

Monitoring Power Quality of Transmission System – Smart Grid Aspect

輸電系統電力品質監控

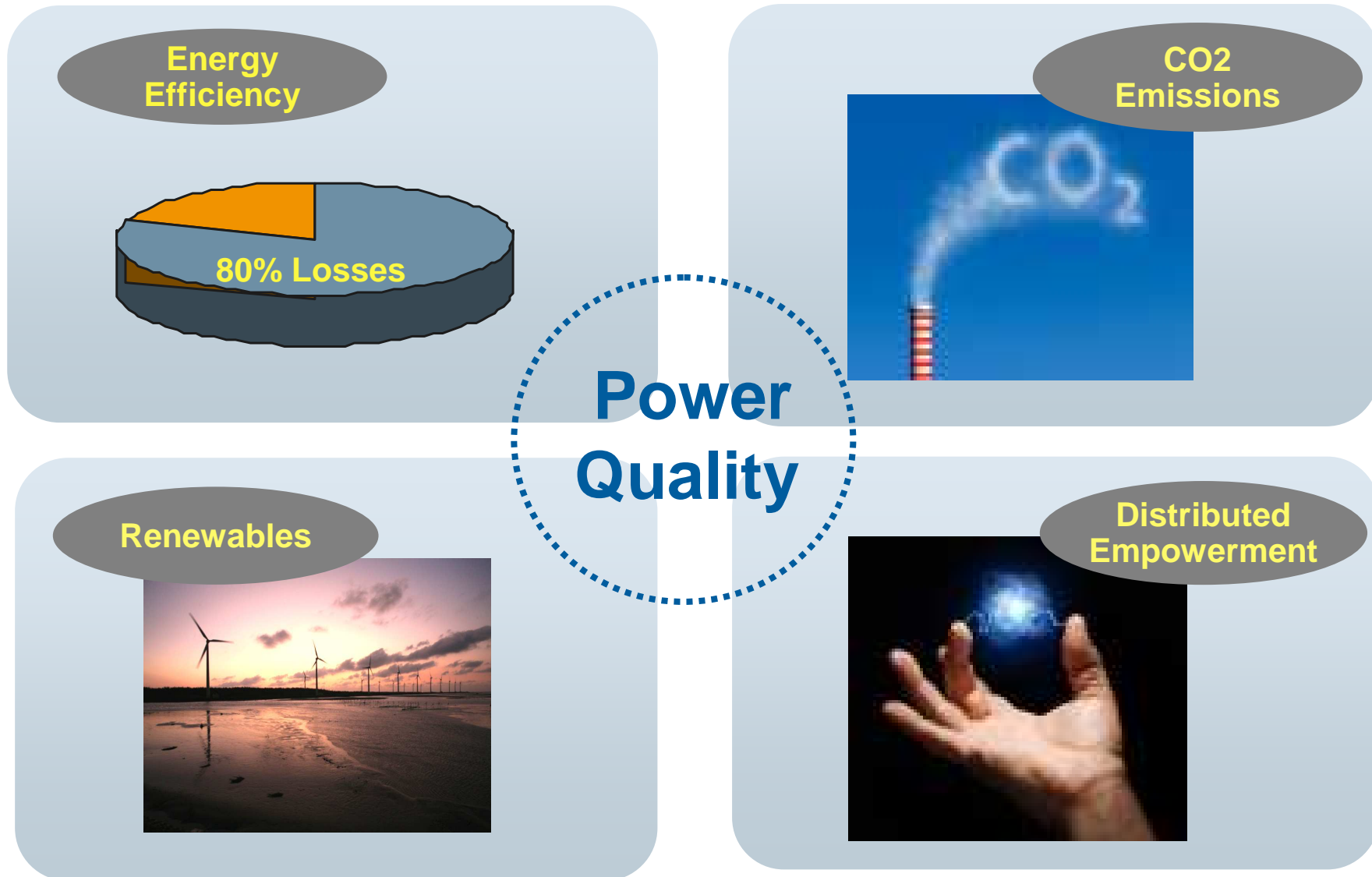


Gary W. Chang, PhD, PE, FIEEE
Department of Electrical Engineering
National Chung Cheng University

Outline

- Smart Grid Driving Forces
- Overview of Power Quality Disturbances
- Power Quality and Smart Grid
- Power Quality Measurement Issues
- Advanced PQ Measurement Techniques
- Case Studies
- More PQ Measurement Issues under Smart Grid
- Conclusions

Smart Grid Driving Forces

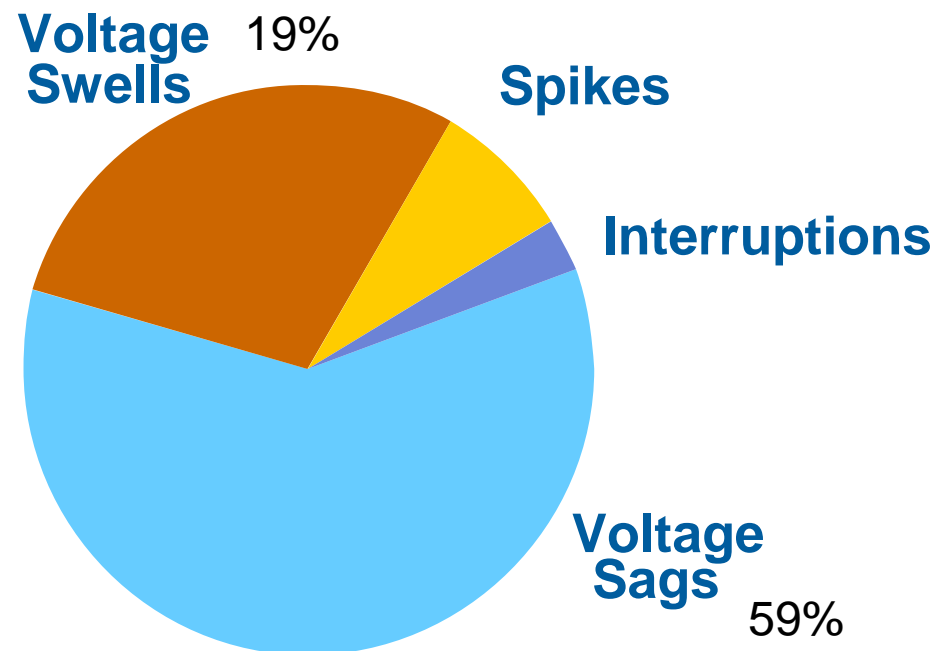


Source: Alstom Power

Overview of Power Quality Disturbances

What is Power Quality (PQ)?

- Any occurrence manifested in voltage, current, or frequency deviations that results in failure or malfunction of utilities' and customers' equipment.



Typical PQ Disturbances

Voltage

sags/swells/interruptions

Causes: sudden change in load current, fault on feeder

Effects: process interruption, data loss, data transmission errors, PLC or computer malfunction

Transients

Causes: lightning strikes, capacitor energizing, load or source switching

Effects: insulation breakdown, semiconductor device damage, shorts, accelerated aging, loss of data or stability

Harmonics

Causes: power electronic devices, arcing, transformer saturation

Effects: equipment overheating, high voltage/current, protective device mis-operations

Voltage fluctuations

Causes: high current loads, arc furnaces, windmill-generated power

Effects: illumination flickers, frequent operations of OLTC, malfunctions of electronic devices

Power Quality Issues

- Harmonics/Interharmonics
- Imbalance
- Voltage Fluctuations
- Voltage Sags/Swells/Interruptions
- Transients
- Standards, Limits, Diagnostics, and Alternative Indices
- Combined Effects
- Power Quality Economics
- Measurement Protocols
- Probabilistic Approach
- Modeling & Simulation
- Advanced Techniques (Wavelet, Fuzzy Logic, Neural Net, GA)
- Integrated Perspective of Power Quality Programs
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Importance of PQ-related Issues

- **Proliferation of highly sensitive computerized equipment places more stringent demands on PQ**
 - Semiconductor industry
 - Computers and computer-related businesses
 - Variable-speed drives or robots
 - Programmable logic controllers
- **Nonlinear loads result in more PQ problems**
- **Impact to High-tech Firms**
 - One cycle interruption causes a silicon device worthless
 - Five-minute shut down of a chip fabrication plant makes delay from a day to a week
 - One-second power outage causes e-commerce sites lose millions of dollars worth of business
- **Cost of PQ Losses: \$20~25 billion/year (US)**

Power Quality and Smart Grid

Characteristics of Smart Grid

The U.S. Department of Energy's National Energy Technology Laboratory (NETL) states that the “Modern Grid” will have the following characteristics:

- Self-Heals
- Motivates and Includes the Consumer
- Resists Attack
- **Provides Power Quality for 21st Century Needs**
- Accommodates All Generation and Storage Options
- Enables Markets
- Optimizes Assets and Operates Efficiently

Power Quality and Smart Grid (cont.)

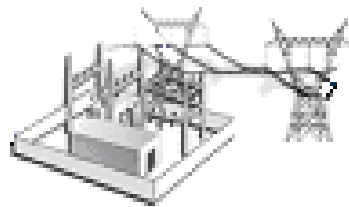
The use of advanced information and communication technologies to link all aspects of the electric grid together with sensors and intelligent devices to provide the following enhanced operational capabilities:

- 1) Engage **CONSUMERS** with the ability to wisely use electricity, electric devices and new services
- 2) Ensure **EFFICIENCY** of using the electric grid (optimizing current assets while integrating emerging technologies such as renewables and storage devices); and
- 3) Enhance **RELIABILITY** (protecting the grid from cyber and natural attacks, increasing **power quality** and **self-healing** capabilities).

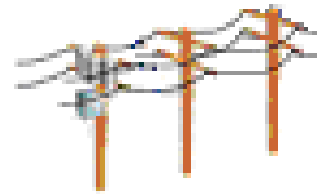
Generation



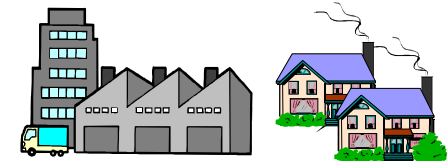
Transmission



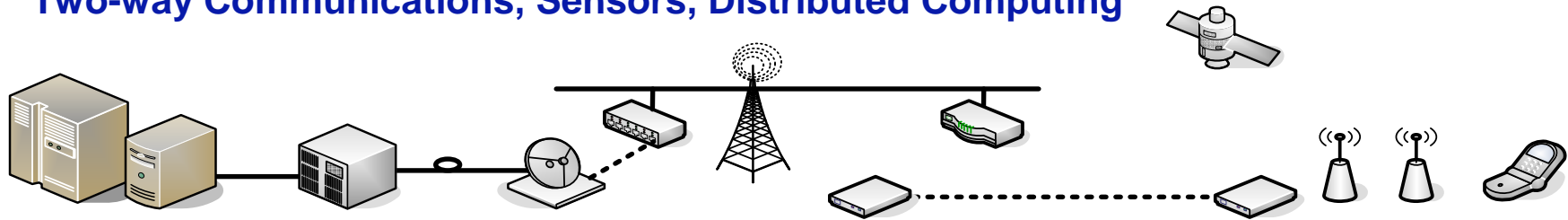
Distribution



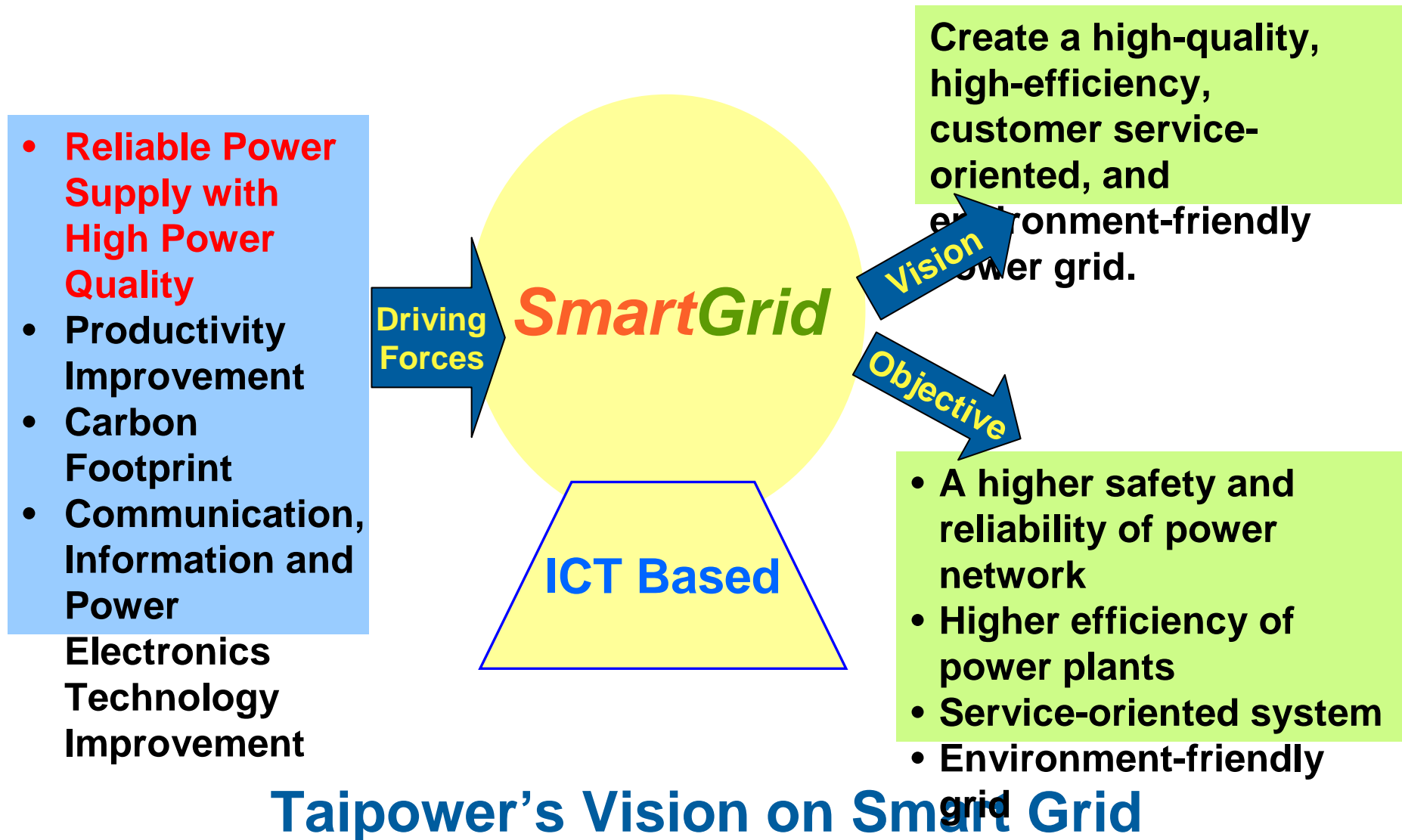
Consumer



Two-way Communications, Sensors, Distributed Computing



Power Quality and Smart Grid (cont.)



Taipower's Vision on Smart Grid

Source: TPC

Power Quality and Smart Grid (cont.)

- Classic sensing remote terminal units (RTUs) are relatively simple and low-resolution devices that report only the most basic parameters of the power system.
- IEDs at substations lack unified communication and information protocols and interoperability.
- In today's Smart Grid, we need additional information about the state of the system. The additional information provided by permanently installed and network-connected power quality monitoring enables operators and engineers to measure the quality of service, react more effectively to unexpected system events, and provide the forensic information necessary to determine cause, effect and future mitigation methods for more serious system events.

Power Quality and Smart Grid (*cont.*)

- Monitors, diagnoses, and responds to PQ issues
- Supplies various grades of power quality at different pricing levels
- Greatly reduces consumer losses due to PQ
- Quality Control for the grid
- Performs continuous self-assessments
- Detects, analyzes, responds to, and restores grid components or network sections
- Handles problems too large or too fast-moving for human intervention
- Self heals - acts as the grid's *immune system*
- Supports grid reliability, security, and power quality

Today

Focus on outages not PQ
Protect assets following disruption

Tomorrow

Premium power options
Prevent disruptions, minimize impacts,
fast restoration (FDIR)

Power Quality and Smart Grid (cont.)

- **Advanced metering** is a generic term referring to “smart” hardware and software for intelligently measuring the consumption of electricity.
- **Three functions that make a meter smart:**
 - The ability to take interval measurements, measuring both what was consumed and when.
 - Automatic transmission of the resulting data, eliminating the need for manual reading.
 - Two-way communications: the ability to both “listen” and “talk.”
- **Those benefits offered by advanced metering:** outage management, system reliability, power quality, time-of-use rates, on-demand reads, distribution automation, declining total cost of ownership.

Power Quality and Smart Grid (*cont.*)

- Utility customers think the reliable electric power is both free of interruption and disturbance (i.e. **clean power**).
- **Advanced components** will apply the latest in superconductivity, energy storage, and power electronics to improve power quality.
- The Smart Grid will employ **appropriate measures** to prevent PQ disturbances from feeding back into the grid.
- **PQ problem identification** will happen quickly because modern communicating meters will find and report it immediately.
- Smart Grid technologies require **the coordinated efforts of government, utilities, regulators, and standards bodies**.

Power Quality Standards

The key power quality measurement standards include:

- *IEC 61000-4-30* – basic power quality monitoring functionality
- *IEC 61000-4-15* – light flicker measurement
- *IEC 61000-4-7* – harmonics and interharmonics measurement
- *EN 50160* – voltage characteristics of electricity supplied by public electricity networks
- *IEEE 1159* – standardized power quality disturbance categorization and best practices
- *IEEE 1159.3* – standardized power quality data interchange format
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- *Standards should enable future functionality of the Smart Grid (e.g. NIST Framework and Roadmap for Smart Grid Interoperability Standards, NIST PAP 0~17)*
- *Global standards are needed*
- *Need to be robust & up-to-date*

Power Quality Measurement Issues

In general, the PQ measurement system should include the following elements to implement the Smart Grid through well-integrated applications:

- Service-based architecture
- Technology layering and isolation and ability to be easily upgraded
- Well-defined interfaces and points of interoperability
- Information models and discoverability
- Application of industry and international standards
- Distributed computing (modular, network connected components)
- Network and system management

Power Quality Measurement Issues *(cont.)*

- **Two emerging trends in PQ measurement** important to utilities:
 - Consumers' rising energy requirements are causing the load on each phase to rise.
 - An accelerated increase in the use of non-sinusoidal loads
- **Key attributes of PQ measurement system** under Smart Grid
 - Embedded grid intelligence measures power quality metrics
 - Measures voltage, current, harmonic distortion, and more
 - Sag and swell logging with configurable threshold and duration
 - Neighborhood meter network data analysis
 - PQ-affiliated logging and alarms built-in and configurable through software

PQ Measurement for Power Network

For Transmission System:

- Automated Asset Condition Assessment
- Automated Fault Location
- Waveform Capture & Fault Classification
- Wide Area Monitoring & Control

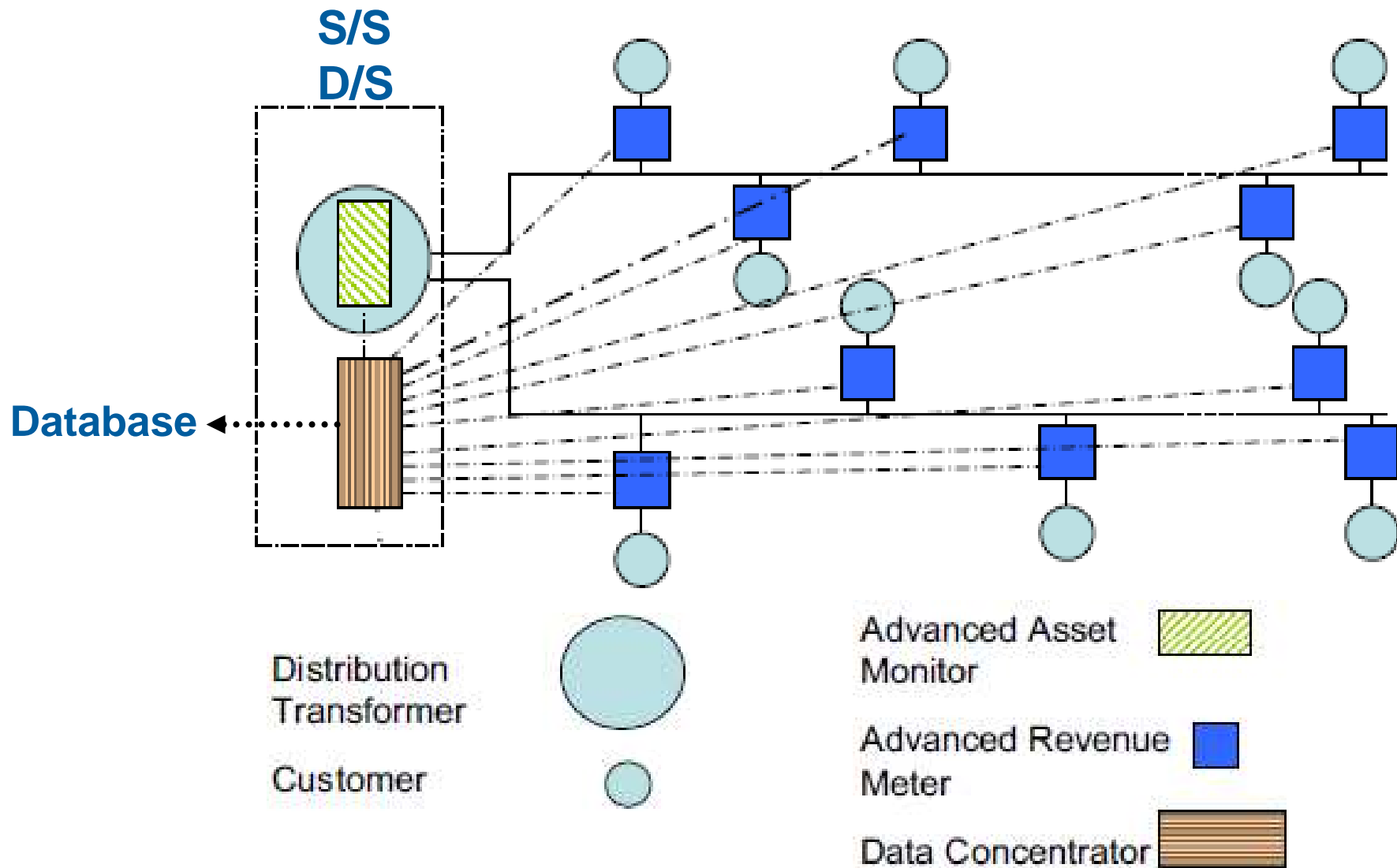
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For Distribution System:

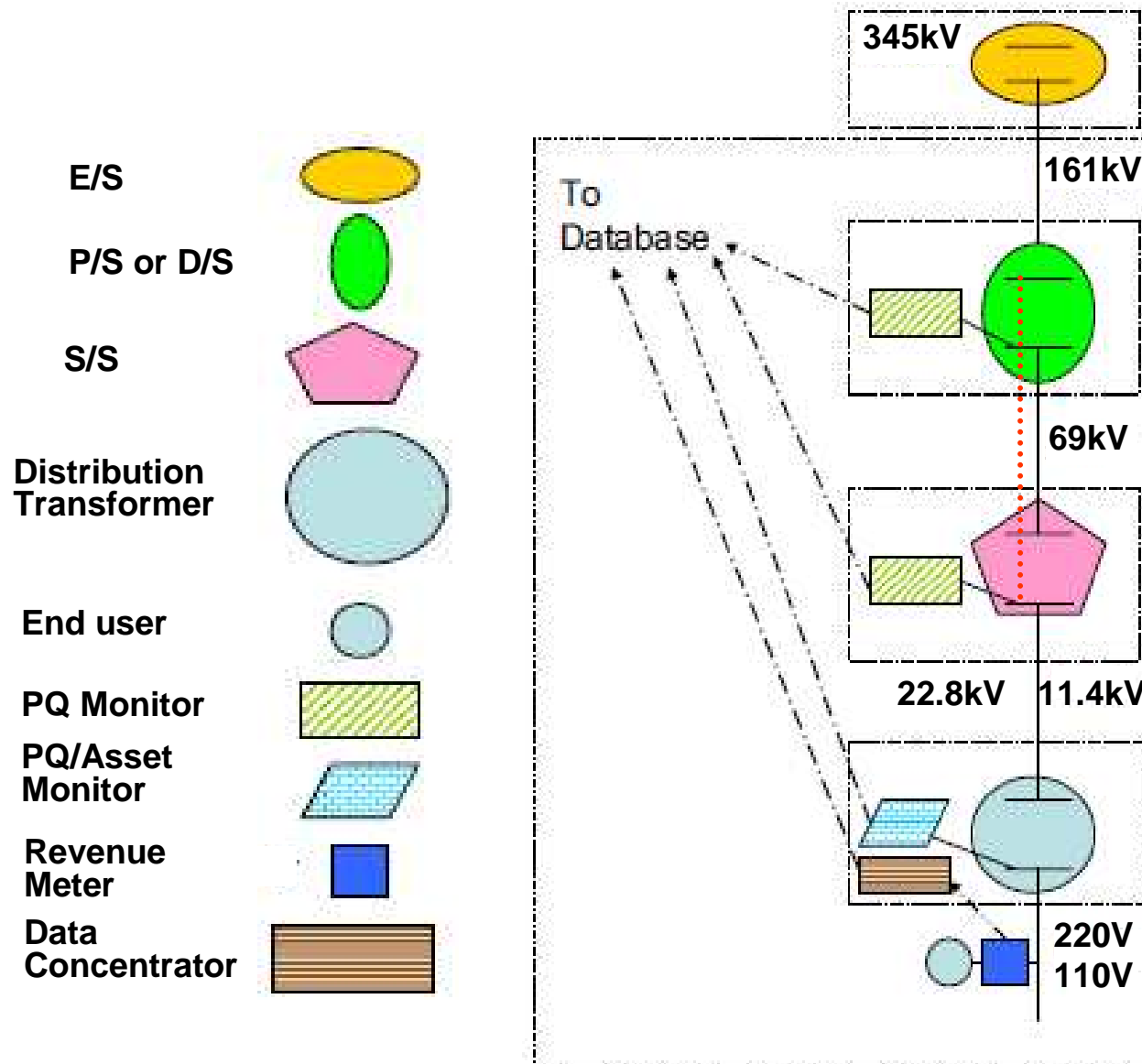
- Feeder Automation
- Remote Monitoring of Fault Indicator
- Equipment Condition Monitoring
- Substations Automation
- Micro-Grid Management
- Large Customers

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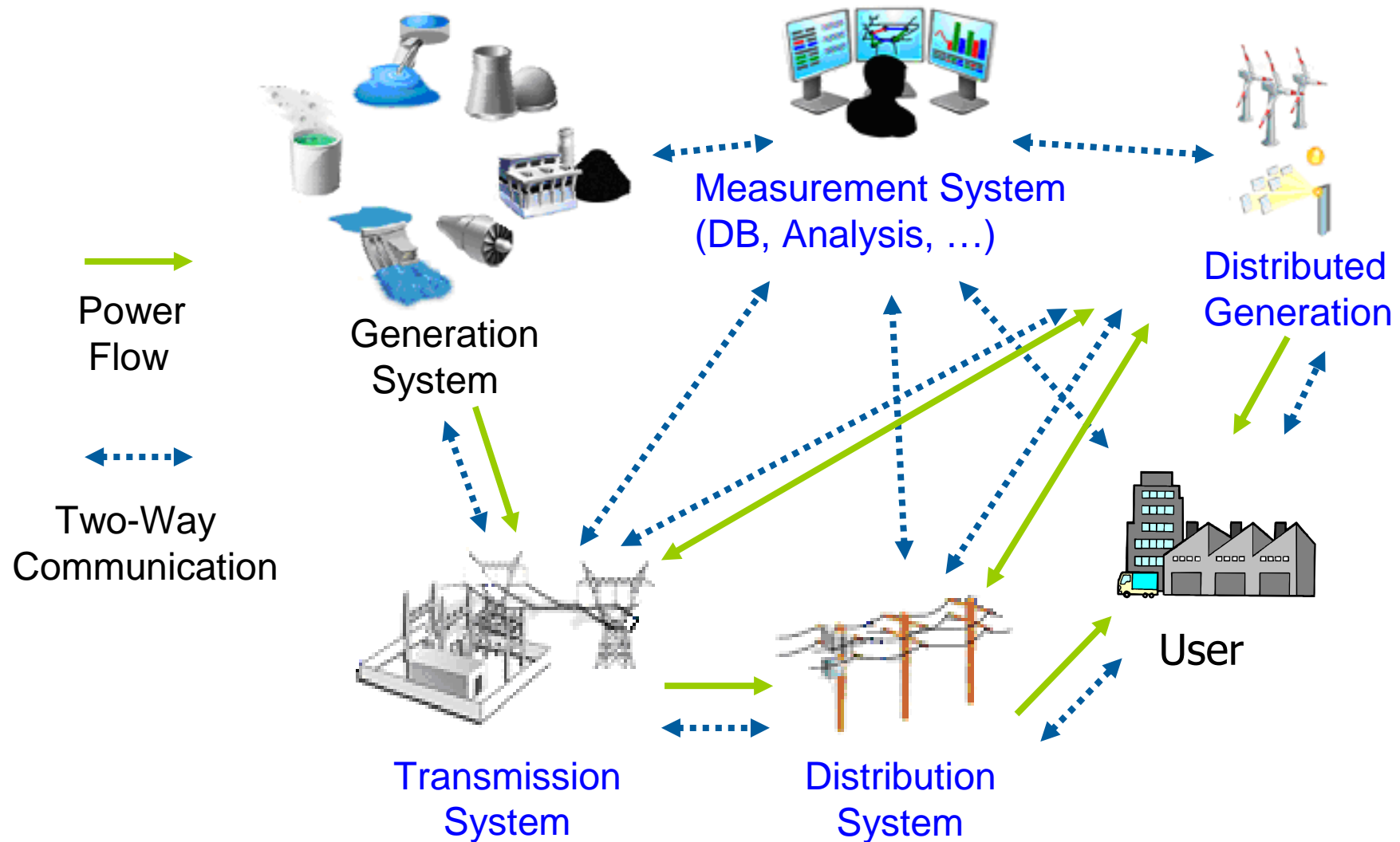
Distribution System Monitoring Scheme



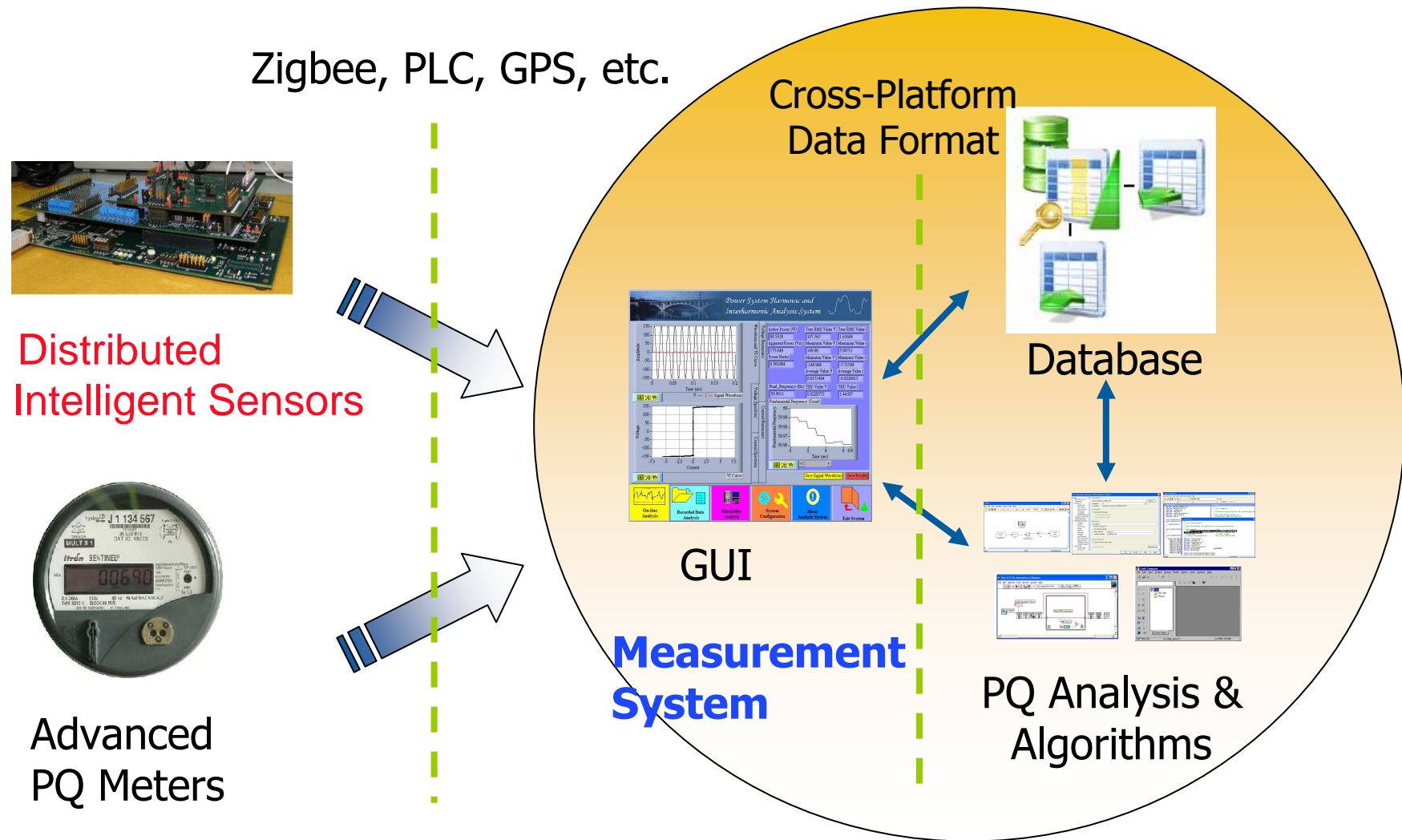
Distribution System Monitoring Scheme (cont.)



Smart PQ Monitoring Scheme



Smart PQ Monitoring Scheme (cont.)



PQ Disturbance Emission and Immunity

Disturbance	Immunity	Emissions
Sags and Swells	ITIC/SEMI F47	Protection Settings; Impedances; fault characteristics
Waveform Distortion	61000-3-2,4,12	61000-3-6
Voltage Fluctuations & Flicker	61000-3-3,5,11	61000-3-7
Transients	BIL	Not prescribed
Imbalance	Varies greatly for types of equipment	61000-3-13

PQ Monitor Specifications

Designed for energy usage metering
Collect fundamental voltage/current/power
Some have minor PQ functions
Cheaper than dedicated PQ monitors



Suitable for S/S or D/S
Supply 10-,15- or 30-minute data
Useful for network planning and asset management
Some PQ functions



Highly accurate
Measure full range of PQ disturbances
Comply with major PQ monitoring standards
May have two-way communication capability
Expensive

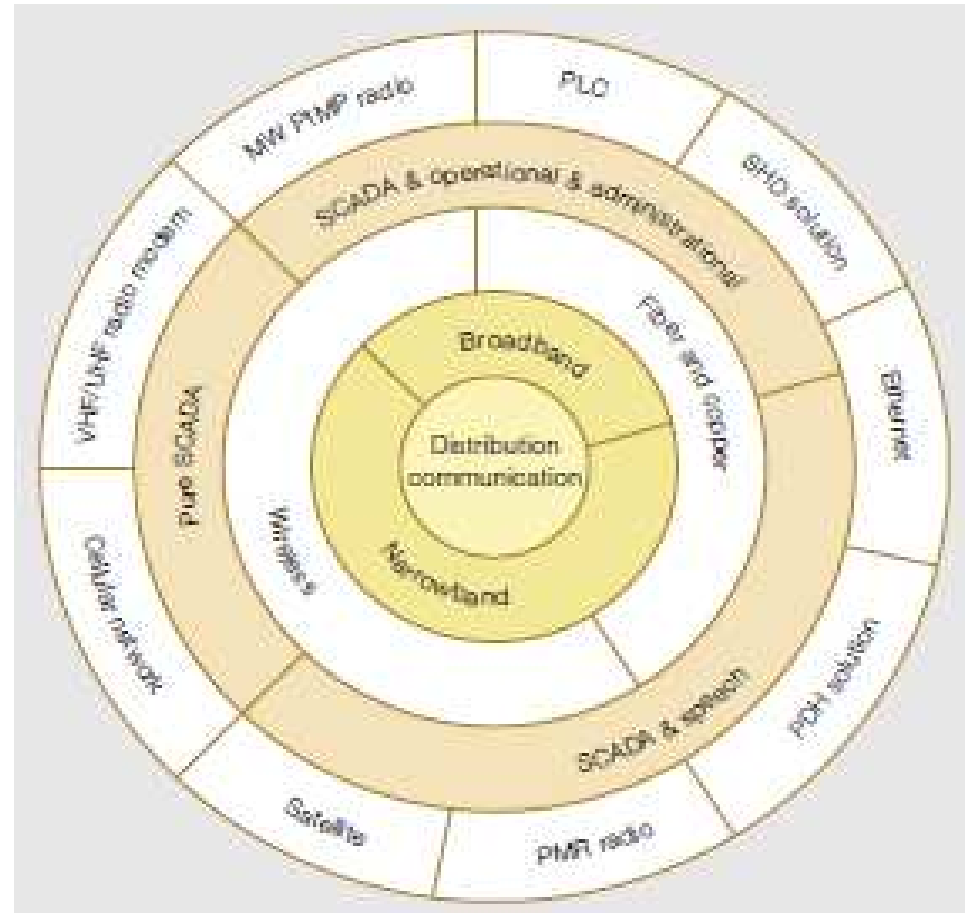


Location of PQ Monitors

- Network Monitor Sites
 - A small number of complex substation sites
 - A large number of simple distribution substation sites
 - A much larger number of customer sites
- Monitor Location Strategies
 - Network topology including future changes to meet forecast loads
 - Availability of suitable transducers
 - Monitoring technologies
 - Other required or desirable monitoring functions

Communication Systems

- Need considerable improvement to fully realize an intelligent network
- Wireless and/or non-wireless communications
- Various radio schemes
- Optic fiber would be ideal
- Dedicated network may provide infrastructure
- Comply with major protocols for substation, distribution, & feeder automations (IEC 61850, DNP3, ...)



Communication options for distributed communication for the smart grid

Source: ABB

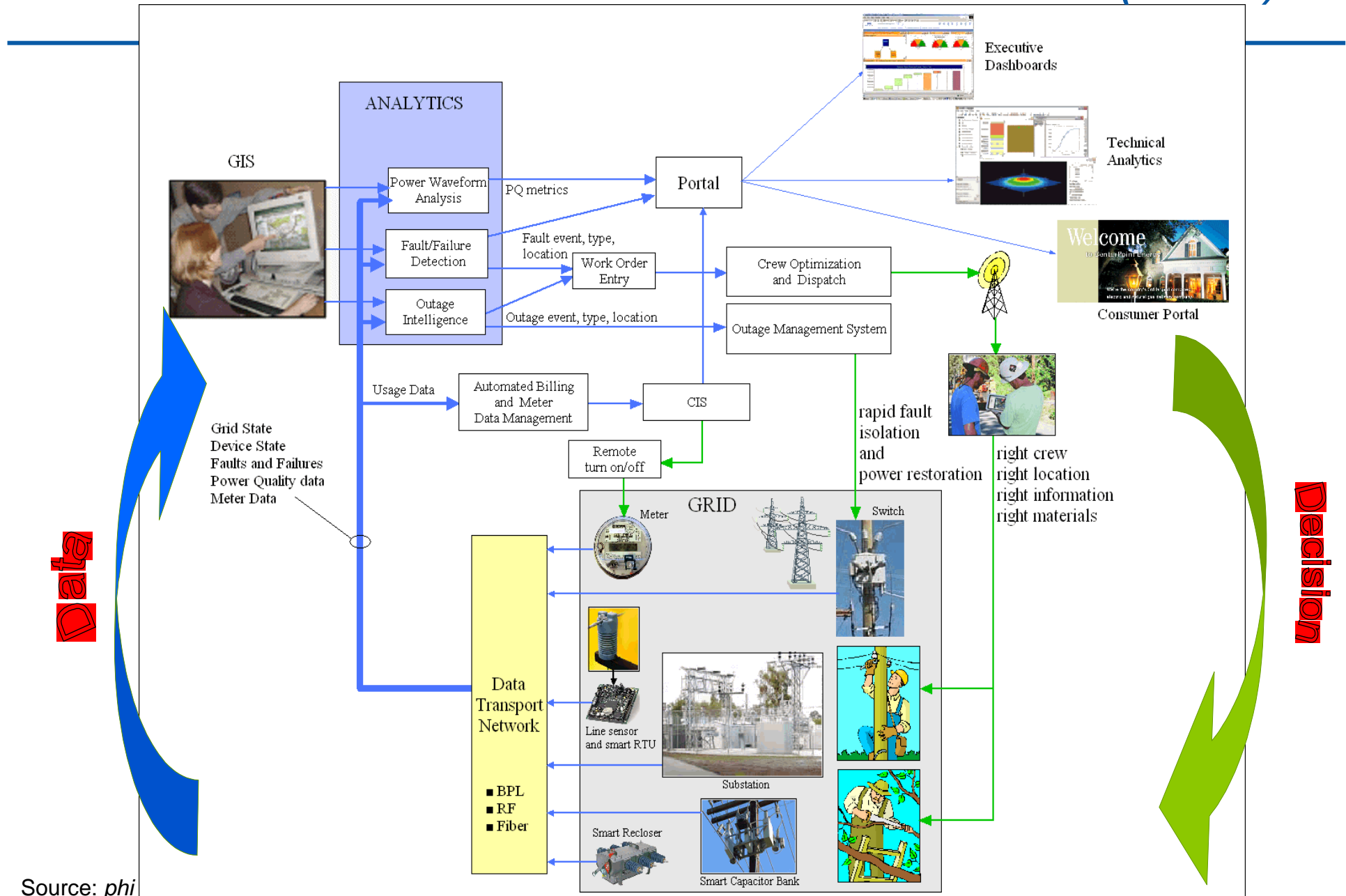
Data Management Issues

- Managing a large and growing database
- Backing up data
- Extracting data (Data Mining)
- Data quality affected by
 - Instrument transformer errors
 - Secondary wiring issues
 - Faulty PQ monitors
 - Communication failures
 - Data corruption
 - Reduce raw data to something understandable without the loss of important detail
- Use reporting indices
 - Continuous disturbance indices based on statistical methods
 - Advanced visualization and decision support

Metrics for PQ Measuring Progress

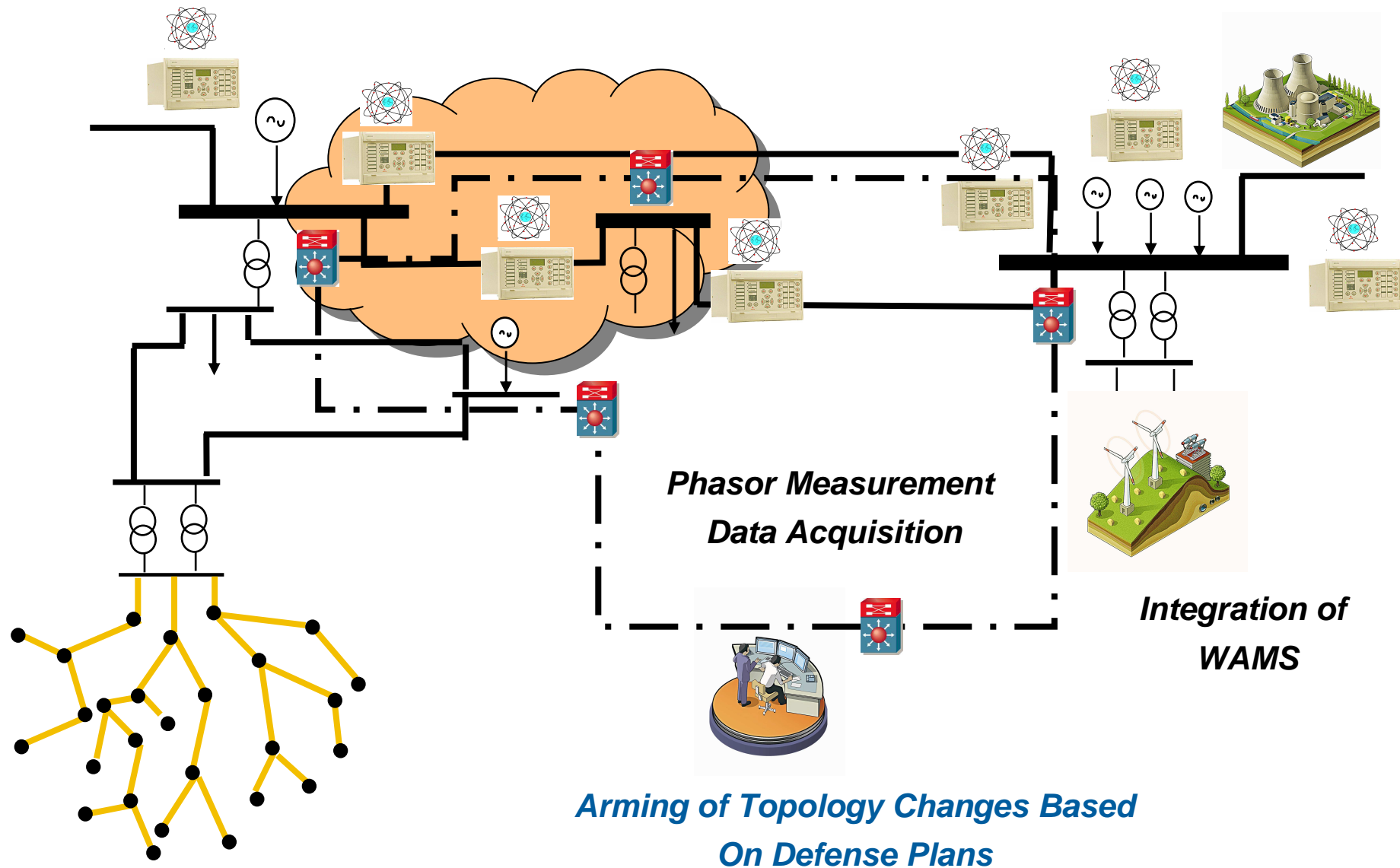
- Number of PQ measurement points divided by number of customers
- Number of PQ incidents that you can identify and even better anticipate over time
- Number of devices divided by the improvement in reliability indices
- Number of customer complaints regarding PQ issues
- Number of jurisdictions that have defined electric rate structure for PQ service levels based on societal and market needs

PQ Measurement for Power Network (cont.)



Source: phi

PQ Measurement for Power Network (cont.)

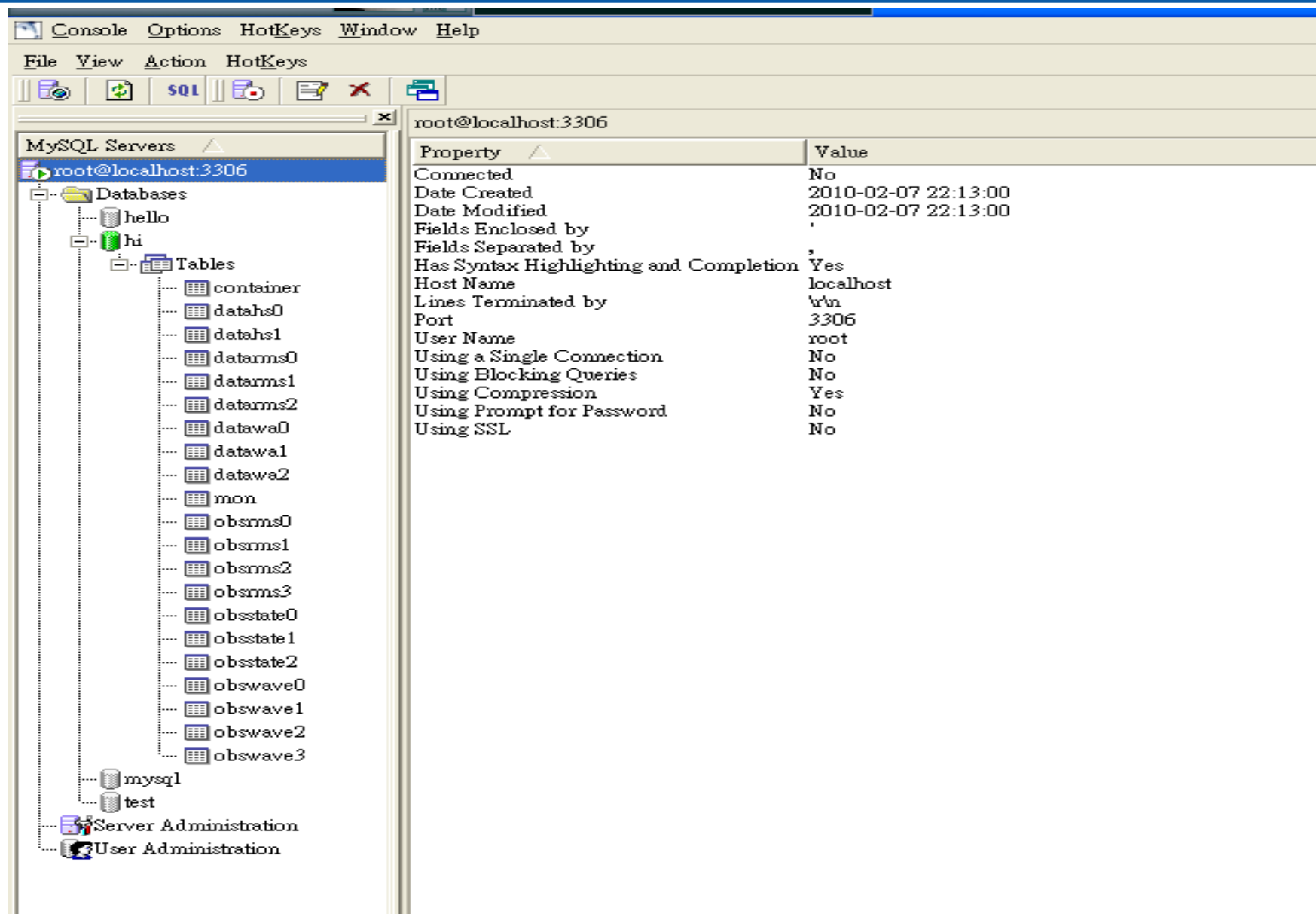


Source: Areva

Advanced PQ Meter Functions

High Accuracy	True Four-Quadrant Metering
Daily/Hourly/15 Minute Interval Meter Reads	Communication to Field Network/In-Home Devices
Voltage Sag/Swell Recording	Waveform Capture
Human-Machine Interface	Harmonic Metering
Flicker Assessment	Connect/Disconnect Switch
K-Factor Calculation	Synchronized Phasor Measurements
Secure and Encrypted Data Transmissions	Predictive Demand
Interoperability	Tamper/Theft Detection
Configurable Settings and Internal Clock	Support for Home Area Network, Distribution Automation, and Demand Response
Time-of-Use Metering	Remote Upgradeability of Firmware

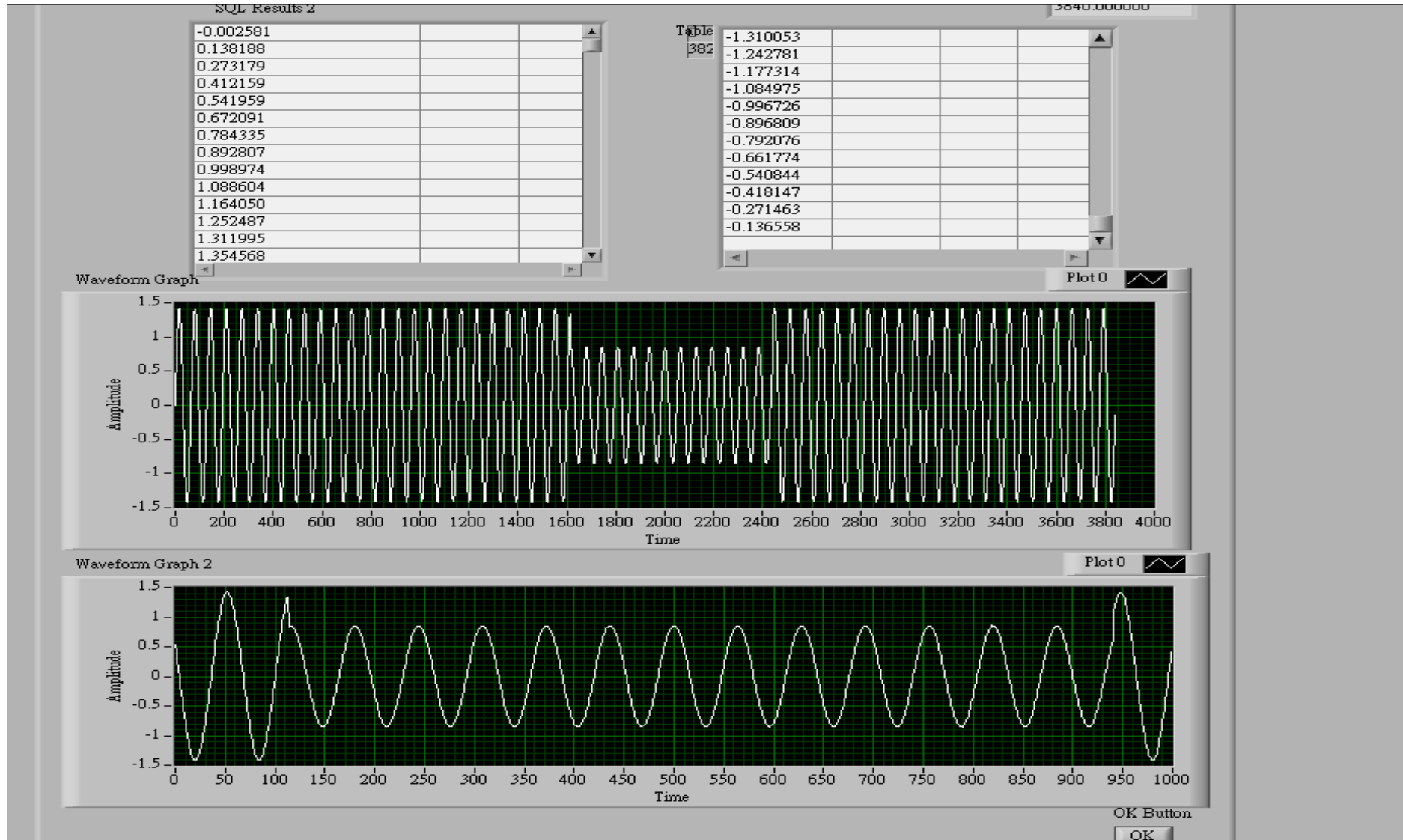
PQ Database Design & Implementation



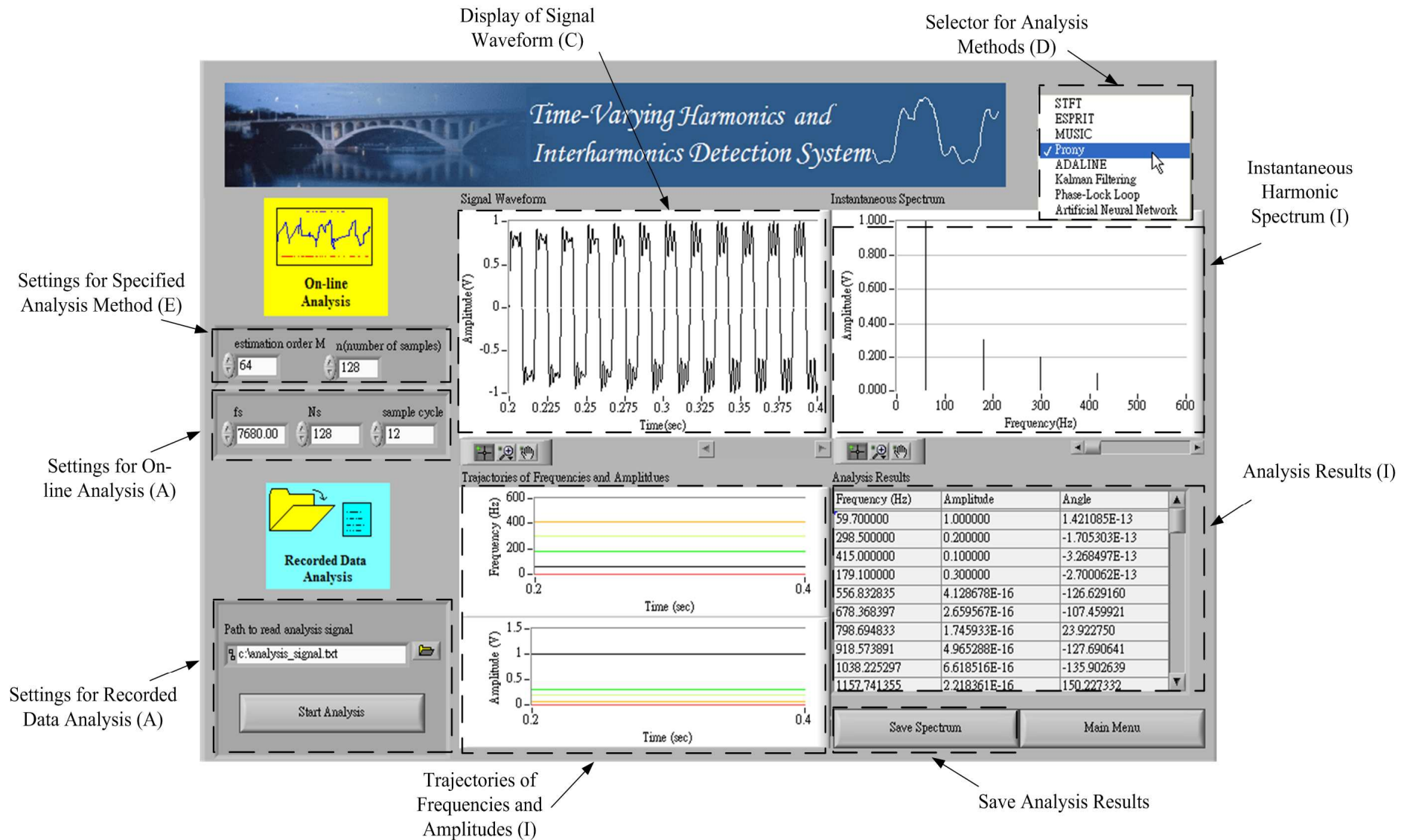
The screenshot displays the MySQL Workbench interface. The left pane shows the 'MySQL Servers' tree with a connection to 'root@localhost:3306' selected. Under this connection, the 'Databases' folder is expanded to show 'hello' and 'hi'. The 'hi' database is further expanded to show a 'Tables' folder containing a long list of tables: container, datahs0, datahs1, datarms0, datarms1, datarms2, datawa0, datawa1, datawa2, mon, obsrms0, obsrms1, obsrms2, obsrms3, obsstate0, obsstate1, obsstate2, obswave0, obswave1, obswave2, and obswave3. Other databases like 'mysql' and 'test' are also visible. The right pane shows the 'root@localhost:3306' connection properties table.

Property	Value
Connected	No
Date Created	2010-02-07 22:13:00
Date Modified	2010-02-07 22:13:00
Fields Enclosed by	'
Fields Separated by	,
Has Syntax Highlighting and Completion	Yes
Host Name	localhost
Lines Terminated by	\r\n
Port	3306
User Name	root
Using a Single Connection	No
Using Blocking Queries	No
Using Compression	Yes
Using Prompt for Password	No
Using SSL	No

Waveform Capture and Data Storage



Visualization and Decision Support

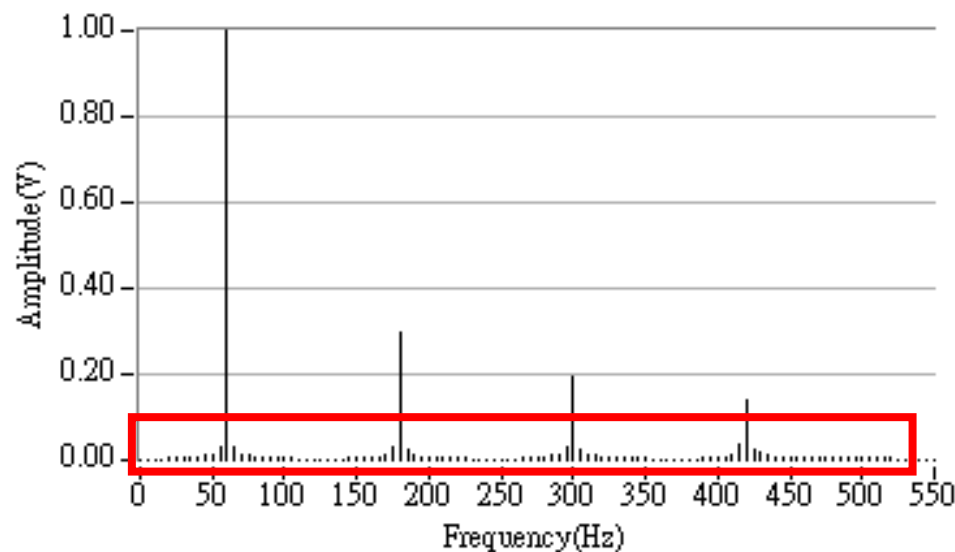


GUI of the integrated virtual instrument for on-line and recorded data PQ analyses

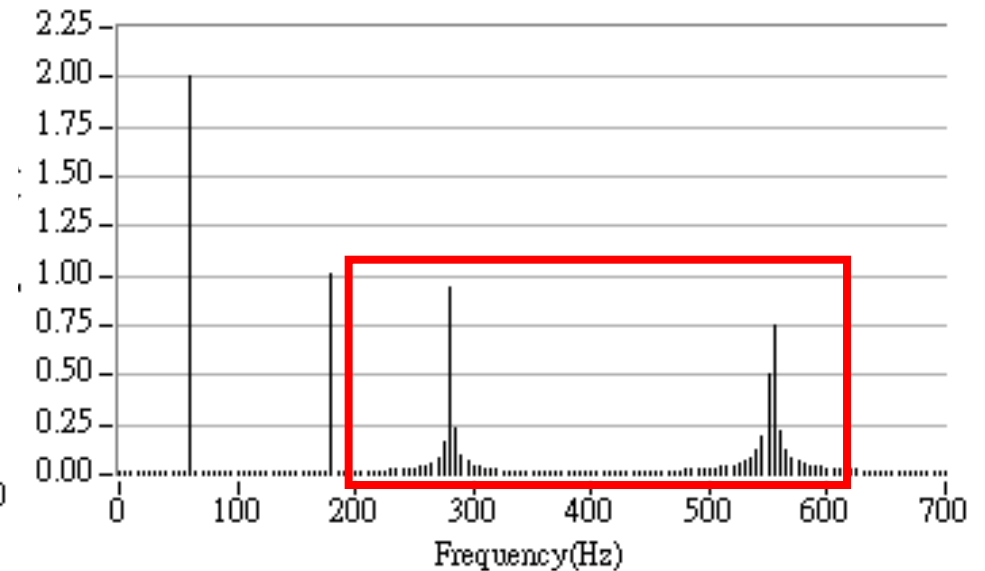
Measurement of Harmonics/Interharmonics

$$v(t) = \sin(59.85 \times 2\pi t) + 0.3 \sin(179.55 \times 2\pi t) \\ + 0.2 \sin(299.25 \times 2\pi t) + 0.15 \sin(418.95 \times 2\pi t)$$

$$v(t) = 2 \sin(60 \times 2\pi t) + \sin(180 \times 2\pi t) \\ + \sin(281 \times 2\pi t) + \sin(553 \times 2\pi t)$$

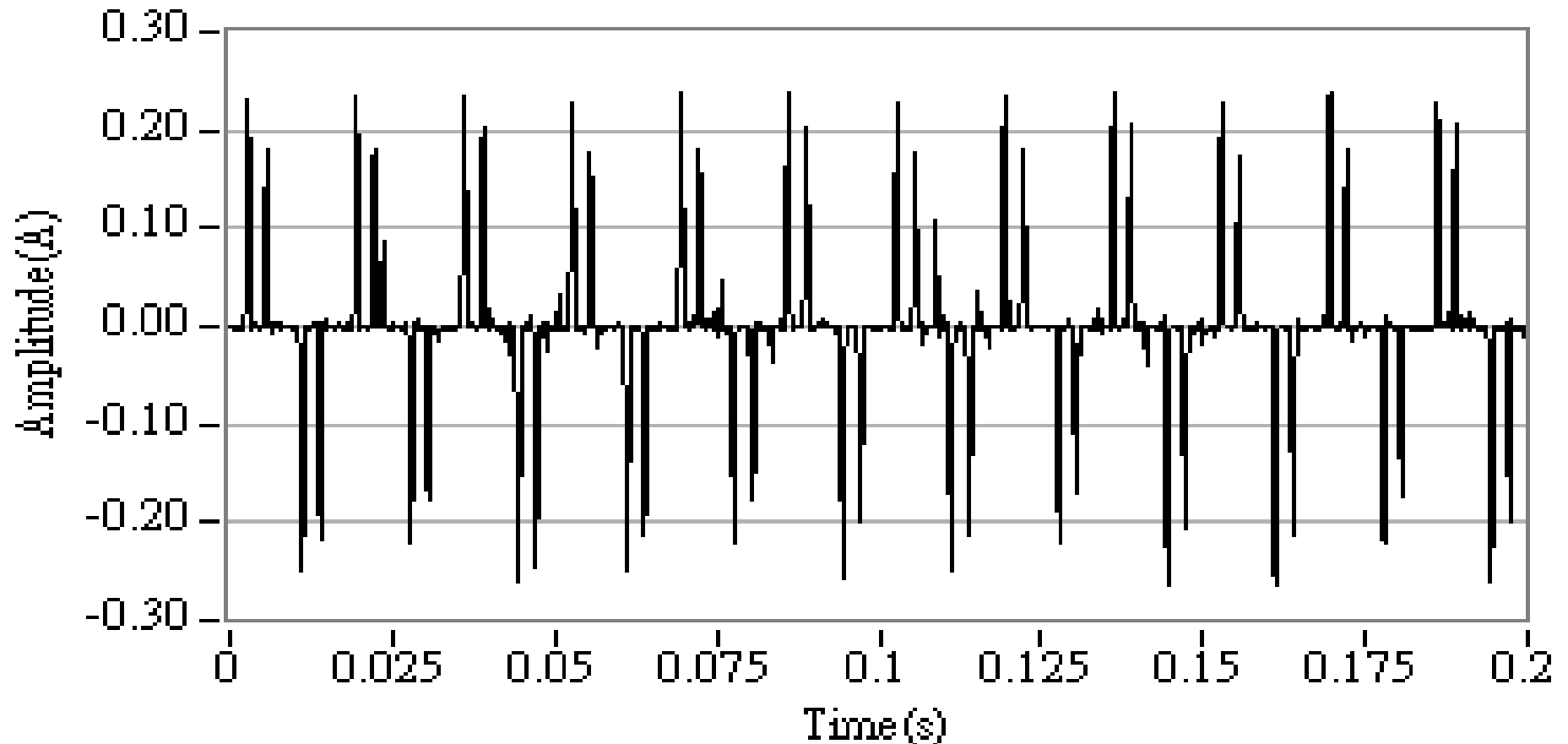


Spectral Leakage



Picket-Fence Effect

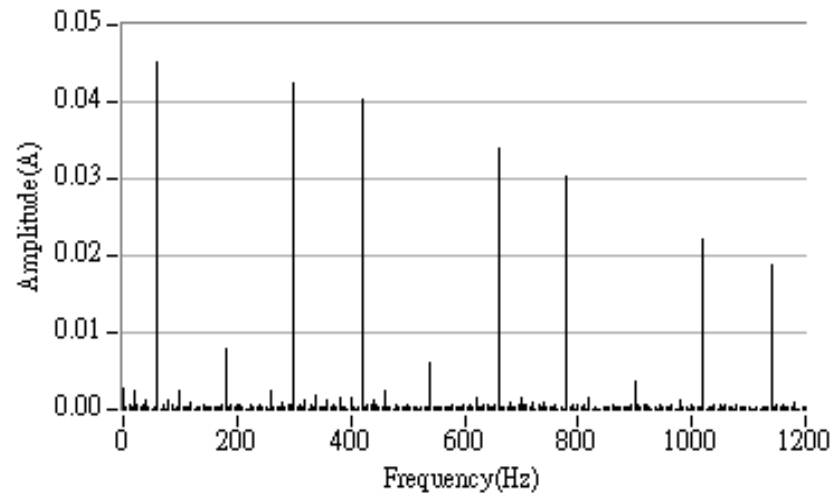
Case Studies (Case 1)



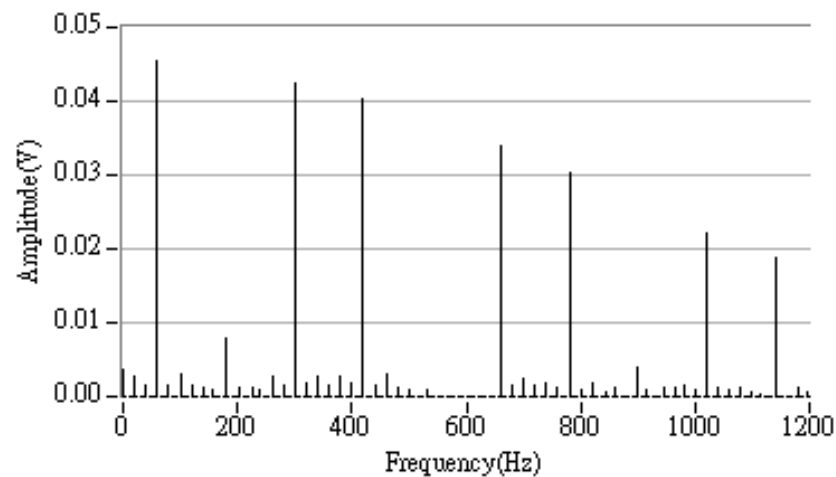
Measured Adjustable Speed Motor Drive input current waveforms

Case Studies (cont.)

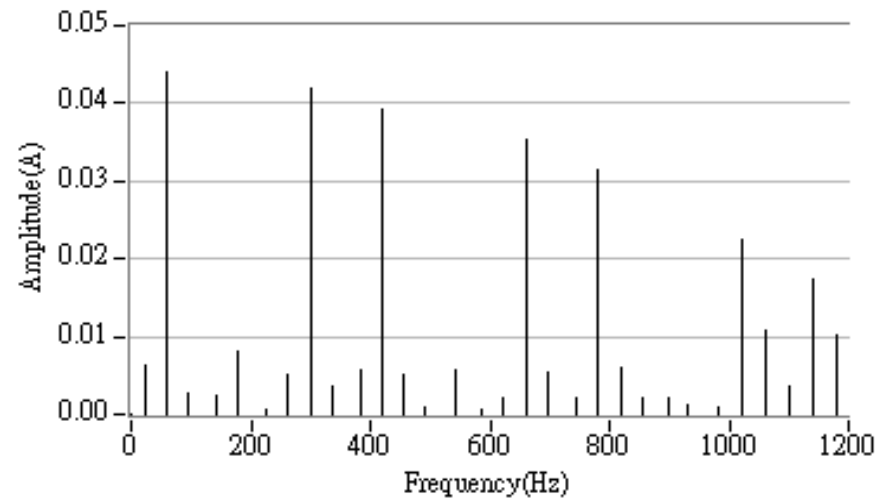
FFT without corrections



IEC grouping method

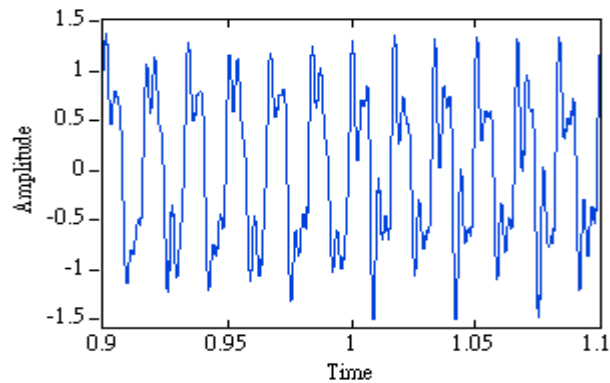


New method

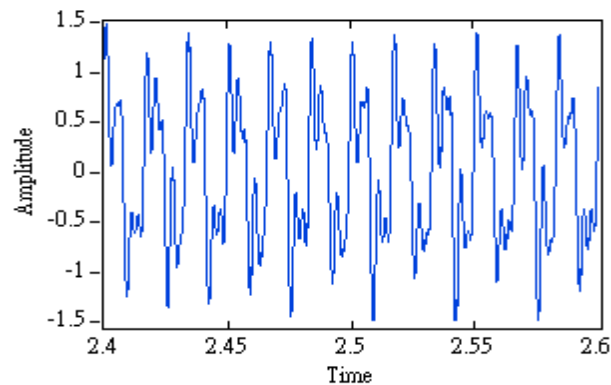


Case Studies (Case 2)

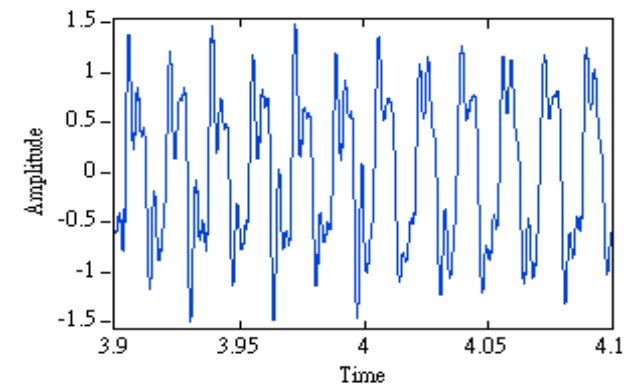
New Method for Time-Varying Harmonics Tracking



$t = 1 \text{ sec}$

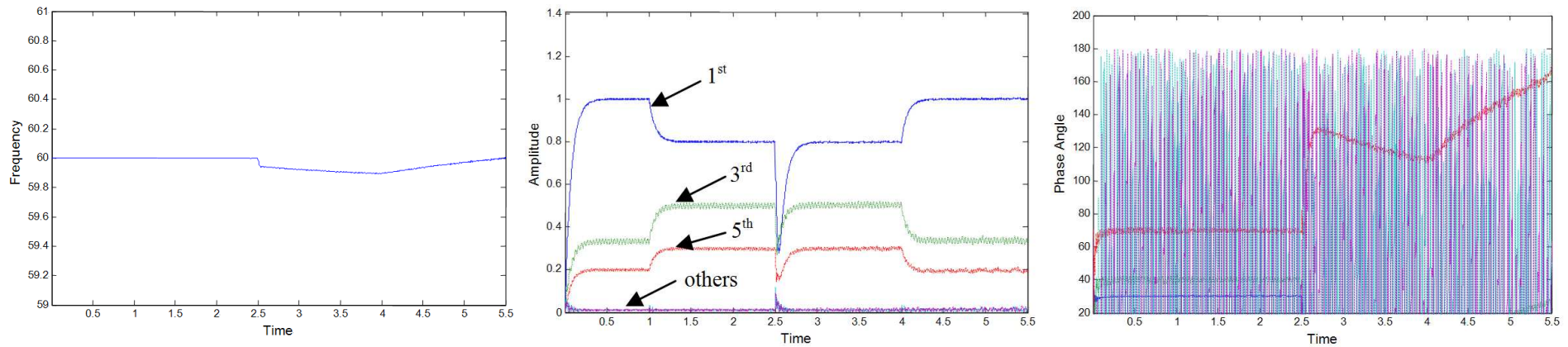


$t = 2.5 \text{ sec}$

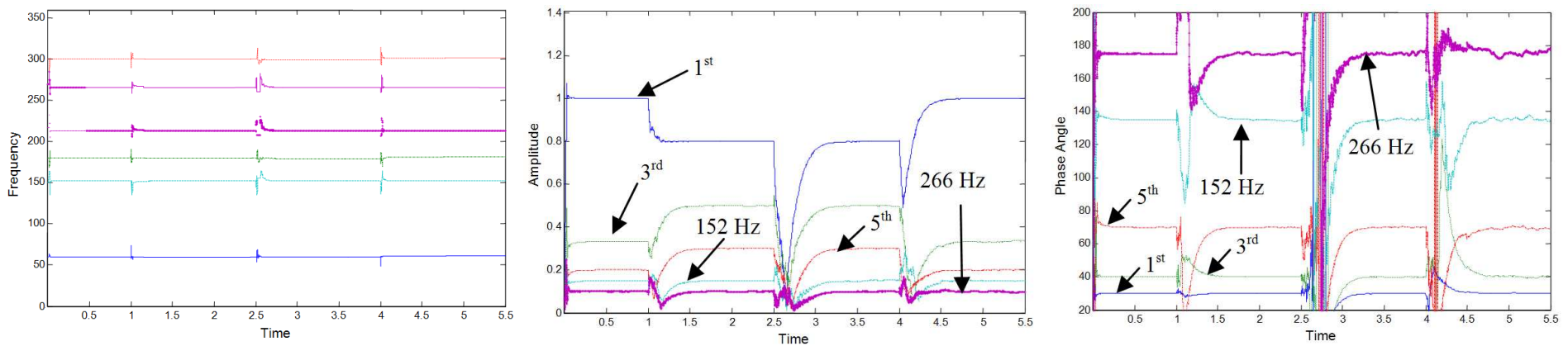


$t = 4 \text{ sec}$

Case Studies (cont.)



Traditional method



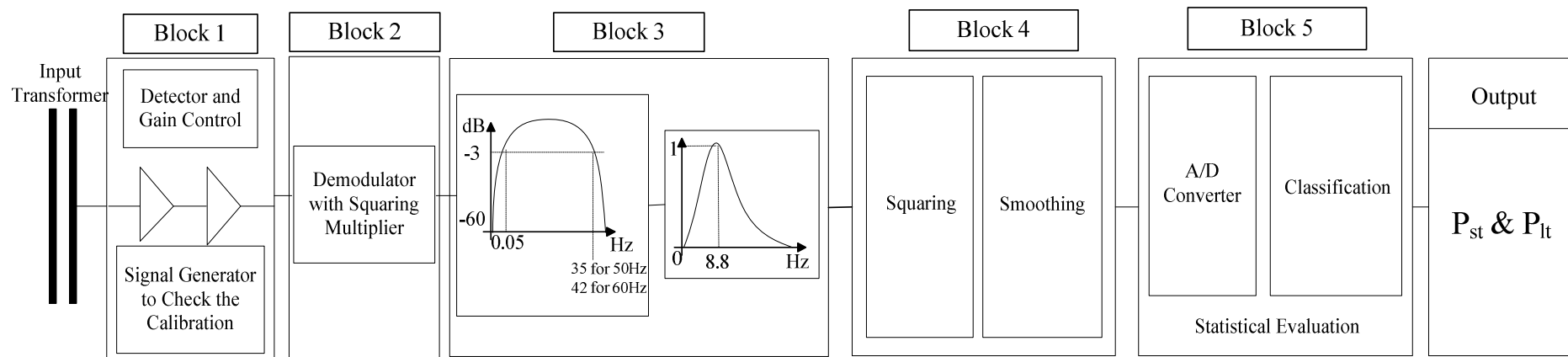
New method

Measurement of Flicker

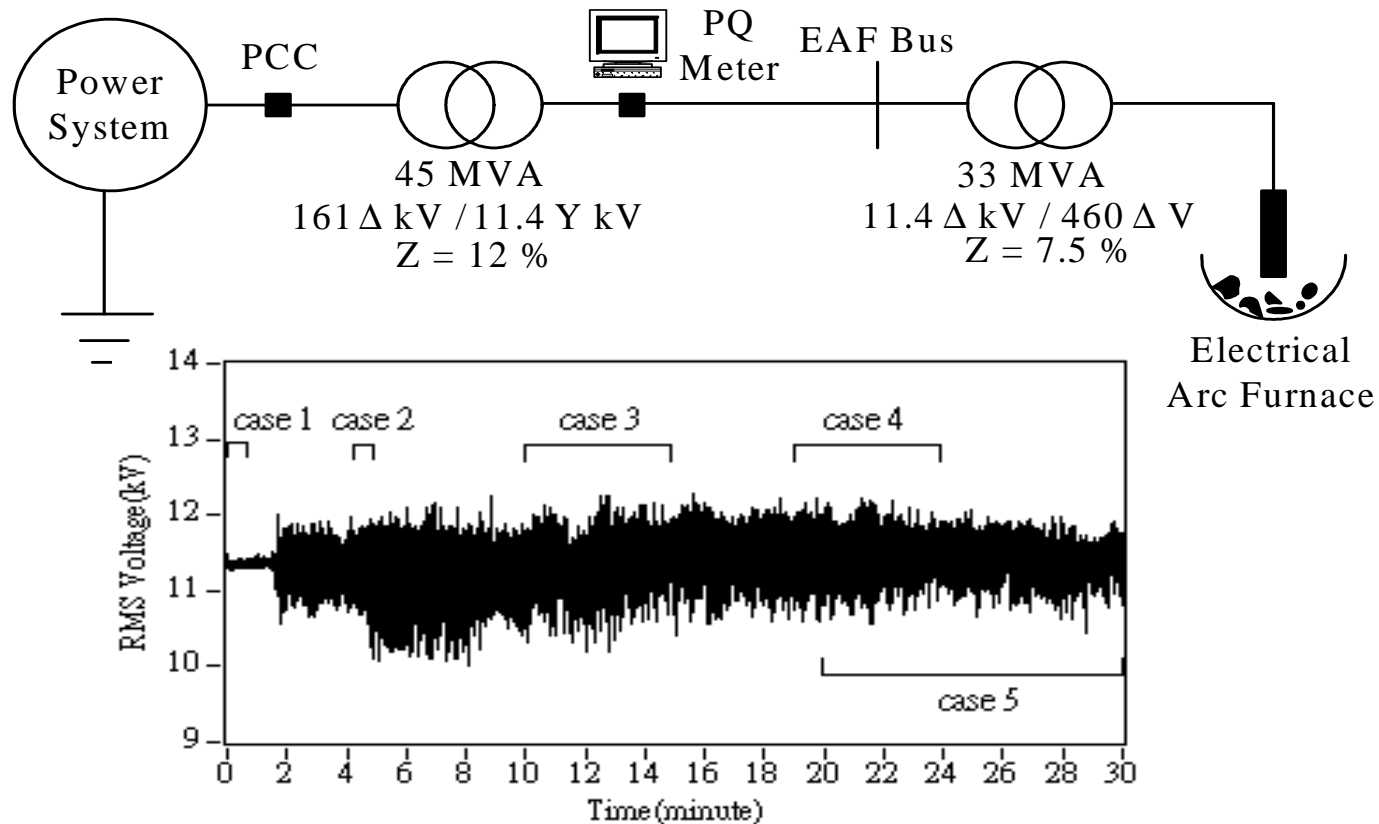
- IEC Flickermeter
- Squaring Demodulation Method
- Discrete Wavelet Synchronous Detection Method
- ADALINE Detection Method
- EPLL Detection Method
- New Approach for Implementation of IEC Flickermeter

Measurement of Flicker (cont.)

- International Electrotechnical Commission (IEC) Standard 61000-4-15 provides both functional and design specifications for flicker measurement and the flickermeter architecture is described by the block diagram as follows.

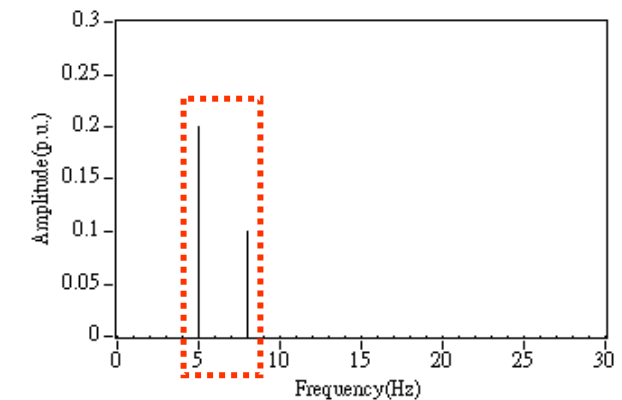
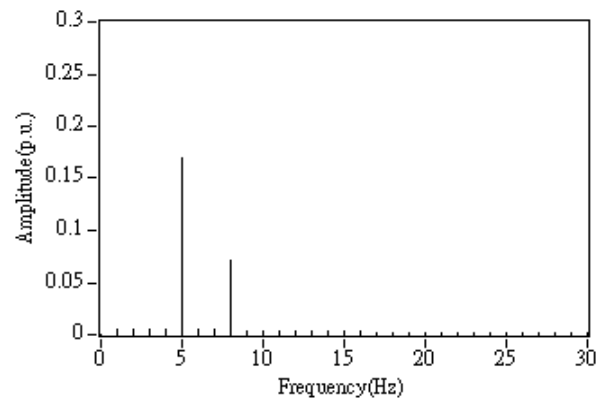
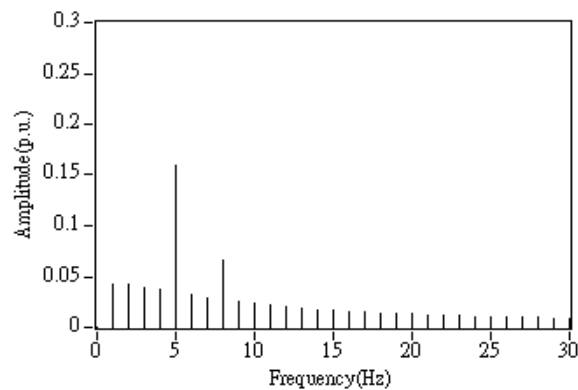
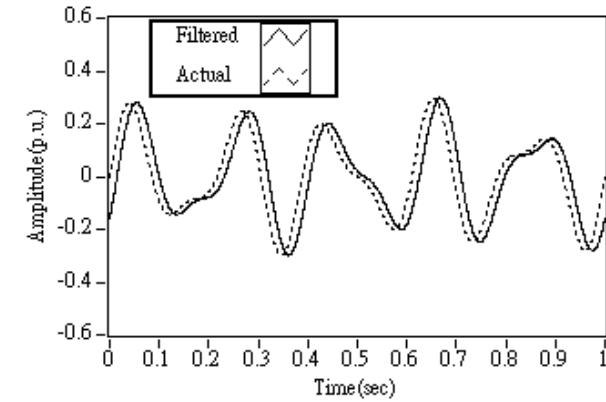
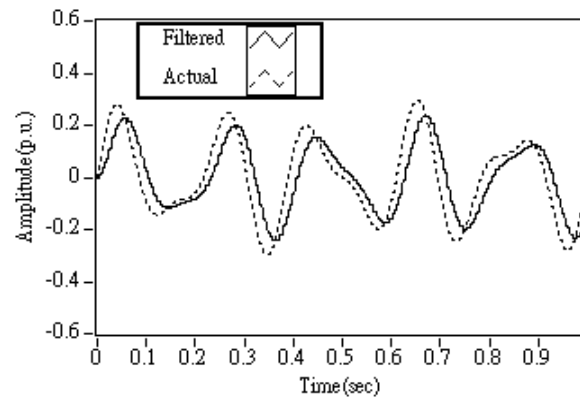
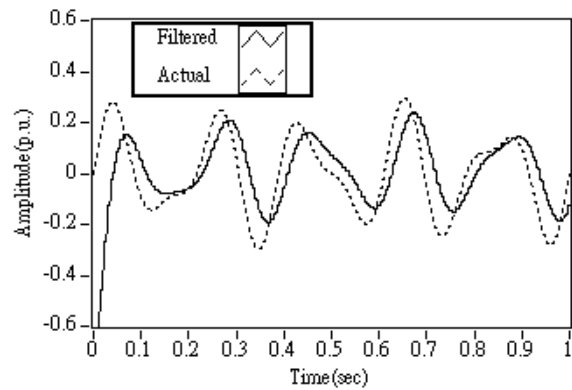


Case Studies (Case 3)



Pst	Case 1	Case 2	Case 3	Case 4	Case 5
IEC 61000-4-15	1.1325	6.5320	8.8694	9.2112	6.3733
Proposed Method	1.1102	6.3912	8.9557	9.1165	6.4136
Relative Error (%)	1.9691	2.1555	0.9730	1.0281	0.6323

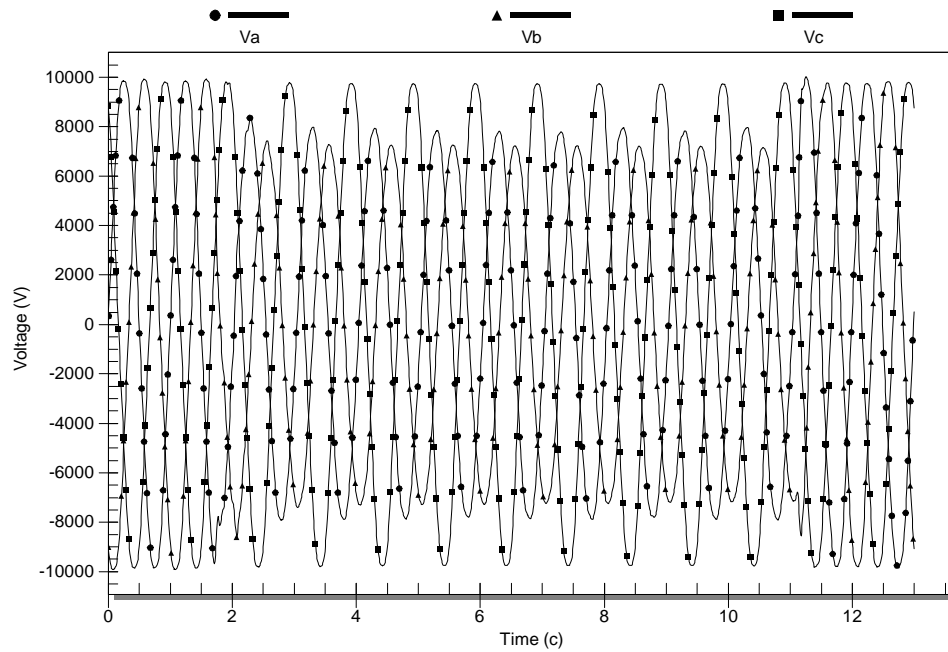
Case Studies (cont.)



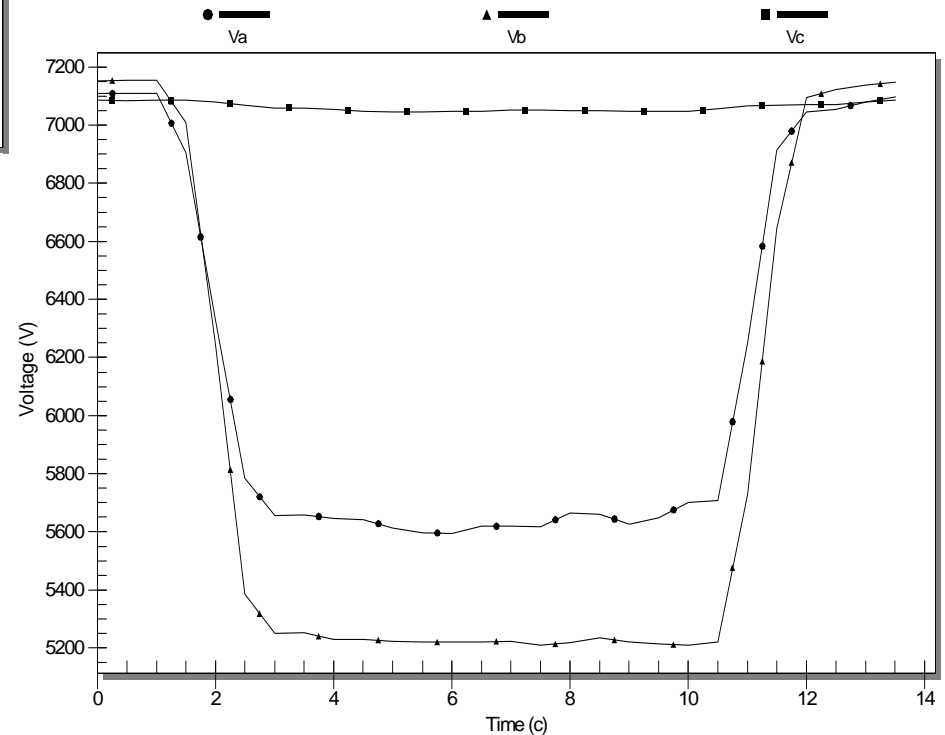
Other methods

New method

Analysis of Sags/Swells/Interruptions



Three-Phase Voltage Sag Waveform



Three-Phase Voltage RMS Voltage Sag

Analysis of Sags/Swells/ Interruptions (*cont.*)

IEEE Std. 1159 - 1995

Categories		Typical duration	Typical voltage magnitude
Short duration variations	Instantaneous Sag	0.5 - 30 cycles	0.1 - 0.9 pu
	Instantaneous Swell	0.5 - 30 cycles	1.1 - 1.8 pu
	Momentary Interruption	0.5 cycles - 3 sec	< 0.1 pu
	Momentary Sag	30 cycles - 3 sec	0.1 - 0.9 pu
	Momentary Swell	30 cycles - 3 sec	1.1 - 1.4 pu
	Temporary Interruption	3 sec - 1 min	< 0.1 pu
	Temporary Sag	3 sec - 1 min	0.1 - 0.9 pu
	Temporary Swell	3 sec - 1 min	1.1 - 1.2 pu
Long duration variations	Interruption, sustained	> 1 min	0.0 pu
	Undervoltages	> 1 min	0.8 - 0.9 pu
	Overvoltages	> 1 min	1.1 - 1.2 pu

Analysis of Sags/Swells/Interruptions *(cont.)*

Several parameters of power quality events are necessary to be identified:

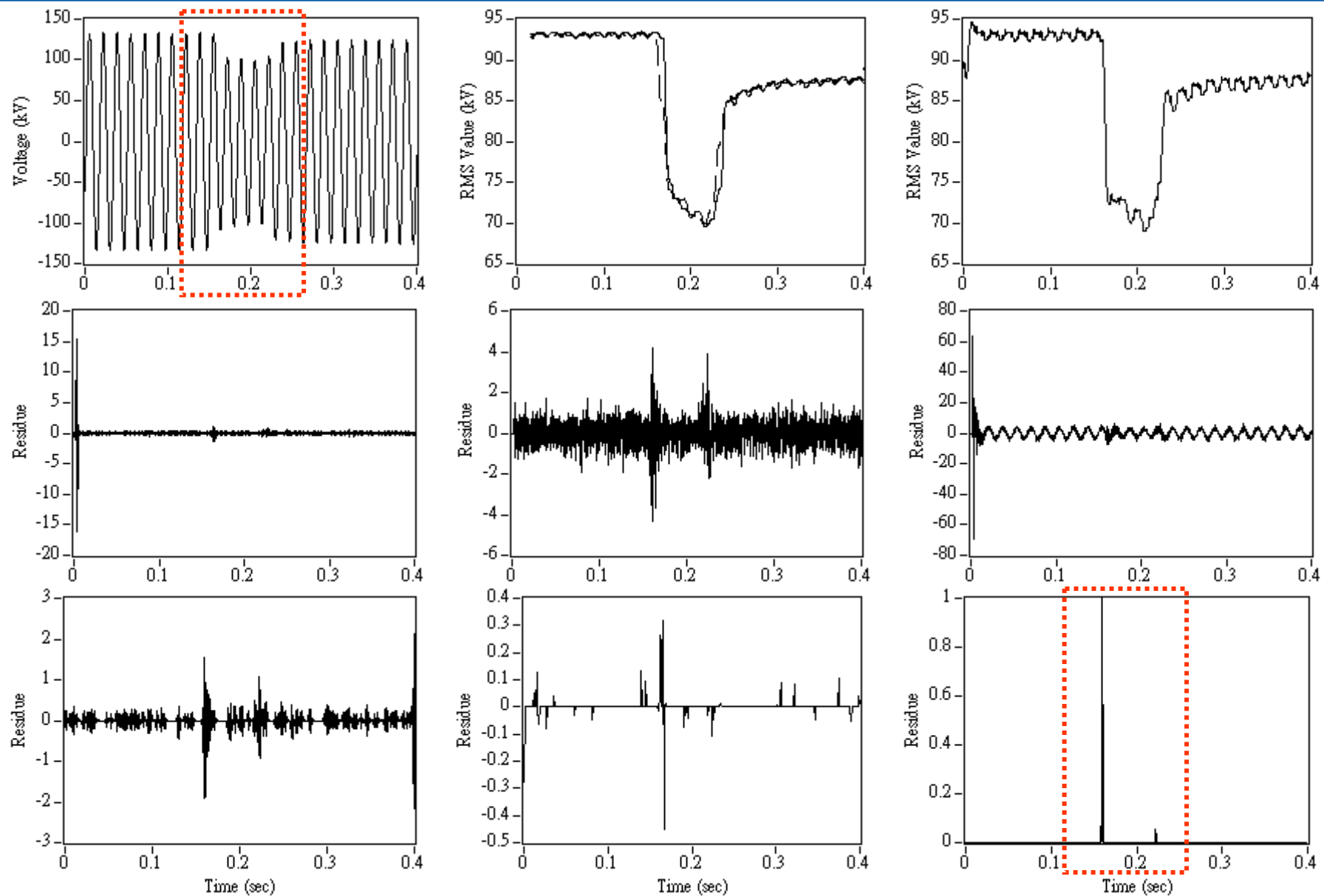
- Starting-time localization of events
- Ending-time localization of events
- Duration of events
- Classification of events
- Variation of events

Analysis of Sags/Swells/Interruptions *(cont.)*

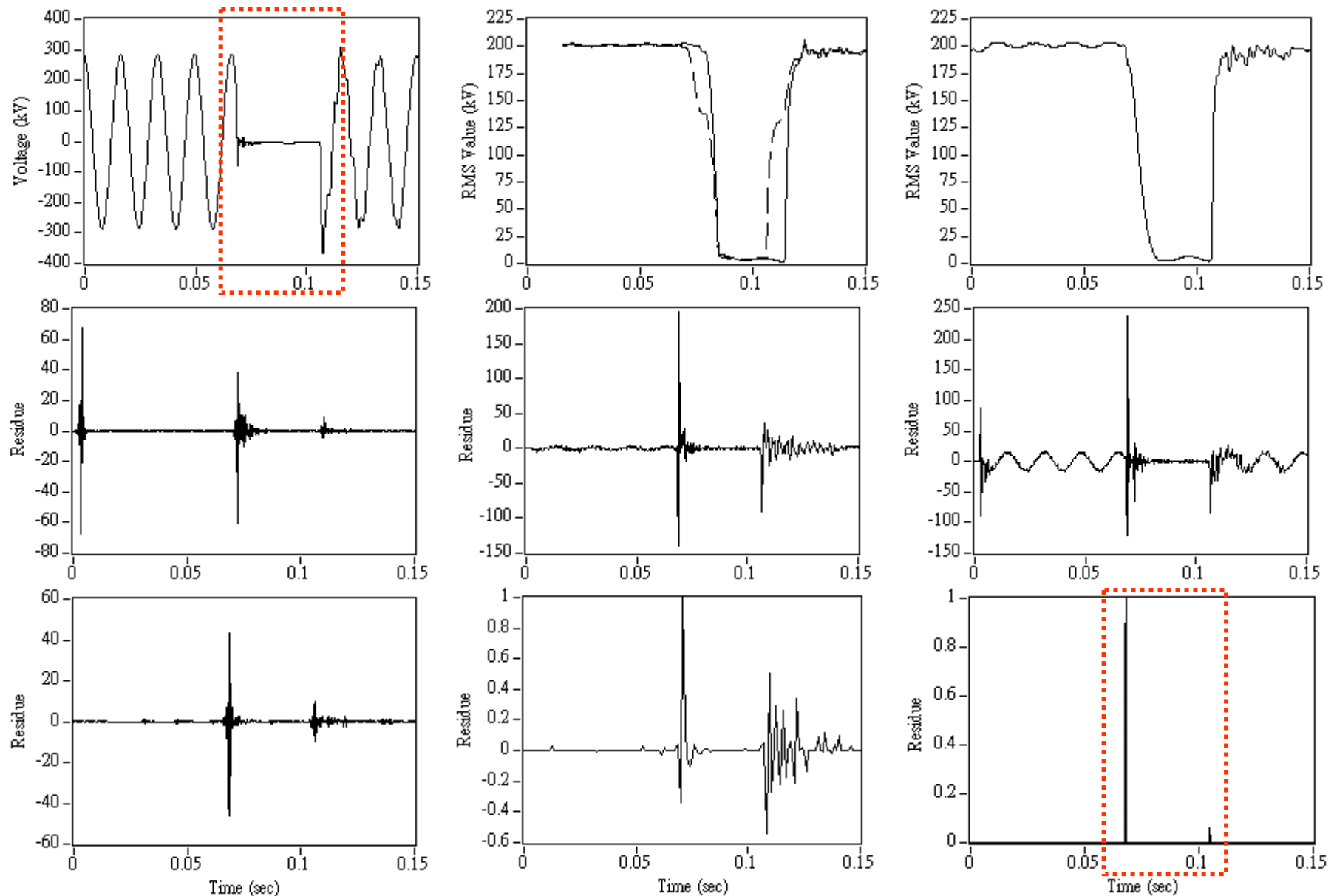
Commonly seen approaches:

- Direct Estimation of RMS Value
- ADALINE Detection Method
- High-pass Filtering
- Autoregressive (AR), Moving-Average (MA), and ARMA Models
- Wavelet Analysis
 - Squaring Method
 - Shrinkage Method
 - Inter-scale Dependency
- New Approach

Case Studies (Case 4)

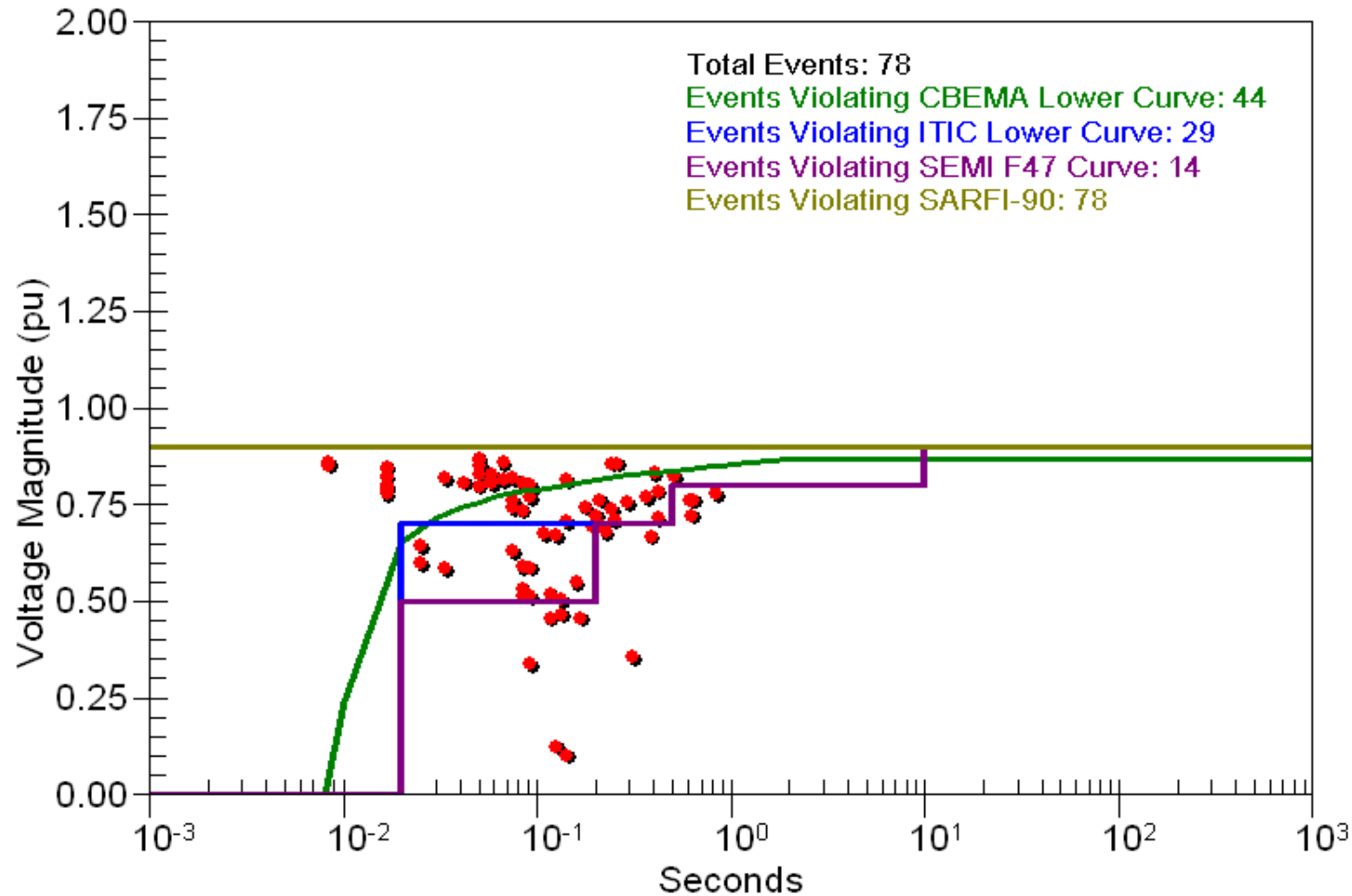


Case Studies (Case 5)



Case Studies (cont.)

RMS Variation Magnitude-Duration Scatter Plot



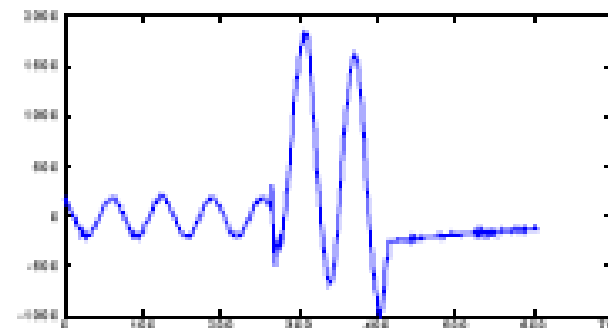
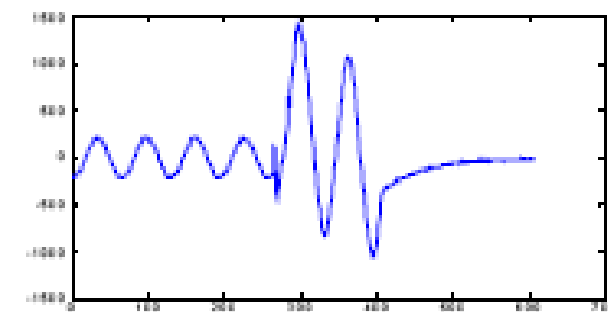
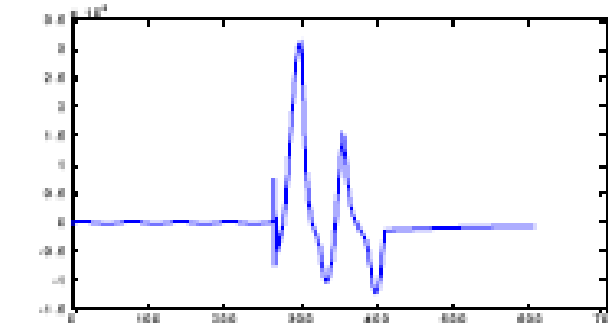
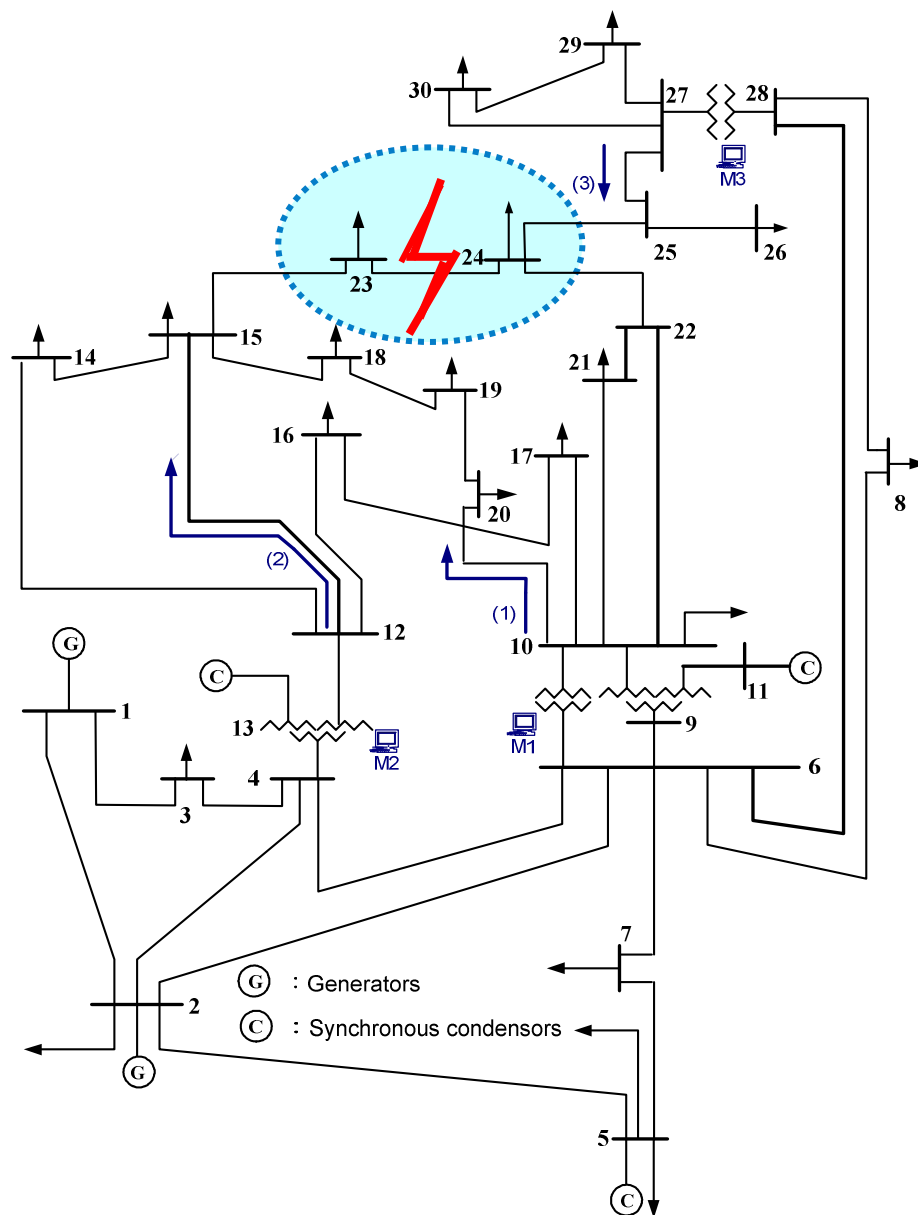
Scatter plot with recorded voltage sags indicated

More PQ Measurement Issues

More Smart Grid PQ Measurement Issues

- (1) Smart Meter with Advanced PQ Analysis Functions**
- (2) Wide Area Monitoring Scheme with PQ Disturbance Identification and Remedy**
- (3) Integration of Measured PQ Data and Database Design**
- (4) Tracking PQ Disturbances and Real-time PQ Analysis**
- (5) Deployment of Advanced PQ Meters in Power Network**
- (6) Embedding Advanced PQ Monitoring Functions in Substation/Feeder Automations**
- (7) Commutation Protocols for PQ Monitoring**
- (8) PQ-related Standards Development**
- (9) Measurement and Analysis of PHEV-related PQ Impacts on Distribution System**

Smart PQ Disturbance Source Location Tracking/Identification



Conclusions

- Future measurement devices under Smart Grid shall include functions for
 - Power Quality
 - Energy metering
 - Asset condition monitoring
 - Operational status monitoring
- Improved communications between different measuring devices are essential
- Data management of PQ assessment will be a challenge
- Better understanding of PQ emissions and network asset conditions
- Optimization of asset usage by customers
- Need effective metrics for assessment of PQ measuring progress



Thank

You!
wchang@ee.ccu.edu.tw (張文恭)

<http://140.123.111.49/teacher/main33.htm>