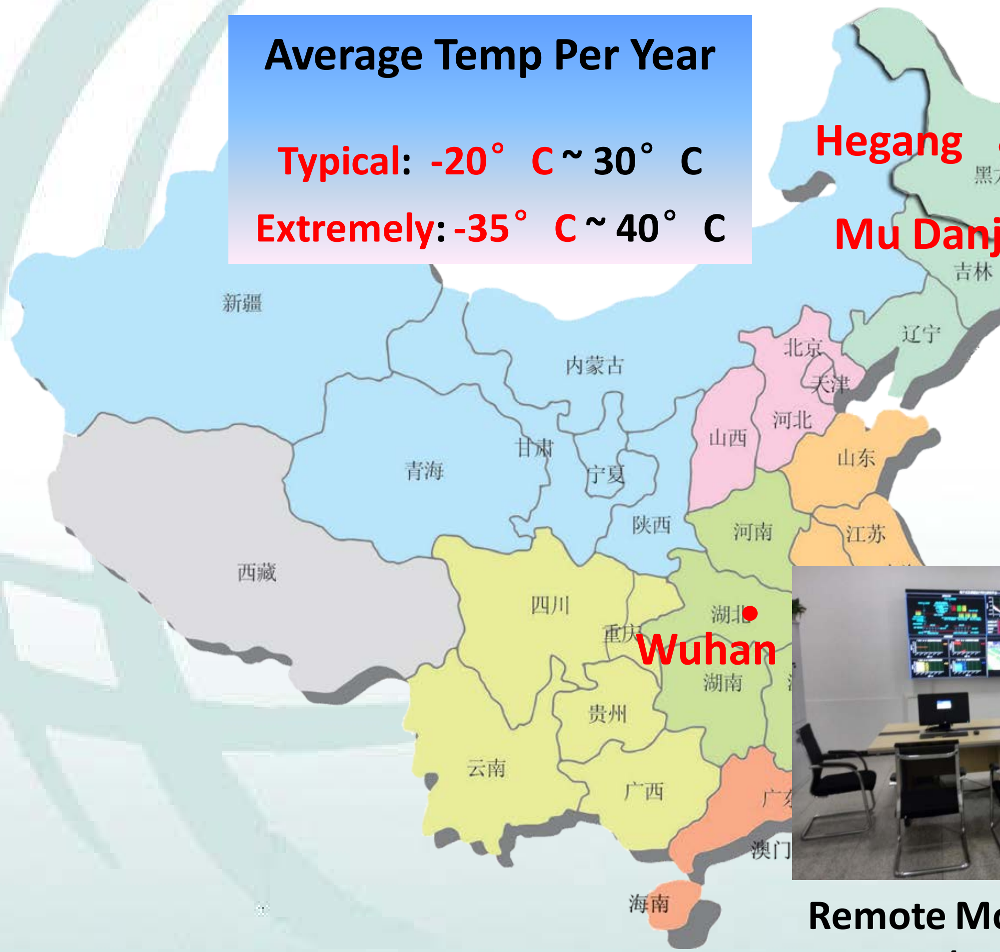
4 Further Research

A 110kV Test System Setup in Hei Longjiang

Average Temp Per Year

Typical: -20° C ~ 30° C

Extremely: -35° C ~ 40° C



Test System

Hei Longjiang
110kV Dongshan Substation
10KV Mudanjiang Substation
Local System

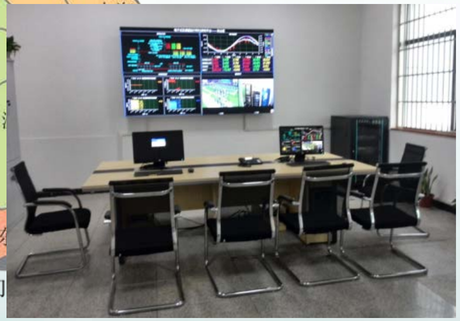
Ratio/Phase Error

Environmental Data

Video

Energy Error

Wuhan
Remote System



Remote Monitor System (Wuhan)

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EITs Test System Setup in 110kV Substitution

—— Pilot Project Start in 2014.5

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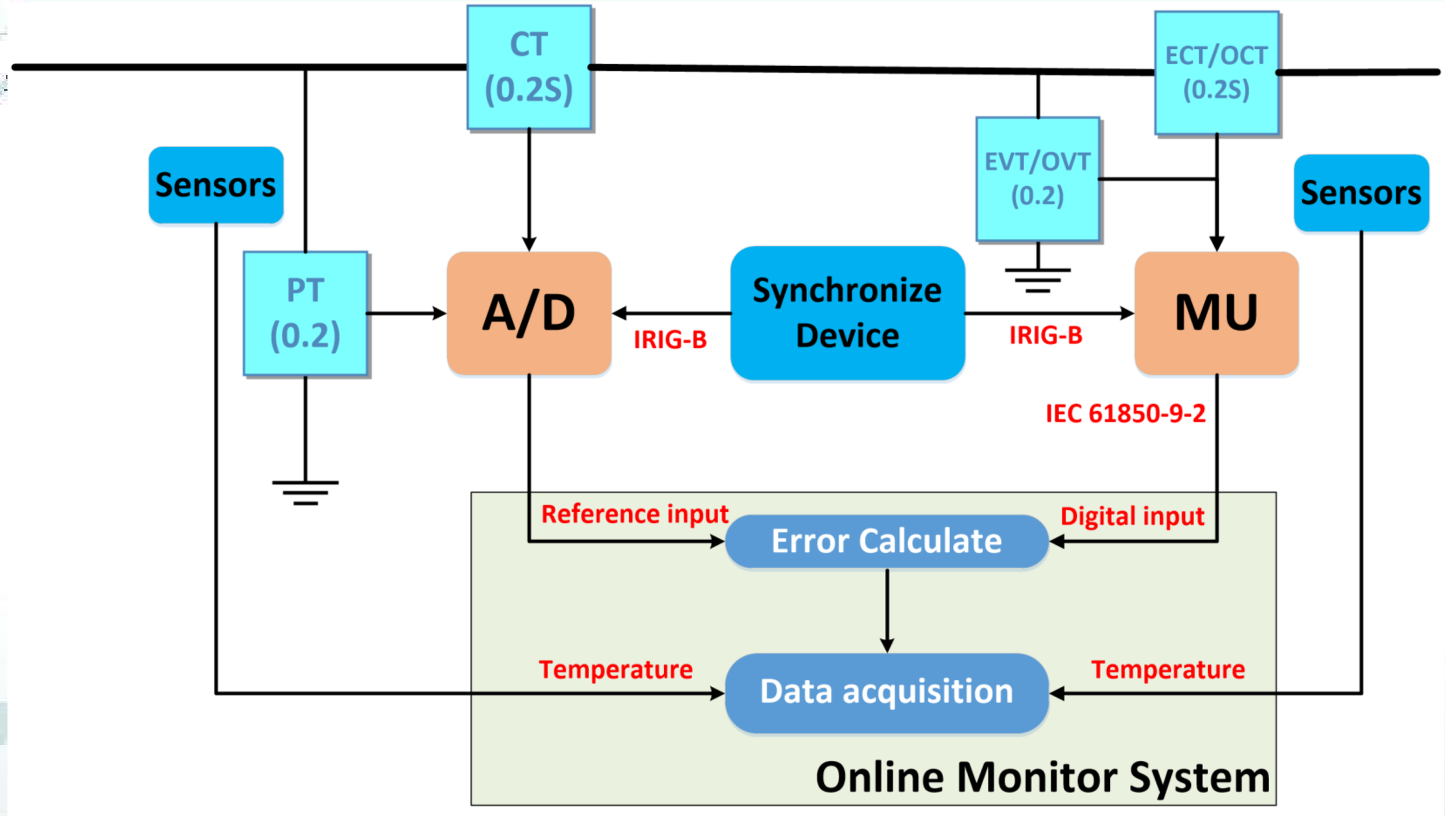
EITs Test System Setup in 10kV Substitution

—— Pilot Project Start in 2016.7

Energy system Principle:

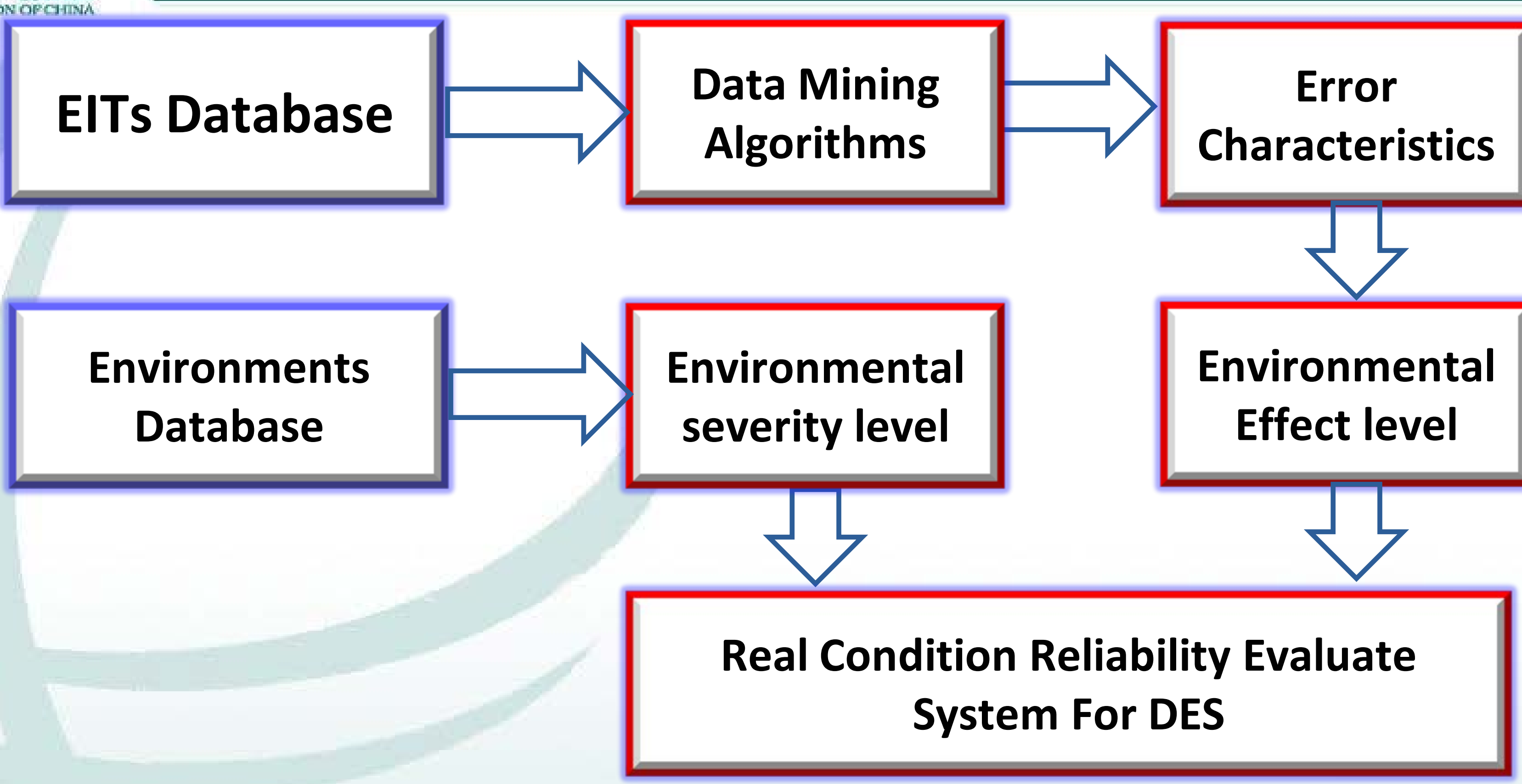
- ◆Traditional Switchgear: TA + TV + Electronic Energy Meter
- ◆Digital Switchgear No.1: Sensors(analog Output) + IED + Digital Energy Meter
- ◆Digital Switchgear No.2: Sensors(Digital Output) + Merge Unit + Digital Energy Meter

Online Calibration Principle



- **Instrument Transformer** for **Reference**
- **Climate Sensor** for Temperature Measurement
- **Online Monitor System** for **EITs Characteristics Analyzed**

Reliability Evaluate of Digital Energy System.



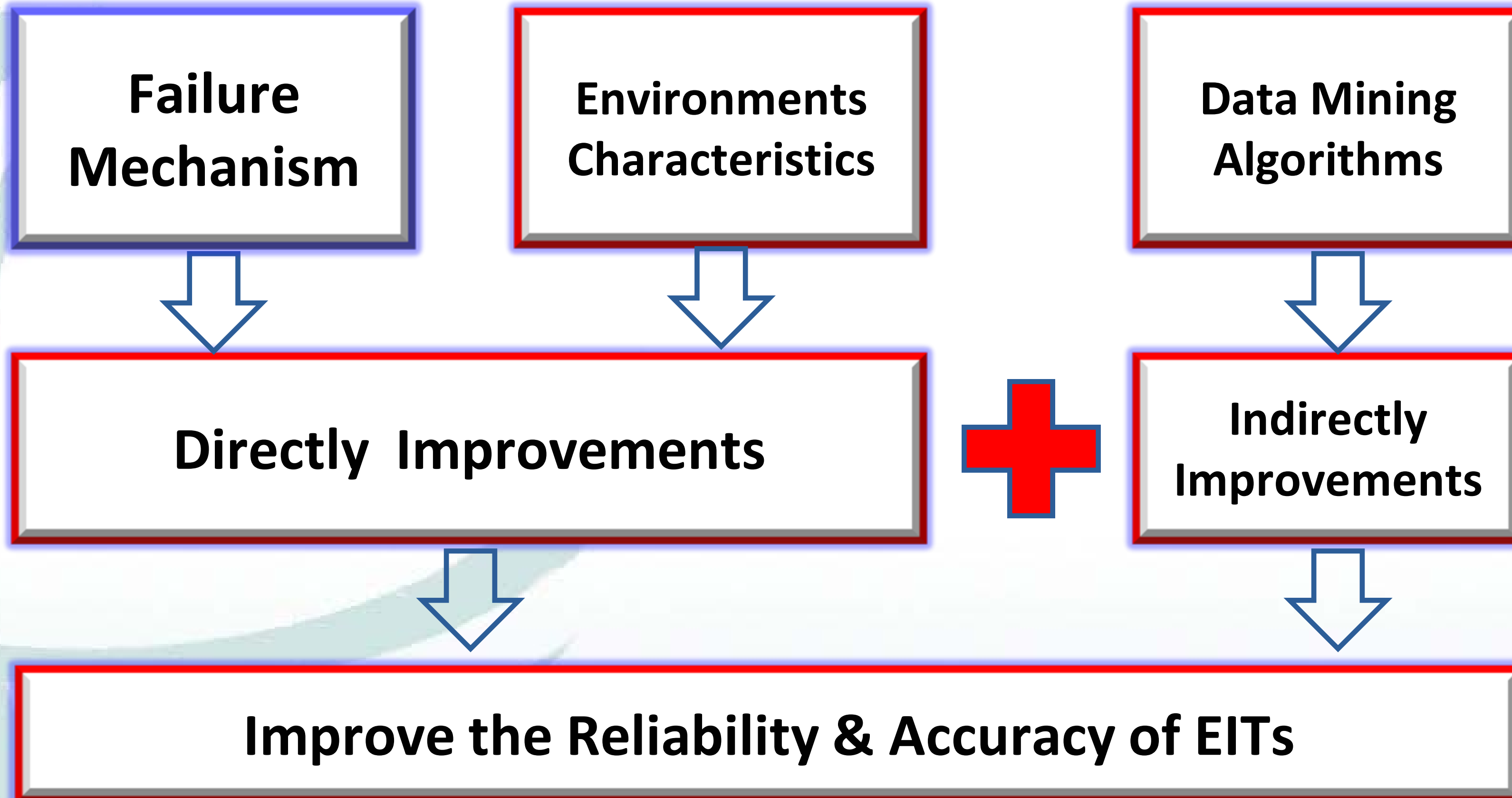
Data Mining Algorithms: Decision Tree, BP, SVM, K-Means.

Error Characteristics: Independence Characteristics(Temp, Hum, EM, Vib).

Environments Database: Build Climate Database.

Evaluate System: Functional relation for Error & Fault Prediction.

Optimal Design For EITs



Directly Improvements: Architecture, Electrical & EM improvement.

Indirectly Improvements: Error Correction By Software or Hardware.

EITs Big Database Establishment

Data Acquisition → **Database Size**

Data acquisition rate: 1S/s

- Measurement time
- Manufacturer name
- Temperature
- Ratio error
- Phase error
- Standard value
- Measurement value

1 S/s	3600 s/h	24 h/d	30 d/m	12 months	EITs 1

1 × 3600 × 24 × 30 × 9 × 1

1 Sensor
Data Size/Year
31,104,000

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Data Processing Methods

Sampling information

	Ratio Error [%]	Phase error [Min]	Ref Voltage [kV]	
20	-0.28926	-1.604	67.3018	67.1071
20	-0.28925	-1.98487	67.2129	67.0185
20	-0.28924	-2.25037	67.3028	67.1082
20	-0.28923	-2.1405	67.1996	67.0053
20	-0.28921	-2.547	67.046	66.8521
20	-0.28921	-2.547	67.0284	66.8341
20	-0.28921	-2.547	66.993	66.8021
20	-0.28921	-2.547	67.0241	66.8336

The Ratio Error and Phase Displacement did not change,

But

Reference Voltage had already been changed

Original Database → Characteristic Analyzed Database

Delete outliers

Eliminating outliers using Rajda Criteria(3σ Criteria)

Arithmetic Mean Value

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

Experimental Standard Deviation

$$s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$$

If satisfied $|x_d - \bar{x}| \gg 3s$, X_d is a outlier

Sampling information

	Ratio Error [%]	Phase error [Min]	Ref Voltage [kV]	
20	0.046306	6.3384	67.6384	67.6697
20	0.049849	4.716	67.6424	67.6762
20	0.045233	7.164	67.6192	67.6498
20	-0.06212	6.3528	67.7072	67.6651
20	-0.09215	34.776	67.7275	67.6651
20	0.041513	4.8144	67.6931	67.7212
20	0.036759	5.5992	67.6708	67.6957
20	0.041713	5.5944	67.6689	67.6971

The phase error with red mark is a questionable value.

Determined as an outlier using Rajda criteria

Environment Attributions Dimension Reduction

Analyzing the operation data through the decision tree analysis method, and the influence weight of the single error source can be sorted by the error source, The algorithm is:

Information Entropy: $Info(D) = -\frac{x_{\cdot 1}}{N}\log_2(\frac{x_{\cdot 1}}{N}) - \frac{x_{\cdot 2}}{N}\log_2(\frac{x_{\cdot 2}}{N}) - \cdots - \frac{x_{\cdot k}}{N}\log_2(\frac{x_{\cdot k}}{N}) = -\sum_{j=1}^{k} p_j \cdot \log_2(p_j)$

Information under Attribute A_i $Info(A_i)$: $Info(A_i) = -\frac{x_{i1}}{x_{i\cdot}}\log_2(\frac{x_{i1}}{x_{i\cdot}}) - \frac{x_{i2}}{x_{i\cdot}}\log_2(\frac{x_{i2}}{x_{i\cdot}}) - \cdots - \frac{x_{ik}}{x_{i\cdot}}\log_2(\frac{x_{ik}}{x_{i\cdot}})$

Information under Attribute A $Info(A)$: $Info_A(D) = \frac{x_{1\cdot}}{N} Info(A_1) + \frac{x_{2\cdot}}{N} Info(A_2) + \cdots + \frac{x_{l\cdot}}{N} Info(A_l) = \sum_{i=1}^{l} \frac{x_{i\cdot}}{N} Info(A_i)$

Information Gain: $Gain(A) = Info(D) - Info_A(D)$

group	Attribution				
	Load Current	Temp	Humidity	Vibration	Magnetic field
ECT Ratio error	0.415	0.018	0.343	0.109	0
ECT Phase Displacement	0.177	0.415	0.415	0.017	0
EVT Phase Displacement	/	0.730	0.364	0	0

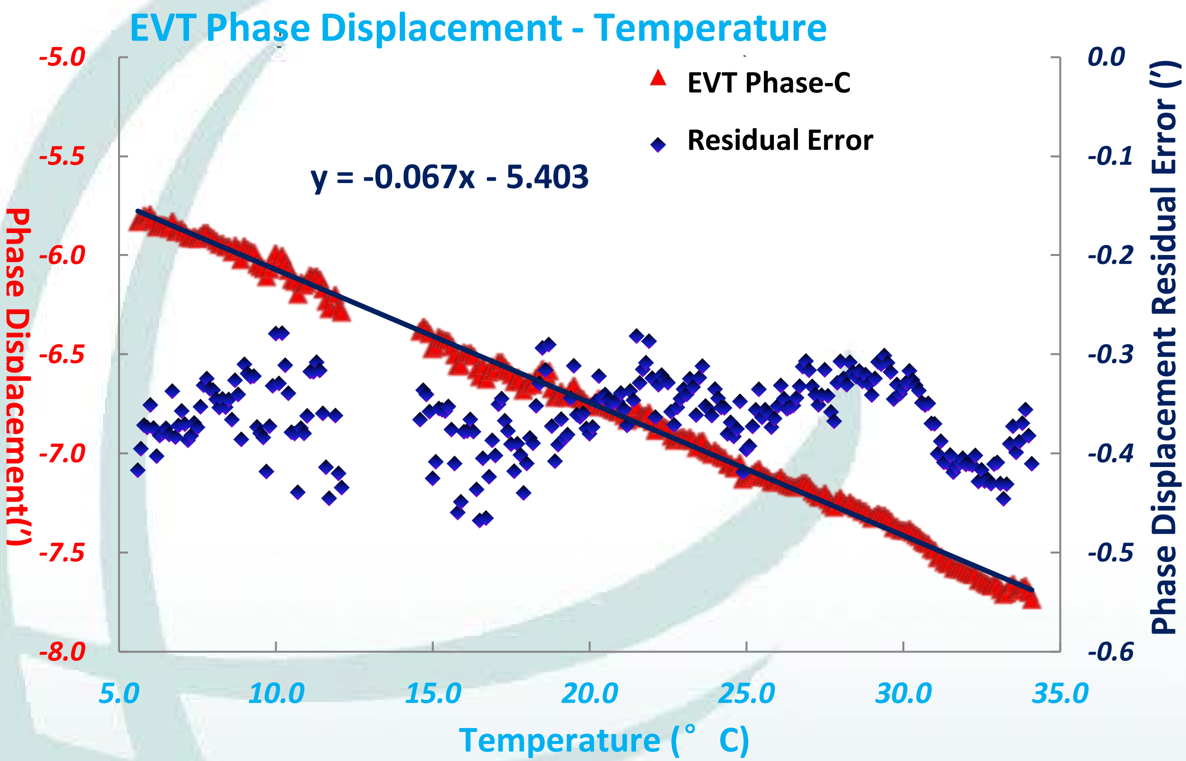
ECT/5 kinds attribution
EVT/4 kinds attribution

Dimension Reduction

ECT
Load Current +
Temperature +
Humidity
3 Main Attributions

EVT
Temperature +
Humidity
2 Main Attributions

Optimize Improve the Accuracy of EITs



Based on the error corrected, the single EVT operation data regression line can be optimized, and the phase displacement is reduced.

Regression line：

$$\hat{\varphi}_i = \hat{\beta}_0 + \hat{\beta}_1 T_i$$

Residual error e_i :

$$e_i = \varphi_i - \hat{\varphi}_i$$

Minimize the Sum of Squared Error :

$$SSE = \sum_{i=1}^{n} \varepsilon_i^2 = \sum_{i=1}^{n} (\varphi_i - \hat{\varphi}_i)^2$$

Regression coefficients $\hat{\beta}_0$、$\hat{\beta}_1$:

$$\hat{\beta}_1 = \frac{\sum_{i=1}^{n} T_i \varphi_i - n\bar{T}\bar{\varphi}}{\sum_{i=1}^{n} {T_i}^2 - n\bar{T}^2}$$

$$\hat{\beta}_0 = \bar{\varphi} - \hat{\beta}_1 \bar{T}$$

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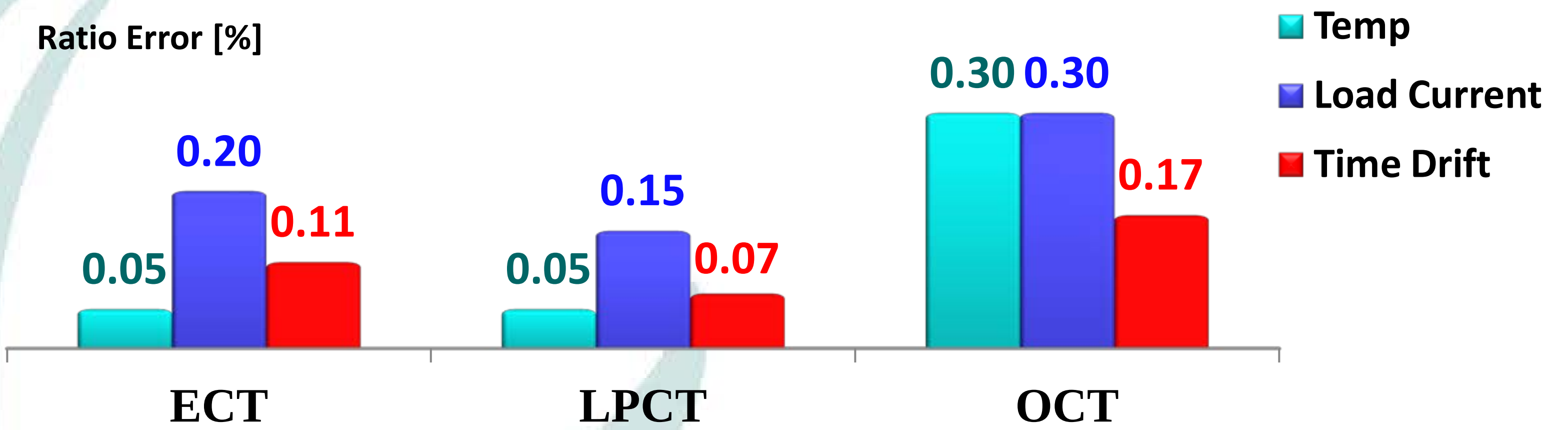
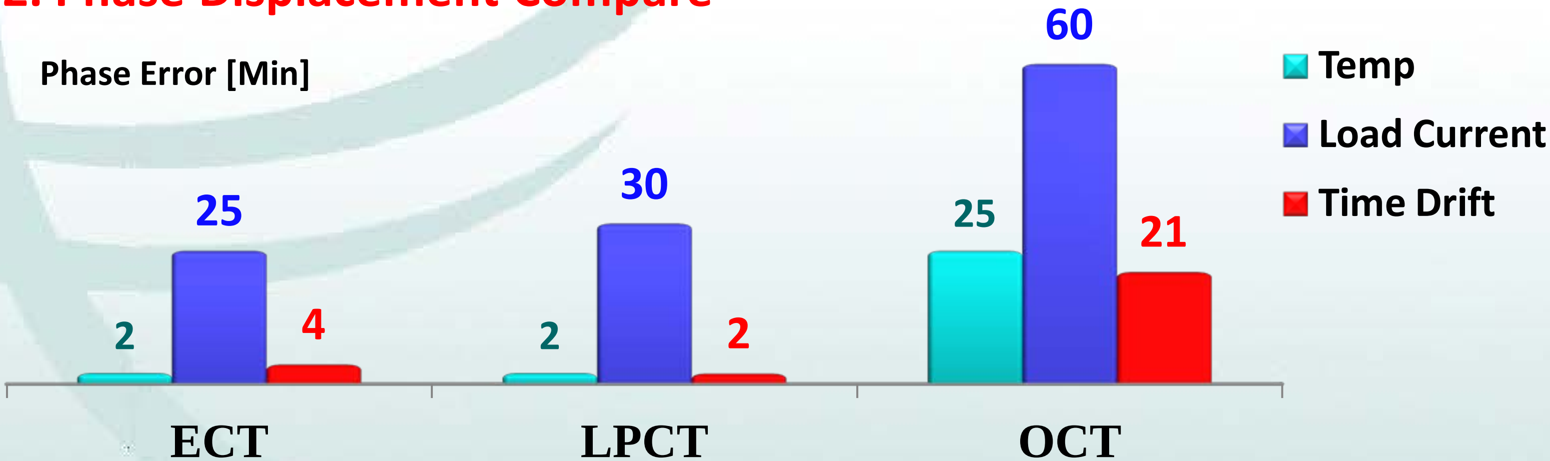
110kV ECTs Error Characteristics Compare Results

1. Ratio Error Compare



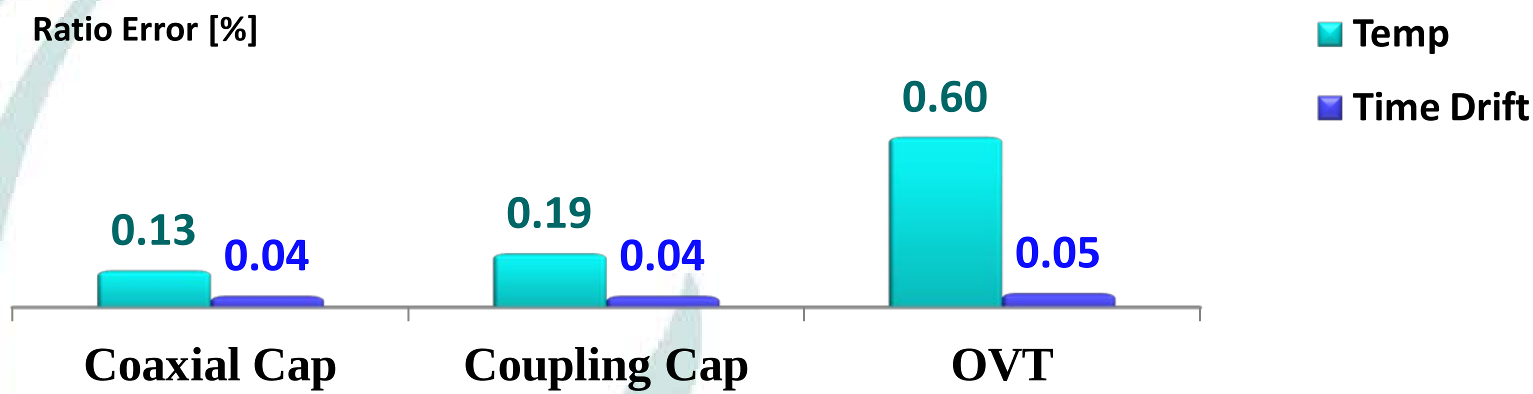
2. Phase Displacement Compare



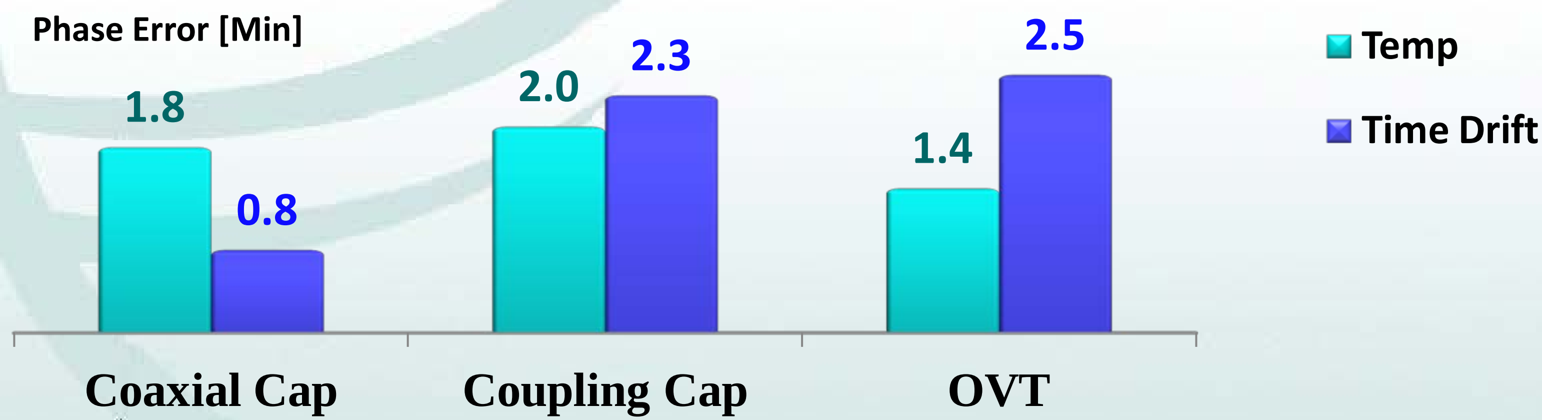
Stability & Reliability Compare for ECTs： LPCT > Rogowski Coil > OCT

110kV EVTs Error Characteristics Compare Results

1. Ratio Error Compare



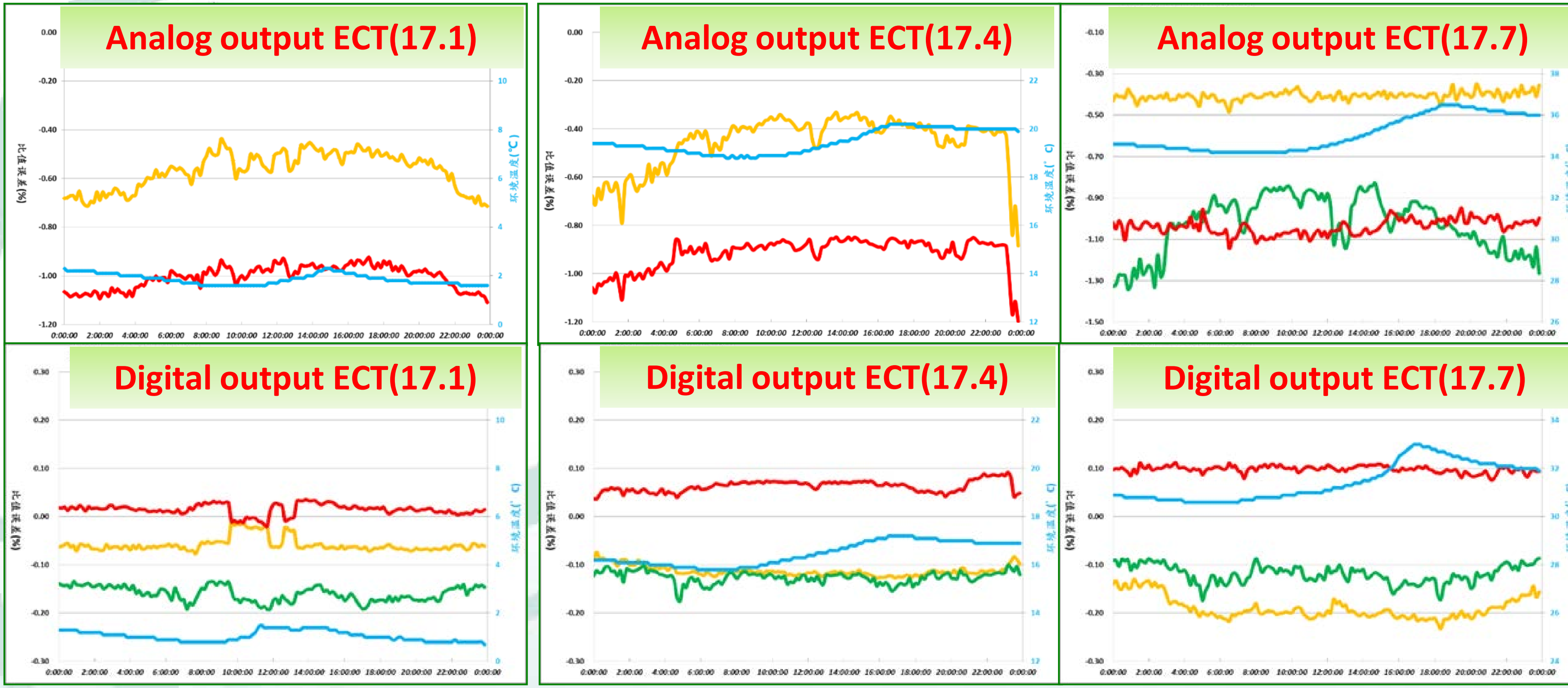
2. Phase Error Compare



Stability & Reliability Compare for EVTs： Coaxial Cap ≈ Coupling Cap > OVT

10kV ECTs Error Characteristics Compare Results

(2016/8/6~2017/7/6, totally 12days operation data)



EVT(Digital output): Ratio Error 0.06%, 0.09% and 0.03%(Phase A/B/C)

Phase Displacement 2.8', 2.9' and 3.7'(Phase A/B/C)

The accuracy of digital output ECT is higher than the analog output ECT

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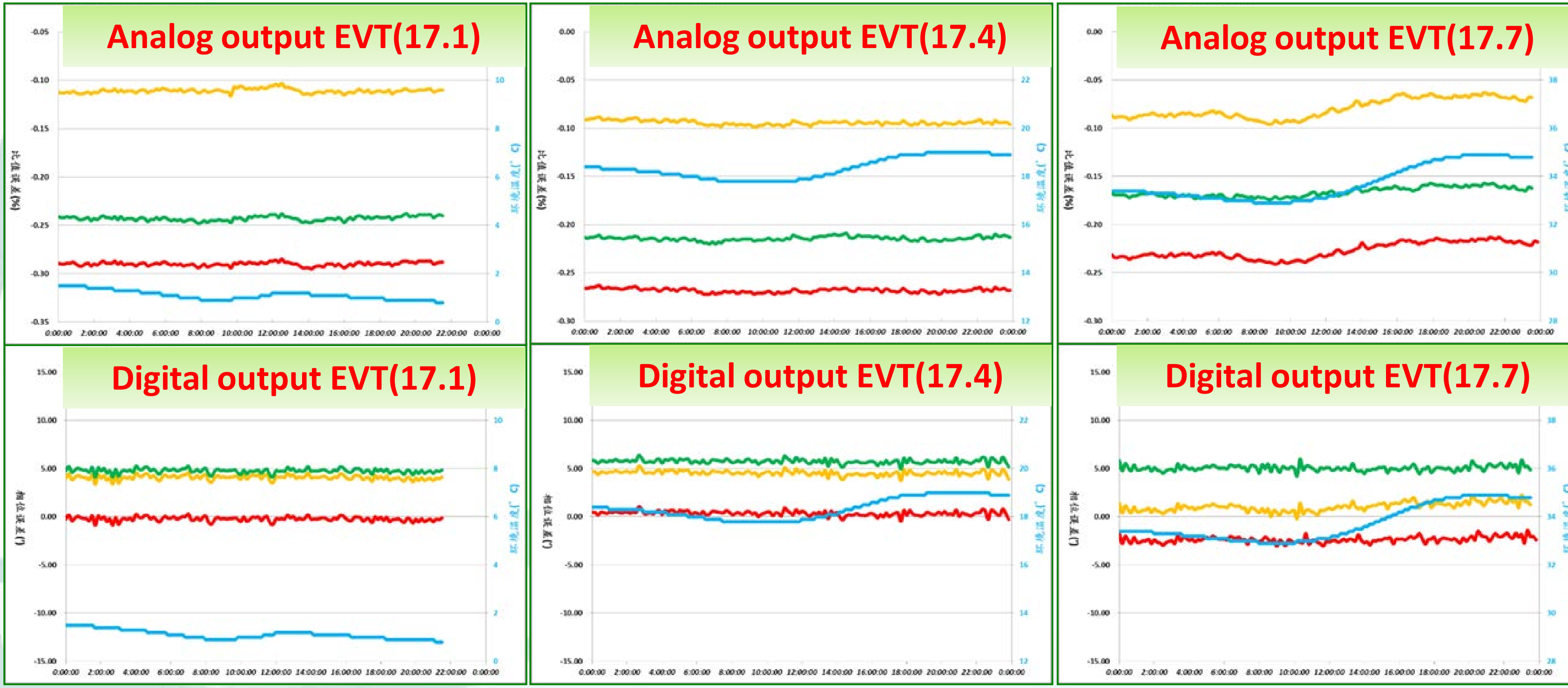
10kV EVTs Error Characteristics Compare Results



EVT(Analog output): Ratio Error 0.05%, 0.05% and 0.07%(Phase A/B/C)

Phase Displacement 5.0', 5.0' and 5.0'(Phase A/B/C)

EVT(Digital output): Ratio Error 0.05%, 0.03% and 0.03%(Phase A/B/C)

Phase Displacement 2.5', 10.0' and 2.5'(Phase A/B/C)

EVT accuracy meet the requirements of 0.2 Class.

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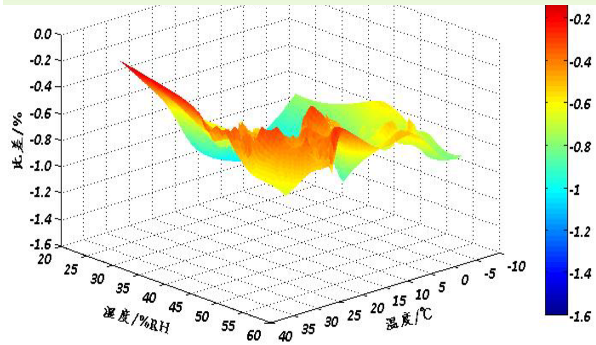
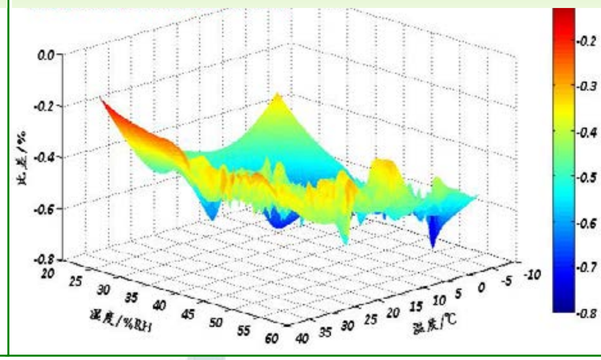
10kV ECTs 3-D Error Characteristics Compare Results

Temperature-Humidity-Error

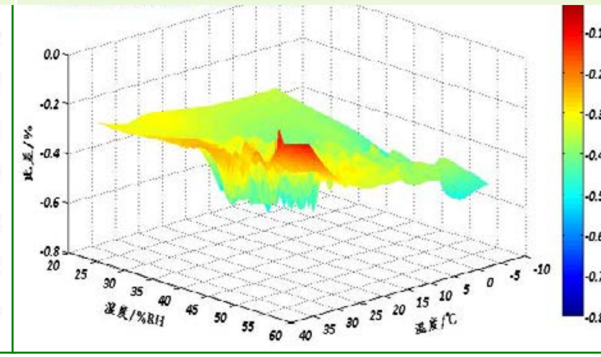
Analog output ECT Temperature and humidity -ratio error (load5A±0.5A)



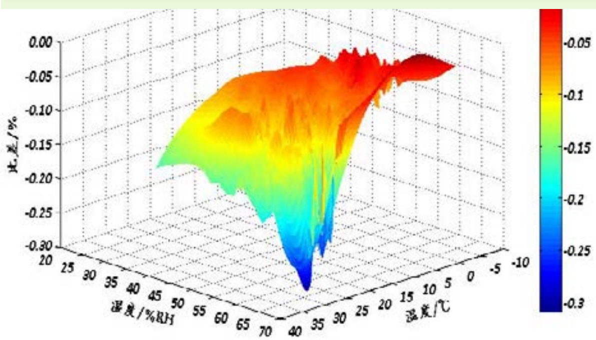
Analog output ECT Temperature and humidity -ratio error (load 10A±0.5A)



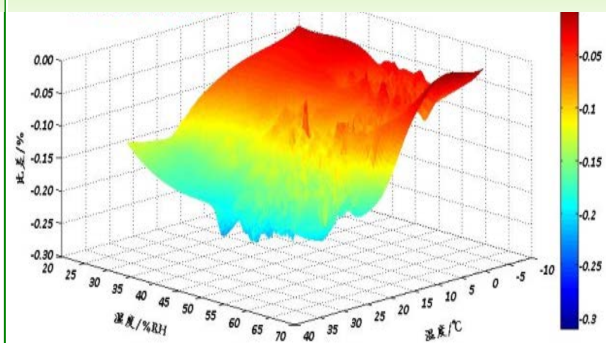
Analog output ECT Temperature and humidity -ratio error (load 20A±0.5A)



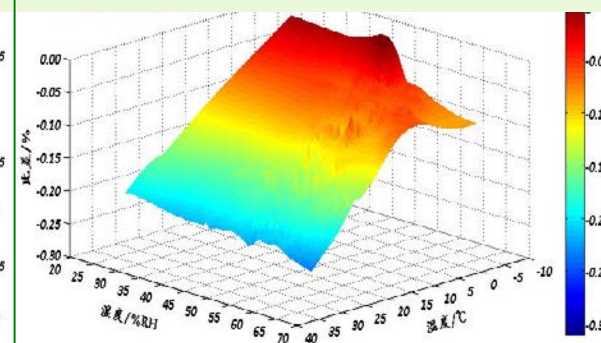
Digital output ECTTemperature and humidity -ratio error (负荷5A±0.5A)



Digital output ECT Temperature and humidity -ratio error(load 10A±0.5A)



Digital output ECT Temperature and humidity -ratio error(load 20A±0.5A)



When the load is low, for analog output and digital output two kinds ECT, their measurement error surface is not smooth with big error fluctuations. With the load increasing, the error surface gradually become smooth, and the operation of the transformer become more stable;
the extreme points of ECT error often appear in the extreme point of the environment, that is, high temperature and high humidity, low temperature and low humidity, high temperature and low humidity and low temperature and high humidity.

10kV EVTs 3-D Error Characteristics Compare Results

Temperature-Humidity-Error

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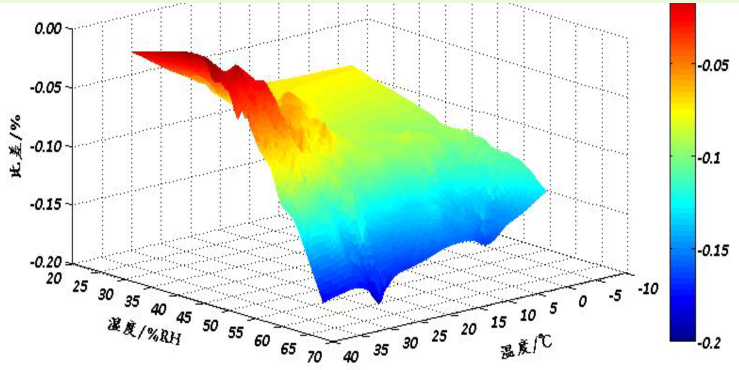
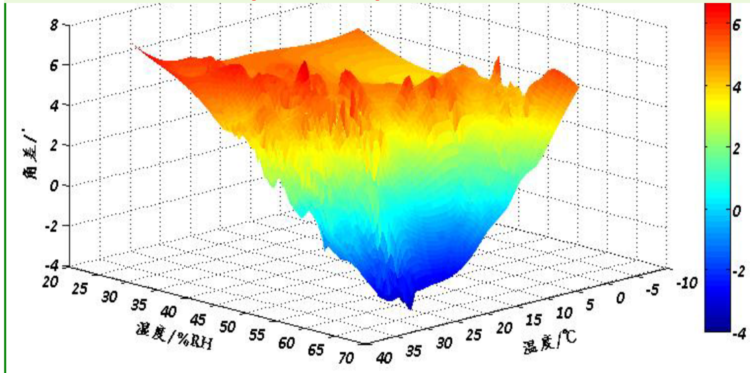
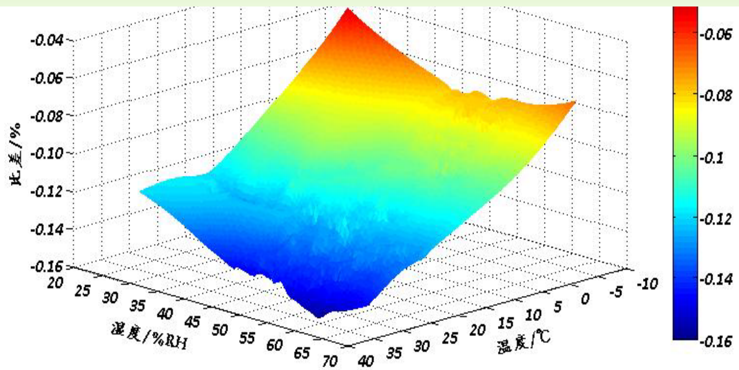
Analog output EVT Temperature and humidity ratio error



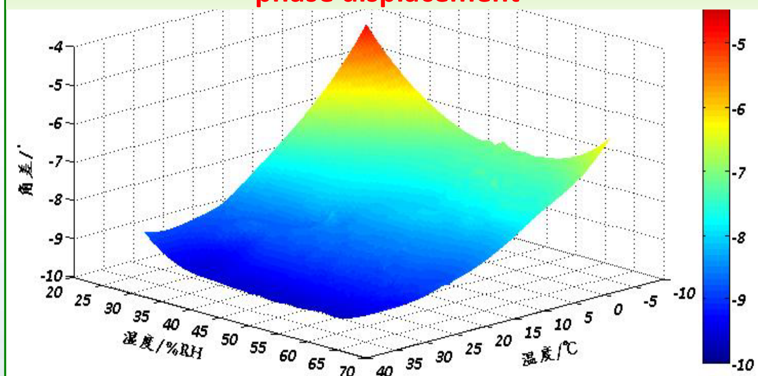
Analog output EVT Temperature and humidity phase displacement



Digital output EVT Temperature and humidity ratio error



Digital output EVT Temperature and humidity phase displacement



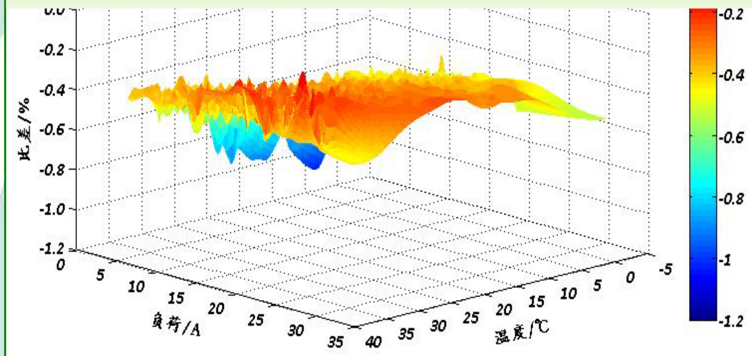
For the analog output EVT, in the high temperature, the effect of humidity on the error will be higher; especially when the temperature rise to above 30 ℃. The high humidity produces an effect of about -0.15% on the ratio error, and about 8′ on the phase displacement.

For the digital output EVT, high temperature and high humidity environment will produce an effect of about -0.1% on the ratio error of phase A,C ,and about -4‘ on phase displacement.

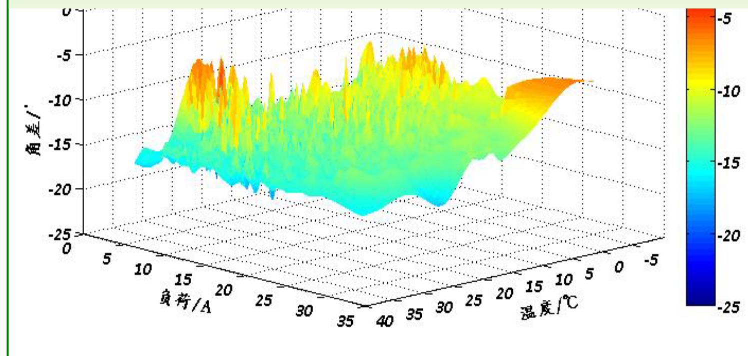
10kV ECTs 3-D Error Characteristics Compare Results

Temperature-Load Current-Error

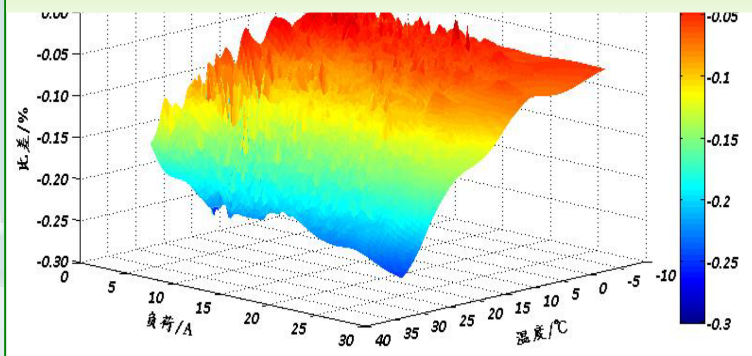
Analog output ECT Temperature and load -ratio error



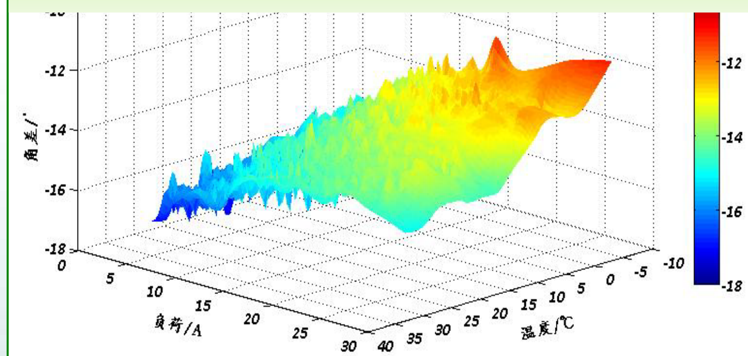
Analog output ECT Temperature and load -angle error



Digital output ECT Temperature and load -ratio error



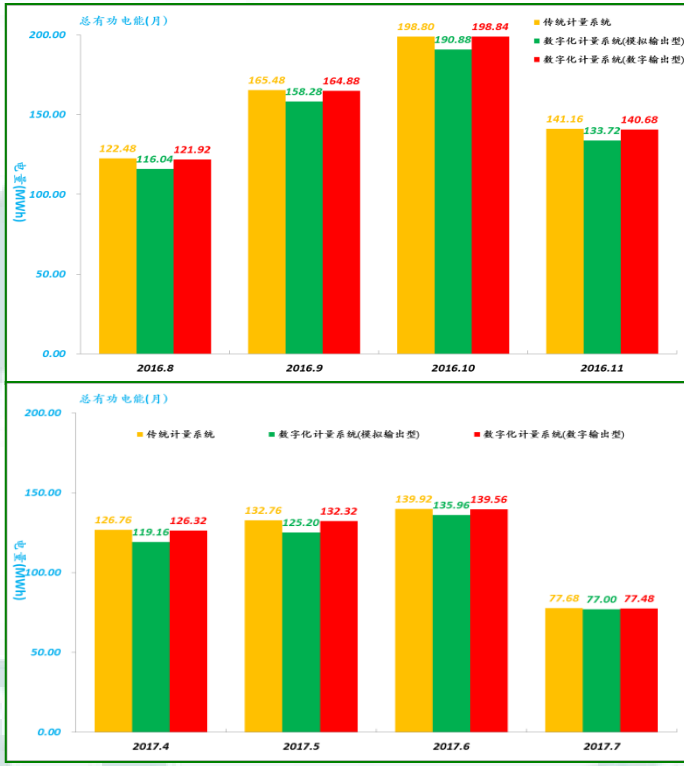
Digital output ECT Temperature and load -angle error

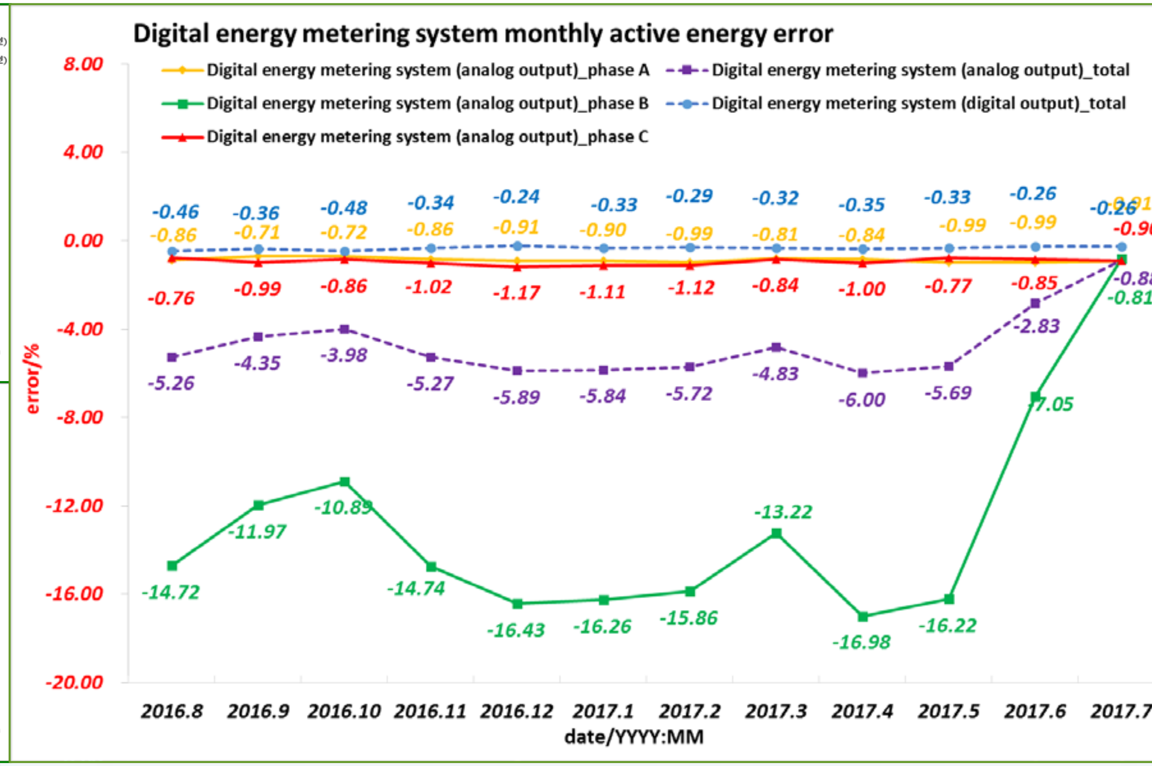


In the lower load part, for the analog output and digital output two kinds ECT, the error fluctuate higher with the temperature changes. However, when the load is bigger than 20A, the error changes more stable.

Digital Energy System Error Characteristics

Active Energy Error





Maximum Active Energy Error Per Month:

-0.48% (Digital Output), -6.0% (Analog Output), -0.99% (Analog Output phase-A), -1.17% (analog output phase C).

Stability (Maximum Month Error – Minimum Month Error):

0.24% (Digital Output), 0.28% (Analog Output Phase-A), 0.41% (Analog Output Phase-C).

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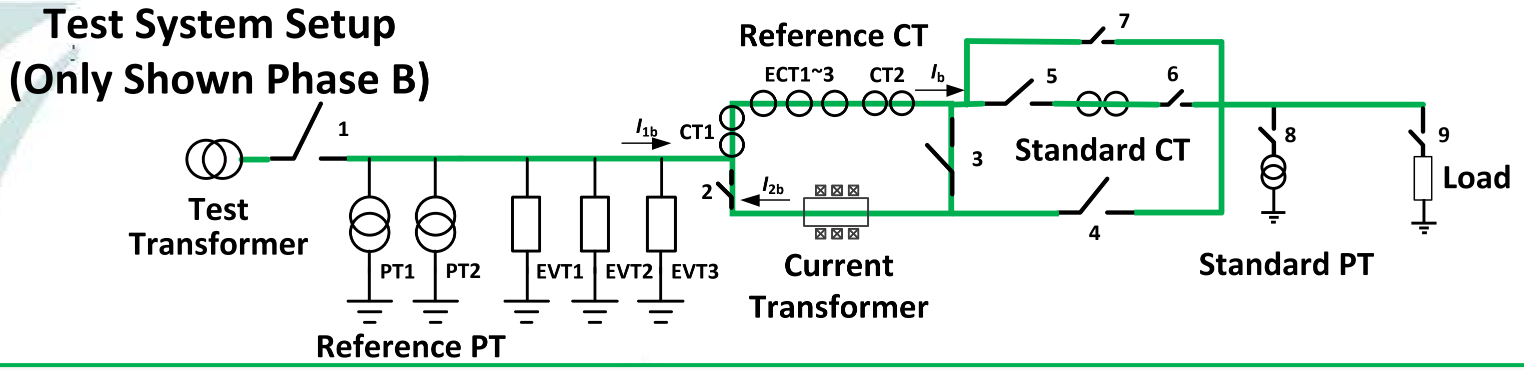
EITs Test System in Lab



1. Test Current: $I_b = I_{1b} + I_{2b}$, Total Current(I_b), Load Currnet(I_{1b}) and Virtual Current(I_{2b}).
2. Reference Mode & Calibration Mode Selected by Control High Voltage Switch.
3. Double Reference Enhance Reference Value Accuracy and Reliability.

Test System in SGCC Tibet Lab!!!
Established in 2017.9

On Going !!!
Mohe Lab in 2017.11
Tulufan Lab in 2018.4
Meizhou Lab in 2018.6

EITs Intelligence Maintenance Technique

Based on the machine learning, the digital energy metering equipment is able to analyze typical fault reasons and feature, and evaluate the operation running situation.

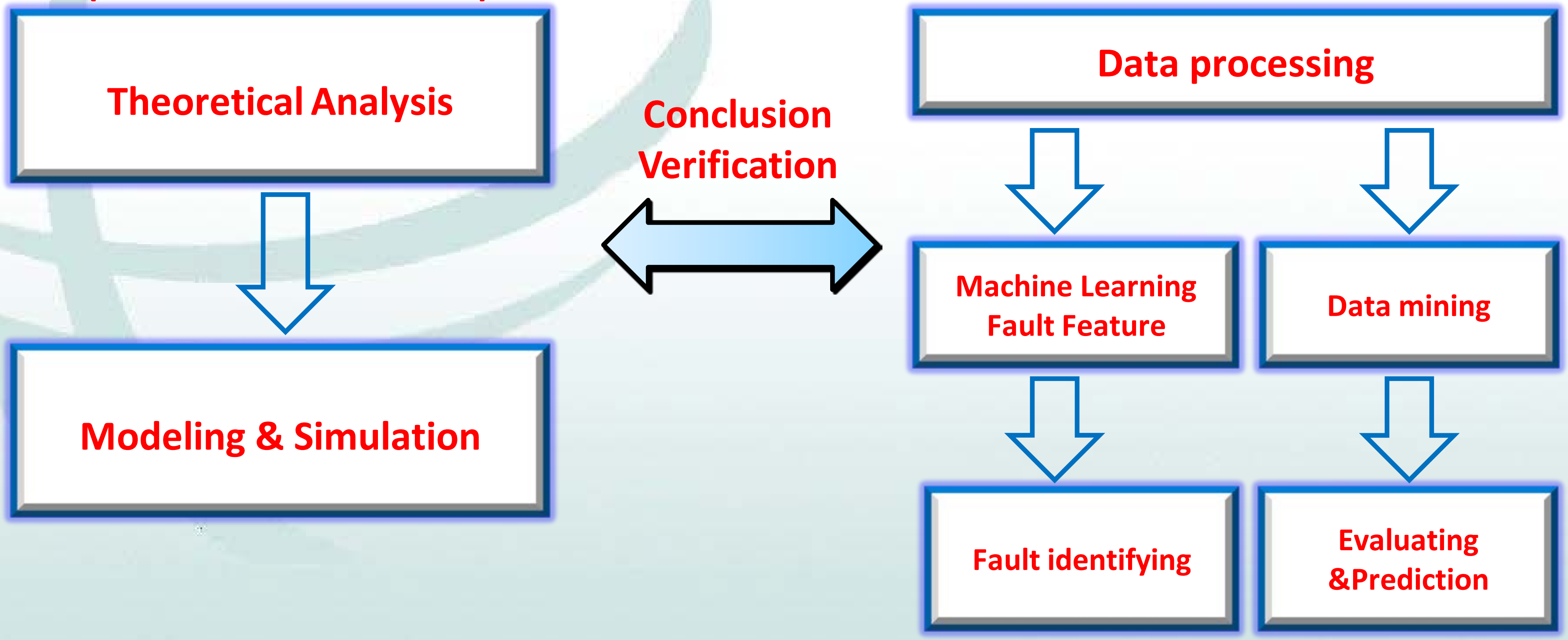
Theoretical Analysis

+ Simulation + Experiment

(Conventional Method)

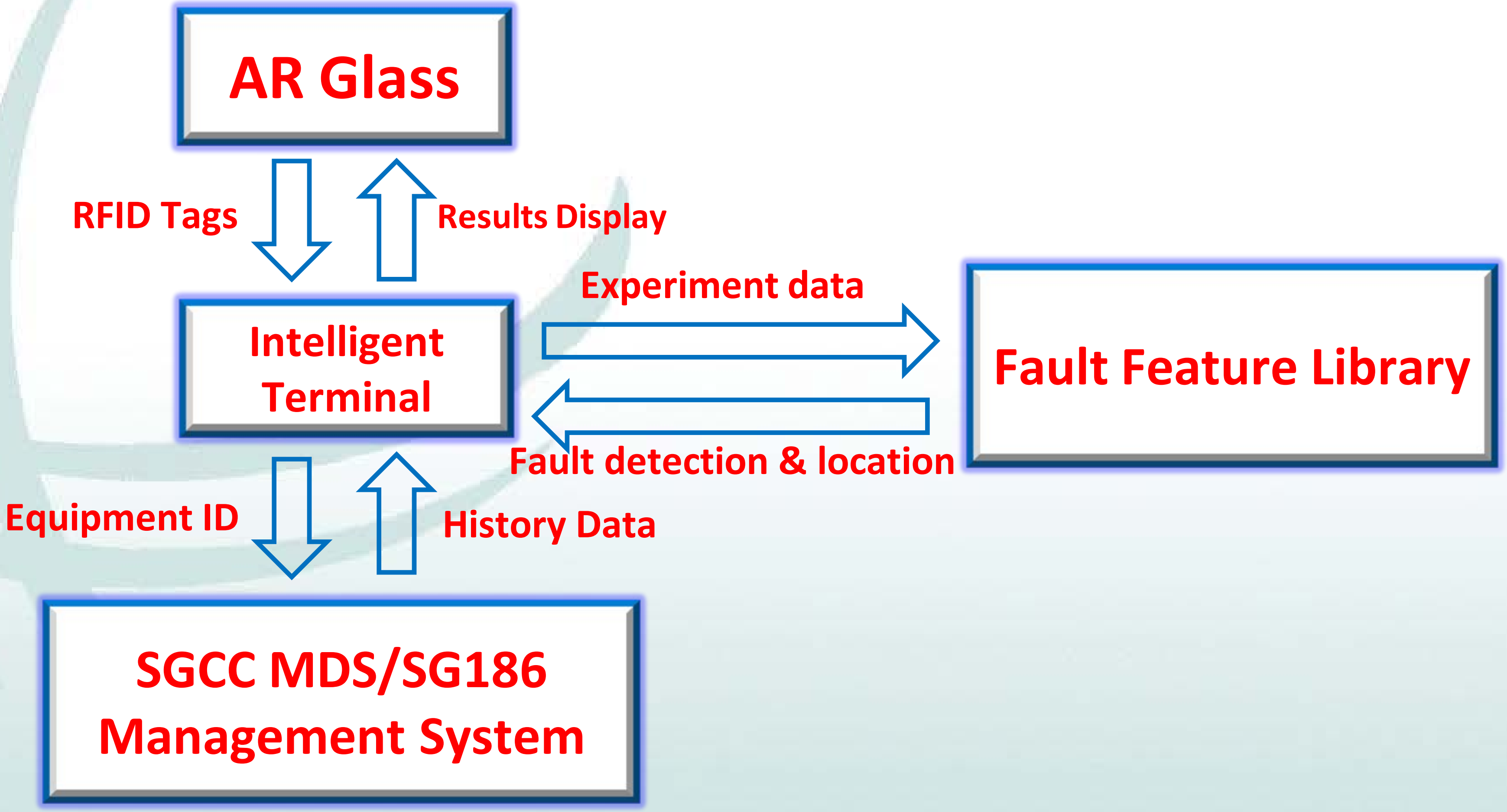
Data Mining + Machine Learning

(Big Data + AI Method)



EITs Intelligence Maintenance Technique

Develop an intelligent detection terminal of the digital metering equipment, to achieve rapid fault location by the use of fault feature recognition.



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Question & Answer

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