INTEGRATION OF OPERATIONAL AND NON-OPERATIONAL DATA FOR IMPROVED EMS MONITORING

Mladen Kezunovic
Texas A&M University

November 18, 2008

©2008 Mladen Kezunovic, All Rights Reserved
OUTLINE

- Introduction
- System View
- Substation Processing
- EMS Uses: FL Example
- Q/A

©2008 Mladen Kezunovic, All Rights Reserved
INTRODUCTION

- What is operational and non-operational data?
- Why integration?
- When it makes sense?
- How it is done?
WHAT IS OPERATIONAL AND NON-OPERATIONAL DATA?
WHY INTEGRATION?
Redundant measurements
WHY INTEGRATION?
Improved capturing of events

Operational data

Non-operational data

©2008 Mladen Kezunovic, All Rights Reserved
WHEN IT MAKES SENSE?

- When redundancy matters:
  - bad measurements
  - inconsistent measurement
  - communication failures

- When capturing dynamic signals matters:
  - faults (transients)
  - evolving dynamics (phasors)
  - fast equipment switching
HOW IT IS DONE?

Database:
Raw and pre-processed measurements
System configuration data

Information Exchange

Data Integration

DFRs  DPRs  CBMs  SERs  PLCs  PQ Meters  RTUs  PMUs

©2008 Mladen Kezunovic, All Rights Reserved
OUTLINE

- Introduction
- System View
- Substation Processing
- EMS Uses: FL Example
- Q/A
SYSTEM VIEW: Flow of data and computations

Data Sources
- SCADA (operational data)
- PMU (synchronized phasors)
- IEDs (non-operational data)

Data Integration

Applications
- Intelligent Alarm Processor
- Optimized Fault Location
- Other Applications: -- Cascading analysis
  -- Optimized maintenance

Control Center Visualization
- Construction Model Graphics (e.g. circuit breaker, tower)
- Physical View (e.g. satellite view, electrical measurements)
- Electrical Topology View (e.g. system one-line diagram)

©2008 Mladen Kezunovic, All Rights Reserved
## SYSTEM VIEW: Inputs

<table>
<thead>
<tr>
<th>Applications</th>
<th>Input Information</th>
<th>Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intelligent Alarm Processor (IAP)</strong></td>
<td>Circuit Breaker control circuit signals</td>
<td>1. Timestamp;</td>
</tr>
<tr>
<td></td>
<td>SCADA measurements</td>
<td>2. Analysis result;</td>
</tr>
<tr>
<td></td>
<td>Phasors (or synchrophasors)</td>
<td>3. Suggested actions;</td>
</tr>
<tr>
<td></td>
<td>Alarm signals</td>
<td>4. Additional information</td>
</tr>
<tr>
<td><strong>Optimized Fault Location (OFL)</strong></td>
<td>IED samples of voltage and current</td>
<td>1. Estimated fault section</td>
</tr>
<tr>
<td></td>
<td>Synchrophasors</td>
<td>2. Fault location within the estimated section;</td>
</tr>
<tr>
<td></td>
<td>SCADA data</td>
<td>3. Fault type</td>
</tr>
<tr>
<td><strong>Other applications (e.g. cascading analysis, optimized maintenance)</strong></td>
<td>Phasors or synchrophasors</td>
<td>1. Cascade detection</td>
</tr>
<tr>
<td></td>
<td>IED samples of voltage and current</td>
<td>2. Cascade classification</td>
</tr>
<tr>
<td></td>
<td>SCADA data</td>
<td>3. Equipment failure rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. Optimized maintenance shedule</td>
</tr>
</tbody>
</table>

©2008 Mladen Kezunovic, All Rights Reserved
Reports can be customized according to the need of a particular category of users and disseminated via fax, e-mail, website, pager, etc.
OUTLINE

- Introduction
- System View
- Substation Processing
- EMS Uses: FL Example
- Q/A
SUBSTATION PROCESSING

- Switchyard Interface
- IED Processing
- Data Integration
SWITCHYARD INTERFACE

DATA SENSING & ACCURACY
DATA SENSING: Sources of Data

Measurement devices (sensors):
- Transducer
- Relaying transformer
- Metering transformer
- Electronic (optical) transformer
- Control circuit transformers

©2008 Mladen Kezunovic, All Rights Reserved
DATA SENSING:
Location of System Measurements

©2008 Mladen Kezunovic, All Rights Reserved
ACCURACY OF SENSORS

Accuracy classes and standard burdens for metering and relaying transformers from

- IEEE Standard C57.13 on Requirements for Instrument Transformers
- IEC Standard 60044 on Instrument Transformers
  - 60044-1 : Part 1: Current Transformers
  - 60044-2 : Part 2: Inductive Voltage Transformers
  - 60044-5 : Part 5: Capacitor Voltage Transformers
SUBSTATION PROCESSING

IED PROCESSING

DATA ACQUISITION & TIMING

©2008 Mladen Kezunovic, All Rights Reserved
DATA ACQUISITION: Sources of Data

Intelligent Electronic Devices

- Substation remote terminal unit (RTU)
- Phasor measurement unit (PMU)
- Other IEDs
  - Digital protective relay (DPR)
  - Digital fault recorder (DFR)
  - Power quality meter (PQM)
  - Sequence of event recorder (SER)
  - Fault locator (FL)
  - Circuit breaker monitor (CBM)
DATA ACQUISITION: Internal Processing of IEDs

Analog Inputs → Analog Processing → Sampling and A/D Conversion → Digital Signal Processing → Digital Outputs

Clock Signal → Time Stamping

GPS Clock Receiver
DATA ACQUISITION: Accuracy

Impact on accuracy

- Auxiliary transformers
- Mode of sampling
- Anti-aliasing filter
- Sampling rate
- Resolution of A/D conversion
DATA ACQUISITION: Timing of Data Sampling

Scanning

Synchronous Sampling

©2008 Mladen Kezunovic, All Rights Reserved
DATA ACQUISITION: Time Stamping

CH 1 \( \rightarrow \) S/H \rightarrow MUX \rightarrow S/H \rightarrow A/D \rightarrow PROCESSOR + MEMORY (time stamping)

CH 2 \( \rightarrow \) S/H \rightarrow sampling

CH n \( \rightarrow \) S/H \rightarrow sampling

LOCAL CLOCK \rightarrow GPS CLOCK RECEIVER

GPS ANTENNA \( \rightarrow \) 1PPS \( \rightarrow \) LOCAL CLOCK

TIME CODE

©2008 Mladen Kezunovic, All Rights Reserved
SUBSTATION DATA INTEGRATION & INFORMATION EXTRACTION
DATA INTEGRATION: Substation Database

- Static system data containing description of the system components and their connections
- Data from IEDs and RTUs (operational and non-operational data)
- Substation interpretation data to correlate recording device channels and static system model
DATA INTEGRATION: Standards

Types of standards

- Data Acquisition (IEC 61850-9.2)
- Data Format (COMTRADE, Synchrophasor, PQDIF, Naming Convention)
- Data Communications (IEC61850, DNP)
- Data Modeling (IEC61970, IEC 61968)
OUTLINE

- Introduction
- System View
- Substation Processing
- EMS Uses: FL Example
- Q&A
EMS USES:
FAULT LOCATION EXAMPLE

- Requirements
- Traditional Data Handling
- Automated Data Handling
- Visualization
REQUIREMENTS:
Detect Occurrence and Confirm Clearing

©2008 Mladen Kezunovic, All Rights Reserved
REQUIREMENTS:
Verify Equipment Operation

Fault is temporary

Fault is permanent

Trip signal

Circuit breakers
REQUIREMENTS:
Determine type of fault (temporary)

Equipment reacts automatically.
Fault is cleared.
No need for operator action, but event is recorded and archived.

Normal Operation

Fault Occurred

Fault is Cleared

Automatic Fault Clearing (Realys&Circuit Breakers)
REQUIREMENTS:
Determine Type of Fault (Permanent)

Automatic fault clearing makes decision to disconnect faulted part of the power system without any more attempts to automatically recover disconnected part → LOCKOUT
→ Disconnected part must be returned to working state MANUALLY

©2008 Mladen Kezunovic, All Rights Reserved
TRADITIONAL DATA HANDLING: The Role of Personnel

**Operator** tracks system 24/7; coordinates other groups as needed.
Output: Event report

**Protection Group** analyses events 8am-5pm; identifies fault location and equipment misoperation.
Output: Comprehensive analysis report

**Maintenance** responds to calls 24/7; inspects and repairs equipment as needed.
Output: Repair report from field visits

©2008 Mladen Kezunovic, All Rights Reserved
TRADITIONAL DATA HANDLING: Action For Permanent Fault

Maintenance

Protection

Operator

Archive

Normal

Fault occurred

Protection & Maintenance informed

Fault Location identified

Operator Informed

System Back to Normal

Brief report archived

FL report archived

Summary report archived

Data Retrieved (DFRs, DPRs)

Fault Analysis

Work order issued

Repair

Normal
AUTOMATED DATA HANDLING: Improved Timeline

- Maintenance
  - Work order issued
  - Repair

- Automated Analysis
  - Fault Analysis
  - Data Retrieved (DFRs, DPRs, CBMs)

- Protection
  - Data Retrieved (DFRs, DPRs)
  - Fault Analysis

- Proposed
- Existing

Less time spent
Normal

©2008 Mladen Kezunovic, All Rights Reserved
AUTOMATED DATA HANDLING:
Data Requirements

- **Field data:**
  - Event data recorded by different IEDs after occurrence of any abnormality

- **System level data:**
  - Historical SCADA Data
  - Power system model data
  - Satellite Data

©2008 Mladen Kezunovic, All Rights Reserved
AUTOMATED DATA HANDLING: Preparation of measurements

- Extraction of phasors
- Synchronization of phasors
- Retrieval of the Power Grid Switching Status
AUTOMATED DATA HANDLING:
System Architecture

- PSS/E Short Circuit Program
- Fault Location
- DFR Assistant
- Visual-Interactive-Distributed VIDSpreadSheet
- Fault Report
- Power World
- SCADA EMS PI HISTORIAN

©2008 Mladen Kezunovic, All Rights Reserved
AUTOMATED DATA HANDLING: Fault Location Module

- Single-end fault location
- Two-end fault location
- Fault location using sparse measurements

Optimal FL algorithm selection

Fault Report

Updating:
- Branches
- Generators
- Load

- Interpretation file
- COMTRADE file
- DFR Fault Report

Line Model

PSS/E Short Circuit Program

SCADA EMS PI Historian

DFR Assistant

Case data

System Model

©2008 Mladen Kezunovic, All Rights Reserved
AUTOMATE DATA HANDLING:
DFR Assistant™

The bus breaker opened in 11 cycle
The middle breaker opened in 11 cycle
The middle breaker opened in 2 cycle after the trip
The bus breaker opened in 2 cycle after the trip
The bus breaker OK?
The middle breaker OK?
Backup relay did not trip since the fault was not detected!

*** Event Origin ***
DFR Assistant Client: Limestone
Substation: Limestone
DFR Native File Name: Event807.pre
Affected Circuit: TP&L - Jewett Gkt 74

*** Event Summary ***
Trigger Date and Time: 10-15-2008 04:58:47
Event Description: END FAULT
Fault Location: 7.282910 [miles]
Event Outcome: NO_CLEARANCE
Breaker Operation: 1st, CR_OK
Breaker Operation: 2nd, CR_OK
Relay Operation: BACK, RL_NOTRIP_OK

*** Analog Signal Values ***

<table>
<thead>
<tr>
<th>Prefault Values</th>
<th>Fault Values</th>
<th>Postfault Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>I0 = 0.6191 [kA]</td>
<td>I0 = 10.3239 [kA]</td>
<td>I0 = 0.0006 [kA]</td>
</tr>
<tr>
<td>Ia = 1.8076 [kA]</td>
<td>Ia = 18.4111 [kA]</td>
<td>Ia = 0.0018 [kA]</td>
</tr>
<tr>
<td>Ib = 1.1996 [kA]</td>
<td>Ib = 0.5773 [kA]</td>
<td>Ib = 0.0022 [kA]</td>
</tr>
<tr>
<td>Ic = 1.2574 [kA]</td>
<td>Ic = 0.8960 [kA]</td>
<td>Ic = 0.0005 [kA]</td>
</tr>
<tr>
<td>U0 = 3.1848 [kV]</td>
<td>U0 = 49.7262 [kV]</td>
<td>U0 = 7.6336 [kV]</td>
</tr>
<tr>
<td>Va = 277.0459 [kV]</td>
<td>Va = 136.1295 [kV]</td>
<td>Va = 2.6929 [kV]</td>
</tr>
<tr>
<td>Vb = 275.5326 [kV]</td>
<td>Vb = 259.8359 [kV]</td>
<td>Vb = 9.8694 [kV]</td>
</tr>
<tr>
<td>Vc = 273.4484 [kV]</td>
<td>Vc = 258.2197 [kV]</td>
<td>Vc = 7.9171 [kV]</td>
</tr>
<tr>
<td>Uab = 474.7668 [kV]</td>
<td>Uab = 497.4030 [kV]</td>
<td>Uab = 12.5097 [kV]</td>
</tr>
<tr>
<td>Ubc = 488.8124 [kV]</td>
<td>Ubc = 470.4873 [kV]</td>
<td>Ubc = 9.2593 [kV]</td>
</tr>
<tr>
<td>Uca = 484.5191 [kV]</td>
<td>Uca = 398.9922 [kV]</td>
<td>Uca = 9.2578 [kV]</td>
</tr>
</tbody>
</table>

©2008 Mladen Kezunovic, All Rights Reserved
VISUALIZATION: Modules

VID Spread Sheet

2D View

3D View

Tower View

3D Construction

3D Operation

Fault Report

SCADA
EMS
PI
Historian

Power World

Fault Location Estimation

©2008 Mladen Kezunovic, All Rights Reserved
VISUALIZATION: Traditional View
VISUALIZATION: 2D SATELLITE IMAGE
VISUALIZATION: 3D View

©2008 Mladen Kezunovic, All Rights Reserved
VISUALIZATION:
TOWER VIEW

©2008 Mladen Kezunovic, All Rights Reserved
VISUALIZATION:
CB CONSTRUCTIONAL VIEW

©2008 Mladen Kezunovic, All Rights Reserved
CONCLUSION

- Data Handling is Automated:
  - Data Collection
  - Data Processing
  - Data Integration
  - Data Extraction

- Performance is Improved:
  - Understanding of Events is Enhanced
  - Reaction Time is Reduced
  - Decision Making is Facilitated

©2008 Mladen Kezunovic, All Rights Reserved
Questions?