PROTECTING AND MONITORING TRANSMISSION LINES WITH ENHANCED POWER FLOW

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Our agenda

Enhancing power flow along transmission lines

- Relief from congestion and renewable curtailment
- Benefits of grid-enhancing technologies (GETs)

Static line ratings

Dynamic System Rating (DSR) WAMPACS

- Dynamic line ratings (DLR)
- Dynamic power rating (DPR)
- Optimal power-flow controllers (OPFC)

Implementing a DSR WAMPACS

What DSR provides to operators and to EMS

Simulation results

Congestion / renewable-curtailment relief needed now

National Renewable Energy Laboratory grid capacity must triple to achieve zero carbon by 2035

US consumers paid $21 billion USD in congestion costs in 2022

More than 1.4 terawatts of renewable energy projects are stuck in interconnection queues

Europe to reduce greenhouse-gas emissions by at least 55% by 2030 and source 40% energy from renewables

Australia has 67 GW of renewable energy projects cannot connect because of congestion

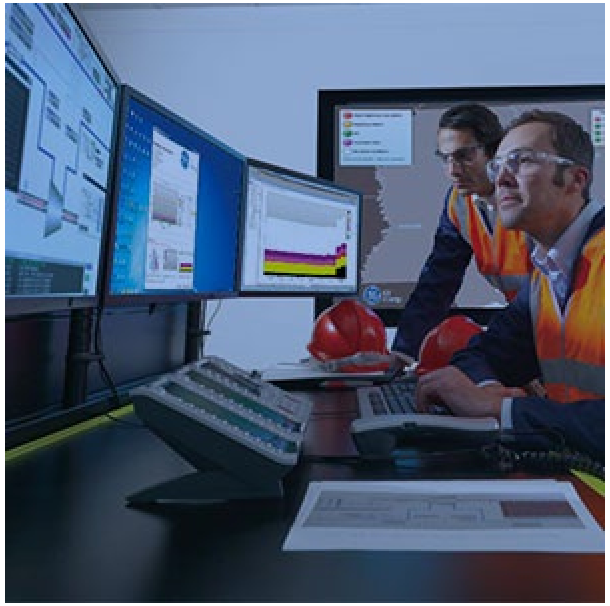
Grid-enhancing technologies (GETs) benefits

Situational awareness for safer, real-time operation

Asset deferral, to give time to implement longer-term solutions

Increased grid resilience

Asset health monitoring



Static line ratings

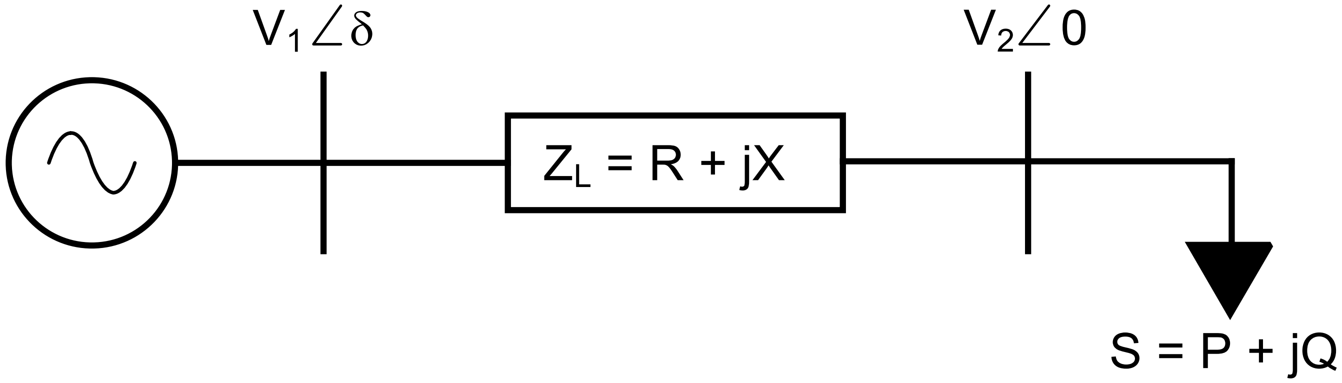
Maintain safe operating conditions on power lines from generation to loads

IEEE 738 “IEEE Standard for Calculating Current Temperature Relationship of Bare Overhead Conductors”

Conservative assumptions limit line usage

- Static weather conditions
- Average wind speeds and direction
- Average ambient temperatures
- Solar conditions for summer and winter

Cannot take advantage of favorable conditions



FERC 881 ambient ratings

Public utility transmission providers implement ambient-adjusted ratings (AAR) on transmission lines

Regional transmission organizations and independent system operators (RTO / ISO) update transmission-line ratings electronically, at least hourly

Public utility transmission providers

- Determine emergency ratings
- Share transmission line ratings and transmission line rating methods with respective transmission provider(s) and with market monitors in RTOs/ISOs
- Maintain database of transmission owners' transmission line ratings and transmission line rating methods
- Open Access Same-Time Information System (OASIS) website

Dynamic system rating, DSR = DLR + DPR

DSR optimizes transmission network

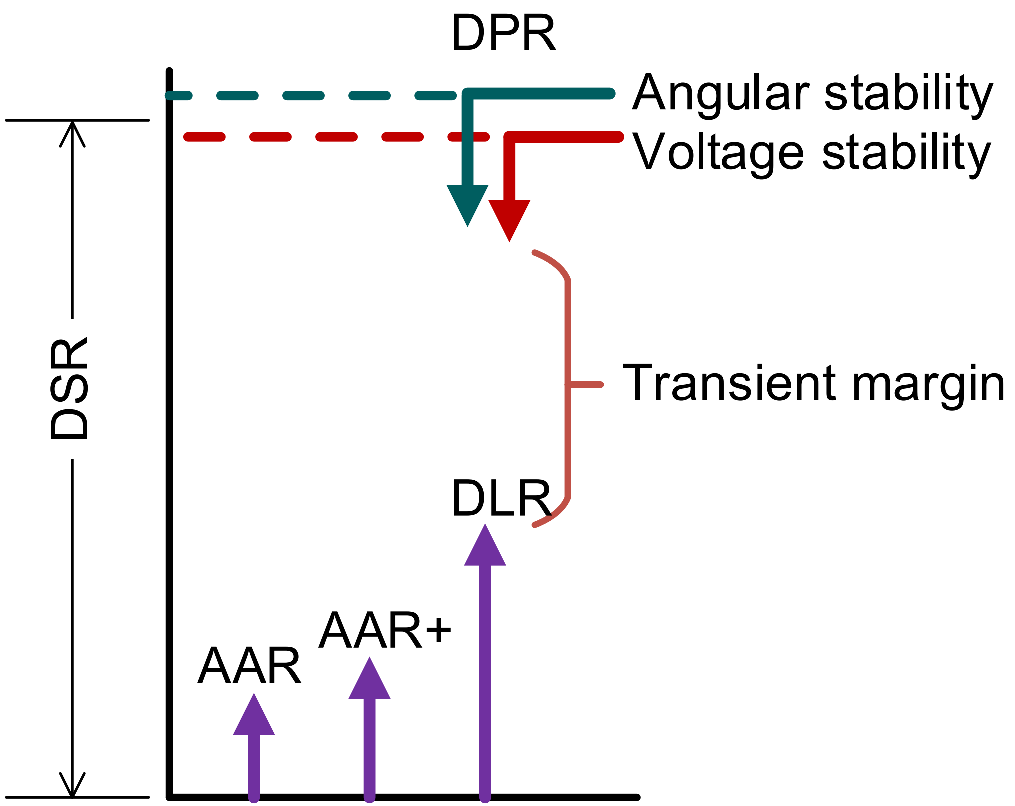
- DLR—dynamic line rating
- DPR—dynamic power rating

DLR—thermal measurement improvement over previous methods

- AAR—ambient-adjusted ratings
- AAR+—ambient-adjusted ratings, new

DPR from phasor-measurement units (PMUs)

- Angular stability
- Voltage stability

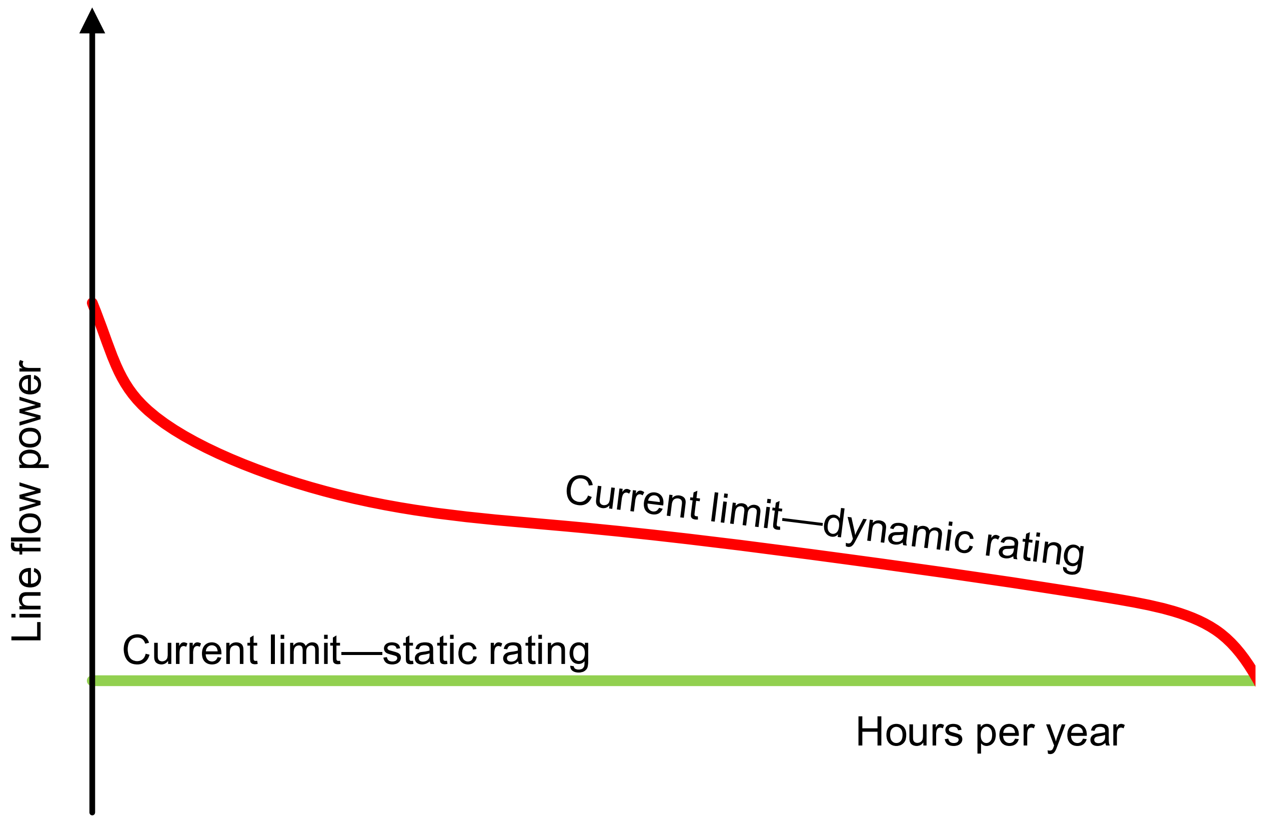


Dynamic line rating (DLR) increases thermal limit

Thermal line capability

- Sensor and computational analysis
- Computational fluid dynamics

Increases line power flow



Dynamic power rating (DPR); angular stability

where

P_{E1} is electrical power

P_{M1} is mechanical power

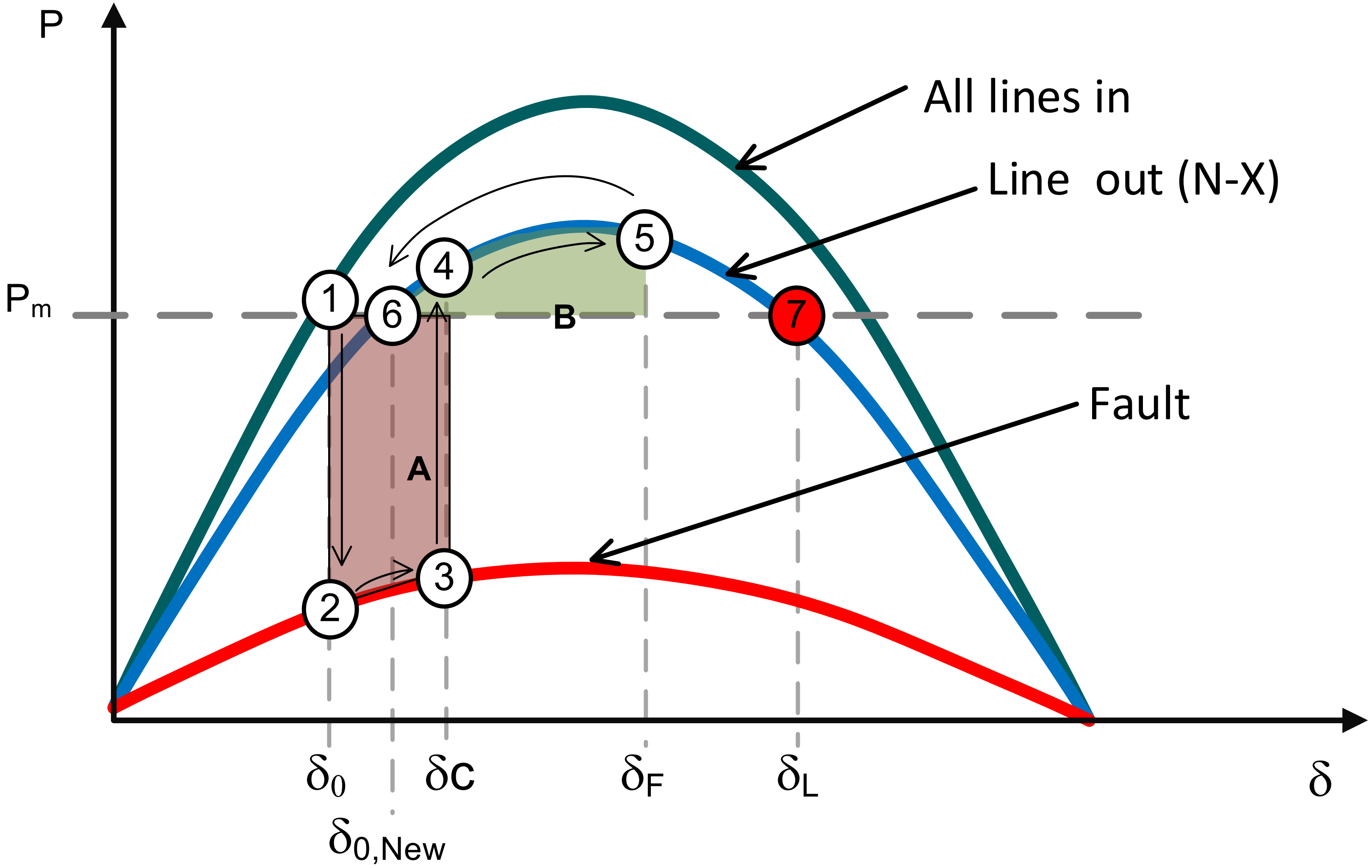
V_1 is transmitting line-terminal voltage

V_2 is receiving line-terminal voltage

X is line Impedance (neglect resistance R)

sin is sine of the line angle

Dynamic power rating (DPR); equal -area criterion



Dynamic power rating (DPR); voltage stability

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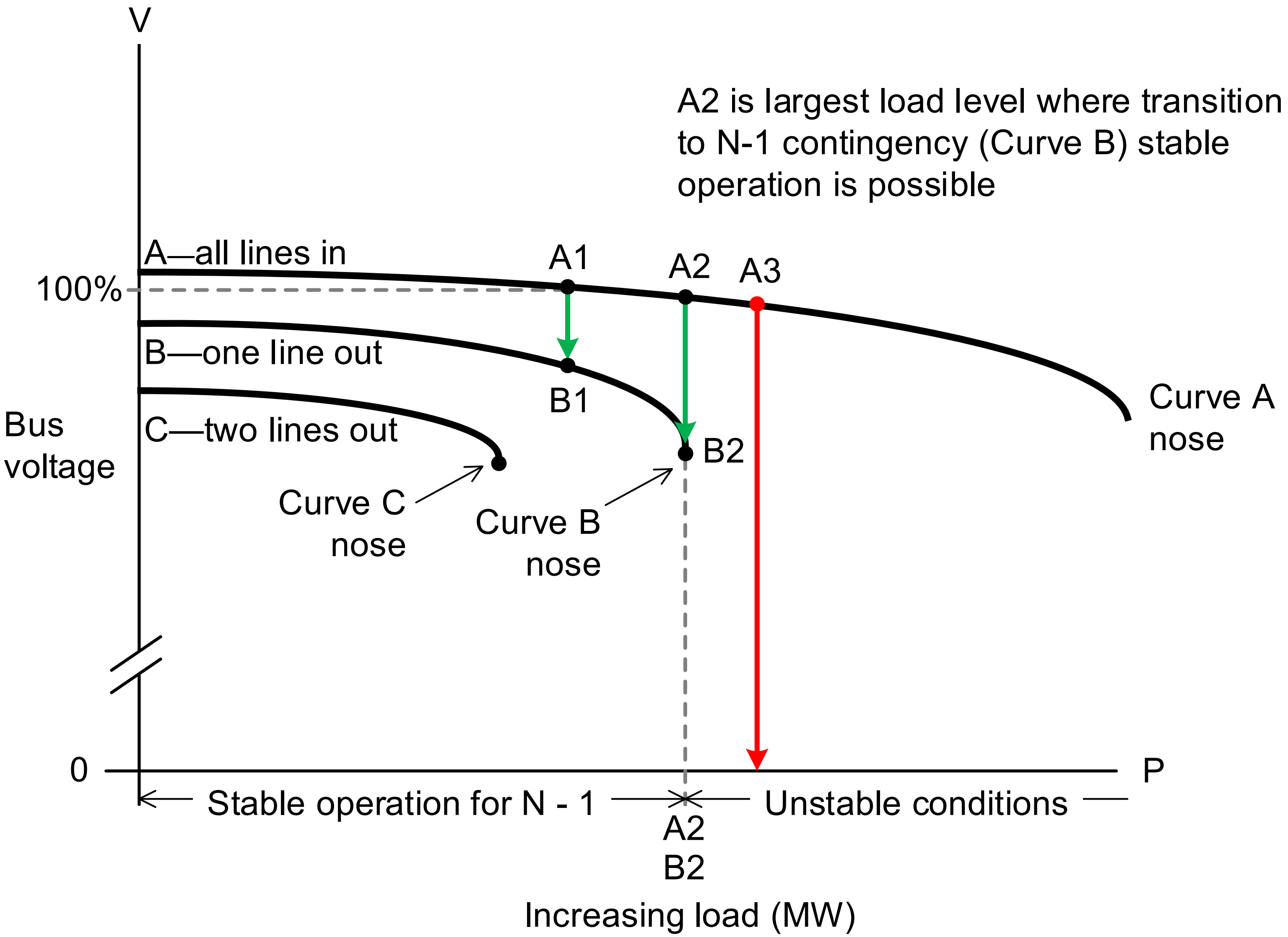
Dynamic power rating (DPR) nose curves



Optimal power-flow control (OPFC)

Adjust local resources

Shunt-connected devices change V1 and V2

Series-connected devices change jX

Phase-shifting transformers change δ

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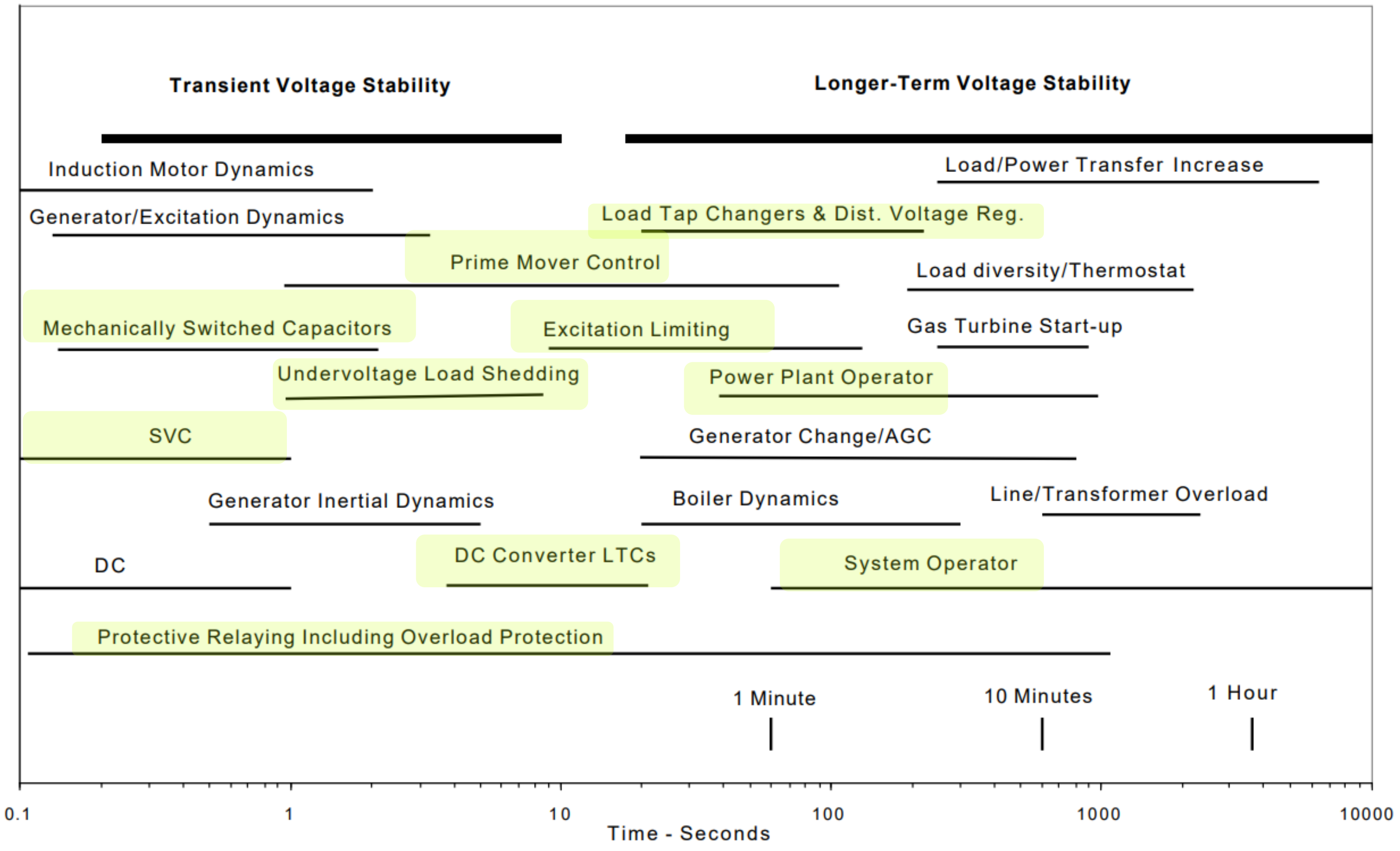
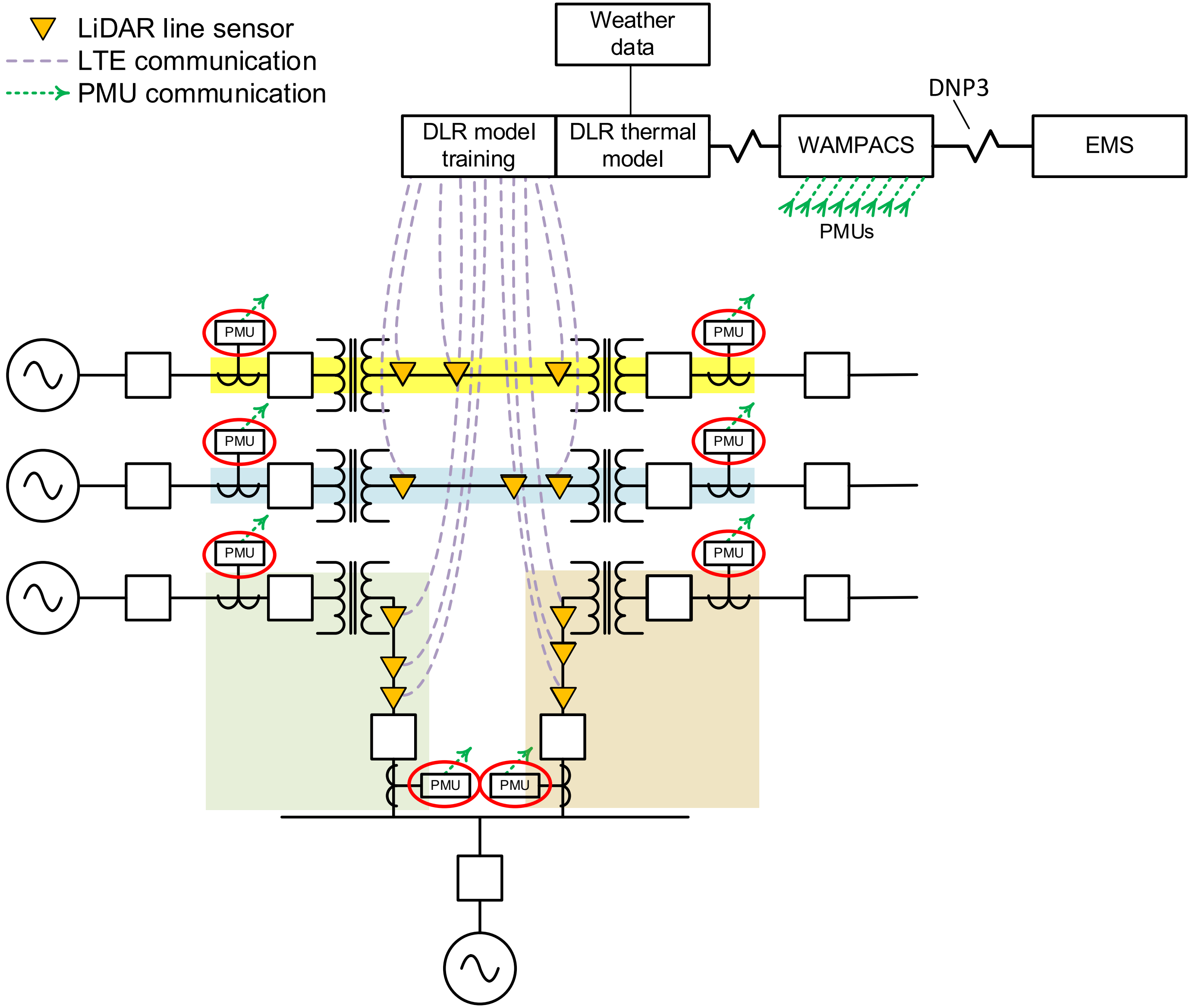
Shunt connected change voltages, V1 and V2	Series connected change impedance, jX
Static VAr compensators (SVCs)	Fixed, series-compensation capacitors
Synchronous condensers SSCs	Static synchronous series compensators (SSSC)
Static synchronous compensator (STATCOM)	
Shunt capacitors	
Load-tap-changing transformers	
Phase-shifting transformers change phase angle, δ	

Stability control over time

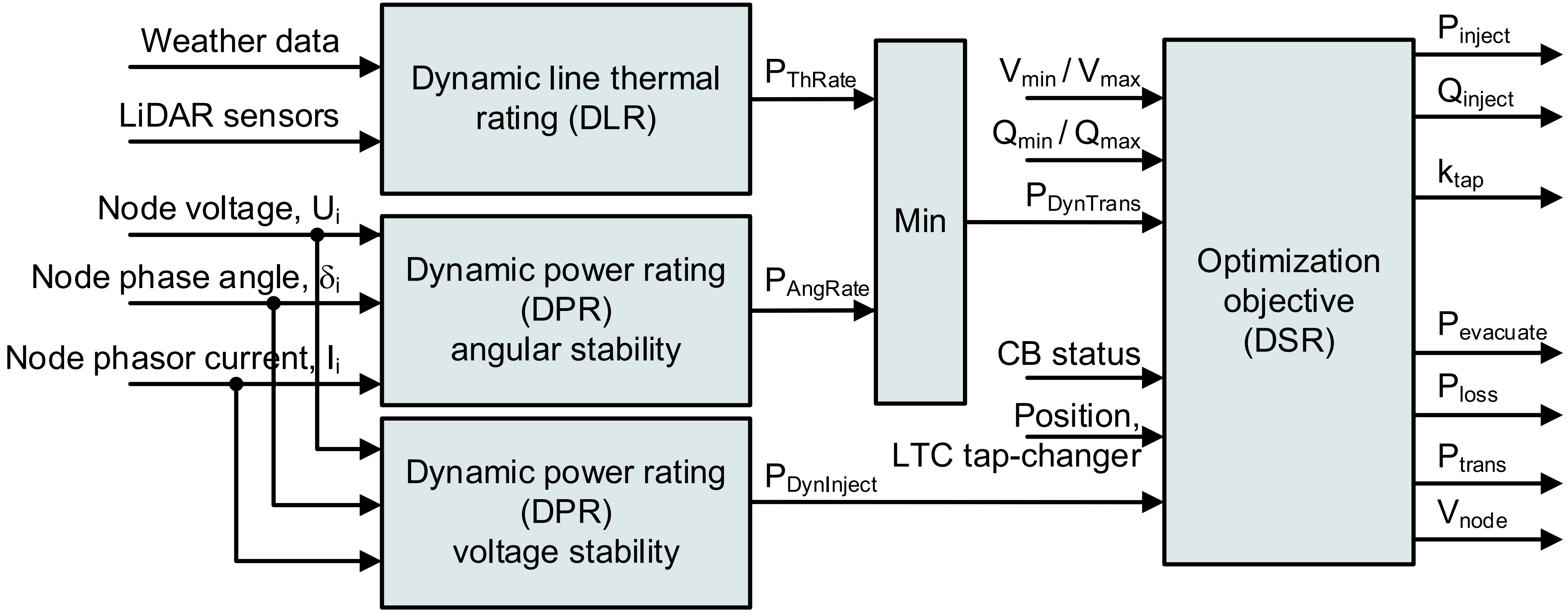


C. W. Taylor, "Power System Voltage Stability," McGraw-Hill, 1994

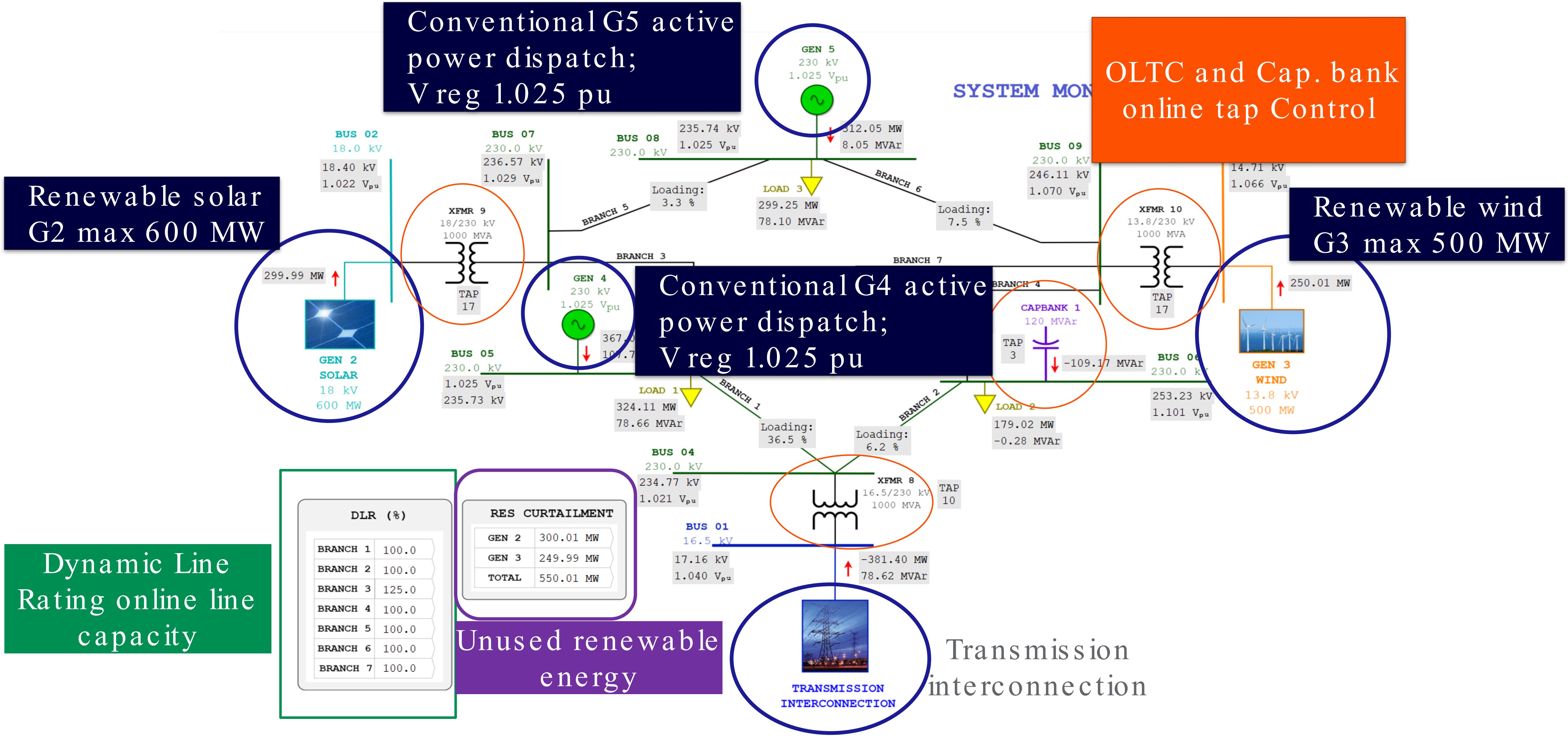
Implementing proactive DSR WAMPACS: increasing DLR



DSR I/O and calculations



Dynamic System Rating simulation use case



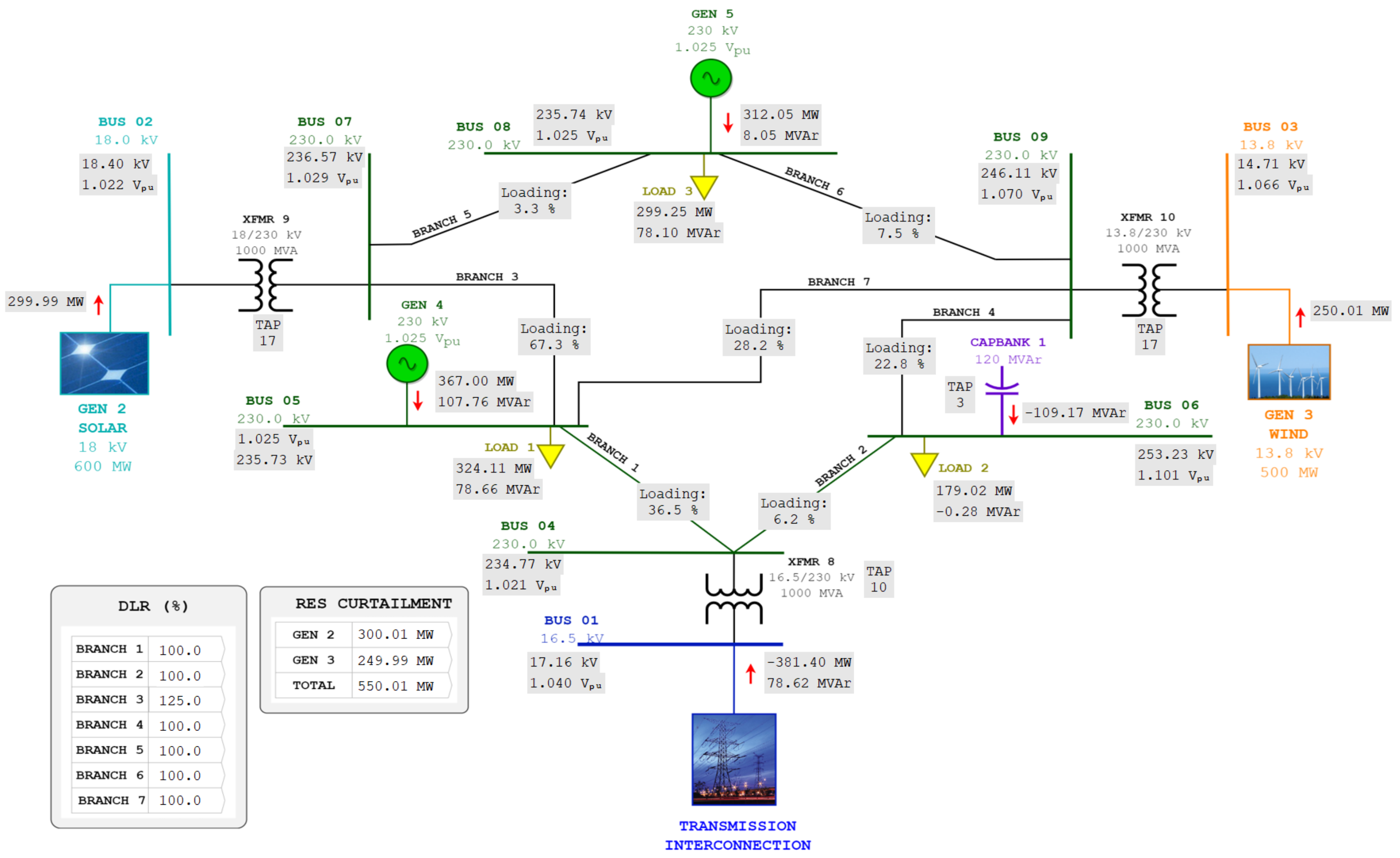
DLR (%)	
BRANCH 1	100.0
BRANCH 2	100.0
BRANCH 3	125.0
BRANCH 4	100.0
BRANCH 5	100.0
BRANCH 6	100.0
BRANCH 7	100.0

RES CURTAILMENT	
GEN 2	300.01 MW
GEN 3	249.99 MW
TOTAL	550.01 MW

Without DSR (base case)

System initial conditions

- Renewables at 50%
- Cap bank at Tap 0
- Xfmr OLTCs at centers
- Branch 3 loading at 67%



DLR (%)

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RES CURTAILMENT

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GEN 3	249.99 MW
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Maximizing renewables with DPR power evacuation

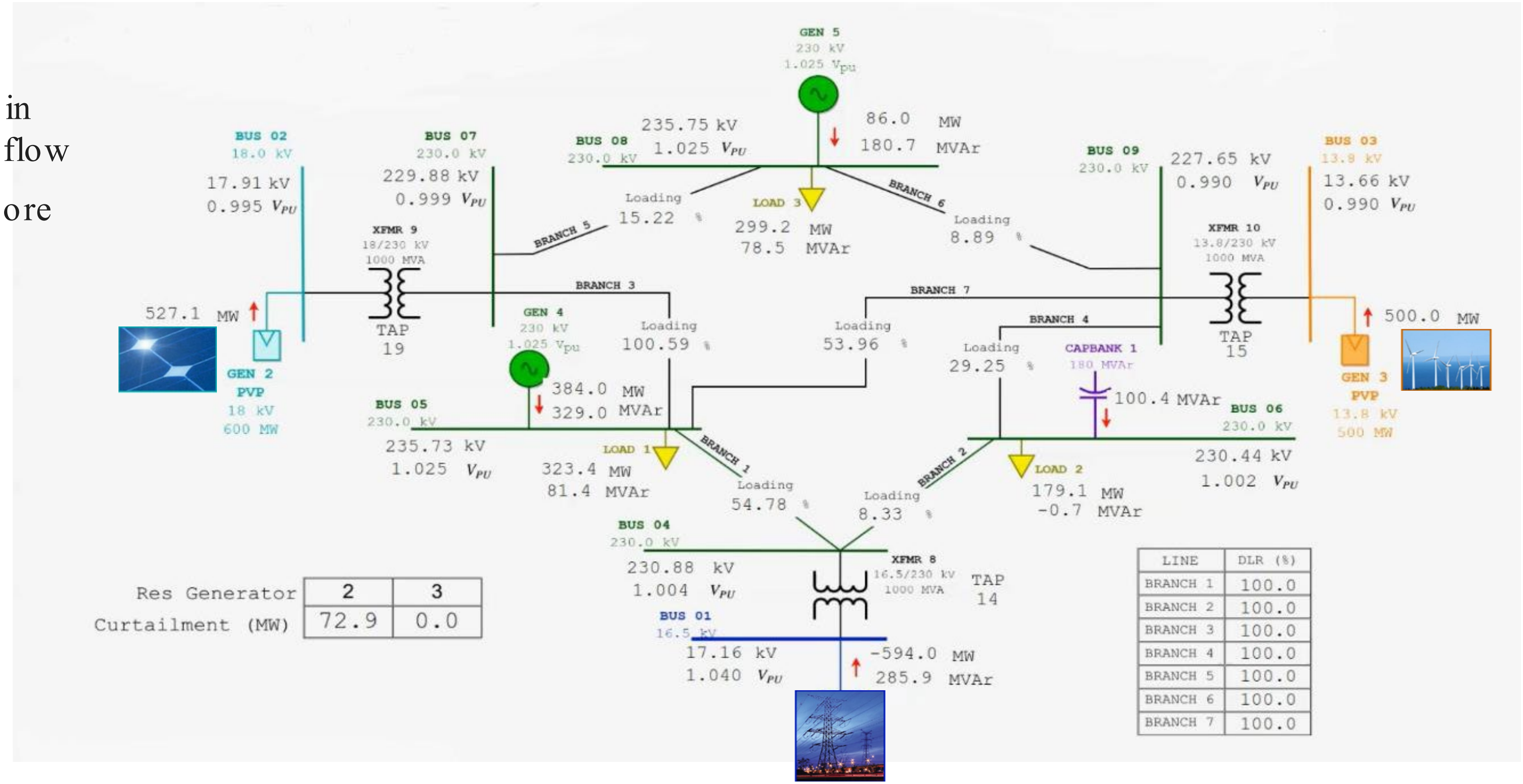
Use controllable elements in local zone to adapt power flow

Gen 2 injecting 230 MW more

Gen 3 increased to full capacity

Taps optimized

Branch 3 loading at 100% (static rating)



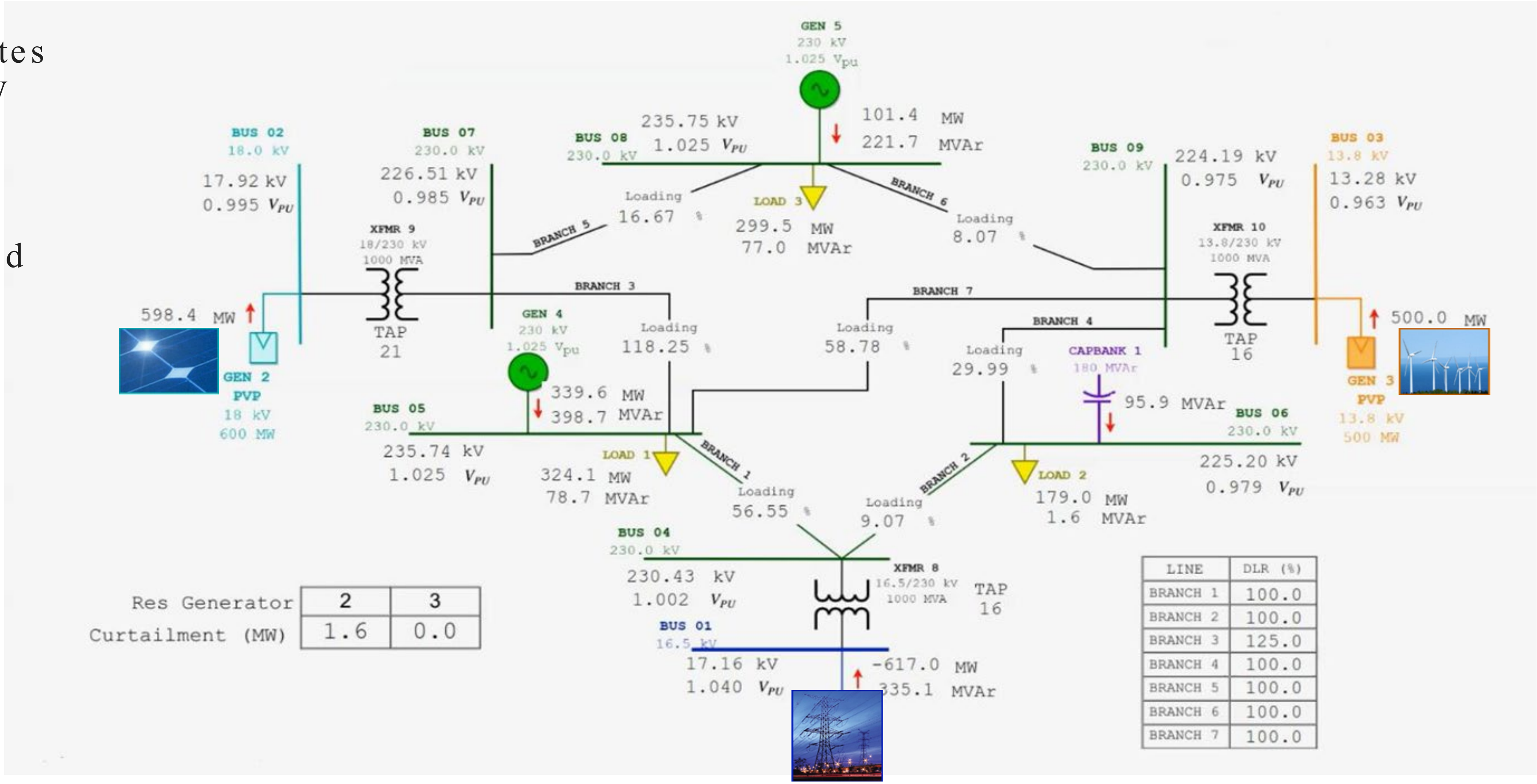
DSR fully optimized; DPR plus DLR

Dynamic Line Rating updates Branch 3 rating to 125 MW

WAMPACS algorithms recalculate system ratings

Gen 2 and Gen 3 increased to full capacity; minimal curtailment

Branch 3 at 118% loading (within dynamic line rating limit)



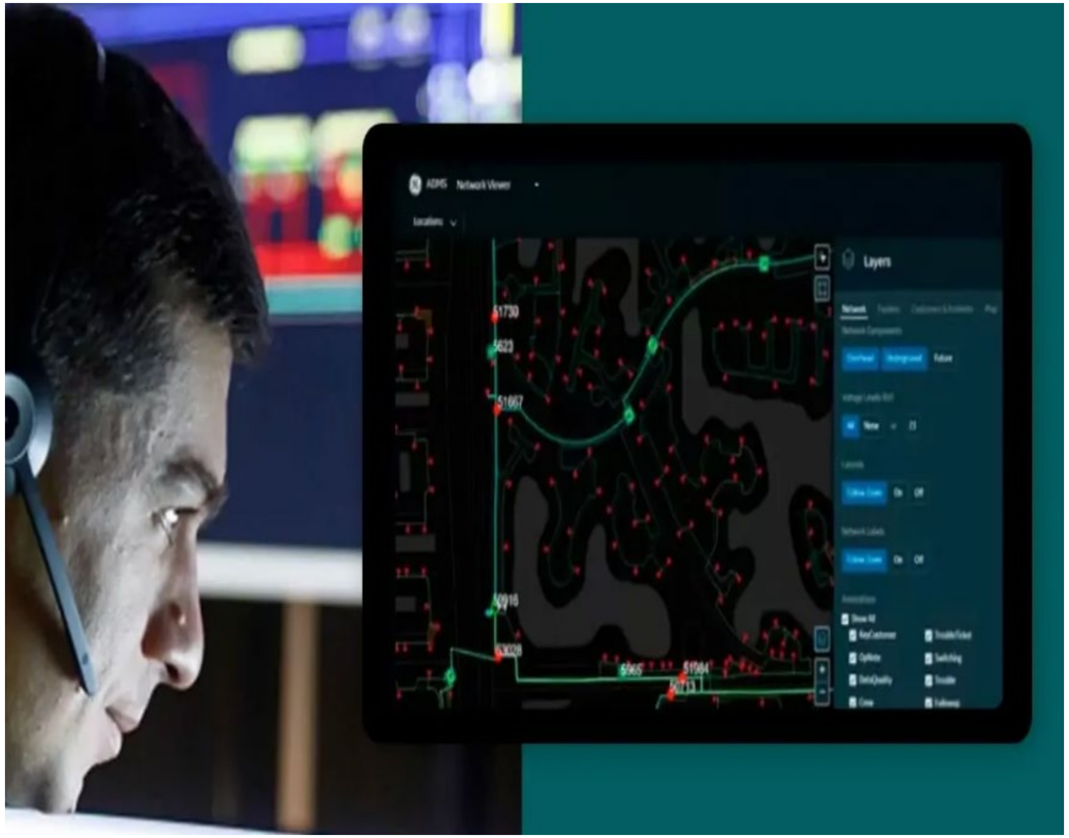
What DSR provides to operators and to EMS

Information

- Power-transfer limits per line in a power corridor
- DLR (thermal) and DPR (angular and voltage stability) for each line
- Worst-constraint limit (overall dynamic system limit)

Actions

- Operator suggestions for control of power-flow elements to optimize energy transfer, changing operating schedule (redispatch)
- Commands for operator confirmation (e.g., L1 West Terminal: raise LTC two taps)
- Direct control of power-flow elements where fast response is needed (e.g., "Bus 3: SVC to 3 MVAr")



Benefits of DSR

Enables more power transfer across a line

Fosters use of the least-cost marginal power from renewable sources

Accelerates interconnection of renewable assets

Reduces congestion and curtailment

Enhances grid resilience

Increases situational awareness

Supports asset health insight

Conclusions

Traditional methods used static ratings and state estimation

Now, proactive WAMPACS employs dynamic system rating (DSR)

DSR combines dynamic power rating (DPR) voltage / angle calculations to supplement thermal dynamic line rating (DLR)

Real-time calculation and contingency analysis redirects and redispatches power flow

Maximum safe power flow occurs on lines and load buses in PMU monitored area

DSR relieves grid congestion and curtailment

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