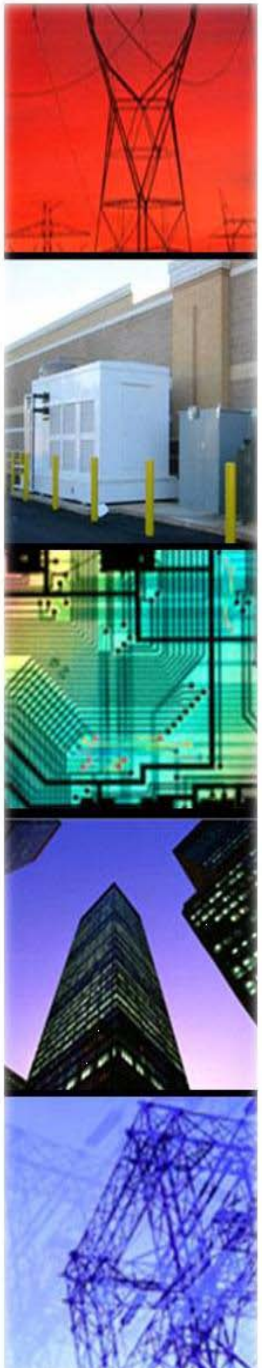
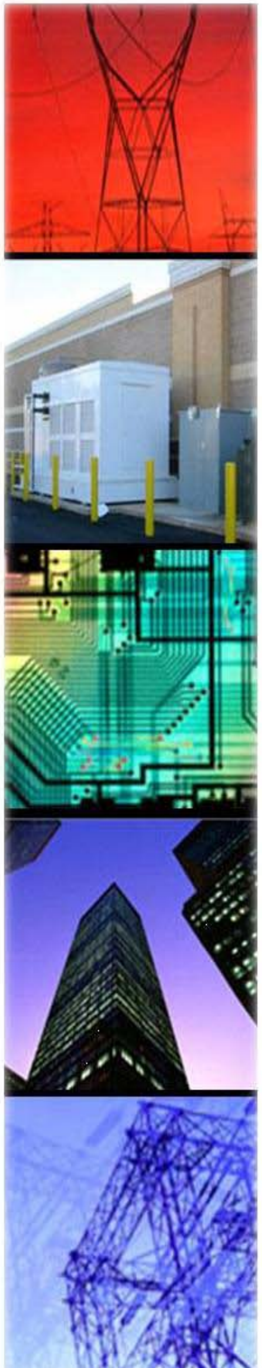


FMEA Committee Forum
E & O Committee
April 26-27, 2011
Orlando, FL

Larger Scale DG Impact on Distribution Systems

NexGear
Intelligent Power Systems

A PowerSecure Company: POWR



Contact Information

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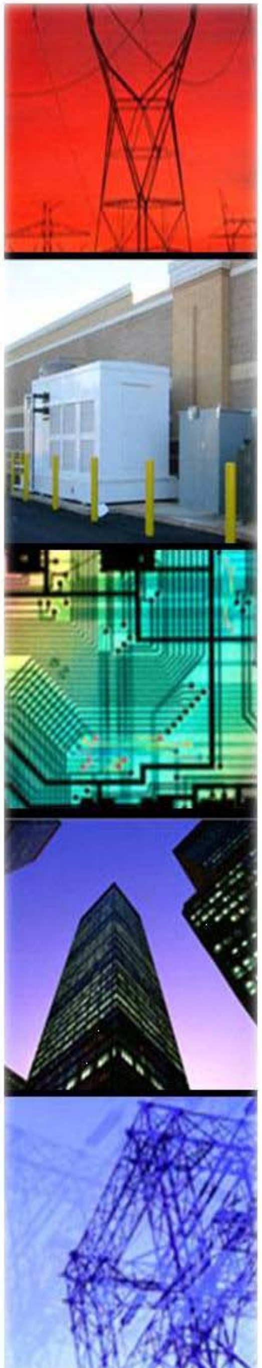
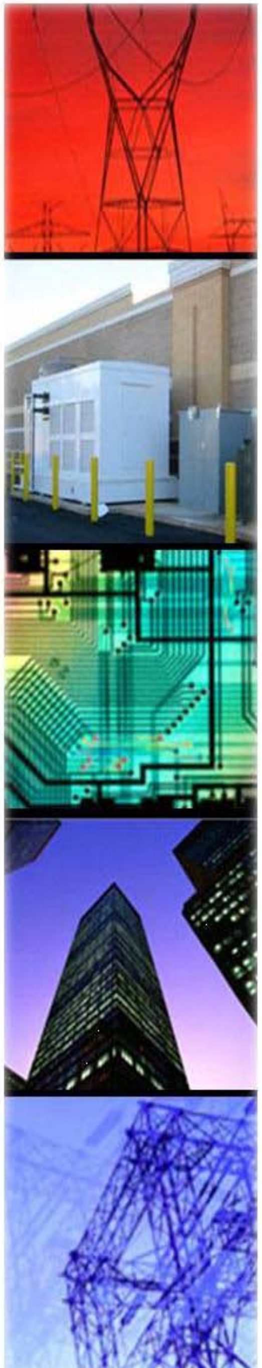


Distributed Generation: Definition

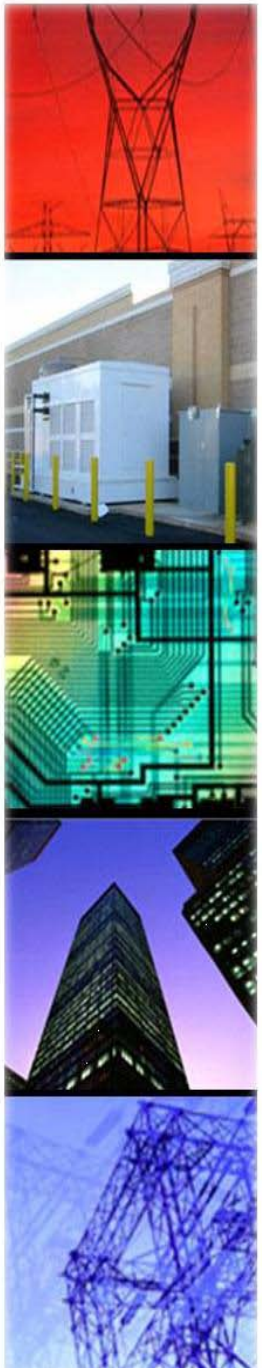
- DG is small generation placed into the distribution system
  - Small = < 10MW; 1kW – 5MW common
  - Distribution = <= 44kV; 120V-15kV class common
- DG may be synchronous machines, induction machines, PV array, fuel cell, wind, battery storage and other technologies
- DG may be renewable or non-renewable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

DG is also designated as DR (Distributed Resource)
In this presentation, DR indicates Distributed Resources (not demand response)



Distributed Generation: Today

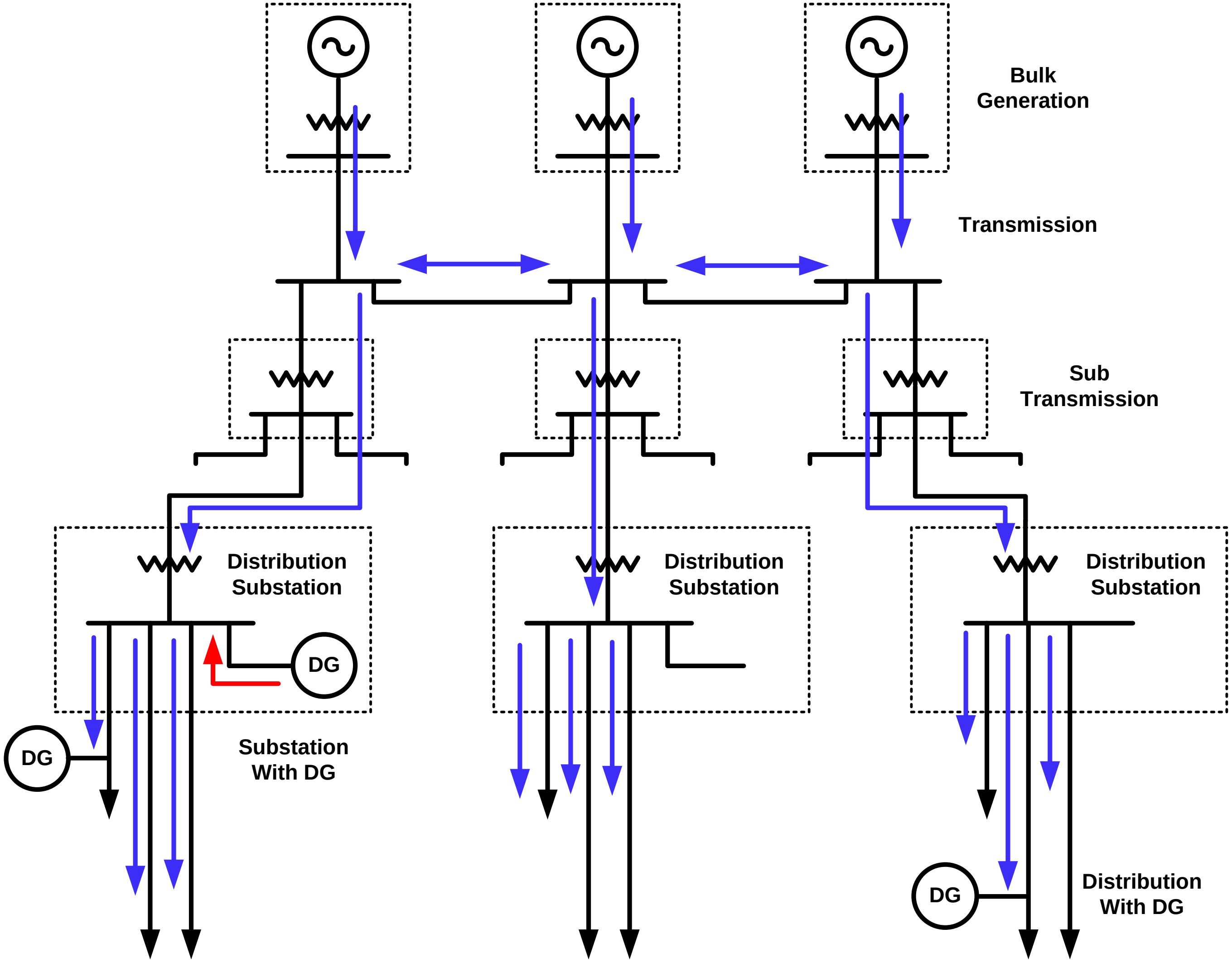
- Low proliferation
- Viewed as a pain rather than a resource
- Most DG does not export
- Some DG under Utility control for demand response
  - Standby Generation Rates
  - Interruptible Rates
- DG Interconnection Standards are "individual DR-centric"
  - IEEE 1547, UL 1741
- Holistic view on wide scale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



Distributed Generation: Future

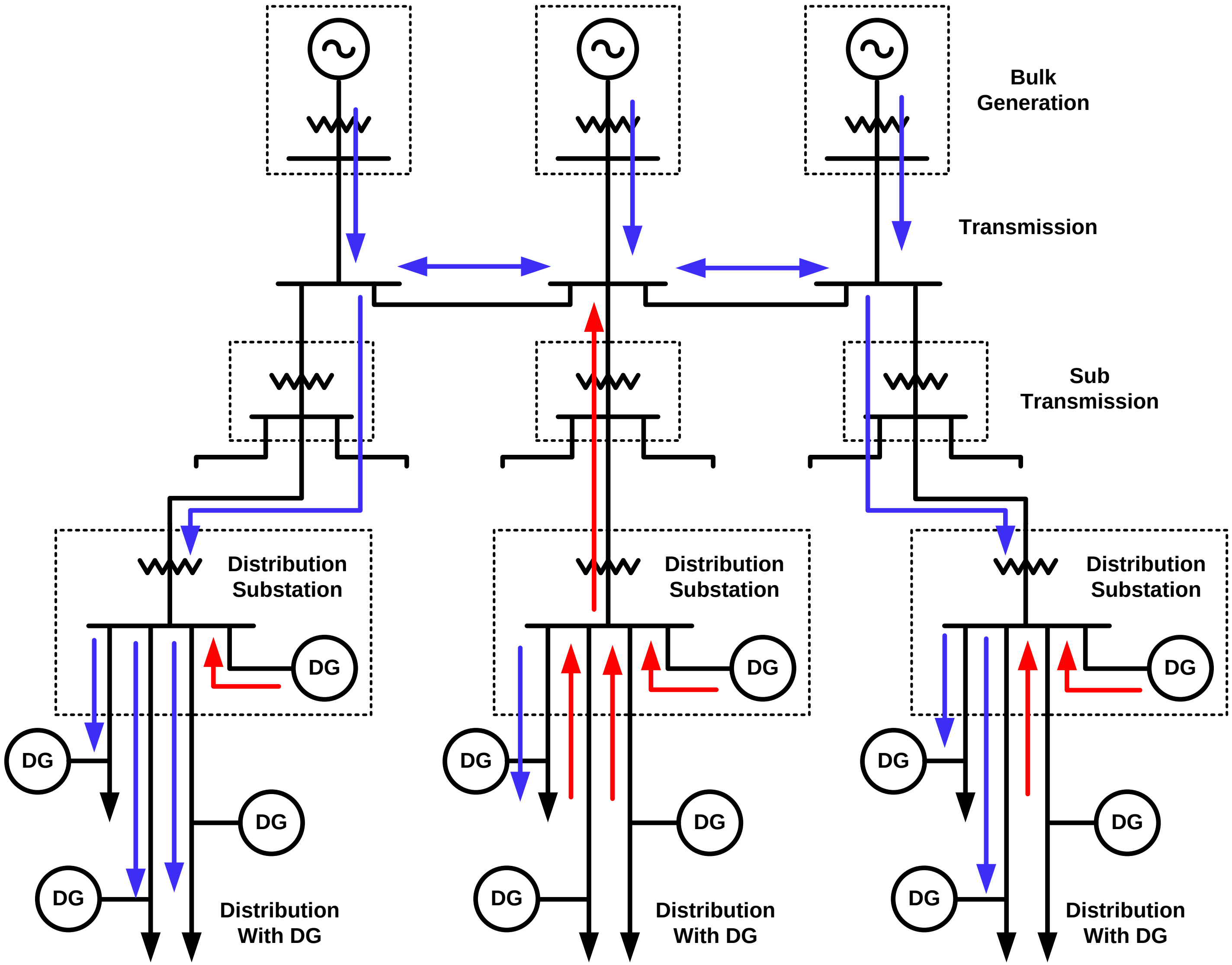
- High proliferation
- Viewed as a resource rather than a pain
- More DG under Utility control for demand response *and* capacity
  - Standby Generation Rates
  - Interruptible Rates
  - Feed In Tariffs
  - Ancillary Services Rates (reserves, VAR support)
- DG may export
  - May be controlled by DMS
  - May be uncontrolled by DMS
- More holistic view on wide scale DG proliferation in distribution will develop

DG Today

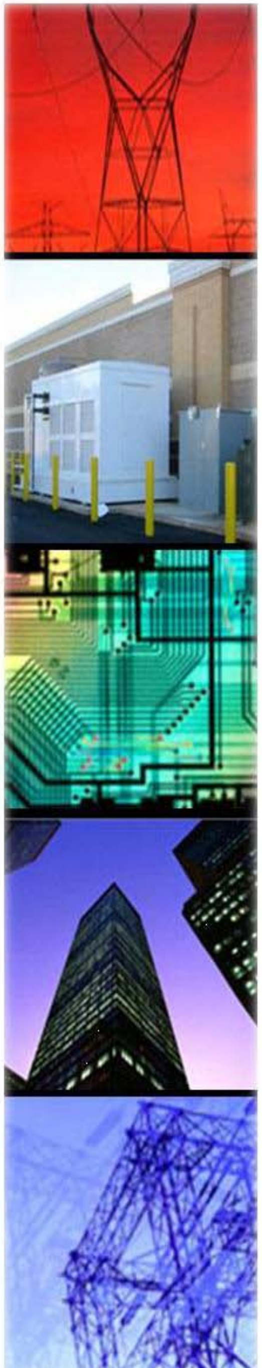


Gen→Tran→SubTran→Dist→Utilization

DG Tomorrow



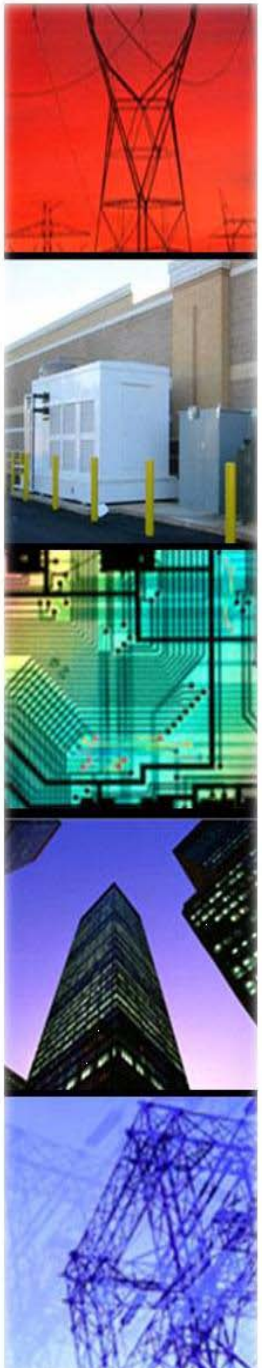
Bi-Directional Powerflows



Distribution System Variants

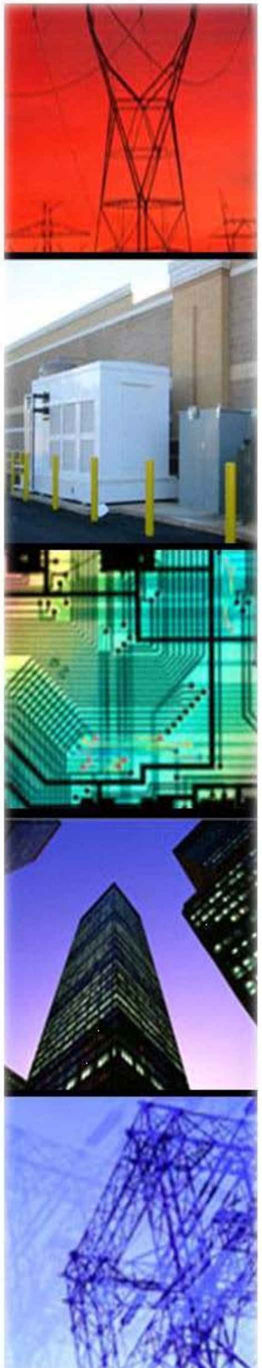
- Radial, no DG
- Loop, no DG
- Mesh, no DG
- Radial, with DG
- Loop, with DG
- Mesh (Network), with DG

- Small DG, limited proliferation
- Small DG, large proliferation
- Large DG



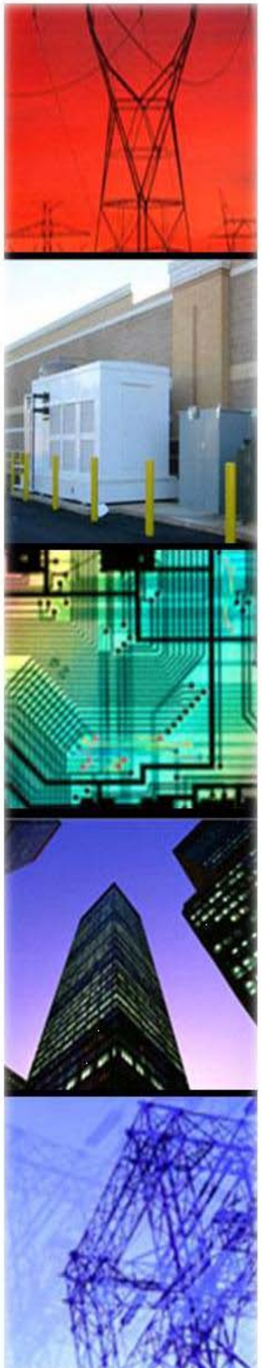
Considerations: DG in Distribution

- **Feeder Load Changes & Bidirectional Powerflows**
  - Feeder load is reduced with or without DG export to system
  - Issues:
    - V/VAR control (VVO)
    - Coping with Variability
    - TLM/FLM



Considerations: DG in Distribution

- **Bidirectional Fault Currents**
  - Feeder considerations
  - Substation considerations
  - Issues:
    - Protection settings at substation, midline and DG
- **Reclosing Coordination**
  - No DG
  - With DG; Voltage Supervision
  - Issues
    - Reclosing setting changes
    - Reporting of unsuccessful DG removal

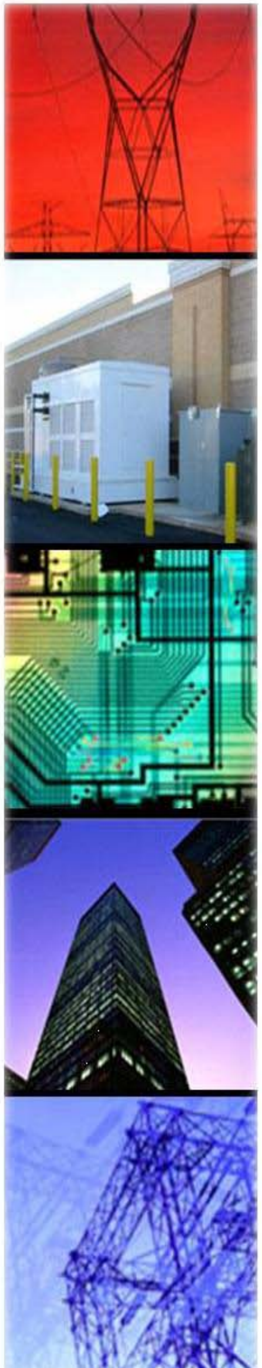


Bidirectional Powerflows:

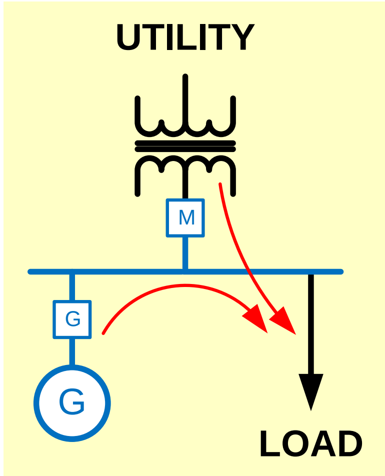
Some DG/DR Can Be Controlled

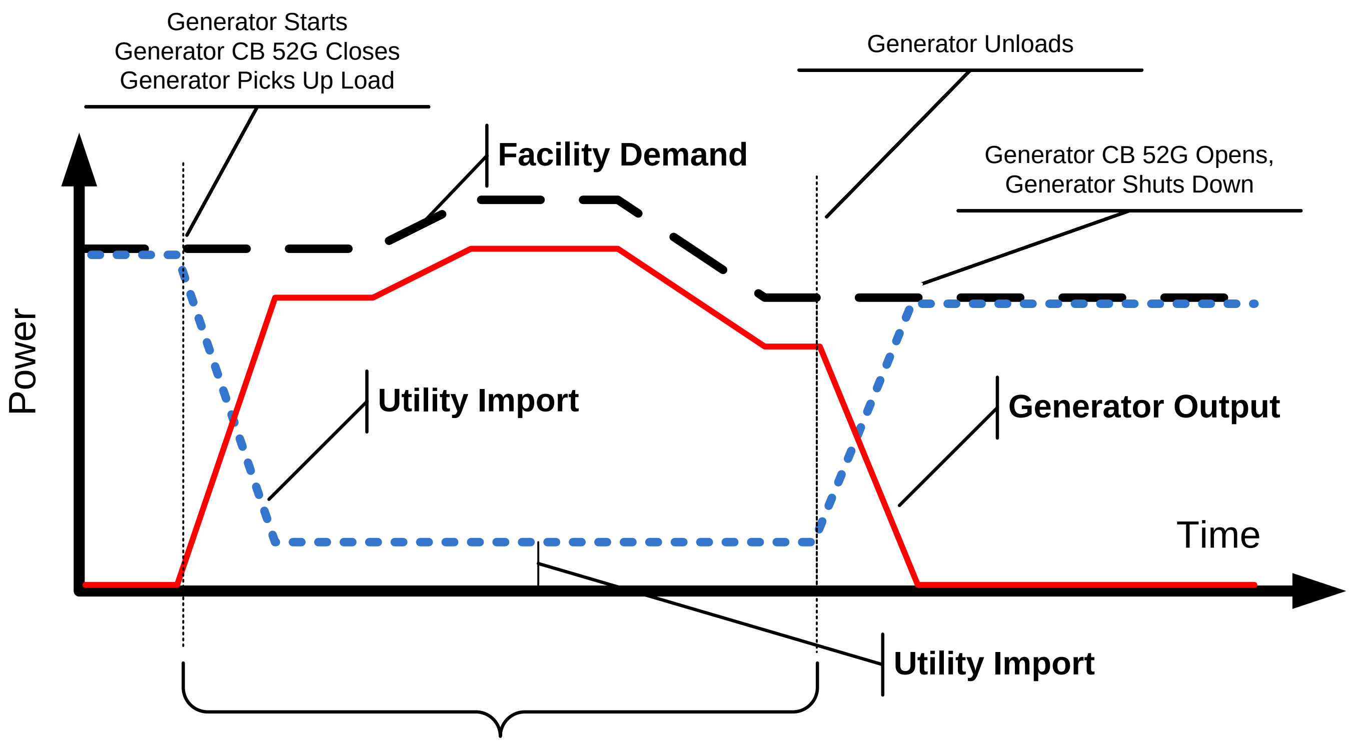
- DR ***real*** power control:
  - Load Follow Mode ("float" the interconnection)
    - Called "Process Control of DG"
  - Export Power Mode
    - Called "Baseloading the DG"
  - Power modes can be selected by DMS action
    - With greater feeder loading (peak time), selectively allow export

- DR ***reactive*** power control:
  - Load Follow Mode ("float" the interconnection)
    - Called "Process Control of DG"
  - Export Power Mode
    - Called "Baseloading the DG"
  - Power modes can be selected by DMS action
    - With greater feeder loading (peak time), selectively allow export

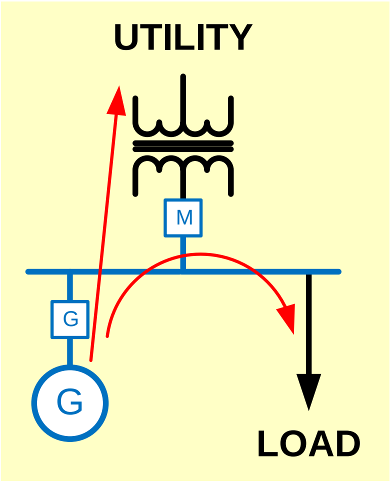


DG: No Export
“Negawatting”
Load Follow Mode

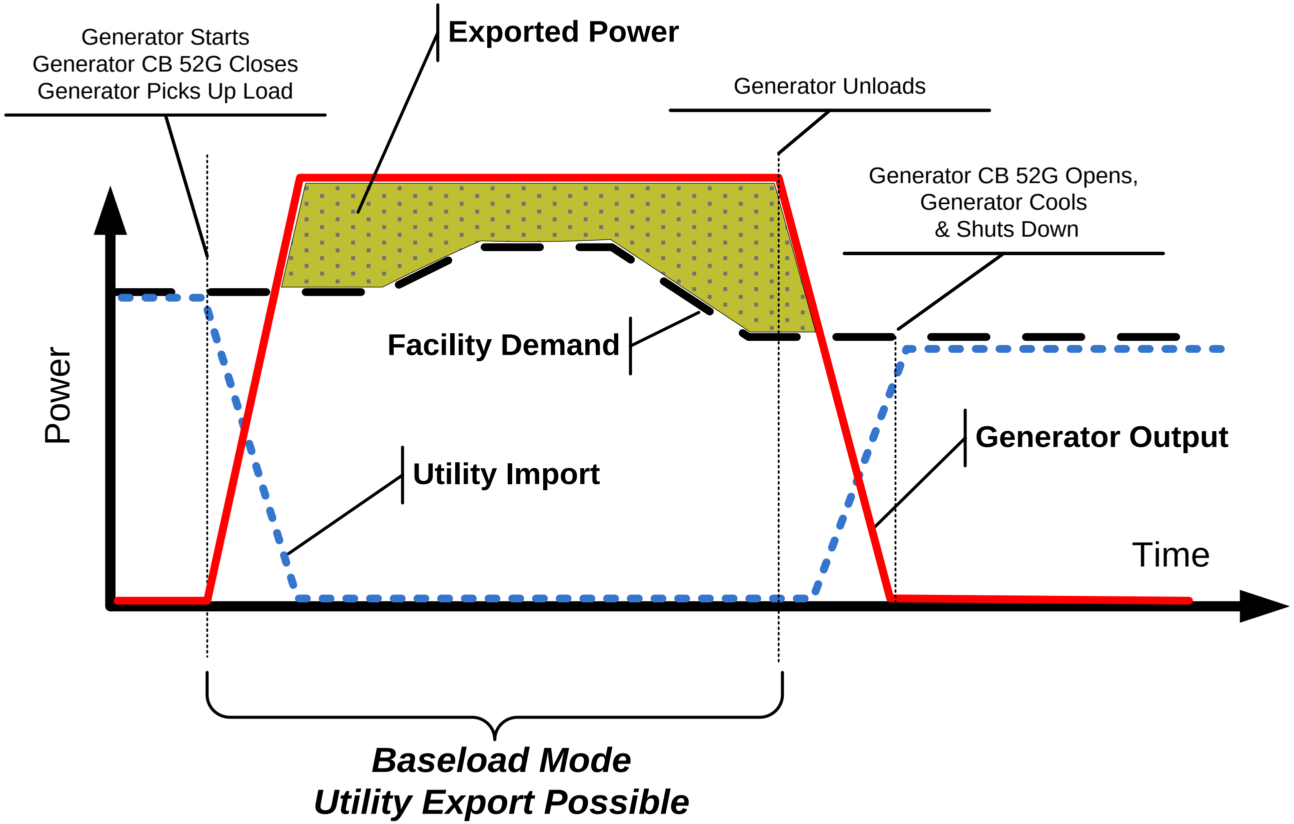




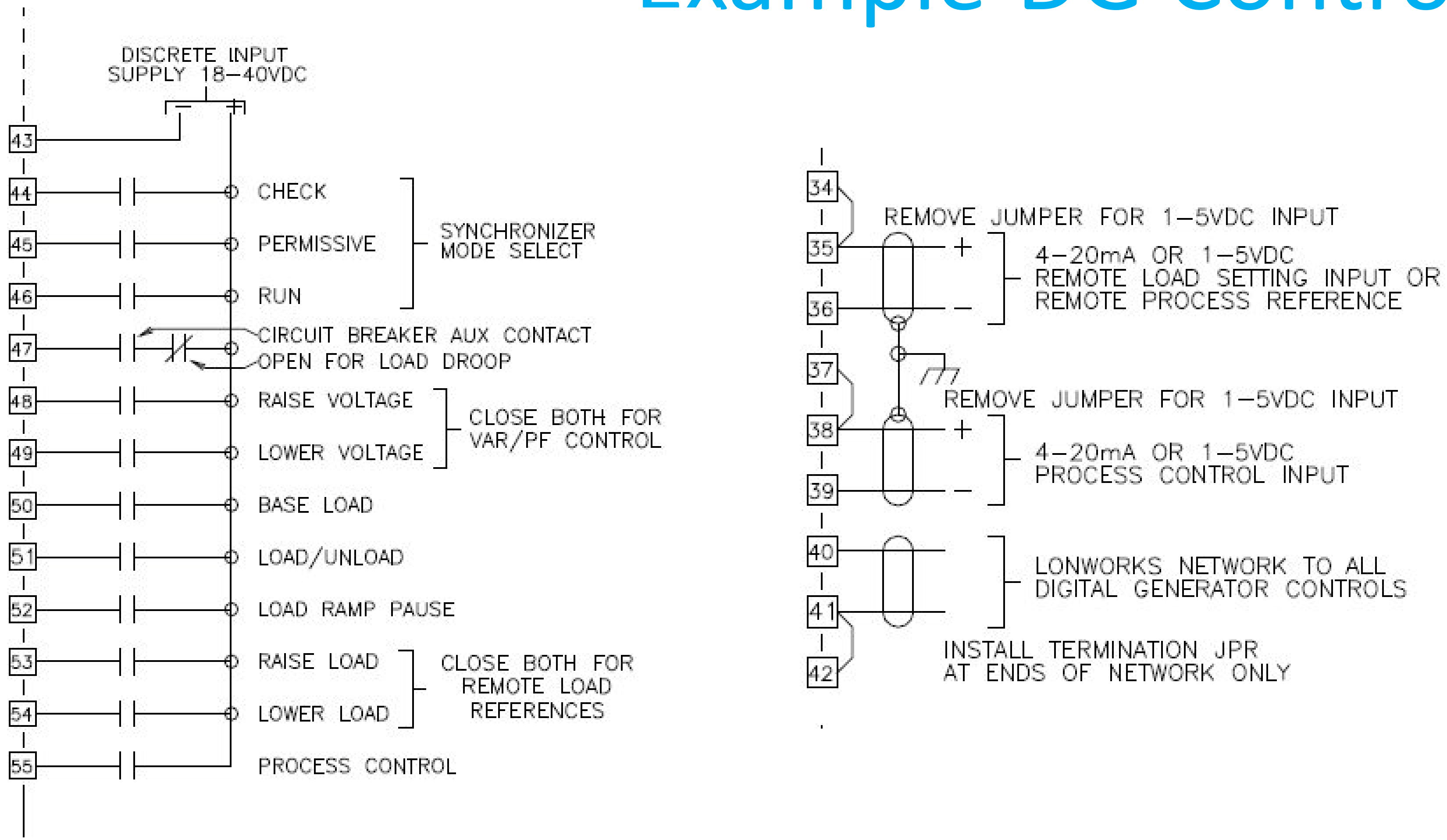
Load Follow Mode
No Export (Minimal Import)



DG: Export
"Negawatting Plus"
Baseload Mode

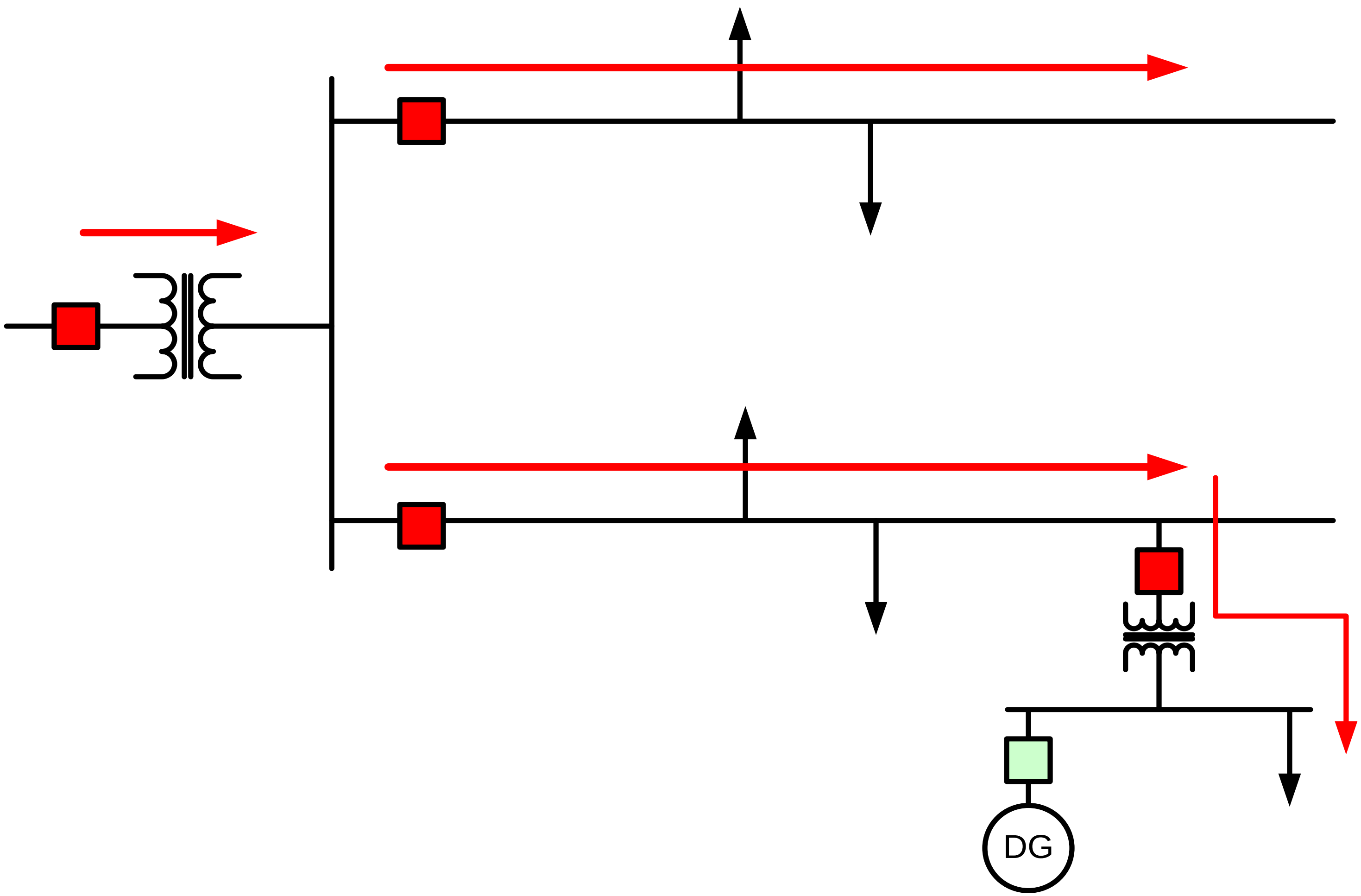


Example DG Control



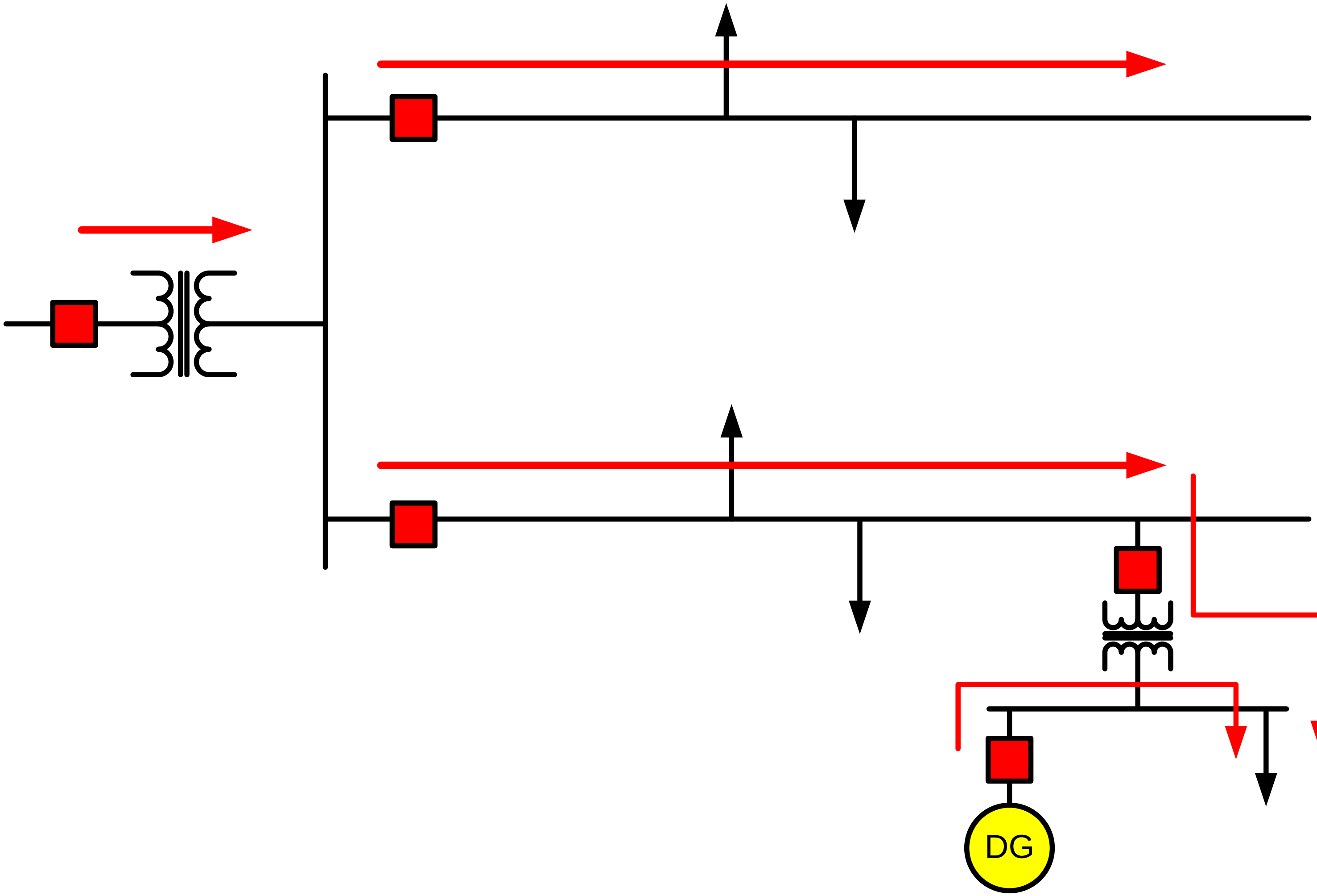
Controls incorporate setpoints, deadbands, ramp timers, etc.

Bidirectional Powerflows: Feeder



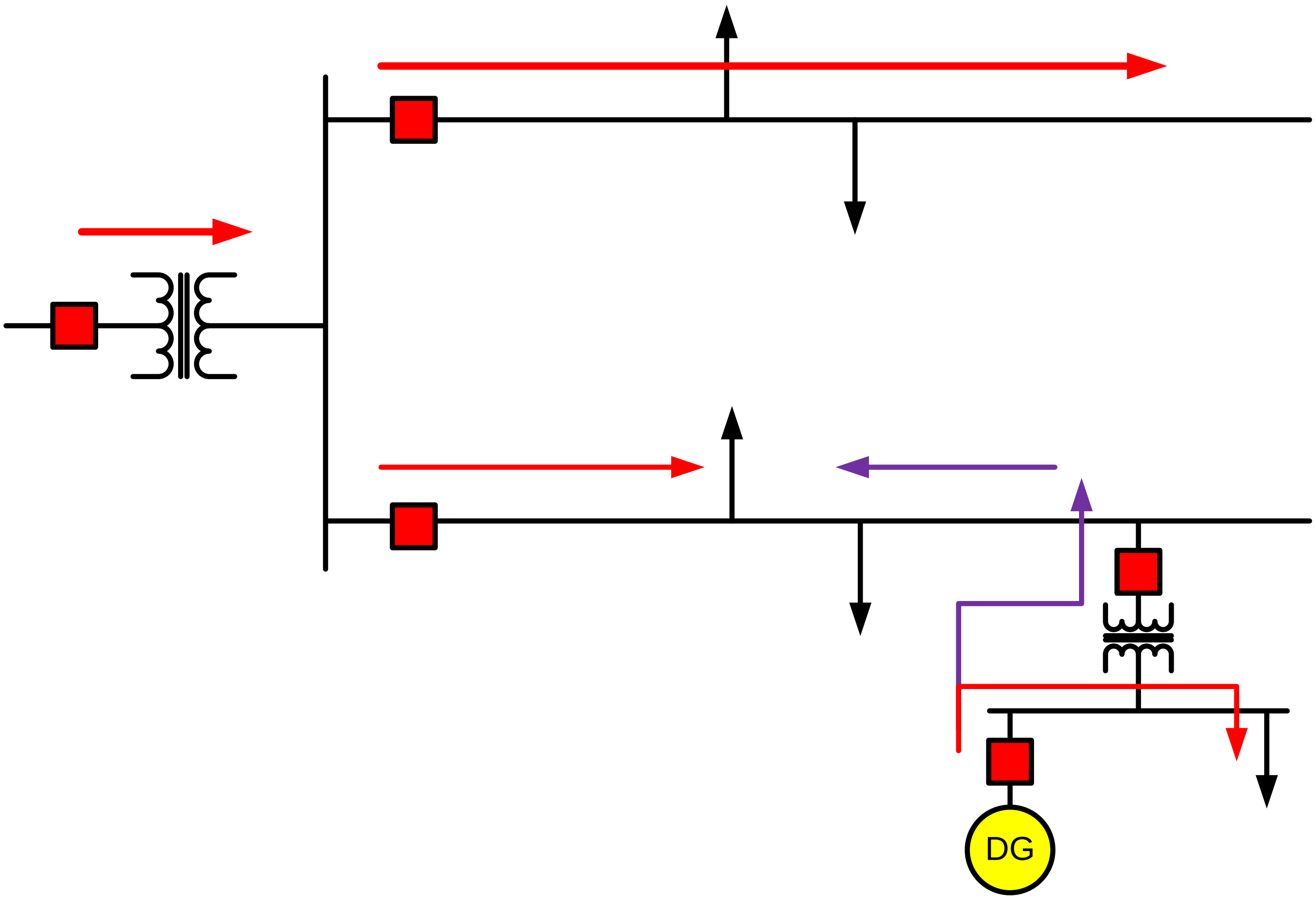
- DR Off, Normal Powerflow

Bidirectional Powerflows: Feeder



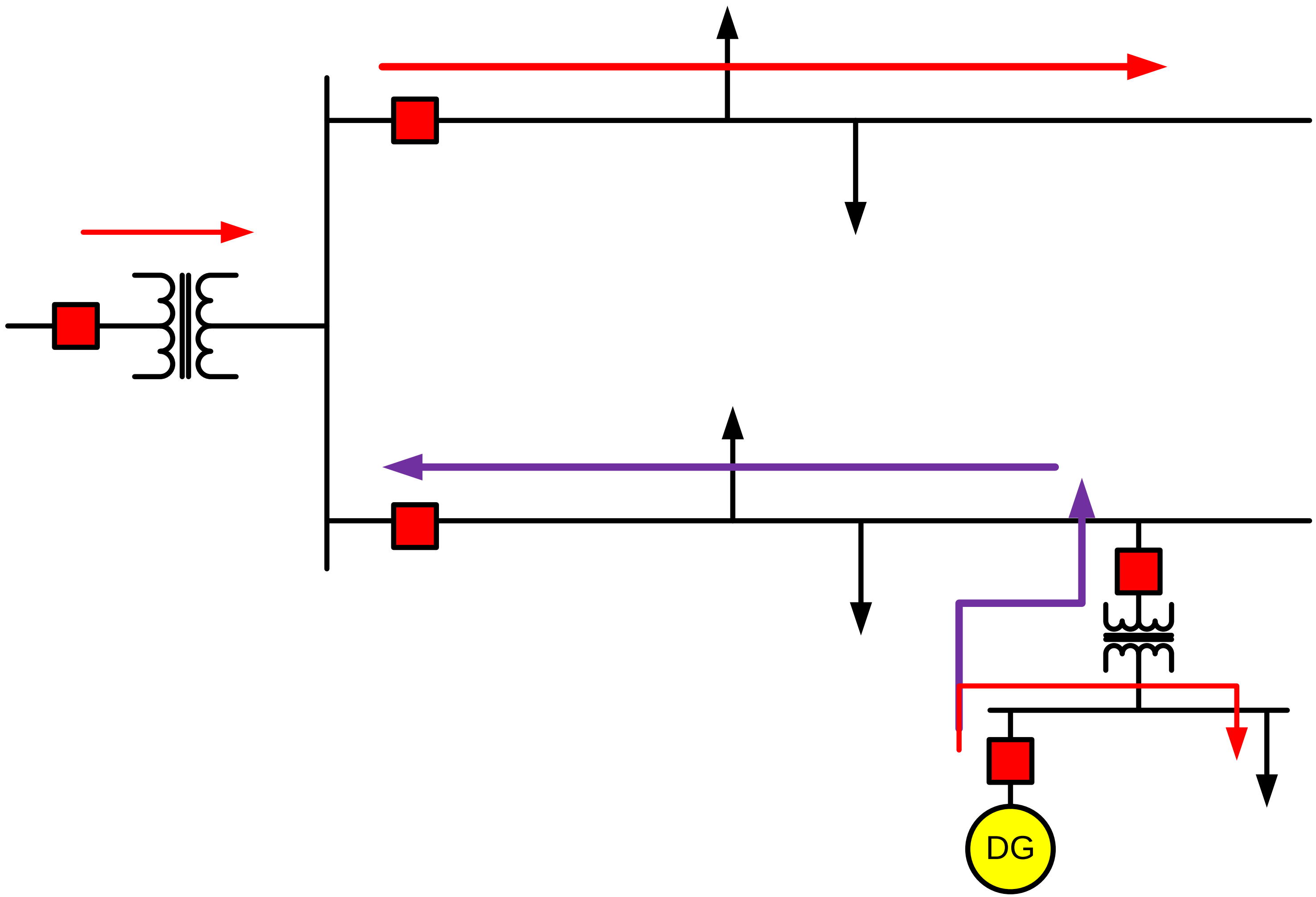
- DR On, No Export, Normal Powerflow

Bidirectional Powerflows: Feeder



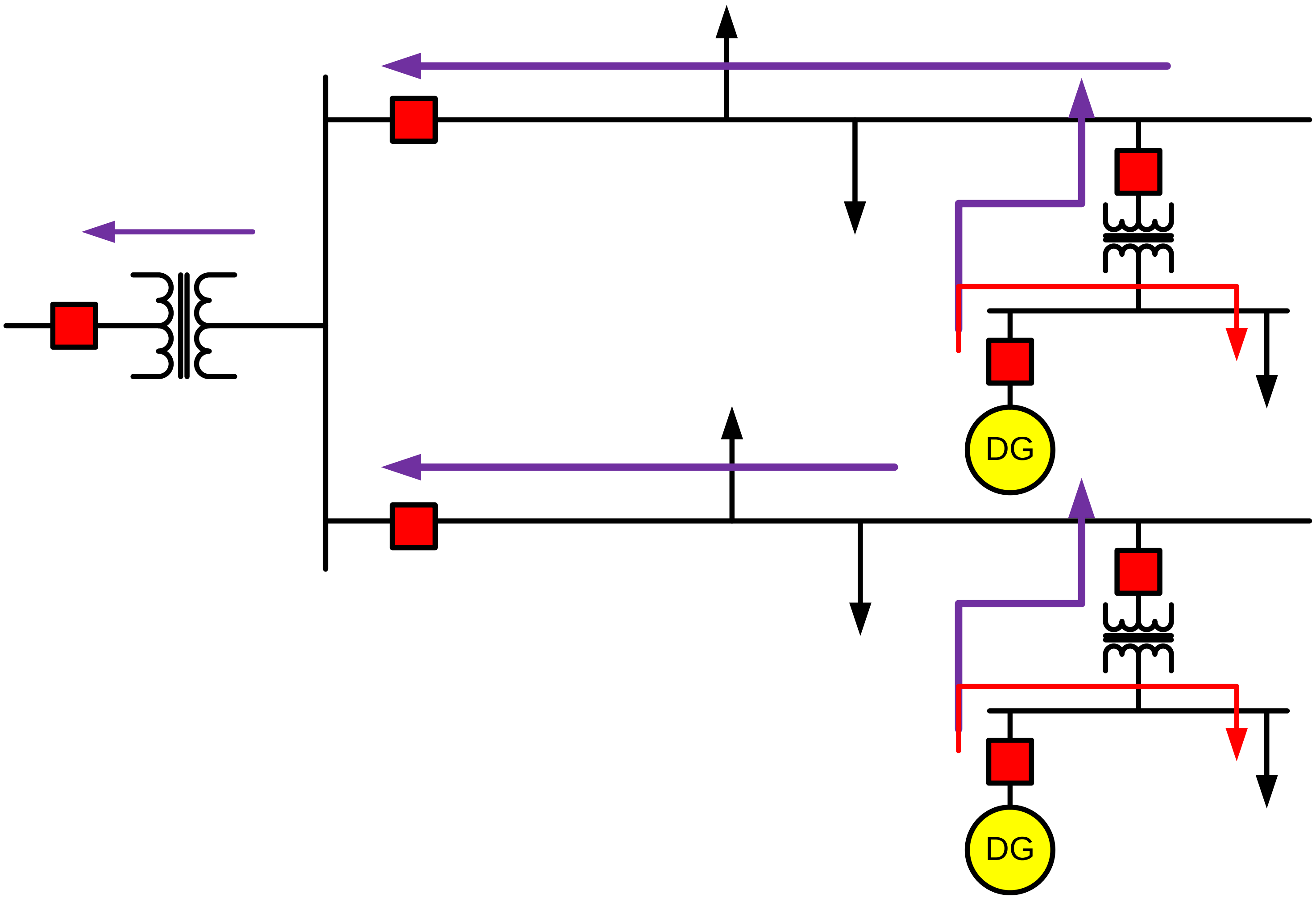
- DR On, Export, Partial Feeder Reverse Powerflow

Bidirectional Powerflows: Feeder



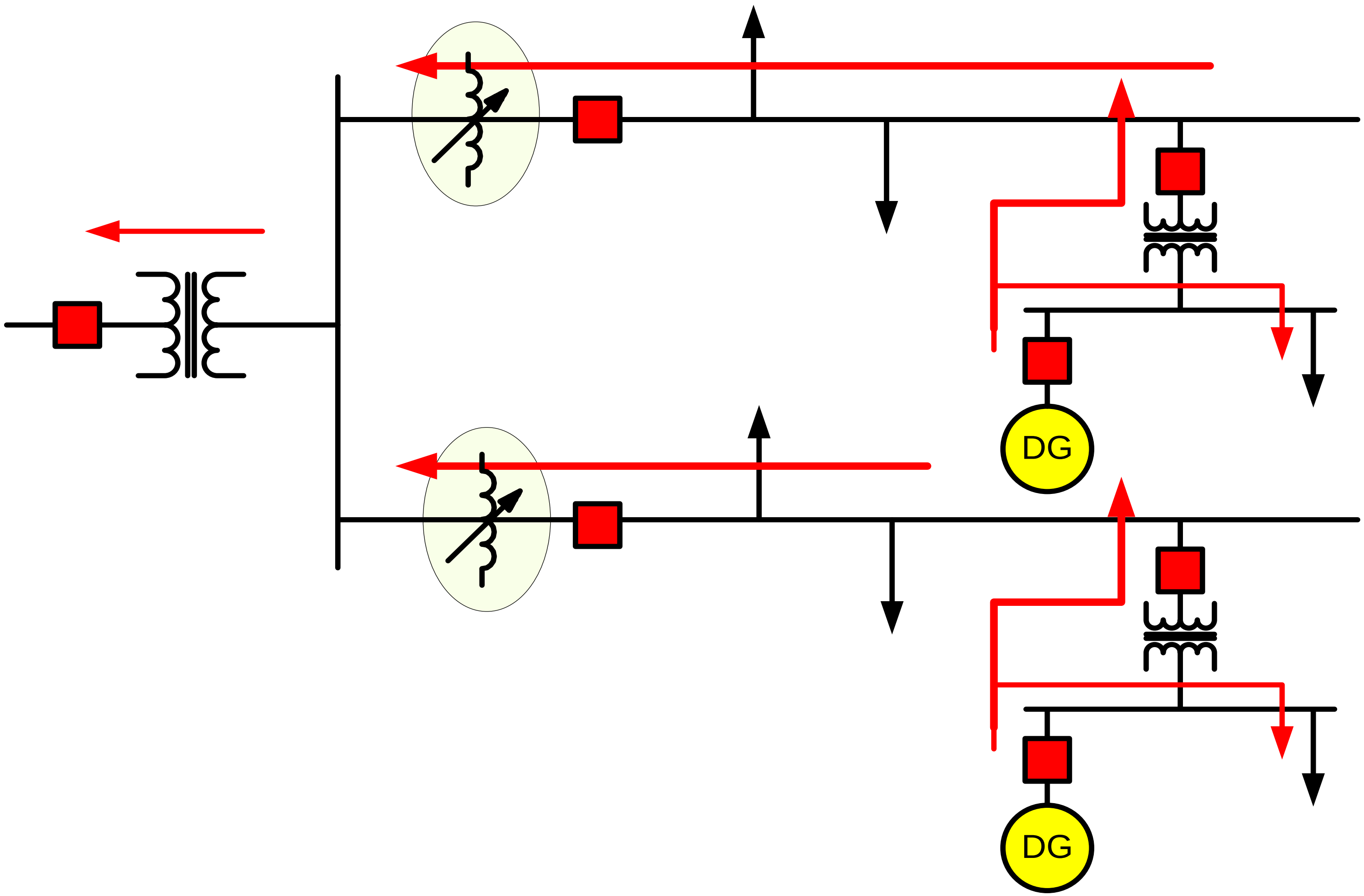
- DR On, Export, Full Feeder Reverse Powerflow

Bidirectional Powerflows: Substation

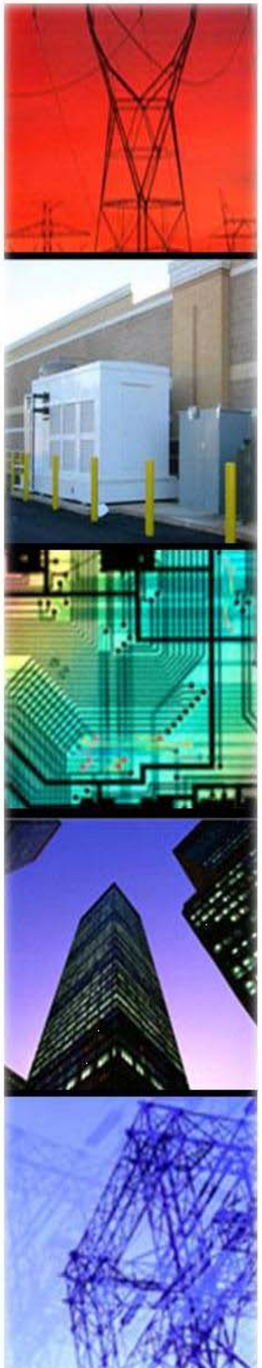


- DR On, Export, Full Feeder/SS Reverse Powerflow

Add Regulators



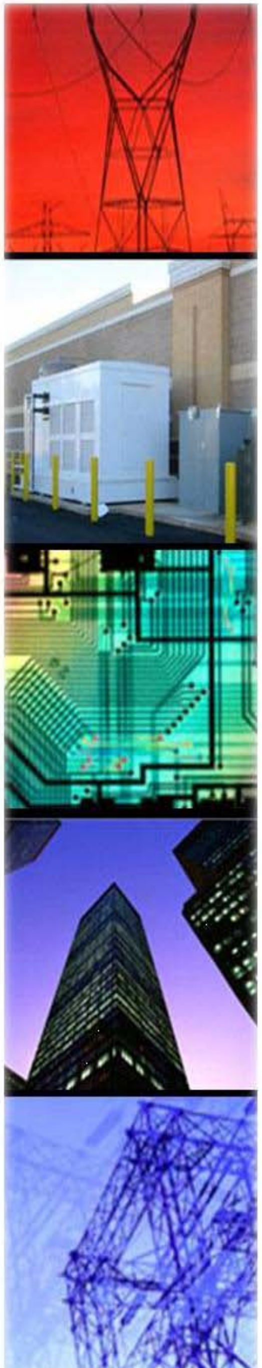
- How does power change impact regulation?

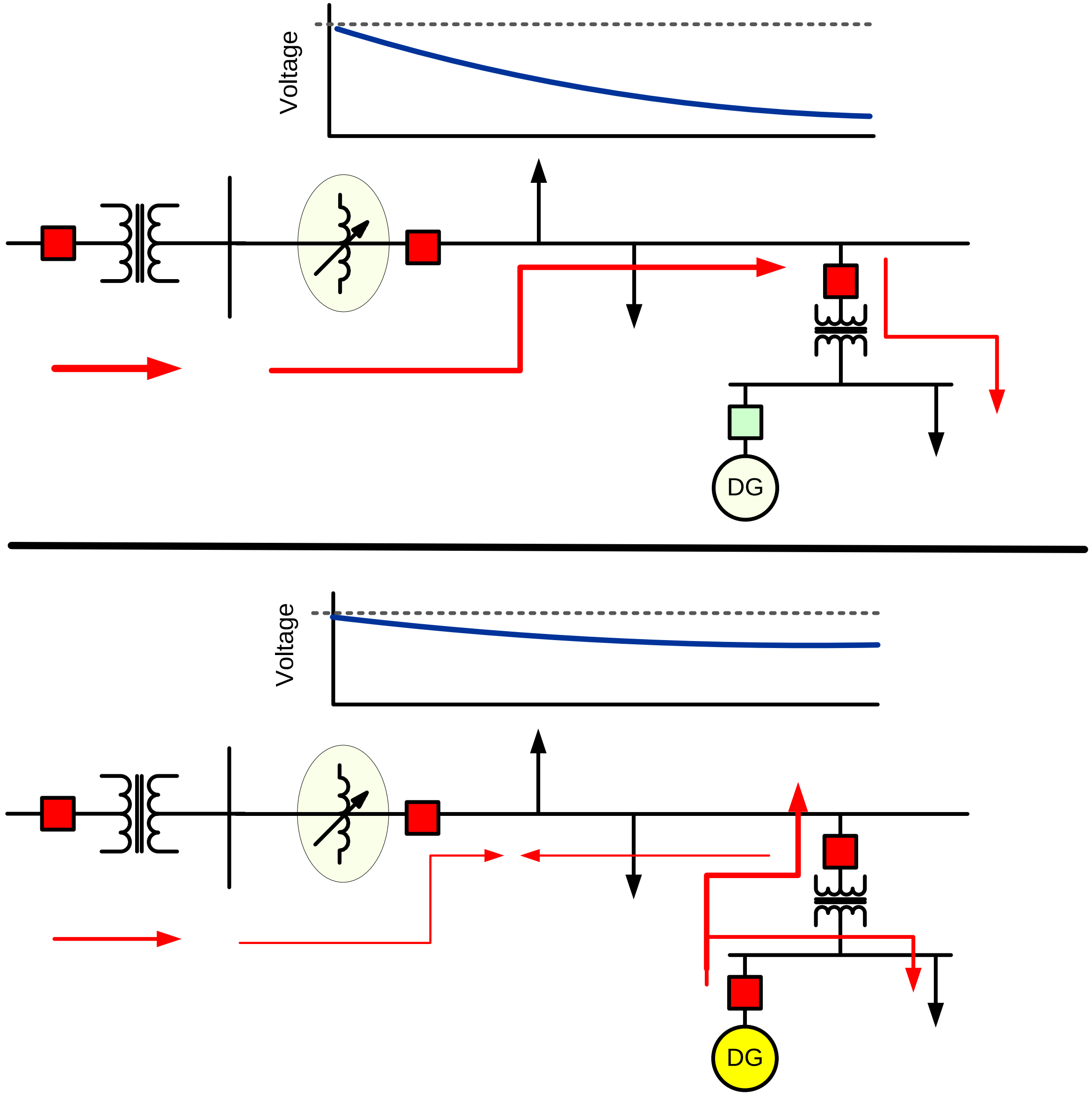


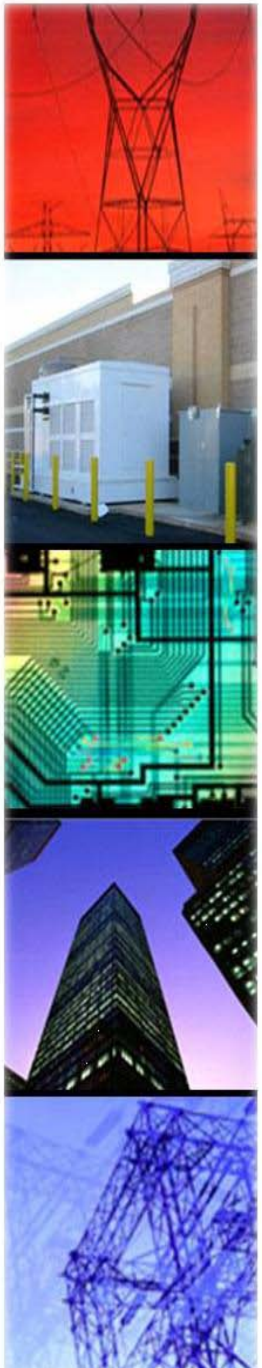
Bidirectional Powerflows: V/VAR Issues

- Voltage drop along line flattens as load is relieved as there is less I^2R and I^2X_L loss
- Line drop compensation decreases as there is less I^2R and I^2X_L loss
- Regulators will "tap down" as more power is removed from feeders by DG contribution (negawatting)

Voltage Profile with/without DR





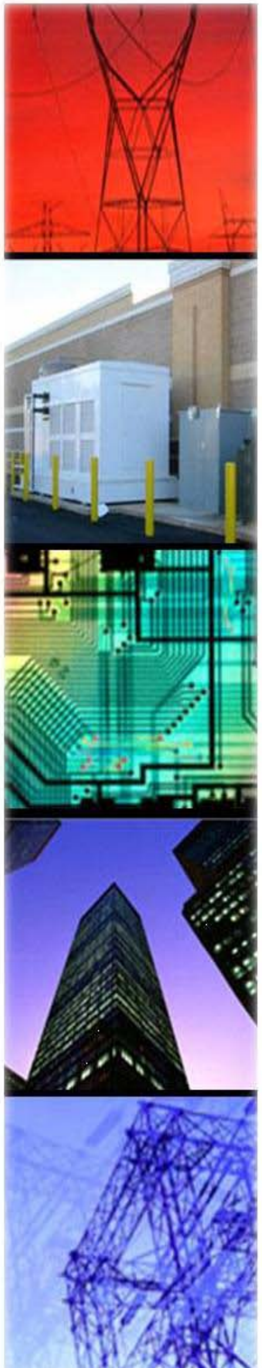


Bidirectional Powerflows: V/VAR Issues

- With conventional DG, “unload” the DG slowly so the system can “reload” slowly
- Due to variability of renewable DR, if DR output drops dramatically, line drop losses will suddenly reappear (load on feeder picks up)
  - Voltage on line will quickly fall as I^2R and I^2X_L losses return
- Due to variability of renewable DR, if DR output rises dramatically, line drop losses will suddenly reduce (load on feeder decreases)
  - Voltage on line will quickly rise as I^2R and I^2X_L losses increase

Bidirectional Powerflows: V/VAR Issues

- Coping Methods for Fast DR Variability:
  - Consider that regulators change taps *sequentially* ensure voltage on feeder is quickly restored
    - Using sequential over non-sequential operation shortens time to restore voltage
  - Consider substation and line caps be controlled on VAR/pf with high voltage and low voltage override

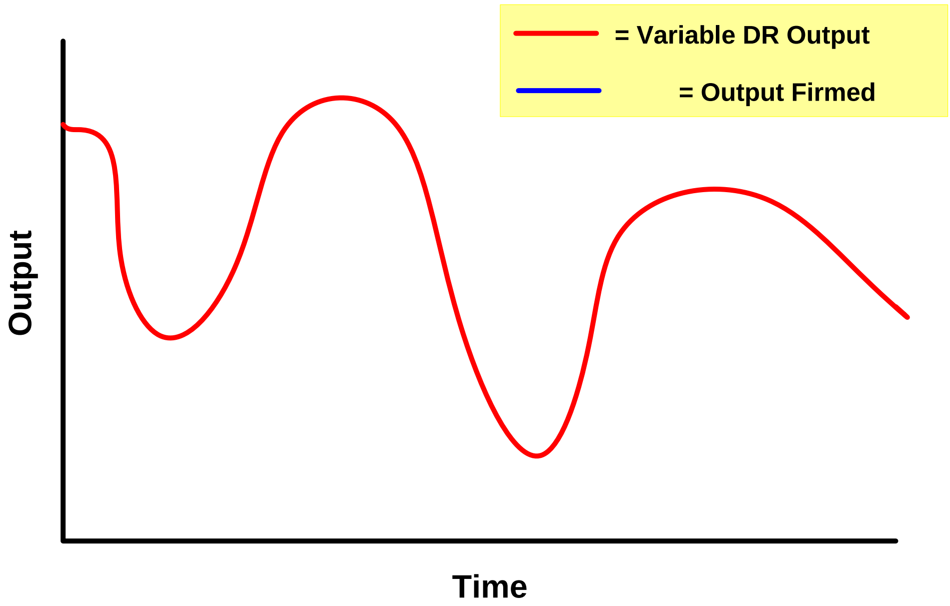


Bidirectional Powerflows: V/VAR Issues

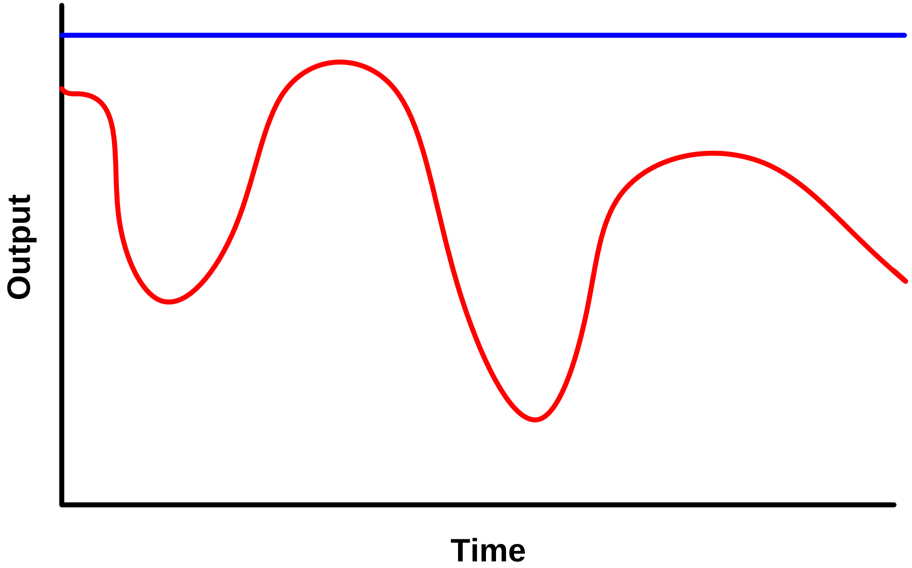
Coping Methods for Fast DR Variability:

- Using DMS and Controllable Assets
  - “Ramp Rate” or “Capacity Fill” Dispatch
    - **Conventional “fast start” distributed generation to supply real/reactive power**
    - **Distributed synchronous condensers to supply/sink reactive power**
    - **Storage/conversion to supply/sink real power**
    - **Storage/conversion to supply reactive power**
  - May be accomplished by DSM
    - Starting/Stopping
    - Direct setpoint control or initiating setting group changes

Constant Capacity from "Capacity Fill" Assets

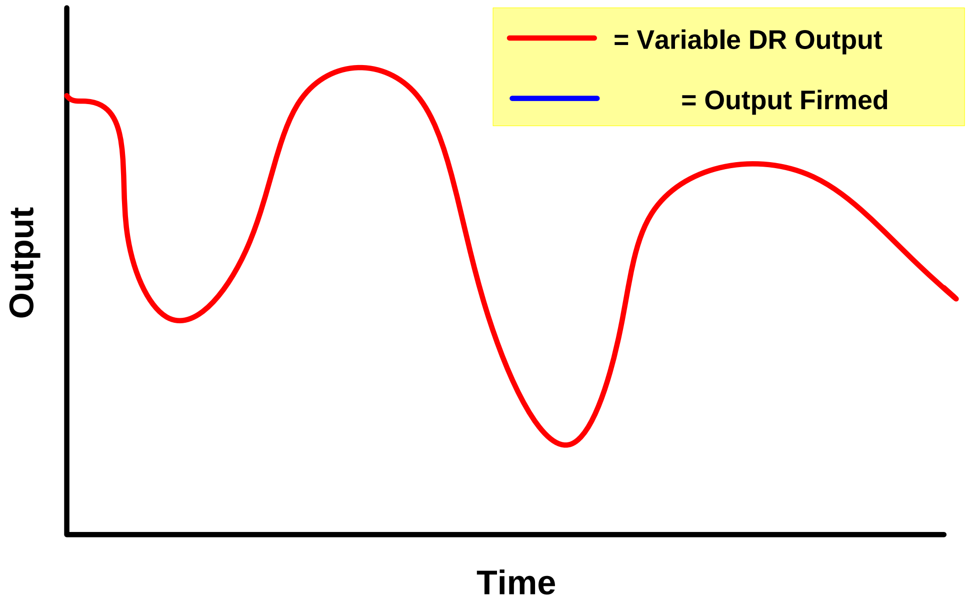


- Not Firmed



- Firmed

Ramped Capacity from "Capacity Fill" Assets



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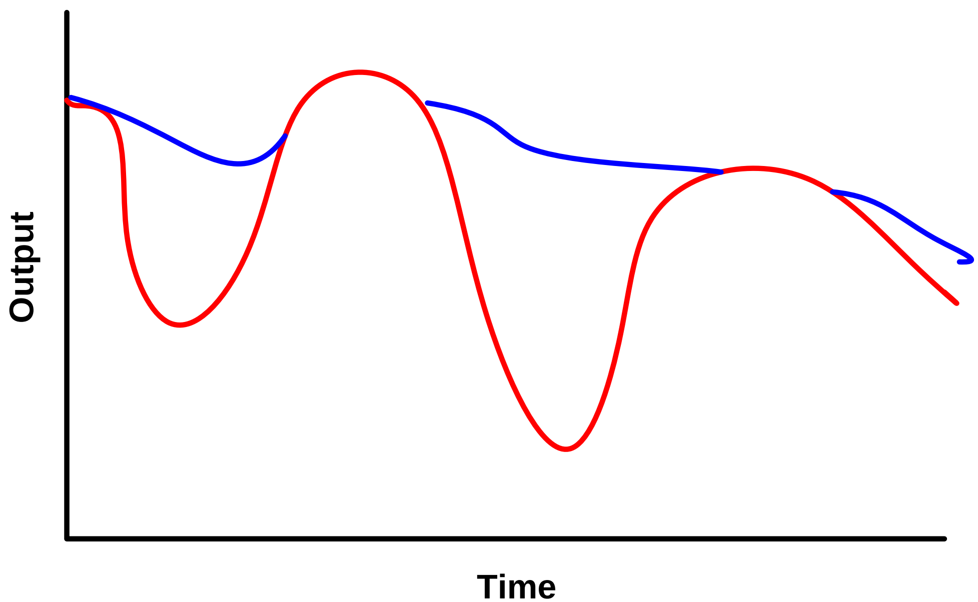
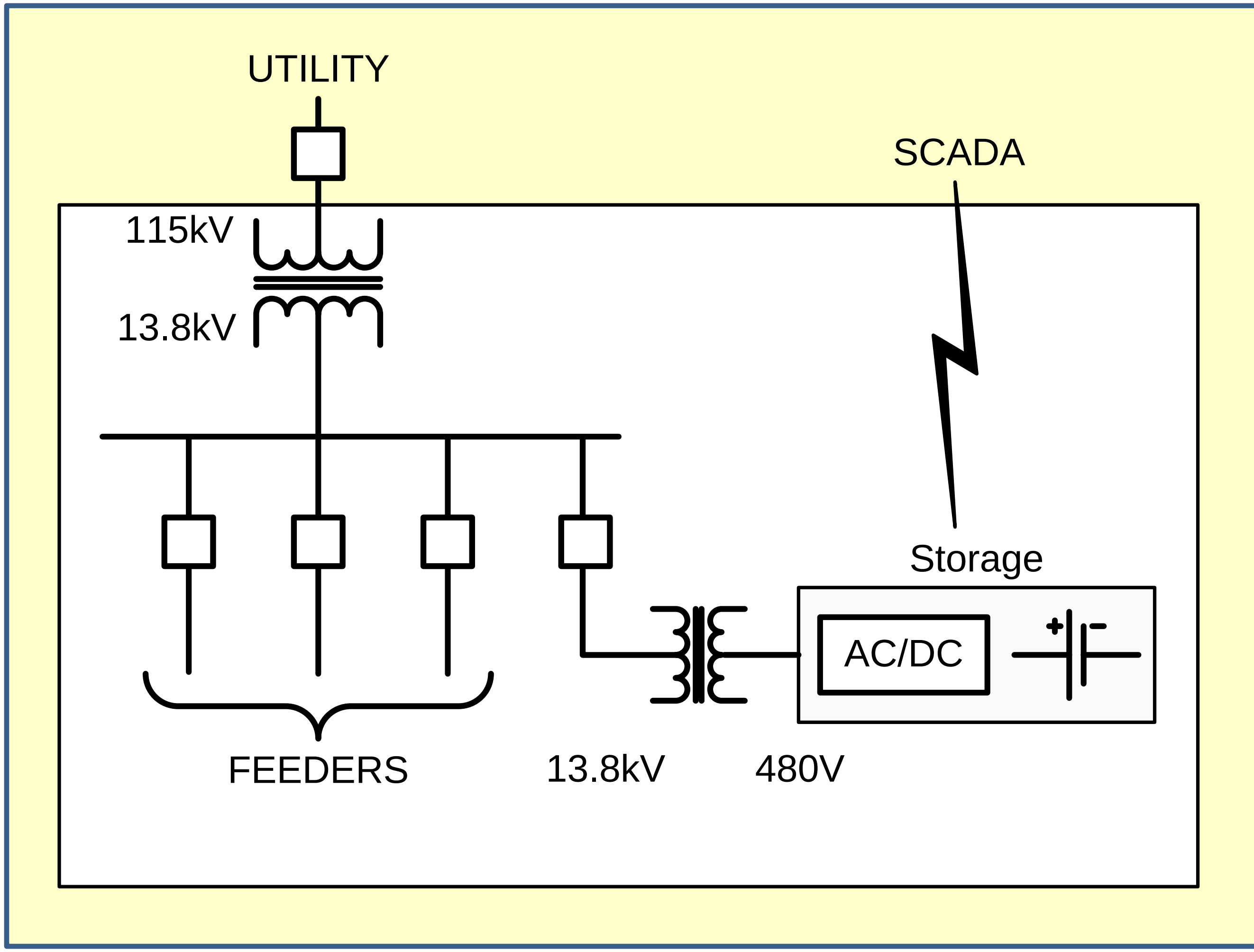


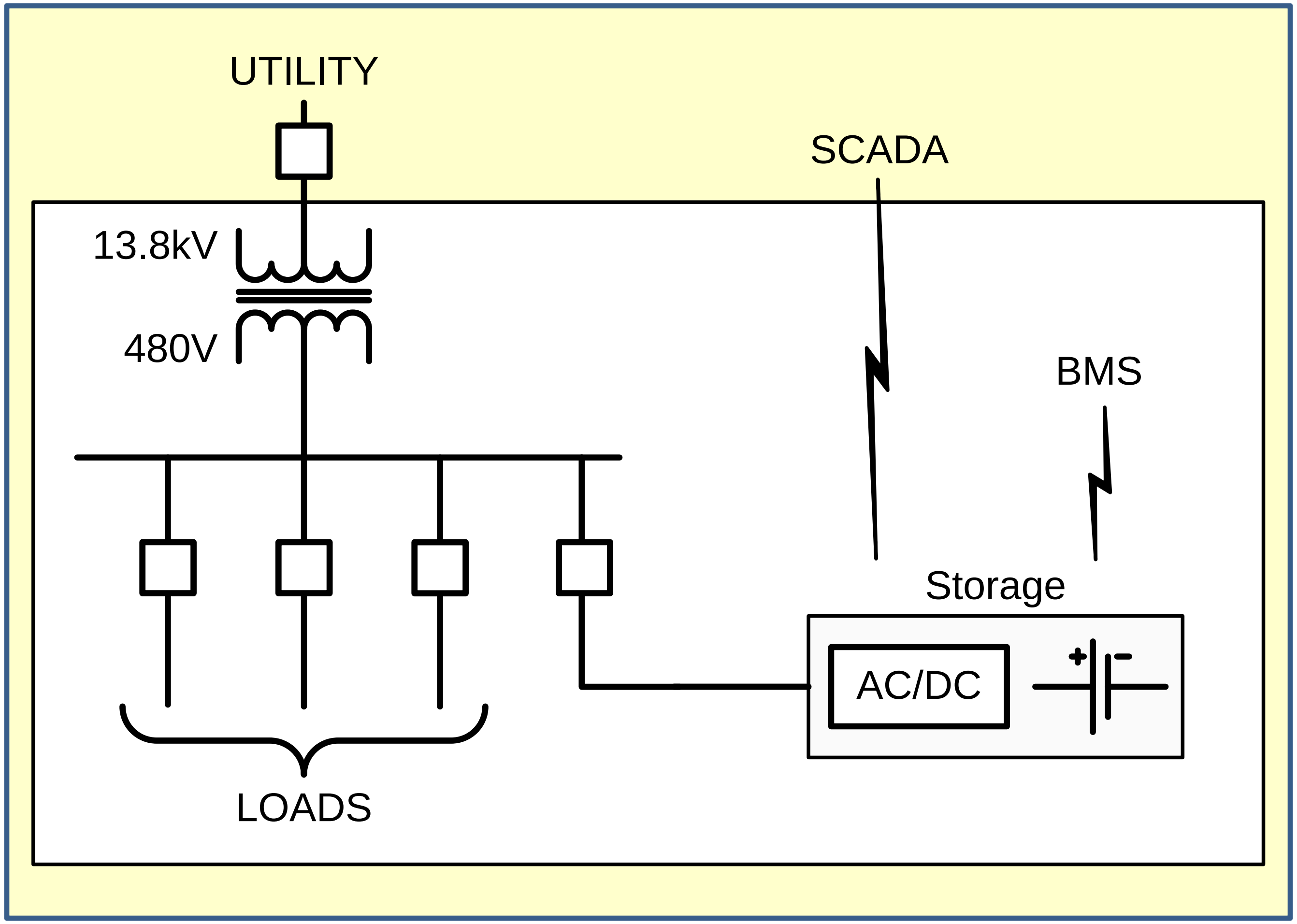
- Firmed

Storage Applications



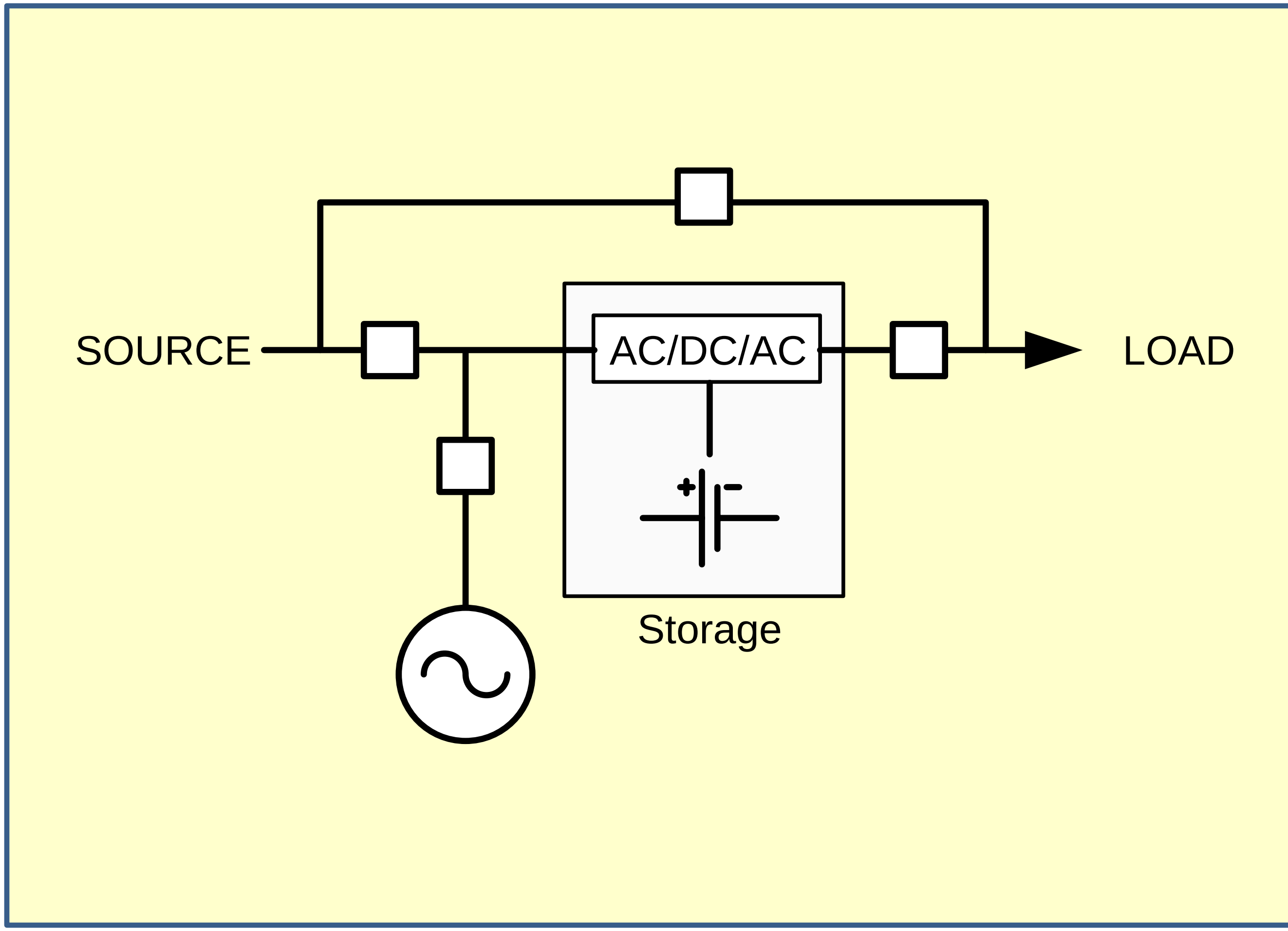
Utility Distribution Substation Storage for Demand Response Use

Storage Applications



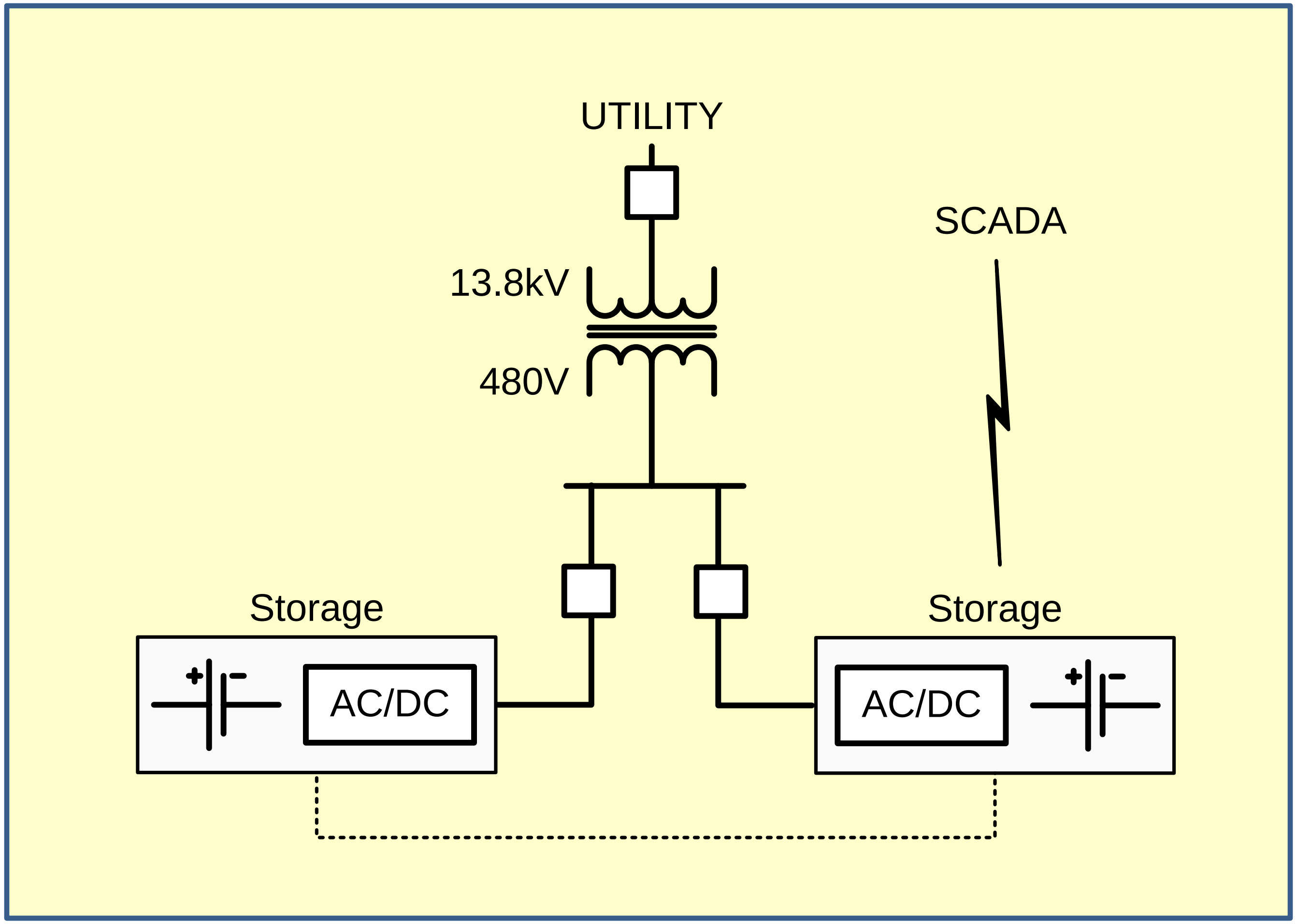
Facility Storage
for Demand Response Use

Storage Applications



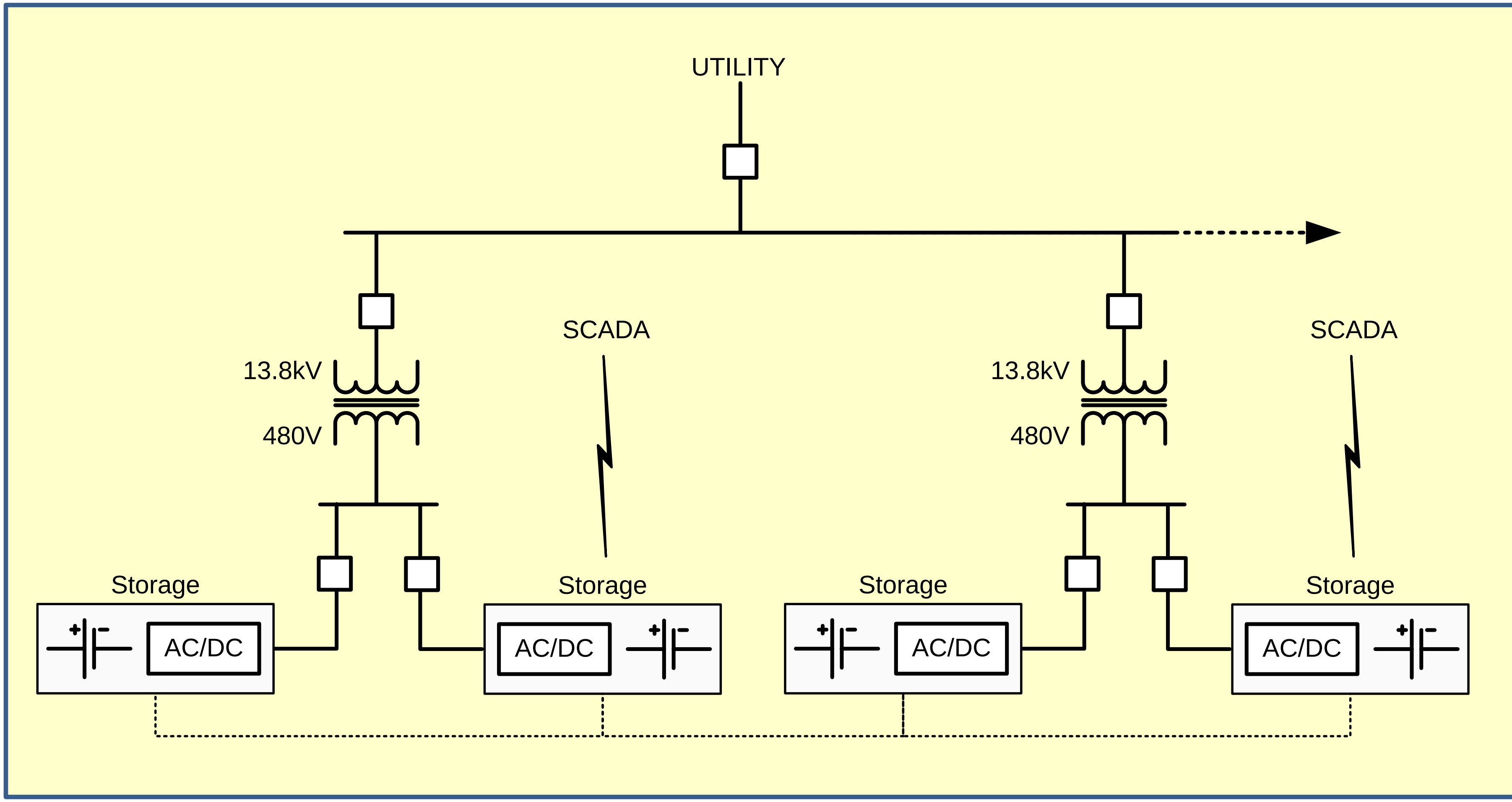
Facility Use for UPS for E-Gen Start on Source Failure and Demand Response Use

Storage Modularity and Scalability



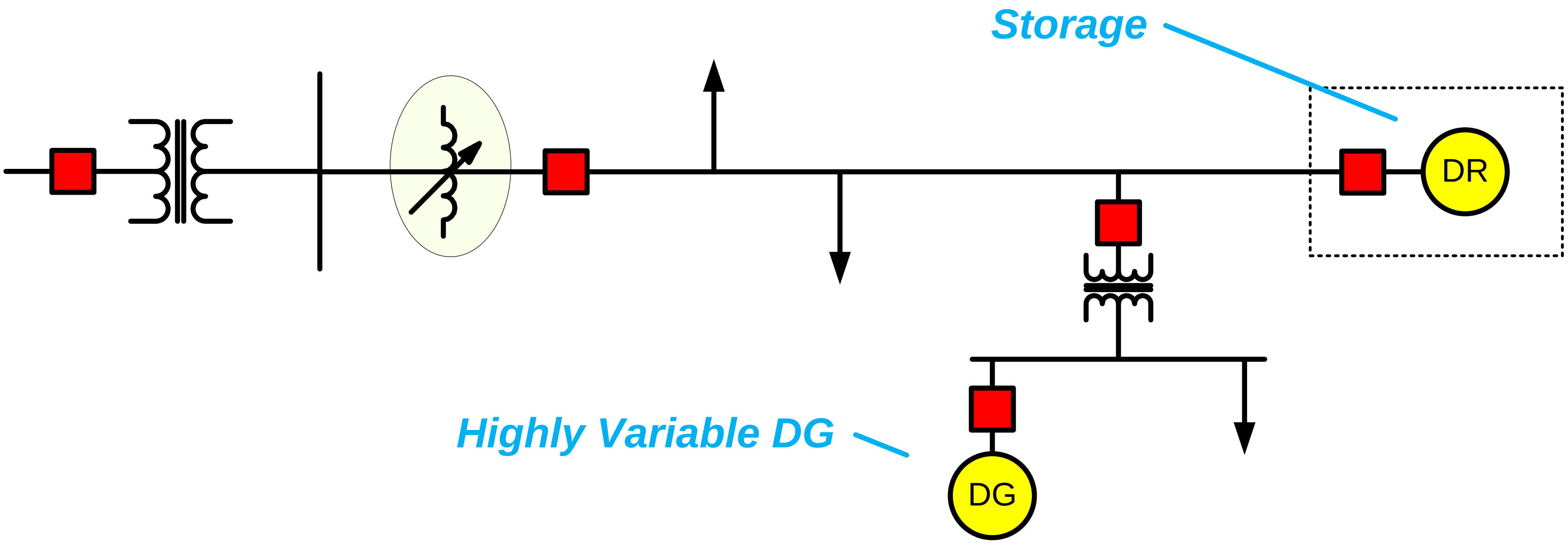
Build Capacity for
Storage Demand and Duration

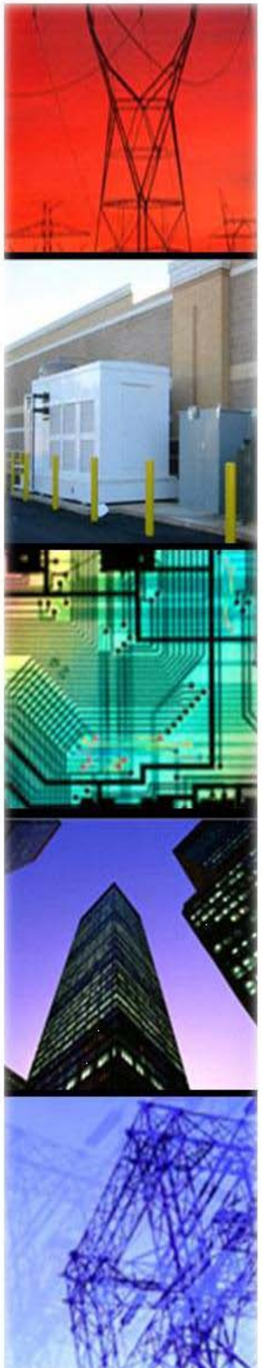
Storage Applications



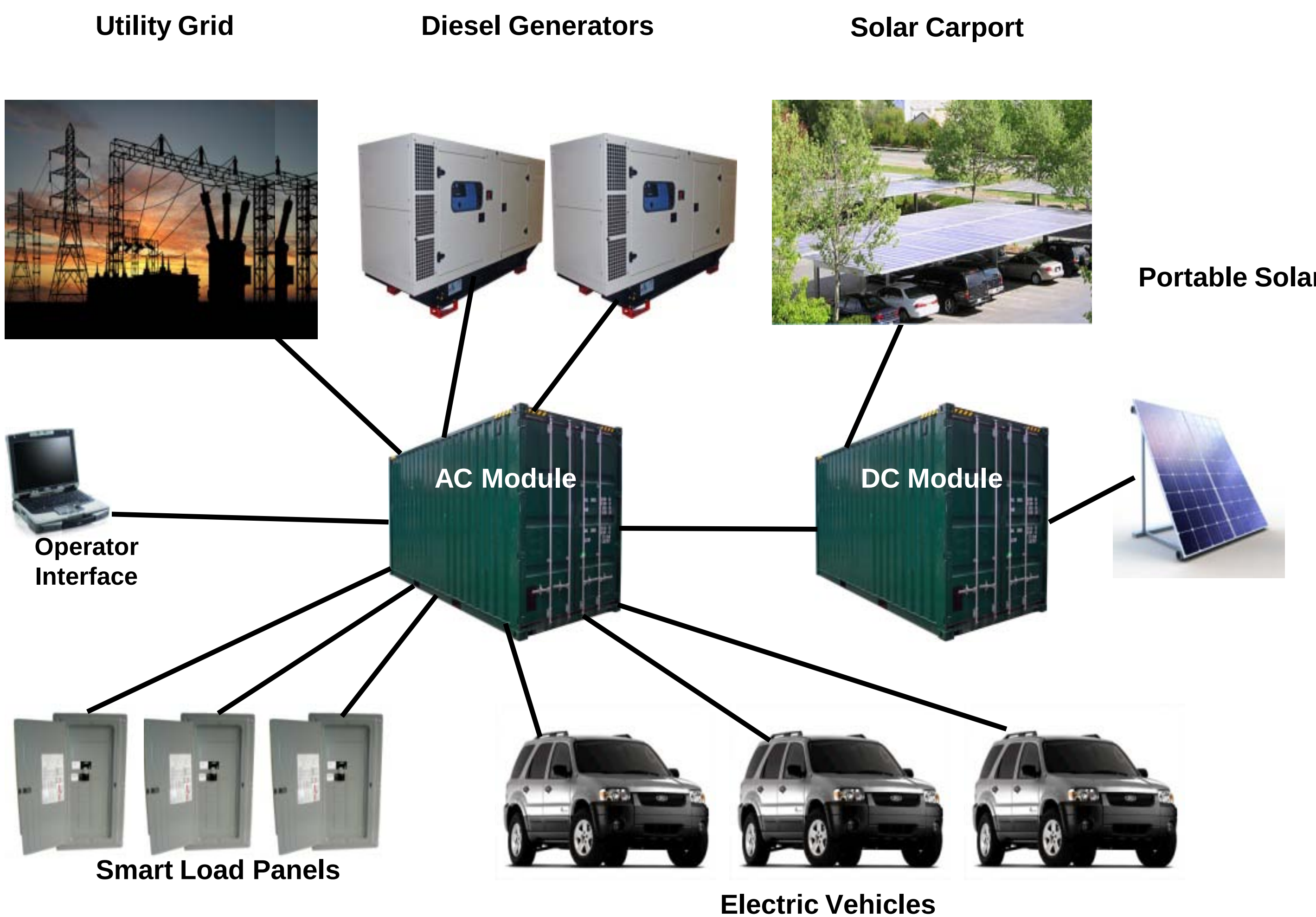
Adjust Storage Capacity for
Scalable Demand and Duration

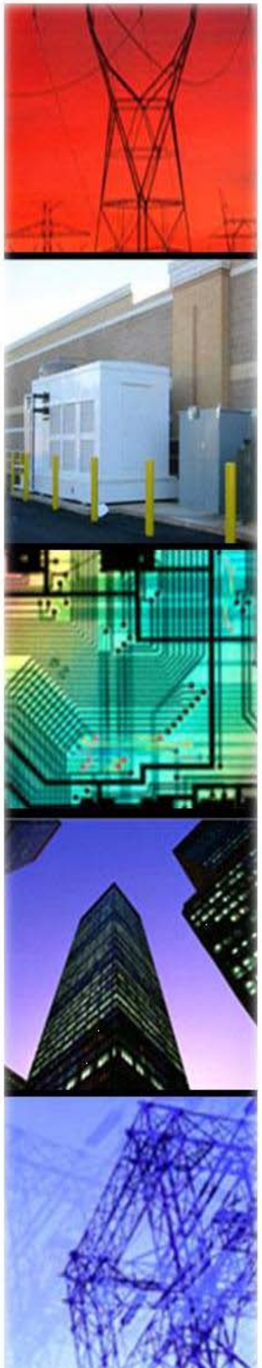
Storage Placement





MicroGrid & Storage





MicroGrid & Storage

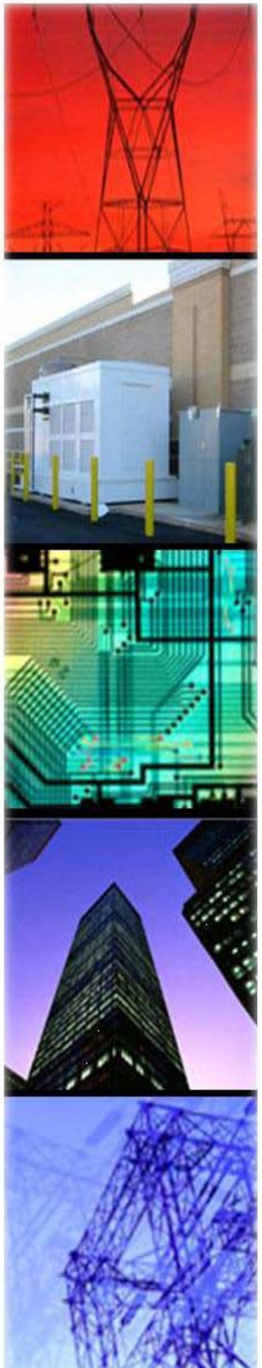
Solar Carport

Intelligent Switchgear Modules
with Storage

Electric Vehicles/
Charging Stations

(2) 150kW
Diesel Generators

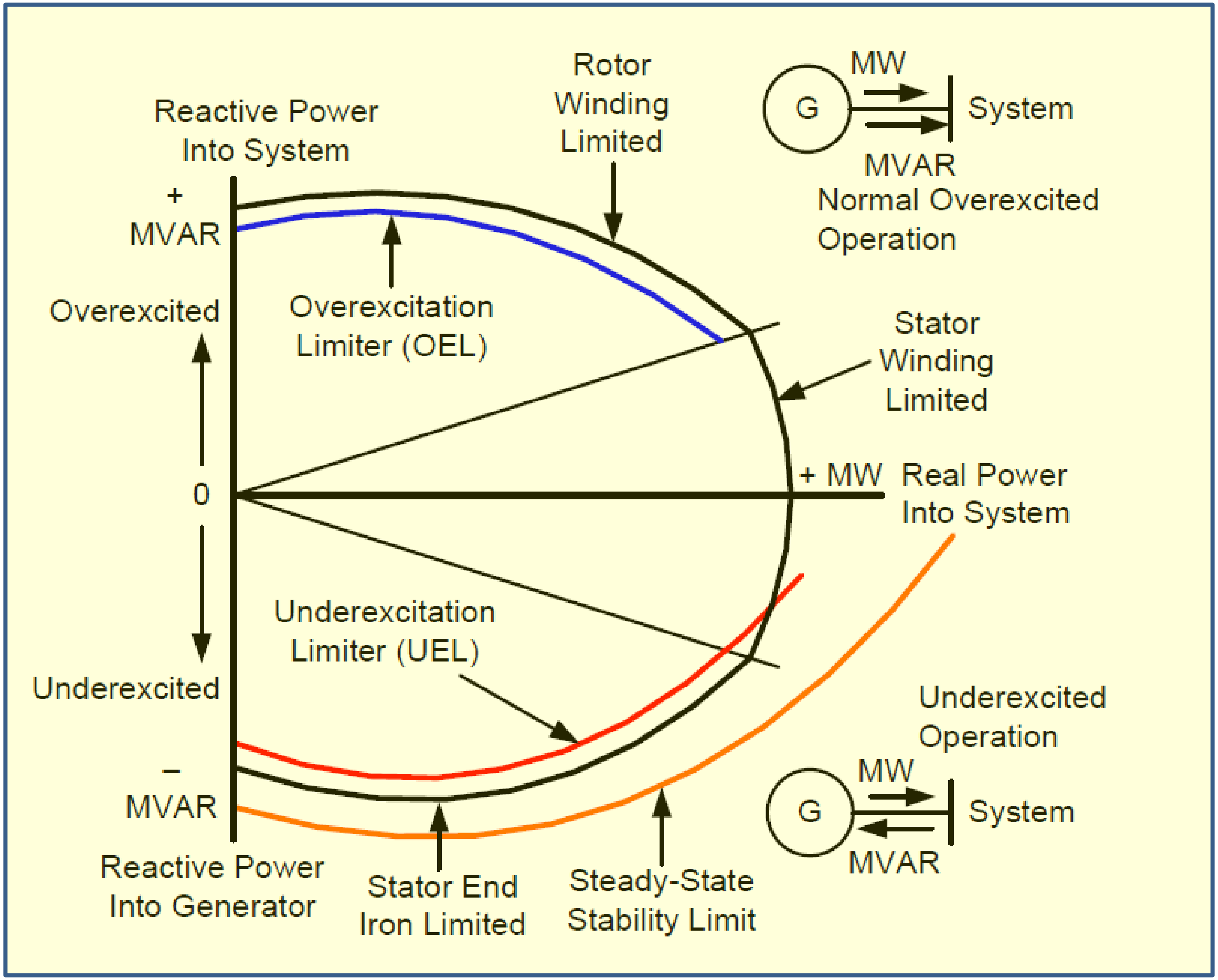
Site Layout



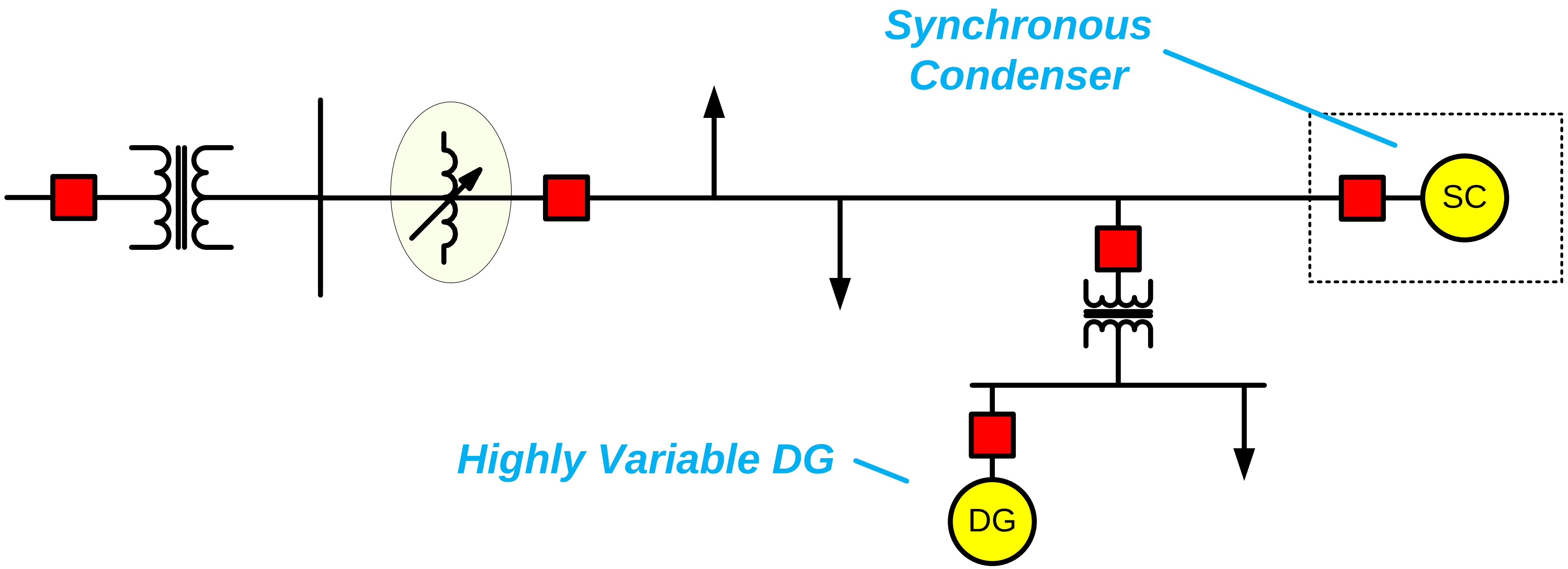
Synchronous Condensers

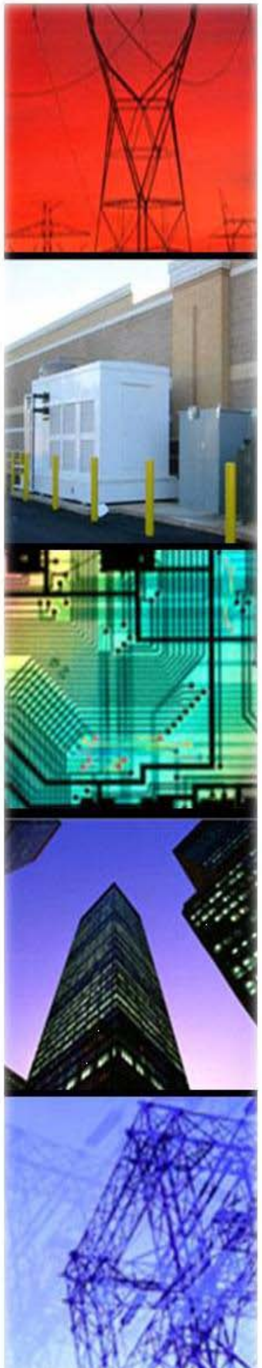
- In large scale Utility application, they are older generators decoupled from the turbines
  - Used to retire inefficient generation assets
  - Take in real power, typically <1%, to “spin” synchronous generator
- Field controlled to deliver/absorb VARs to limits of the generation (or synchronous motor)

Synchronous Condenser Operation



Synchronous Condenser Placement

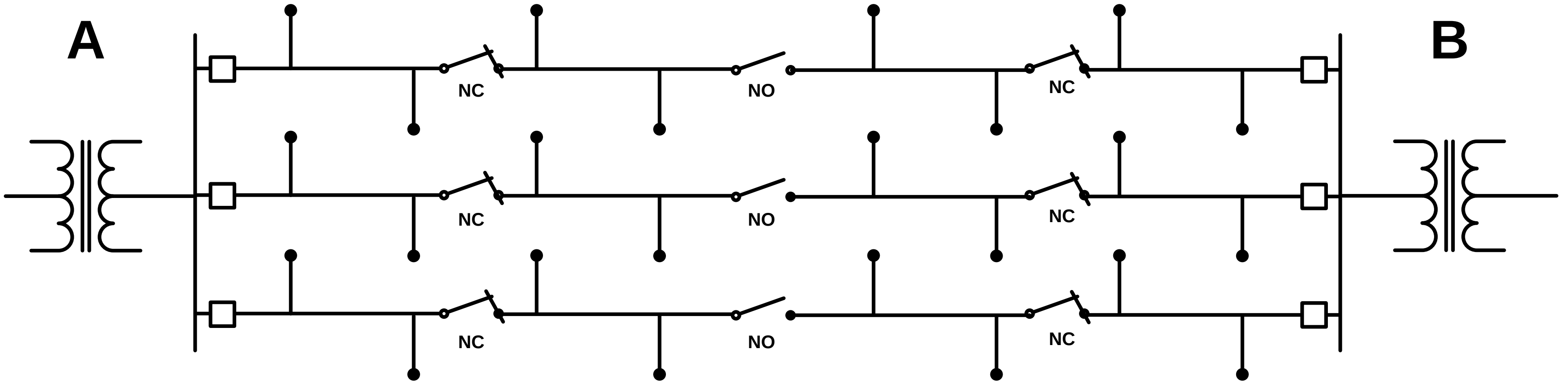




Asset Loading Issues

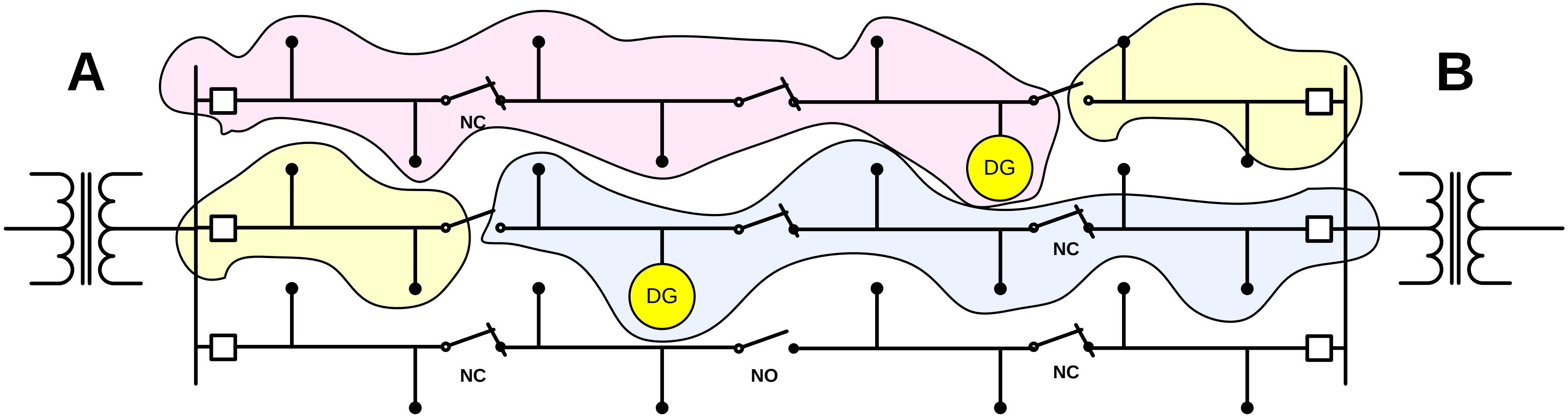
- TLM/FLM with DMS
  - Knowing where the various DG is located, and if operational, on feeders with TLM/FLM capability
    - Alter decisions on TLM/FLM based on DG load relief/power export capability
    - Employ strategic sectionalizing to use DG
  - Enacting proper Volt/VAR control and protection system changes pursuant to location, amount of and export capacity of DG on feeder sections
  - May be done by direct control or initiating setting group changes on control assets

DG as a FLM/TLM Asset



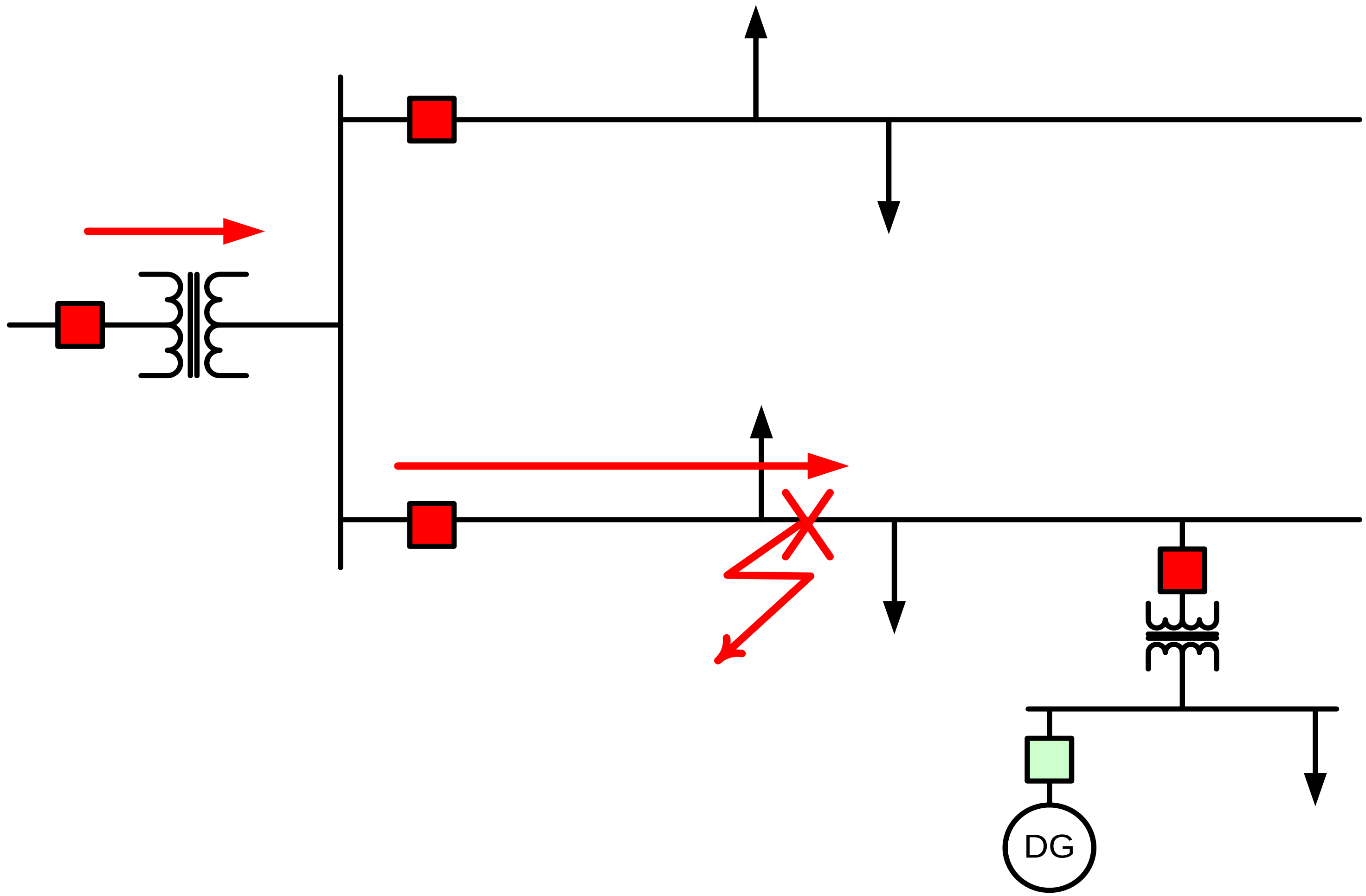
- *Pre FLM/TLM Resectionalizing*

DG as a FLM/TLM Asset



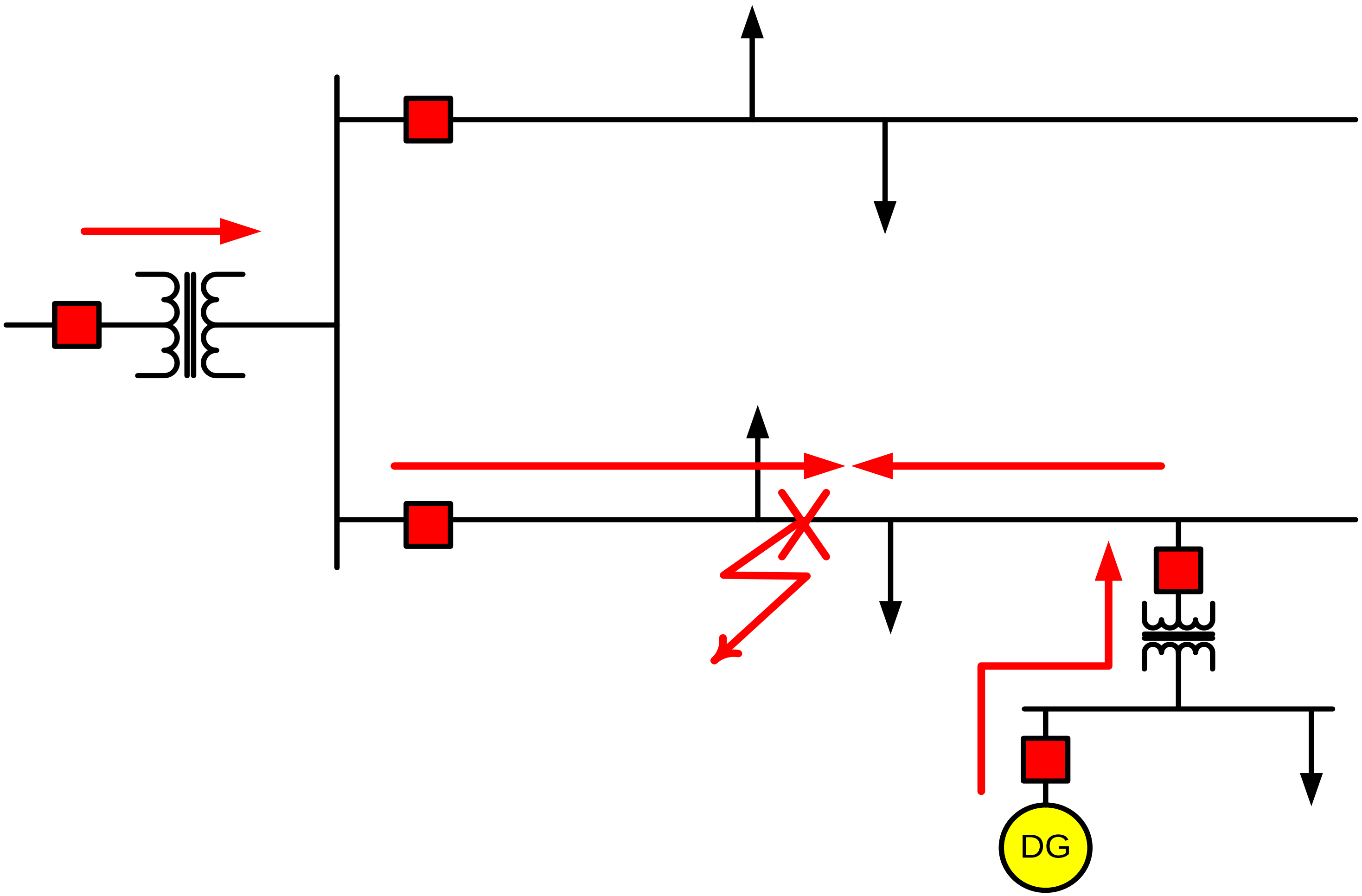
- *FLM/TLM Resectionalizing using DG*

Bidirectional Fault Currents: Feeder



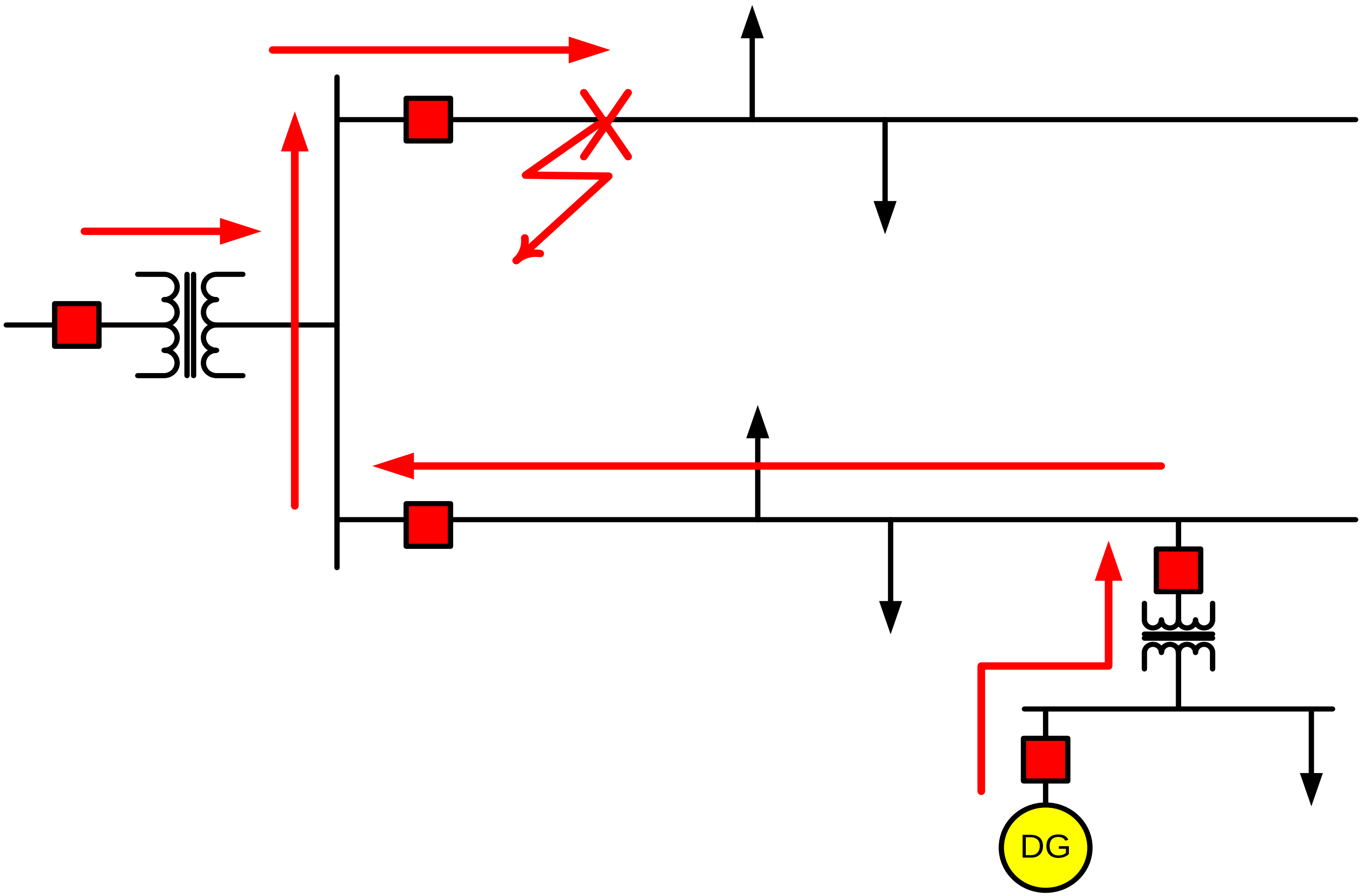
- DR Off, Normal Fault Current Flow

Bidirectional Fault Currents: Feeder

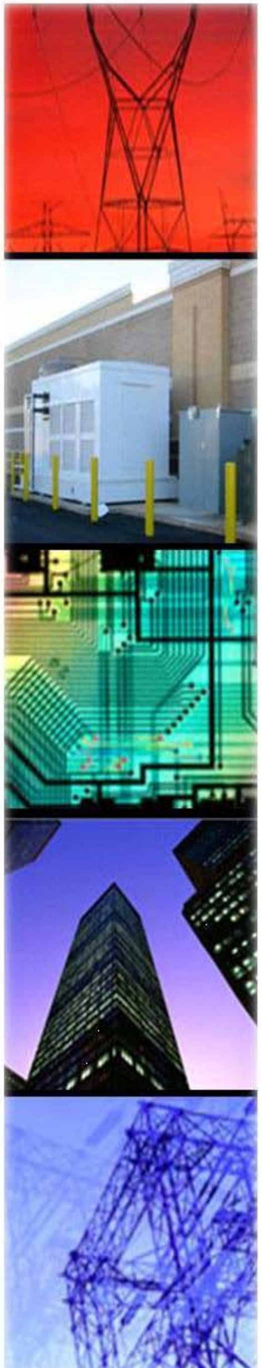


- DR On, Possible Reverse Fault Current Flow

Bidirectional Fault Currents: Feeder

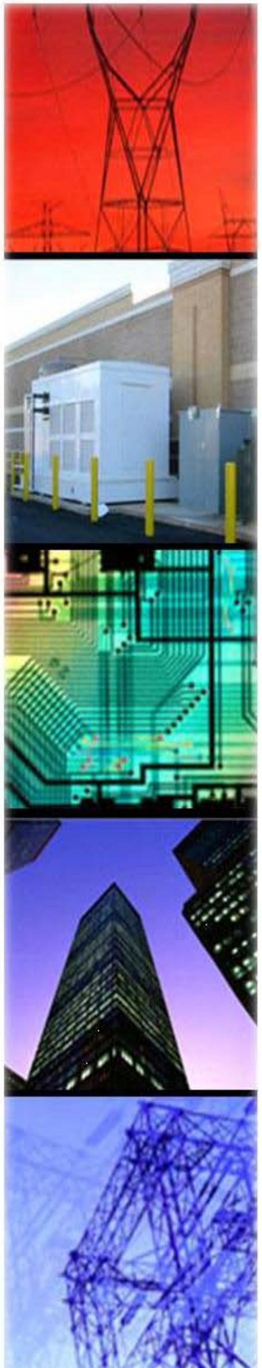


- DR On, Possible Reverse Fault Current Flow



Small Generator
Fault Current Contribution

- It's all about x''_d and t''_d
  - x''_d used for fault level determination
    - $1/x''_d$ allows conceptualization of multiples of rated current
      - $x''_d = 0.15pu$
      - $1/0.15pu = 6.6pu$
  - t''_d used to define the duration of the x''_d fault level

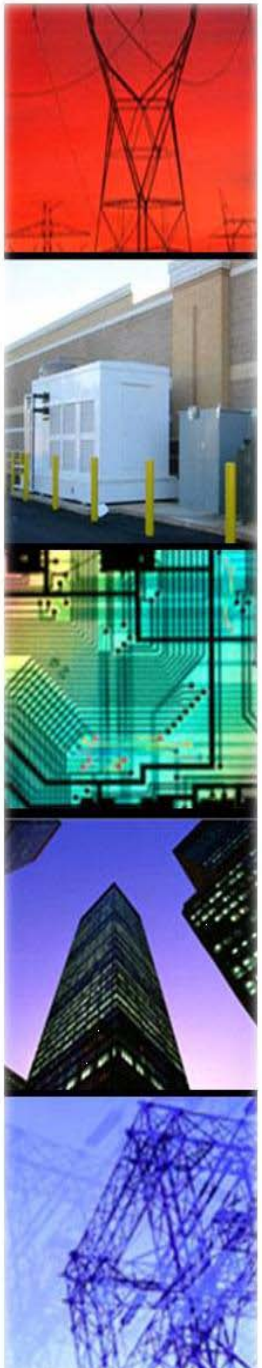


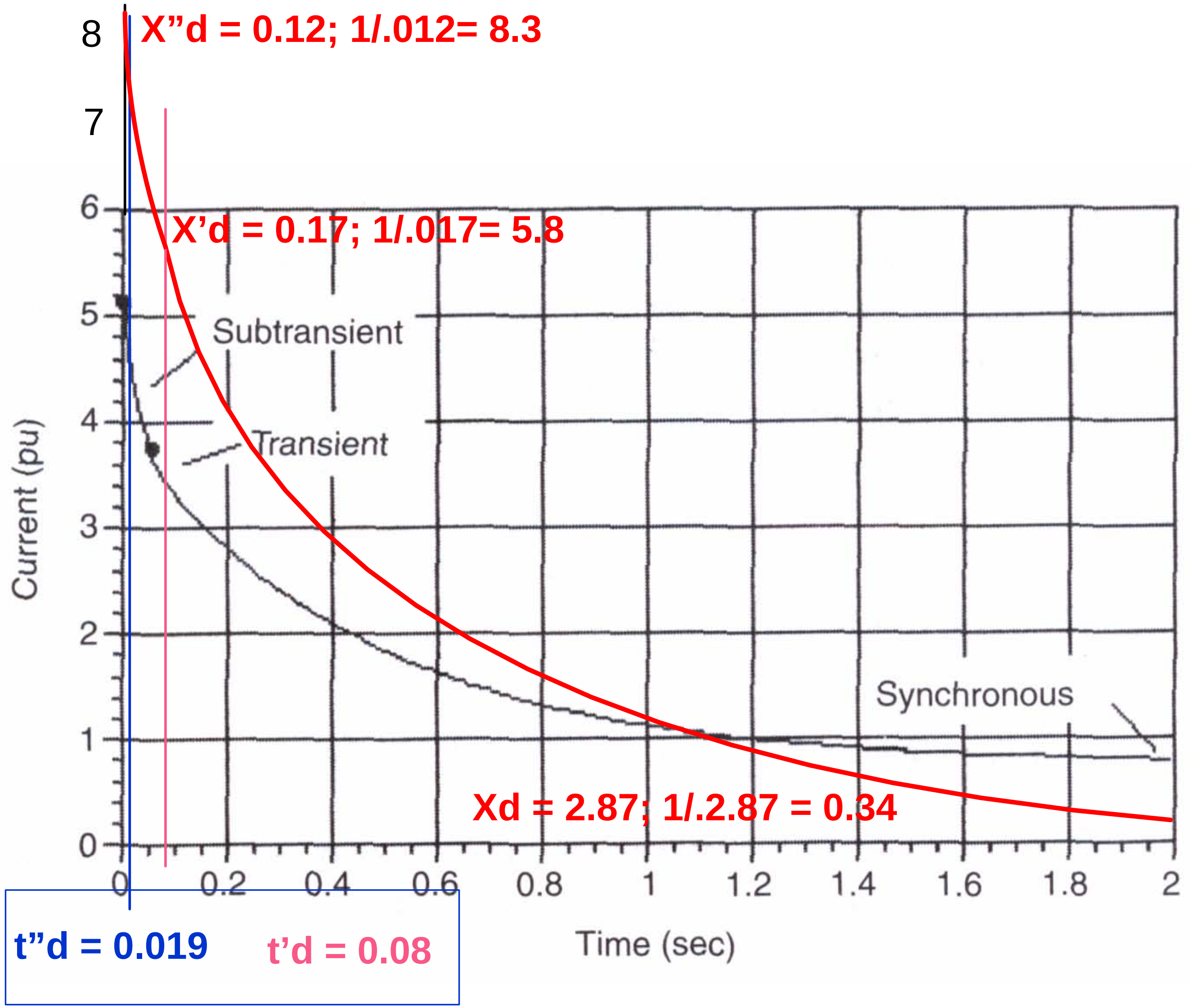
≈400kVA Generator

	50 Hz				60 Hz			
TELEPHONE INTERFERENCE	THF<2%				TIF<50			
COOLING AIR	0.8 m³/sec 1700 cfm				0.99 m³/sec 2100 cfm			
VOLTAGE SERIES STAR	380/220	400/231	415/240	440/254	416/240	440/254	460/266	480/277
VOLTAGE PARALLEL STAR	190/110	200/115	208/120	220/127	208/120	220/127	230/133	240/138
VOLTAGE SERIES DELTA	220/110	230/115	240/120	254/127	240/120	254/127	266/133	277/138
kVA BASE RATING FOR REACTANCE VALUES	350	350	350	350	400	420	440	440
Xd DIR. AXIS SYNCHRONOUS	3.01	2.71	2.52	2.24	3.47	3.26	3.12	2.87
X'd DIR. AXIS TRANSIENT	0.20	0.18	0.17	0.15	0.21	0.20	0.19	0.17
X''d DIR. AXIS SUBTRANSIENT	0.14	0.13	0.12	0.11	0.15	0.14	0.13	0.12
Xq QUAD. AXIS REACTANCE	2.58	2.33	2.16	1.92	2.92	2.74	2.63	2.41
X''q QUAD. AXIS SUBTRANSIENT	0.36	0.32	0.30	0.27	0.41	0.38	0.37	0.34
X_L LEAKAGE REACTANCE	0.07	0.06	0.06	0.05	0.08	0.08	0.07	0.07
X_2 NEGATIVE SEQUENCE	0.24	0.22	0.20	0.18	0.28	0.26	0.25	0.23
X_0 ZERO SEQUENCE	0.10	0.09	0.08	0.07	0.10	0.09	0.09	0.08
REACTANCES ARE SATURATED	VALUES ARE PER UNIT AT RATING AND VOLTAGE INDICATED							
T'd TRANSIENT TIME CONST.	0.08s							
T''d SUB-TRANSTIME CONST.	0.019s							
T'do O.C. FIELD TIME CONST.	1.7s							
Ta ARMATURE TIME CONST.	0.018s							
SHORT CIRCUIT RATIO	1/Xd							

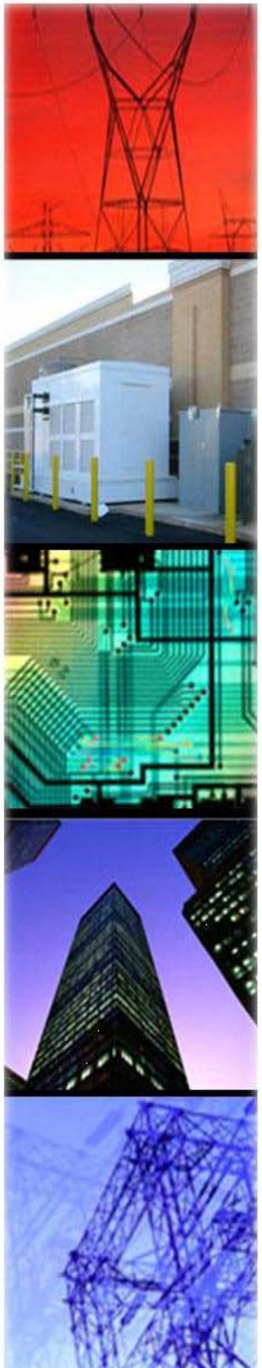
Rated Amps = 482A

≈400kVA Generator



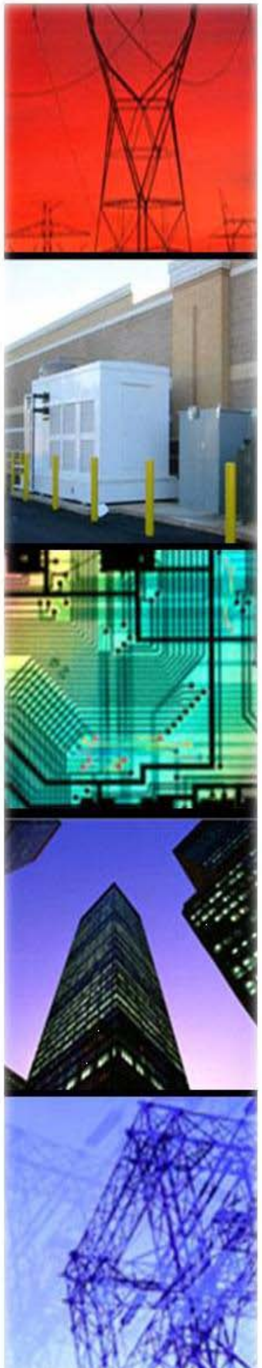


400kVA @ 480V = 482A



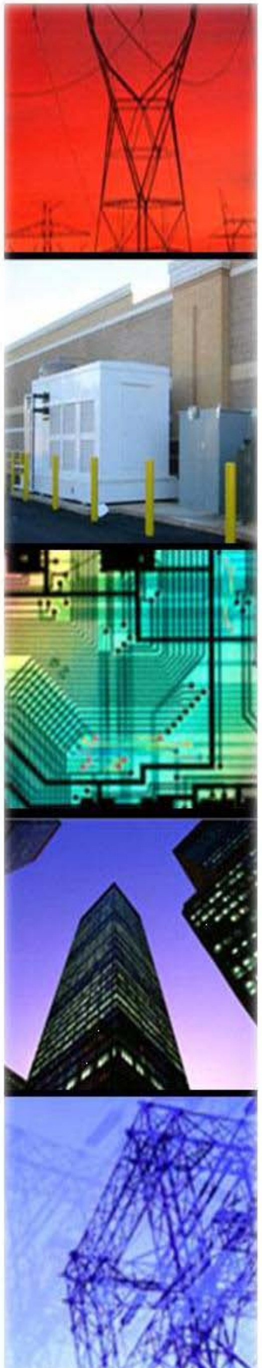
How Cleared?

- Use *directional* overcurrent protection at the DG point of common coupling (PCC)
  – Directionalize to trip with current flowing from the DG to the Utility
- Typical Settings
  – (67/50) 8pu rated current instantaneous
  – (67/51V) 1.25puI@1puV; 0.25puI@0.25puV
  – (67/51) 1.33puI@10 cycles
  – Similar philosophy for ground protection

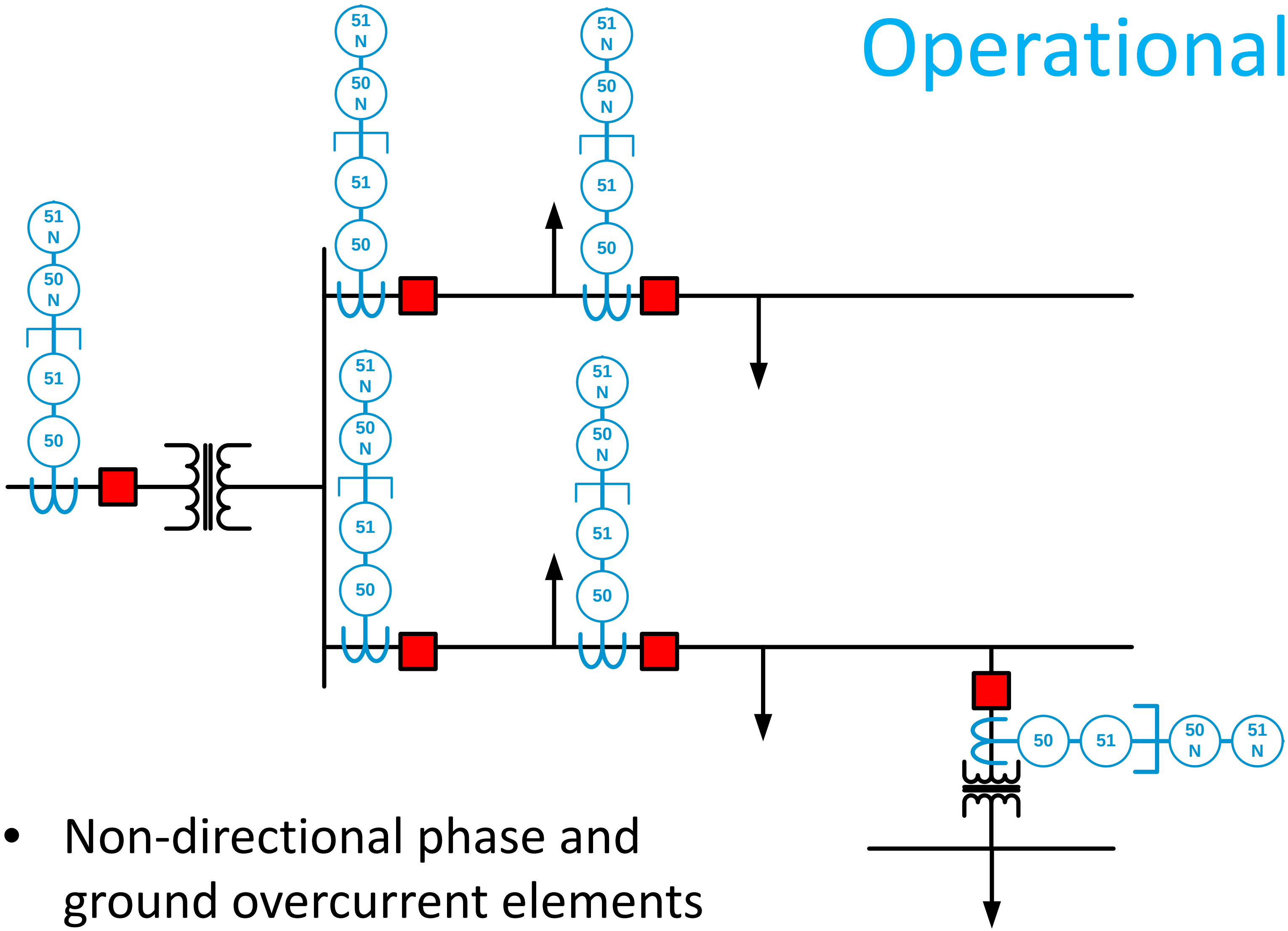


Bidirectional Fault Currents: Coordination

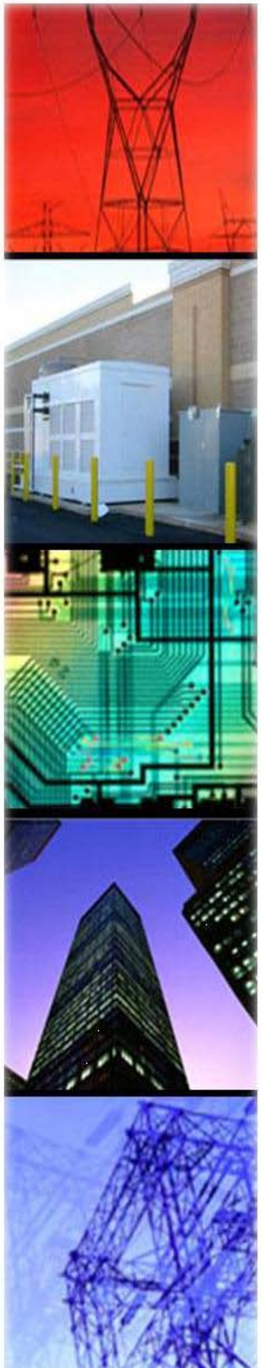
- Use directional elements in substation protection, mid-line reclosers and DG
  - Substation
    - Supervise 50/51 with 67 and 50N/51N with 67N
    - Trip direction away from substation (downstream)
  - Reclosers
    - Supervise 50/51 with 67 and 50N/51N with 67N
    - Trip direction away from substation (downstream)
  - DG
    - Supervise 50/51 with 67 and 50N/51N with 67N
    - Trip direction away from DG (upstream)



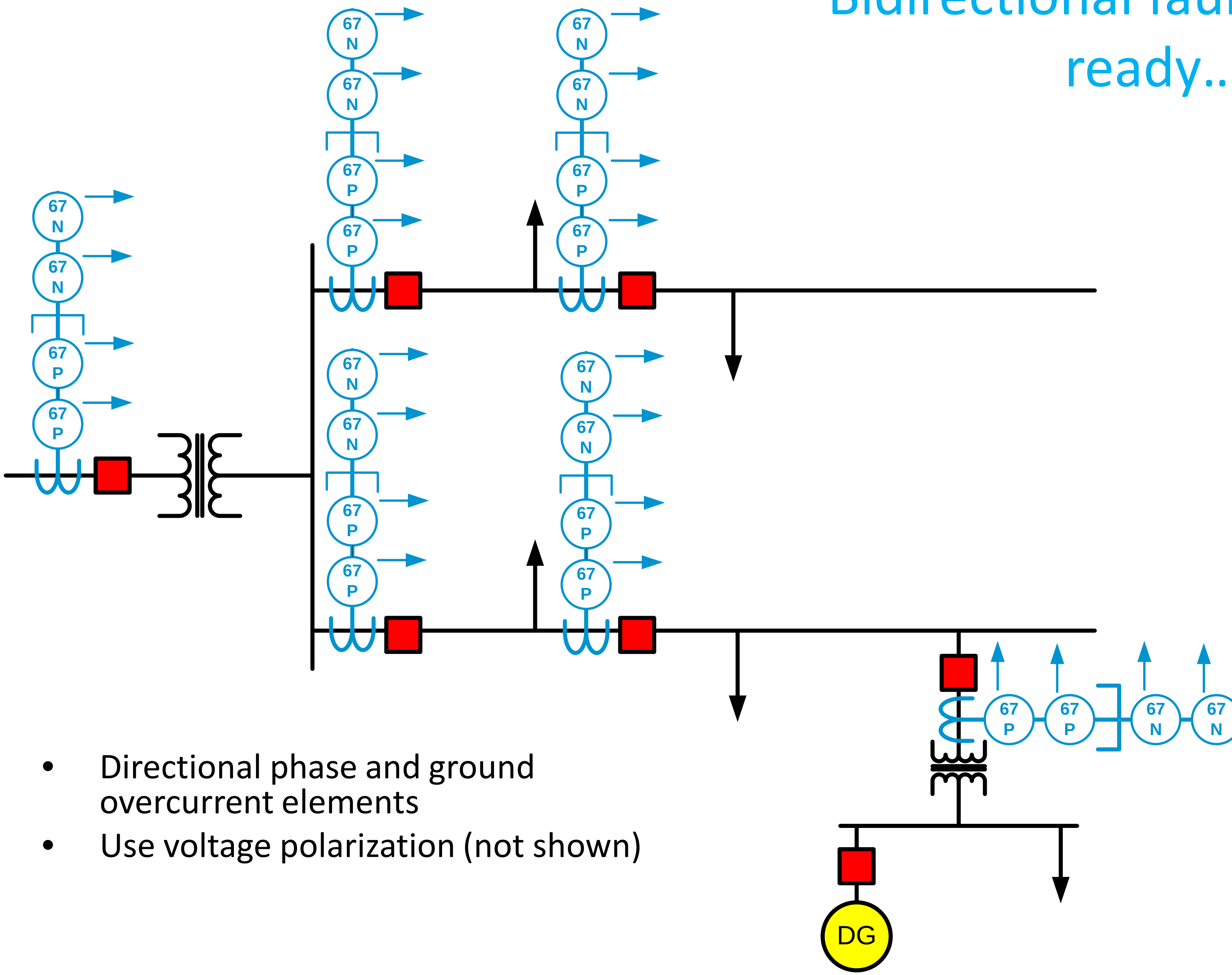
No DG Operational



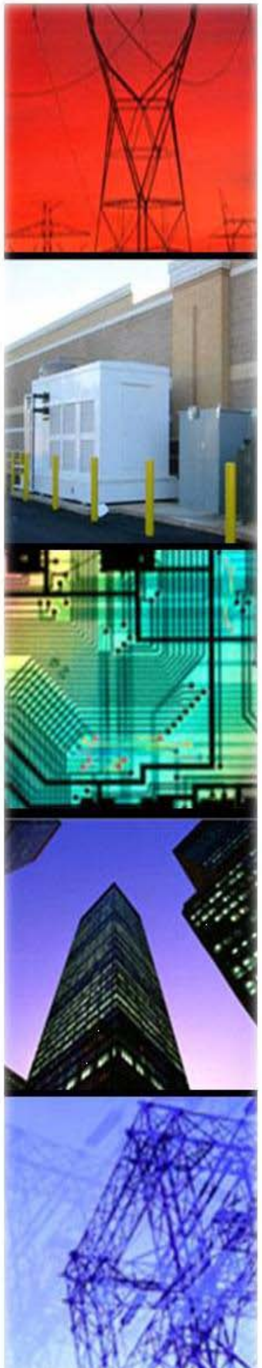
- Non-directional phase and ground overcurrent elements



DG Operational:
Bidirectional fault ready….

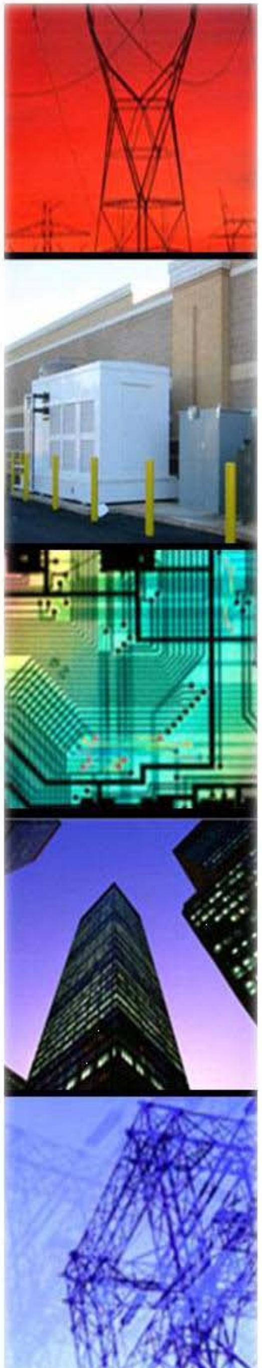


- Directional phase and ground overcurrent elements
- Use voltage polarization (not shown)



DMS Control

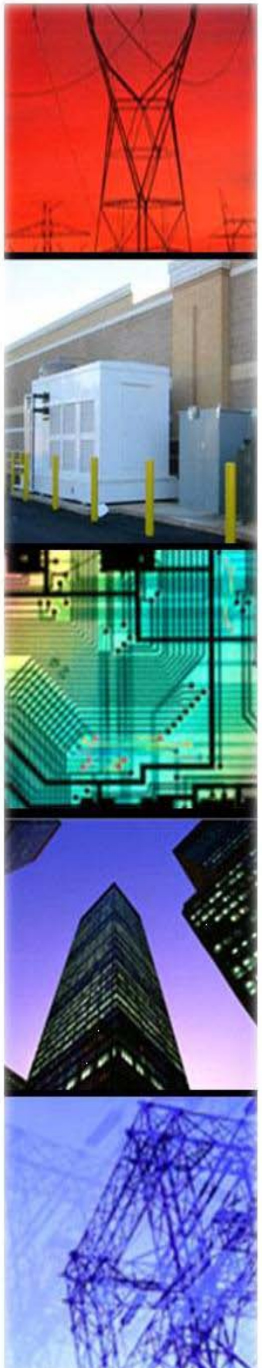
- DG and Utility Protections
  - Knowing where the various DG is located, and if operational, on feeders
  - Enacting proper protection system changes pursuant to location, amount of and export capacity of DG on feeder sections
  - If protection changes autonomous, provide feedback that they have occurred or block certain DG operation
    - Run or no run
    - Limit operation to non-exporting
  - May be accomplished by direct control or initiating setting group changes on control assets



Reclosing Coordination

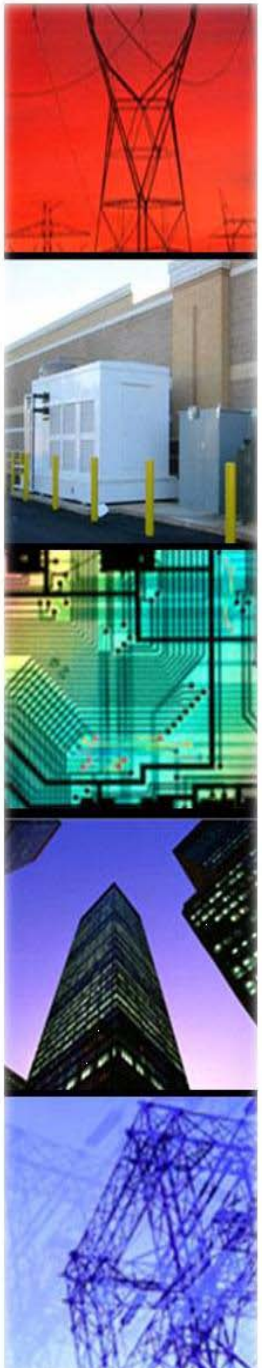
- Although DR anti-islanding protection trips fast (10 cycles), instantaneous reclosing at the substation and mid-line reclosers may need to be delayed

- For extra security, Utilities have been employing adaptive reclosing
  - Voltage supervision ensures all DR is off line
  - If DR stays on, holding up feeder voltage, reclosing is blocked until either:
    - DR shakes off
    - DR is removed

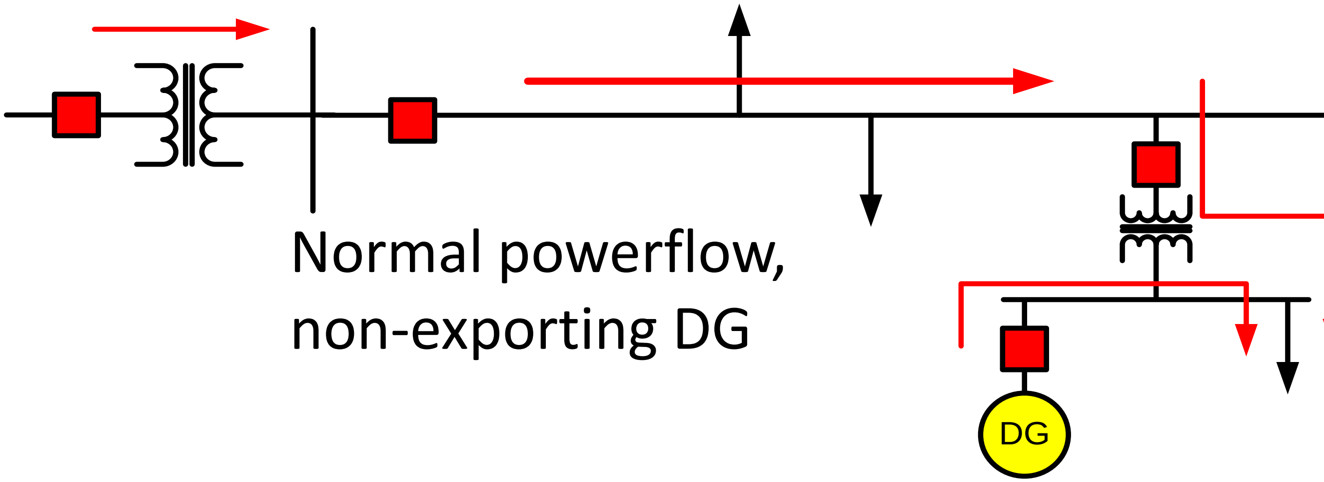


Reclosing Considerations with DG

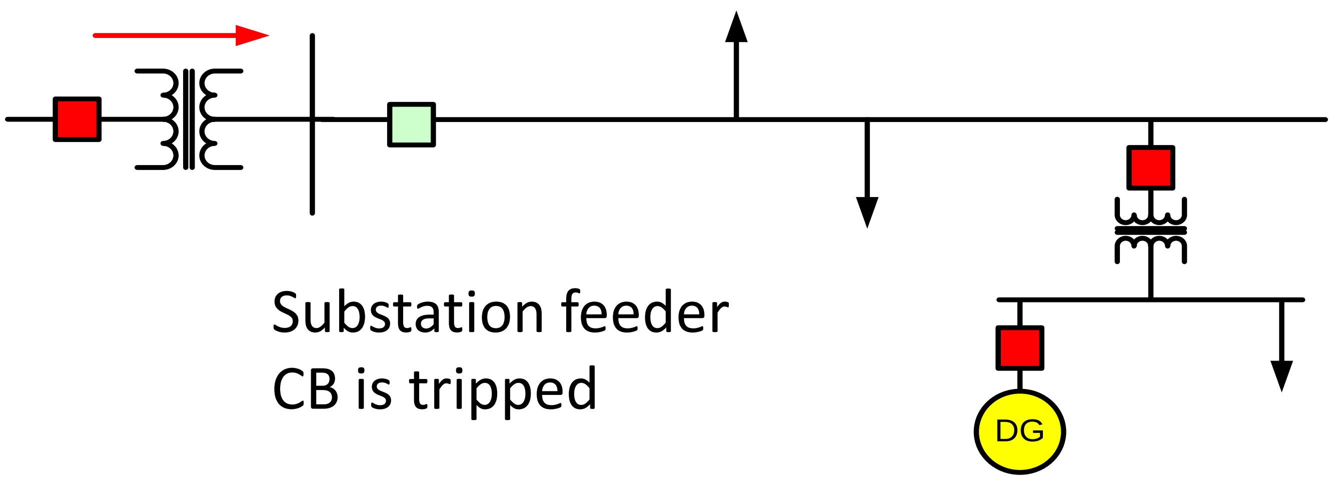
- Lengthen reclosing at substation
  - Negative impact when DG is not operational
- Adaptive reclosing using voltage supervision
  - Keeps shot time low if all DG is removed from feeder



Supervised Reclosing

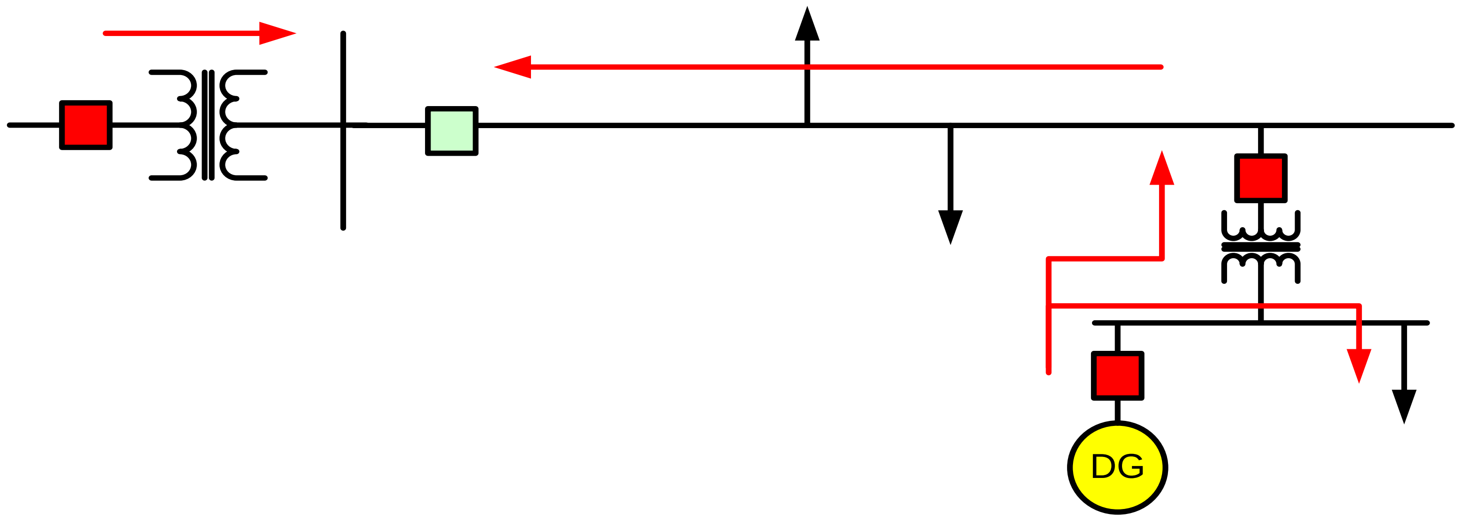


Normal powerflow,
non-exporting DG



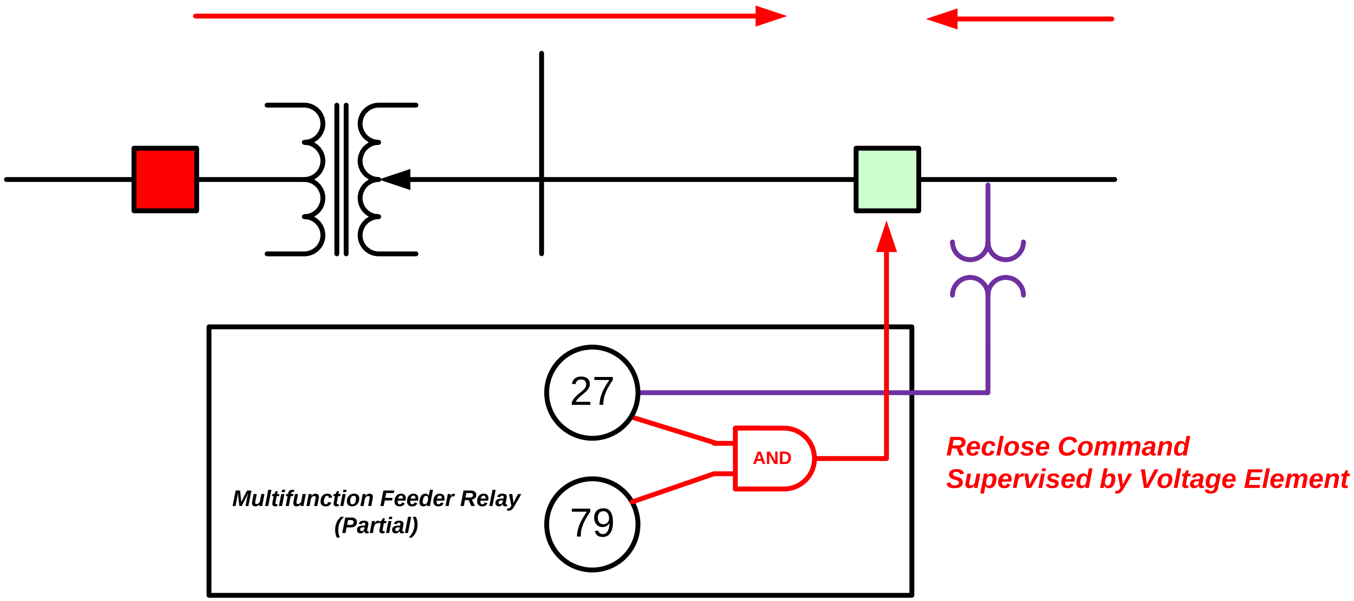
Substation feeder
CB is tripped

Supervised Reclosing

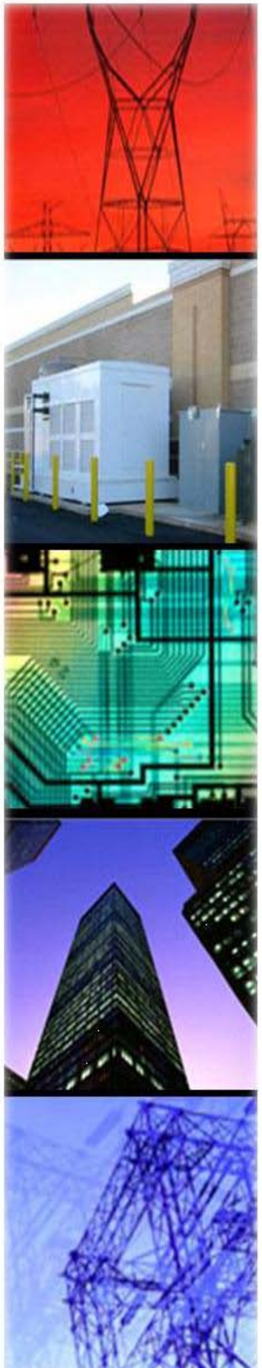


- Contingency: Substation opens CB, but DR fails to disconnect from feeder
- Voltage can be sensed at the feeder substation CB and reclosing modified

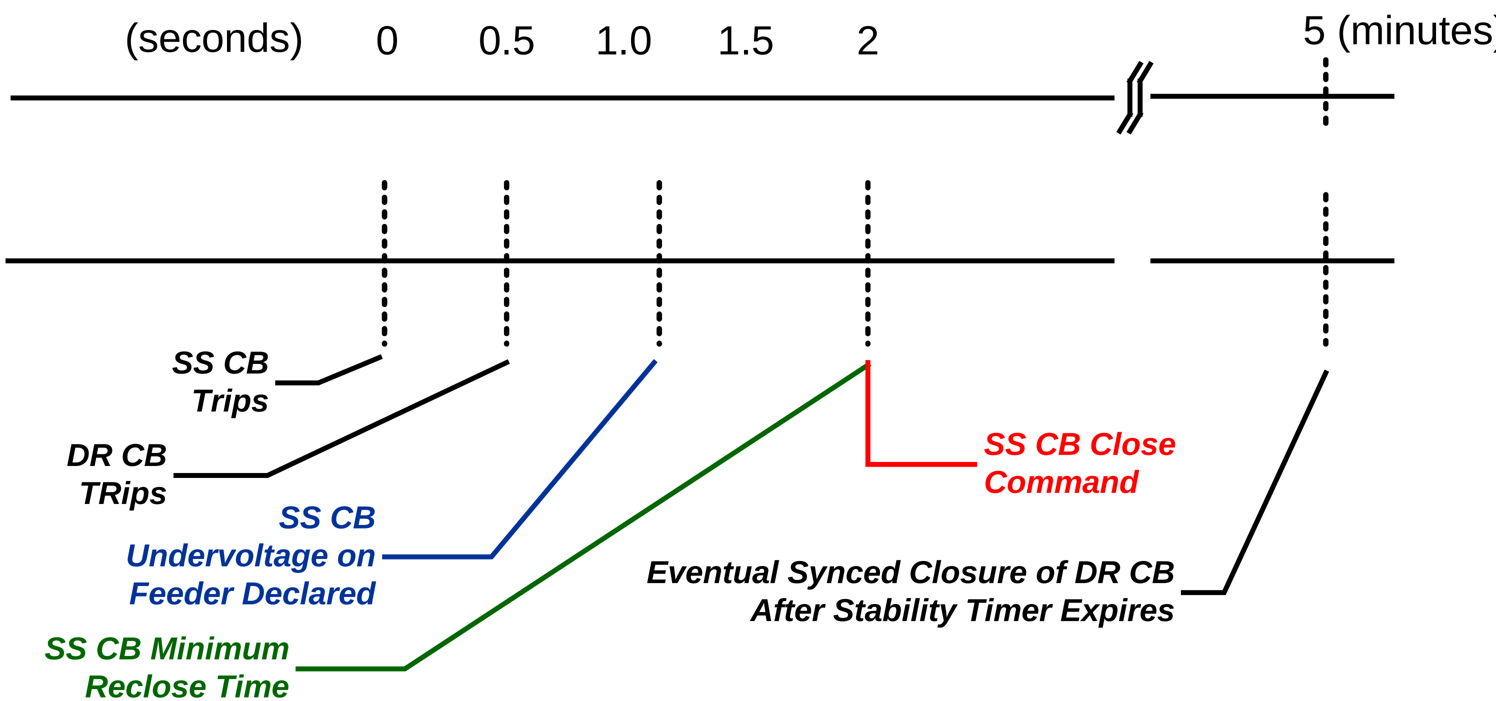
Voltage Supervised Reclosing



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

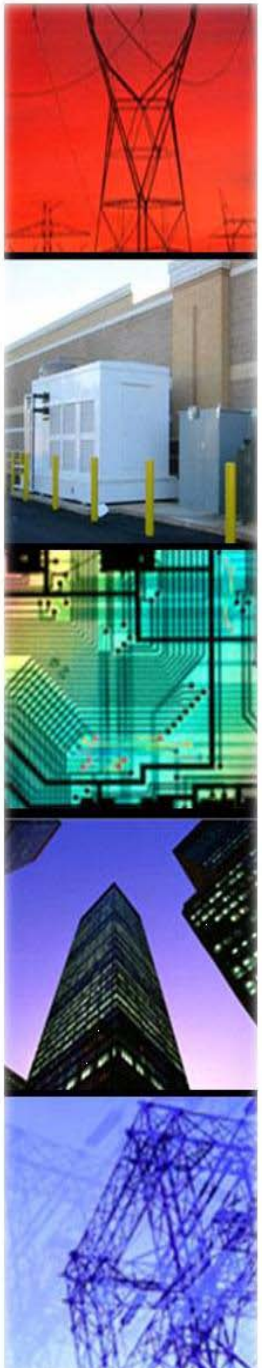


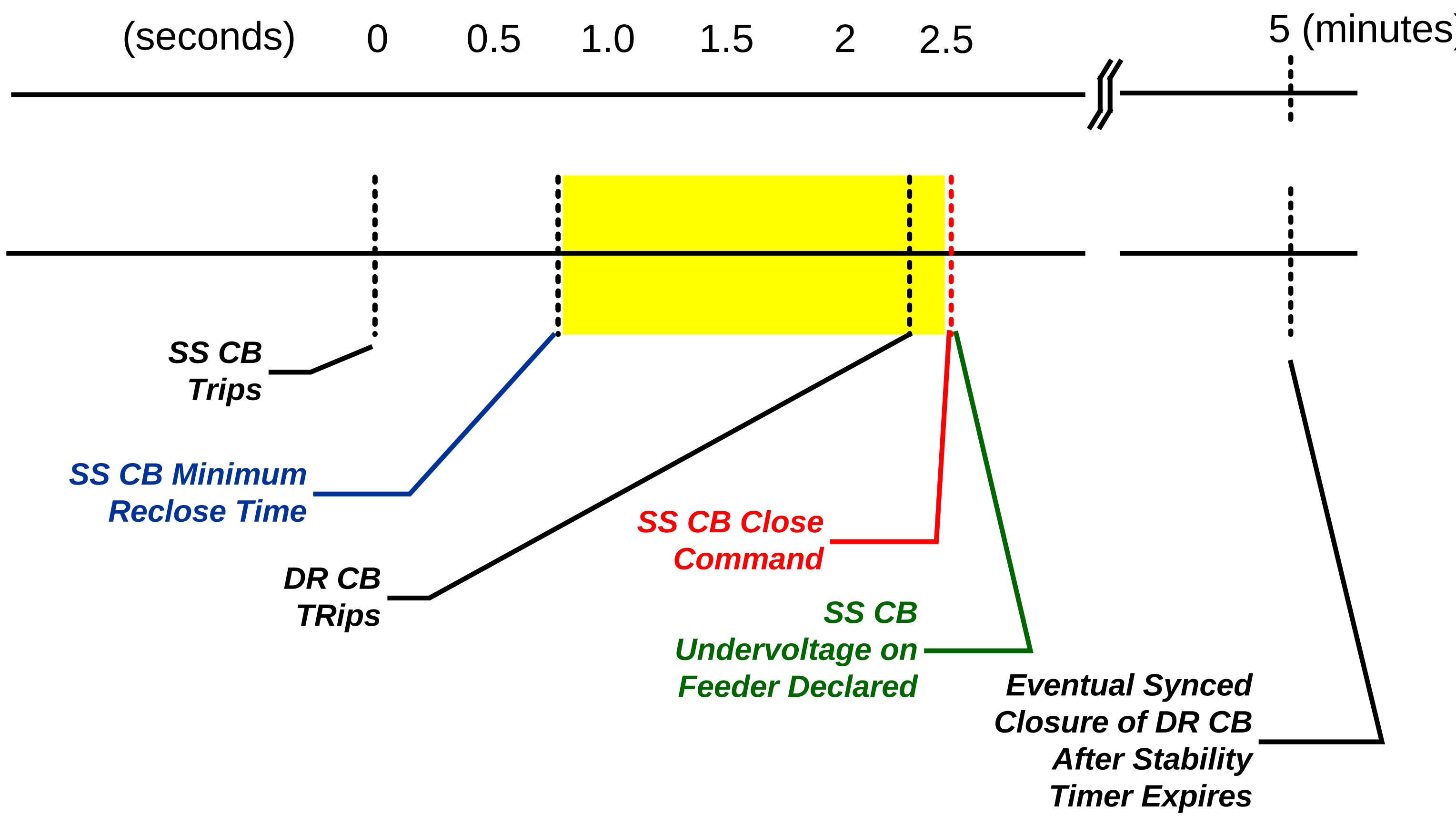
Normal Reclose



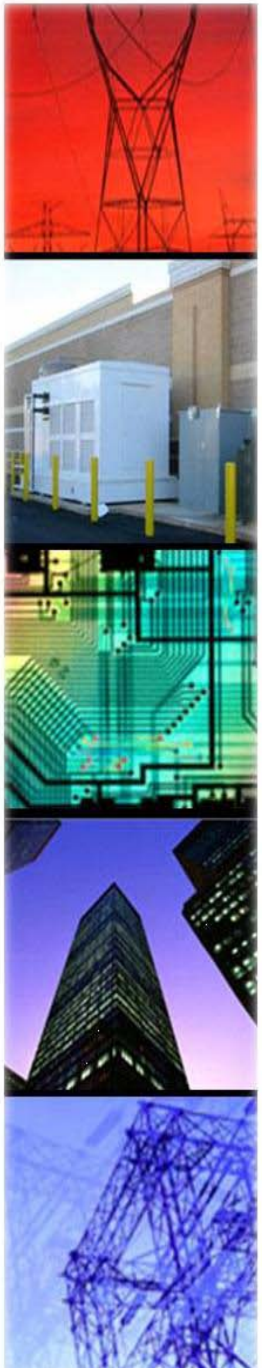
- Feeder undervoltage declared *before* minimum reclose time delay expire

Voltage Supervision Delayed Reclose

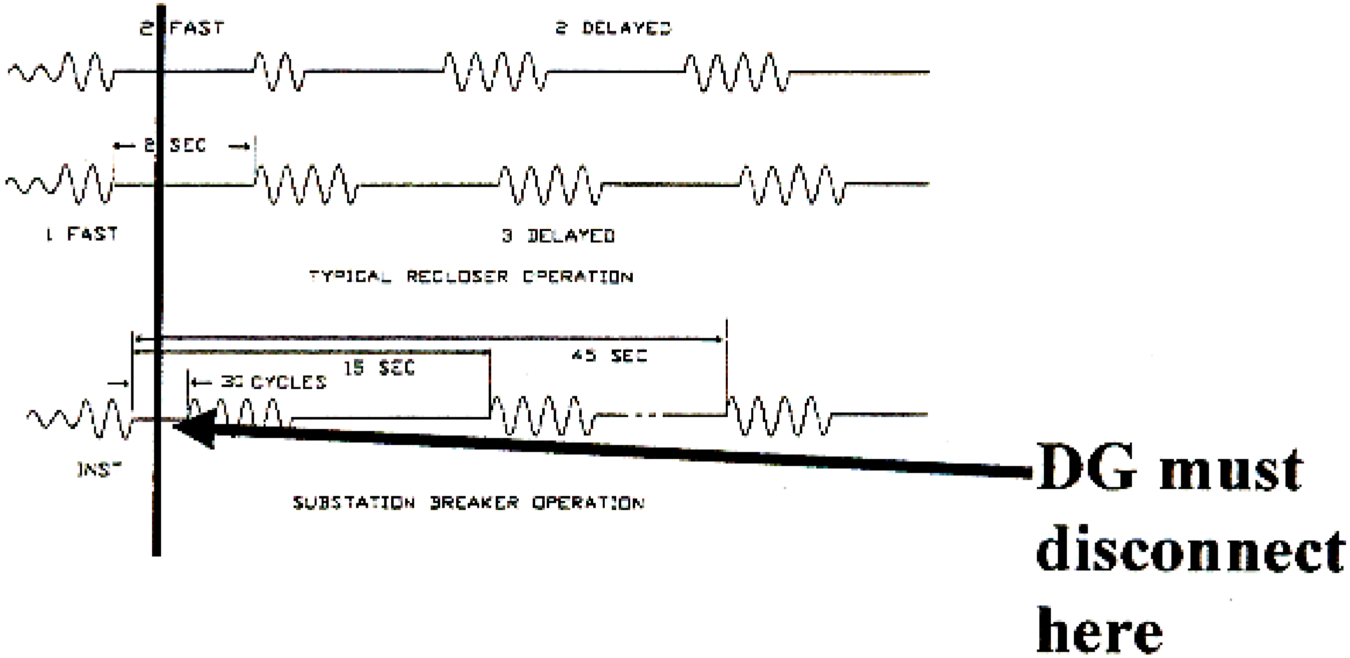




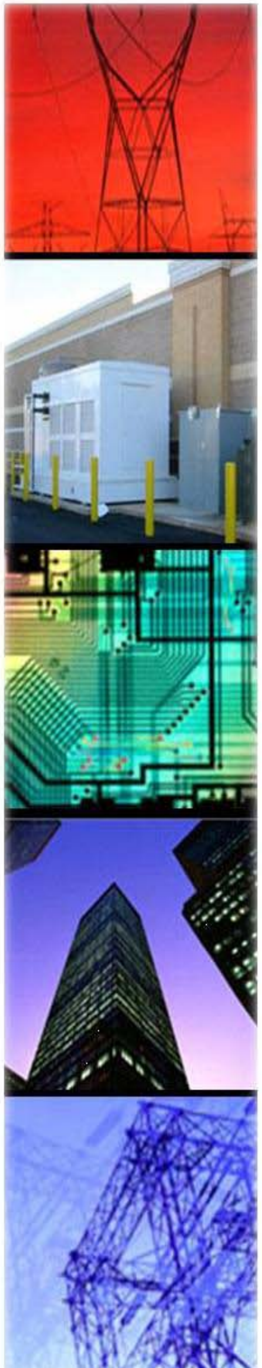
- Feeder undervoltage declared ***<u>after</u>*** minimum reclose time delay expire



Reclosing

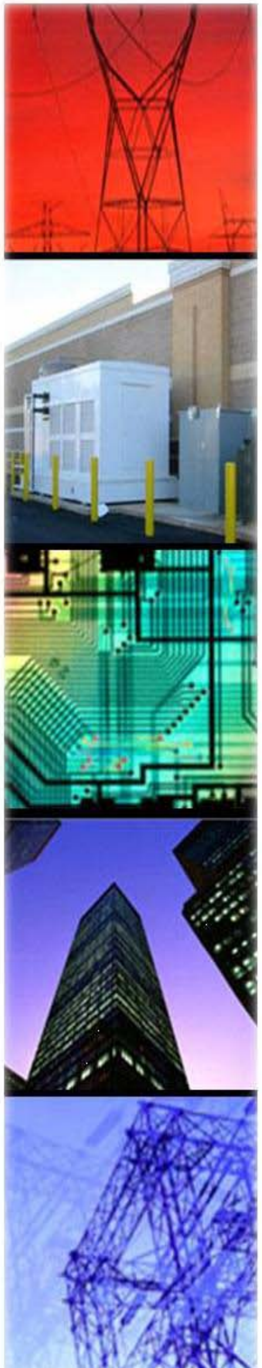


- If high speed reclosing is employed, the DG interconnection protection must be faster!
- Clearing time includes protection operation and breaker opening
  - 10 cycles is typical minimum



DMS Control

- Reclosing Control
  - Knowing where the various DG is located, and if operational, on feeders
  - Enacting proper protection system changes pursuant to location of DG on feeder sections
  - Report on success of reclosing with permitted time allotment to detect problematic DG
  - May be accomplished by direct control or initiating setting group changes on control assets



Recommended Reading

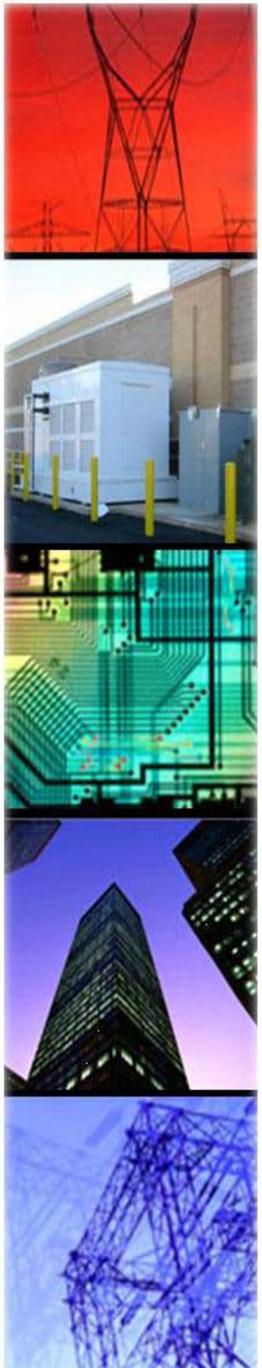
- ***IEEE 1547, Standard for Interconnecting Distributed Resources with Electric Power Systems***, http://grouper.ieee.org/groups/scc21/

- ***Distribution Line Protection Practices Industry Survey Results***, *Dec. 2002,* IEEE PSRC Working Group Report

- ***Effects of DA on Protection***, PSRC WG, Draft

- ***On-Site Power Generation***, by EGSA, ISBN# 0-9625949-4-6

- ***Combined Heating, Cooling & Power Handbook***, Marcel Dekker, by Neil Petchers, ISBN# 0-88173-349-0



Recommended Reading

- ***Electric Power Distribution Engineering,*** McGraw Hill, by Turan Gonen, ISBN# 0-07-023707-7
- ***Intertie Protection of Consumer-Owned Sources of Generation 3 MVA or Less,*** IEEE PSRC WG Report
- ***Standard Handbook of Powerplant Engineering***, McGraw Hill, Section 4.3, Electrical Interconnections, W. Hartmann, ISBN# 0-07-019435-1
- ***How to Nuisance Trip Distributed Generation***, W. Hartmann, presented at the Power System Conference, Clemson University, Clemson, SC, March 2003