Translational Knowledge: From Collecting Data to Making Decisions in a Smart Grid

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• Background
• Optimal Fault Location
• Intelligent Alarm Processing
• Inherently Adaptive Fault Detection and Classification
• Conclusions

Outline

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• Data Integration
• Information Exchange
• Temporal Considerations
• Spatial Considerations

Background
Data Integration

LEVEL I CENTRALIZED LOCATION

LEVEL II SUBSTATION

LEVEL III SWITCHYARD INTERFACE

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Information Exchange

Database:
- Raw and pre-processed measurements
- System configuration data

Information Exchange

Data Integration

DFRs  DPRs  CBMs  SERs  PLCs  PQ Meters  RTUs  PMUs

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Information Exchange

Engineer

Comprehensive Report

Dispatcher

Brief Report

Technician

Summary Report

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Temporal Considerations

<table>
<thead>
<tr>
<th>GPS receiver</th>
<th>Local Clock</th>
<th>Two line ends</th>
<th>Local/Central time stamp</th>
<th>Synchronization</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMU</td>
<td>DPR</td>
<td>FL</td>
<td>RTU</td>
<td>IED Application</td>
</tr>
</tbody>
</table>

Phasor Measurements:  $10^{-6}$ s
Relaying:  $10^{-3}$ s
Fault Location:  $10^{-1}$ s
State Estimation:  $10^{0}$ s

Time Scale

Inputs $\rightarrow$ IED $\rightarrow$ Outputs

Signal Measurement
- Synchronous
- Scanning

Signal Representation
- Waveform
- Phasor

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Temporal Considerations

- Relative and absolute time as a reference for correlating power system events
- Sampling clock time as a reference for synchronous signal sampling vs. scanning
- Time window as a reference for waveform representation in time and frequency domain
- Implementation of the time reference
Synchronous Sampling vs. Scanning

Scanning

Synchronous Sampling

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GPS Synchronization

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Spatial Considerations

Network

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Spatial Considerations

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Spatial Considerations

- Location as a reference for data processing and information extraction
- Location as a reference for model representation

<table>
<thead>
<tr>
<th>Application</th>
<th>Temporal</th>
<th>Spatial</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimal Fault Location</td>
<td>Synchronized or unsynchronized phasor or sample vector</td>
<td>Local and system-wide</td>
<td>Power System Network for short circuit study</td>
</tr>
<tr>
<td>Intelligent Alarm Processing</td>
<td>Synchronized or unsynchronized phasors</td>
<td>Substation and system-wide</td>
<td>Petri-Net Logic for cause-effect representation</td>
</tr>
<tr>
<td>Inherently Adaptive Fault Detection and Classification</td>
<td>Synchronized sample vector</td>
<td>Local</td>
<td>Power system model for training pattern clustering</td>
</tr>
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• Overview
• Translational knowledge
  – Data Processing
  – Information Extraction
  – Implementation
• Case Study

Optimal Fault Location
Overview of Fault Location Algorithms

- Phasor based Methods
  
  *Use fundamental frequency component of the signal and lumped parameter model*

- Time-domain based Methods
  
  *Use transient components of the signal and lumped or distributed parameter model*

- Traveling wave based Methods
  
  *Use correlation between the forward and backward travelling waves along a line or direct detection of the arrival time*

- Single end
- Double end
- Synchronized
- Unsynchronized
- Phasors
- Samples

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An Optimal Solution

• Substation Data Flow

Control Center
- Application and User interface

Substation
- Information Exchange
- Data Integration

Switchyard
- RTUs
- IEDs

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Data Processing

• System level data
  – Power system model data
  – PI Historian data
  – Sequence data
• Field data (recorded by IEDs)
  – Event data
  – Waveform data
• Substation interpretation data
Information Extraction

• Extraction of phasors
  – Remove high-frequency noise
  – Remove decaying dc-offset
• Synchronization of phasors
• Tuning the power system model with real-time power system conditions
  – Updating power grid topology
  – Updating generation and load data
Translational Knowledge through matching system wide sparse measurement with power system model

1. Initial Fault Location
2. Simulation study and generation of simulated waveforms
3. Matching between simulated and recorded waveforms

- Is matching criteria satisfied?
  - Yes: Get Fault Location result
  - No: Modify Fault Location
Implementation

DFR Assistant → DFR raw data → DFR data in COMTRADE format

Input: substation interpretation file → Total DFR information file entered by user

Phasors and pre-fault breaker status → Input: static system model data → Input: PI Historian data

Synchronization of phasors and tuning of static system model

Obtain a list of possible faulty branches

GA based waveform matching approach

Result: Fault location and fault resistance

Stop

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Case Study

Evaluate the following issues:

• Various number of files
• Specifying the search region
• Using preprocessed fault location estimation
• Using different quantities for the match
• Evaluating differences in the accuracy

One test case provided by the utility:

• Two subsequent (in 5 ms gap) phase to ground faults
• PI Historian data provided for two substations
• DFR triggered for only one substation

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Intelligent Alarm Processing

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Overview of Alarm Processing

*Issues that operators face:*

- Alarms which are not descriptive enough
- Alarms which are too detailed
- Too many alarms during a system disturbance
- False alarms
- Multiplicity of alarms for the same event
- Alarms changing too fast to be read on the display
- Alarms not in priority order

*Alarm processing algorithms:*

- Expert System (ES) technique
- Fuzzy Logic (FL) technique
- Petri-Nets (PN) technique
- Fuzzy Reasoning Petri-Nets (FRPN) technique

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Solution by Matching Data with Models

This approach assumes that filed data and model of the relay actions are matched leading to a cause-effect analysis.

• Suppress multiple alarms from one event;
• Generate a single conclusion through logical cause-effect relationship;
• Automate the process to get answers quickly;
• Make graphical and numerical information concise and easy to follow.
## Data Processing

- **Input data list:**

<table>
<thead>
<tr>
<th>Data from RTU of SCADA (Main data)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 CB status change alarms (Opening and Closing)</td>
<td></td>
</tr>
<tr>
<td>2 Trip signal of main transmission line relays</td>
<td></td>
</tr>
<tr>
<td>3 Trip signal of primary backup transmission line relays</td>
<td></td>
</tr>
<tr>
<td>4 Trip signal of secondary backup transmission line relays</td>
<td></td>
</tr>
<tr>
<td>5 Trip signal of bus relays</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data from Digital Protective Relays (Additional data)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Pickup &amp; Operation signals of main transmission line relays</td>
<td></td>
</tr>
<tr>
<td>2 Pickup &amp; Operation signals of primary backup transmission line relays</td>
<td></td>
</tr>
<tr>
<td>3 Pickup &amp; Operation signals of secondary backup transmission line relays</td>
<td></td>
</tr>
<tr>
<td>4 Pickup &amp; Operation signals of bus relays</td>
<td></td>
</tr>
</tbody>
</table>
Information Extraction

- Stage I: System topology is analyzed based on CBs status data;

- Stage II: FRPN diagnosis and operation.
Implementation

Translational Knowledge through matching SCADA and relay data with the reasoning diagnosis model

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Implementation

- A FRPN model for BBSES_60A fault
- An Example of “Weighted Average” Operation
### Case Study

- **Alarm Screen Shot**

<table>
<thead>
<tr>
<th>AREA</th>
<th>CATEGORY</th>
<th>EVENT</th>
<th>EXCEED</th>
<th>LOCATION</th>
<th>TEXT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1004</td>
<td>GENERAT</td>
<td>ASC</td>
<td>MAJOR</td>
<td>9</td>
<td>RDMW</td>
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<tr>
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<td>GENERAT</td>
<td>ASC</td>
<td>MINOR</td>
<td>9</td>
<td>RSHOL</td>
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<tr>
<td>1006</td>
<td>GENERAT</td>
<td>ASC</td>
<td>MAJOR</td>
<td>9</td>
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<td>RSHOL</td>
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<tr>
<td>1008</td>
<td>EROST</td>
<td>LOG2</td>
<td>1</td>
<td>AASOGG</td>
<td>LOCAL</td>
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<tr>
<td>1009</td>
<td>EROST</td>
<td>LOG2</td>
<td>1</td>
<td>AASOOG</td>
<td>LOCAL</td>
</tr>
<tr>
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<tr>
<td>1011</td>
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<td>MAJOR</td>
<td>9</td>
<td>RSHOL</td>
</tr>
</tbody>
</table>

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Case 1:

**Condition:** No protective relay signals. CB4210, 4220, 4160 4920 status changes are detected.

**Diagnosis result:** Line BBSES_60A is faulted, and its truth value is 0.5130.

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Case 2:

**Condition:** Operation of CB is tripped by associated relays. Received relays signals. CB4210, 4220, 4160 4920 status changes are detected.

**Diagnosis result:** Line BBSES_60A is faulted, and its truth value is 0.8550. with the input of related relay signals, the fault certainness has been increased dramatically.
Advantages

• The fault alarm analysis report can be generated automatically and immediately after the fault occurs.
• The FRPN models can be built in advance based on power system and protection system configurations and stored in files.
• The FRPN models can be easily modified according to the changes of input data as well as power system and protection system configuration.
• This solution can use only SCADA data and does not need detailed data from IEDs or other measurement devices.
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Inherently Adaptive Fault Detection and Classification

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Overview of Neural Network Algorithms

The diagram illustrates a simple neural network model with input signals, synaptic weights, and an activation function. The input signals are denoted by $x_1, x_2, \ldots, x_n$, each connected to a corresponding weight $w_{ki}$. The weighted inputs are summed up at the summing junction, represented by the sum symbol $\Sigma$. The summation is then passed through an activation function $\phi(\cdot)$ to produce the output $y_k$. The bias term $b_k$ is also included in the summation process.
Fuzzy ART Neural Network Algorithm

Data From Power System Simulation

Data From Substation Historical Database

Data From Real System CVT, CT

Data Processing

ART Neural Network Training

Prototypes of trained clusters

Selection of K nearest neighbour Clusters

Fuzzy K-NN Classification

Fault Detection, Type & Zone

Knowledge

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Implementation

Detecting and Classifying Faults by Mapping Data to Labeled Clusters

- The raw training patterns - information
- The patterns are allocated to the clusters after a training processing - knowledge
Fuzzification of NN outputs
Final Implementation
Case Study

Error results of neural network fault classification tools

Basic K-NN (K=1) = 1.74%,  Fuzzy K-NN (K=4,m=1.4) = 1.52%
• **Fault location**: matching field data with model data creates an optimal solution;

• **Alarm processing**: matching data to the model of relaying logic creates an intelligent cause-effect analysis;

• **Protective relaying**: matching data vectors from the field signals with cluster of patterns designating fault types created an inherently adaptive protection.

Conclusions
Thank you!
Questions?

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