Distribution Automation – Smart Feeders in a Smart Grid World

Distribution Management Systems

Bob Uluski
DMS Defined

• Distribution Management System

A Decision Support System to assist the control room and field operating personnel with the monitoring and control of the electric distribution system

Note: Not to be confused with Demand Side Management (DSM)!
DMS Defined – What’s included?

• Basic operating tools
  – Distribution SCADA (DSCADA)
  – “Person in Charge” software tools
    • managing permits, clearances, safety protection guarantees
    • Generating switching orders
DMS Defined – What’s included?

• Advanced Distribution Applications
  – On line power flow
  – Load forecasting (short and long term)
  – State estimation
  – Fault location
  – Distribution contingency analysis
  – Distribution “congestion management”
  – System optimization (e.g. Optimal Network Reconfiguration)
**DMS Defined – What’s included?**

- May be a host for DA (feeder automation) applications
  - Fault location isolation and service restoration (FLISR)
  - Volt-VAR optimization (VVO)
The DMS Concept at BC Hydro
Topics

• DMS Functions pertaining to DA
  – On-Line Power Flow (OLPF)
  – State estimation
  – Fault Location
  – Switch Order Management (SOM)
  – Contingency Analysis
  – Congestion management

• System Integration (Hahn)
State Estimation

- **Objectives**
  - Topology verification
  - Estimation of loads
  - Validation of telemetered data
  - Load calibration

- **A Data Consolidation Process**
  - Take the advantages of sufficient measurement redundancy ($M/N > 1.5$)
  - Correct data errors due to conflict/incorrect/inaccurate/asynchronous measurements

- **Candidate State Variables (independent variables)**
  - Voltages
  - Branch Currents
  - Nodal Injections
DMS State Estimation

• DMS State Estimation (SE) - a procedure used to calculate the state of distribution system based on:
  – distribution system configuration (topology),
  – real time measurements and
  – customer load profiles – pseudo measurement

• Consists of:
  – Static state estimation
  – Identification and re-estimation of bad measurements and parameters
**On-Line Power Flow (OLPF)**

- **What is OLPF?**
  - A real-time version of the well known engineering power flow tool (“off line” power flow)

- **What does it do?**
  - Calculates electrical conditions (voltage, current, real/reactive power) at all points along the feeder.

- **OLPF objectives:**
  - Provide operators with nearly continuous “visibility” of all points along the feeder where no SCADA measurements exist (“state estimator” for distribution circuits)
  - Provide feeder electrical information needed by other DMS applications (FLISR, IVVC, Switch order management, etc)
On-Line Power Flow

• How does it work?
  – Works in much the same way as the engineering tool
  – Uses one of the many available iterative solution techniques:
    • Newton Raphson, YBus, ZBus, Forward/Backward “Sweep”
  – Must be able to handle radial circuit and “weakly meshed” circuit
    • Note: “Weakly meshed” means there may be a few loops
  – Unlike off-line engineering tool, OLPF results are scaled to match available real-time measurements
    • Substation end of feeder (breaker via DSCADA)
    • Mid line measurements (recloser via feeder SCADA)
    • Handful of AMI measures from strategically-placed measurements (distribution transformer, voltage at feeder extremities)
How DG is Modeled By DMS Vendors

- **Variations exist** in the way the DMS vendors handle DG resources:
  - **Full regulating model**
    - Generally the best approach for modeling the dynamic behavior of the DG units under normal and emergency conditions.
    - PQ type (fixed real and reactive power) or PV type (fixed real power and target regulating voltage).
  - **Negative Load Model**
    - Can be profiled, such as CHP (combined heating and power) units.
    - Fault current contribution is not accounted for in fault-level calculations.
    - Cannot be the only source of power for de-energized island.
  - **No model** – DER outputs captured by SCADA in real-time.
    - No guesswork regarding generator status and output.
    - May not be able to determine fault current contribution without a dynamic model.
    - Not really suitable for outage planning and engineering analysis (study mode).
  - **Three phase and single phase models**
    - Some vendors cannot handle single phase DER units, others can.
    - Some require balanced 3 phase generator output, other models support unbalanced performance.

- **Conclusion:**
  - Regulating Model (PQ or PV) is needed to properly model the effects of DG units under normal and emergency conditions (e.g. fault contribution).
  - Not all DMS vendors support the necessary facilities for handling DG.
  - Need to ask detailed questions; and make decisions accordingly.
On-Line Power Flow Models

• Feeder electrical model
  – Unbalanced 3-phase representation
  – Some DMS applications (especially IVVC) require modeling from substation transformer high side to distribution service transformer
  – Handle radial and weakly meshed circuits
  – Modeling of distributed generating resources
    • Fully regulating model
    • Negative load
  – Creating and maintaining the model
    • Via Geographic Information System (GIS) for large systems
    • Via existing engineering model or OMS
    • Manually (small systems only)
On-Line Power Flow Models

• Load models
  – OLPF solution requires load approximation for each distribution service transformer – *Load Estimator* function handles this
  – Conventional approach – use *load profile* obtained via statistical load survey
Viewing OLPF results

- Tabular display (SNC Lavalin)

![Power Flow Results Display](image)
Viewing OLPF results

- Graphical display (Telvent)
Viewing OLPF results

• Abnormal conditions (Areva)
Fault Location

• Objective: Assist field crews in pinpointing fault location
• Fault distance provided by protective relay IEDs not accurate:
  – Assumes homogeneous wire size/arrangement
  – Fault impedance unknown
• DMS Approach:
  – “Reverse short circuit” analysis
    • Obtain fault magnitude and type (A, B, C, A-B, etc) from relay IED
    • Determine possible fault locations using DMS short circuit analysis tool and associated feeder model
    • Determine electrical distance using reactance to fault – eliminate effects of mostly resistive fault impedance

© 2010 Quanta Technology LLC
Fault Location – DMS Reverse SCA Approach
Switching Orders

• Allows dispatcher to create, save, and print switching orders
• Dispatcher selects the switch and initiates the switching order menu item
• Switching order can include:
  – *Date and time in and out*
  – *Type of operation*
  – *Permit to work (Permit number, issue time, cancellation time)*
  – *Reason for order (planned outage, maintenance, test, etc.)*
• **Pre Switching Analysis**
Generation of Schematic Displays
Switch Order Management (SOM)

- In its simplest form, a computerized version of manual switch orders
- DMS version:
  - Graphical interface to create switch orders manually
  - Automatic creation of switch orders based on safety rules
  - Verification of switching orders
Switch Order Management
DMS Switching Plan

![Switching Plan Interface](image-url)

- **Device Information**
  - Type: SWITCH
  - ID: RFX34-RFX36-1

- **Step Search**
  - Column Name: No.
  - Search Criteria: 
  - Operation: 
  - Result: 

<table>
<thead>
<tr>
<th>No</th>
<th>Exec</th>
<th>Dev Type</th>
<th>Dev Id</th>
<th>Device State</th>
<th>Operation</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>E</td>
<td>SWITCH</td>
<td>RFX34-RFX...</td>
<td>In Service</td>
<td>Open</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>SWITCH</td>
<td>RFX34-RFX...</td>
<td>In Service</td>
<td>Add Tag</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>SWITCH</td>
<td>RFX34-RFX...</td>
<td>In Service</td>
<td>Remove Tag</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>SWITCH</td>
<td>RFX34-RFX...</td>
<td>In Service</td>
<td>Close</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>LNE</td>
<td>RFF32-RFX...</td>
<td>In Service</td>
<td>Linecut Add Tag</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>LNE</td>
<td>RFF32-RFX...</td>
<td>In Service</td>
<td>Connect Line Delete Tag</td>
<td>Make sure to wear rubber boots for this step</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Make sure to wear rubber boots for this step</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>LNE</td>
<td>RFF32-RFX...</td>
<td>In Service</td>
<td>Linecut Add Tag</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>LNE</td>
<td>RFF32-RFX...</td>
<td>In Service</td>
<td>Connect Line Delete Tag</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>SWITCH</td>
<td>RFX34-RFX...</td>
<td>In Service</td>
<td>Open</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>SWITCH</td>
<td>RFX34-RFX...</td>
<td>In Service</td>
<td>Add Tag</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td></td>
<td>SWITCH</td>
<td>RFX34-RFX...</td>
<td>In Service</td>
<td>Remove Tag</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td>SWITCH</td>
<td>RFX34-RFX...</td>
<td>In Service</td>
<td>Close</td>
<td></td>
</tr>
</tbody>
</table>
**Switch Order Verification**

- “Simulates” execution of the switch order

- Verifies that simulated steps don’t create undesirable electrical conditions

- Two Variations:
  - Maintenance planning mode (“day before”)
  - Near-Real-Time mode
Optimal Network Reconfiguration

• **Objectives**:  
  – Minimize energy losses on feeder lines (time frame of multiple hours or days)  
  – Balance loads among phases, feeders, substations, transformers  
  – Plan outages for equipment or feeder section maintenance

• **Seasonal Optimization**  
  – Goal => optimize topology for steady state operations  
    • Minimal power and energy losses  
    • Maximum reliability  
    • Best load balance  
    • Best voltage profiles

• **Near Real-Time Optimization**  
  – Normal operations => Loss Optimization Mode  
  – Emergency operations => Voltage Reduction Mode  
  – Peak load shaving => MW Reduction Mode

© 2010 Quanta Technology LLC
Distribution Contingency Analysis

• Objectives:
  – N-1 Screening for outages on potential devices/segments
  – Find out the critical outages that could result in key customers out of services

• Recommend remedial actions
  – Controls:
    • Reconfigure the feeder network
    • Reduce load, use local resources, etc.
  – Control Constraints:
    • Voltage Hi/Lo operation limits at each node and at any time interval
    • Loading limit at each line section, switch, Xfmr at any time interval

© 2010 Quanta Technology LLC
DER Congestion Management

- A function for monitoring, controlling, scheduling, and managing Distributed Energy Resources (DER) and Demand Response (DR).
- Provides two-way visibility between retail/demand-side resources, wholesale energy markets, and all the intermediate levels of the business hierarchy.
- Manages diverse types of demand-side resources – from dispatchable, voluntary, price responsive and dynamic tariff-based DR programs to distributed generation, storage, and PEV/PHEV.
- Forecasts and schedules DER and DR in support system and market operations.
- Allows participation of DER and DR in Energy, Capacity, and various Ancillary Services markets.
- Monitors distribution grid condition affected by DR/DER, including equipment loading constraints, voltage max/min constraints per phase, phase imbalances, and use distributed generation for satisfying voltage constraints.

© 2010 Quanta Technology LLC
Emerging trend – Integration of DMS/OMS Functionality

• There are some distinct differences between DMS and OMS
  – DMS generally has more real time monitoring and control functionality than OMS
  – OMS tends to have more customer-oriented functionality and crew dispatching capabilities

• There is a considerable amount of overlap between DMS and OMS
  – Maintenance of an up to date distribution system topology model (a huge task!)
  – Generation and simulation of switching orders

© 2010 Quanta Technology LLC
Benefits of DMS/OMS Integration

• Automatic capture of all automated restoration device operations
  – Reduced number of customers affected by the sustained outage
  – Reduced time to restore sustained outage due less time spent on manual sectionalizing

• Accurate accounting of outage durations as experienced by the customer (eliminate dependency on crew for outage start/stop time)

• DSCADA/DA/OMS operators have seamless view of DA schematic circuits & OMS geospatial circuits

• Operators have base platform for future advanced applications to be added – Switching & Tagging, System Estimation, IVVC etc

© 2010 Quanta Technology LLC
Emerging trend – Integration of DMS/OMS Functionality

• Traditional DMS/DSCADA vendors have or are developing OMS solutions
• Traditional OMS vendors have or are developing DMS/DSCADA solutions
• Will become even harder to distinguish DMS and OMS!