A PMU in Every Household?

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First Generation FDR
Partial list of frequency disturbance recorder (FDR) locations in US/Canada
Sample automatic event alert

Event Estimation:
420MW EI Generator Trip at 06:18:55UTC, on 02/02/2010 near Edwin I Hatch power plant (SERC).
(Appling, GA 31513; Latitude: 31.7837, Longitude: -82.3486)

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Online Oscillation Mode Estimation

FNET Mode Estimation Result

- Freq #1
- Damping Ratio #1
- Freq #2
- Damping Ratio #2

Interconnection and FDR selection
Wide area oscillation detection

Three area oscillates

10/27/2009 10:56:11 UTC

Frequency: 0.227Hz
Inter-area Oscillation Damping by Wind

El Wide-area Wind Generation Control for Inter-area Oscillation Damping

Wide-area Wind Control

No Control
Islanding Detection – Bulk & Micro Grid

• Case 1 (EI 09/18/2007 10:21:23 UTC)
  - Winnipeg 1.0431Hz
  - Bismarck 1.0577Hz
  - Chicago 1.0577Hz
  - Winnipeg 498.2 s
  - Bismarck 498.3 s
  - Chicago 498.2 s

• Case 2 (WECC 06/01/2010 23:37:32 UTC)
  - Winnipeg 19.4321 rad
  - Bismarck 19.4299 rad
  - Chicago 19.4299 rad
  - Winnipeg 495.8 s
  - Bismarck 498.1 s
  - Chicago 498.1 s

Location | Alberta
---|---
$|\Delta f_{\text{max}}|$ | 0.7925 Hz
$(t_{\Delta f \geq f_{th}})_{\text{max}}$ | 281.1 s
$|\theta_{t+M_{\text{th}}} - \theta_t|_{\text{max}}$ | 14.8595 rad
$(t_{\Delta \theta \geq \theta_{th}})_{\text{max}}$ | 280.9 s
Off Grid Detection for Hospitals and Data Centers

Grid → UPS → Grid Detected

Central alarm system in operation
- Frequency Response of Linda’s Voice
Case analysis – Houston police recording compared with FDR data collected in Huston, TX

- Audio record: Houston police 05-07-2009, 11:00-11:20 CDT
- Sample rate: 11kHz
- Recorded from equipment ground loop hum

Power grid signature as authentication tool
20070716-002749 (UTC time) in Memphis, FDR at Jackson.
Sampling rate 600Hz

Voltage of Bus 151

Time/s

Voltage/p.u.

- System response
- Known 20 pts
- Known 30 pts
- Known 50 pts
- Known 150 pts
Contactless PMU Development

**Magnetic Field Based PMU**

- Voltage Signal from Magnetic Field Transducer
- Amplifier
- Low pass filter
- A/D converter
- Microprocessor
- Ethernet Card

**Electric Field Based PMU**

- Voltage Signal from Electric Field Transducer
- Amplifier
- Low pass filter
- A/D converter
- Microprocessor
- Ethernet Card

Lab Testing  
Field Testing  

Framework from Frequency Disturbance Recording Unit
Enhanced LOng-RAnge Navigation (eLoran) systems

- The core eLoran system comprises modernized control centers, transmitting stations and monitoring sites.
- eLoran transmissions are synchronized to the source of Coordinated Universal Time (UTC) by a method wholly independent of GNSS.
- **Timing:** +/- 50 ns from UTC; Stratum-1 frequency standard.
FDR Operates with eLoran Timing
UN152A (eLoran) vs Cesium

Phase difference between Cesium and UN152A

Std of zoomed data is: 17.782285425(ns)
Max of zoomed data is: 61.828816511(ns)
Min of zoomed data is: -73.671183489(ns)
Comparison of Angle and Frequency

Angle and Frequency Comparison

Angle Comparison of GPS-FDR with eLoran-FDR

- Angle of GPS-FDR
- Angle of eLoran-FDR

Time (s)
Unwrap Angle (radian)

Frequency Comparison of GPS-FDR with eLoran-FDR

- Frequency of GPS-FDR
- Frequency of eLoran-FDR

Time (s)
Frequency (Hz)

Angle difference between GPS-FDR and eLoran-FDR

Time (s)
Angle difference (degree)

Frequency difference between GPS-FDR and eLoran-FDR

Time (s)
Frequency difference (mHz)
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Focus on Wide-Area Measurement Applications