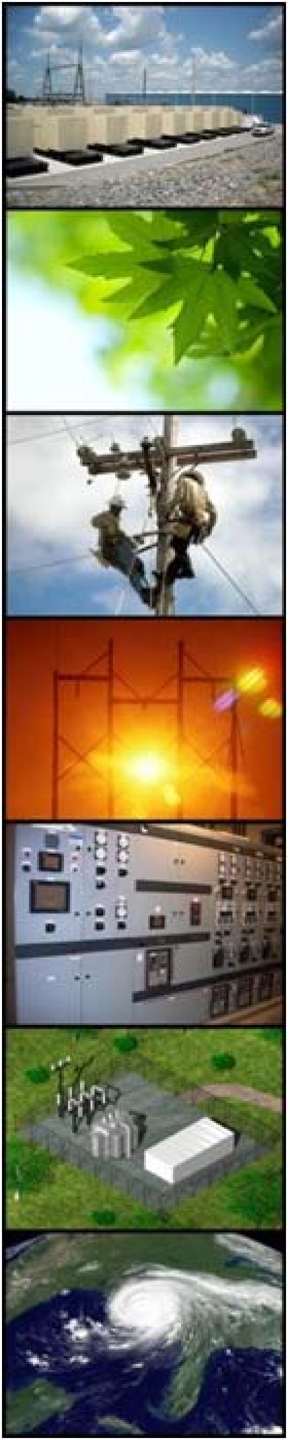

Florida PUBLIC POWER
ENERGY and ELECTRIC UTILITY INDUSTRY

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FLORIDA MUNICIPAL ELECTRIC ASSOCIATION

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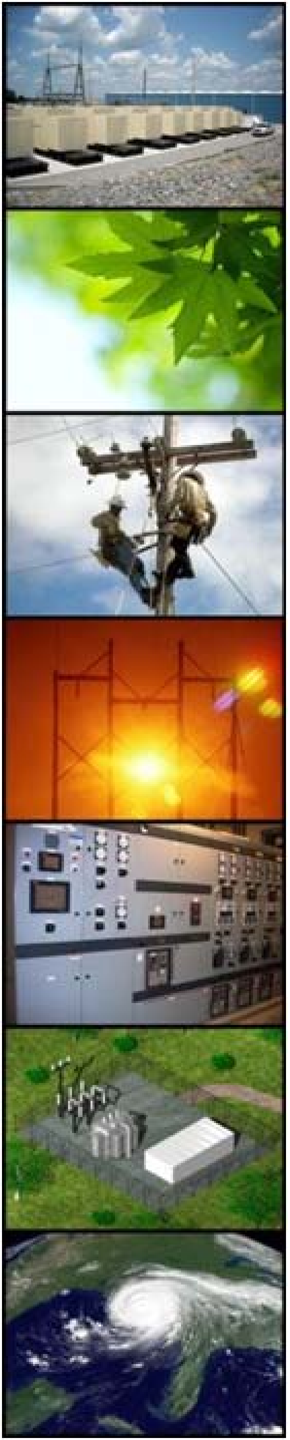
Sept. 15-16, 2009 Gainesville and Jupiter Beach, FL

SmartStation

Meeting the Challenges of Smart Grid in Distribution Substations

PowerSecure



Contact Information

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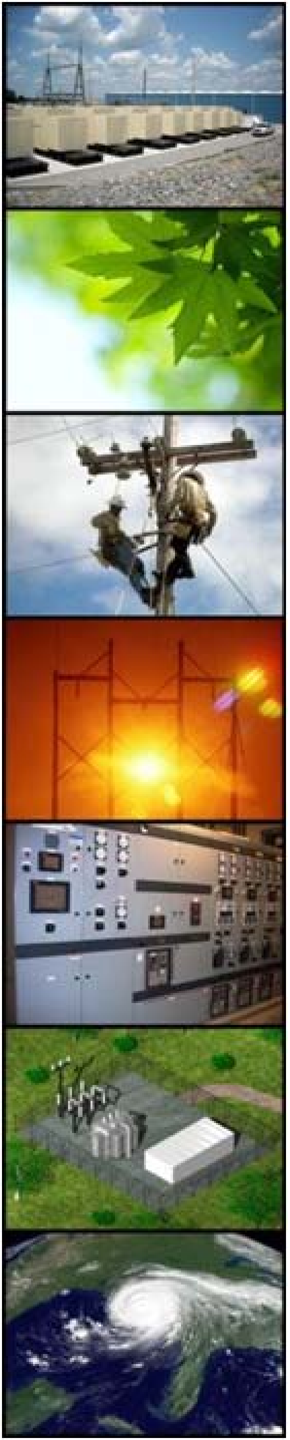
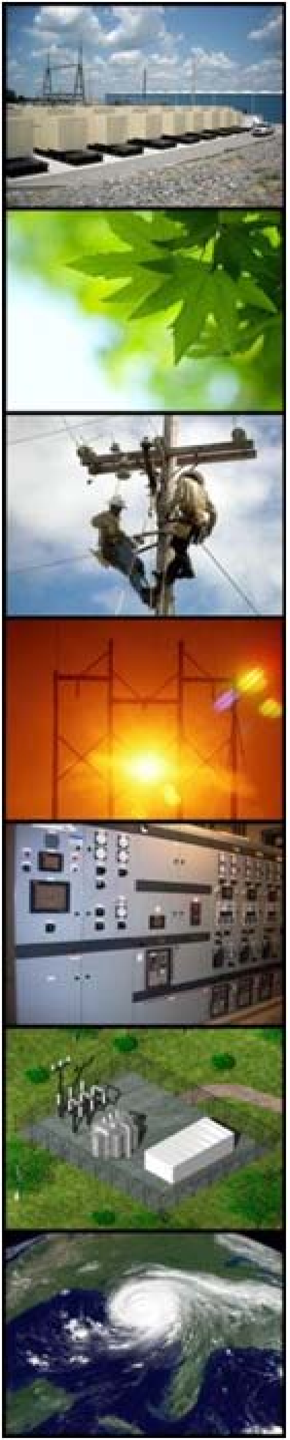


Objectives

- Review Smart Grid Goals
- Explore DR Today and Tomorrow
- Discuss Impacts of Wide Scale DR to Distribution
- Dimension the Issue of Bidirectional Powerflows and Fault Current Flows
- Suggest Mitigation and Optimization Strategies in for Distribution Substations

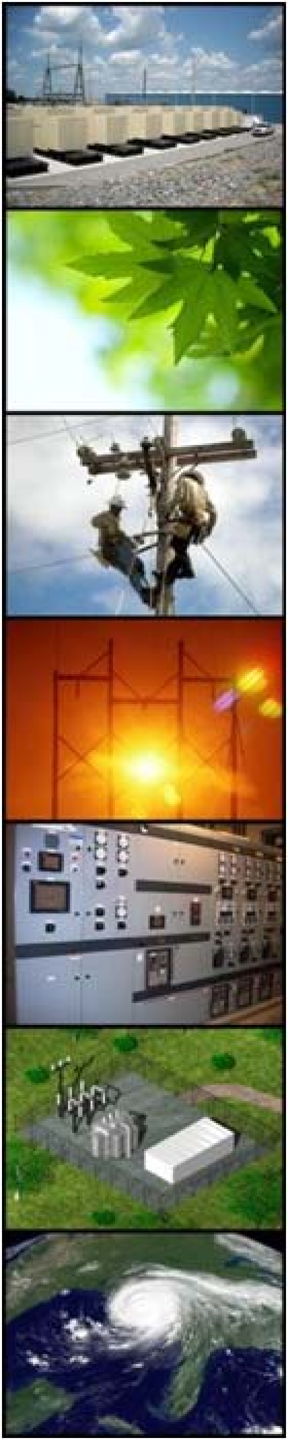


Smart Grid Defined

- National Energy Technology Laboratory (NETL), has identified the following characteristics or performance features of a smart grid:
  - Self-healing from power disturbance events
  - Enabling active participation by consumers in demand response
  - Operating resiliently against physical and cyber attack
  - Providing power quality for 21st century needs
  - Accommodating all generation and storage options
  - Enabling new products, services, and markets
  - Optimizing assets and operating efficiently

How a SmartStation Meets SmartGrid Attributes

- Self-healing from power disturbance events
  - Use of adaptive protection and control (P&C)
- Enabling active participation by consumers in demand response
  - Allows high proliferation of DR in distribution with proper substation operation
- Operating resiliently against physical and cyber attack
  - Physical protection by enclosure; cyber protection using secure Ethernet communications
  - Microgrids
- Providing power quality for 21st century needs
  - Ability to monitor for PQ events and alarm
  - Mitigation

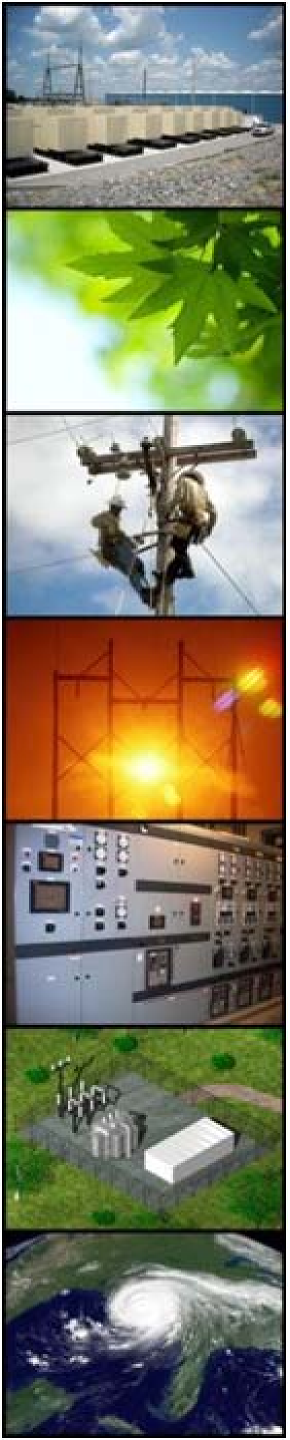


How a SmartStation Meets SmartGrid Attributes

- Accommodating all generation and storage options
  - Proper P&C strategies for DR proliferation in distribution
- Enabling new products, services, and markets
  - DR integration into distribution system
- Optimizing assets and operating efficiently
  - Advanced diagnostics and predictive maintenance

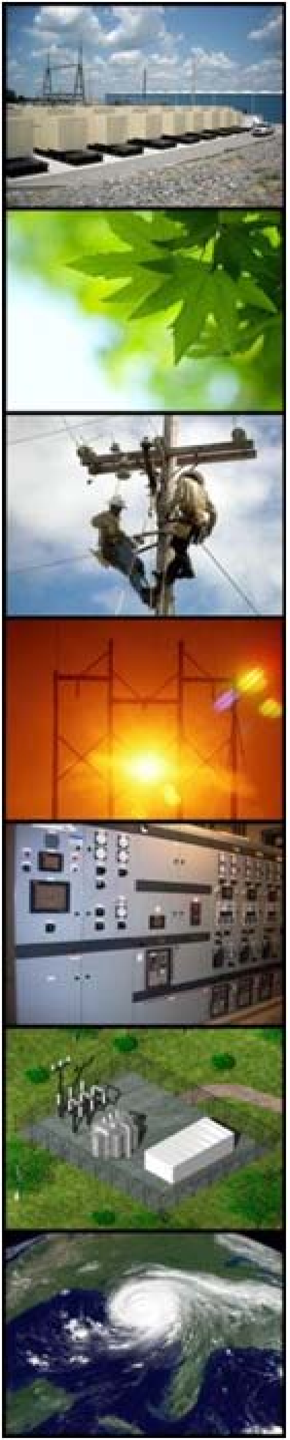
DR as Part of Smart Grid

- Enabling active participation by consumers in demand response
  - Allows high proliferation of **DR** in distribution with proper substation operation
- Accommodating all generation and storage options
  - Proper P&C strategies for **DR** proliferation in distribution
- Enabling new products, services, and markets
  - **DR** integration into distribution system
- Operating resiliently against physical and cyber attack
  - Microgrids using **DR**



Distributed Resource: Definition

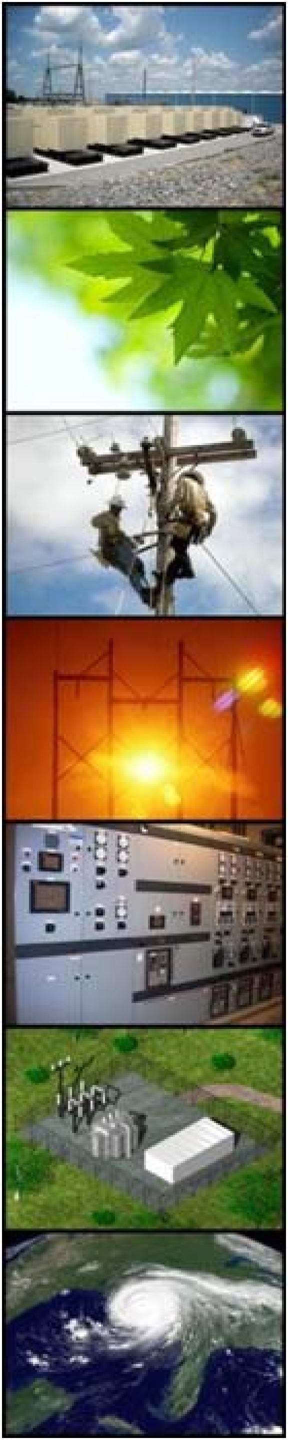
- DR is small generation placed into the distribution system
  - Small = < 10MW; 1kW – 5MW common
  - Distribution = <= 44kV; 120V-15kV common
- DR may be synchronous machines, induction machines, PV array, fuel cell, wind and other technologies
- DR may be renewable or non-renewable
- DR may be coupled directly to system or indirectly
  - Direct = rotating machinery
  - Indirect = power electronics with DC or AC input

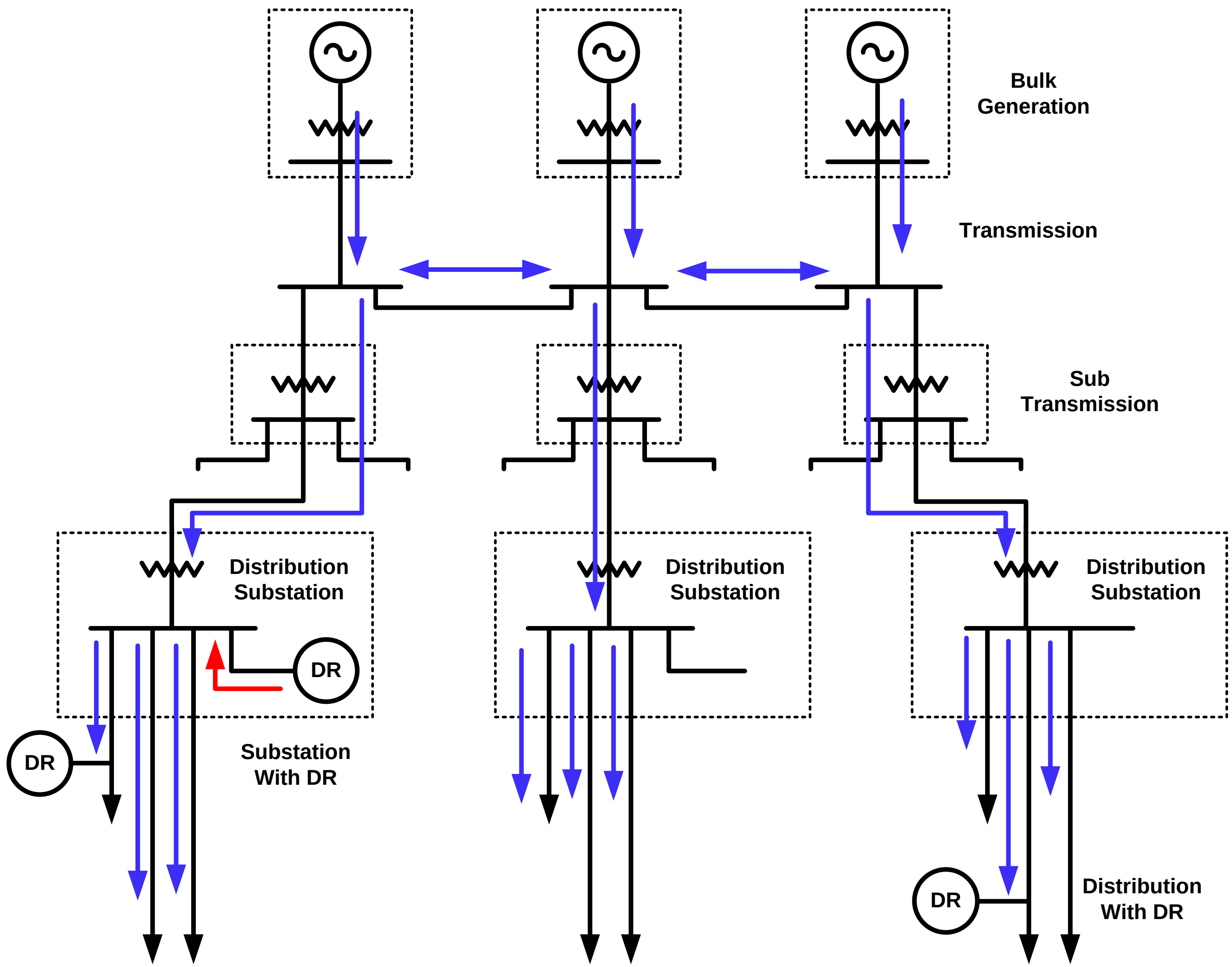


Distributed Resource: Today

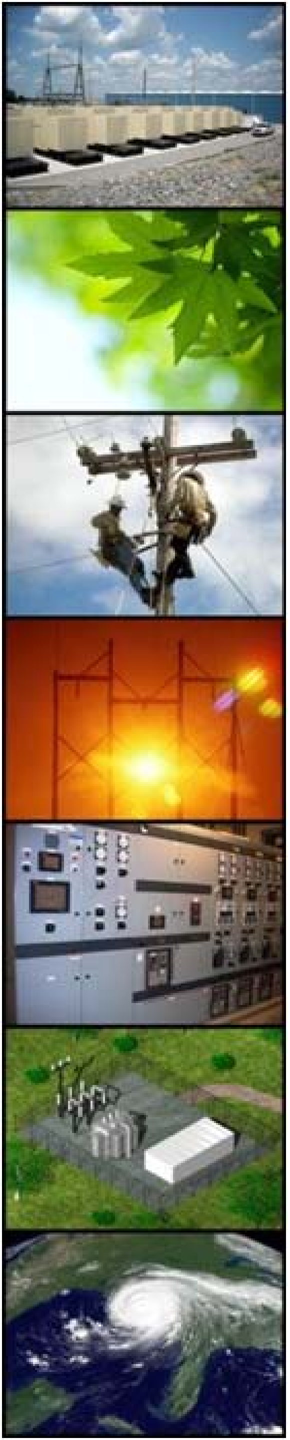
- Low proliferation
- Viewed as a pain rather than a resource
- Most DR does not export
- Some DR under Utility control for demand response
  - Standby Generation Rates
  - Interruptible Rates
- DR Interconnection Standards are individual DR-centric
  - IEEE 1547, UL 1741
- Holistic view on wide scale proliferation in distribution not well understood
  - New IEEE Standards Group, P2030, has opened to address the more holistic approach to DR proliferation

DR Today

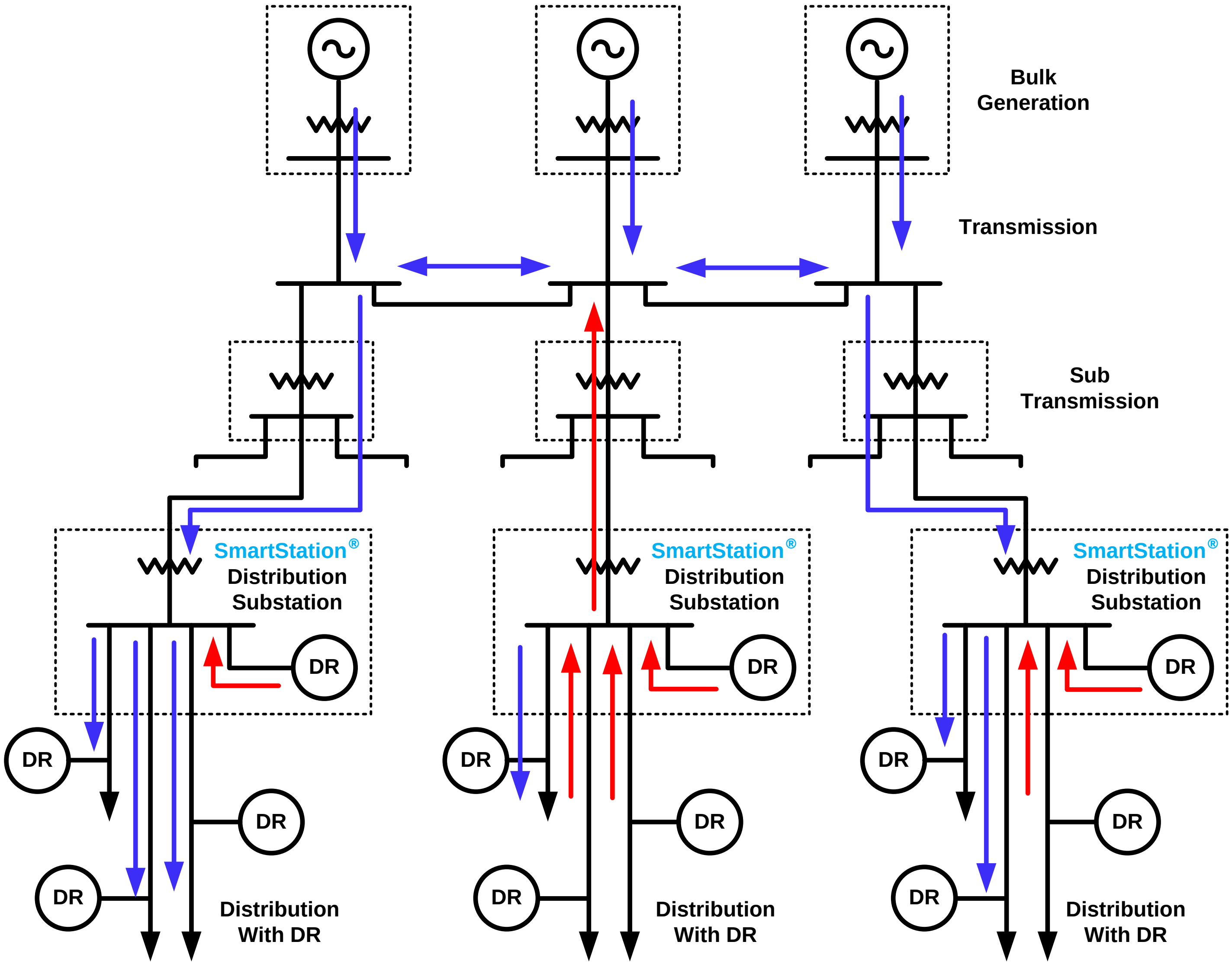




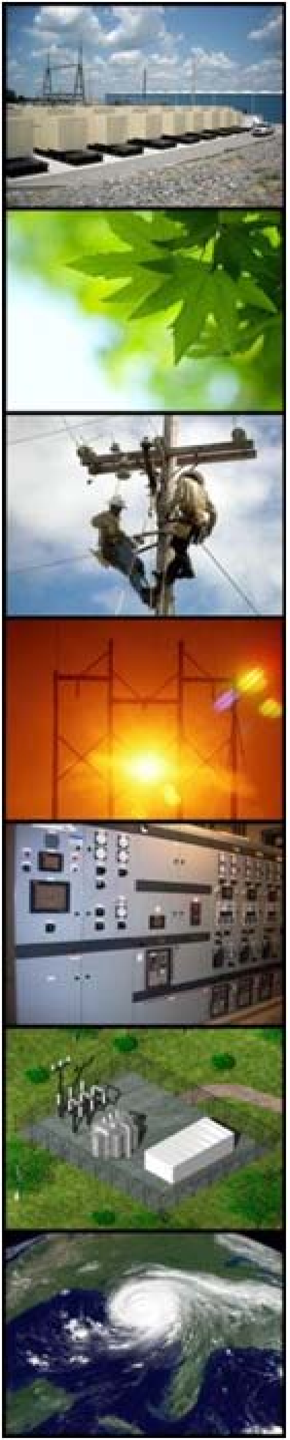
Gen→Tran→SubTran→Dist→Utilization



DR Tomorrow

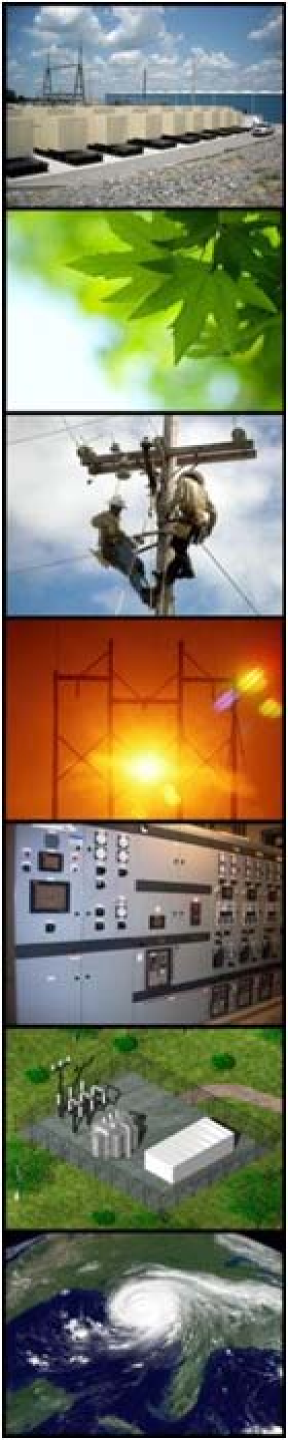


Bi-Directional Powerflows

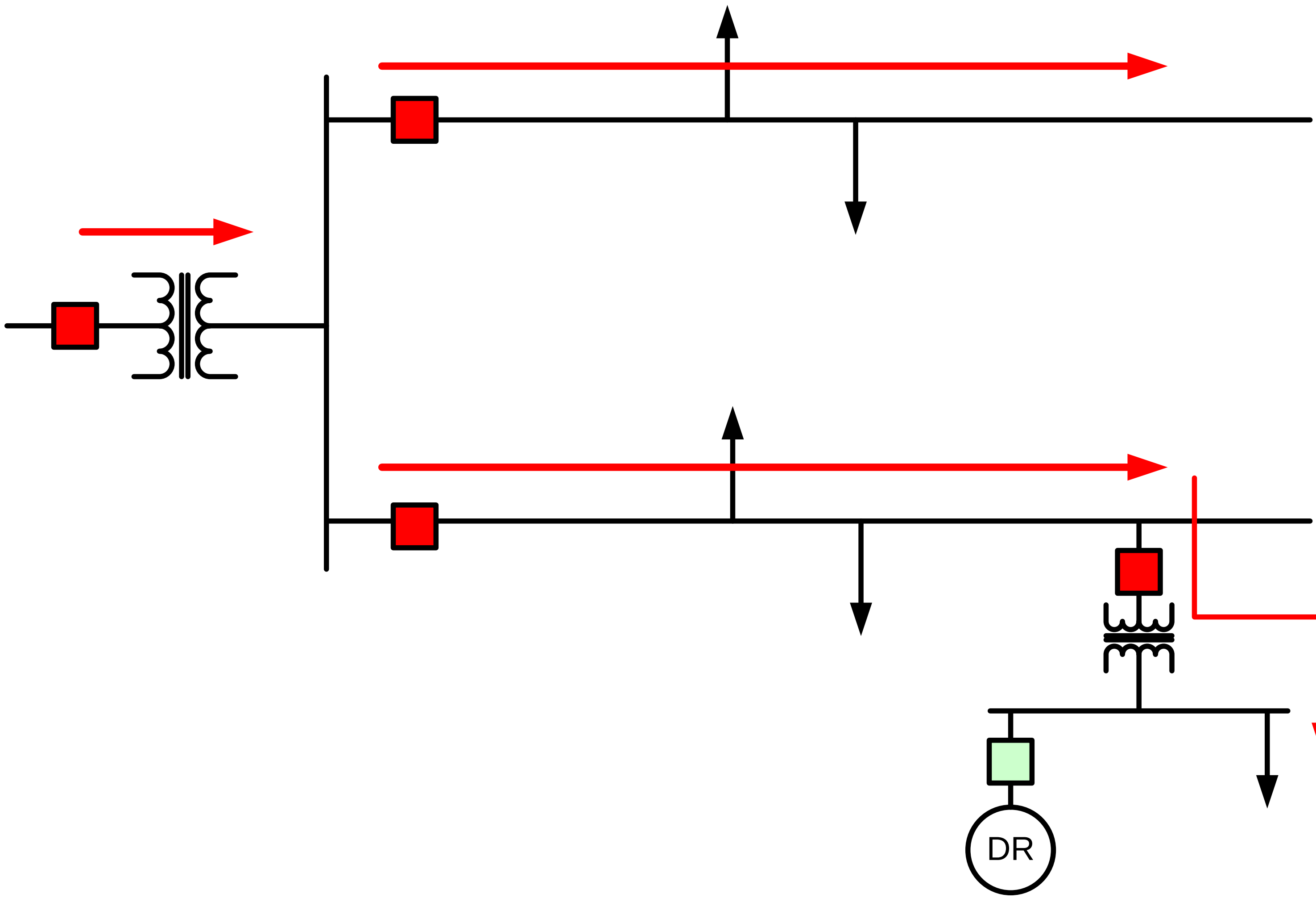


Issues: DR in Distribution

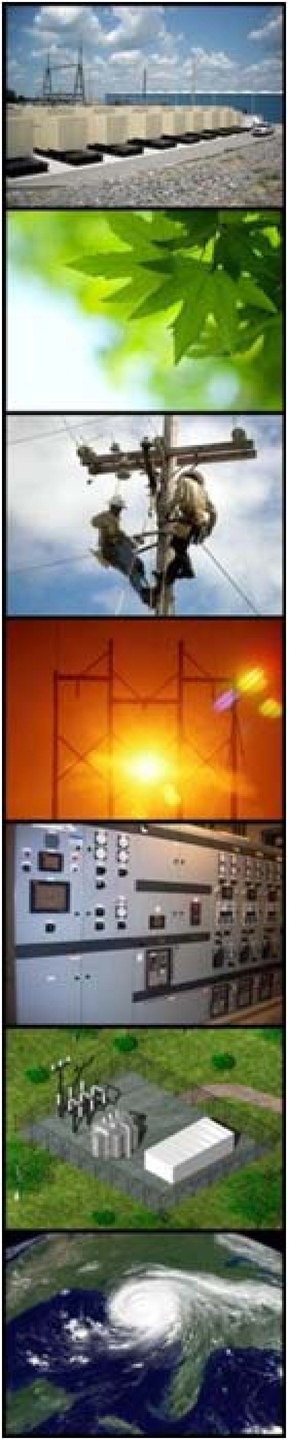
- Bidirectional Powerflows
  - If DR is allowed to export, power may run ‘uphill’ through feeders into substations
  - May be real (W) and reactive (VAR)
- Bidirectional Fault Currents
  - Feeder considerations
  - Substation considerations
- Reclosing Coordination
  - Normal system
  - Microgrid Consideration
- DR Dispatch
  - Calling for Export vs. Non-Export
  - Transfer Tripping sing Internet and IEC-61850



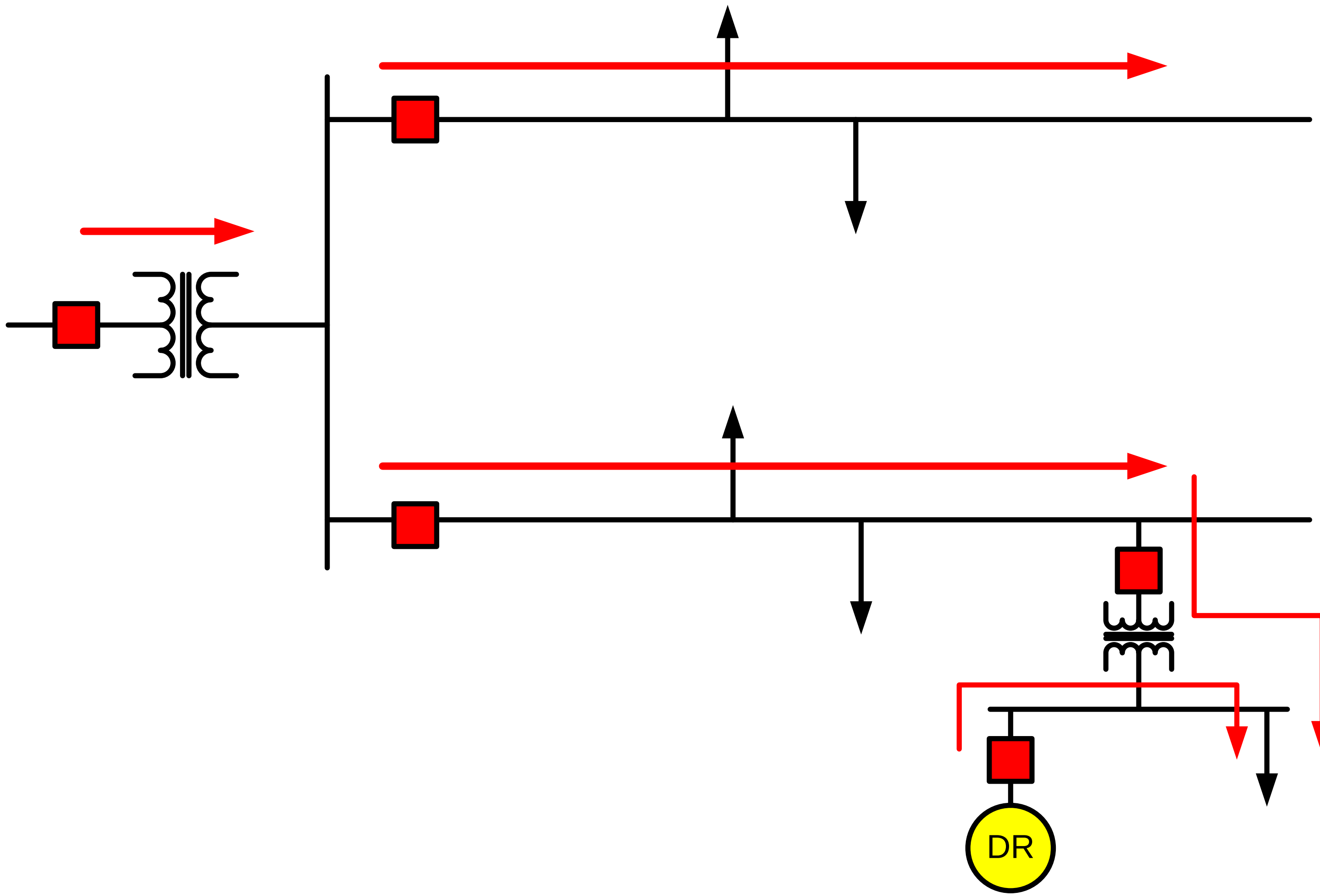
Bidirectional Powerflows: Feeder



- DR Off, Normal Powerflow

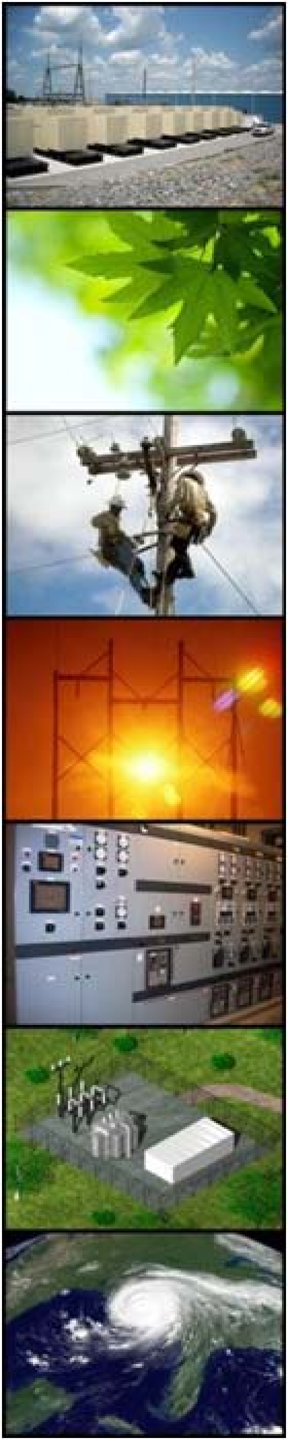


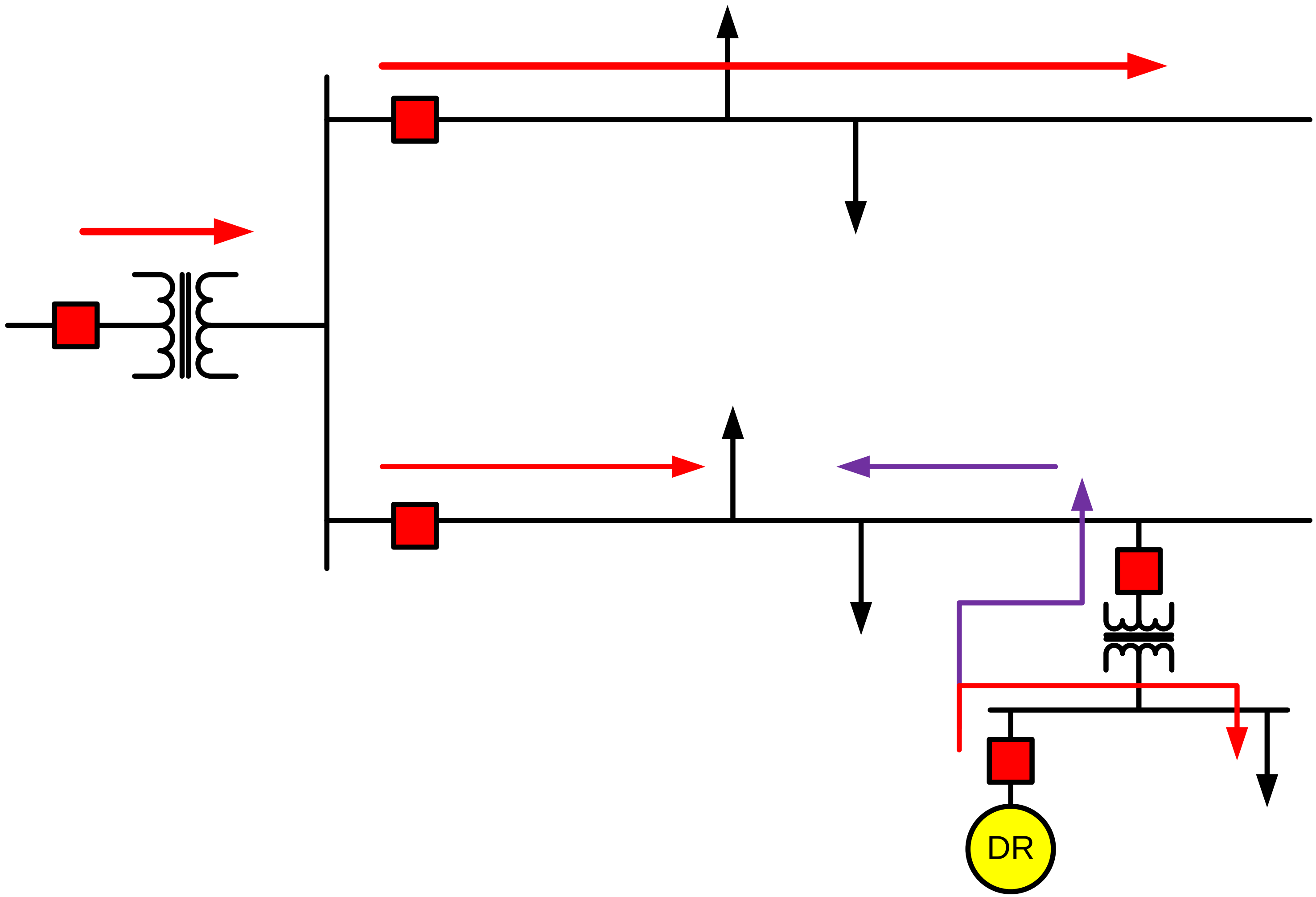
Bidirectional Powerflows: Feeder



- DR On, No Export, Normal Powerflow

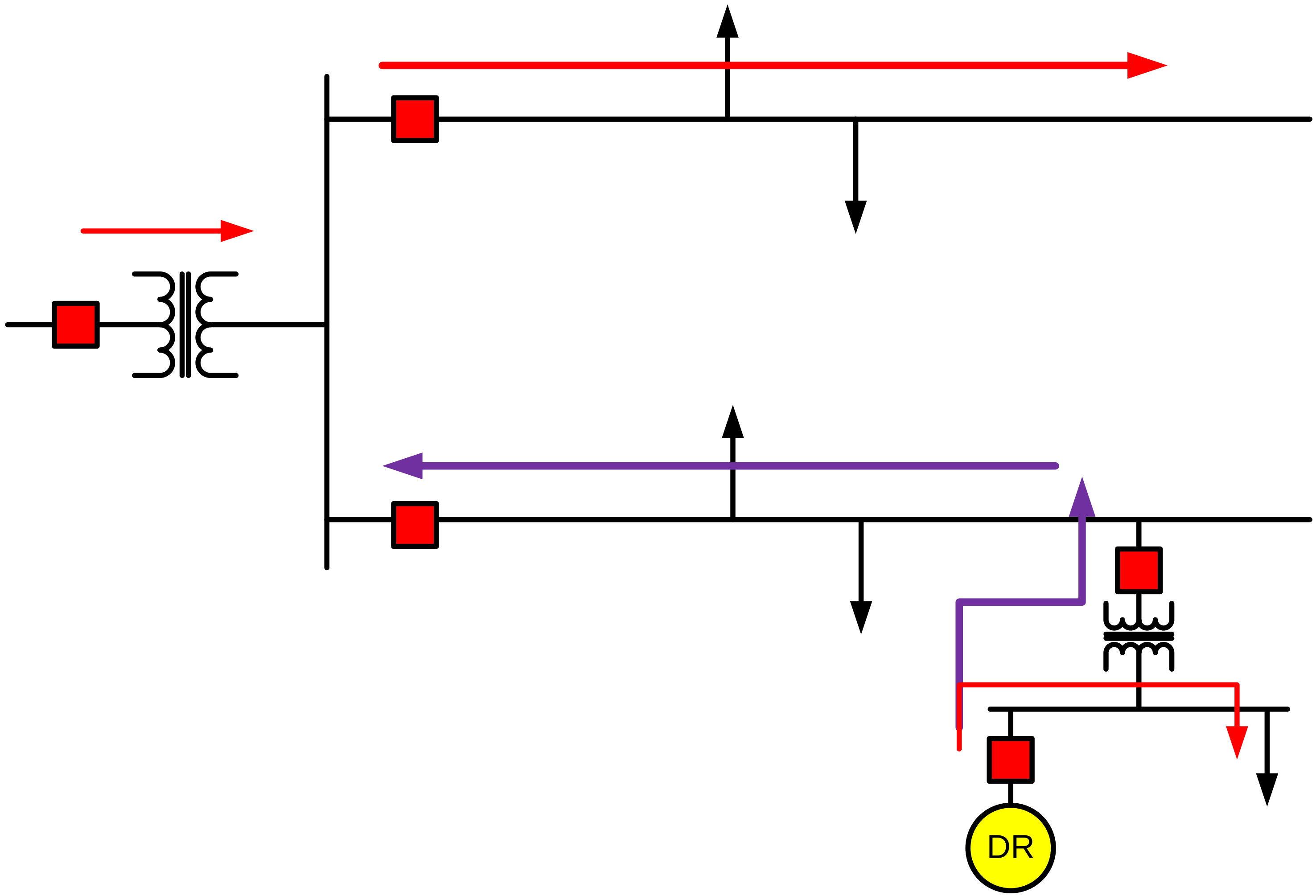
Bidirectional Powerflows: Feeder





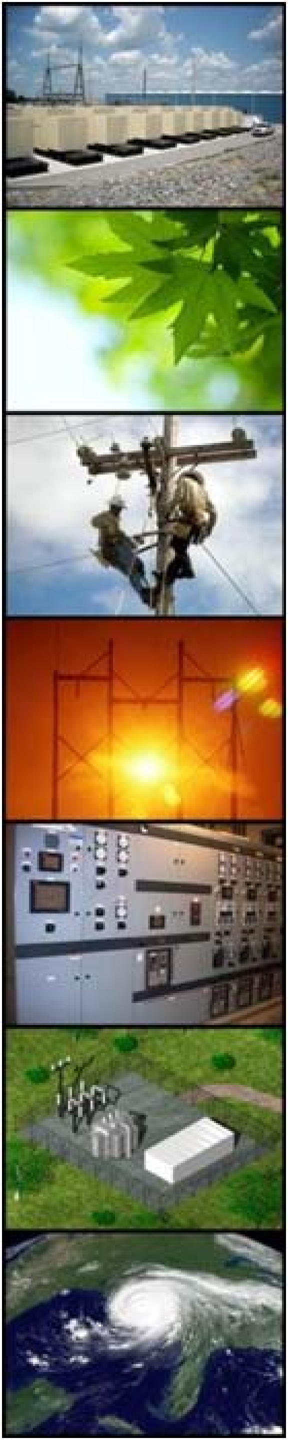
- DR On, Export, Partial Reverse Powerflow

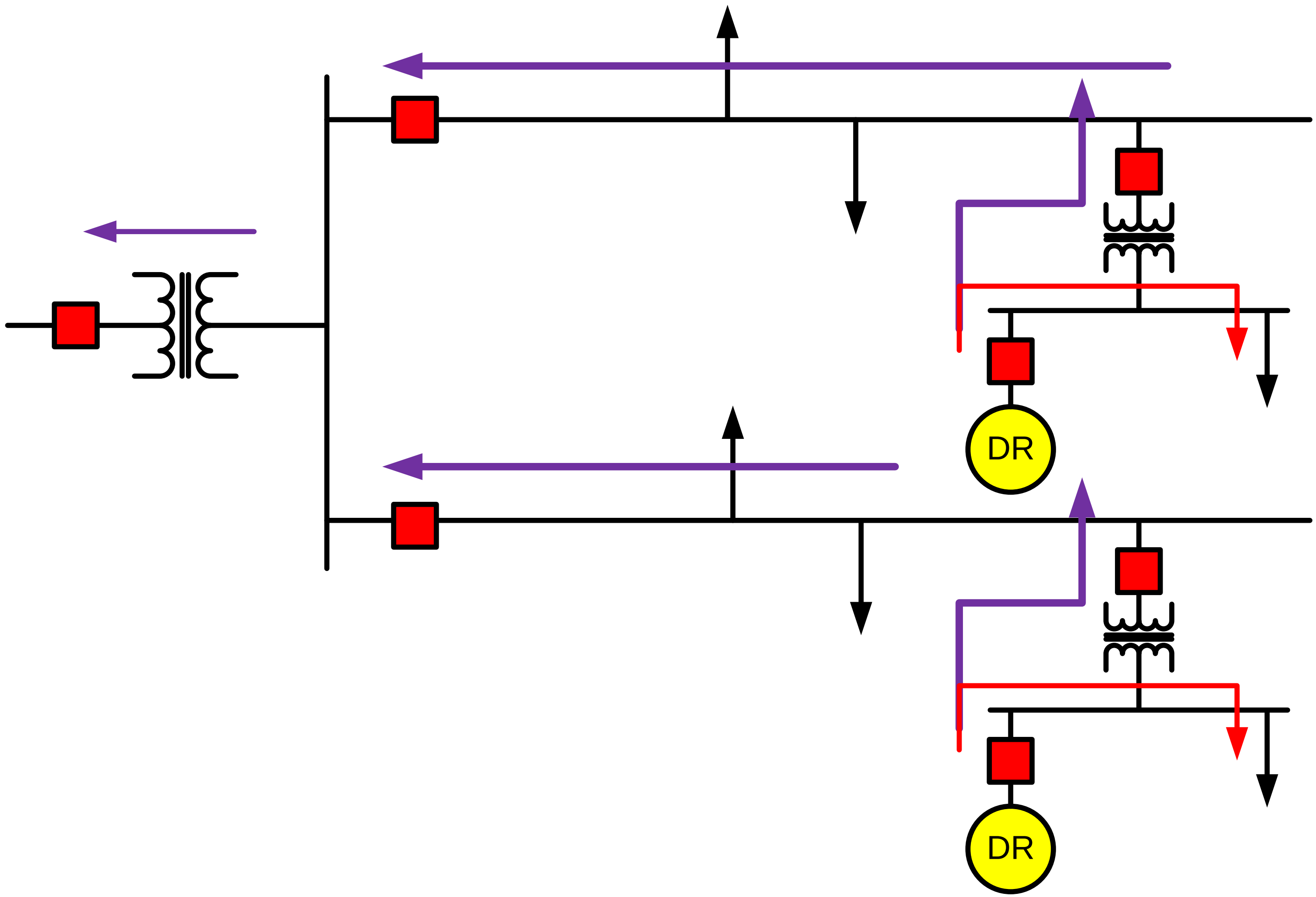
Bidirectional Powerflows: Feeder



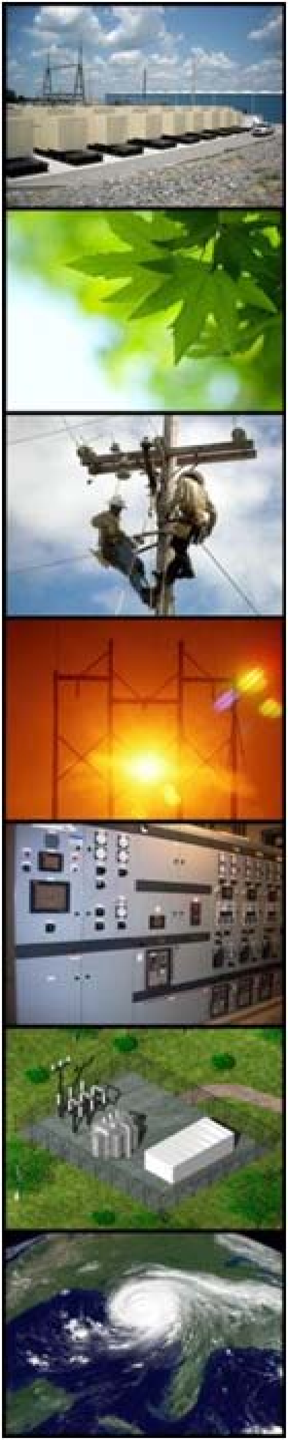
- DR On, Export, Full Reverse Powerflow

Bidirectional Powerflows: Substation

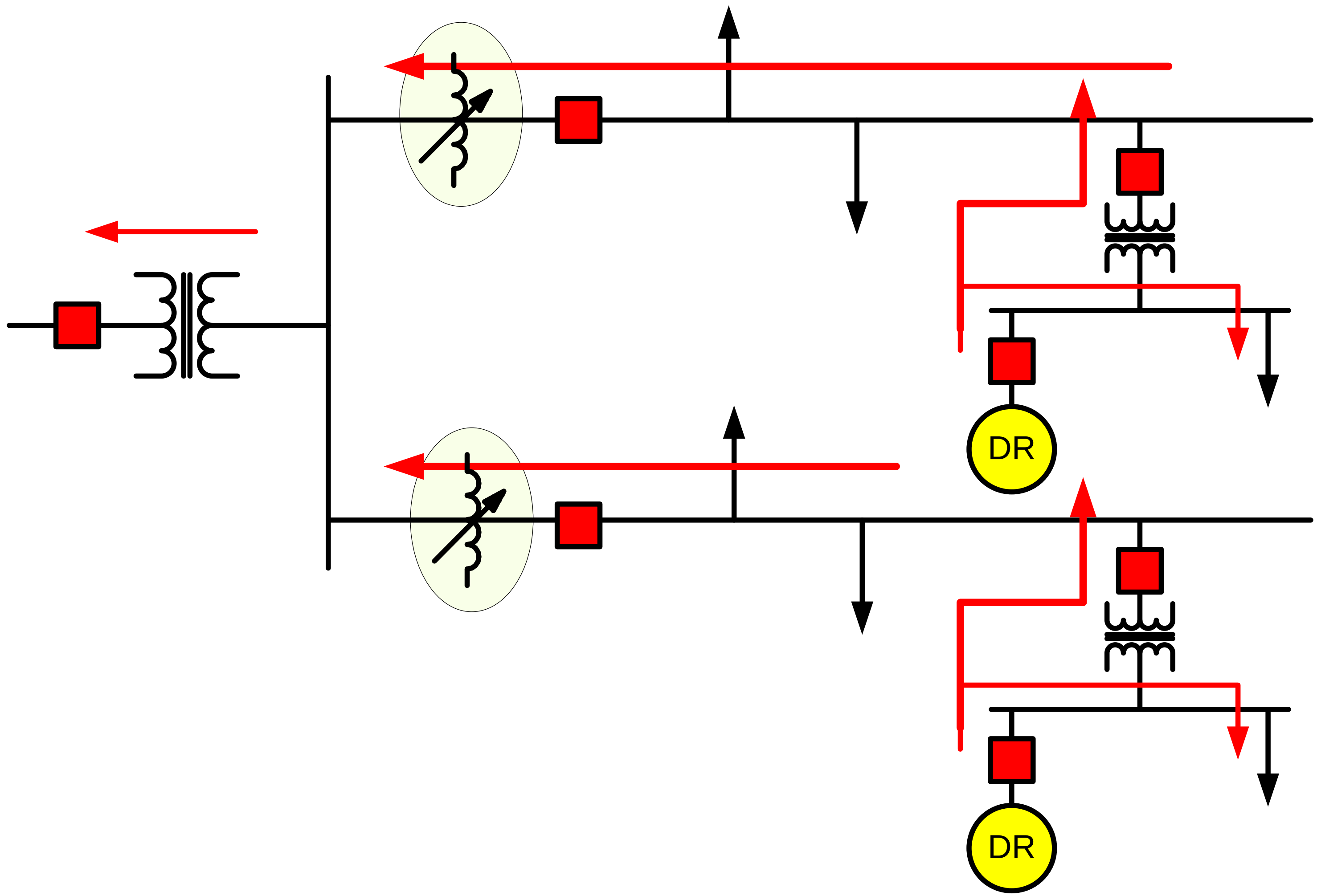




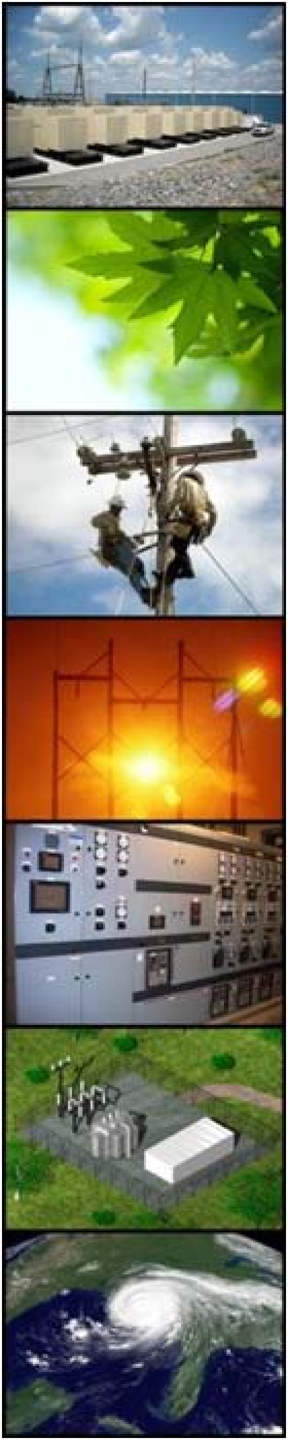
- DR On, Export, Full Reverse Powerflow



Add S/S Regulators

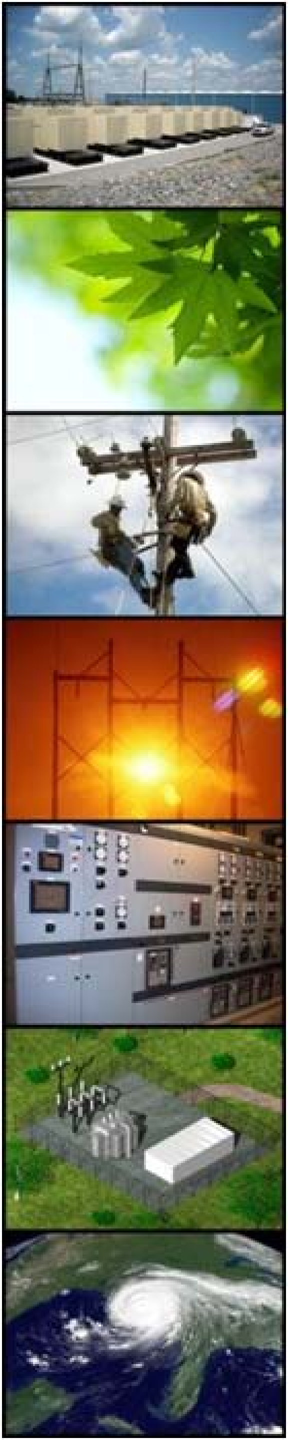


- How does reverse real power impact regulation?



Bidirectional Powerflows: Coordination

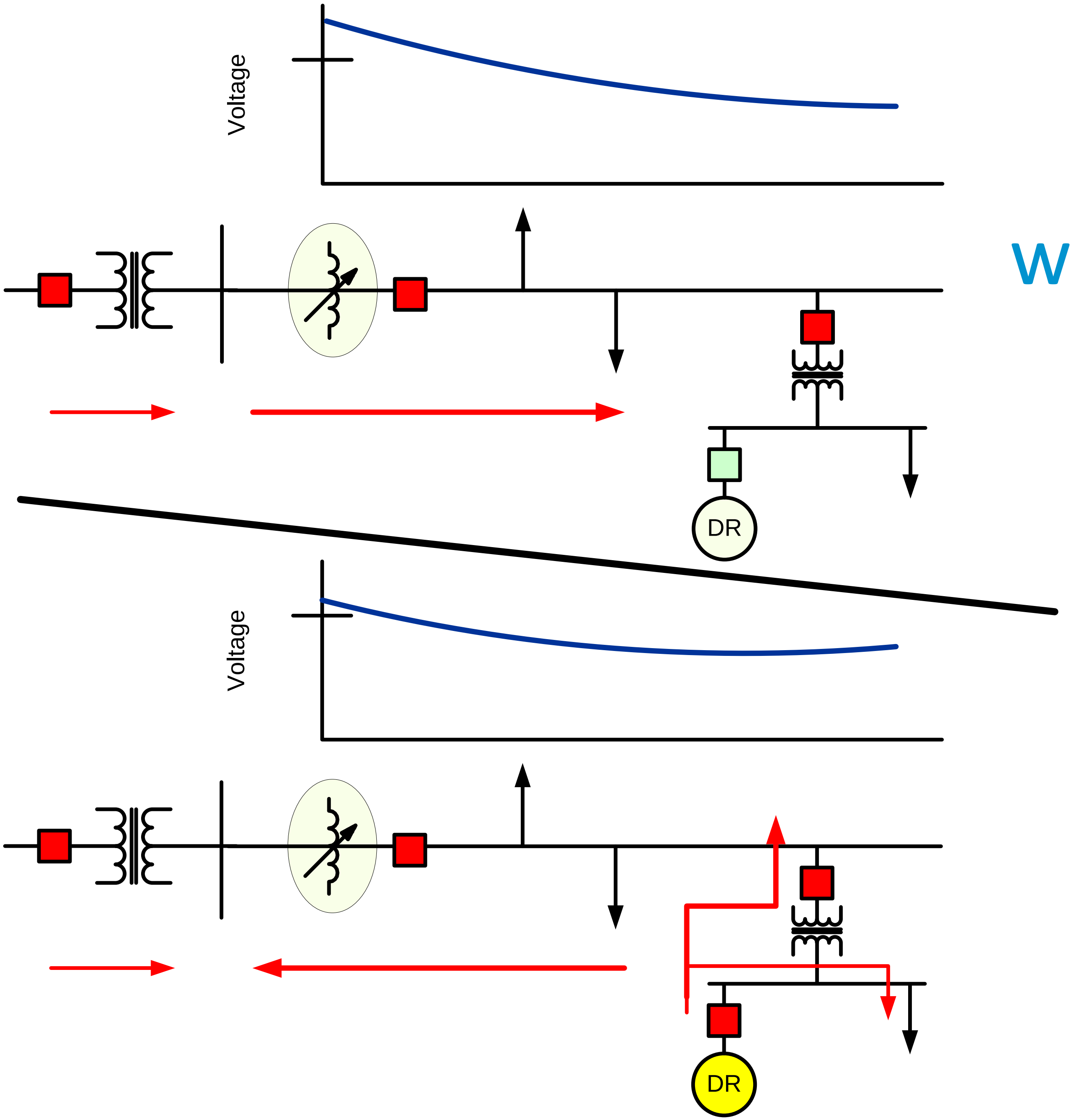
- DRs should operate load sharing baseload mode (all DRs have same droop)
- DRs should operate with excitation control in load sharing baseload mode, with pf setpoint to unity (all DRs have same droop)
- VAR flow across PCC is zero
- Voltage drop along line changes as load is relieved as there is less I^2R and I^2X_L loss
- Line drop compensation changes as there is less I^2R and I^2X_L loss
- Regulators will tap down as more power is removed from feeders

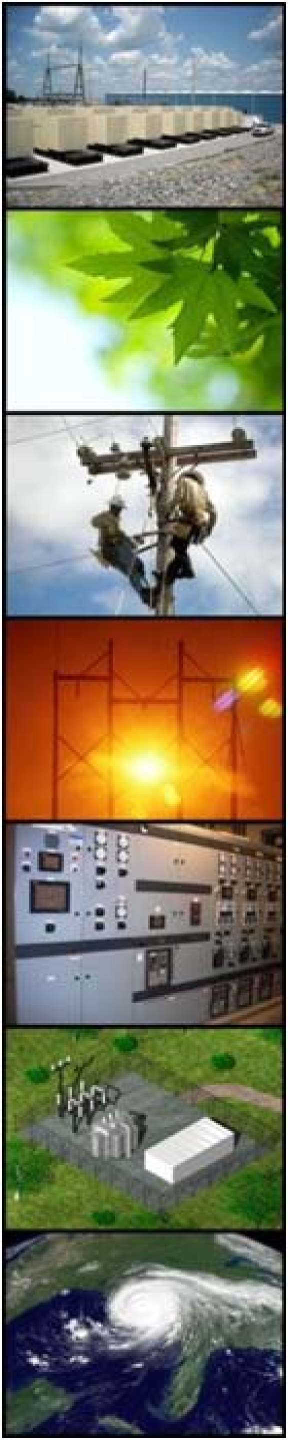


Bidirectional Powerflows: Coordination

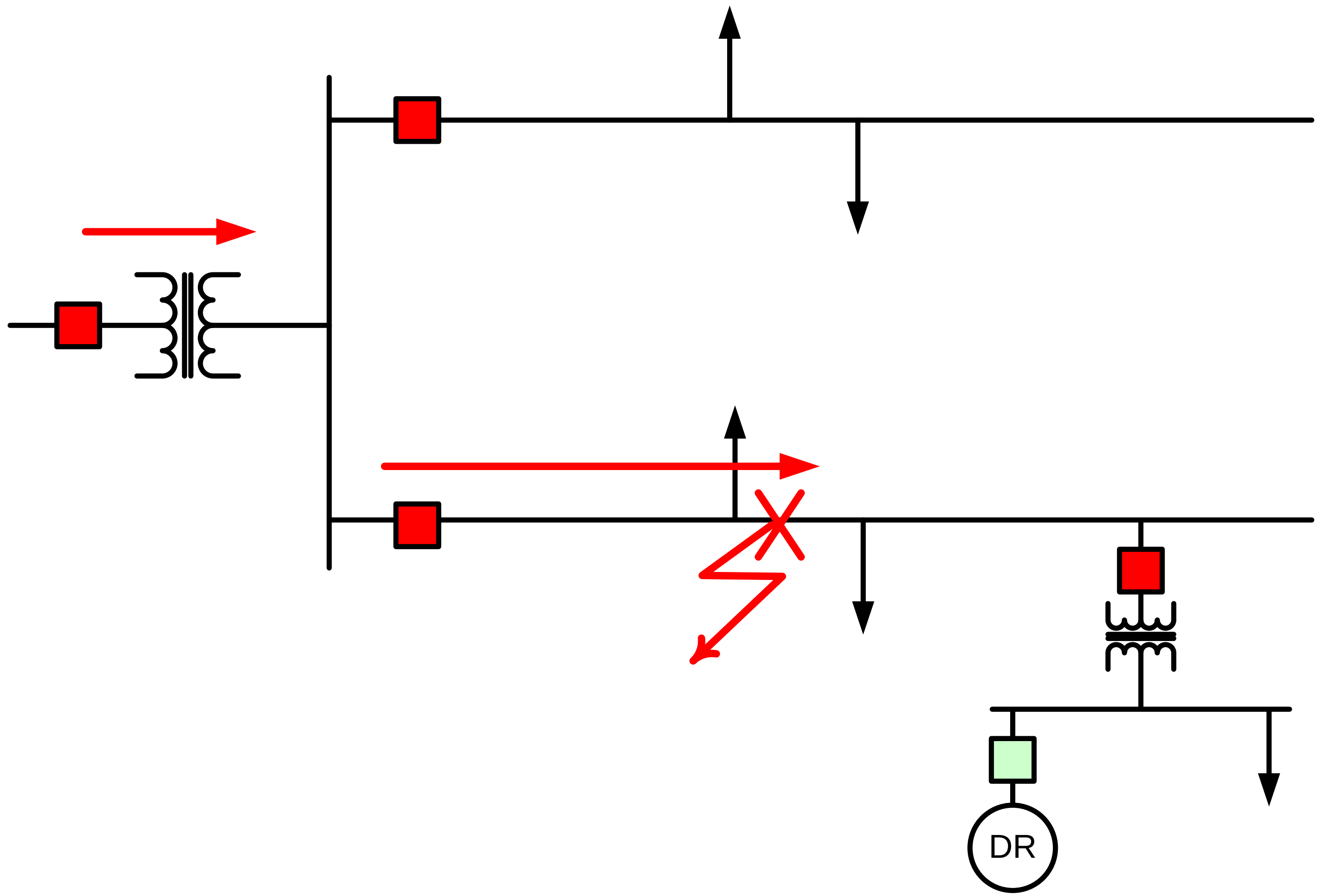
- If DR is lost, line drop losses will suddenly reappear
- Regulators should sequentially tap back up to ensure voltage on feeder is quickly restored
- Using sequential over non-sequential operation shortens time to restore
- Substation caps should be on VAR of PF control

Voltage Profile with/without DR

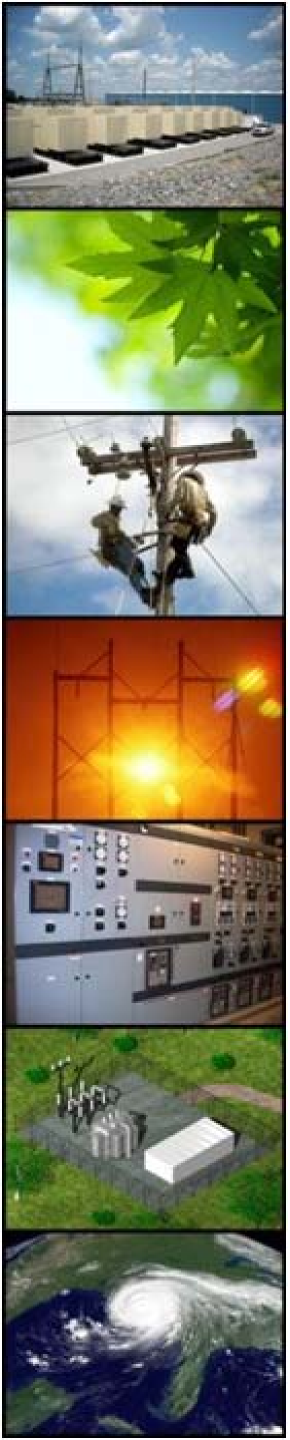




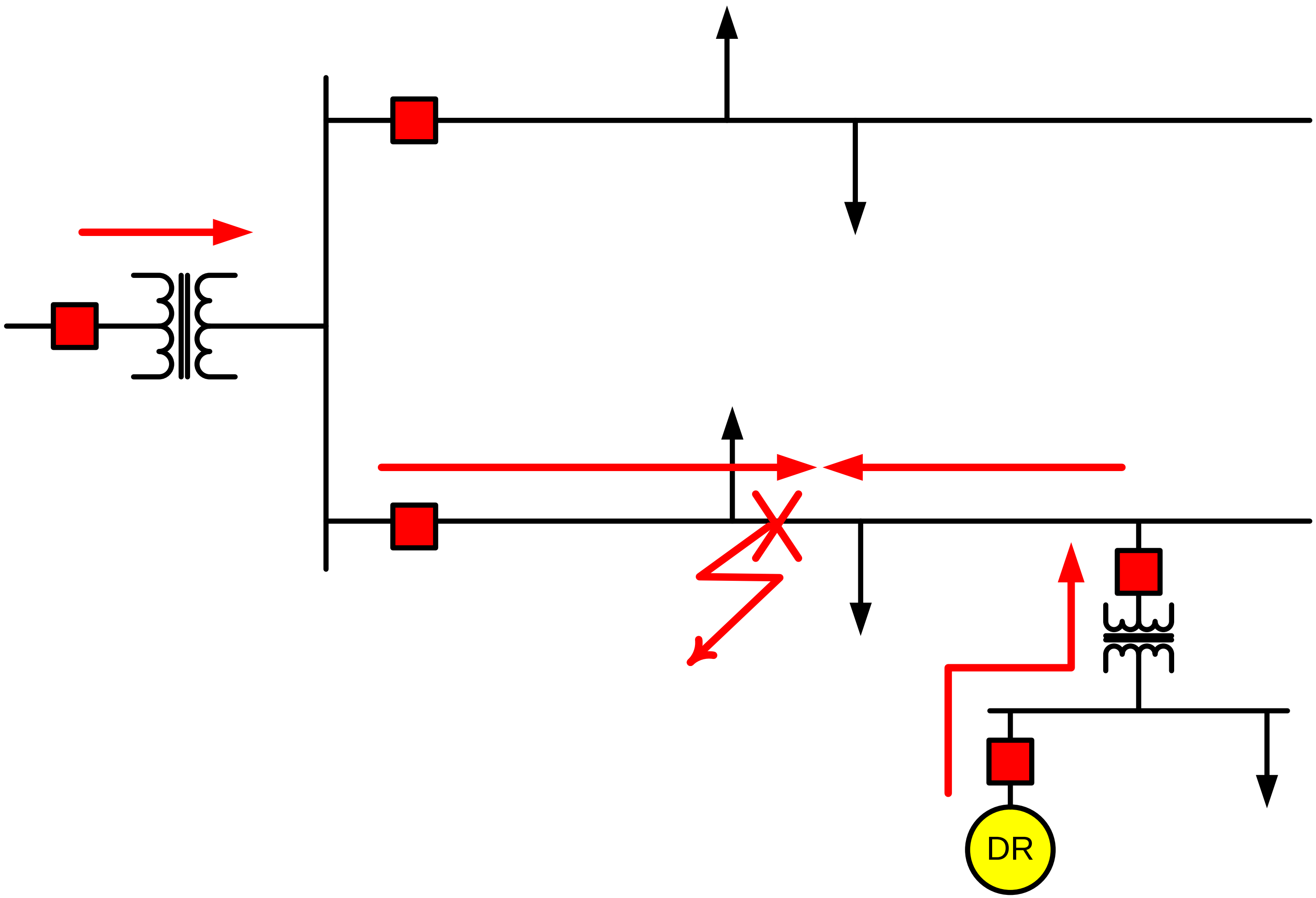
Bidirectional Fault Currents: Feeder



- DR Off, Normal Fault Current Flow

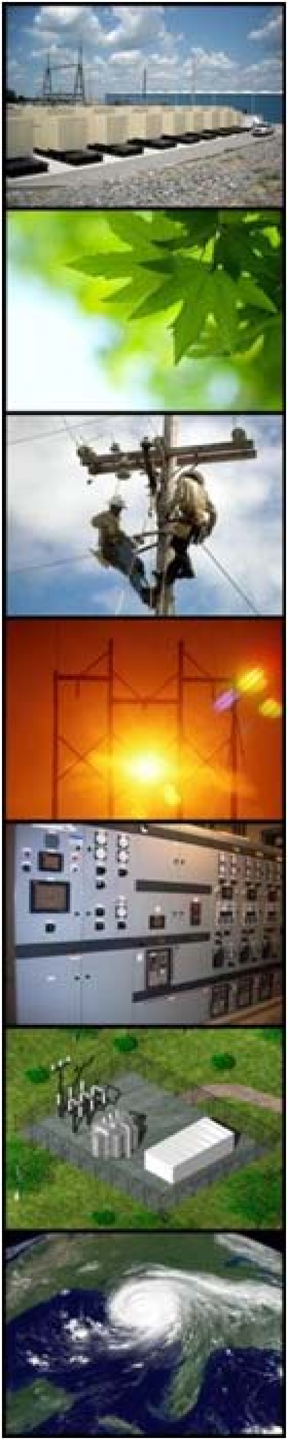


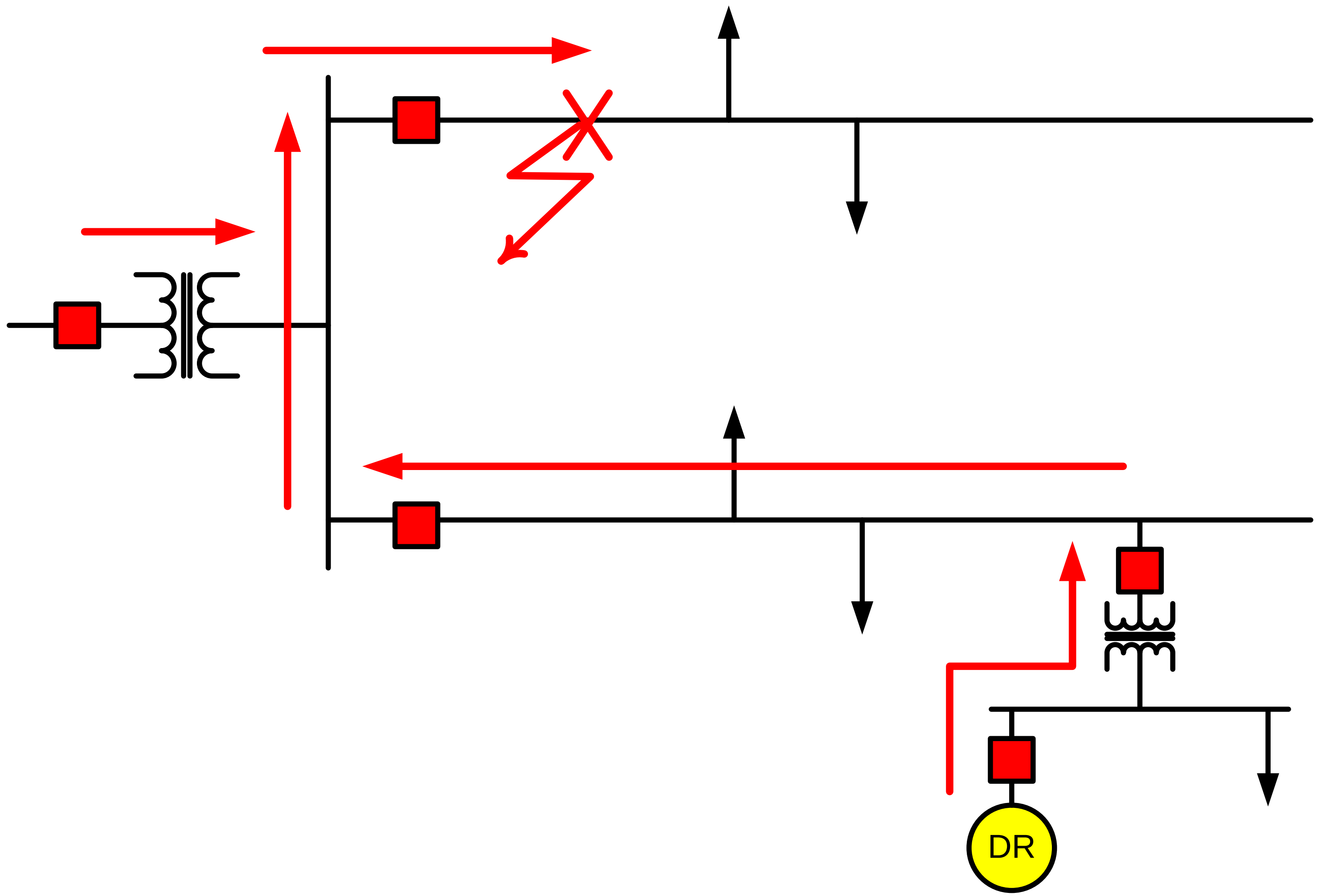
Bidirectional Fault Currents: Feeder



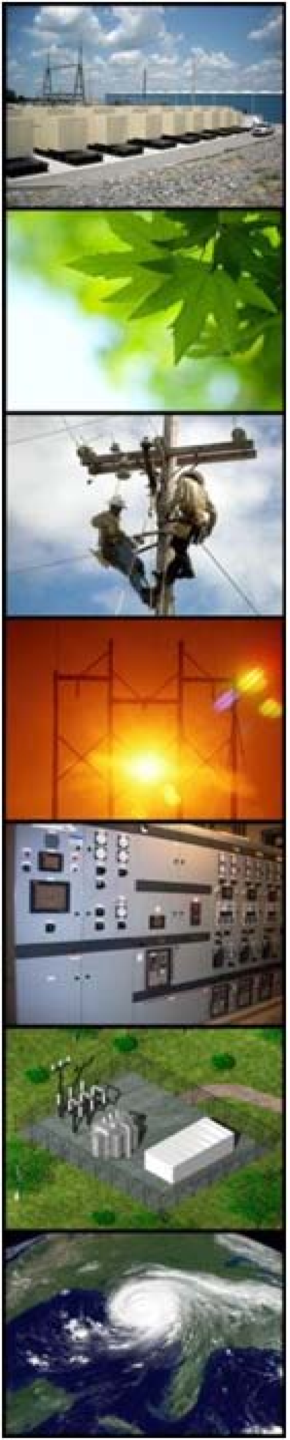
- DR On, Possible Reverse Fault Current Flow

Bidirectional Fault Currents: Feeder



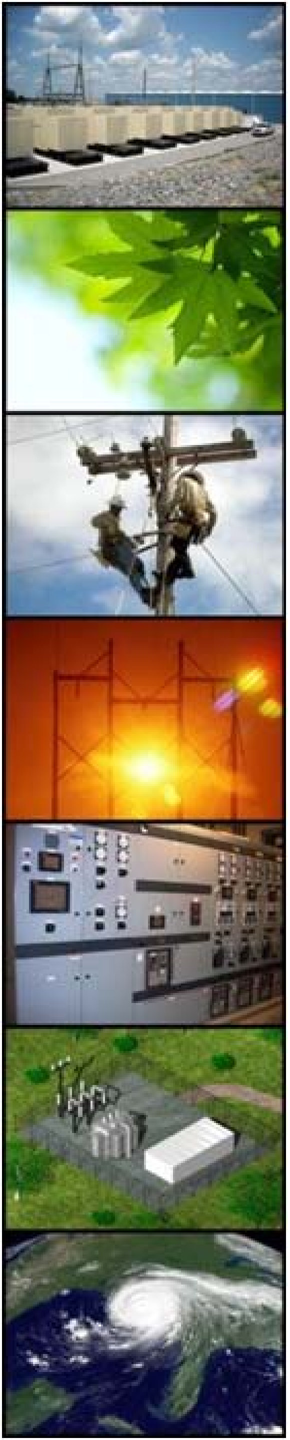


- DR On, Possible Reverse Fault Current Flow



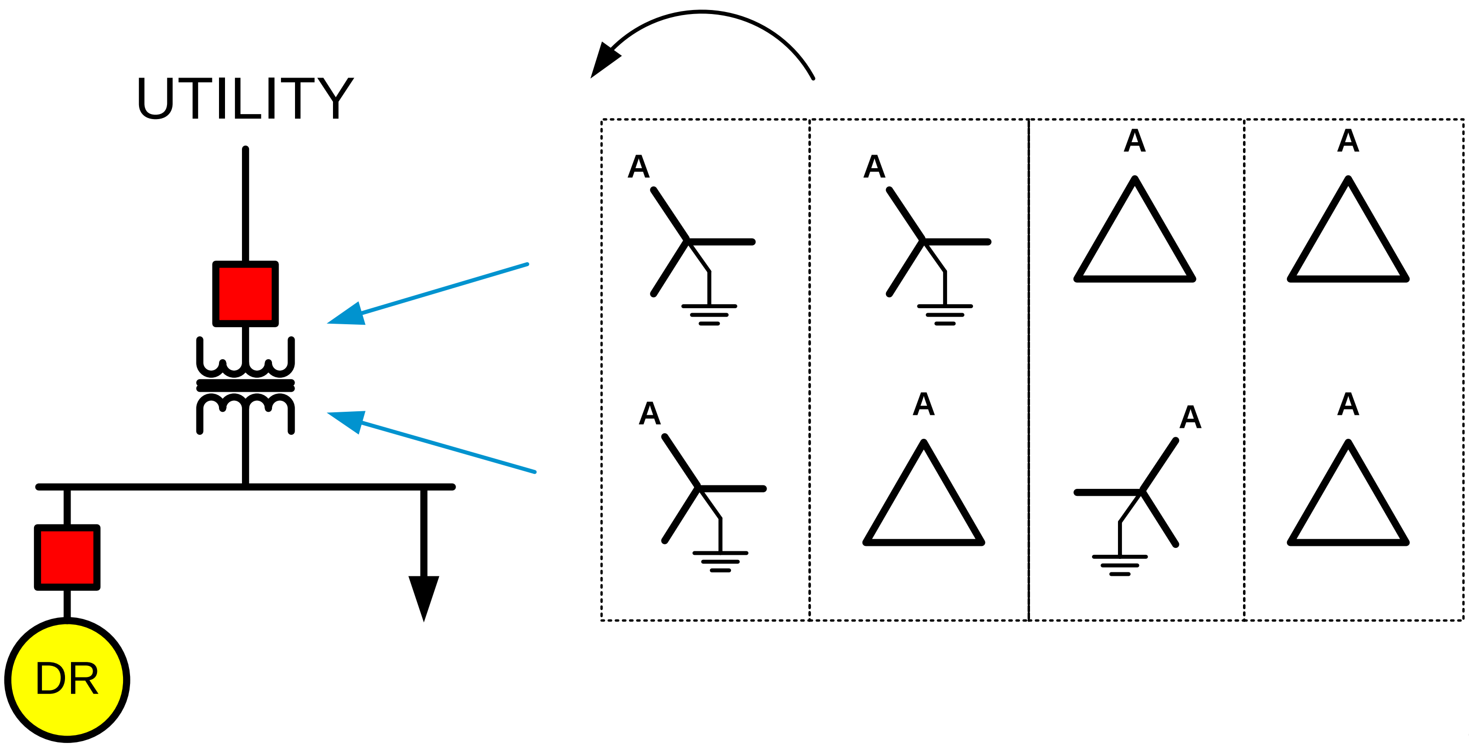
Fault Types

- Phase: Ph-Ph faults will result in unwanted fault current flow direction
- Ground: Ph-Gnd faults may result in unwanted fault current flow direction based on DR source grounding

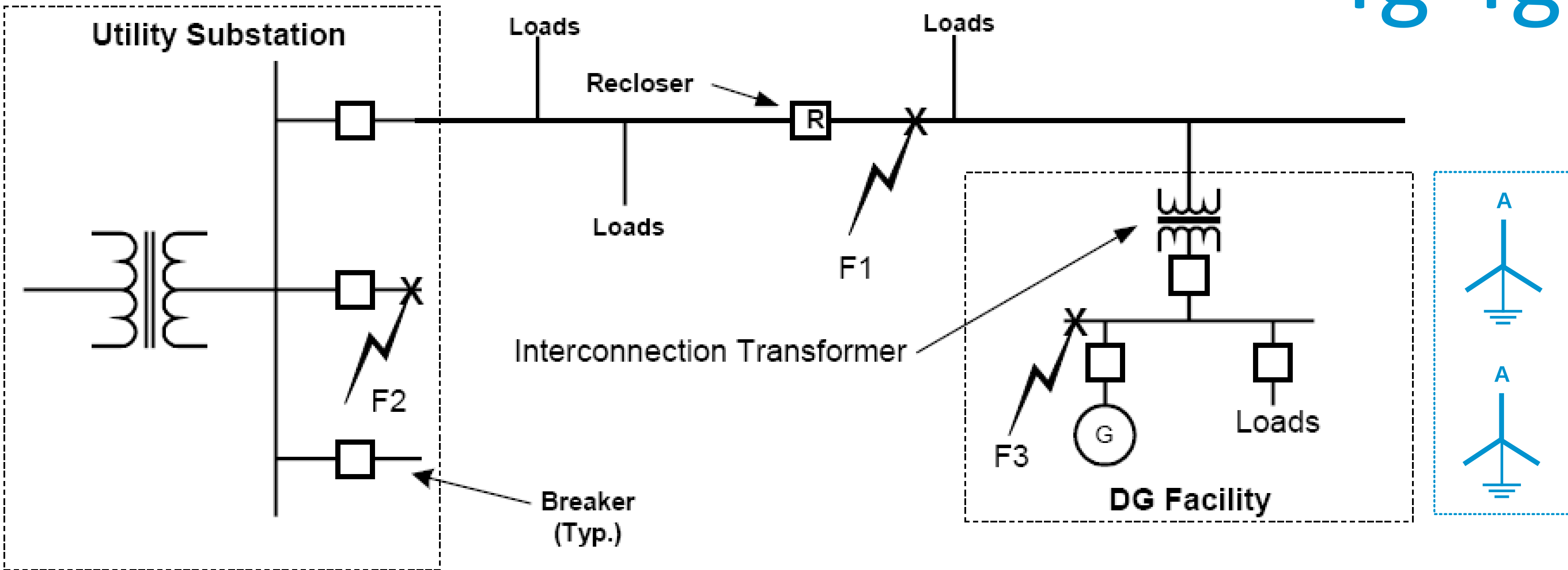


Ground Faults

- Typically the DR interconnection transformer primary winding/grounding determines if the DR will contribute ground fault current back into the system

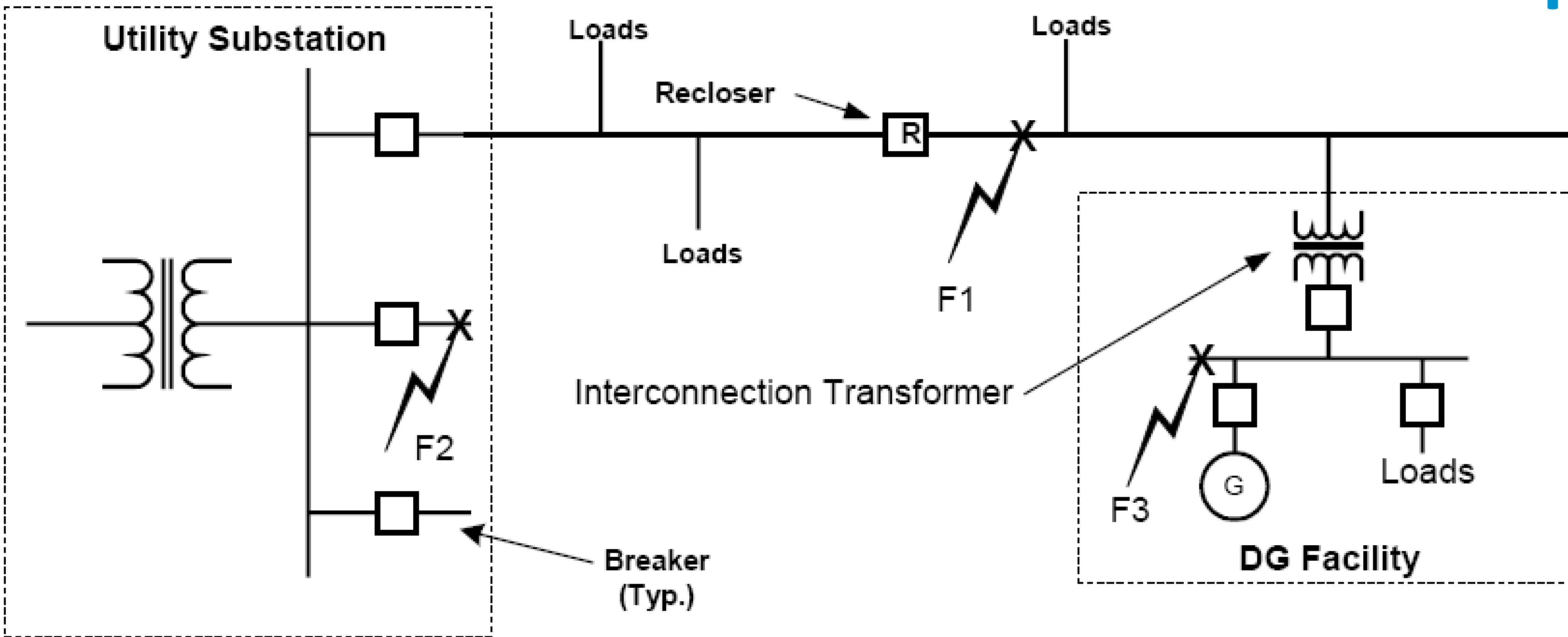


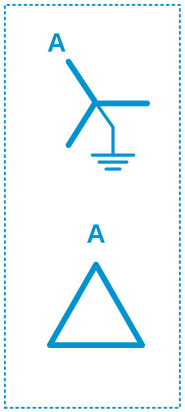
Yg-Yg



- Pros:
  - Does not cause an overvoltage for a ground fault at F1
  - Supplies a ground source for DG facility
- Cons:
  - Provides an unwanted ground current for supply circuit faults at F1 or F2
  - Supplies ground current from Breaker 1 for a fault at F3

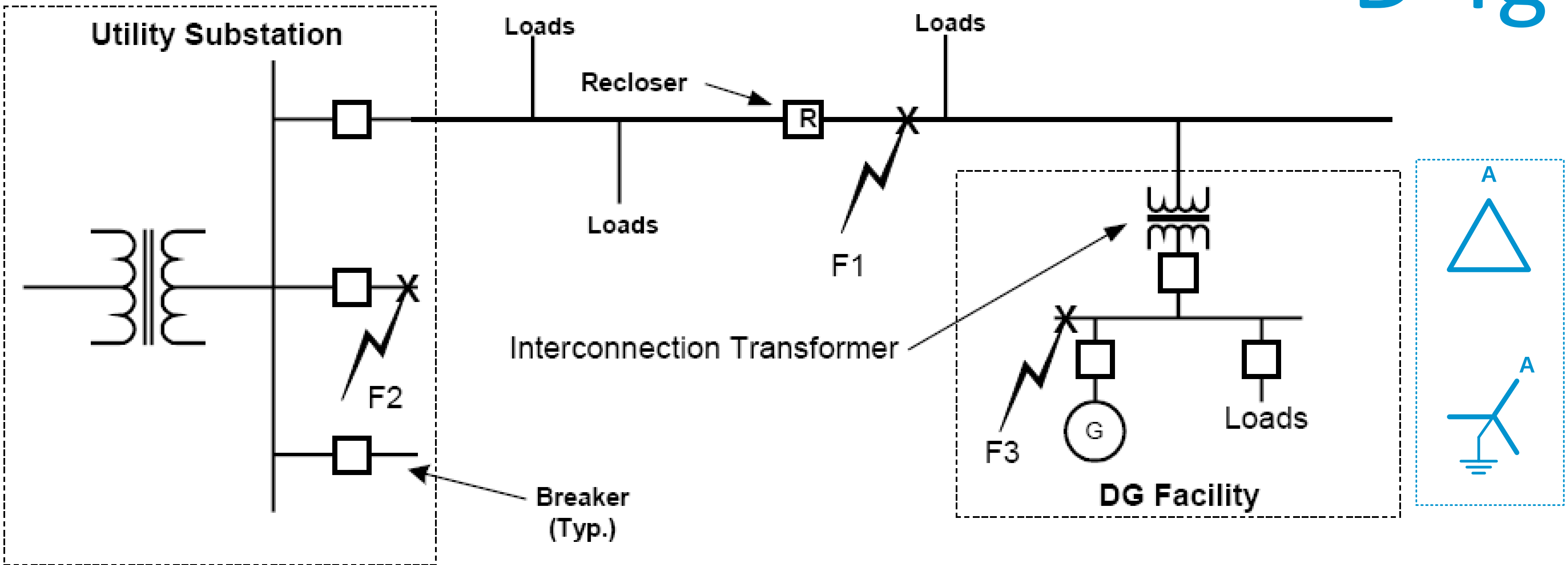
Yg-D





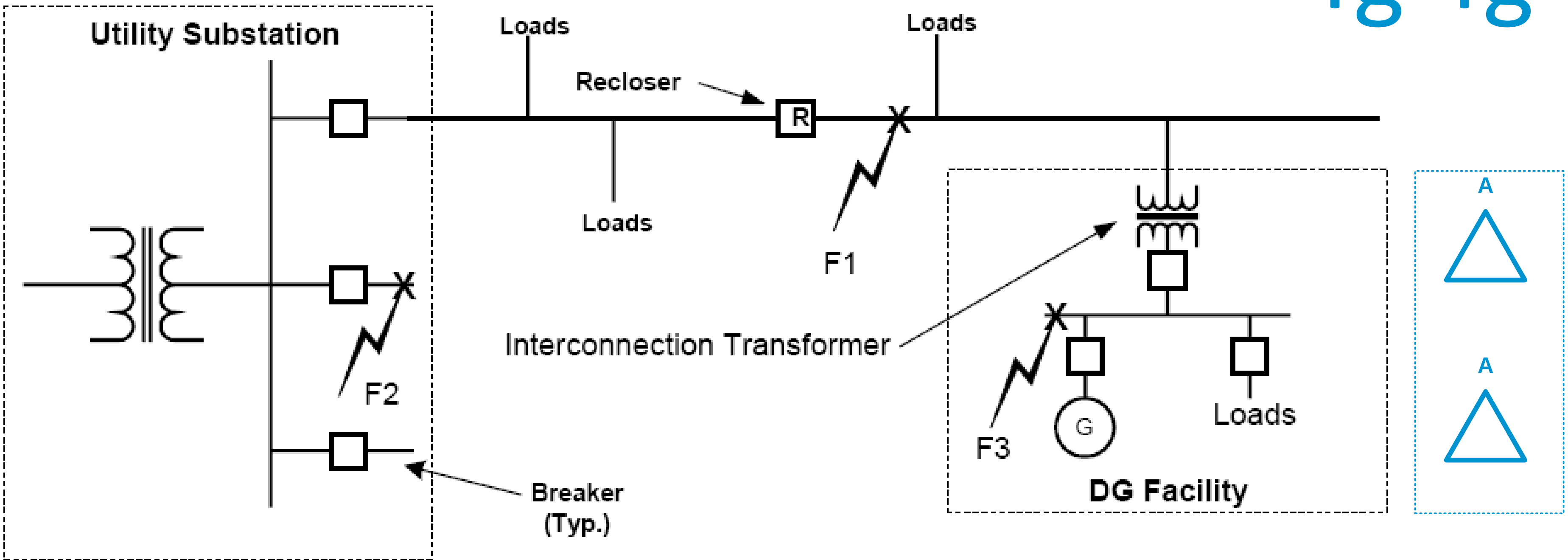
- Pros:
  - Does not supply ground current from Breaker 1 for a fault at F3
  - Does not cause an overvoltage for a ground fault at F1
- Cons:
  - Provides an unwanted ground current for supply circuit faults at F1 or F2

D-Yg

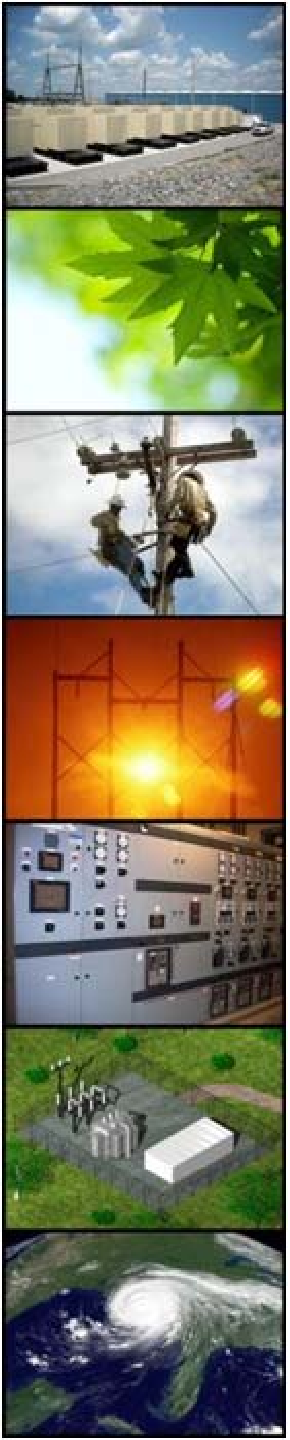


- Pros:
  - Does not provide ground fault backfeed for a fault at F1 or F2
  - Does not provide ground current contribution from Breaker 1 for a fault at F3
  - Supplies a ground source for DG facility
- Cons:
  - Can supply the feeder circuit from an ungrounded source after substation Breaker 1 trips and causes overvoltage

Yg-Yg



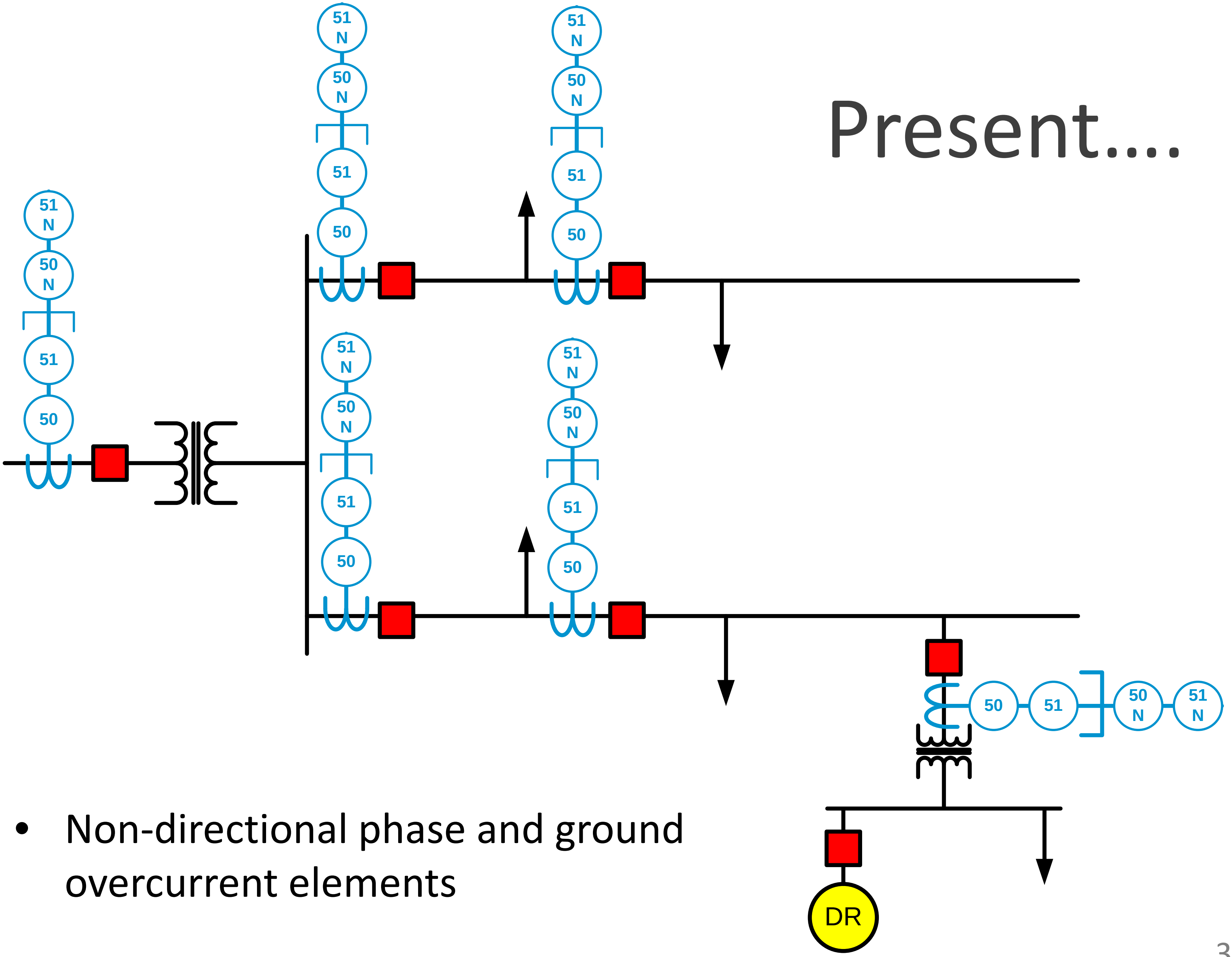
- Pros:
  - Does not provide ground fault backfeed for a fault at F1 or F2
  - Does not provide ground current contribution from Breaker 1 for a fault at F3
- Cons:
  - Can supply the feeder circuit from an ungrounded source after substation Breaker 1 trips and may cause an overvoltage
  - Does not supply a ground source for DG facility



Bidirectional Fault Currents: Coordination

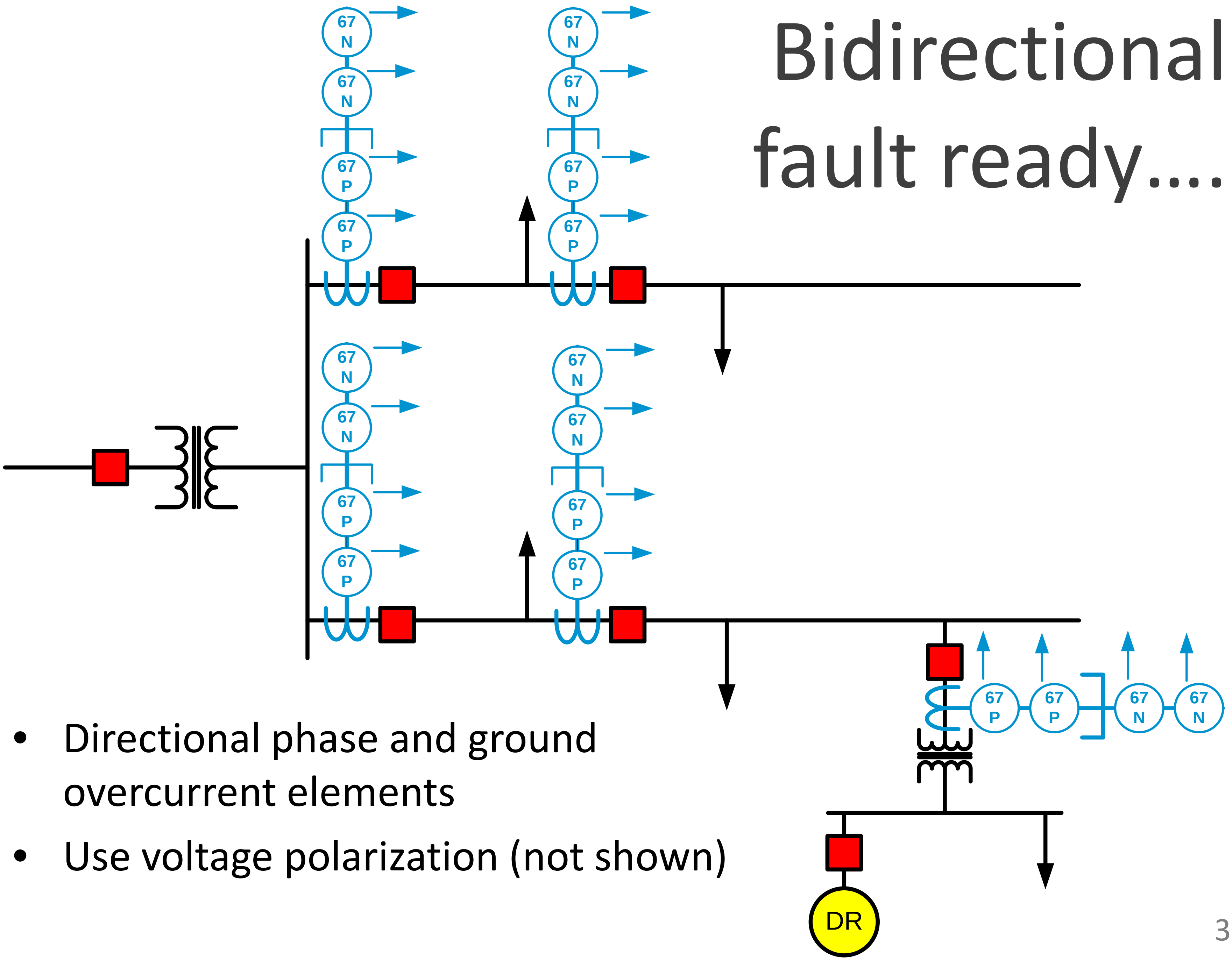
- Use directional elements in substation protection as well as mid-line reclosers
- Supervise 50/51 with 67
  - Trip direction away from substation
- Supervise 50N/51N with 67N
  - Trip direction away from substation

Present….

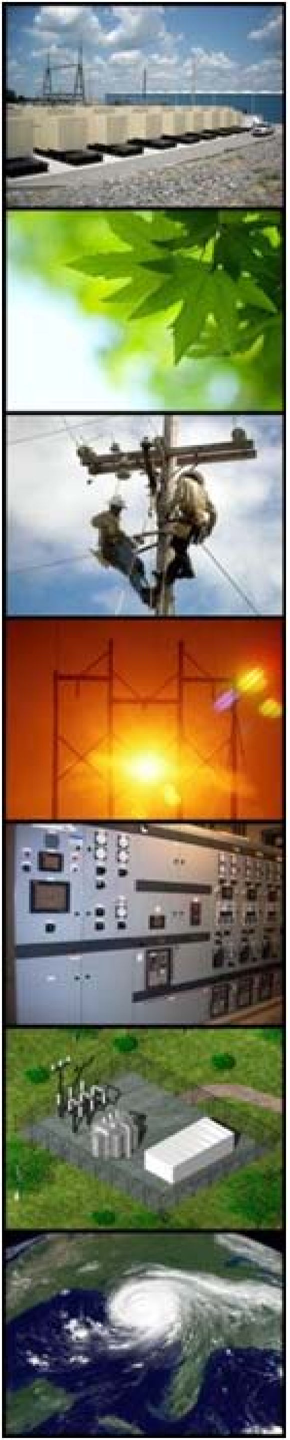


- Non-directional phase and ground overcurrent elements

Bidirectional fault ready….

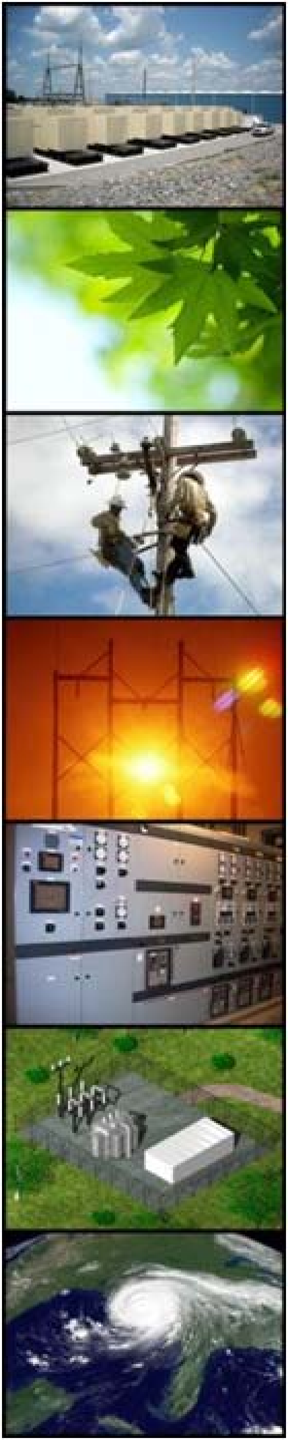


- Directional phase and ground overcurrent elements
- Use voltage polarization (not shown)



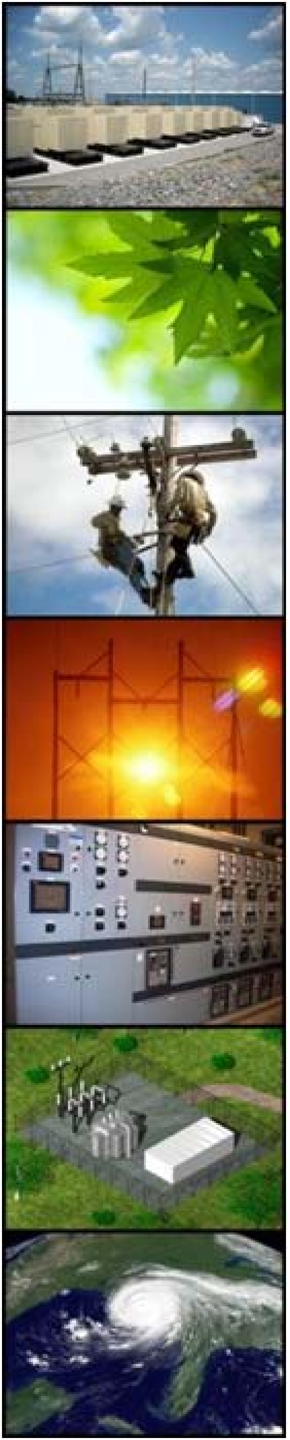
Reclosing Coordination

- Although DR protection trips fast (30-90 cycles), instantaneous reclosing at the substation and mid-line reclosers may need to be delayed
- For extra security, Utilities have been employing adaptive reclosing
  - Voltage supervision ensures all DR is off line
  - If and DR stays on, holding up feeder voltage, reclosing is blocked and an alarm is raised

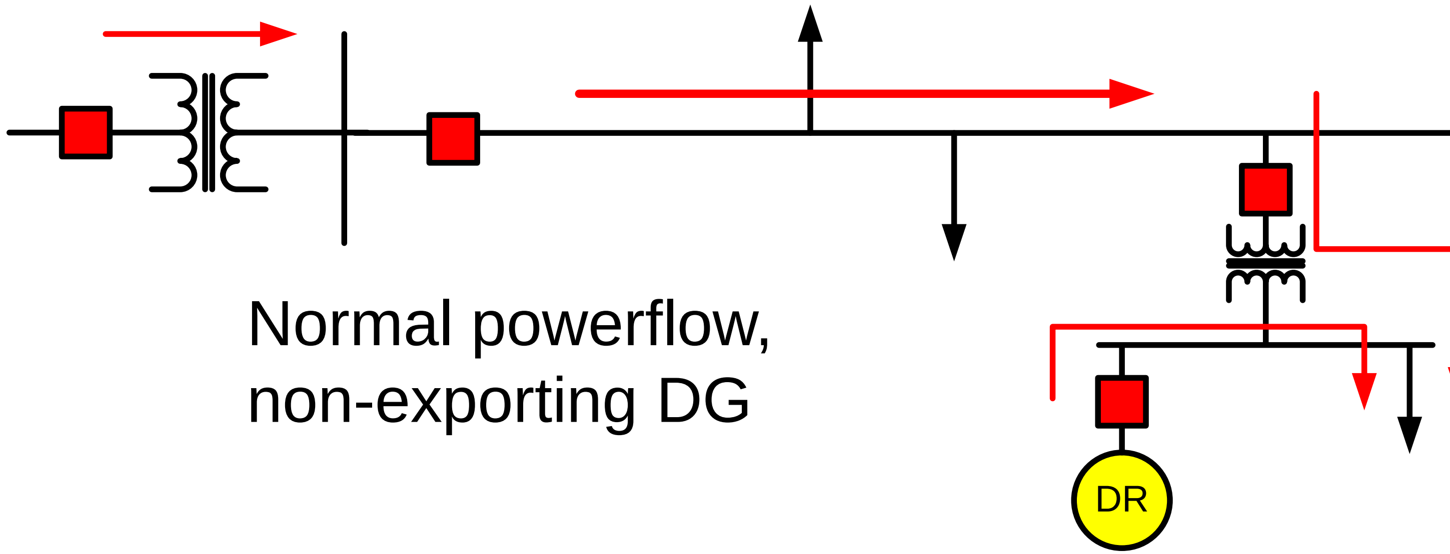


Reclosing Consideration

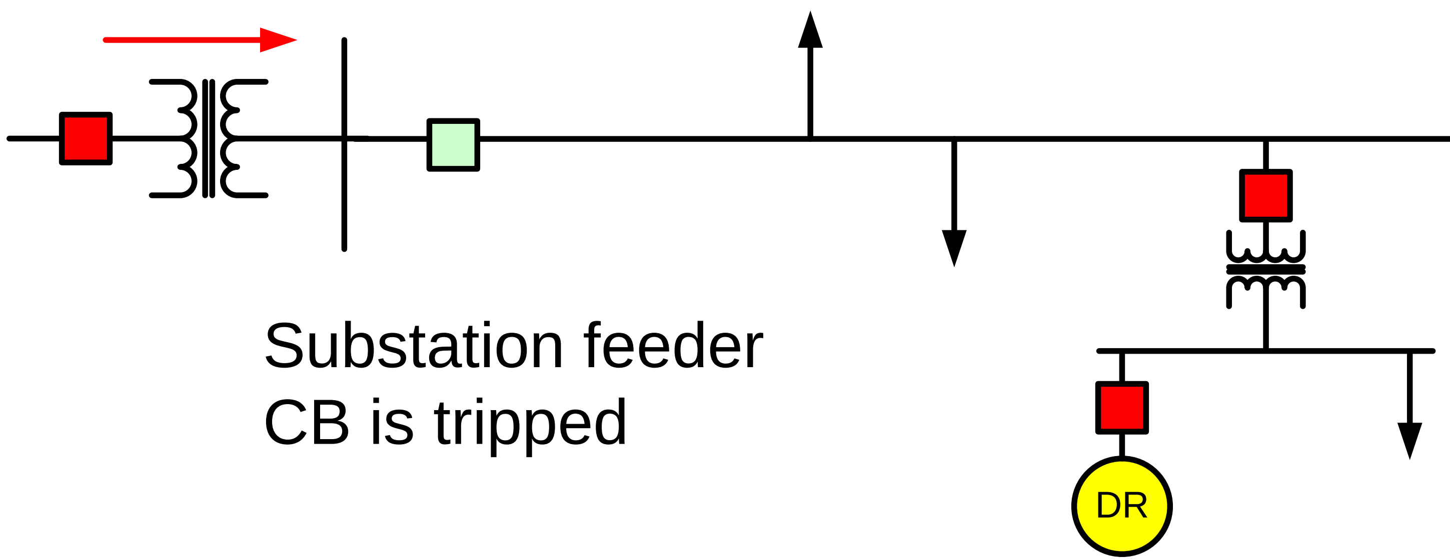
- Today: No intentional islanding is allowed
- Future: Intentional islanding may be permitted
  - Microgrids
- Treatment of two scenarios different
  - No islanding
    - Lengthen reclosing at substation
    - Adaptive reclosing using voltage supervision
  - Islanding
    - Use sync check element at substation to sync microgrid back to Utility system



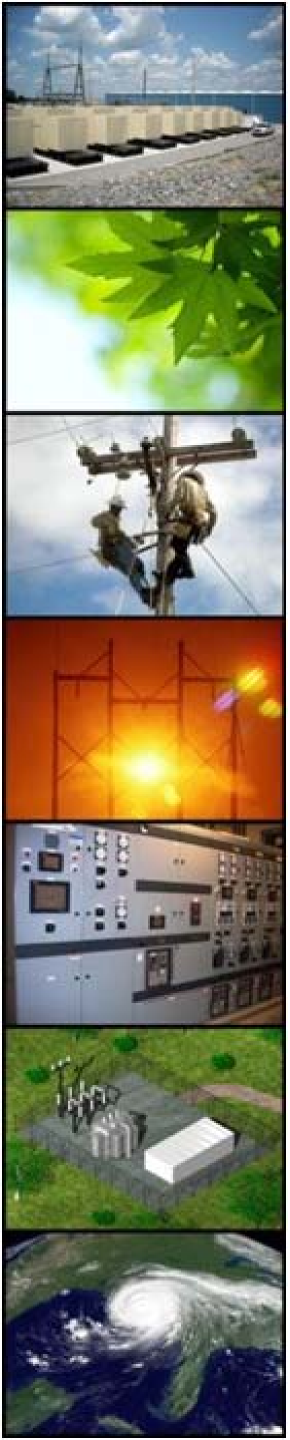
Supervised Reclosing



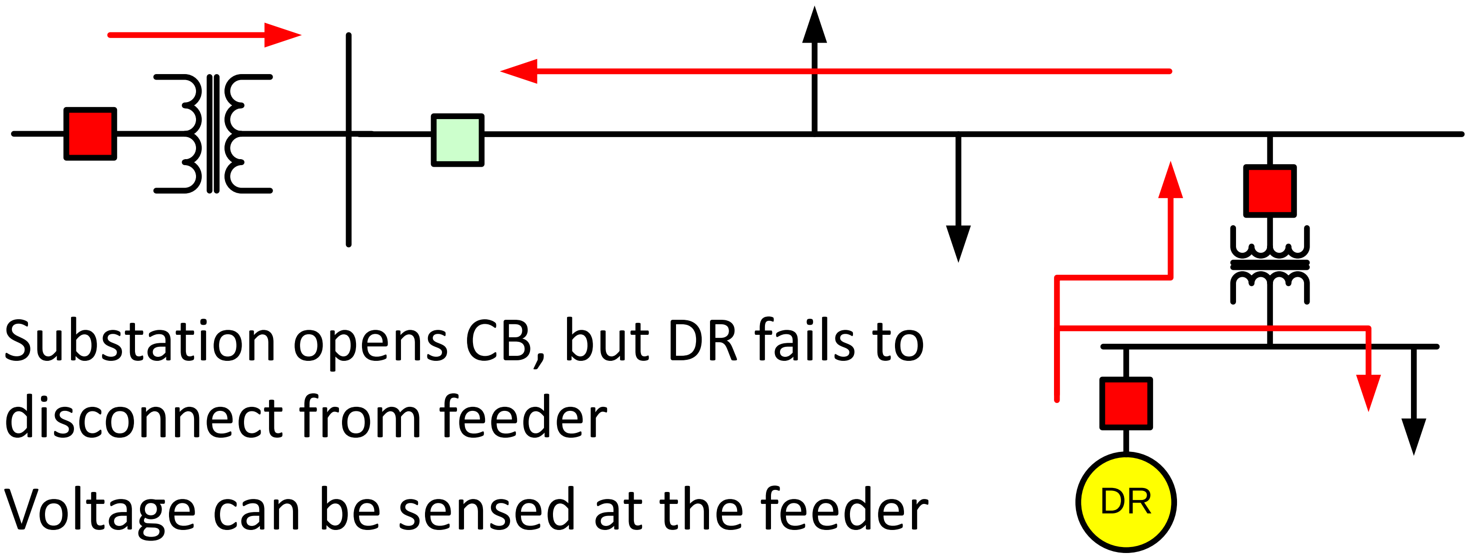
Normal powerflow,
non-exporting DG



Substation feeder
CB is tripped

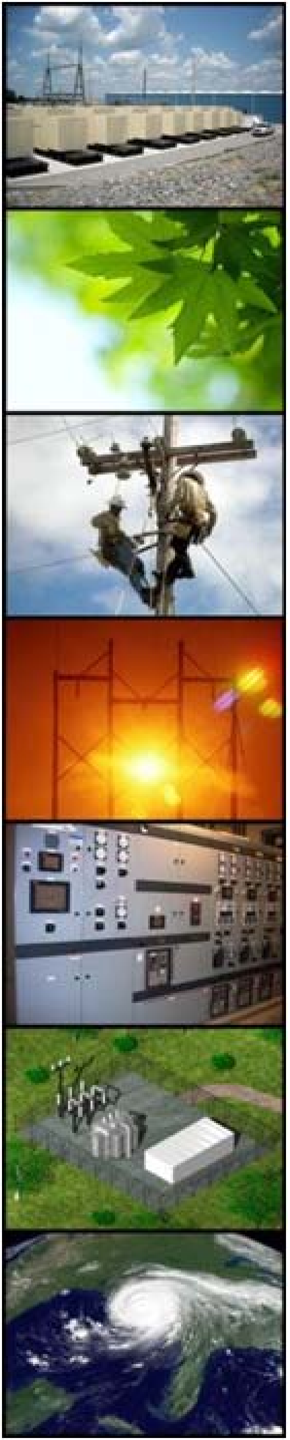


Supervised Reclosing

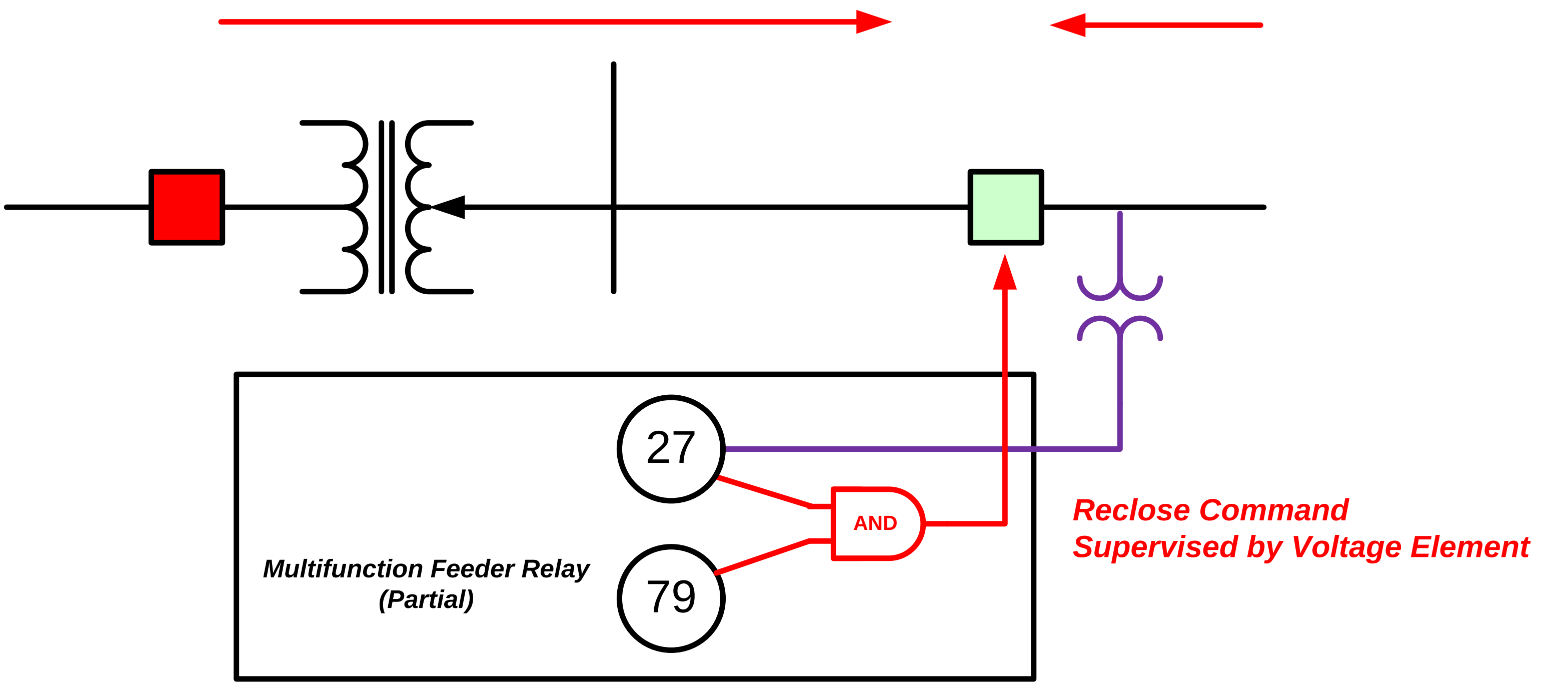


- Substation opens CB, but DR fails to disconnect from feeder
- Voltage can be sensed at the feeder substation CB and reclosing blocked

- If you <u>**do not**</u> want an <u>island</u>, use **voltage supervised reclosing** to ensure all DR is disconnected from the feeder
- If you <u>**do**</u> want an <u>island</u>, use **sync check supervised reclosing** to ensure the substation is hot and in sync with the islanded feeder (microgrid)

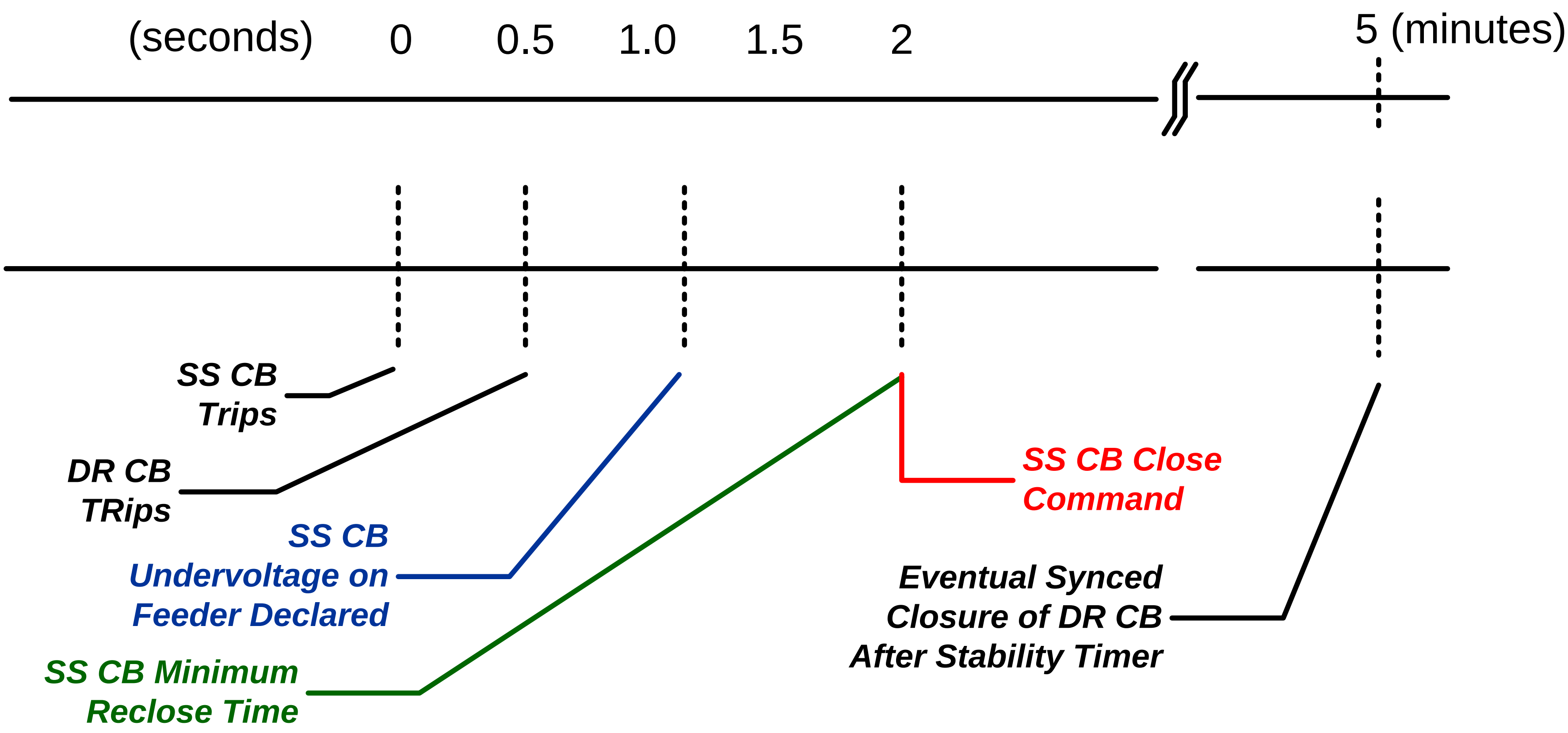


Voltage Supervised Reclosing



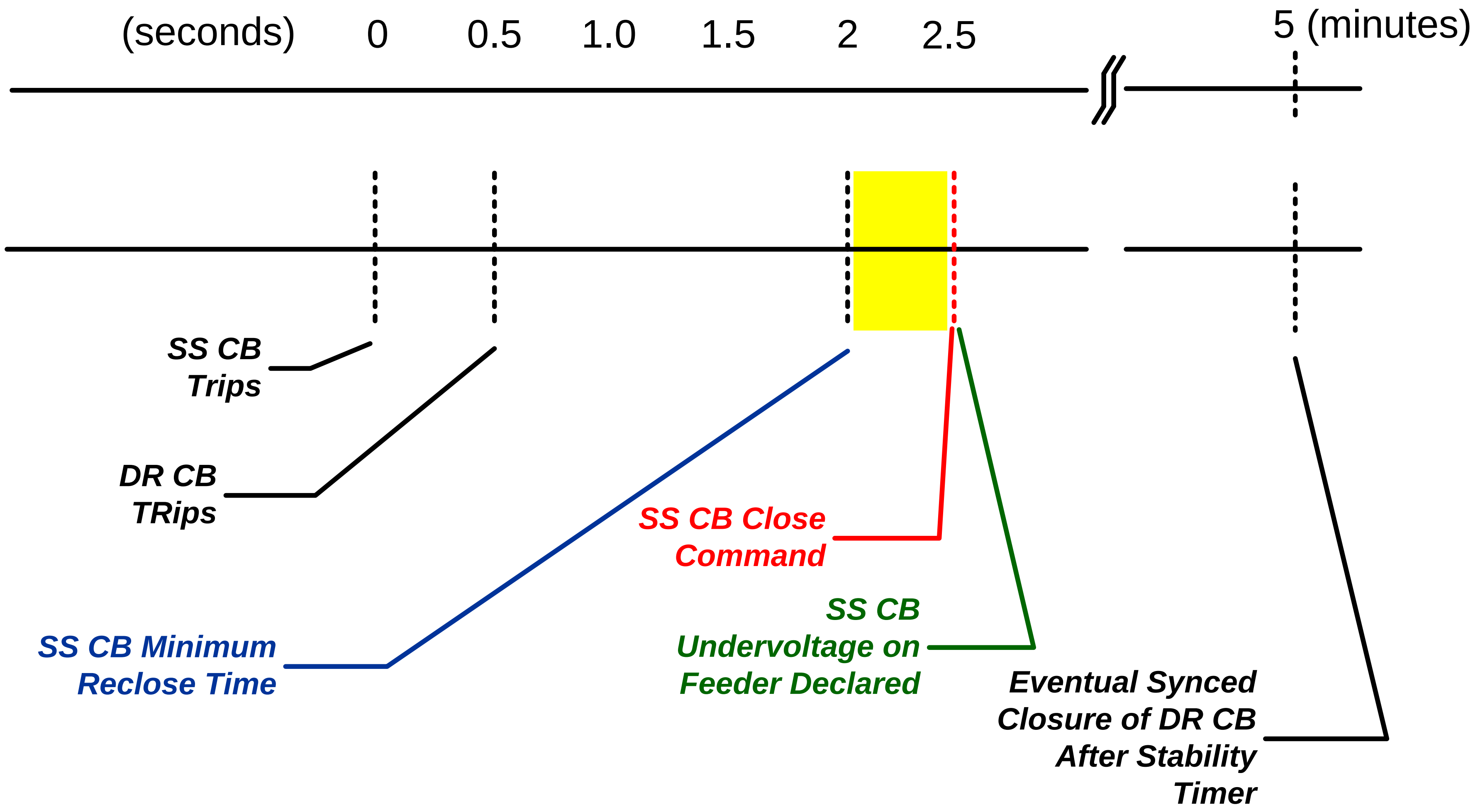
- Reclose will be as fast as voltage disappears from the feeder
- This ensures no DR is left energized on the feeder

Normal Reclose



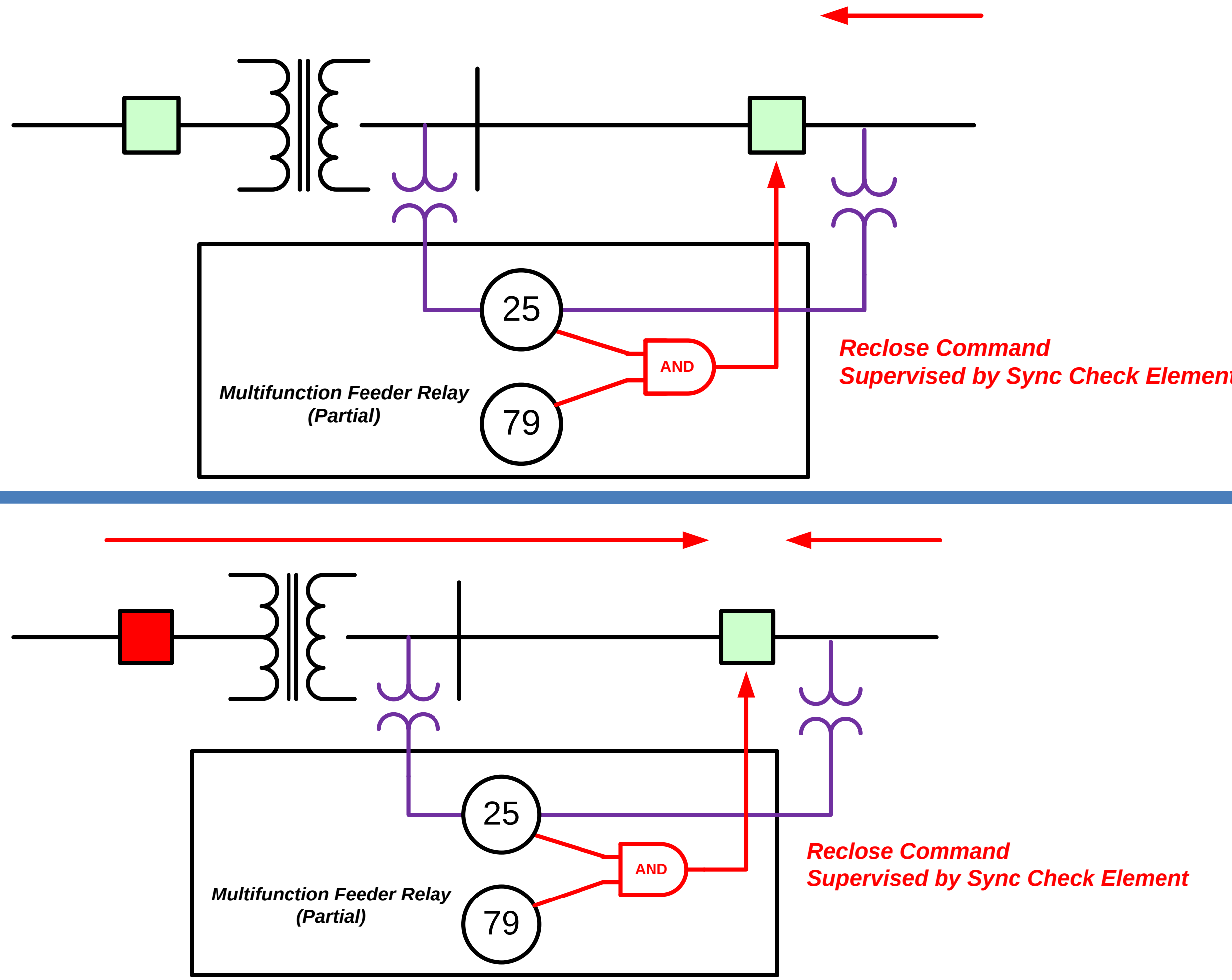
- Feeder undervoltage declared _before_ minimum reclose time delay expire

Voltage Supervision Delayed Reclose



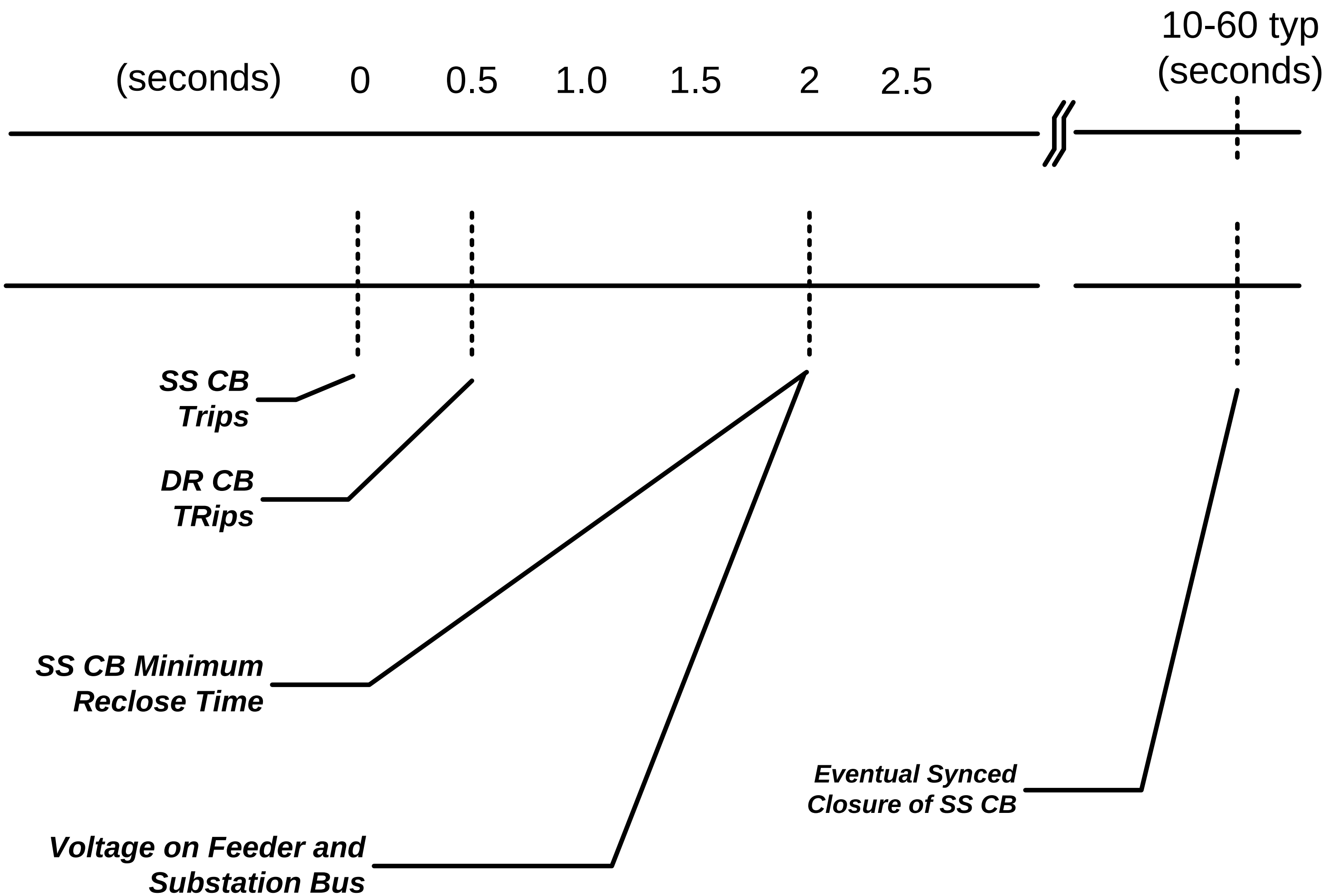
- Feeder undervoltage declared ***after*** minimum reclose time delay expire

Sync Check Supervised Reclosing

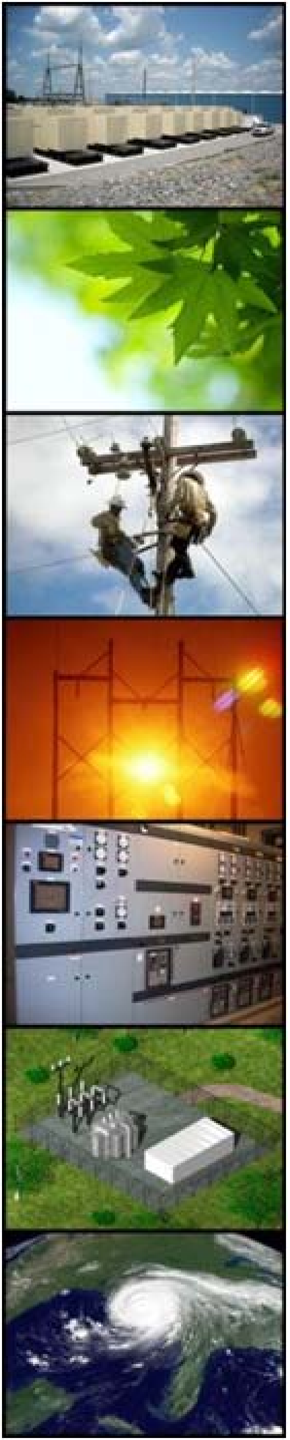


- Reclose will occur when substation voltage returns, and substation and islanded feeder with DR (microgrid) is with permissible sync limits

Sync Check Supervised Reclose

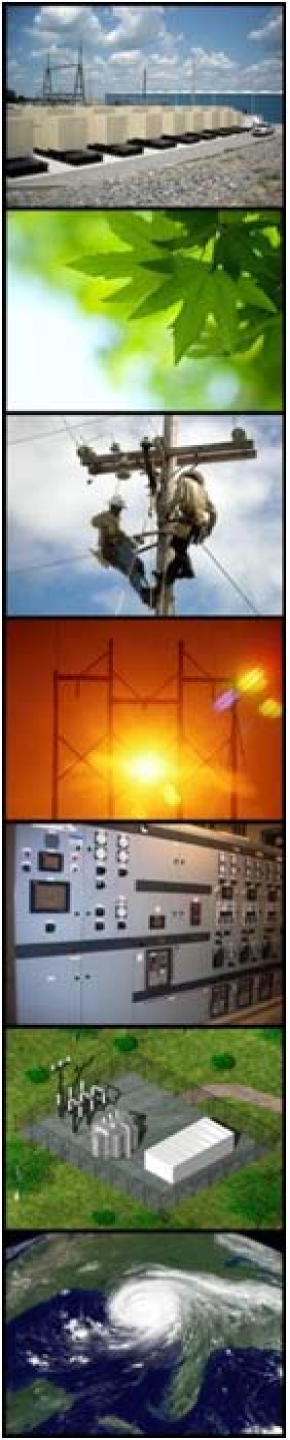


- Sync check closes after substation is reenergized and feeder DR (microgrid) and power system are in synchronism



DR Dispatch & Status

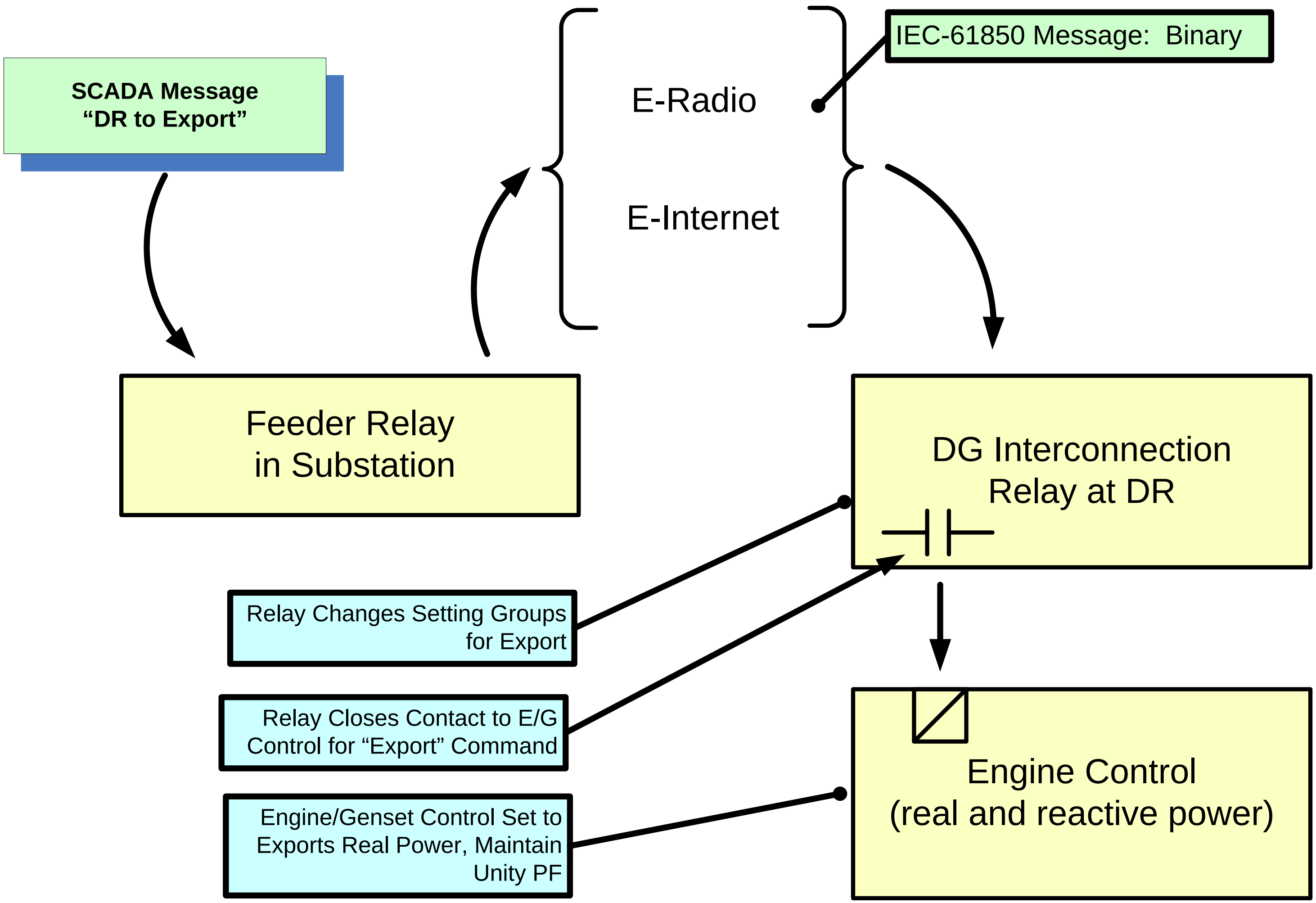
- Protective relays that employ the IEC-61850 protocol can use Internet to communicate to/from the substation to the DR
  - **From S/S to DR**
    - **Dispatch**
      - Start & Run; Stop
    - **Transfer Trip**
    - **Export Signal**
      - Change generator control settings for microgrid
      - Change DR protection settings



DR Dispatch & Status

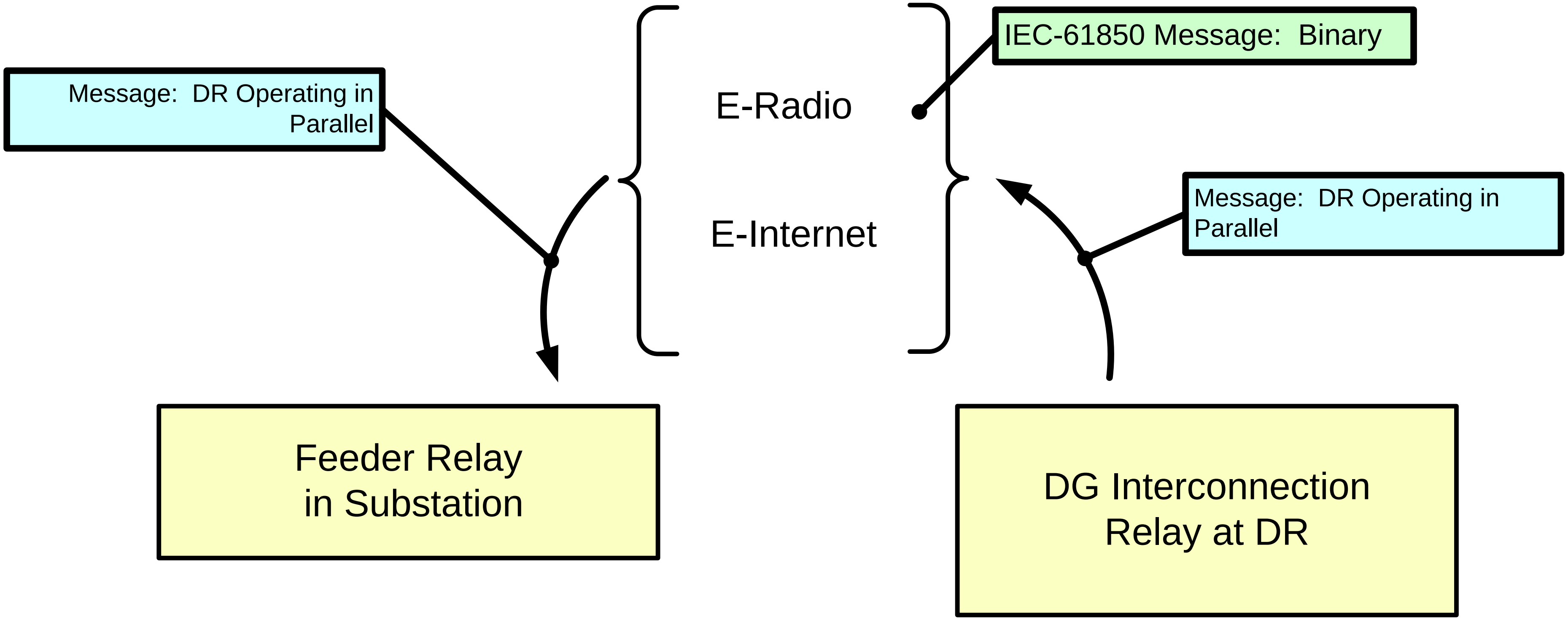
- Protective relays that employ the IEC-61850 protocol can use Internet to communicate to/from the substation to the DR
  - **From DR to S/S**
    - **Status**
      - Signal from DR to S/S that it is running parallel to grid
    - **Heartbeat**
      - If messages between S/S and DR fail, do not allow export operation & alarm

SS ↔ DR Communications



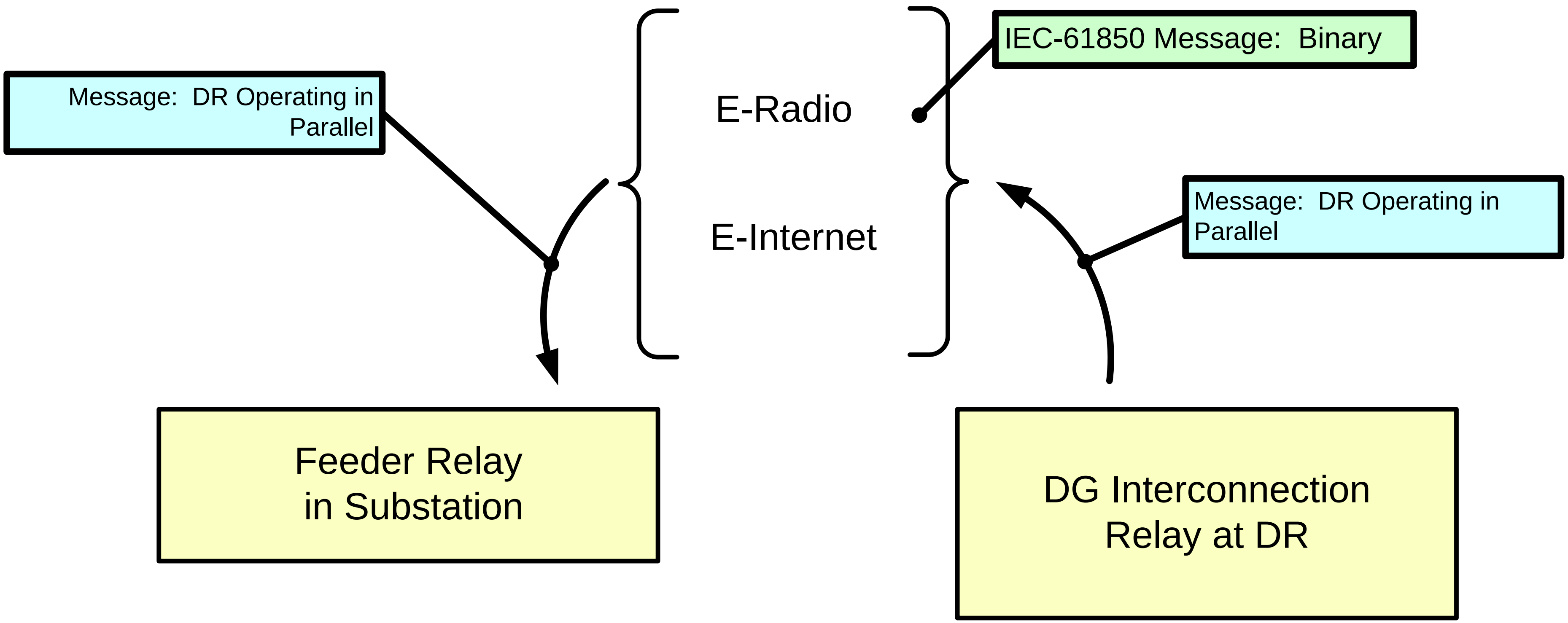
- DR Commanded to Export

SS ↔ DR Communications

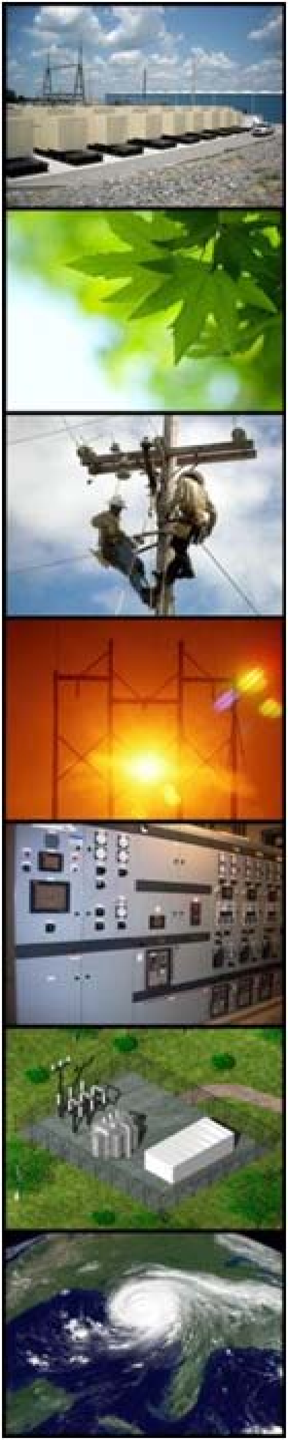


- DR Operating Status to SS

SS ↔ DR Communications



- SS Transfer Trip Command to DR

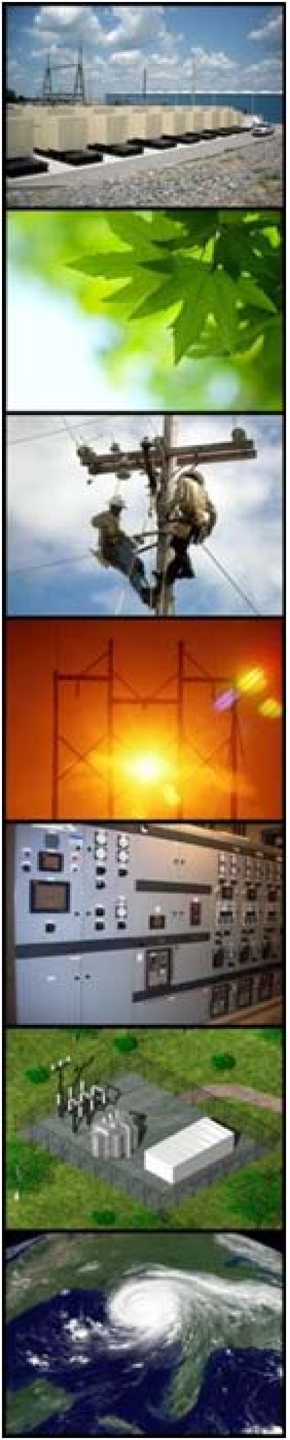


Summary

- Thoughtful substation protection and control design can meet challenges of DR
- Voltage regulators and DR control can be coordinated for proper response under varying conditions of powerflow
- Protection can be modified to properly response to bisectional fault current flows
- Reclosing can be made adaptive to speed cycles and ensure safety
- Protection system based Internet communications (IEC-61850) may be applied for substation to DR for a host of two-way applications at reasonable cost

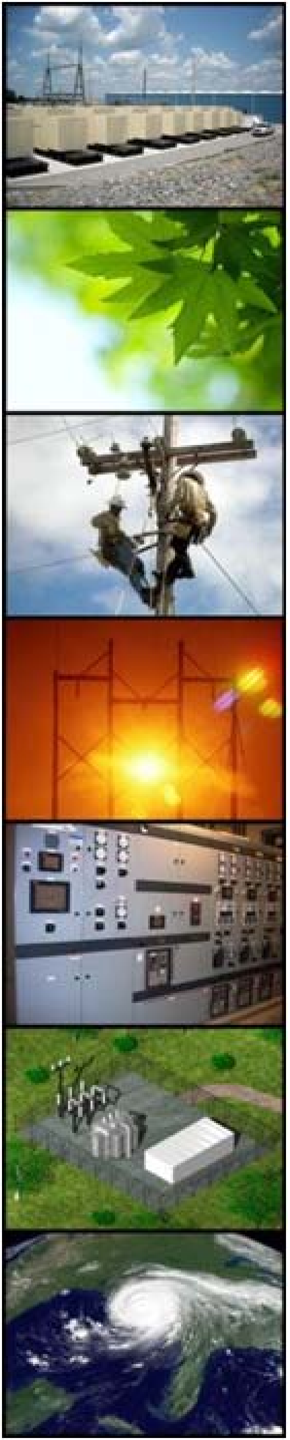
References

- **IEEE 1547**: Standard for Interconnecting Distributed Resources with Electric Power Systems
- **IEEE C37.104**: Guide for Automatic Reclosing of Line Circuit Breakers for AC Distribution and Transmission Lines
- **IEEE PSRC Special Report**: Impact of Distributed Resources on Distribution Relay Protection



References

- **IEEE P2030**: Draft Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), and End-Use Applications and Loads
- **Interconnection Transformer Winding Arrangement Implications for Distributed Generation Protection**, Wayne Hartmann, EGSA Article, 2002
- **Standard Handbook of Powerplant Engineering**, 2Ed, Chapter 4, Electrical Interconnections, Wayne Hartmann



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Thanks! Q&A