Distribution Automation – Smart Feeders in a Smart Grid World

Automatic Feeder Switching

Bob Uluski
Introduction

• Distribution Feeder Automation is the monitoring and control of devices located out on the feeders themselves
  – Line reclosers
  – Load break switches
  – Sectionalizers
  – Capacitor banks
  – Line regulators
Main Feeder Automation Applications

• Automated Line Switching (ALS)
• Volt/VAR Control (VVC)
  (Discussed in next Seminar Module)
Automatic Line Switching: The Value proposition

• Reduce system SAIDI & SAIFI significantly
• Accommodate and take advantage of distributed energy resources
• Optimal network reconfiguration
  – Reduce peak loading and total technical losses via load balancing
Primary ALS Application – “FLISR”

• **Fault Location, Isolation, and Service Restoration**

• *Use of automated feeder switching to:*
  – Detect feeder faults
  – Determine the fault location (between 2 switches)
  – Isolate the faulted section of the feeder (between 2 feeder switches)
  – Restore service to “healthy” portions of the feeder

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Nature of the Problem

• When a permanent fault occurs, customers on “healthy” sections of the feeder may experience a lengthy outage.

• FLISR provides the means to restore service to some customers before field crews arrive on the scene.

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Time Line Without and With FLISR

**Without FLISR**
- Fault Occurs
- Customer Reports Outage
- Travel Time: 5 – 10 minutes
- Fault Investigation & Patrol Time: 15 – 30 minutes
- Time to Perform Manual Switching: 15 – 20 minutes
- Repair Time: 10 – 15 minutes
- 1 - 4 Hours

**Power Restored to Customers on Healthy Sections of Feeder**
- Customer Reports Outage
- Field Crews On-Scene
- Patrol Time
- Repair Time
- Feeder Back to Normal: 1 to 5 minutes

**With FLISR**
- Fault Occurs
- Travel Time: 15 – 30 minutes
- Fault Located: 5 – 10 minutes
- Time to Perform Manual Switching: 5 - 10 minutes
- Repair Time: 1 - 4 Hours

**Power Restored to Customers on Healthy Sections of Feeder**
- Customer Reports Outage
- Field Crews On-Scene
- Patrol Time
- Repair Time
- Feeder Back to Normal: 1 to 5 minutes

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Terminology – Sample Feeder
Terminology – Automated Switches

- All switches must be **electrically operable**
- Can be **load break** or **fault interrupting** devices

**Substation #2**
- Normally closed (line) switch

**Substation #1**
- Normally open (tie) switch

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Terminology – Fault Detector (FD)

FD installed on every switch. FD indicates whether fault current has passed through the switch.

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Terminology – Feeder Sections

Section: a portion of the feeder between two automated switches

Substation #1

Substation #2

“Healthy” Feeder Section

Faulted Feeder Section

Substation #3

Fault
Terminology – Sources

“Strong” Source
– Capable of carrying a significant part of feeder 1 if necessary

“Weak” Source
– Capable of carrying only a small part of feeder 1

• Alternate sources required for maximum DA benefit
• Strong or Weak Source
Permanent fault occurs in section surrounded by switches 2, 3 and 6. FDs at switches 1 and 2 detect the fault. FLISR stores value of load through each switch just prior to the fault (usually a fifteen minute average). FLISR logic does not yet open/close any switches.
CB Trips – Feeder Deenergized

Circuit breaker trips
Entire circuit de-energized (dotted line)
FDs at switches 1 and 2 remain picked up
Still no FLISR control actions
CB Recloses – Fault Still There

Substation #2

FDs at switches 1 and 2 remain picked up
Still no FLISR control actions

Substation #2

Substation #1

Substation #3

Fault

Fault

Fault

Fault

Fault

Fault

Fault

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CB Trips Again – Feeder Deenergized

Circuit breaker trips and locks out

Entire circuit de-energized (dotted line)

FDs at switches 1 and 2 remain picked up

FLISR open/close logic triggered

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FLISR Step 1 – Identify Faulted Section

FDs 1 & 2 saw a fault
FDs 3 and 6 did not see the fault
Fault must be in section between switches 2, 3, & 6
FLISR Step 2 – Isolate Faulted Section

- Automatically open switches 2, 3, & 6
- Faulted Substation Section
- Substation #2
- Substation #3
- Substation #1
**FLISR Step 3 – Restore “Upstream” Section**

“Upstream” = between substation and faulted section

FLISR closes CB

No need to check load – we know CB can carry the first section

FD at switch # 1 resets
FLISR Step 4 – Restore “Downstream” Load

(This is the tricky part)

“Downstream” = between faulted section and end of feeder

Substation #2 is a “strong” source – it can carry additional load
Close switch 4 to pick up part of faulted feeder

Substation #1
Substation #2
Substation #3

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FLISR Step 5 – Restore “Downstream” Load (continued)

Substation #3 is a “weak” source – can’t carry additional load at this time
Switch 7 remains open
Feeder section between switches 6 and 7 remain de-energized
End of FLISR operation
**FLISR Benefits**

- **Reliability Improvement** - Significant portion of customers restored quickly (1 minute or less, versus 45 – 75 minutes without FLISR)

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**SAIDI Improvement Versus Baseline**

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<th>Conventional recloser</th>
<th>DA With Load Break Switches</th>
<th>DA With Reclosers</th>
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<td>Improvement</td>
<td>33%</td>
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**SAIFI Improvement Versus Baseline**

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<td>18%</td>
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**SAIFI(MI) Improvement Versus Baseline**

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**CAIDI Improvement Versus Baseline**

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Estimating Reliability Improvement Benefits From FLISR

Some Useful Formulas

**Note:** These formulas assume that customers are evenly distributed over the length of the feeder, faults are equally likely to occur anywhere **AND** there is a suitable alternative source that is located downstream of the switch.

- **% customer minute (CM) & customers interrupted (CI) savings with DA**
  - Assumes all DA switches have a suitable “downstream” source.
  - No reclosers initially:
    - **% Improvement = \( \frac{\text{NSW}}{\text{NSW} + 1} \times 100 \)**
      - Where NSW = # of normally closed DA switches.
      - Example: if NSW = 3, % improvement = \( \frac{3}{3+1} \times 100 = 75\% \)
  - Have reclosers to start with:
    - **% Improvement = 0.5 \times \frac{\text{NSW}}{\text{NSW} + 1} \times 100**
      - Example: If NSW = 3, % improvement = \( 0.5 \times \frac{3}{3+1} \times 100 = 37.5\% \)
Other FLISR Benefits

• **Labor Savings** – Less fault investigation and patrol time because fault location is narrowed down considerably

• **Reduction in Unserved Energy** – Get some meters turning sooner

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**Feeder Load Balancing**

- **Objective:** Reduce peak demand on feeders/substations by periodically shifting load between connected feeders to achieve better balance.
- Must have significant diversity between feeders.

- “Make before break” to avoid momentary outages.
Load Balancing – Normal Configuration

Substation #2

Sub #1 at Peak Load

Substation #1

Substation #3

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Load Balancing – Sub#1 At Peak Load

Sub #1 at Peak Load

Load Transferred To Sub #3
Load Balancing – Sub#3 At Peak Load

Substation #2

Sub #3 at Peak Load

Load Transferred To Sub #1

Substation #1

Substation #3

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Load Balancing - Benefits

• Reduction of Peak Demand on individual substation
  – Defer capacity addition
  – Reduce individual substation demand charges

• Reduction of Electrical Losses
  – Total losses with balanced load < Total losses with one heavily loaded feeder and one lightly loaded feeder
Beyond Load Balancing –

*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
Cold Load Pickup

• **Objective:** Reduce the time to restore load following extended outage for which cold load conditions apply

• Restore service a section at a time via remote control
Cold Load Pickup Example

Substation #1

Substation #2

Substation #3
Cold Load Pickup Example

Open all switches via remote control
Cold Load Pickup Example

Substation #2

Substation #1

Substation #3

Restore one section at a time
Cold Load Pickup Example

Substation #1

Substation #2

Substation #3

Restore one section at a time
Cold Load Pickup Benefits

• Reliability Improvement Benefit: Faster overall service restoration

• Labor Savings: Fewer manual switching activities, less travel time
Emergency Load Shedding

• Some utilities are limited in amount of load shedding that is possible due to presence of critical (non-interruptible) loads

• Automated switches can be used to shed load on such feeders without impacting non-interruptibles
Load Shedding Using Line Switches

Substation #2

Non-Interruptible Customer in this section

Substation #3

Open This Switch

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Use of Faulted Circuit Indicators

Remotely monitored faulted circuit indicator can assist in pinpointing fault location
Benefits of FCI Monitoring

Fault Prediction by OMS/AMI
Benefits of FCI Monitoring

Fault Prediction by OMS/AMI & FCI
Risk – Section “Net Load” Problem

With DG running, pre-fault load through switch 6 is 1 MW
However, total load in this section is 3 MW (DG supplying 2 MW)
FLISR may use prefault load thru switch 6 to make downstream switching decision
This could overload Substation 3
FLISR with Large DG or Distribution Networks

FLISR fault detectors might predict fault beyond switch number 6, and…. 
FLISR with Large DG or Distribution Networks

Substation #2

Trip switch 6, ultimately resulting in…

Substation #1

Fault Current

Substation #3

Fault

No Fault

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FLISR with Large DG or Distribution Networks

Substation #2

Entire feeder outage

Substation #1

Substation #3

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FLISR with Large DG or Distribution Networks

With directional fault indicators, FLISR would locate the fault properly, resulting in...
FLISR with Large DG or Distribution Networks

Power restored to as many customers as possible!
Use of Line Reclosers for FLISR

Substation #1

Substation #2

Substation #3

Line Recloser

Fault

No Fault
If line reclosers are used instead of load break switches, only a portion of the feeder is interrupted, but…. 
FLISR With Line Reclosers

• May have difficulty coordinating several reclosers in series
  – Trip faster than upstream switches
  – Trip slower than downstream switches
  – Trip slower than downstream fuses
Line Recloser Trips –
Portion of Feeder Deenergized

Substation #2

May have difficulty coordinating a series of line reclosers, resulting in….

Substation #1

Substation #3

1
Fault

2
Fault

3
No Fault

4
Line Recloser

5

6
Fault

7
Fault

8

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Line Recloser Trips – Coordination of Reclosers in Series

This switch must operate slower than downstream fuse, but faster than upstream recloser

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Using Directional Blocking Scheme

Controller at “6” detects fault and fault direction

Substation #2

Line Recloser

Substation #1

Substation #3

Fault

Fault

Fault

Fault

No Fault

Radio

Radio

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Using Directional Blocking Scheme

Controller at “6” detects and sends blocking signal to “2”.

Substation #1

Substation #2

Substation #3

Line Recloser

Fault

No Fault

Please don’t trip!

Radio

Radio

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Using Directional Blocking Scheme

Substation #1

Substation #2

Fault

Line Recloser

Fault

No Fault

Fault

Fault

 Fault

Substation #3

Only the recloser at switch 6 trips

Please don't trip!

Radio

Radio

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System Components

Distribution SCADA system
– Remote controlled feeder switches
– Feeder RTU or Controller
– Fault detectors
– Two-way communication facilities
Distribution SCADA System

• Supervisory Control and Data Acquisition (SCADA) system:
  
  – **Minimum requirement:** Allow distribution system operator to **monitor and oversee** operation of the feeder automation facilities
  
  – May also perform the bulk of the feeder automation processing (centralized scheme only – more on this in Module 5)
Feeder Automation Switches

- All switches must be **electrically operable**
- Can be **load break** or **fault interrupting** devices
- Can be **overhead** or **underground** (padmount) switches

Load Break Switch.
Photo courtesy of Bridges Electric

ABB OVR Recloser

Kyle® Type NOVA™ Recloser
Fault Interrupting Device.
Photo courtesy of Cooper Power Systems

Pad Mounted Switch

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Retrofit Motor Operators

may be able to save money by **retrofitting** a motor operator on an existing manual switch

Retrofit Pole Mounted Switch
Photo Courtesy of Cleaveland Price, Inc

Retrofit Padmount.
Photo Courtesy of S&C Electric Co

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# DA Switch Vendors

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Feeder RTU or Local Controller

- Acquires data from FD or local sensors (or can serve as FD!)
- Executes control commands
- May perform bulk of feeder automation processing (distributed architecture)
- Provides interface to communication facilities

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Fault Detector (FD)

• Determines that a fault has occurred “downstream” (further from the substation)

• Basic Requirements
  – Must be able to identify and “capture” the fault information before fault is cleared (in a few cycles)
  – Must be able to detect all kinds of faults
    • Phase faults
    • Ground faults – current may be less than normal load – must use “residual” current

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Two Ways to Accomplish FD

• Faulted Circuit Indicator (FCI)

• Current/Voltage Sensor
Faulted Circuit Indicators

Faulted Circuit Indicator (FCI)
Close a contact when pre-established ampere threshold is exceeded

– Clamp on style
– Current inrush restraint
– Must work in either direction
– Reset conditions
  • Time
  • Restoration of voltage or current
– Local indicator visible from ground level
– Output signal to feeder RTU
  • Radio signal
  • Fiber optic/metallic cable

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Radio Transmitter Style Fault Indicator
Current & Voltage Sensors

- Perform basic current & voltage measurement
- Provide measurement to a separate device for analysis ("does measurement exceed threshold?")
- Doubles as data acquisition unit for feeder monitoring (SCADA) system
- Voltage sensor may also serve as a power source for DA feeder equipment
- Basic requirements
  - Accuracy at least + or - 3%
  - Suitable for measuring fault current (should not saturate)
  - Can be standalone unit(s) or integral part of switch itself

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Current & Voltage Sensors

Can be an integral part of the DA switch

“ScadaMate” by S&C Electric

Current-Voltage Sensor
**Bidirectional Fault Indicators**

- Provide fault detection and direction of fault
- Useful Required for
  - Systems with DG
  - closed loop, paralleled or networked distribution systems

Power Delivery Products

http://www.powerdeliveryproducts.com/directionalfaultindicator.htm

Quanta Technology has seen a growing number of utilities using **directional overcurrent relays** for this purpose

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Communication Facilities

• System requires reliable 2-way communication facilities to feeder locations

• Common approaches:
  – Licensed UHF MAS radio
  – Unlicensed Spread spectrum radio
  – Cellular telephone & other commercial services
  – Power line carrier
  – WiMAX

More details on DA Communications later
Control Panels

• Open/Close Pushbuttons
• Switch status (open/closed) indicators
• Alarm indicators
• Local/remote switch
• Operations counter
  – Electrical operations
  – Mechanical operations?
**Switch Power Supply (SPS)**

- **Key Point:** Most switch operations run off the SPS with the line dead!
  - Should specify a required number of operations with the power off (biggest power drain is radio transmitter)
  - As an **absolute minimum**, must be able to open switch and close switch once without recharging (with the line dead)

- **Power Source**
  - Voltage sensor may provide all the power needed by the switch, controller, and radio
  - If not use **dedicated voltage transformer** or connect to **local secondary circuit**

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Categories for Automated Line Switching

• Approaches categorized on how control is performed:
  – Supervised
  – Semi-Automatic
  – Fully Automatic
**Feeder Automation Categories**

- **Supervised**
  - No automatic control – “person in the loop”
  - System delivers information (recommendations) to Dispatcher
  - Dispatcher initiates remote control actions

  - **Pro’s**
    - Simpler than fully automatic
    - Good “starter” approach until confidence is built up

  - **Con’s**
    - Takes longer to restore service (3 – 5 minutes)
      - Communication time (both ways)
      - Dispatcher decision time
    - Difficult for dispatcher to manage many switches during emergencies involving multiple disturbances
**Feeder Automation Categories**

- **SEMI-AUTOMATIC**
  - Mix of automatic and supervised control
  - Example
    - DA system automatically isolates fault and performs “upstream” restoration (the “easy” part)
    - Dispatcher supervises “downstream” restoration activities based on DA system recommendations (the “hard” part)
  - **Pro’s**
    - Simpler than fully automatic
    - Natural progression from supervised approach
    - Where many utilities end up
    - “Upstream” customers restored in less than 1 minute
  - **Con’s**
    - Takes longer to restore “downstream” service (3 – 5 minutes)
    - Difficult for dispatcher to manage many switches during emergencies involving multiple disturbances
    - Not supported by some DA vendors
Feeder Automation Categories

- FULLY AUTOMATIC
  - All fault isolation and restoration activities performed automatically
  - Current state of the art
  - No dispatcher intervention

• Pro’s
  - Possible to restore all service in less than one minute
  - Less burden on Dispatcher to manage the switching activities

• Con’s
  - Most complex approach
  - Acceptance difficulties
    » Ranges from “Why not?” to “Over my dead body”
Practical Matters to Consider
• Tradeoff: “Permanent” vs. “Momentary” Outages

  • Definitions:
    – Permanent: Duration > threshold
    – Momentary: Duration < threshold

  • Use of FLISR will:
    – Improve permanent outage statistics
      • SAIDI, SAIFI, CAIDI
    – Make momentary outage statistics worse
      • MAIFI

  • Most utilities are willing to accept this tradeoff!
• Limitations on Transferring Load to Adjacent Feeders
  – It is often difficult to transfer all the “healthy” load to adjacent feeders without causing overloads and/or voltage problems
  – Especially true during peak load period
  – May need to split load being transferred to alternative sources
  – May require additional automated switches and addition tie points to accomplish FLISR objectives at certain times of the day
  – Key Point: Must have backup source to get incremental reliability improvement beyond simple recloser!
  – Can use DG, Energy Storage, and other Distributed Energy resources for downstream restoration (More later in DG Section – Farid)
Estimating Reliability Improvement Benefits
Another Useful Formula (Continued)

- **reduction in reliability improvement** if some switches do not have a suitable downstream source

\[
\text{% reduction in reliability Improvement} = \frac{100 \times \left( \sum_{i=1}^{\text{NDSS}} i \right)}{\left( \text{NSW} + 1 \right)^2}
\]

- Where: \( \text{NDSS} \) = # of DA switches that do **not** have a suitable downstream source

- Example: with total of 4 normally closed DA switches (NSW = 4), what is the reduction in benefits if 2 of these switches does not have a suitable downstream source?
  \[100 \times \frac{1 + 2}{(4+1)^2} = \frac{300}{25} = 12\% \text{ reduction in savings}\]
Reliability Improvement versus Number of Switches - Diminishing Returns

Additional reliability improvement benefit declines dramatically as more switches are added

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Reliability Improvement versus Number of Switches

Usually 2 ½ switches is best for reliability improvement BFTB – more switches added due to load transfer constraints, critical customers, and unusual feeder configuration.
**Importance of Switch Placement**

- Predicted reliability improvement varies widely with switch placement strategy

- **KEY POINT!**: Splitting customer count into equal physical parts is only best when customers and fault exposure are evenly distributed across the feeder (rarely the case!)

- Hypothetical Case – all customers concentrated in one spot

  - If Length “A” is really small, and
  - the backup sources is strong (able to carry the entire sample feeder)
  - SAIDI and SAIFI for concentrated load could be nearly reduced to zero!.....

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Importance of Switch Placement

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  - If Length “A” is really small, and the backup sources is strong (able to carry the entire sample feeder)
  - SAIDI and SAIFI for concentrated load could be nearly reduced to zero!.......  

Hypothetical case is not realistic, but shows that it’s beneficial to surround concentrated load with DA switches
Importance of Switch Placement

- Switch placement analysis is not trivial – should use engineering analysis tool!

- Sample variation between equal physical division and optimal placement:
  - SAIDI - 22%
  - SAIFI - 31%
  - MAIFI - 23%

- Small change in placement (a few hundred feet) produced a 5% change in SAIDI!
**Single Phase Tripping**

- Some newer line reclosers support single phase tripping
- Can perform FLISR operation on only the faulted phase – avoid service interruption on unfaulted phases (SAIDI, SAIFI benefit)
- Issues:
  - Adverse impact on 3 phase loads
  - Remaining two phases may trip ground relay on load imbalance
- Typical solution:
  - Trip and reclose single faulted phase for temporary fault
  - Trip and lockout all three phases for permanent fault
Faults on Fused Laterals

• No incremental benefit for permanent faults on fused laterals
  – Must take this into account when computing potential benefits

• For temporary faults:
  – Can apply fuse saving
  – New S&C “TripSaver” Dropout Recloser
**First Segment Fault Detection**

• Always an issue!

• System requires a “lockout for fault” signal from the substation to trigger feeder switching activities
  – Fault has occurred
  – Feeder protection has completed its automatic reclosing cycle

• Works best if a protective relay IED is available in the substation and can be interfaced to the FLISR system
Non-Fault vs Fault Tripping

• System must be able to distinguish between “non fault” and “fault” tripping of the substation circuit breaker/recloser

• “Fault” Tripping
  – A feeder fault has occurred or supply has been lost due to a transmission substation fault
  – FLISR should attempt to restore service

• “Non-Fault” Tripping
  – Substation CB tripped for reasons other than a feeder fault
    • Manual operation by switching personnel or supervisory control from the control center
    • Underfrequency/undervoltage load shedding
  – FLISR should not attempt to restore service
Impact on Feeder Protection

Entire feeder must remain protected following FLISR operation!.....
So if source at substation 1 is lost.....
Impact on Feeder Protection

FLISR May reconfigure feeders as shown.....
Impact on Feeder Protection

Feeder relays at “5” must be able to reach all the way to switch 1.

Note: relay IEDs can switch between setting groups but most DA/DMS systems don’t auto switch the settings.
Safety Issues

• Safety for workers and general public must not be compromised!!!
• Operating practices and procedures must be reviewed and modified if necessary to address presence of automatic switchgear
• Safety related recommendations:
  – Requirement for “visible gap”
  – No automatic closures after two minutes have elapsed following the initial fault
  – System disabled during maintenance (“live line”) work