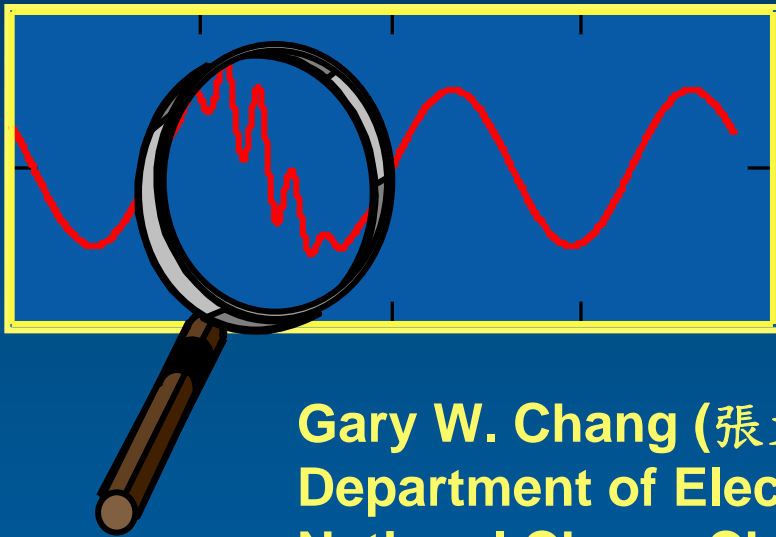


# Monitoring Power Quality of Transmission System – Smart Grid Aspect

## 輸電系統電力品質監控



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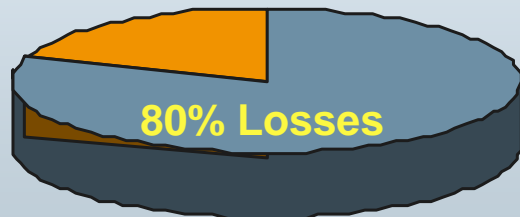
# Outline

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- 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

Energy Efficiency



CO2 Emissions



Power Quality

Renewables



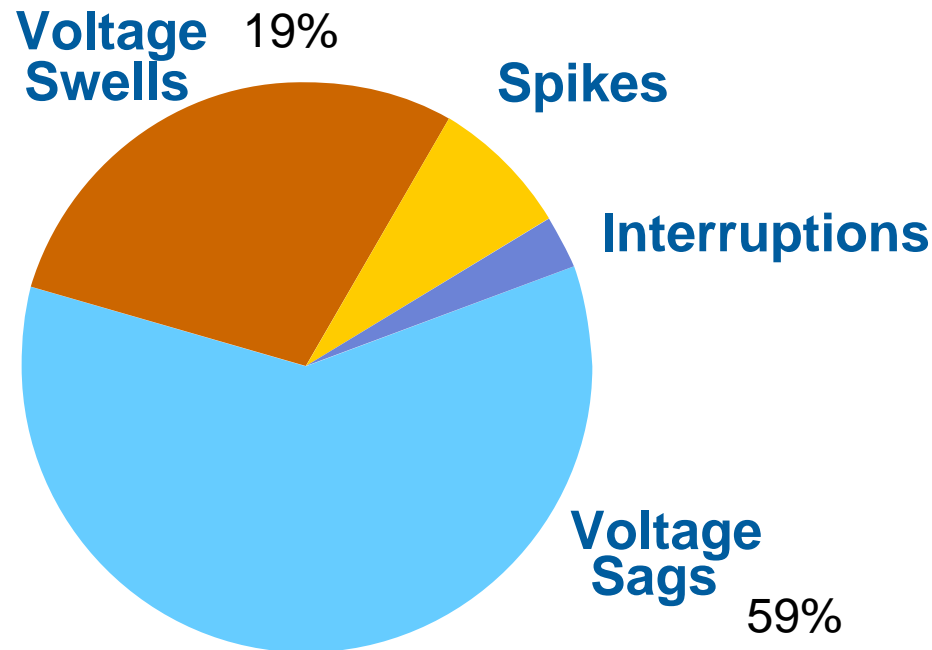
Distributed Empowerment



# 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
- 
- 
-

# 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:

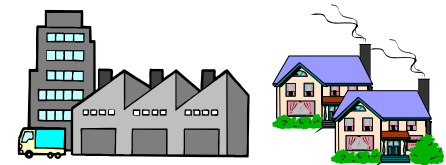
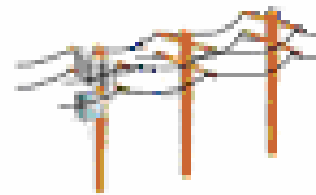
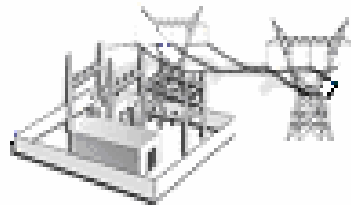
- 1) Engage **CONSUMERS** with the ability to wisely use electricity, electric devices and new services
- 2) Ensure **EFFICIENCY** of using the electric grid (optimizing current assets while integrating emerging technologies such as renewables and storage devices); and
- 3) Enhance **RELIABILITY** (protecting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

Generation

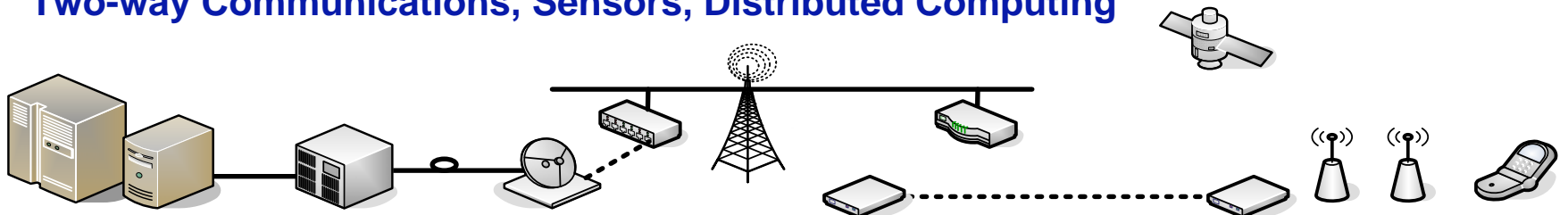
Transmission

Distribution

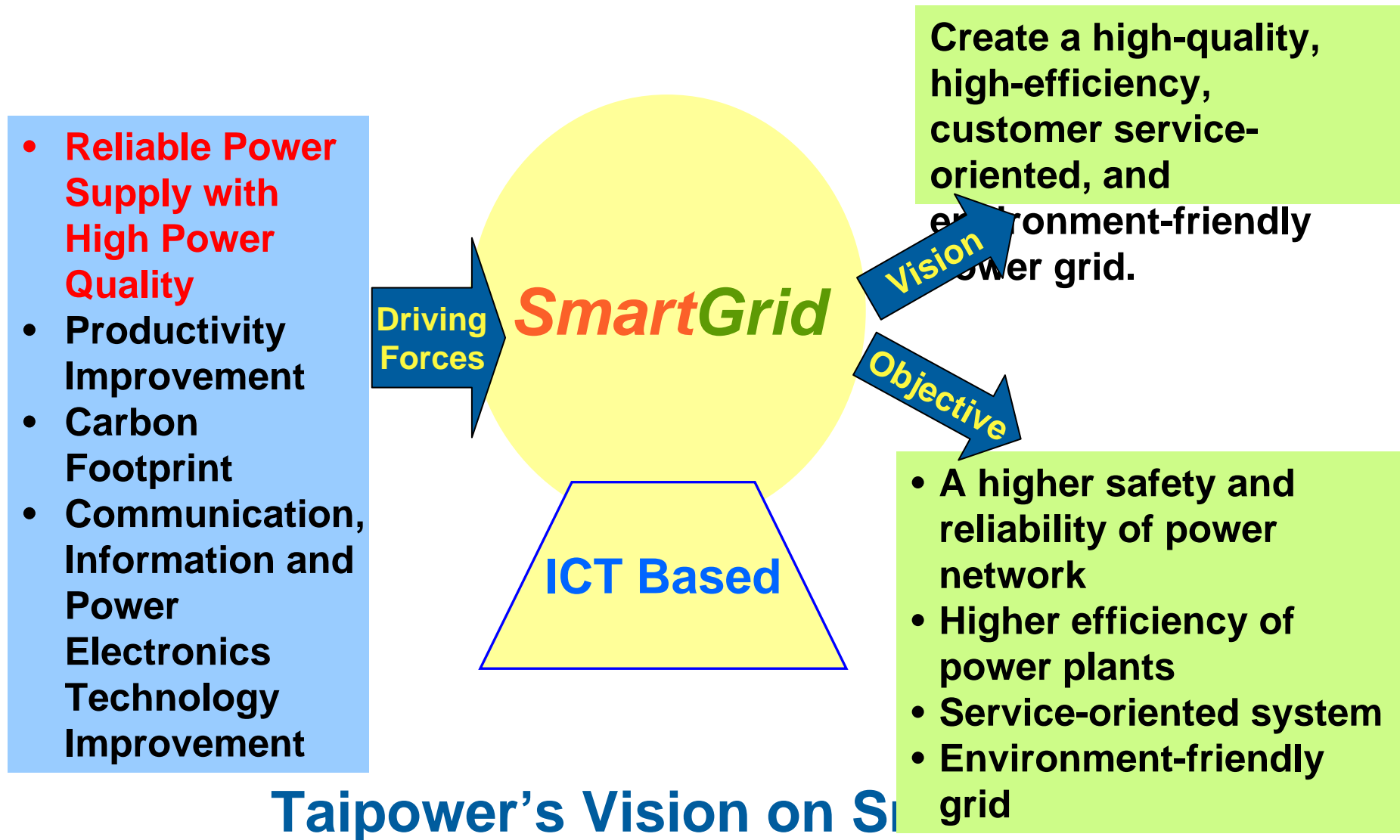
Consumer



Two-way Communications, Sensors, Distributed Computing



# Power Quality and Smart Grid (cont.)



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

<i>Today</i>	<i>Tomorrow</i>
<b>Focus on outages not PQ</b> <b>Protect assets following disruption</b>	<b>Premium power options</b> <b>Prevent disruptions, minimize impacts,</b> <b>fast restoration (FDIR)</b>

# 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
- 
- 
- *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

# Areas of PQ Measurement Applications

## For Transmission System:

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

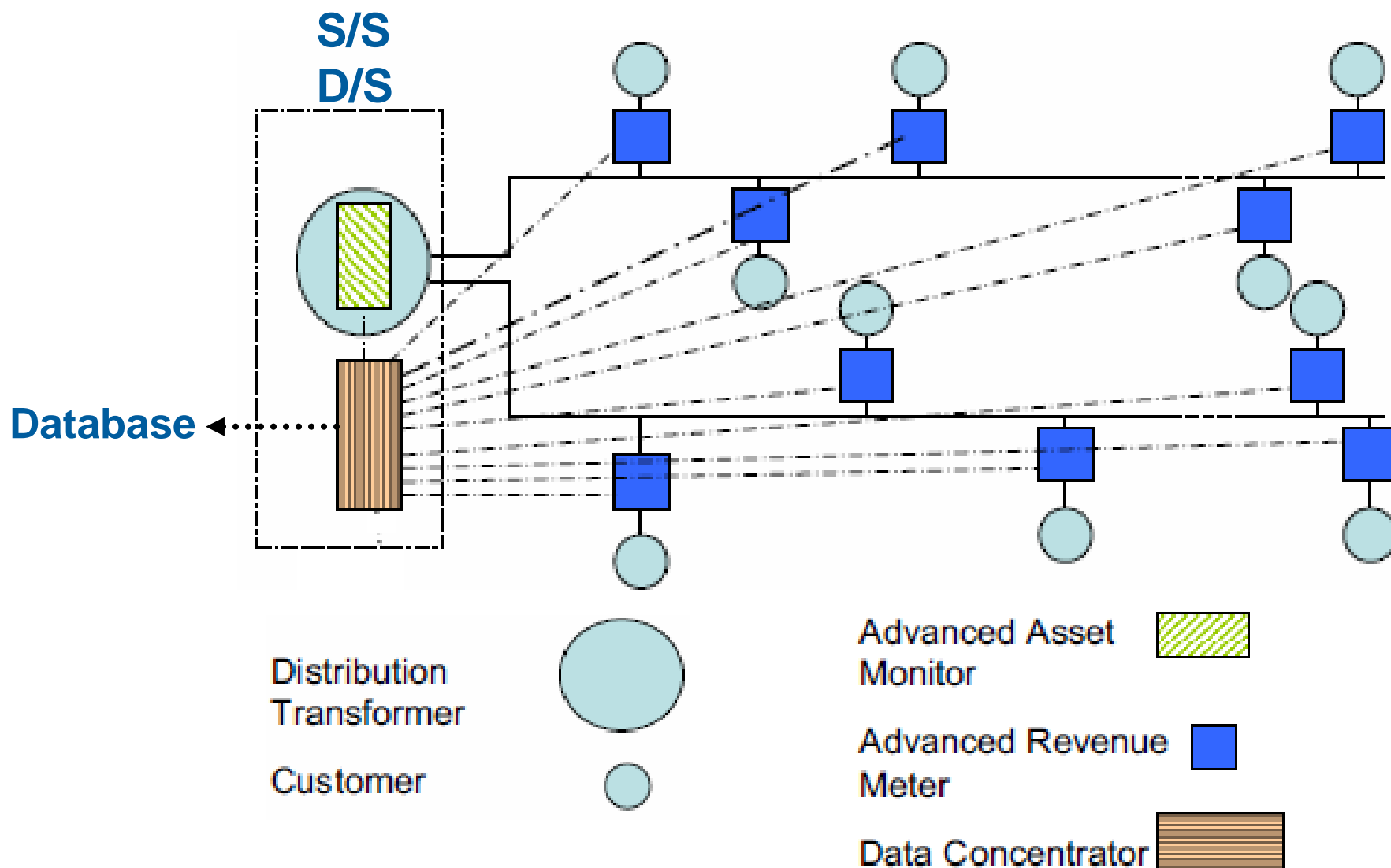
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## For Distribution System:

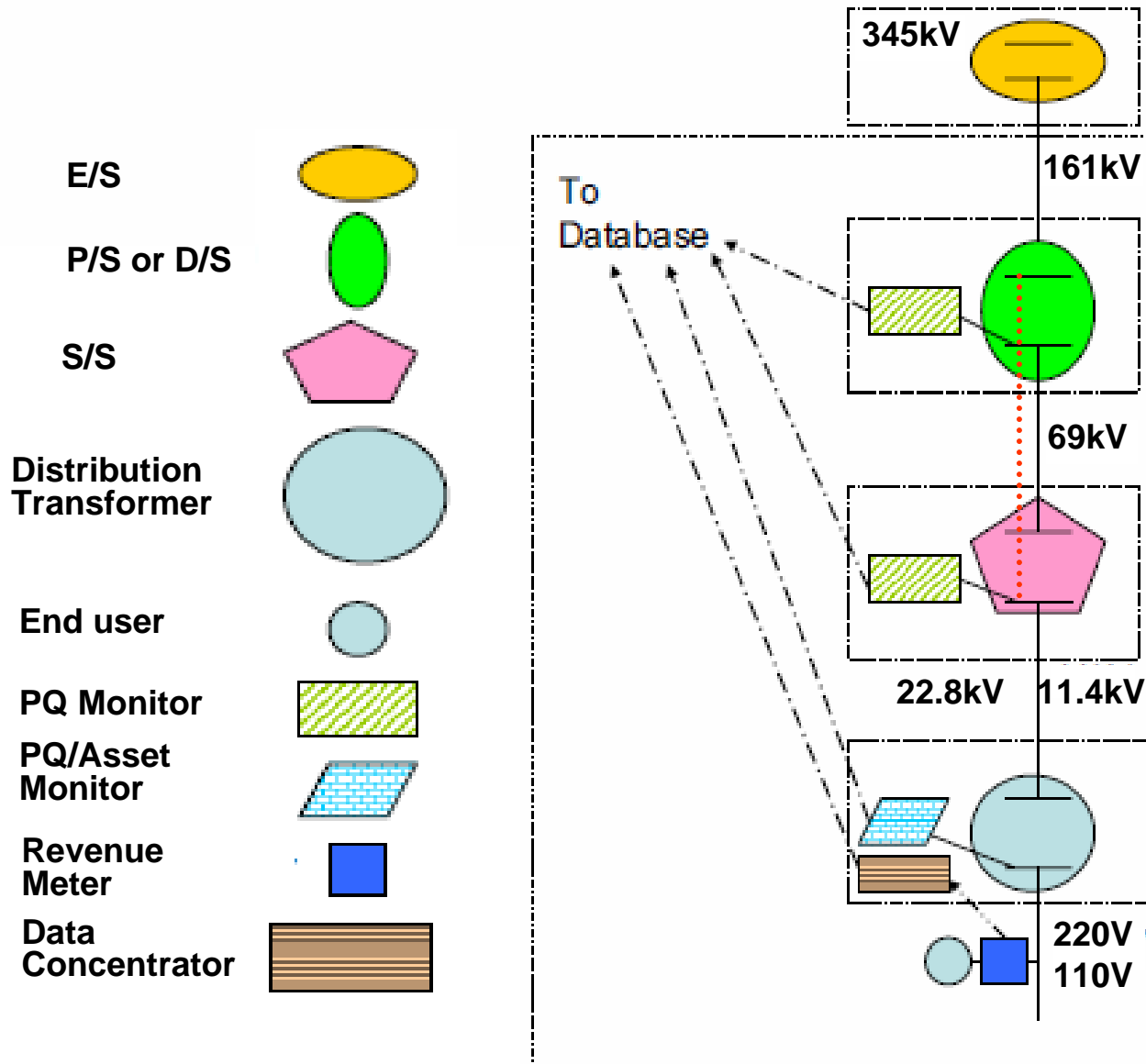
- Feeder Automation
- Remote Monitoring of Fault Indicator
- Equipment Condition Monitoring
- Substations Automation
- Micro-Grid Management
- Large Customers

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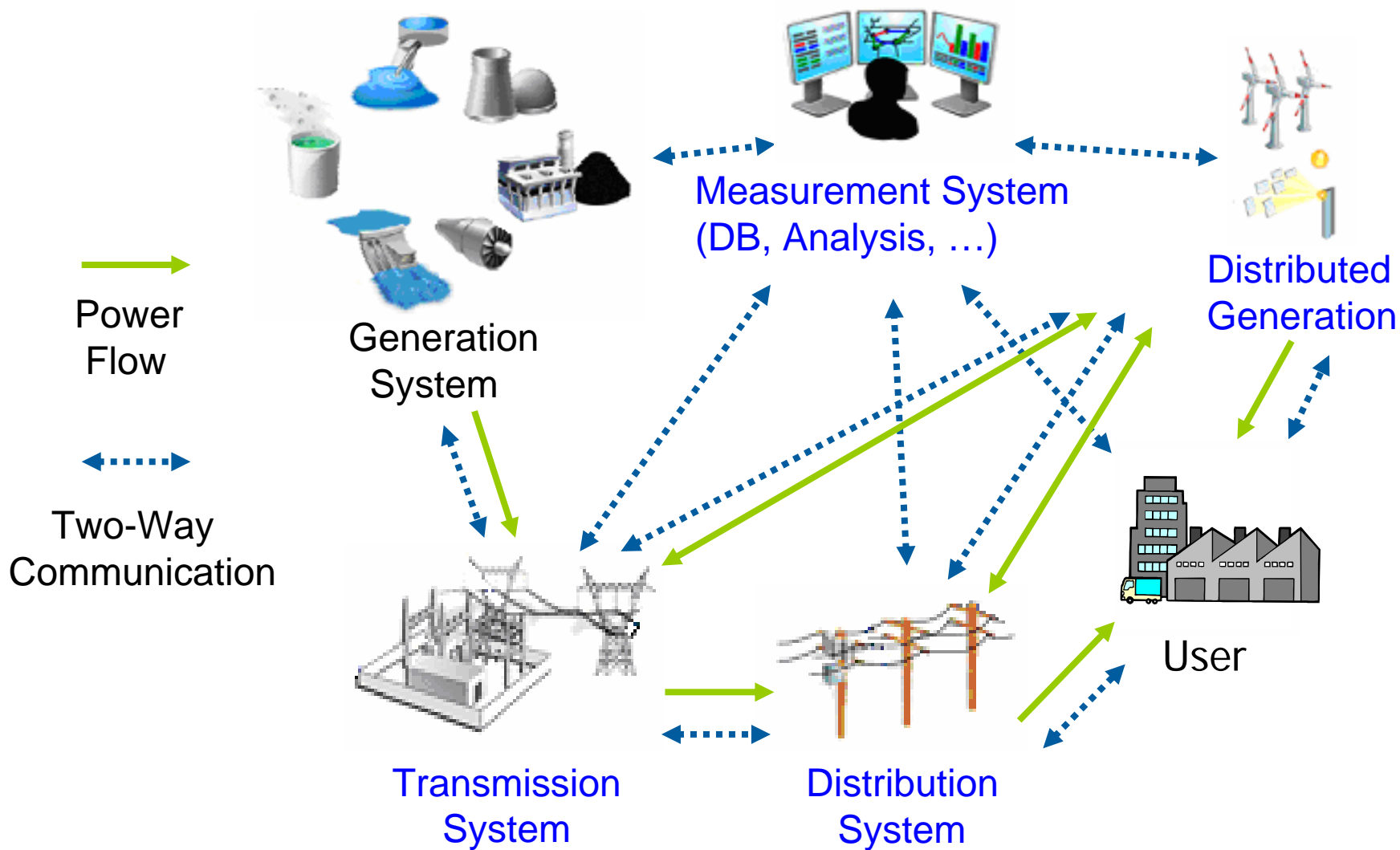
# Distribution System Monitoring Scheme



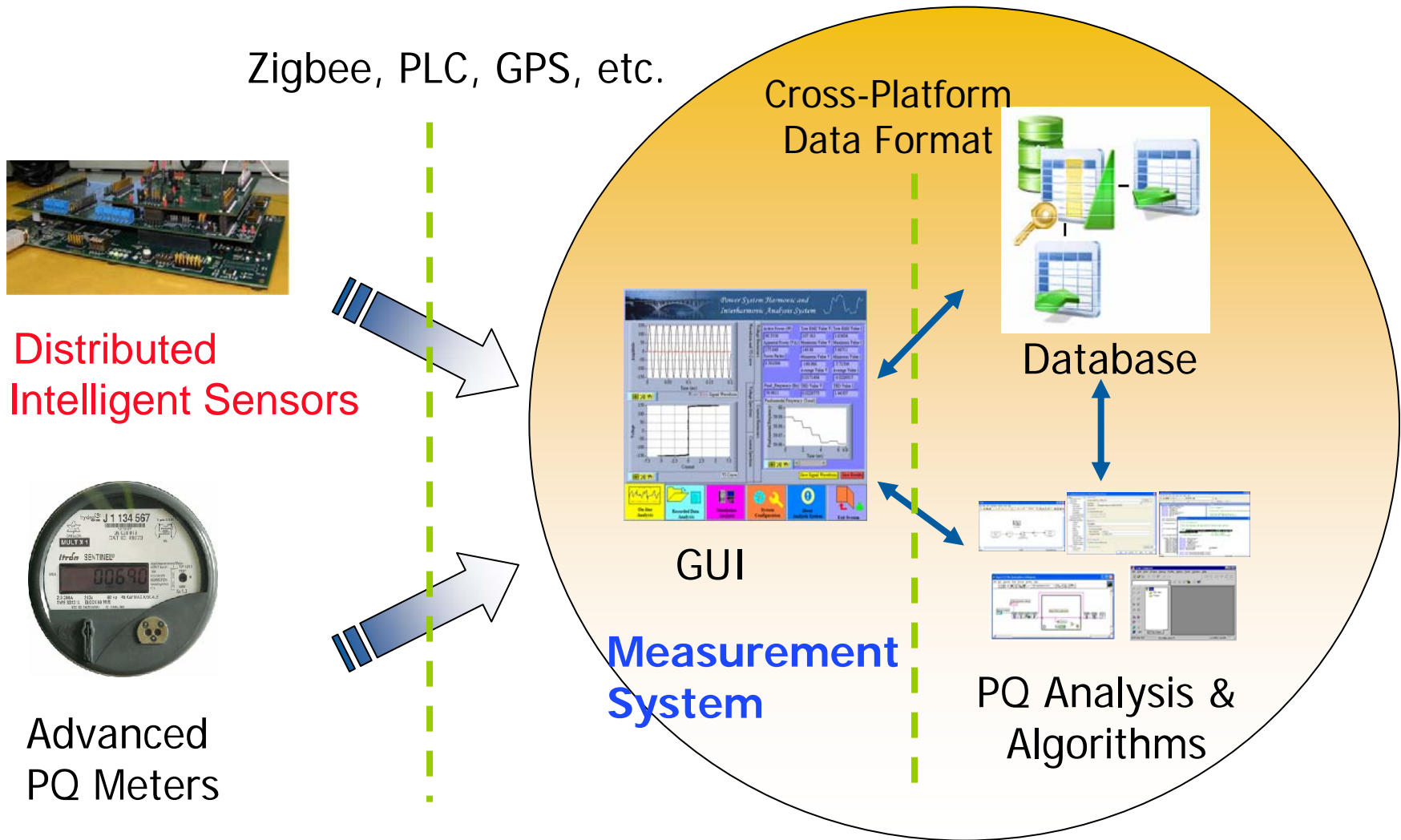
# Distribution System Monitoring Scheme (cont.)



# Smart PQ Monitoring Scheme



# Smart PQ Monitoring Scheme (cont.)



# PQ Disturbance Emission and Immunity

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

# 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**



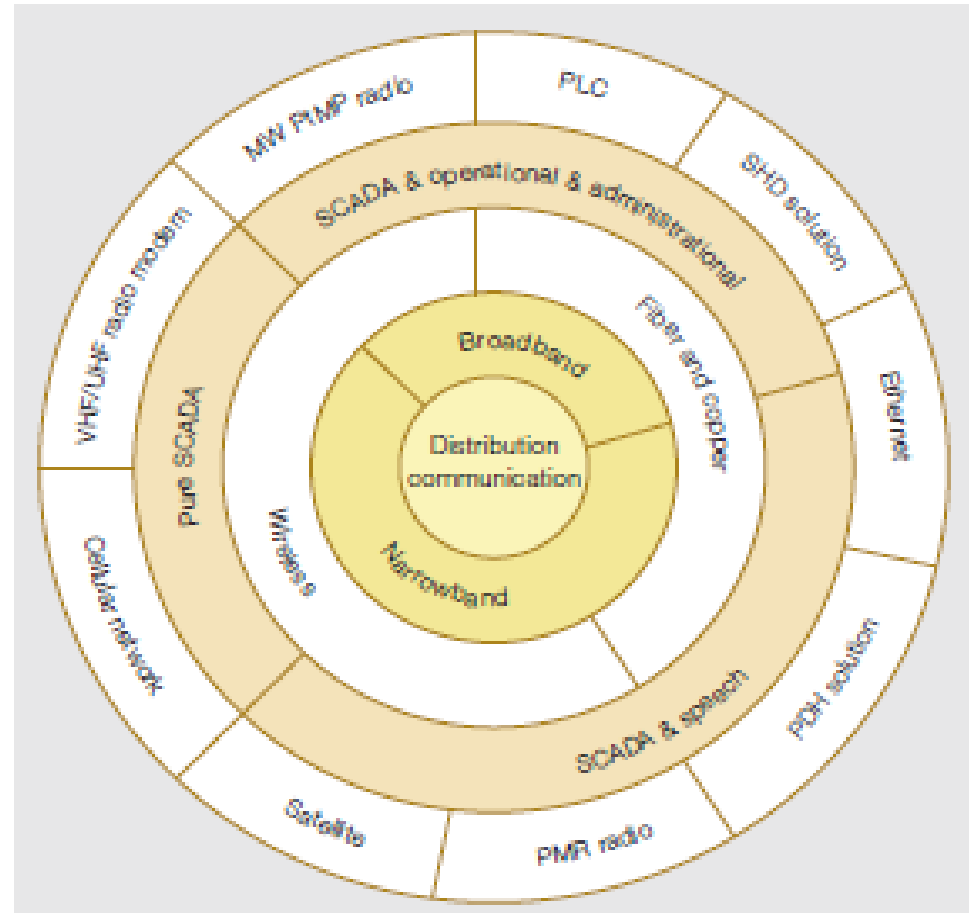


# Location of PQ Monitors

- 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

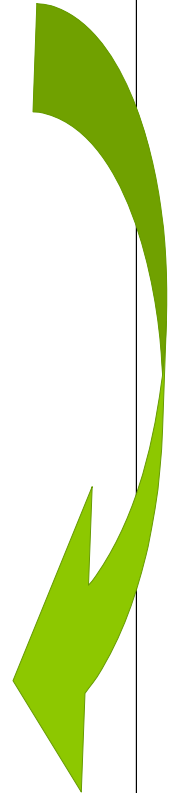
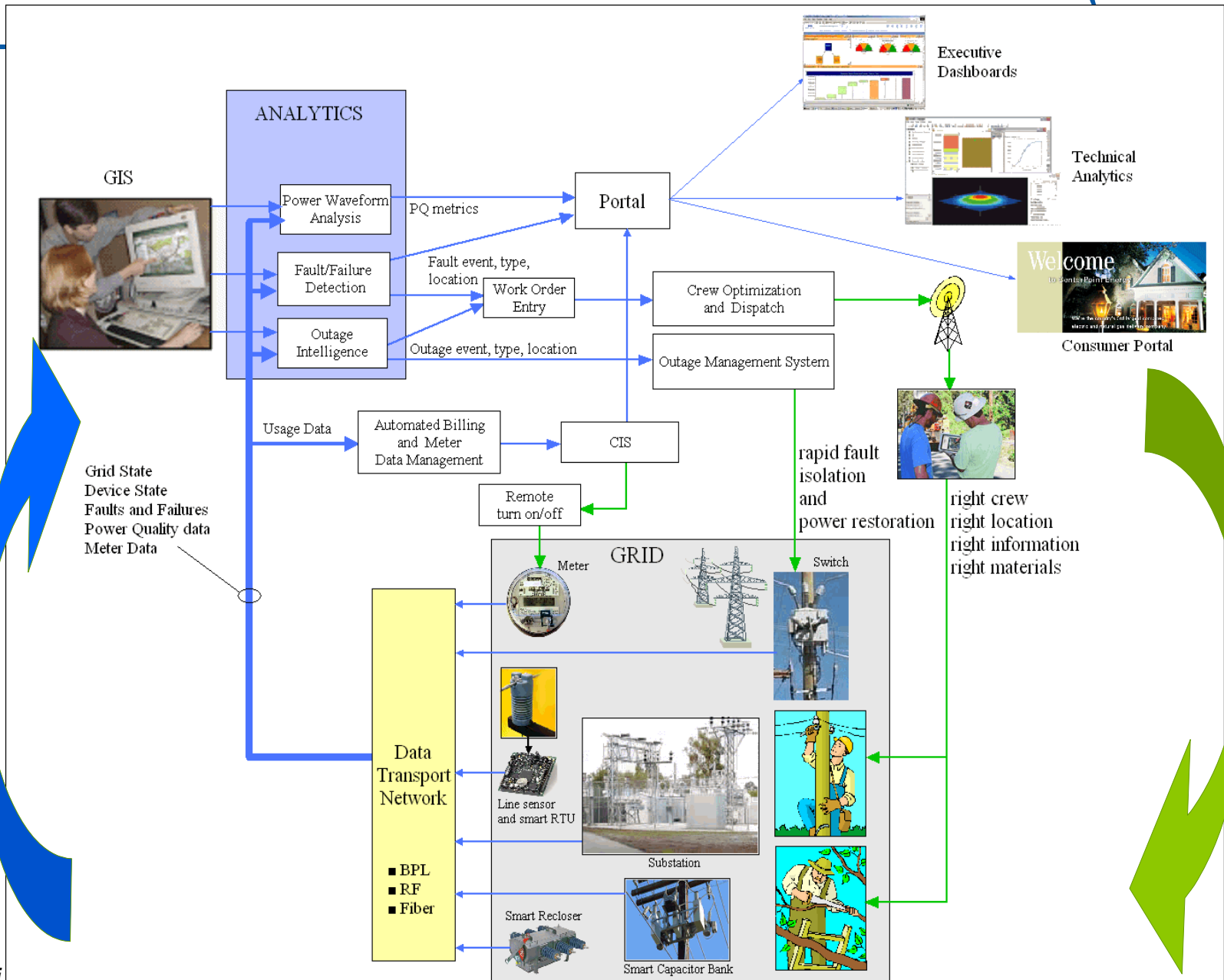
# Metrics for PQ Measuring Progress

- 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.)

Data

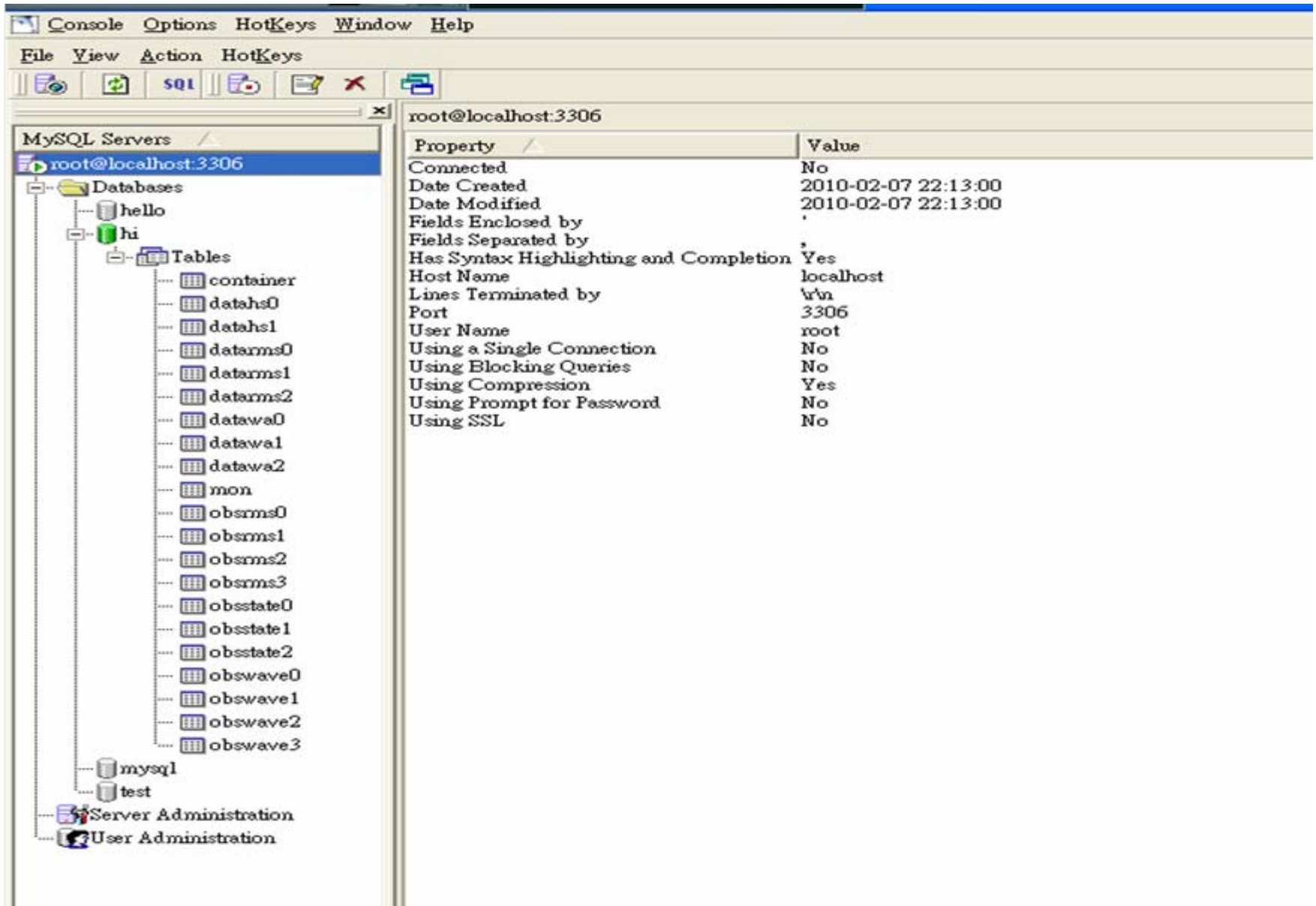
Decision



# Advanced PQ Meter Functions

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

# PQ Database Design & Implementation



The screenshot displays a MySQL client window with a menu bar (Console, Options, HotKeys, Window, Help) and a toolbar. The main area is split into two panes. The left pane shows a tree view of MySQL Servers, with 'root@localhost:3306' selected. Underneath, a tree view of Databases is shown, including 'hello' and 'hi'. The 'hi' database is expanded to show a 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. The right pane shows the properties for the 'root@localhost:3306' connection, listing various properties and their values.

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

SQL Results 2

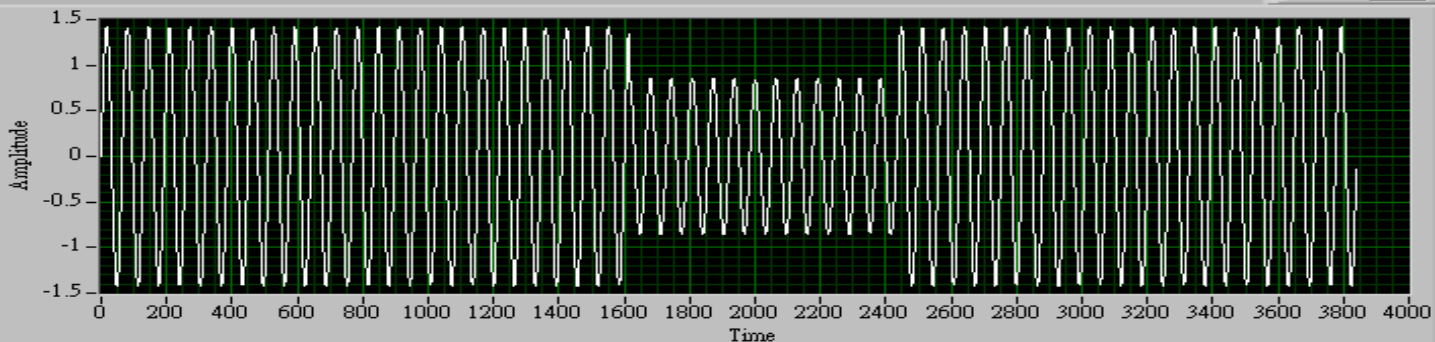
-0.002581		
0.138188		
0.273179		
0.412159		
0.541959		
0.672091		
0.784335		
0.892807		
0.998974		
1.088604		
1.164050		
1.252487		
1.311995		
1.354568		

Table  
382

-1.310053		
-1.242781		
-1.177314		
-1.084975		
-0.996726		
-0.896809		
-0.792076		
-0.661774		
-0.540844		
-0.418147		
-0.271463		
-0.136558		

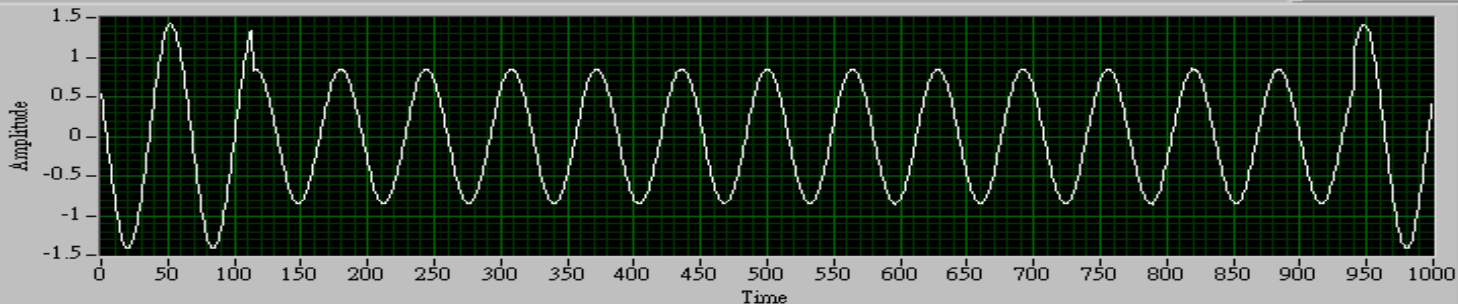
Waveform Graph

Plot 0



Waveform Graph 2

Plot 0

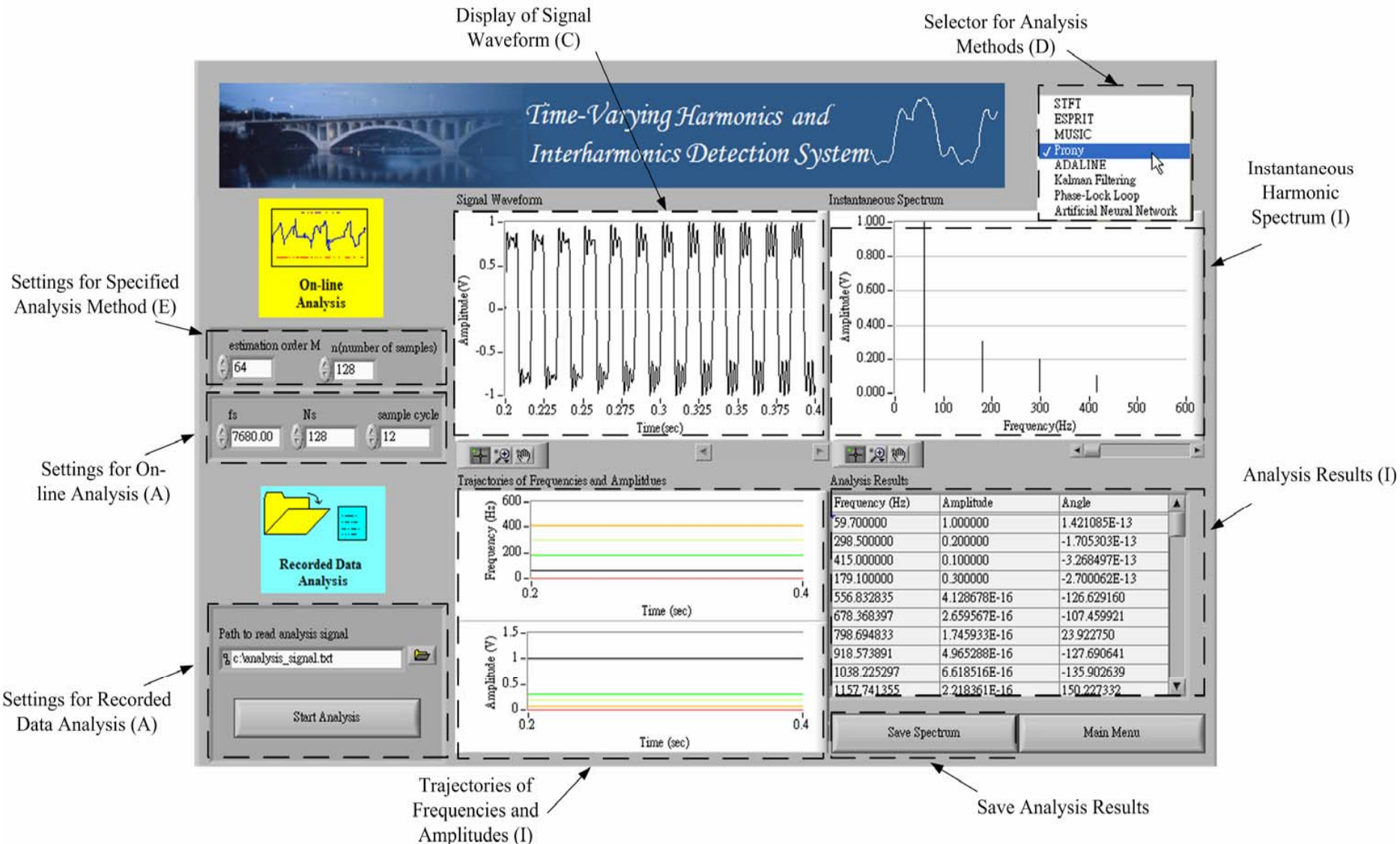


OK Button

OK



# Visualization and Decision Support

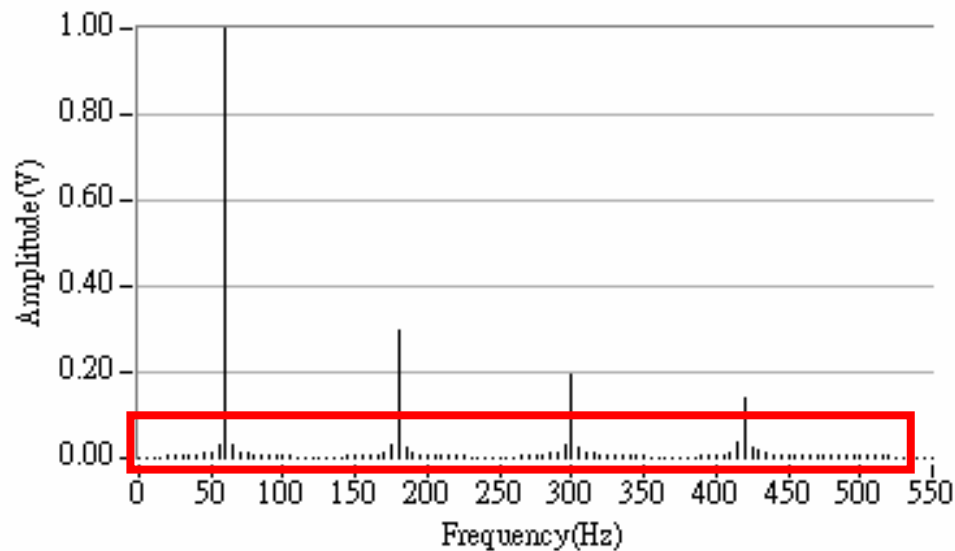


GUI of the integrated virtual instrument for on-line and recorded data PQ analyses

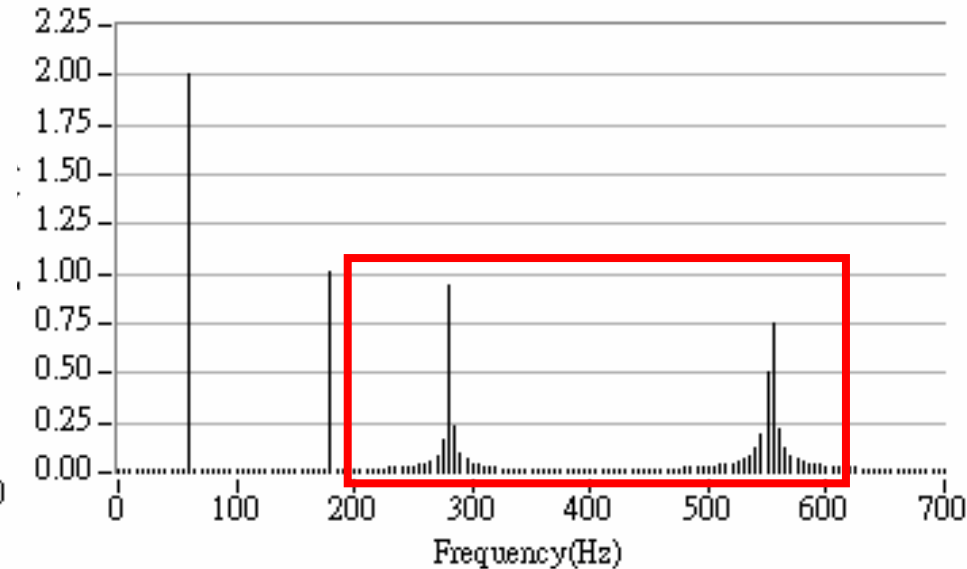
# Measurement of Harmonics/Interharmonics

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

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

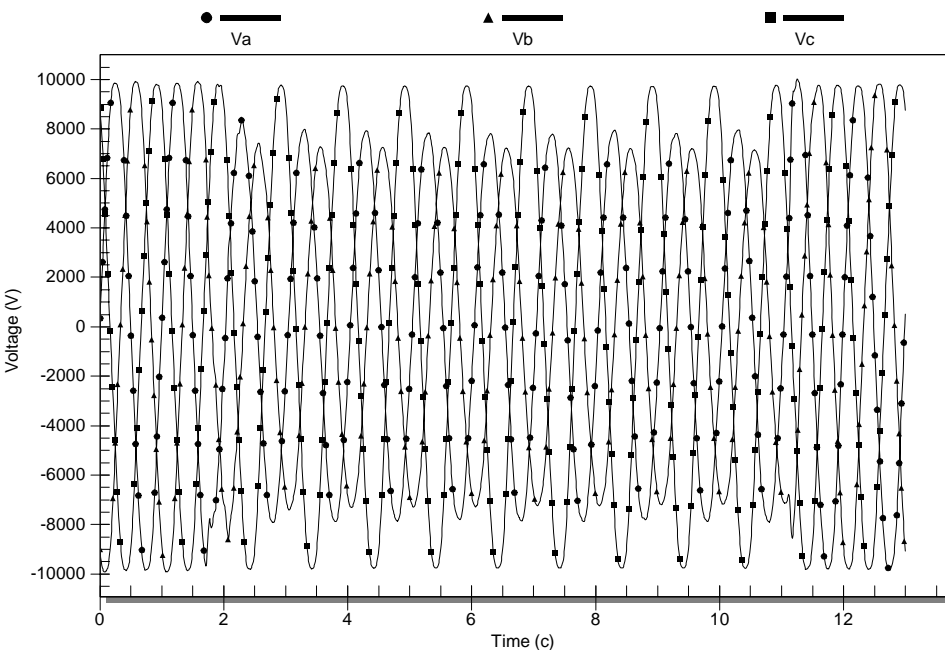


**Spectral Leakage**



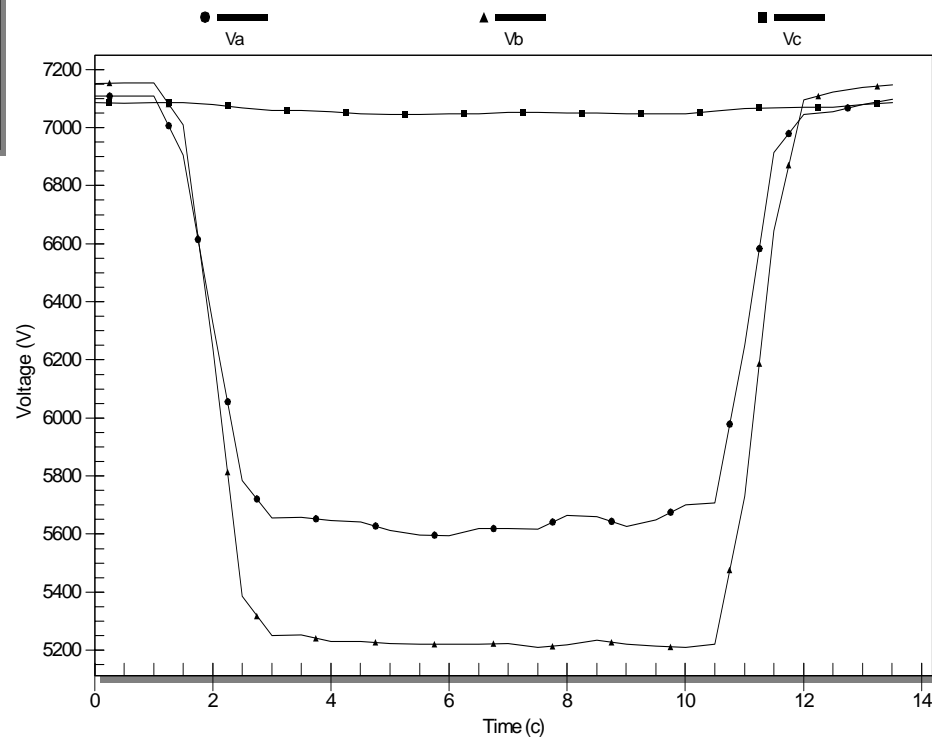
**Picket-Fence Effect**

# 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:

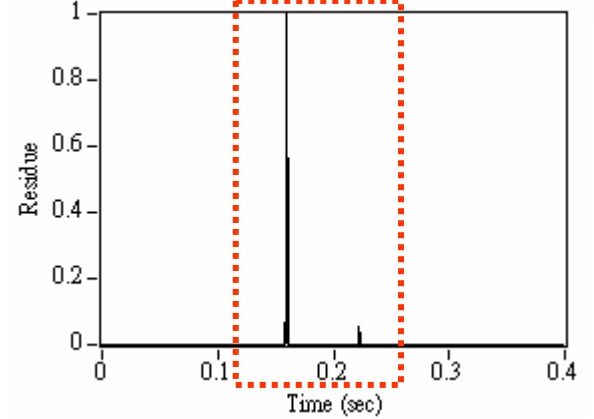
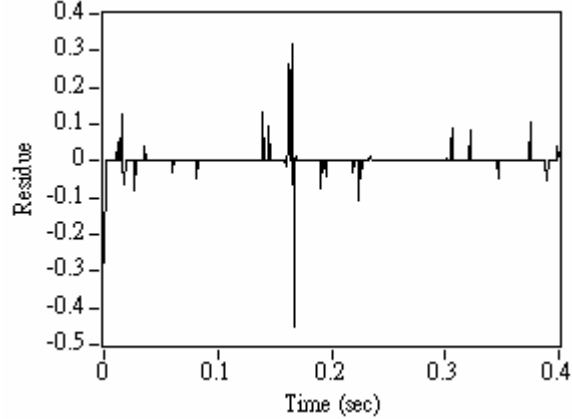
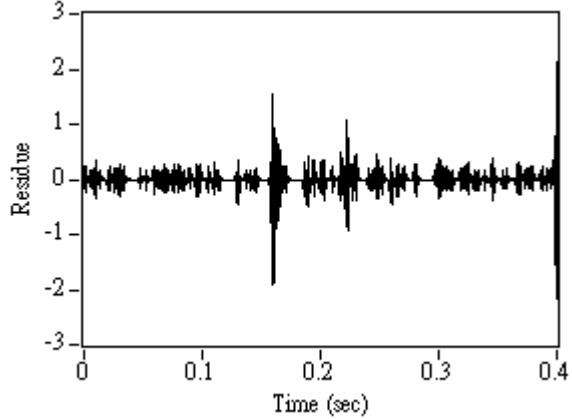
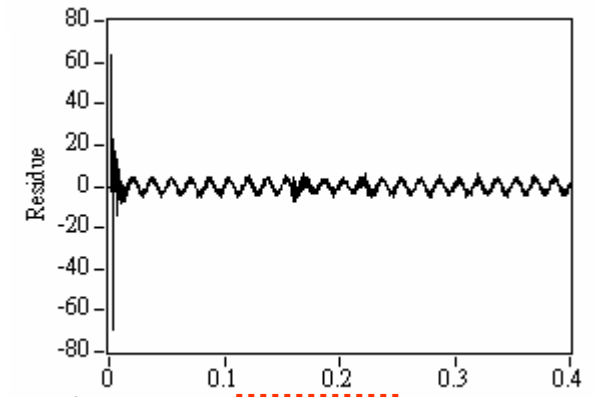
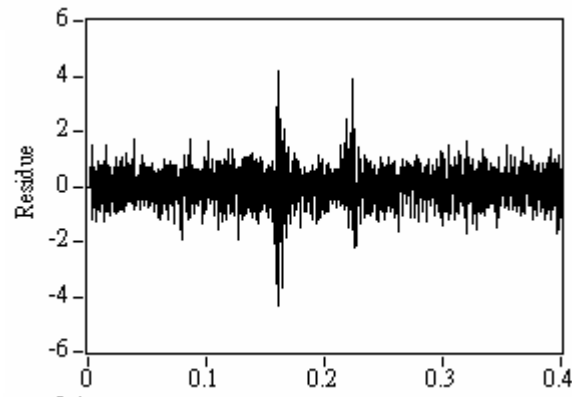
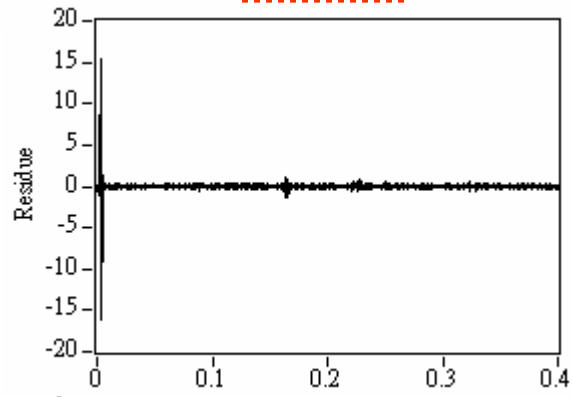
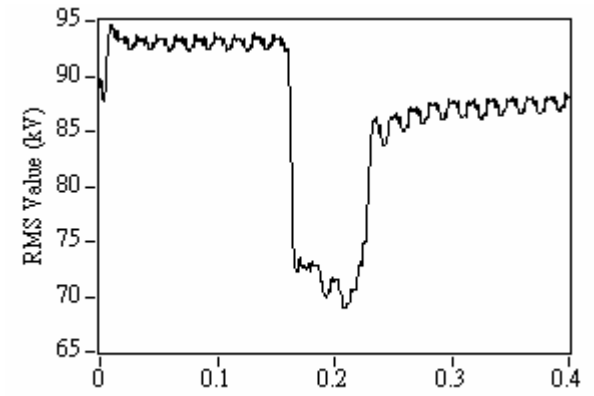
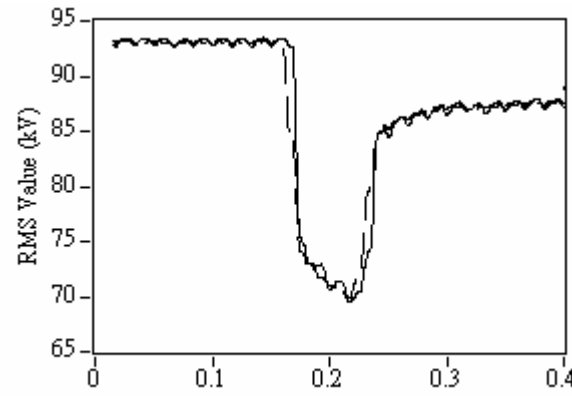
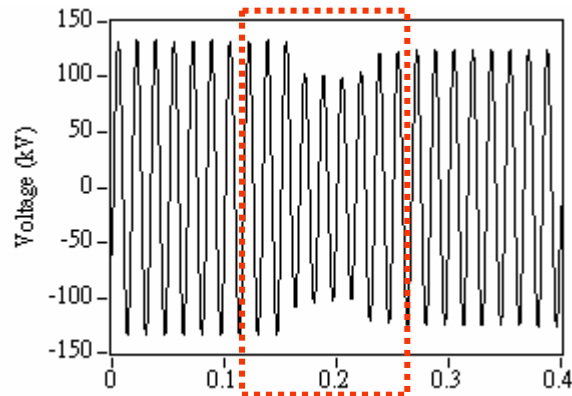
- **Starting-time** localization of events
- **Ending-time** localization of events
- **Duration** of events
- **Classification** of events
- **Variation** of events

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

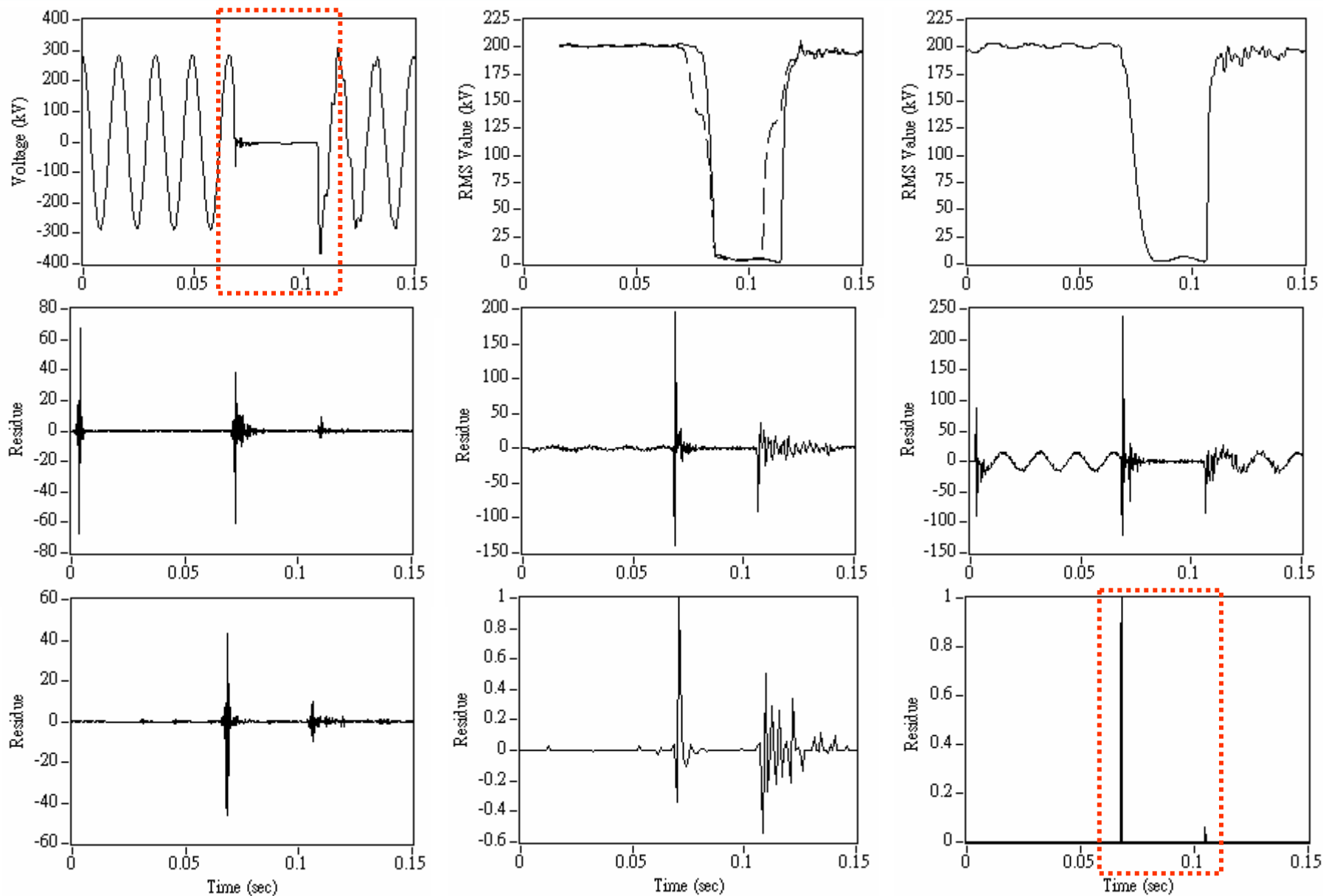
## Commonly seen approaches:

- 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)



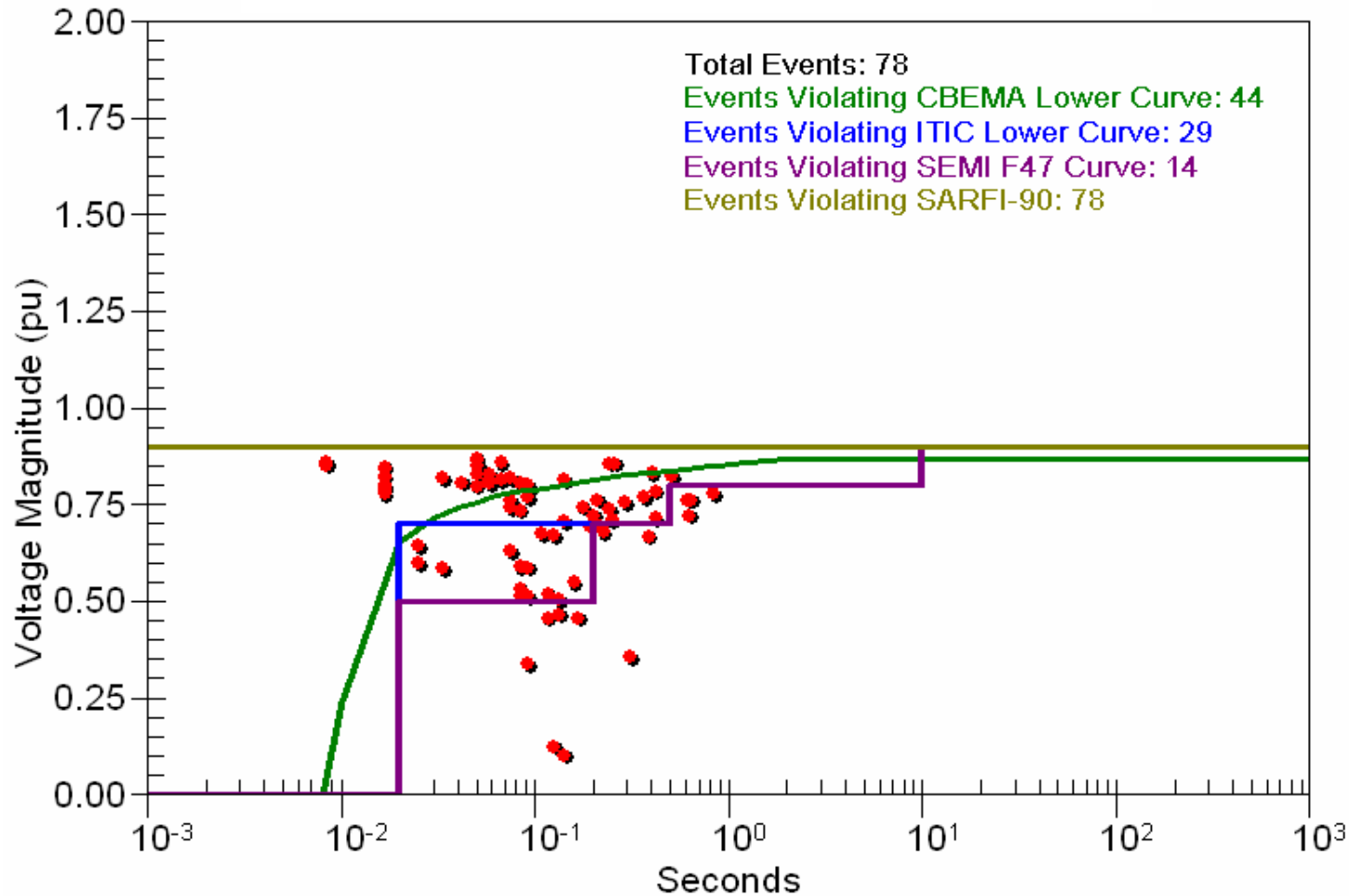
# Case Studies (Case 5)





# Case Studies (cont.)

## RMS Variation Magnitude-Duration Scatter Plot



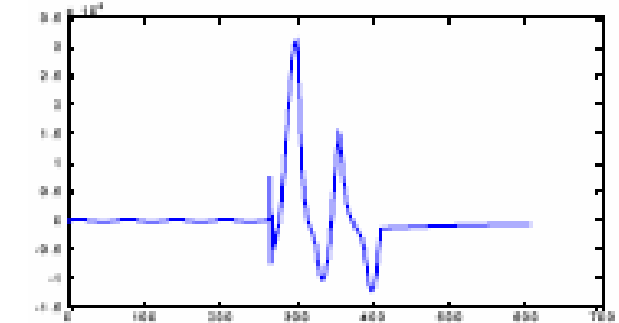
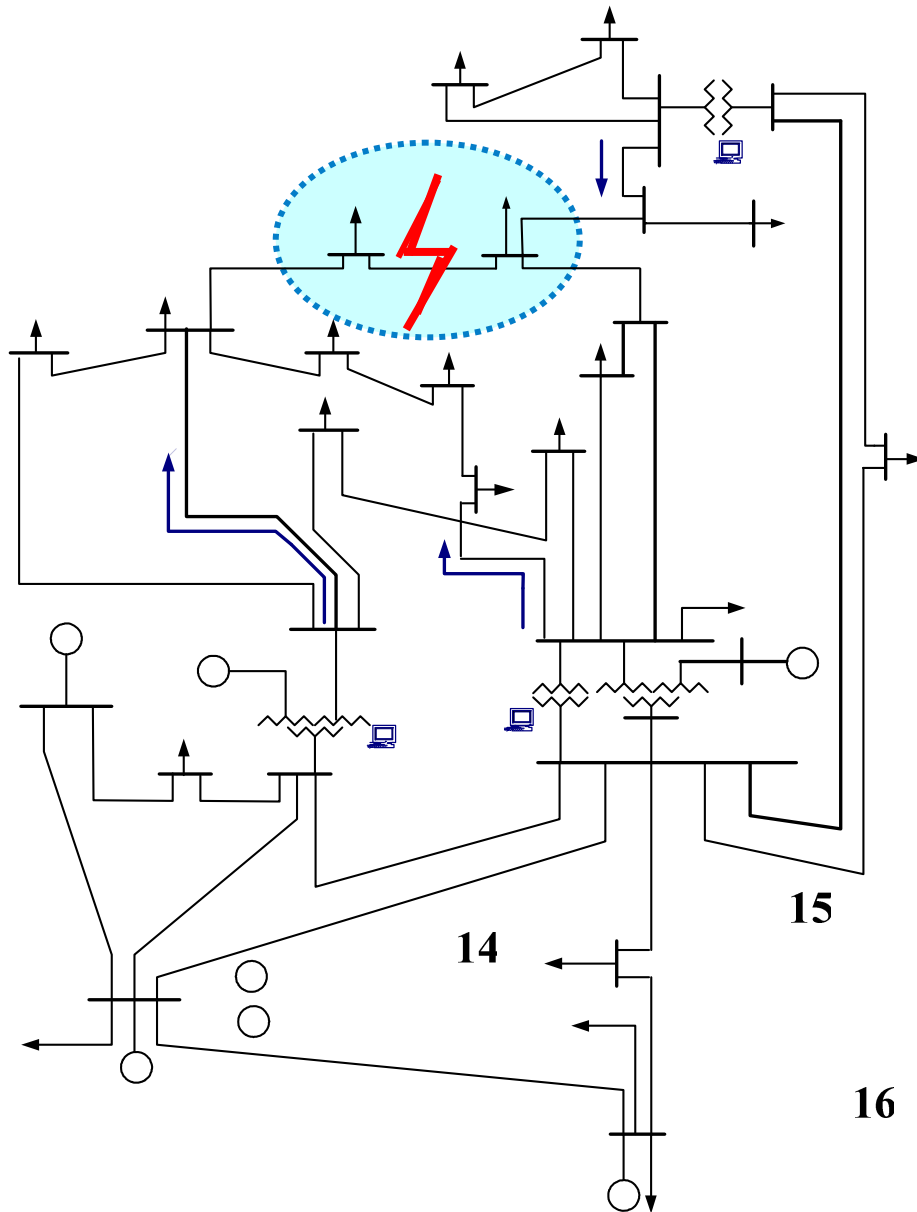
**Scatter plot with recorded voltage sags indicated**

# More PQ Measurement Issues

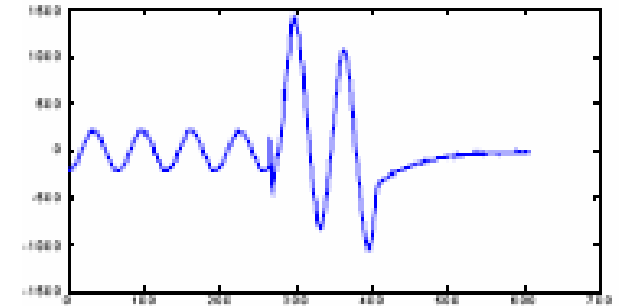
## More Smart Grid PQ Measurement Issues

- (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**

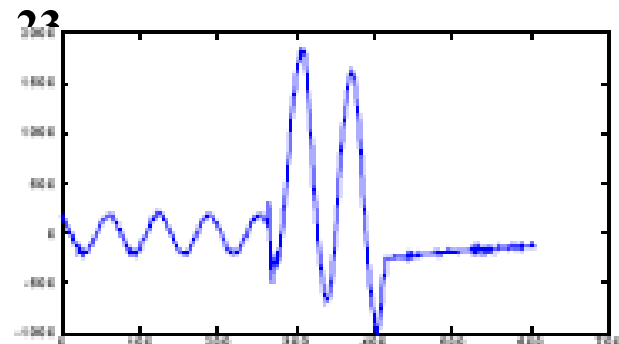
# Smart PQ Disturbance Source Location Tracking/Identification



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# 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
- Need effective metrics for assessment of PQ measuring progress



***Thank You!***

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