GE Energy – T&D

DMS System:

System Modeling & Advanced Applications in Smart Grid

Dr. Jiyuan Fan

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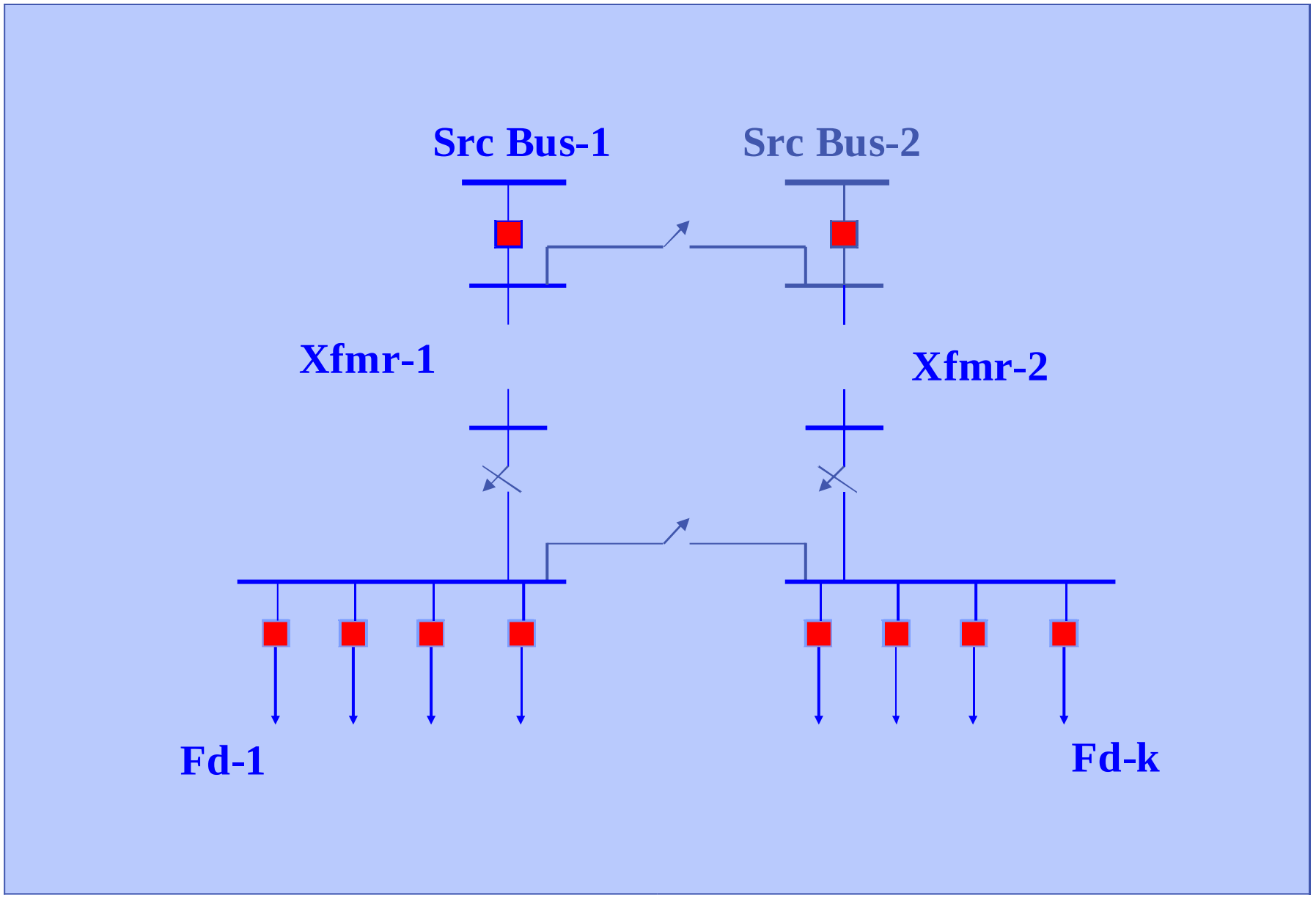
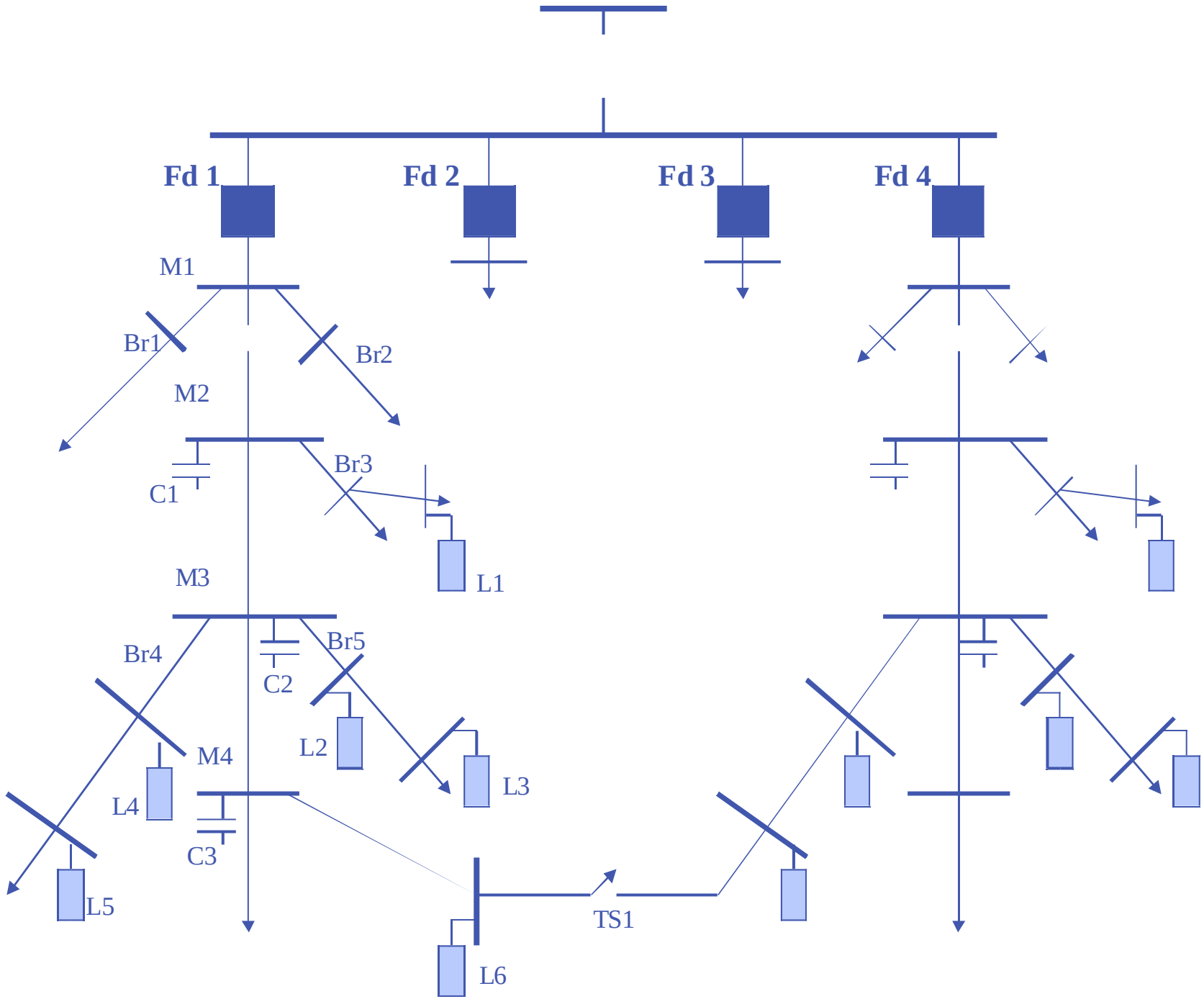
imagination at work

DMS: Distribution Substation Circuits

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Fd 2
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M1
Br1
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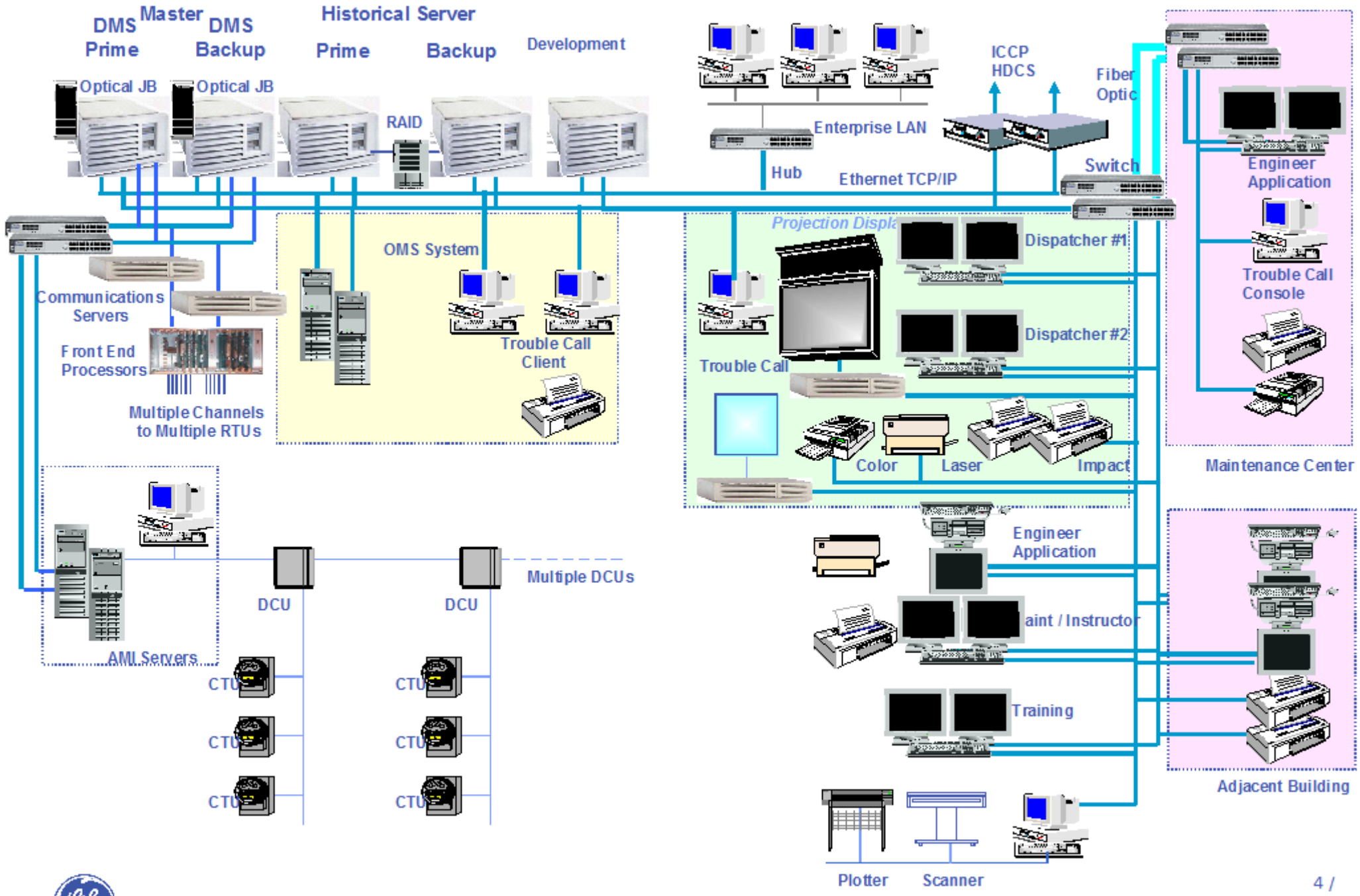
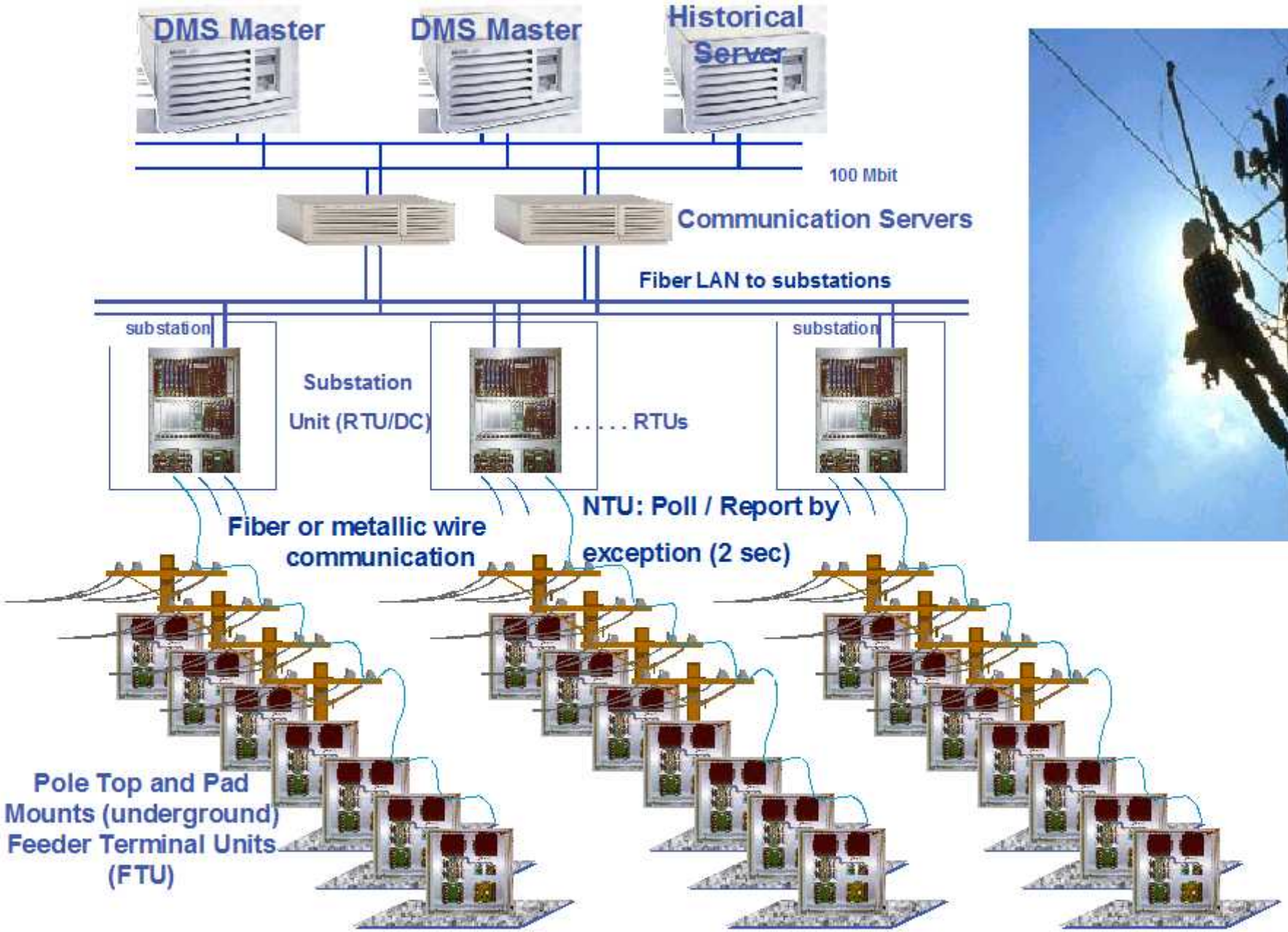
M2
C1
Br3
L1
M3
Br4
C2
Br5
L2
L3
M4
L4
C3
L5
L6
TS1

A Typical Distribution Automation Management System



A Typical DMS Hardware Architecture



Advanced DMS Applications

IVVC → Integrated Volt/Var Control

FDIR → Fault Detection, Isolation, service Restoration

TP → Topology Processor

DPF → Distribution Power Flow

SE → State Estimation

ONR → Optimal Network Reconfiguration

LE → Load Estimation

CA → Contingency Analysis

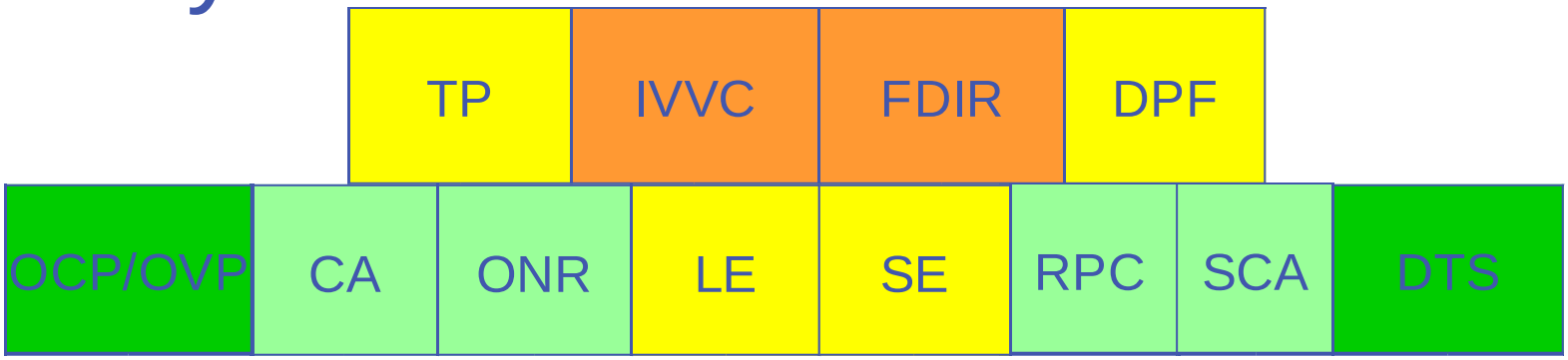
SCA → Short Circuit Analysis

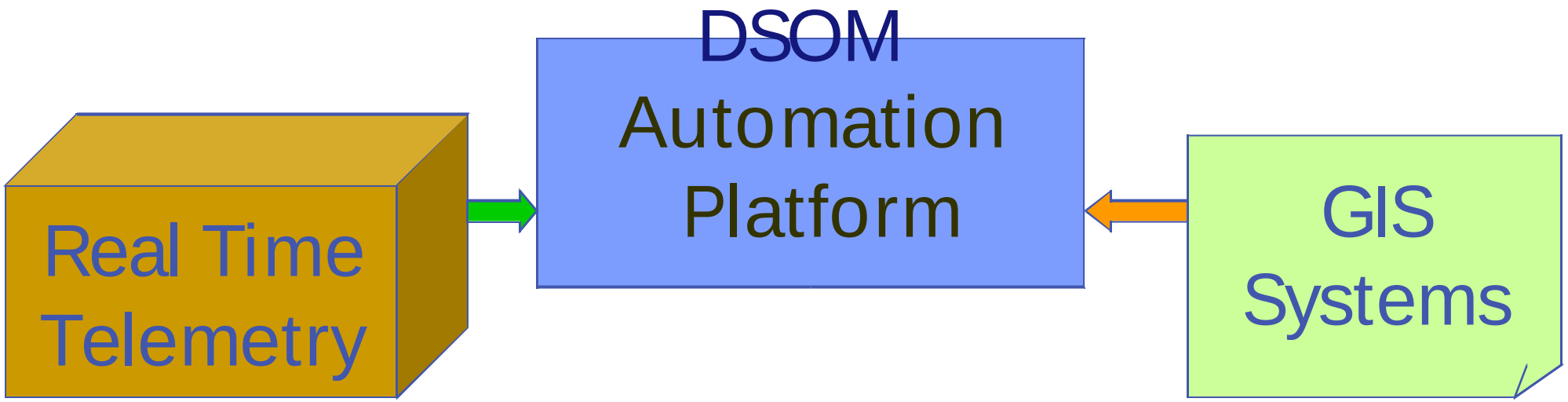
RPC → Relay Protection Coordination

DTS → Dispatch Training Simulator

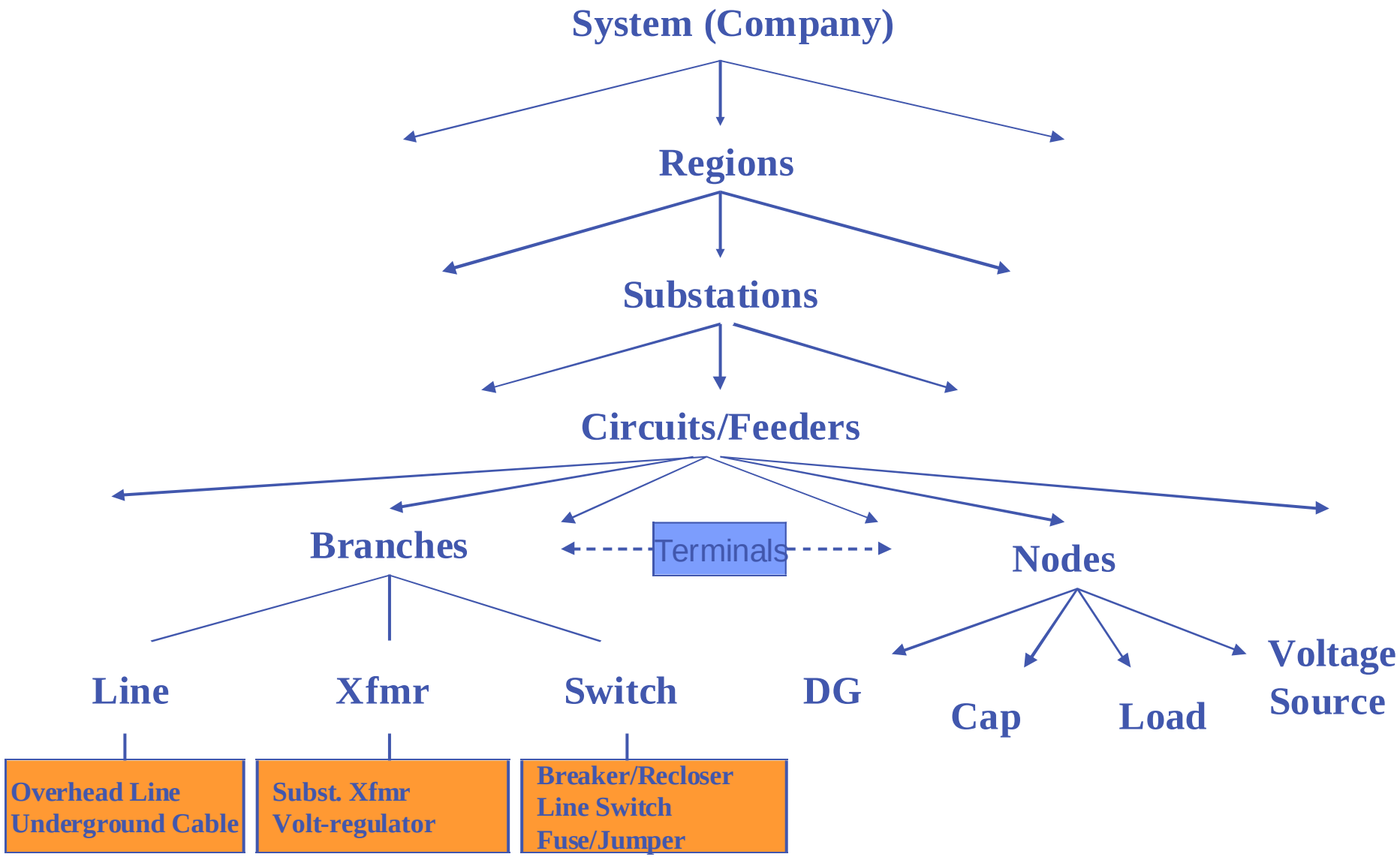
OCP/OVP→ Optimal Cap/VR Placement

Advanced DMS System Layout





DSOM Architecture Hierarchy



Topology Processor (TP)

A Base Function with the Following Features:

- Modeling Switch Configuration in Subs. and Feeder network
- Forming Bus Oriented Network Model for Other APPs.
- Tracing Network Connectivity, Equipments and Paths
- Determining/Coloring Status of Devices, Bus, Island, Loop, etc.
- Detecting Conflicts of Status and Analog Telemetries
- Supporting Intelligent Alarm Processing

Dispatcher Power Flow (DPF)

- **Real-Time Analysis and Study Mode Evaluation**
- **3-phase unbalanced distribution networks and loads**
- **Radial and/or meshed distribution networks**
- **Solves Bus (V, I, P, Q), Branch (I, P, Q, Loss)**
- **Solution algorithms:**

Newton Raphson Method(Expensive, not effective due to high r/x ratio)

Y-Bus Method: (Good for meshed case, inefficient for radial case)

$$I_{abc} = Y_{abc} V_{abc}$$ **(Determined problem, unknowns=equations)**

Forward/Backward Sweeping (Efficient for radial case)

Parallel Calculation (Enhancement for radial case)

Superposition (Efficient for very weakly meshed case)

Combined Y-Bus and F/B Sweeping (Efficient for general)

Integrated Voltage/Var Control (IVVC)

Functional Features & Capabilities :

- **Minimize Feeder Network Energy Loss**
- **Maintain Desired Feeder Network Voltage Profiles**
- **Conservative Voltage Regulation(CVR) for Reduced Load Consumption**
- **Control Devices:**
  - **Substation Transformer Taps**
  - **Feeder Voltage Regulators**
  - **Feeder Capacitor Banks**
- **Control Constraints:**
  - **Voltage Hi/Lo operation limits at each node and at any time interval**
  - **Loading limit at each line section, switch, VR at any time interval**
  - **Number of Cap operation per day**
- **Solution Algorithms:**
  - **Non-linear mixed integer programming (NLMIP)**
  - **Truncated Dynamic Programming (TDP)**
  - **Sequential Committing**

IVVC Objective Functions:

- MWhr management:

  Minimize MWhr consumption within voltage and loading limits

- Economic benefit:

  Maximize benefits within voltage and loading limits

- Circuit performance:

  Minimize losses on distribution feeders close to a given voltage level.

  Minimize feeder voltage drop (Flatten feeder voltage profile)

- Grid support:

  Request Var support to the grid within voltage limits.

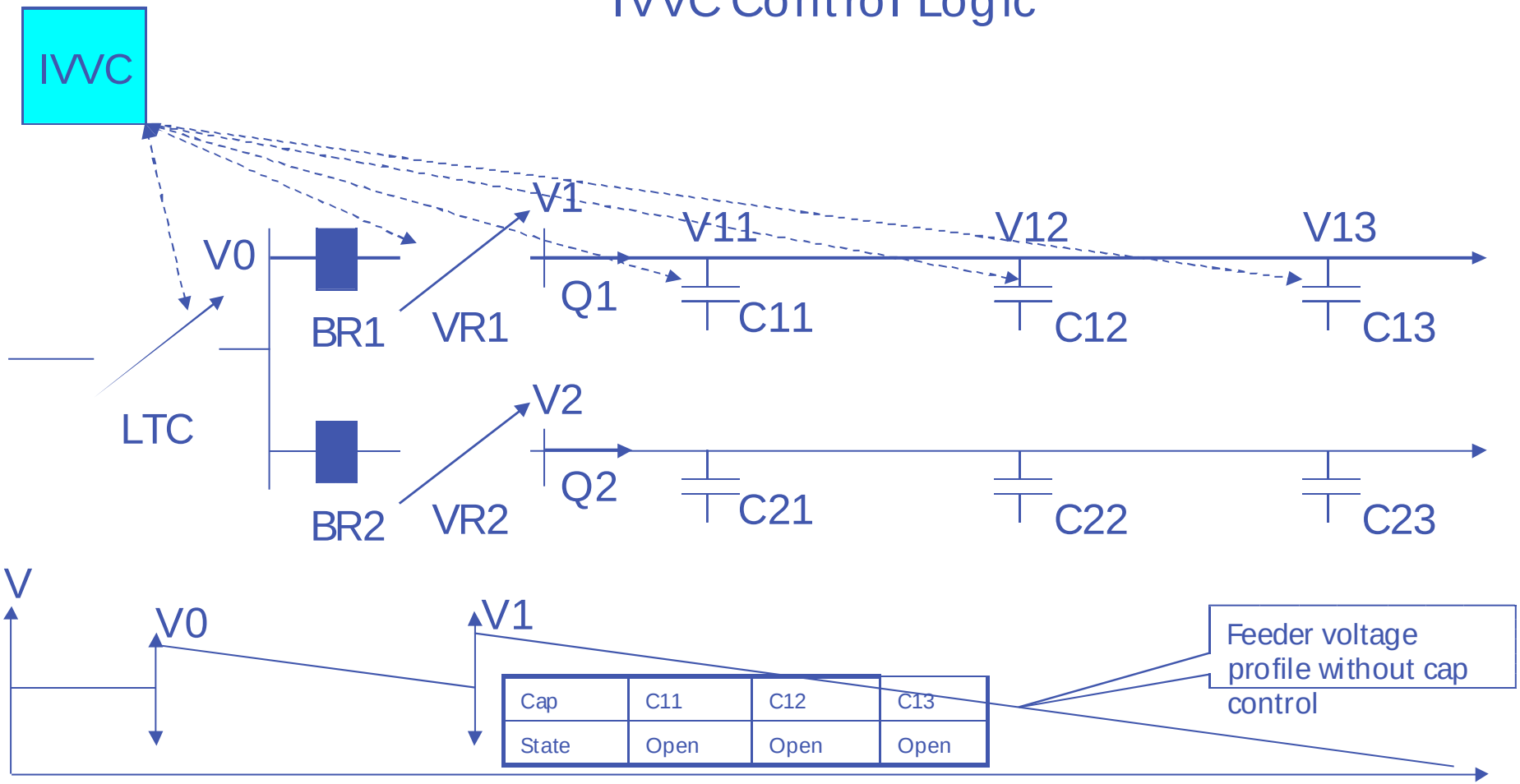
  Requested load reduction within voltage limits

- Operation Modes:

  Closed loop real time automation control with look-ahead

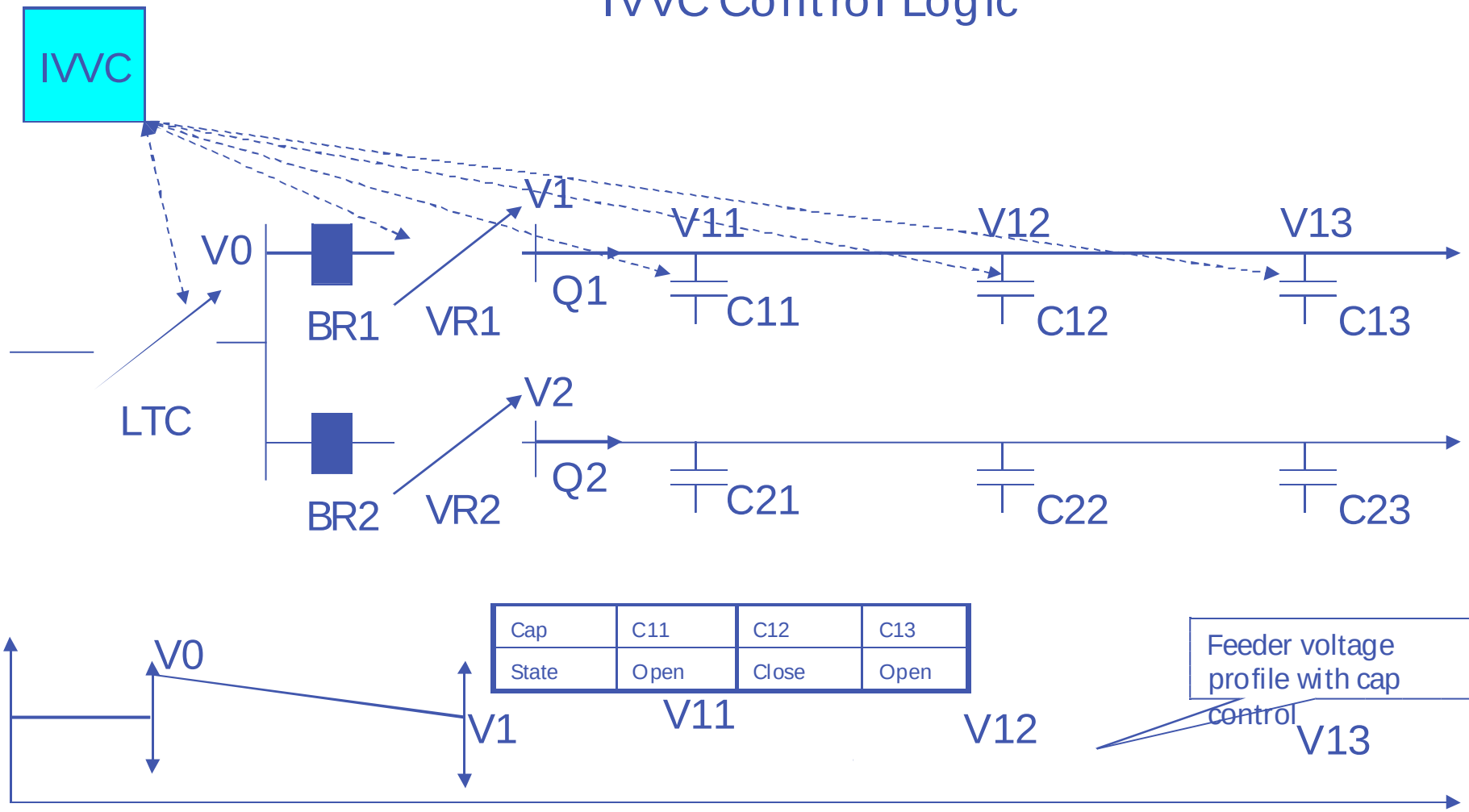
  Advisory/Study analysis with look-ahead for different time frame

IVVC Control Logic



Feeder Voltage Profile Without IVVC Control

IVVC Control Logic



Feeder Voltage Profile With CVR Contrl in IVVC

Fault Detection, Isolation, Restoration (FDIR)

Objectives :

- Detect and isolate fault in a few seconds
- Upstream restoration less than 10 seconds
- Downstream restoration less than 30 seconds

• Control Devices:

- Feeder breaker/recloser
- Feeder line sectionalize

• Control Constraints:

- Voltage Hi/Lo operation limits at each node and at any time interval
- Loading limit at each line section, switch, VR at any time interval

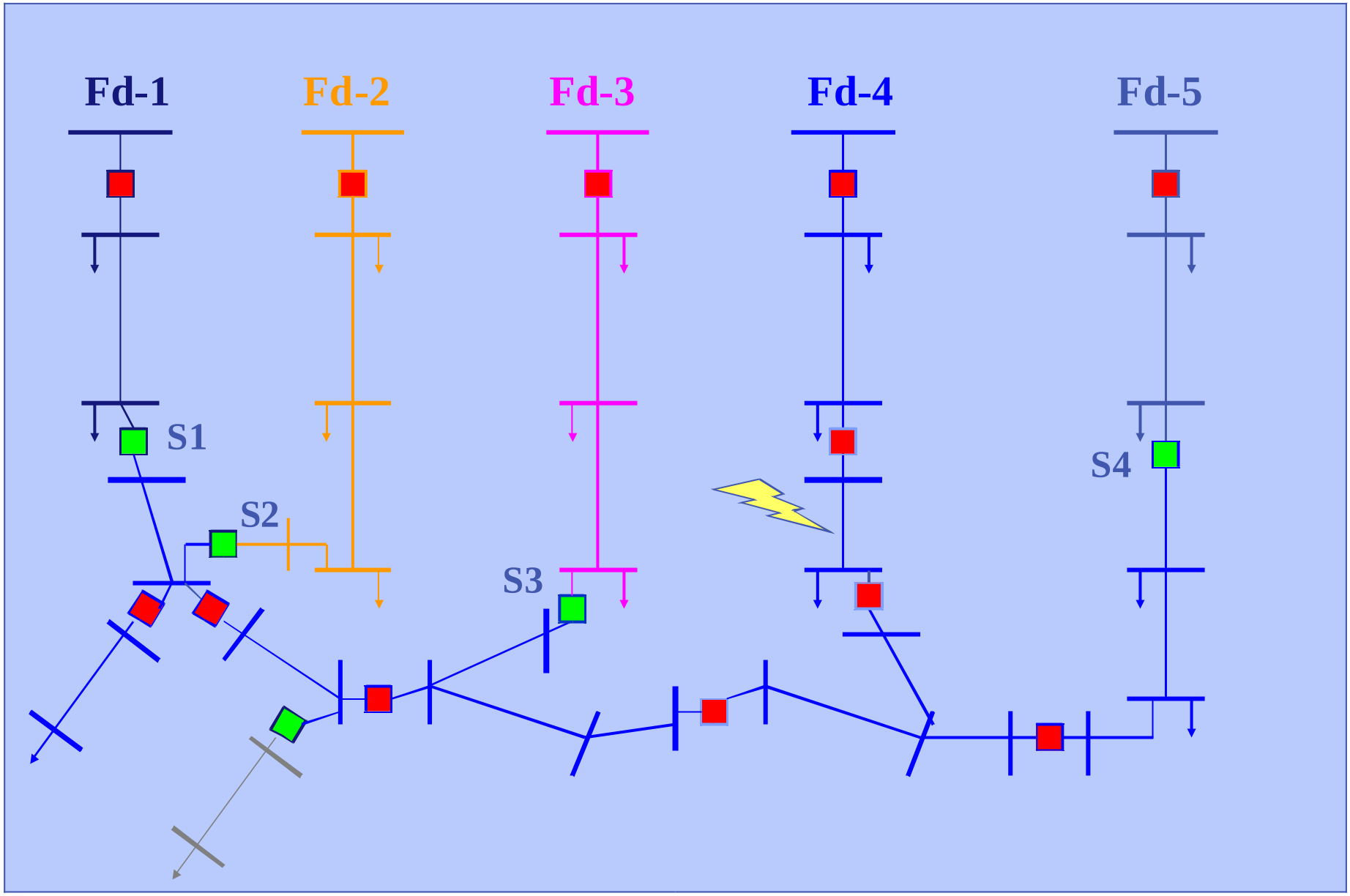
• Solution Algorithms:

- Heuristic rules and exhaustive search

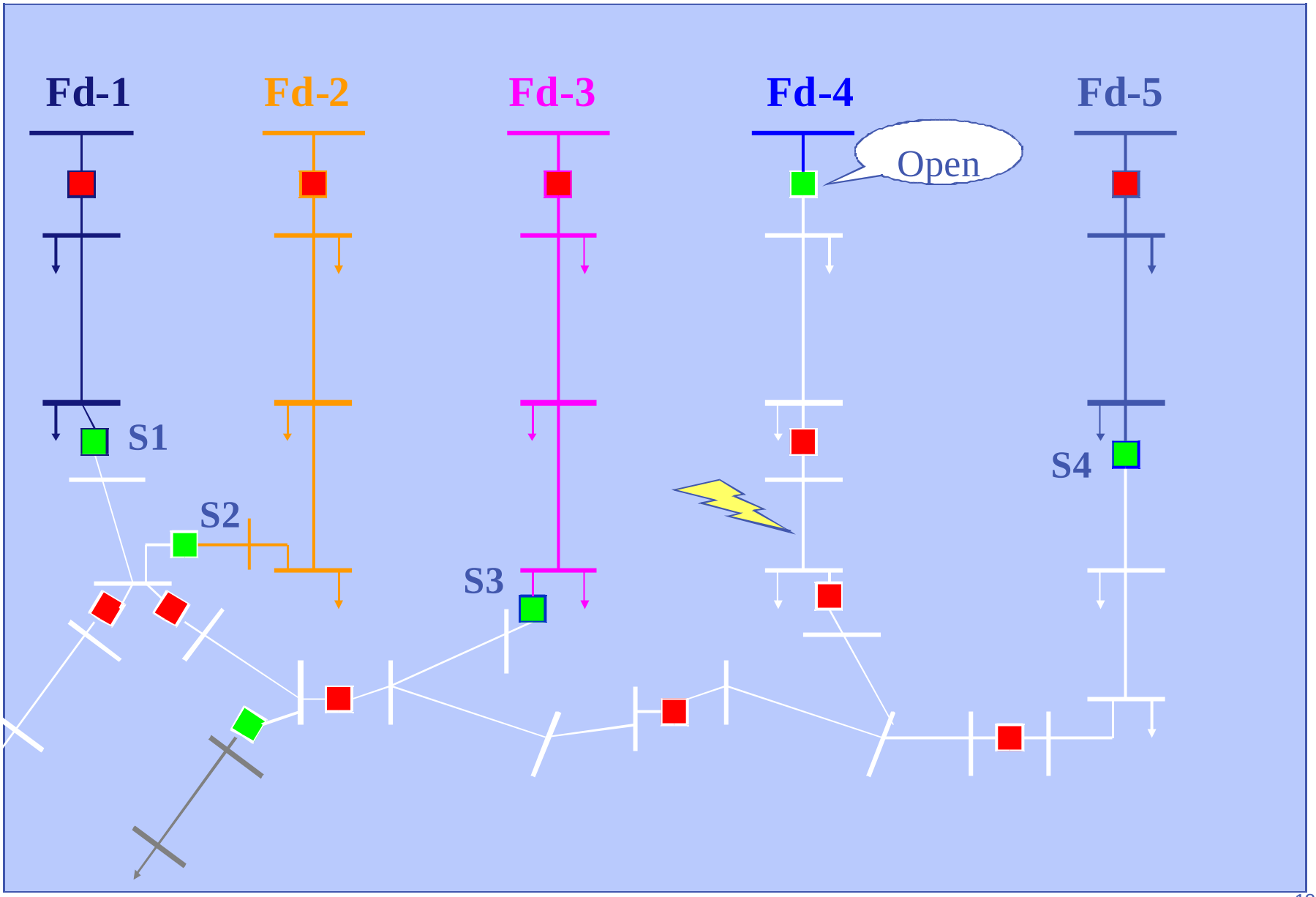
FDIR Objectives:

- Restore services as much as possible
  - Consider load priorities
- Use as less number of sources and switches as possible
  - Use less number of alternative sources
  - Use the sources from the same feeder, or same substation first
- Look-ahead for maximum time frame
  - Minimize the chances for reconfiguration within the repairing time
- Minimize economic loss
  - Minimize feeder line losses wit the new configuration
  - Maintain healthy voltage profile and load balancing

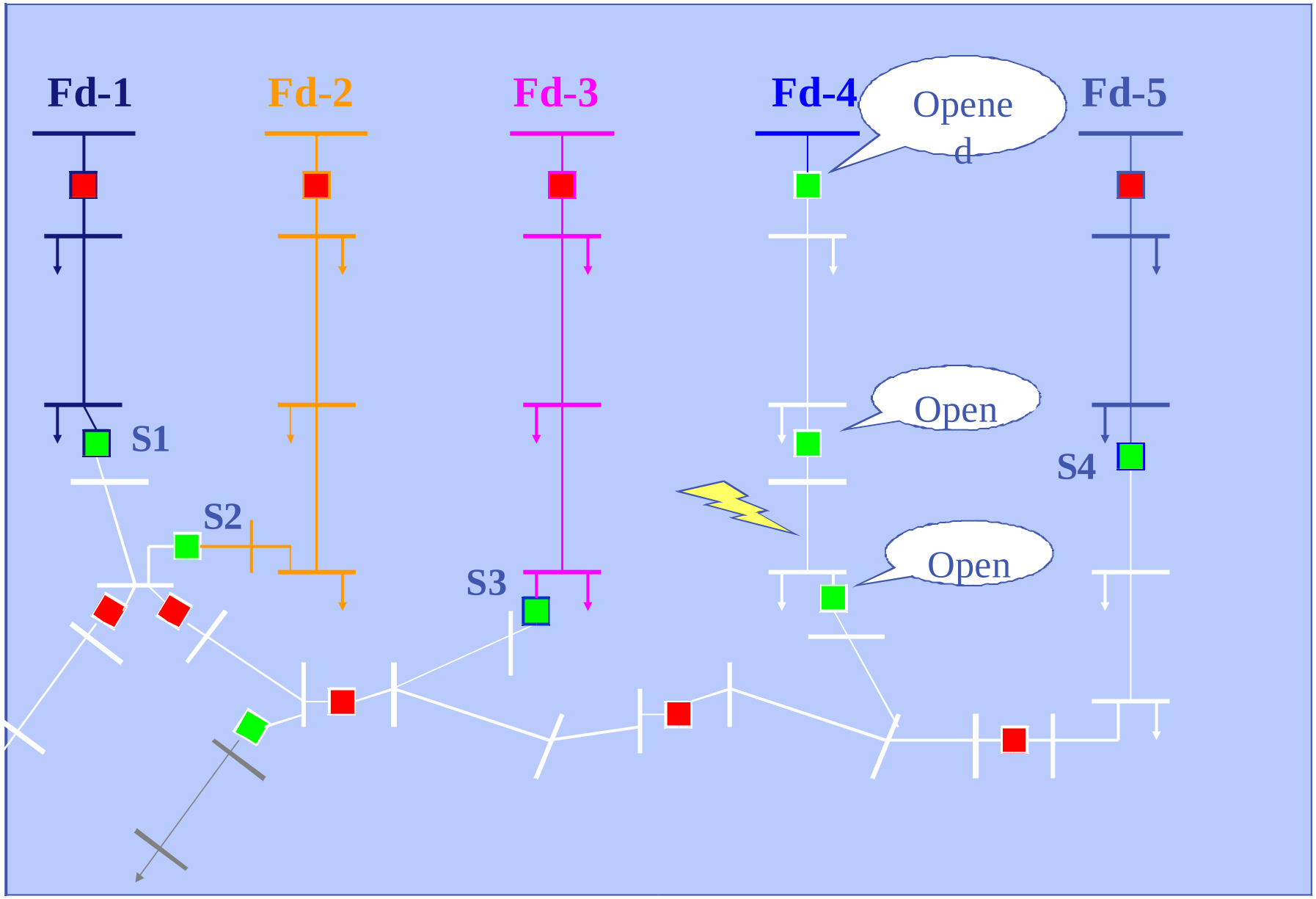
FDIR: Outage Example



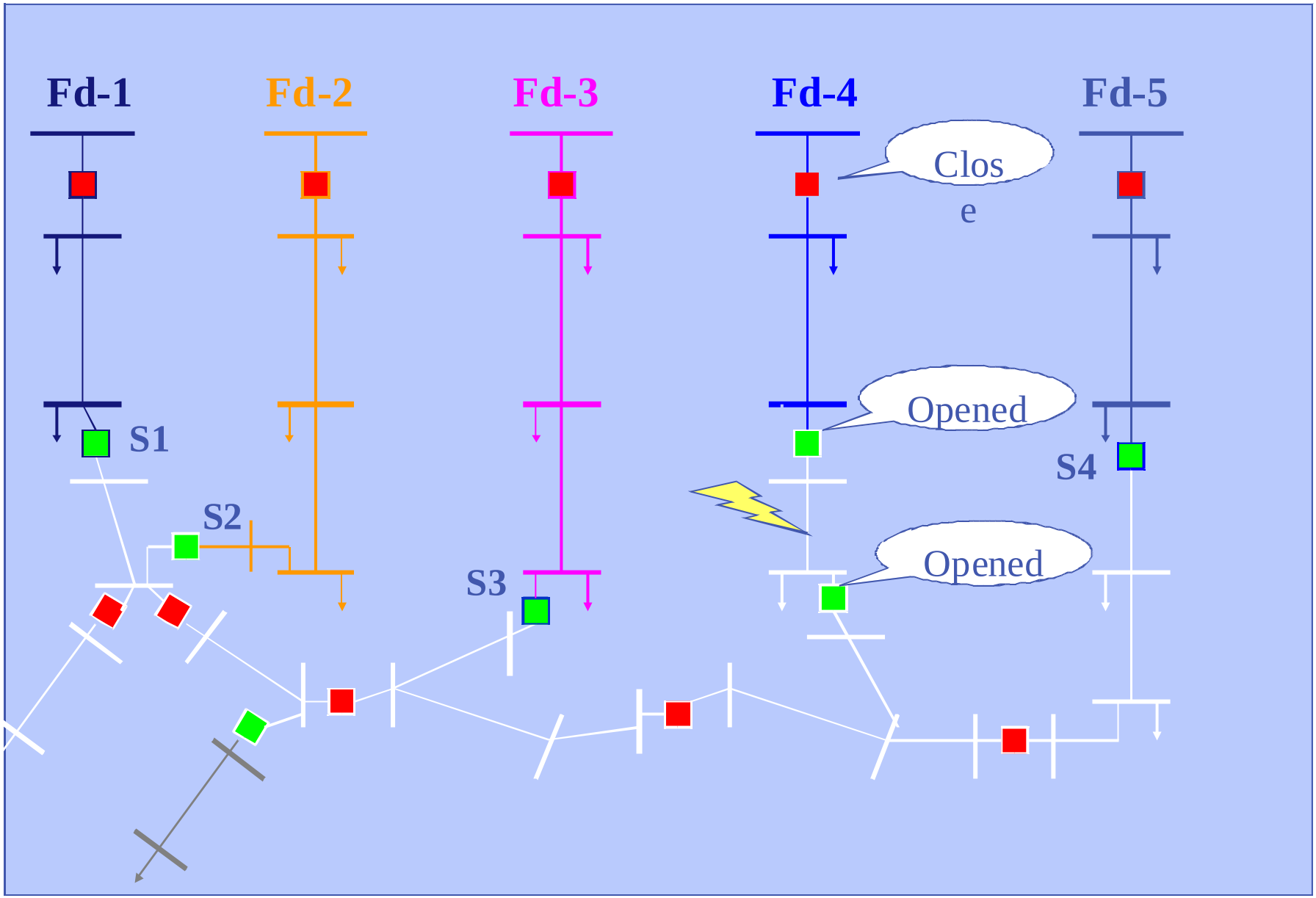
FDIR: Outage Example → isolate



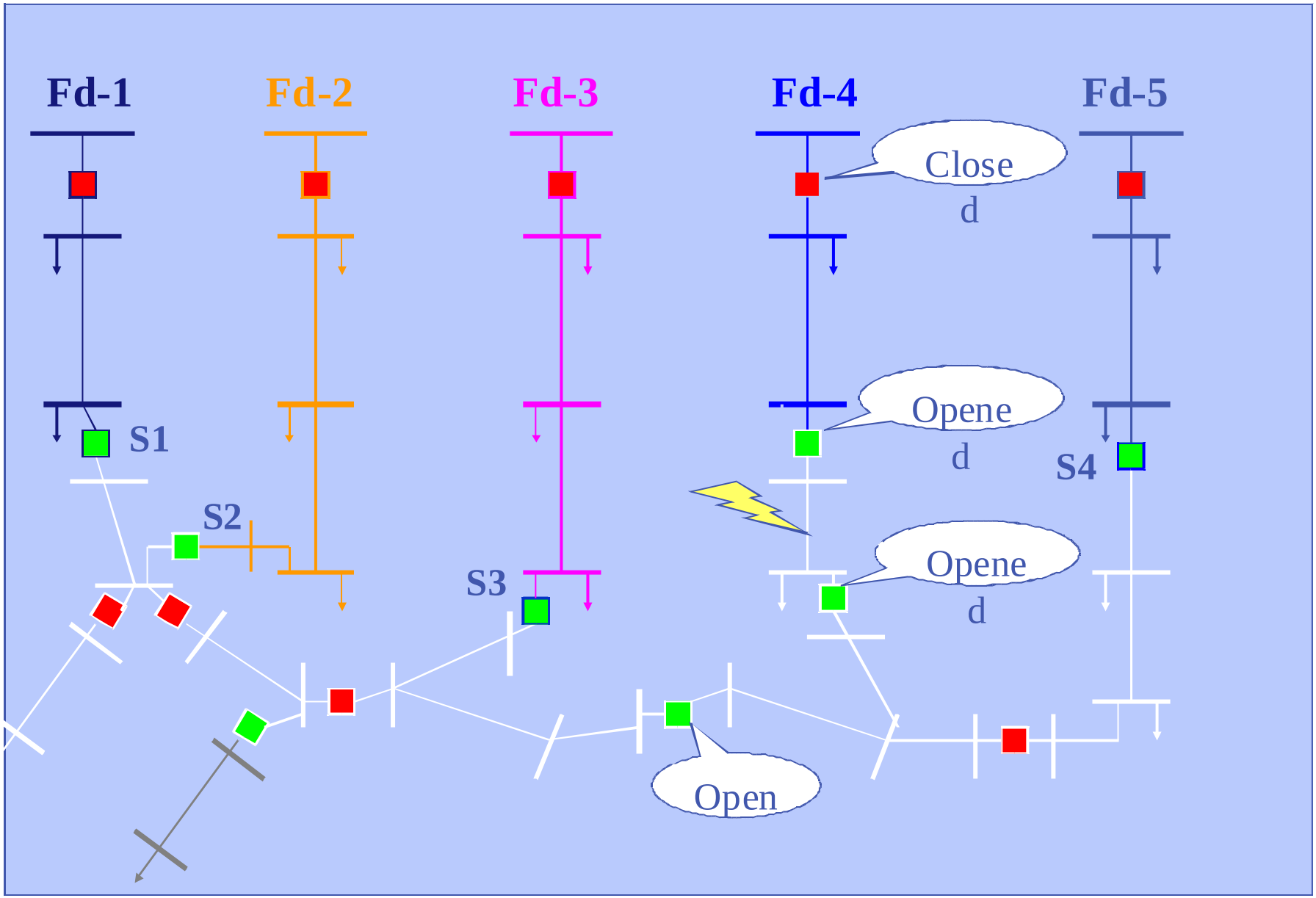
FDIR: Outage Example: isolate



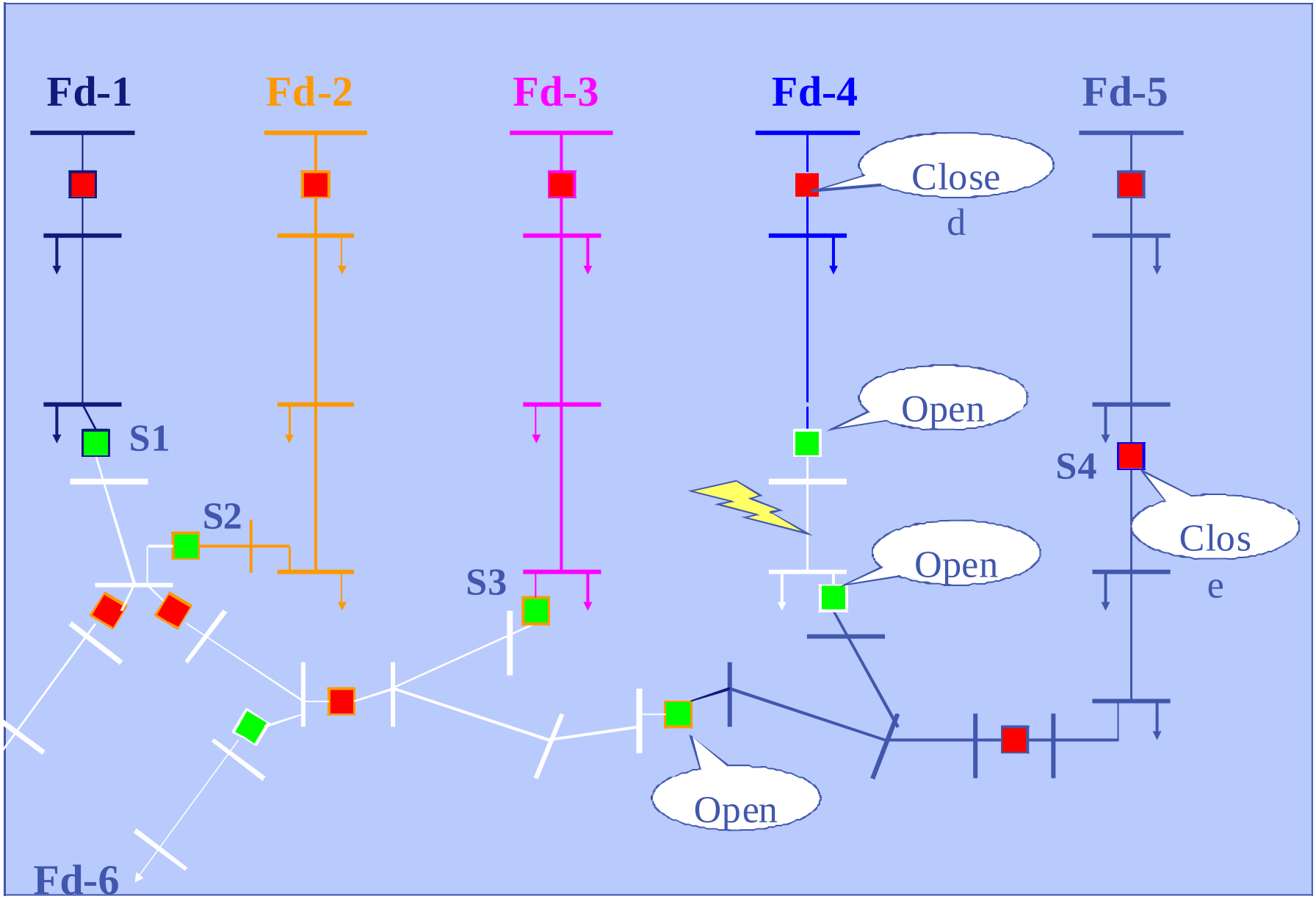
FDIR: Outage Example → upstream restore



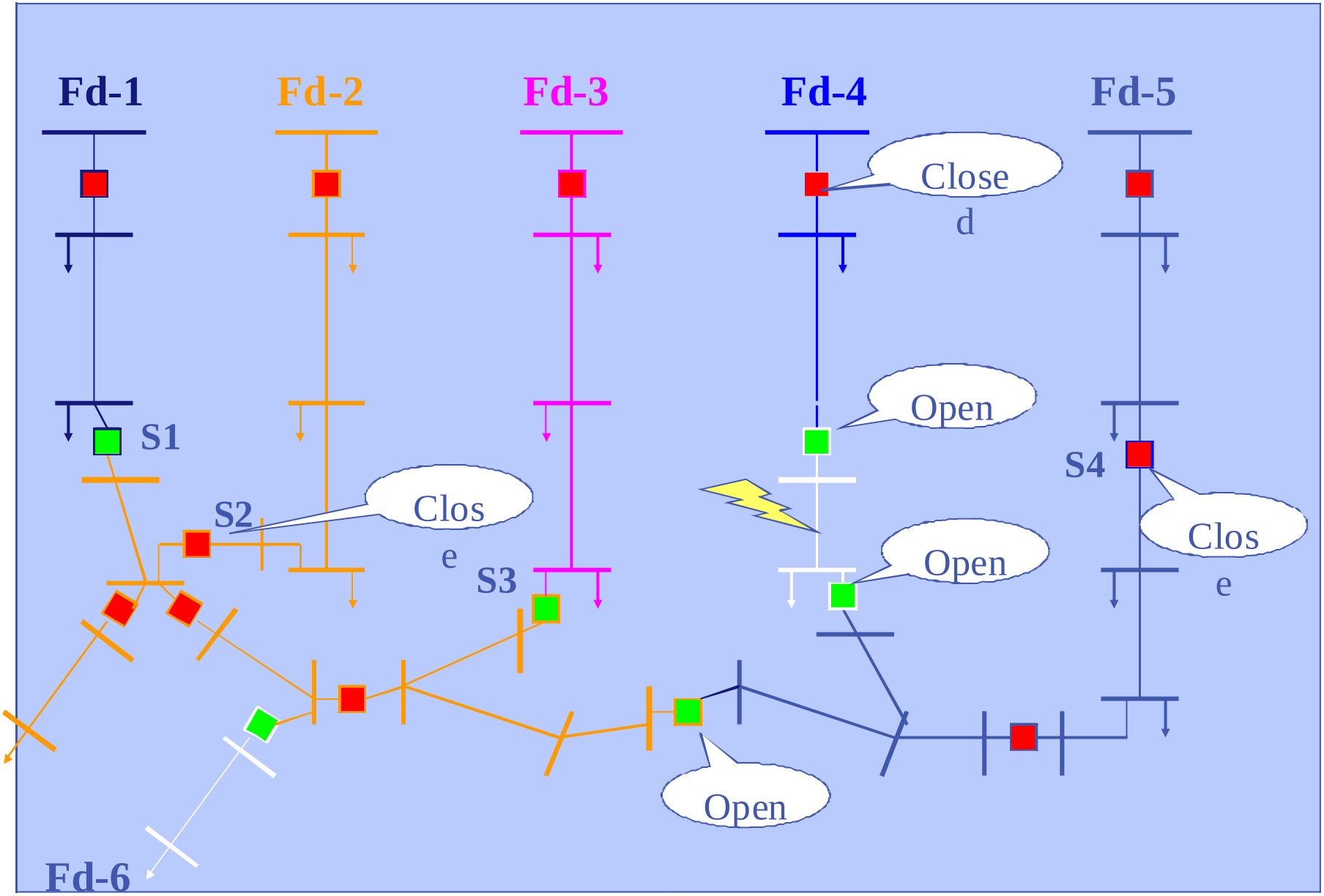
FDIR: Outage Example → Downstream restore



FDIR: Outage Example → downstream restore



FDIR: Outage Example → downstream restore



Optimal Network Reconfiguration (ONR)

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

• Control Devices:

Feeder breaker/reclosers

Feeder line sectionalizers

• Control Constraints:

Voltage Hi/Lo operation limits at each node and at any time interval

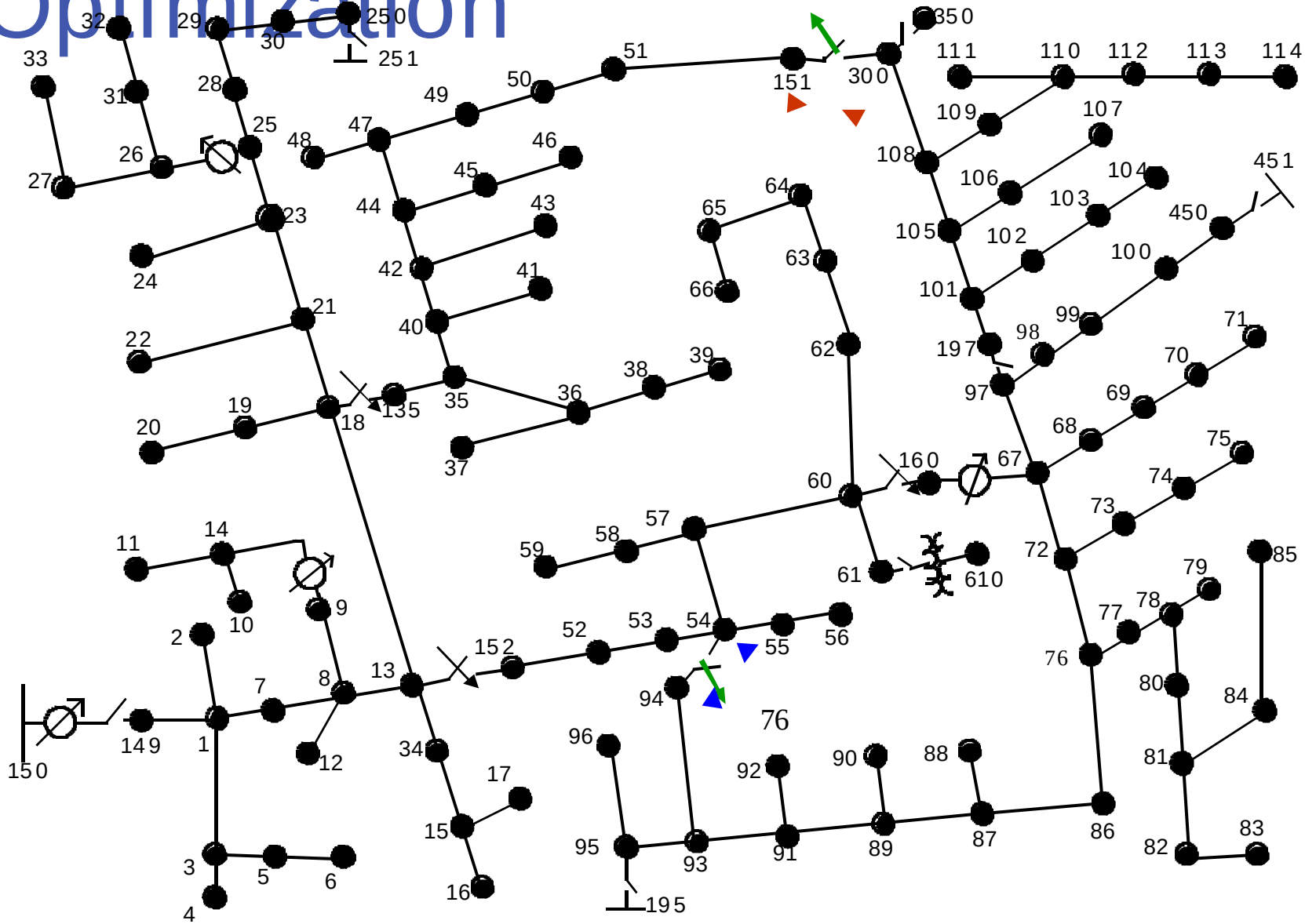
Loading limit at each line section, switch, Xfmr at any time interval

• Solution Algorithms:

Close-all and open-one-by-one (no explicit migration path)

Single Loop Optimization (improvement at each step, no global vision)

Single Loop Optimization



Distribution Contingency Analysis (CA)

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

• Solution Algorithms:

- Topology Processing, Load Flow
- Network Reconfiguration with reliability objectives included

Distribution State Estimation (SE)

- 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)
  - Bus Voltages, Branch Currents, Nodal Injections (bus voltage is commonly used in EMS)
- Characteristics
  - DPF – N equations, M unknowns (N=M), determined problem (no freedom)
  - OPF – N equations, M unknowns (N < M) under determined problem (with freedom)
  - SE - N equations, M unknowns (N > M) over determined problem (conflicted)
- **Solution Algorithms:**
  - Weighted Least Square Method is commonly used
  - Heuristic Rule based Topology Error Detections

Reality on Distribution SE

- SE Application to Distribution Systems
  - Radial or weakly meshed networks
  - Distributed load, distributed generation
  - lack of sufficient real time measurements for high redundancy
  - Not widely accepted and rarely used in DMS systems
- Estimate the system operation condition
  - Estimate the current condition from limited measurements
  - Estimate the look-ahead condition for analysis and operation planning
  - Use real-time measurements, AMI data, Load forecasting, etc.
  - Directly estimate individual loads rather than “States”

Distribution Load Estimation (LE)

- Objectives
  - Estimate the individual distribution loads at every time interval
  - Form standard/conforming daily load profiles for each day type
  - Form non-conforming daily load profiles for individual loads
  - Use hourly, daily or monthly energy consumption of individual loads as the relative allocation factor
- Estimate Loads for the current time
  - Use the real time measurements at branch laterals, feeder heads or at substation levels to estimate the individual loads based on topology connectivity,
  - individual load profiles and the allocation factors
- Estimate Loads for the look-ahead time frame
  - Use the load forecast at substation, region or system levels to estimate the individual loads based on configuration regions, individual load profiles, and the allocation factors
- **Challenges**
  - Impacts from massive deployment of Demand Response, Load Management
  - High penetration of distributed generations from Renewable Resources, HPEV, …

Short Circuit Analysis (SCA)

Objectives :

Calculate network branch currents, bus voltages under faults

Support Real-time and Study mode calculations

- **Various Fault Studies:**

Short Circuit Faults in three phases to ground, or phase-to-phase

Short Circuit Fault in single/double phase to ground

Line Open Fault in single/double lines

A Fault can be at bus or any point of a line

- **Solution Algorithms:**

Full scale network circuit using Y-Bus method

Simplified network circuit via branch aggregation/equivalence

Relay Protection Coordination (RPC)

Objectives :

Coordinate the protections of Feeder CB/Recloser at Feeder head and Reclosers/Fuses at downstream branches/laterals

Verify/Adjust the coordination before/after feeder reconfiguration

New Challenge: Coordinating protections with DGs/MicroGrids

- **Various Fault Studies:**

  Single/two/three phase faults at various locations

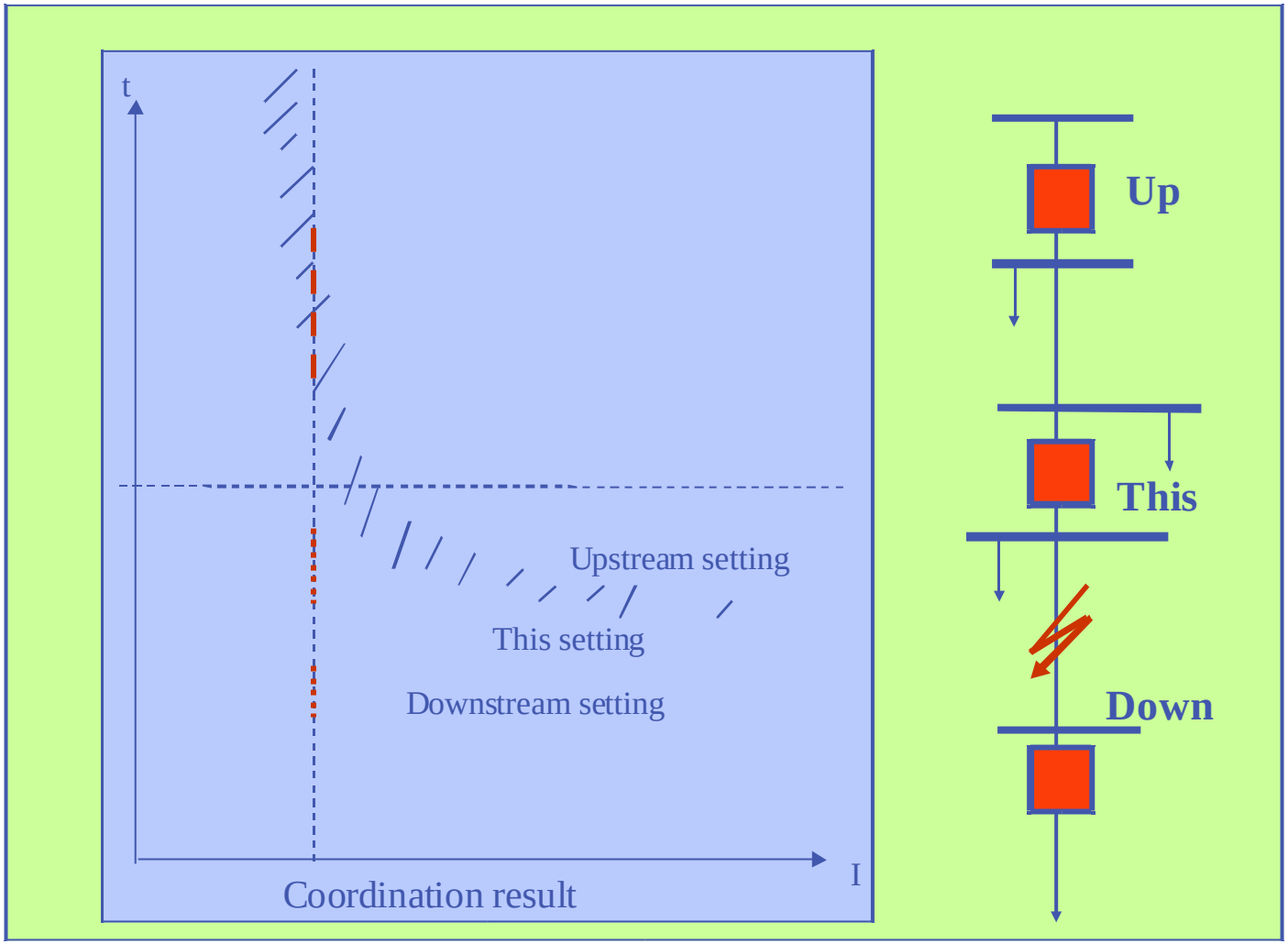
  Protection Zones

  Impacts from Loads and Asynchronous Induction Motors

- **Solution Algorithms:**

  Instantaneous trip/Time Inverse Delay

Relay Protection Coordination



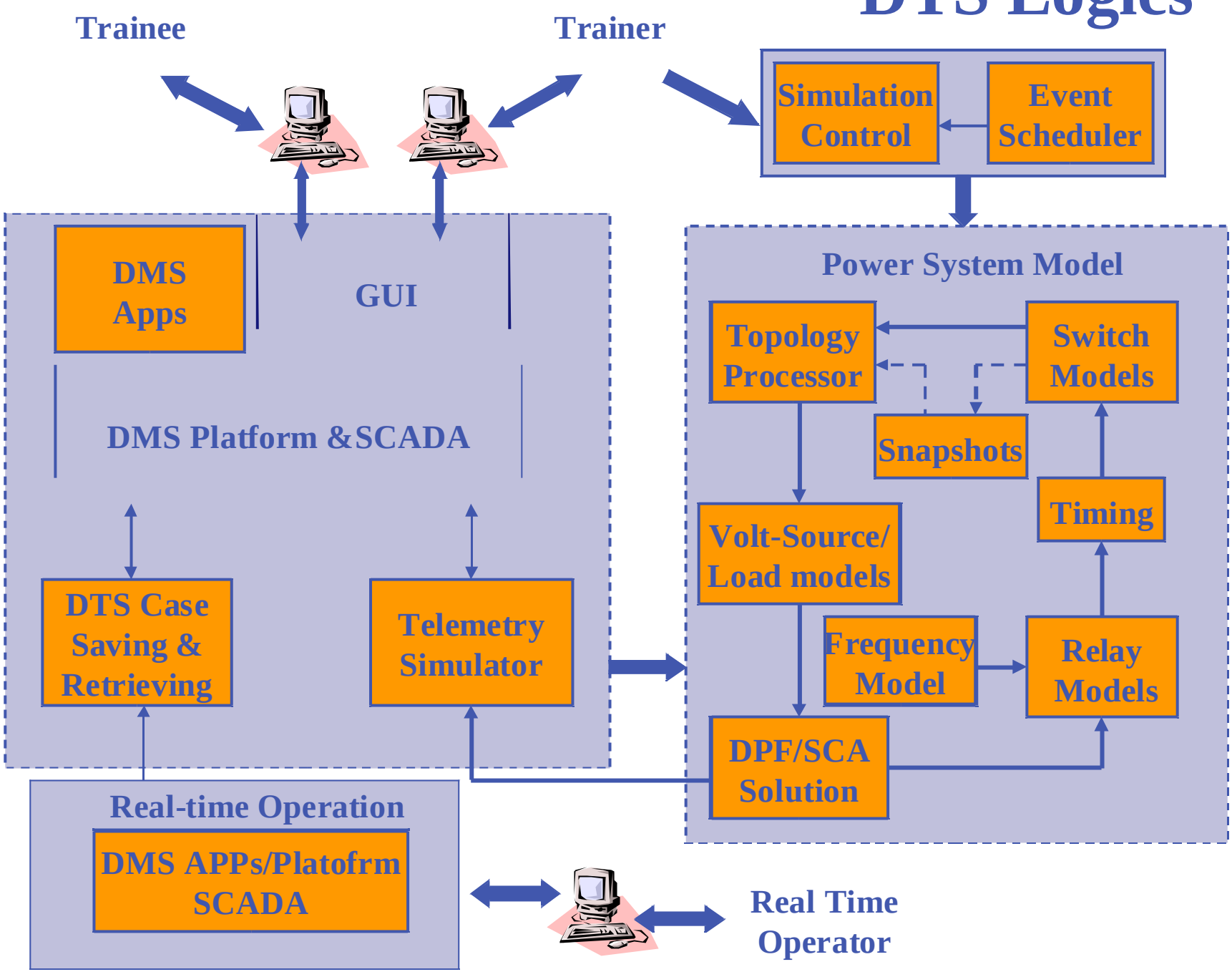
Dispatcher Training Simulator (DTS)

- **Distribution System Simulation (Normal/Faulted):**
  - Distribution Substation and Feeder Network Operation
  - Voltage Sources, Loads (V/F dependent), Caps, Motors, DGs, … Operations
  - Field Protection Device Operations
  - Telemetry/Comm/SCADA Operations
  - Advanced Applications Operations
  - Trainee/Trainer Operations
  - Simulated Events/Scenarios
- **Model Various Relays:**
  - Under/Over Frequency Relays
  - Under/Over Voltage Relays
  - Inverse Time Relays (over load)
  - Auto-reclosure Relays
  - Synchronous-Check Relay

Dispatcher Training Simulator (DTS)

- **Simulated Event/Scenarios:**
  - Switch Device Trip/Close and Out of Service
  - Set/Clear various Faults
  - Voltage Source and DG output Adjustments
  - System wide or individual Loads Adjustments
  - System Frequency Adjustments
  - Equipments/Line Sections Out of Service
- **System Features:**
  - Slow/Normal/Fast Moving Forward
  - Pause/Rewind/Resume Simulation
  - Case Creating/Saving/Retrieving
  - Taking Snapshot of Real-Time System Operation
  - Replaying Saved Cases and Snapshot Cases

DTS Logics


Trainee
Trainer
Simulation Control
Event Scheduler
DMS Apps
GUI
DMS Platform &SCADA
DTS Case Saving & Retrieving
Telemetry Simulator
Power System Model
Topology Processor
Switch Models
Snapshots
Timing
Volt-Source/ Load models
Frequency Model
Relay Models
DPF/SCA Solution
Real-time Operation
DMS APPs/Platofrm SCADA
Real Time Operator

Thank You

IEEE 123-Bus Distribution Network