Fundamentals of Transmission Operations

Operational Parameters/Limits and Reactive Resources

PJM State & Member Training Dept.

Objectives

At the end of this course the student will be able to:

- Define the purpose of thermal, voltage & stability
- Define the purpose of SOLs
- Define the purpose of IROLs
- Define PJM's thermal operating criteria
- State the consequences of violating thermal limits
- State the actions to take to control violations of thermal limits
- Describe how IROLs are determined and monitored in PJM
- Identify the IROLs in the PJM footprint

Objectives

- Define PJM's voltage operating criteria
- State the consequences of violating voltage limits
- State the actions to take to control violations of voltage limits
- Identify PJM's voltage schedule guidelines
- Describe the effects of capacitors & reactors on voltage levels on the BES
- Identify which reactive resources can be switched without instruction from PJM
- Describe the effects of LTCs & PARs adjustments on the voltage profile of the BES

Objectives

- Identify the requirements to submit eDART data for outages of reactive resources
- Verify actions to be taken if reactive capability curve data needs to be updated
- Describe the purpose and process of the Reactive testing program and identify the reporting requirements for test data
- Identify the twice yearly requirements to verify reactive capability curve data in your EMS

Agenda

- Purpose of limits
- PJM Thermal Operating Critieria
- IROLs in PJM
- Post Contingency Local Load Relief Warning (PCLLRW)
- Post Contingency Congestion Management Program
- Transmission Loading Relief (TLR)

Agenda

- Constraint Management Mitigation Program
- Voltage Operating Criteria
- Voltage Control with Generators
- Caps and Reactors
- Transformer Load Tap Changer Operations
- Generator Reactive Testing
- Reactive Capability Changes and Reporting

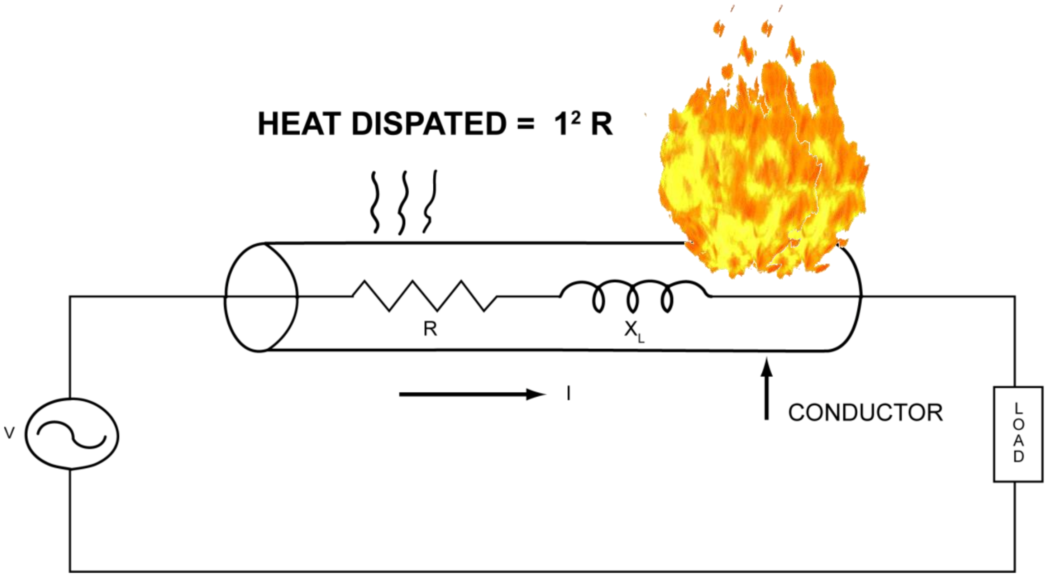
Purpose of Limits

Definitions

- Thermal Limit/Rating
  - A boundary on the current carrying capability of equipment to prevent operation at excessive temperatures
    - A thermal restriction is placed on every piece of equipment that carries current
  - Most commonly stated in MVA but also could be in Amps
  - Varies with
    - Temperature (8 temperature sets)
    - Wind speed (Ratings calculated at fixed wind speed)
    - Daylight intensity (Day vs Night ratings)
    - Equipment (Various limitations on equipment)
    - Time of applied current
      (Normal, Long/Short-Term Emergency, Load Dump)

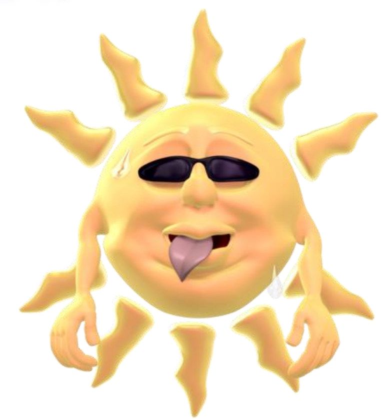
Determination of Thermal Limits/Ratings

- Current - Carrying Capability
  - Depends on ability to dissipate heat
  - Current flowing through conductor heats it up
  - Heat is dissipated through I^2R losses in the conductor

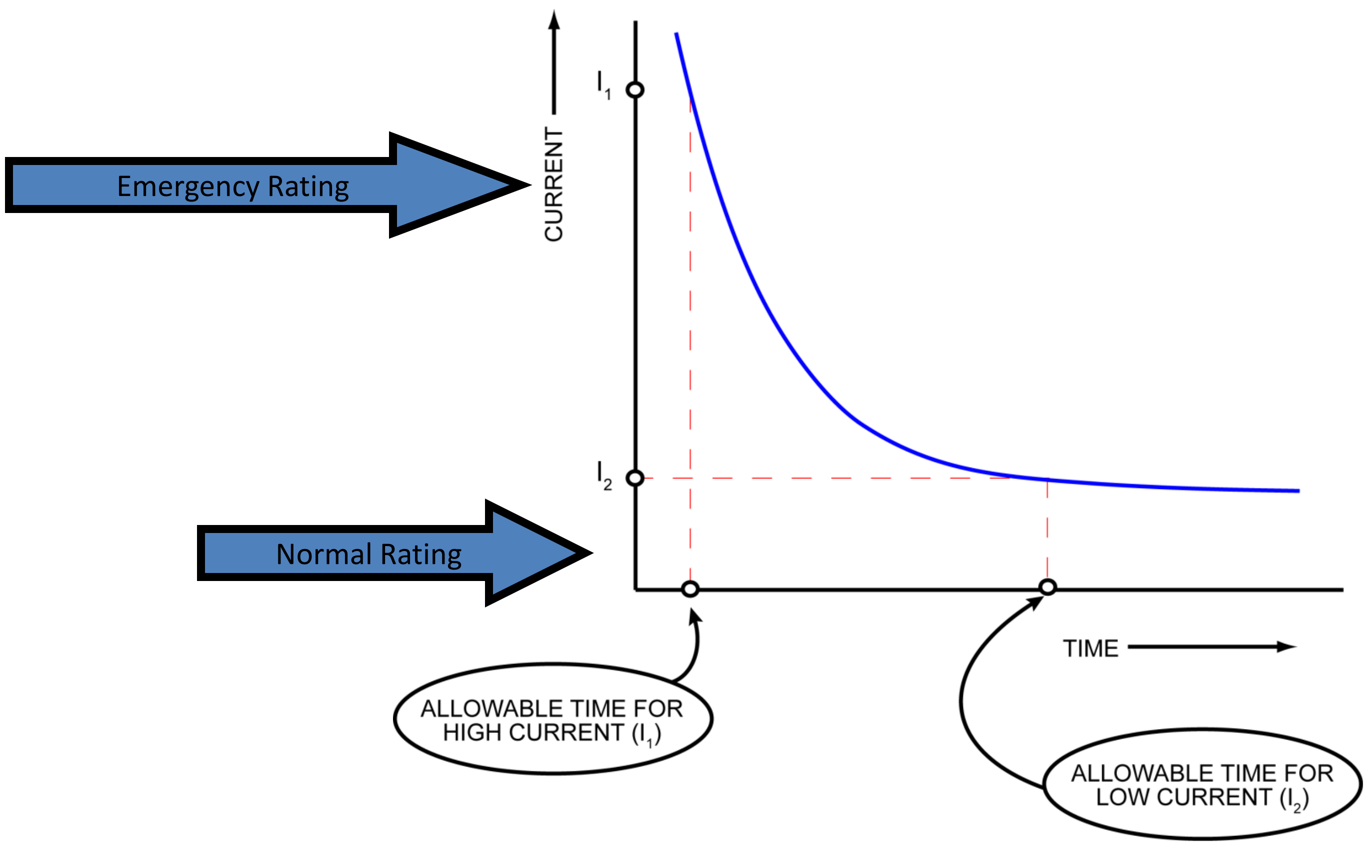


Determination of Thermal Limits/Ratings

- Factors Effecting Ratings
  - Season/Ambient Temperature
    - How fast can heat from the device be transferred to the air
    - As ambient temperature decreases, heat transfer increases
    - As ambient temperature increases, heat transfer decreases
    - PJM has 8“Ambient-adjusted” Rating sets
  - Time
    - As the current increases, it takes less time to incur damage to equipment
    - PJM uses Normal, Long/Short-Term Emergency, Load Dump Rating sets



Determination of Thermal Limits/Ratings



Rating Sets Definition

- All equipment ratings are provided by the owner of the equipment but are based on PJM's rating methodology
  - Normal (Continuous) Rating
    - Equipment can operate at this level for any length of time without incurring damage
  - Emergency Rating (Long-Term – LTE or Short-Term - STE)
    - Used to trigger contingency operation
    - Equipment can be damaged if rating exceeded in real-time
  - Load Dump Rating
    - Aids system operator in identifying speed to correct overload
    - Operation at Load Dump Rating for 15 minutes should not cause line to trip
    - Shed load to return actual flow under Load Dump Rating within 5 minutes

Thermal Limits

Temperature	Normal Limit	Long-Term Emergency Limit	Short-Term Emergency Limit	Load Dump Limit
95°	2650	3015	3015	3467
86°	2725	3090	3090	3554
77°	2780	3145	3145	3617
68°	2830	3195	3195	3674
59°	2849	3250	3250	3738
50°	2855	3300	3300	3795
41°	2855	3350	3350	3853
32°	2855	3405	3405	3916

- LTE and STE limit are identical in most cases
- Many equipment limitations possible: conductor, CB, CT, Meter, Relay, Clearance, Transformer, Wave Trap, Other

Equipment Ratings – Dynamic vs Static

- As previously stated, the rating for a piece of equipment is determined by how effectively the equipment can dissipate the heat generated within it by the flow of power
- Wind, rain/snow, or significant shade effects may allow equipment to exceed its default rating set for a given temperature, because it dissipate more heat
- By using Dynamic ratings, we can make adjustments to the default ratings set to allow for higher flow on a facility when conditions permit

Equipment Ratings – Dynamic vs Static

- Additional equipment needs to be installed in the field to allow real-time monitoring of the specific conditions occurring on the facility with the dynamic ratings, and send those readings back to the company (and PJM) EMS to determine the adjusted ratings to be used
- PJM has used Dynamic ratings at selected facilities in the PS area for several years to help reduce congestion costs

Equipment Ratings – Variations across the footprint

- PJM uses the actual temperatures in each zone to determine that zone's rating set
- Some zones (i.e. – AEP) have multiple sub-zones because of their size. If conditions are such that variations in temperatures are severe across the sub-zones, different rating sets can be used
  - If a line of thunderstorms is crossing the footprint in the summer, it may be cooler behind the storm system. The western sub-zone of AEP may be 10 degrees or more cooler than the eastern sub-zones

Equipment Ratings – Variations across the footprint

Mid-Atlantic

Zone	Reference City
PS	Newark, NJ
PE	Philadelphia PA
PL	Allentown, PA
JC	Morristown, MJ
ME	Reading, PA
PN	Erie, PA
PN	Johnstown, PA

Mid-Atlantic/Southern

Zone	Reference City
AE	Atlantic City, NJ
DPL	Dover, DE
BC	Baltimore, MD
PEP	Washington, DC
DOM	Richmond VA
DOM	Mount Storm, WV

APS/ATSI/DUQ

Zone	Reference City
APSNE	State College, PA
APSNW	Wheeling, WV
APSSE	Cumberland, MD
APSSW	Morgantown, WV
FETOL	Toledo, OH
FESPR	Springfield, OH
FEAKR	Akron, OH
DUQ	Pittsburgh, PA

AEP/COMED/DAY/DEOK

Zone	Reference City
AEPAB	Abingdon VA
AEPCH	Charleston, WV
AEPCL	Columbus, OH
AEPFW	Fort Wayne, IN
AEPRN	Roanoke, VA
COMED	Chicago, IL
OVEC	Piketon, OH
DAY	Dayton, OH
DEOK	Cincinnati, OH

Distribution Factors

Introduction to Distribution Factors

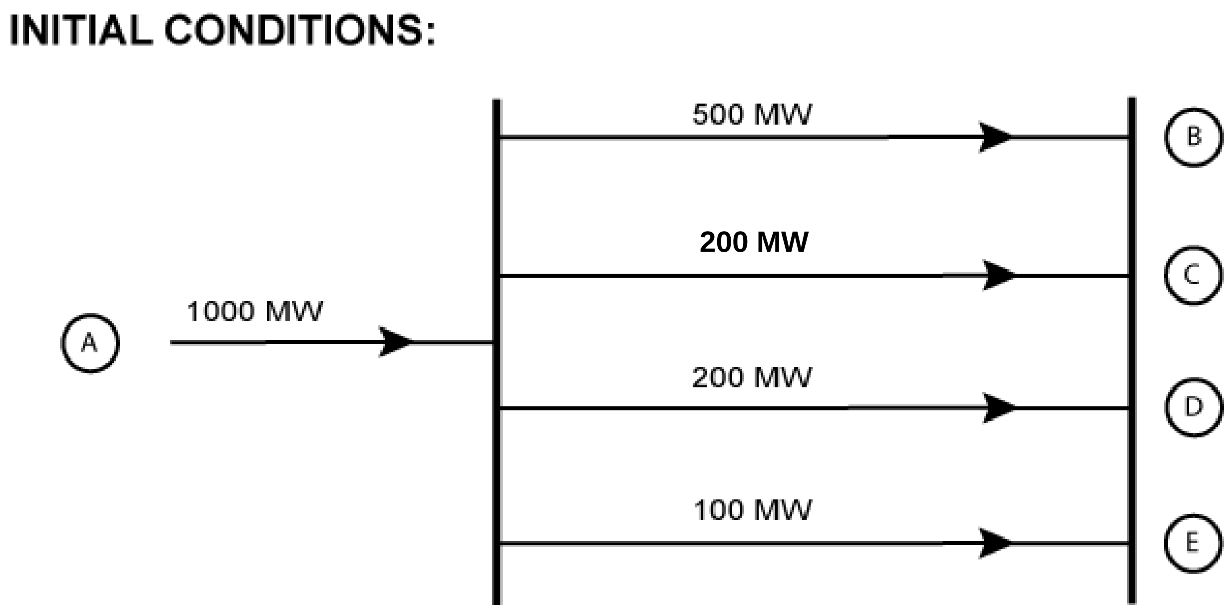
- Definition
  - The percentage of flow currently on a line that will transfer to another line as a result of the loss of the first line
- Characteristics of Distribution Factors
  - Determined by line impedances
  - Computer generated
  - Expressed as a decimal number of 1.0 or less
  - Distribution factor for a line for the loss of itself is -1.0 if line flow is positive

Introduction to Distribution Factors

- Characteristics of Distribution Factors (continued)
  - Can be a positive or negative factor
  - Sum of all distribution factors in a closed system is zero

- Formula:
  - New flow on line = Previous flow + [(Dfax) (Flow on outaged facility)]

Example Simple Calculations

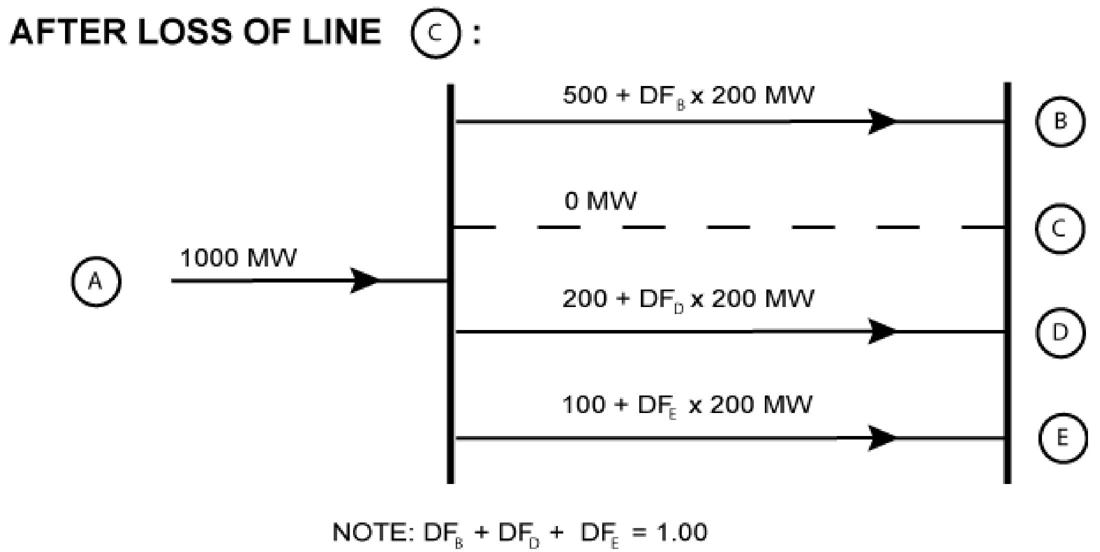


For the loss of line C:

$Dfax_b = 0.5$ $Dfax_c = -1.0$

$Dfax_d = 0.3$ $Dfax_e = 0.2$

Example Simple Calculations



Line B
- = 500 MW+ (0.5)(200 MW)
- = 500 MW + 100 MW = 600 MW

Line C
- = 200 MW + (-1.0)(200 MW)
- = 200 MW – 200 MW = 0 MW

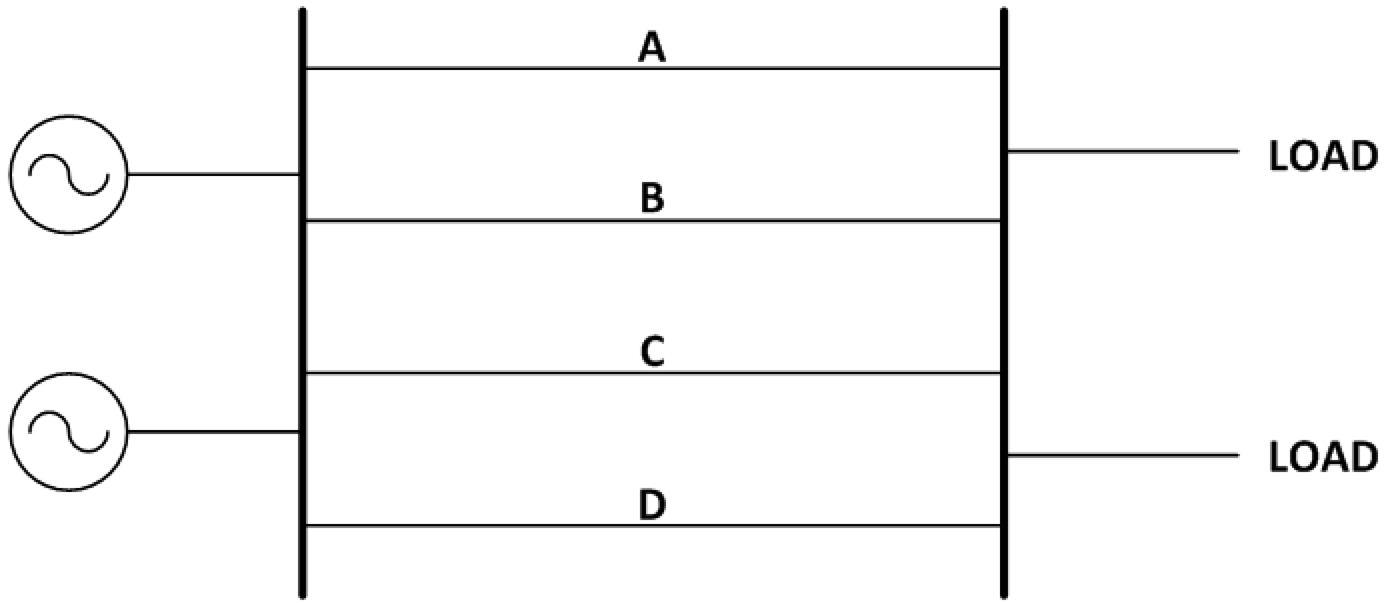
Line D
- = 200 MW + (0.3)(200 MW)
- = 200 MW + 60 MW = 260 MW

Line E
- = 100 MW + (0.2)(200 MW)
- =100 MW + 40 MW = 140 MW

Applications of Distribution Factors

- Line Outages
  - Use distribution factors to estimate how power will flow and predict any flow problems which may result from a line outage
    - Generally performed by computer tool
- Flow Analysis
  - Used to predict the results of losing a specific piece of equipment (Contingency analysis)

Distribution Factor Exercises



Distribution Factors for Loss Of:				
	Line A	Line B	Line C	Line D
On A	-1.0	0.5	0.3	0.3
On B	0.5	-1.0	0.3	0.3
On C	0.25	0.25	-1.0	0.4
On D	0.25	0.25	0.4	-1.0

Distribution Factor Exercises

1) Calculate the line flows for each line following the loss of line B, if the initial flows were:

Line A 400 MW	• = 400 MW+ (0.5)(400 MW) • = 400 MW + 200 MW = 600 MW
Line B 400 MW	• = 400 MW + (-1.0)(400 MW) • = 400 MW – 400 MW = 0 MW
Line C 300 MW	• = 300 MW + (0.25)(400 MW) • = 300 MW + 100 MW = 400 MW
Line D 300 MW	• = 300 MW + (0.24)(400 MW) • =300 MW + 100 MW = 400 MW

Distribution Factor Exercises

2) Calculate the line flows for each line following the loss of line D, if the initial flows were:

Line A 600 MW	• = 600 MW+ (0.3)(675 MW) • = 600 MW + 202.5 MW = 802.5 MW
Line B 500 MW	• = 500 MW + (0.3)(675 MW) • = 500 MW + 202.5 MW = 702.5 MW
Line C 450 MW	• = 450 MW + (0.4)(675 MW) • = 450 MW + 270 MW = 720 MW
Line D 675 MW	• = 675 MW + (-1.0)(675 MW) • = 675 MW - 675 MW = 0 MW

Generation Shift Factors

Generation Shift Factors

- Similar to Distribution Factors
  - Decimal Fraction
  - Used to analyze the effect of generation shifts on MW flow
  - Does <u>NOT</u> add up to 0
- Definition
  - Fraction of change in generation MW output that will appear on a line or facility
  - Used to predict the effect of generation changes on transmission line flow

Generation Shift Factors

- Formula

$$\boxed{\text{New flow on line} = \text{Previous flow} + [(\text{Gen Shift Factor})(\text{Amount of MW Shift})]}$$

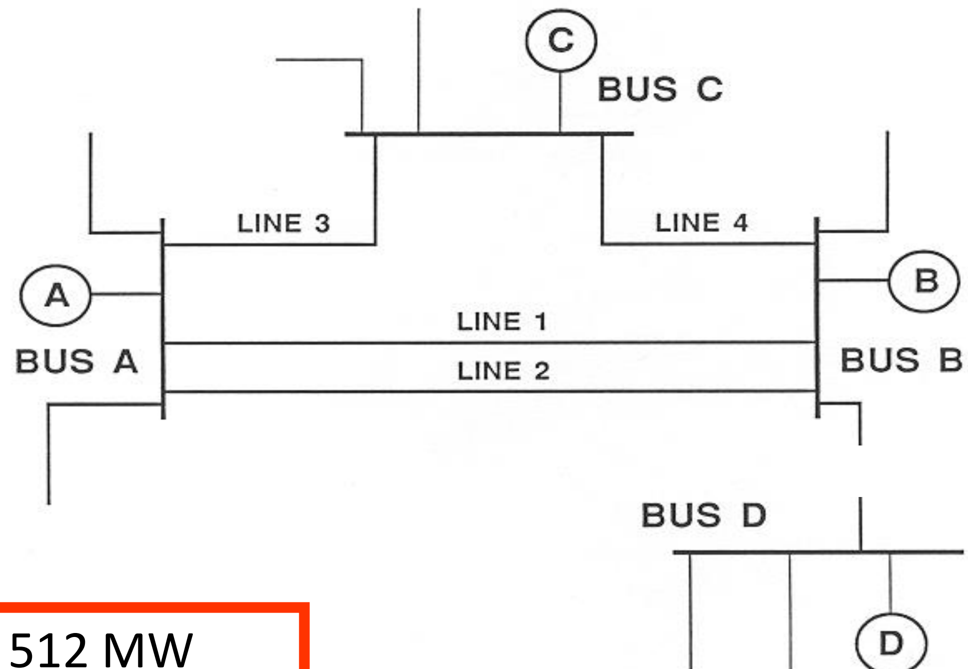
Generation Shift Factors

Line 3 = 500 MW

Increase Gen A by 100 MW.

What is resultant flow on Line 3?

New Flow = 500 MW + (.12)(+100MW) = 512 MW



	Line 1 (A-B)	Line 2 (A-B)	Line 3 (A-C)	Line 4 (C-B)	Line 5 (B-D)
Gen A	0.30	0.30	0.12	0.12	0.30
Gen B	- 0.20	- 0.20	- 0.06	- 0.06	0.40
Gen C	- 0.08	- 0.08	- 0.60	0.60	0.15
Gen D	- 0.12	- 0.12	- 0.03	- 0.03	- 0.50

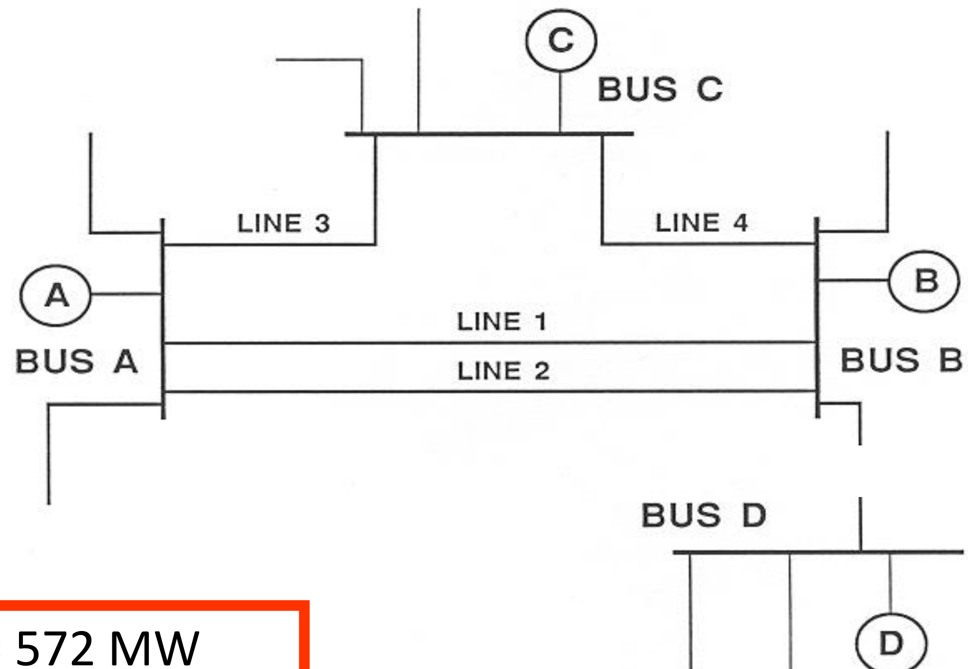
Generation Shift Factors

Line 3 = 512 MW

Now, Generator C is decreased by 100 MW

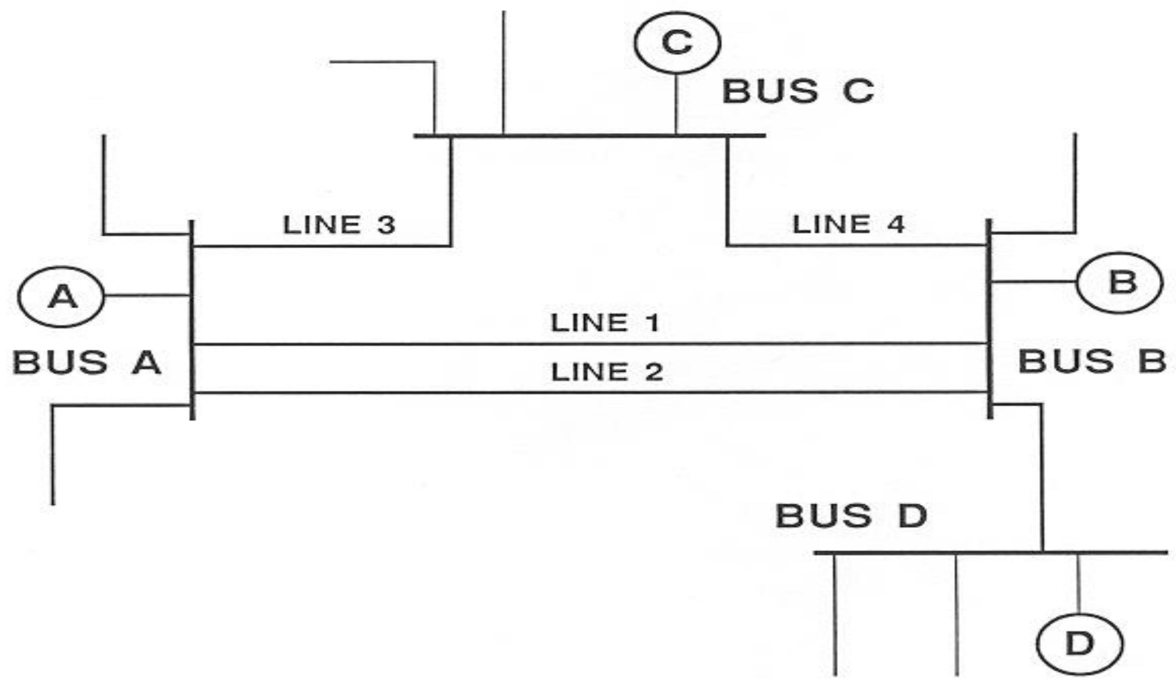
What is resultant flow on Line 3?

New Flow = 512 MW + (-0.6)(-100MW) = 572 MW



	Line 1 (A-B)	Line 2 (A-B)	Line 3 (A-C)	Line 4 (C-B)	Line 5 (B-D)
Gen A	0.30	0.30	0.12	0.12	0.30
Gen B	- 0.20	- 0.20	- 0.06	- 0.06	0.40
Gen C	- 0.08	- 0.08	- 0.60	0.60	0.15
Gen D	- 0.12	- 0.12	- 0.03	- 0.03	- 0.50

Generation Shift Factors



	Line 1 (A-B)	Line 2 (A-B)	Line 3 (A-C)	Line 4 (C-B)	Line 5 (B-D)
Gen A	0.30	0.30	0.12	0.12	0.30
Gen B	-0.20	-0.20	-0.06	-0.06	0.40
Gen C	-0.08	-0.-8	-0.60	0.60	0.15
Gen D	-0.12	-0.12	-0.03	-0.03	-0.50

Generation Shift Factors Exercises

	Line 1 (A-B)	Line 2 (A-B)	Line 3 (A-C)	Line 4 (C-B)	Line 5 (B-D)
Gen A	0.30	0.30	0.12	0.12	0.30
Gen B	-0.20	-0.20	-0.06	-0.06	0.40
Gen C	-0.08	-0.-8	-0.60	0.60	0.15
Gen D	-0.12	-0.12	-0.03	-0.03	-0.50

1) The flow on Line 1 (A-B) is 850 MW. Generator A output is increased by 100 MW. What is the new flow on Line 1 (A-B)?

New Line 1 Flow=

- 850 + (100)(0.30)=850+30=880 MW

2) Now Generator B decreases output by 100 MW. What is the new flow on Line 1 (A-B)?

New Line 1 Flow=

- 880 + (-100)(-0.20)=880+20=900 MW

Generation Shift Factors Exercises

	Line 1 (A-B)	Line 2 (A-B)	Line 3 (A-C)	Line 4 (C-B)	Line 5 (B-D)
Gen A	0.30	0.30	0.12	0.12	0.30
Gen B	-0.20	-0.20	-0.06	-0.06	0.40
Gen C	-0.08	-0.-8	-0.60	0.60	0.15
Gen D	-0.12	-0.12	-0.03	-0.03	-0.50

3) The flow on Line 1 (A-B) is 1100 MW. This flow must be reduced to 1000 MW to relieve an overload. You want to reduce the flow by reducing Generator A output and increasing Generator B output an equal amount. How much should the output on each unit be adjusted?
(Hint: Let the change on A be -X MW, and the change on B will be X MW)

Line 1 Flow

- 1000 MW = 1100 MW + [(-X)(0.3)+(X)(-0.2)]
- 1000 MW = 1100 MW + -0.3X + -0.2X
- 1000 MW = 1100 MW + -0.5X
- 1000 MW – 1100 MW = -0.5X
- -100 MW = -0.5X
- -100 MW/-0.5 = X = 200 MW
- Gen A reduce by 200 MW, Gen B increase by 200 MW

Generation Shift Factors Exercises

	Line 1 (A-B)	Line 2 (A-B)	Line 3 (A-C)	Line 4 (C-B)	Line 5 (B-D)
Gen A	0.30	0.30	0.12	0.12	0.30
Gen B	-0.20	-0.20	-0.06	-0.06	0.40
Gen C	-0.08	-0.-8	-0.60	0.60	0.15
Gen D	-0.12	-0.12	-0.03	-0.03	-0.50

4) The flow on Line 5 (B-D) is 1200 MW and the flow must be reduced to 1000 MW by shifting generation. Select two units to adjust output to eliminate the overload. How many MW does each unit have to change to reduce Line 5 (B-D) flow to 1000 MW?

Line 5 Flow

- 1000 MW = 1200 MW + [(-X)(0.4)+(X)(-0.5)]
- 1000 MW = 1200 MW + -0.4X + -0.5X
- 1000 MW = 1200 MW + -0.9X
- 1000 MW - 1200 MW = -0.9X
- -200 MW = -0.9X
- -200 MW/-0.9 = X = 222 MW
- Gen B reduce by 222 MW, Gen D increase by 222 MW

$/MW Effect

- Adjustment of Shift Factors due to Economics.
- Definition
  - $/MW Effect = (Current Dispatch Rate - Unit Bid) / Unit Generator Shift Factor
  - Unit with lowest $/MW effect is redispatched when system is constrained
  - Other unit operating constraints taken into account (I.e. min run time, time from bus, etc)
  - In an emergency, economics takes the “back seat” to reliability

Types of Limits

Types of Limits

- Thermal Limit/Rating
  - A boundary on the current carrying capability of equipment to prevent operation at <u>excessive temperatures</u>
    - A thermal restriction is placed on every piece of equipment that carries current
- Voltage limit
    - Maintain system reliability
      - High voltage limit protects equipment from damage
      - Low voltage limit protects system from voltage instability and equipment damage

Types of Limits

- Stability Limits
  - Stability is related to the angular separation between points in the power system
  - Typical angular separation of the voltages for a high voltage transmission is small, ranging from 5° to 15°
  - When a system is angle unstable, angle differences grow to larger values
    - For example, angle differences may exceed 90°. System operators lose control of both MW and MVAR flows in an angle unstable system

Types of Limits

- System Operating Limit (SOL)
  - The value (such as MW, MVAR, Amperes, Frequency or Volts) that satisfies the most limiting operating criteria for a specified system configuration to ensure operation within acceptable reliability criteria
  - Based upon certain operating criteria. These include, but are not limited to:
    - Facility Ratings
    - Transient Stability Ratings
    - Voltage Stability Ratings
    - System Voltage Limits

Types of Limits

- Interconnection Reliability Operating Limit (IROL)
  - A System Operating Limit that, if violated, could lead to instability, uncontrolled separation, or cascading outages that adversely impact the reliability of the Bulk Electric System

PJM Thermal Operating Criteria

PJM Thermal Operating Criteria

- Thermal Operating Criteria
  - Actual Flow less than Normal Rating
  - Contingency Flow less than Emergency Rating
  - Operators must be aware when line flows are approaching a limit on both an actual and contingency basis
    - Approaching a system limit
      - Analyze situation
      - Develop game plan
      - Implement plan

Purpose of Limits

- System Operating Limit in PJM
  - All BES facilities and those sub- BES facilities identified as “Reliability and Markets” facilities that are not considered IROL facilities are considered System Operating Limits (SOL)
    - An SOL violation is defined as a non-converged contingency or actual thermal overload violating a limit consistent with the facilities rating duration (i.e. normal limit = 24 hours, LTE limit = 4 hours)

Purpose of Limits

- Interconnection Reliability Operating Limit in PJM
  - PJM classifies a facility as an IROL facility on the PJM system if wide-area voltage violations occur at transfer levels that are near the Load Dump thermal limit
    - An IROL violation is defined as a either flows exceeding the last convergent case transfer limit for 30 minutes or post-contingency simulated flows exceeding the facility load dump limit for 30minutes

Purpose of Limits

- Interconnection Reliability Operating Limit Tv
  - The maximum time that an IROL can be violated before the risk to the Interconnection or other Reliability Coordinator Area (s) becomes greater than acceptable
  - Each IROLs Tv shall be less than or equal to 30 minutes
    - PJM uses 30 minutes as its Tv for all its IROLs

PJM Thermal Operating Criteria

- Thermal Operating Criteria
  - Control all constraints (actual and contingency) within 30 minutes 100% and within 15 minutes 80% of the time
  - At times, operator may be faced with multiple problems at the same time and have to prioritize the order in which to address them

PJM Thermal Operating Criteria

- Control Prioritization
  - First - Non-converged contingency
    - Could be worst problem (voltage collapse) or due to bad data
      - Operator needs to determine cause of non-convergence and take action if problem is real
  - Second – IROL violations
    - Contingency could result in a system collapse
    - Must be controlled within 30 minutes, 100% of time
      - If not, it must be reported to NERC

PJM Thermal Operating Criteria

- Control Prioritization
  - Third - Reactive Transfer Interfaces
    - These are all currently IROL facilities
  - Fourth - Actual Violations
    - Actual flows > Normal limit
    - Prioritize Actual violations based on amount that rating is exceeded and potential system impact
  - Fifth - Contingency Violations
    - Smaller chance of contingency actually occurring
    - If contingency occurs, it becomes actual

PJM Thermal Operating Criteria

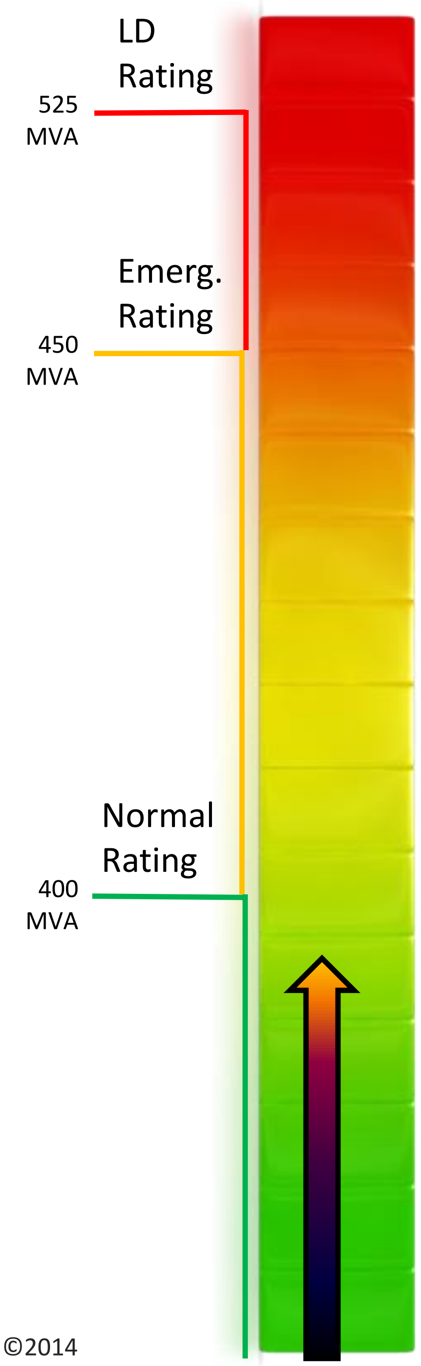
Legend
Non-Cost
Off-Cost
Load Shedding

Thermal Limit Exceeded	Corrective Actions	Time to correct with Load Shed (Note 1)
Normal Rating (Actual flow greater than Normal Rating but less than Emergency Rating)	Non-cost actions, off-cost actions, emergency procedures except load shed	Correct in 15 minutes, load shed is not used
Emergency Rating (Actual flow greater than Emergency Rating but less than Load Dump Rating)	All of the above plus shed load to control violation below Emergency Rating	Within 15 minutes of violation (Note #2)
Load Dump Rating (Actual flow greater than Load Dump Rating)	All of the above plus shed load to control violation below Emergency Rating	Within 5 minutes of violation

Exhibit 1: PJM Actual Overload Thermal Operating Policy

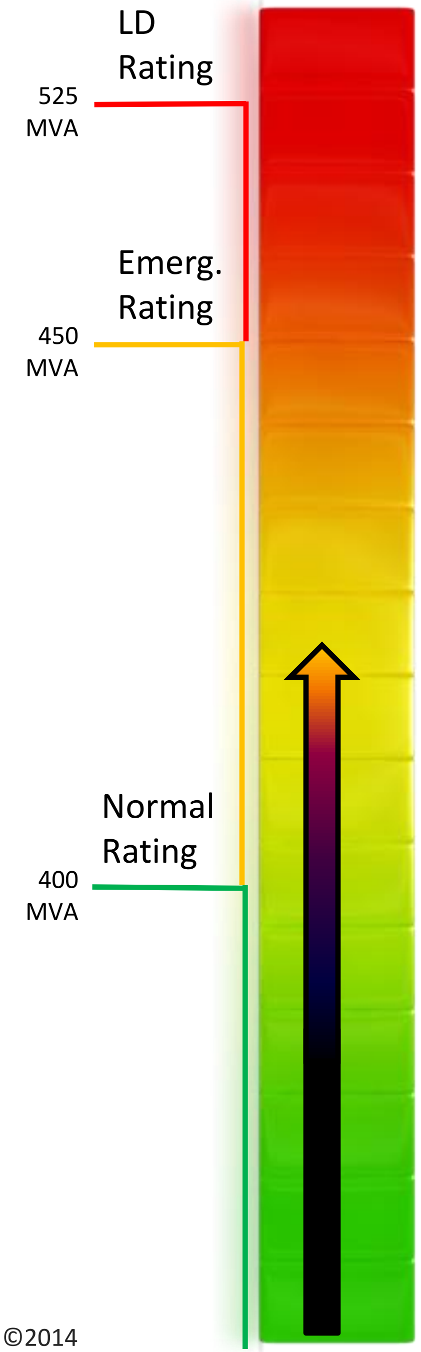
Note 1: TO must dump load without delay upon receipt of PJM Directive to dump load
Note 2: Tos have the option of providing STE limits that are least 30-minutes in duration. The STE rating allows the time before load shed to be extended provided the actual flow does not exceed the STE rating. If the actual flow is above the LTE but below STE, load must be shed within the times indicated in Attachment F for the facility, if other corrective actions were not successful

Example



If Actual Flow < Normal Rating:

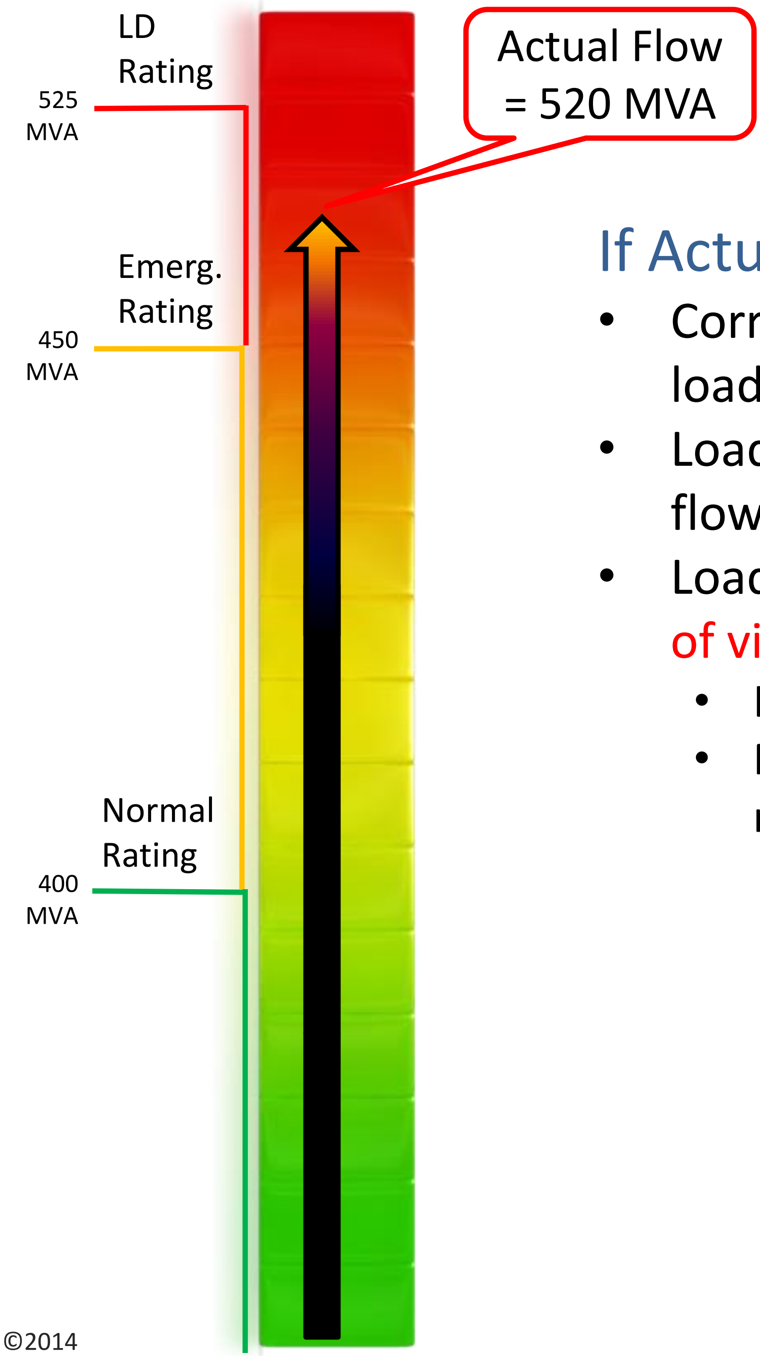
- No corrective actions are required
- No limits are violated



Example

If Actual Flow is < LTE but > Normal Rating:

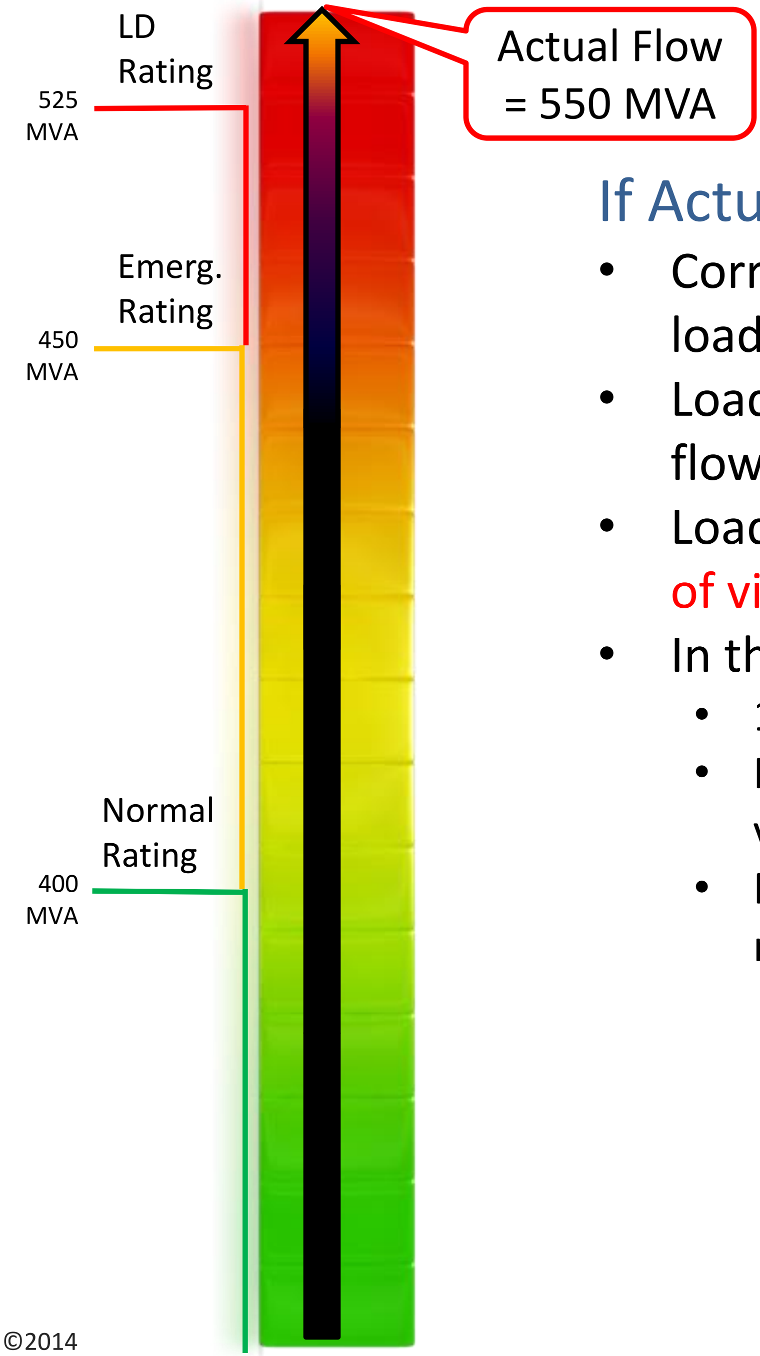
- Corrective Actions include non-cost and off-cost options
- No load shed would be performed
- Goal is to correct problem in 15 minutes
  - May not be possible since load shed is not a controlling action



Example

If Actual Flow is > LTE but < LD:

- Corrective Actions include non-cost, off-cost and load shed options
- Load shed would be performed to return Actual flow below LTE rating
- Load shed would be performed within 15 minutes of violation
  - In this example; 70 MVA of relief is needed
  - Must get Actual Flow under LTE rating within 15 minutes of violation
    - This may require more than 70 MVA of load shed based on distribution factor effect

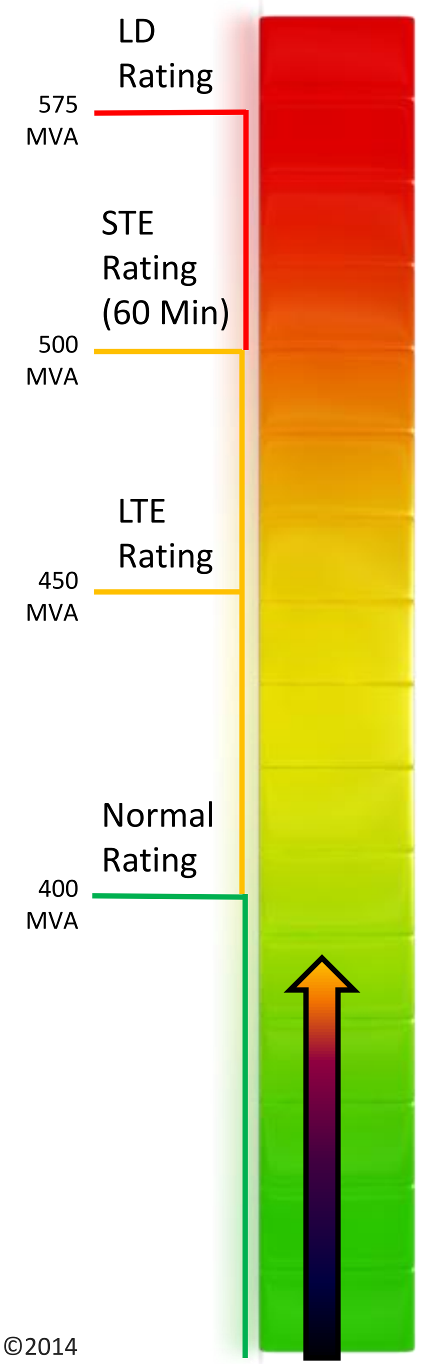


Example

If Actual Flow > LD:

- Corrective Actions include non-cost, off-cost and load shed options
- Load shed would be performed to return Actual flow below LTE rating
- Load shed would be performed within 5 minutes of violation
- In this example:
  - 100 MVA of relief is needed
  - Must get Actual Flow under LD within 5 minutes of violation
  - Must get Actual Flow under LTE within the remaining time
    - This may require more than 100 MVA of load shed based on distribution factor effect
    - If load that is shed in 5 minutes gets Actual Flow below LD rating, but it is still above Emerg., 10 minutes remain to get under the Emerg. within the 15 minute timeframe.
    - Times are not cumulative!

Normal, Long Term, Short Term and Load Dump Example

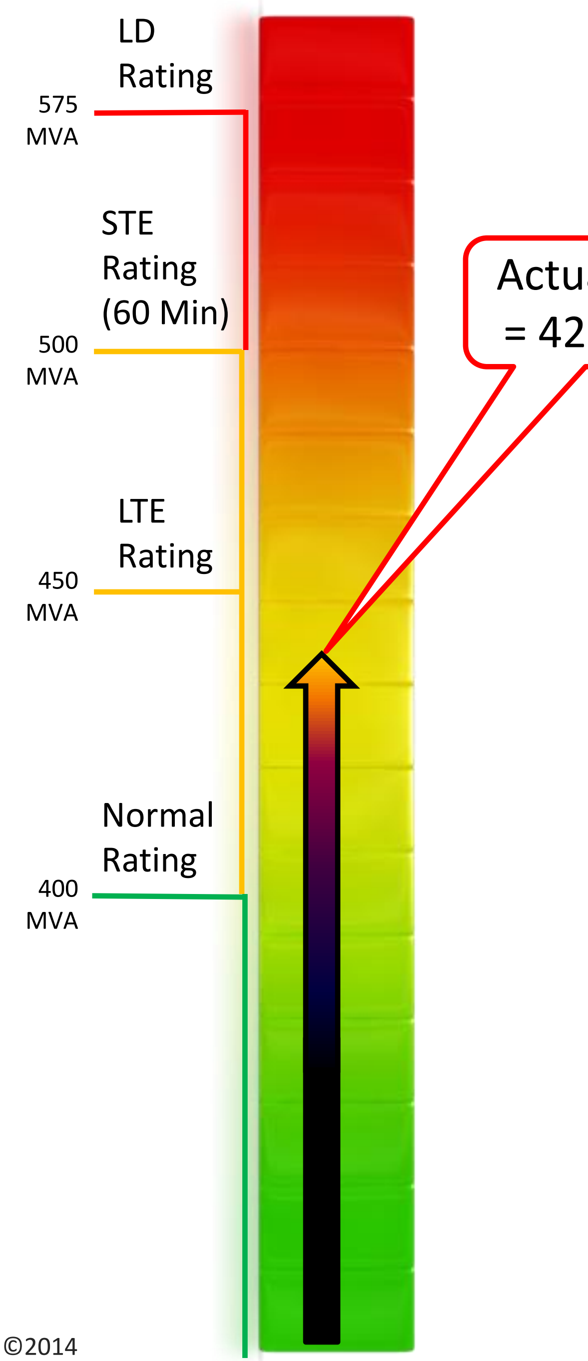


Example

If Actual Flow < Normal Rating:

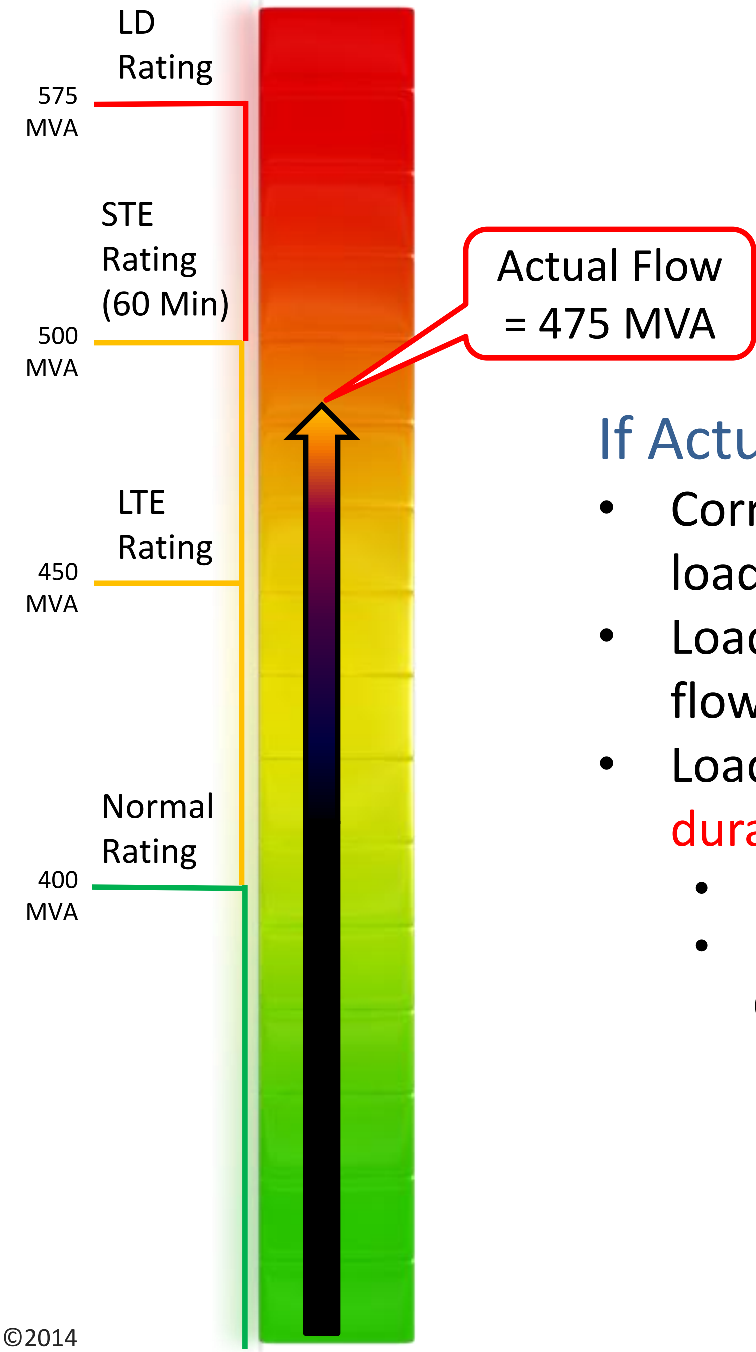
- No corrective actions are required
- No limits are violated

Example



If Actual Flow is < LTE but > Normal Rating:

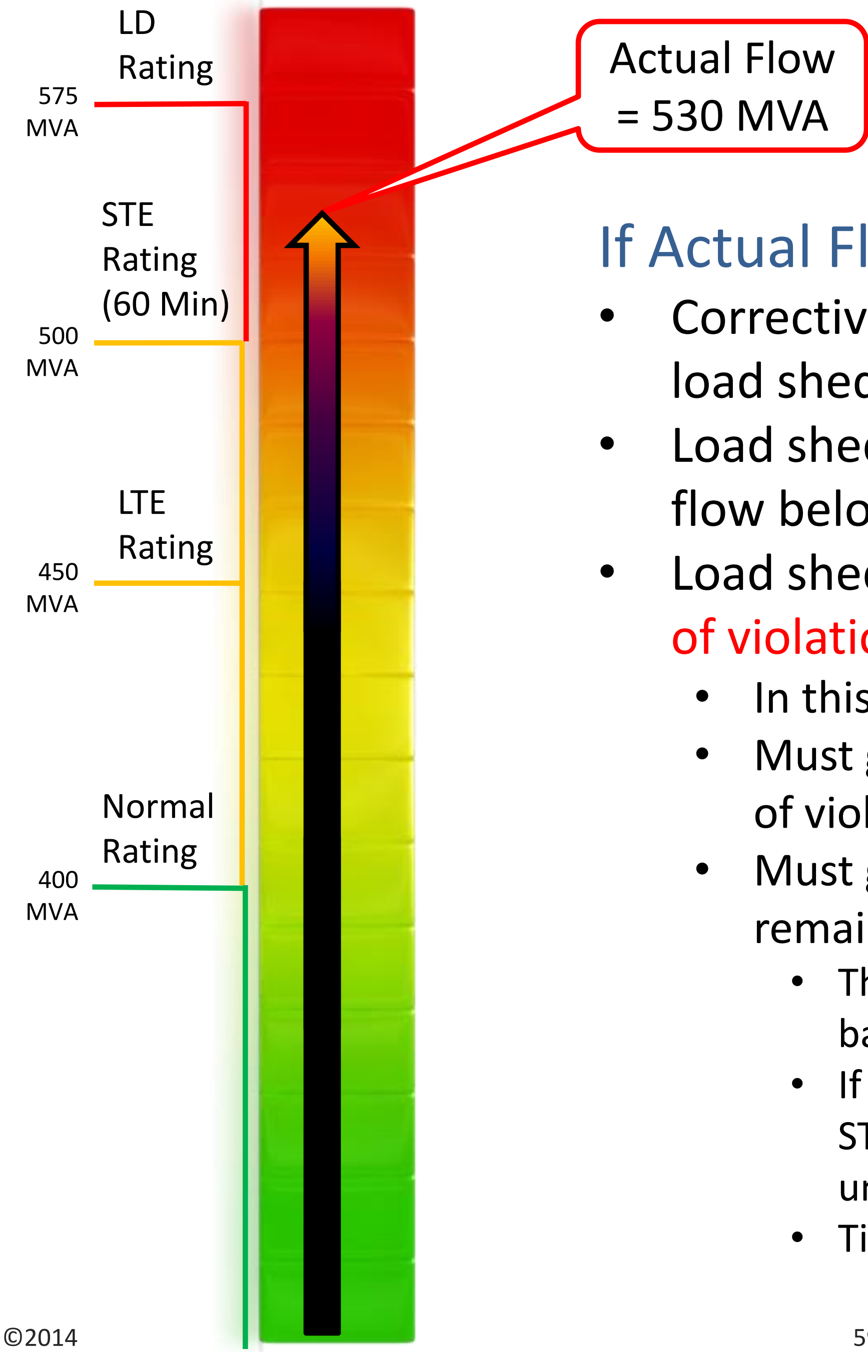
- Corrective Actions include non-cost and off-cost options
- No load shed would be performed
- Goal is to correct problem in 15 minutes
  - May not be possible since load shed is not a controlling action



Example

If Actual Flow is > LTE but < STE:

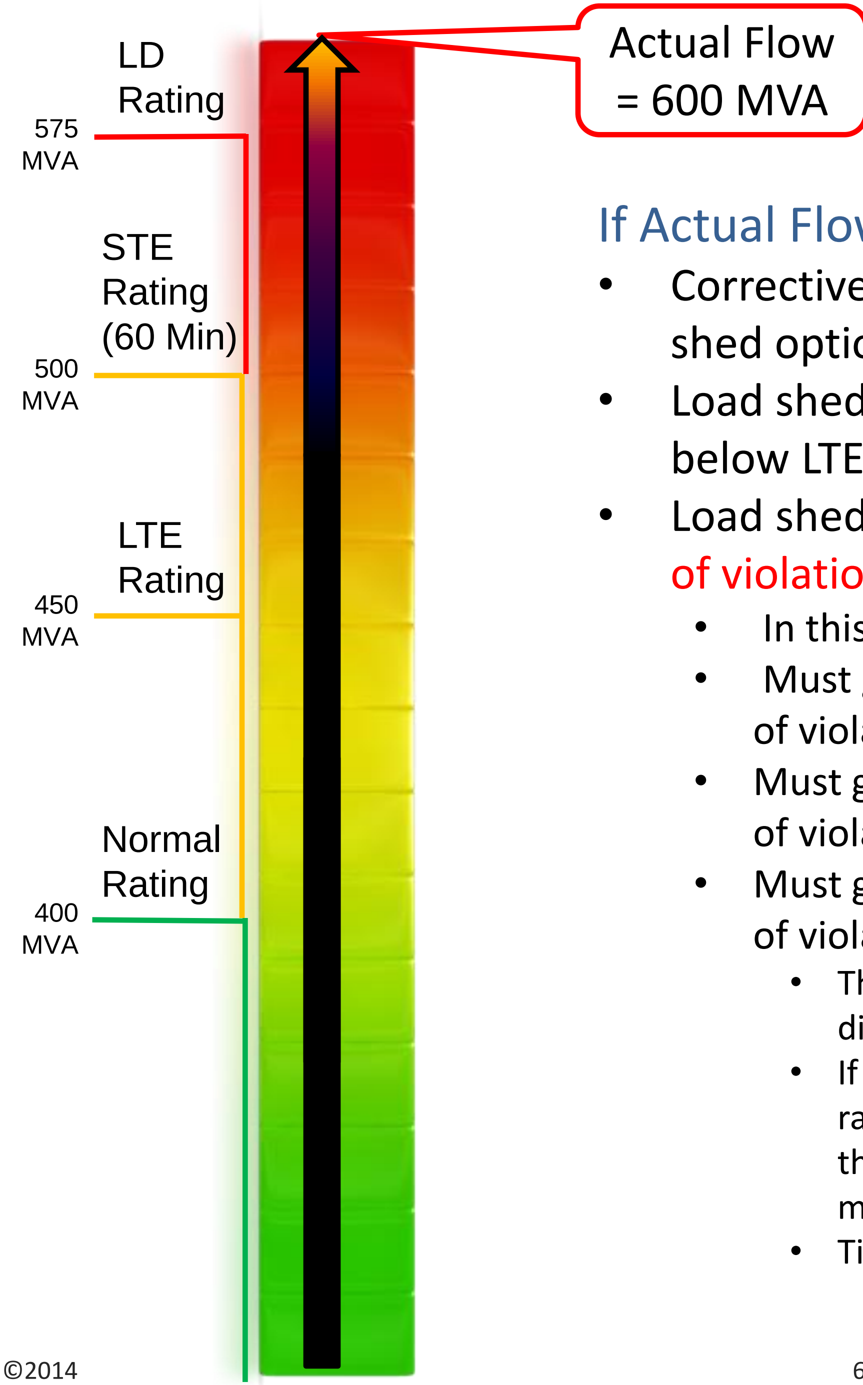
- Corrective Actions include non-cost, off-cost and load shed options
- Load shed would be performed to return Actual flow below LTE rating
- Load shed would be performed within the rating duration of the STE
  - In this example; within 60 minutes
  - In this example; 25 MVA of relief is needed within 60 minutes
    - This may require more than 25 MVA of load shed based on distribution factor effect



Example

If Actual Flow is > STE but < LD:

- Corrective Actions include non-cost, off-cost and load shed options
- Load shed would be performed to return Actual flow below LTE rating
- Load shed would be performed within 15 minutes of violation
  - In this example; 80 MVA of relief is needed
  - Must get Actual Flow under STE within 15 minutes of violation
  - Must get Actual Flow under LTE within the remaining time
    - This may require more than 80 MVA of load shed based on distribution factor effect
    - If load is shed in 15 minutes to get Actual Flow below STE, but is still above LTE, 45 minutes remain to get under the LTE within the 60 minute timeframe.
    - Times are not cumulative!



Example

If Actual Flow > LD:

- Corrective Actions include non-cost, off-cost and load shed options
- Load shed would be performed to return Actual flow below LTE rating
- Load shed would be performed within 5 minutes of violation
  - In this example; 150 MVA of relief is needed
  - Must get Actual Flow under LD within 5 minutes of violation
  - Must get Actual Flow under STE within 15 minutes of violation
  - Must get Actual Flow under LTE within 60 minutes of violation
    - This may require more than 150 MVA of load shed based on distribution factor effect
    - If load is shed in 5 minutes to get Actual Flow below LD rating, but is still above STE, 10 minutes remain to get under the STE within the 15 minute timeframe and the remaining minutes to get under the LTE rating
    - Times are not cumulative!

PJM Thermal Operating Criteria

Legend
Non-Cost
Off-Cost
Load Shedding

Thermal Limit Exceeded	If Post Contingency simulated loading exceeds limit	Time to correct
Normal	Trend – continue to monitor. Take non-cost actions to prevent contingency from exceeding emergency limit	N/A
Emergency	Use all effective actions and emergency procedures except load dump	30 minutes
Load Dump	All of the above however, shed load only if necessary to avoid post-contingency cascading	30 minutes

Exhibit 2: PJM Post-Contingency Simulated Thermal Operating Policy

Note : System readjustment should take place within 30 minutes. PCLLRW should be implemented as post-contingency violations approach 60 minutes in duration. However, PCLLRW can be issued sooner at the request of the Transmission Owner of if the PJM Dispatcher anticipates controlling actions cannot be realized within 60 minutes due to longer generator start-up + notification times

Consequences of Violating Thermal Limits

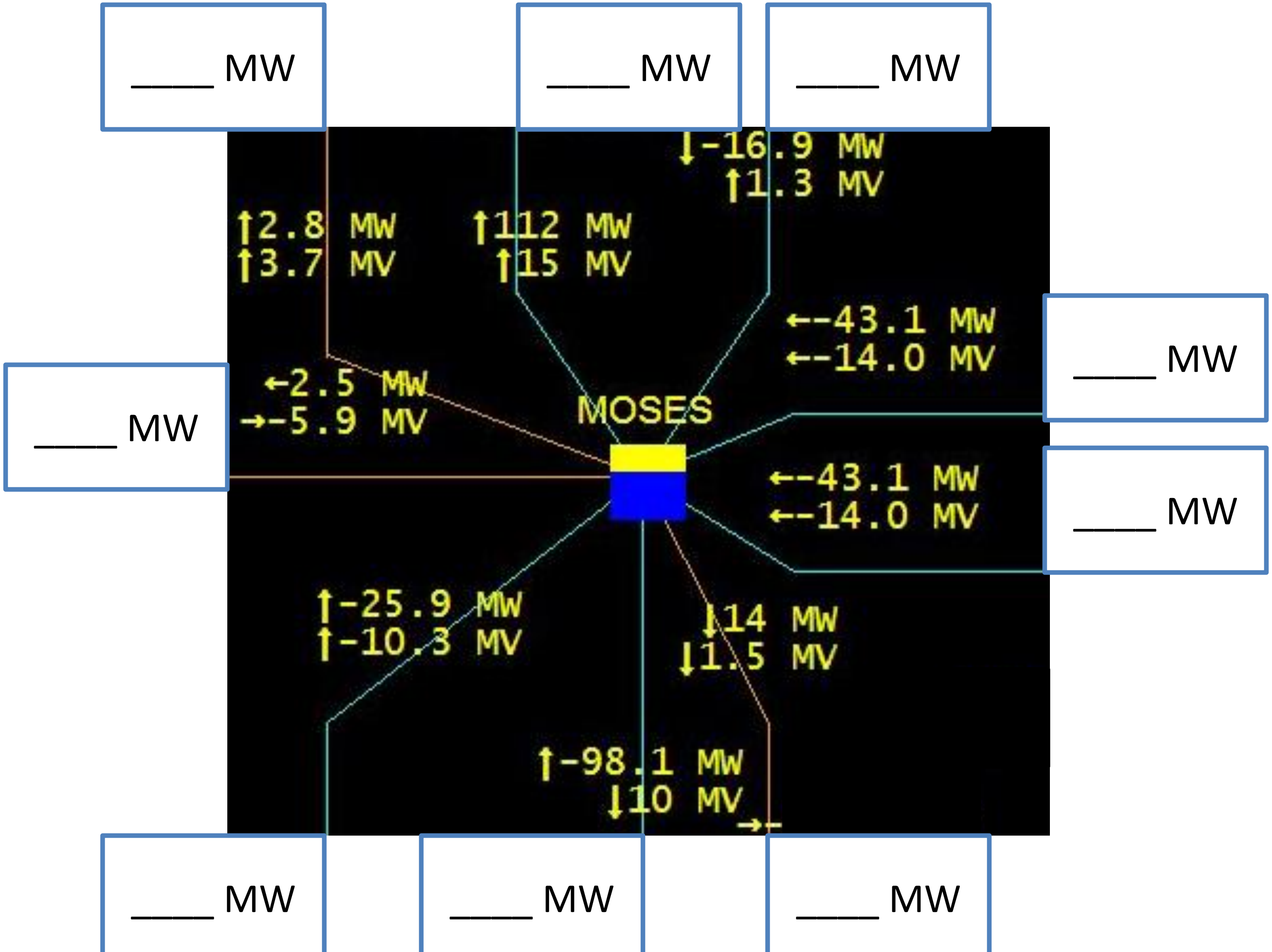
Consequences of Violating Thermal Limits

- Lines
  - Conductor Sag
  - Could lead to loss of the facility
  - Flows will be redistributed on other lines
    - <u>Rule of Thumb</u> - For the loss of a line flowing towards station, the other lines flowing toward station will increase while the lines flowing out of station will decrease
    - <u>Rule of Thumb</u> - For the loss of a line flowing out of a station, the other lines flowing out of station will increase while the lines flowing toward a station will decrease
  - Increased flows could lead to more overloads and if severe enough, possible cascading trips, system separation and blackout

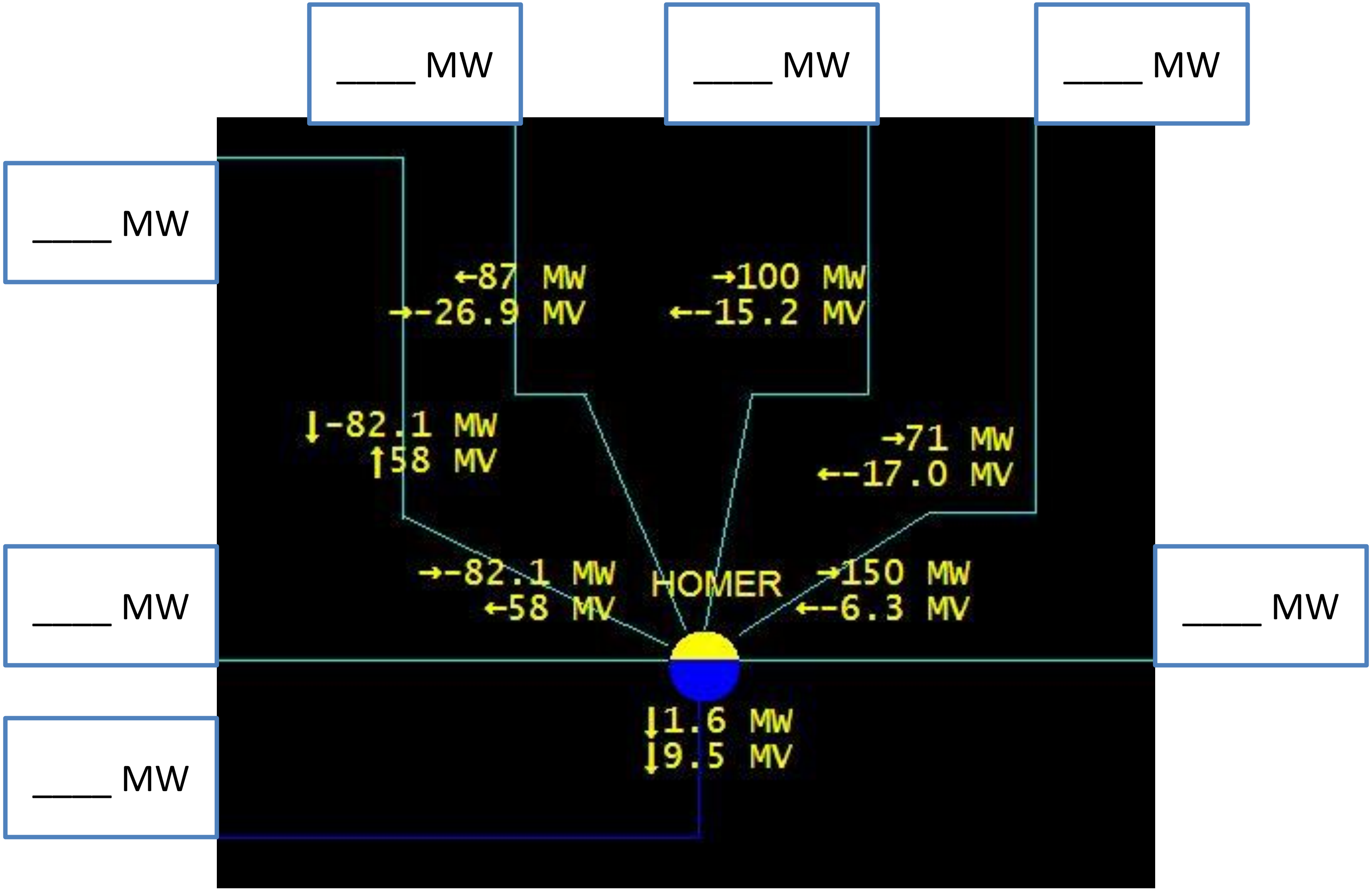
Consequences of Violating Thermal Limits

- Transformers
  - Overheating may cause damage to the winding insulation or thermal damage to the oil
- Generators
  - Rotor and stator winding insulation damage
  - Generator could trip off line to protect it from damage
  - Results in possible voltage drop and MW and MVAR in-flow from the rest of the system
  - Affects on system power flows
    - Rule of Thumb - For a loss of generation, flows toward station will increase and flows out of station will decrease

Events That Can Cause Power Flow Problems



Events That Can Cause Power Flow Problems



Controlling Thermal Violations

- *Non-cost Responses to Thermal Violations*
  - Restore tripped equipment quickly if possible
    - Generally cables and transformers are not reclosed following a tripping
  - Remove faulted equipment from system
    - Isolate faulted equipment through switching
  - Activate Special Purpose Relays
  - Approved switching procedures
  - Adjust Phase Angle Regulators (PARS)

Controlling Thermal Violations

- *Off-cost Responses to Thermal Violations*
  - Curtail Non-firm transactions NOT willing to pay congestion
  - Re-dispatch generation
  - Cancel maintenance
    - Request return of outage equipment
  - NERC Transmission Loading Relief (TLR)
  - Initiate ALL Emergency Procedures EXCEPT Load Shed
    - Including Manual Load Dump Warning and Post Contingency Local Load Relief Warning

Controlling Thermal Violations

- *Load Shedding Response to Thermal Violations*
  - Determine if load shedding is required
    - All other control actions have been exhausted
    - Over emergency or load dump rating on an actual basis
    - Over load dump rating on contingency basis if analysis indicates potential for cascading thermal overloads
  - Determine amount of load shed necessary
  - Determine location of load shed
    - Local vs. System-wide
  - Shed load proportional among Native Load customers, Network customers and firm point-point service

IROLs in PJM

How are IROLs determined and monitored within PJM?

- PJM Manual 37 outlines the IROLs within the PJM footprint, and how they are monitored
- PJM performs IROL analysis in both long-term and short-term planning studies, in the day-ahead studies, and in real time
  - Screening studies include a long list of possible contingencies, studied at estimated peak loads, and include facilities identified as requiring special attention
    - Facilities contributing to the 2003 Blackout
    - The RFC (ECAR) list of critical facilities
    - MAAC assessment limits
    - Others identified by operating experience

How are IROLs determined and monitored within PJM?

- To determine the IROL limits, PJM increases the flow across a given piece of equipment or interface, and looks at any resulting voltage or thermal violations
    - The PJM EMS increases load in Eastern PJM (sink) with an increase in Western Generation (MISO) until a voltage violation (or collapse) is identified
- A Thermal limit violation alone allows the PJM (and company) Dispatchers time to respond without jeopardizing system reliability, and are ***NOT*** IROLs

How are IROLs determined and monitored within PJM?

- PJM classifies a facility as an IROL facility on the PJM system if wide-area voltage violations occur at transfer levels that are near the Load Dump thermal limit
  - Plus case-by-case exceptions as identified in the studies
- In most cases, the IROLs are a limit on MW flows to prevent a ***post-contingency*** voltage violation or collapse…

How are IROLs determined and monitored within PJM?

- Determination of Reactive Transfer Limits
  - Limits are calculated every 2 – 5 minutes on PJM's EMS
  - Each transfer interface has its own set of contingencies and monitored buses

What are the IROLs in the PJM footprint?

- Reactive Interfaces
  - Eastern Interface
    - Wescosville-Alburtis 5044 line, Juniata-Alburtis 5009 line, TMI-Hosensack 5026 line, Peach Bottom-Limerick 5010 line and the Rock Springs – Keeney 5025 line
  - Central Interface
    - Keystone-Juniata 5004 line, Conemaugh-Juniata 5005 line, and Conastone-Peach Bottom 5012 line
  - Western Interface
    - Keystone-Juniata 5004 line, Conemaugh-Juniata 5005 line, Conemaugh-Hunterstown 5006 line, Doubs-Brighton 5055 line

What are the IROLs in the PJM footprint?

- 5004 / 5005 Interface
  - Keystone-Juniata 5004 line and Conemaugh-Juniata 5005 line
- Cleveland Interface
  - Chamberlin-Harding, Hanna-Juniper, Star-Juniper, Davis Besse-Beaver, Carlisle-Beaver Valley, Erie W.-Asthabula 345kV lines, Ford-Beaver, NASA-Beaver, Camden-Beaver, W. Akron-Hickory, W. Akron-Brush, Johnson-Beaver, Edgewater-Beaver, Johnson-Lorraine, National-Lorrane 138kV Lines
- Bedington – Black Oak Interface
  - Bedington – Black Oak 544 line

What are the IROLs in the PJM footprint?

- AP South Interface
  - Doubs - Mt. Storm, Greenland Gap – Meadow Brook, Mt. Storm – Valley 550A and, Mt. Storm-Meadow Brook 500 kV Lines
- AEP – Dominion Interface
  - Kanawha River – Matt Funk 345kV, Baker – Broadford and Wyoming – Jackson's Ferry 765kV lines
- ComEd Interface
  - Interface includes all ComEd tie lines

What are the IROLs in the PJM footprint?

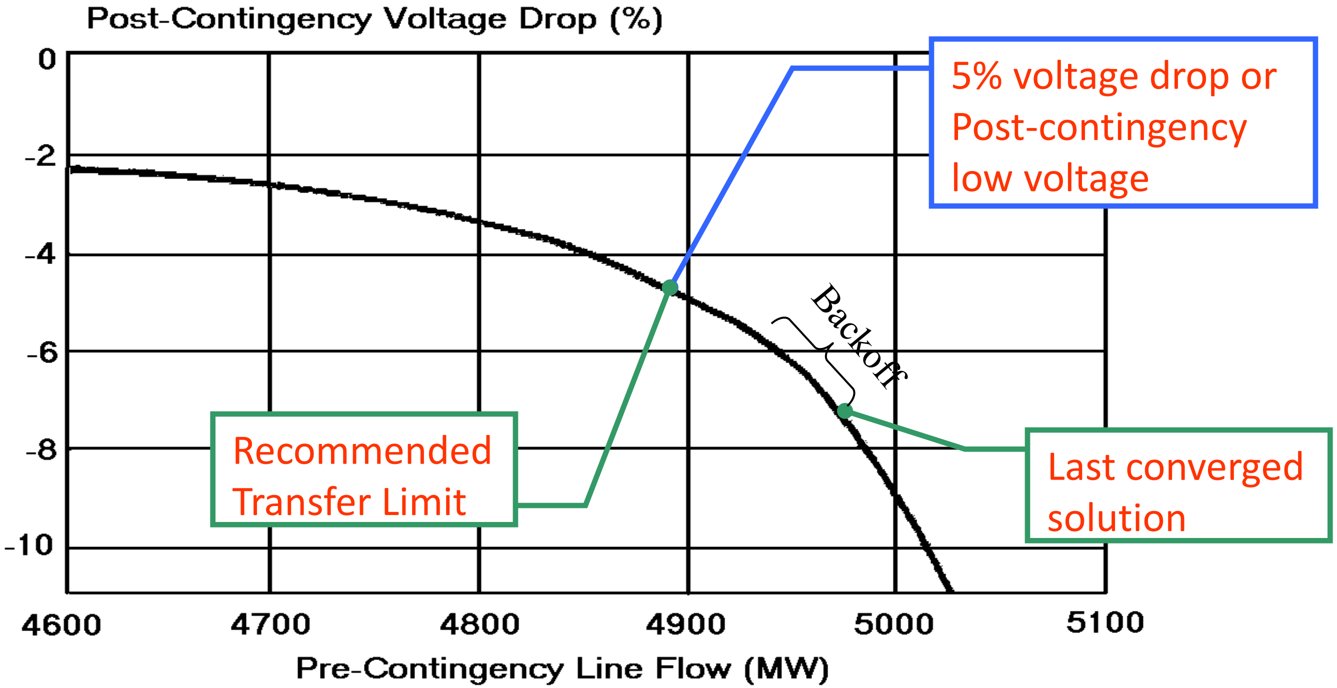
- The Reactive Transfer Limit for an interface is determined as the more restrictive of:
  - The minimum pre-contingency transfer interface flow where a post-contingency voltage drop violation (5%) or post-contingency low voltage violation first occurs

  OR

  - The minimum pre-contingency transfer interface flow with a converged power flow solution minus the user specified MW “back-off” value
    - Generally 50 – 300 MW

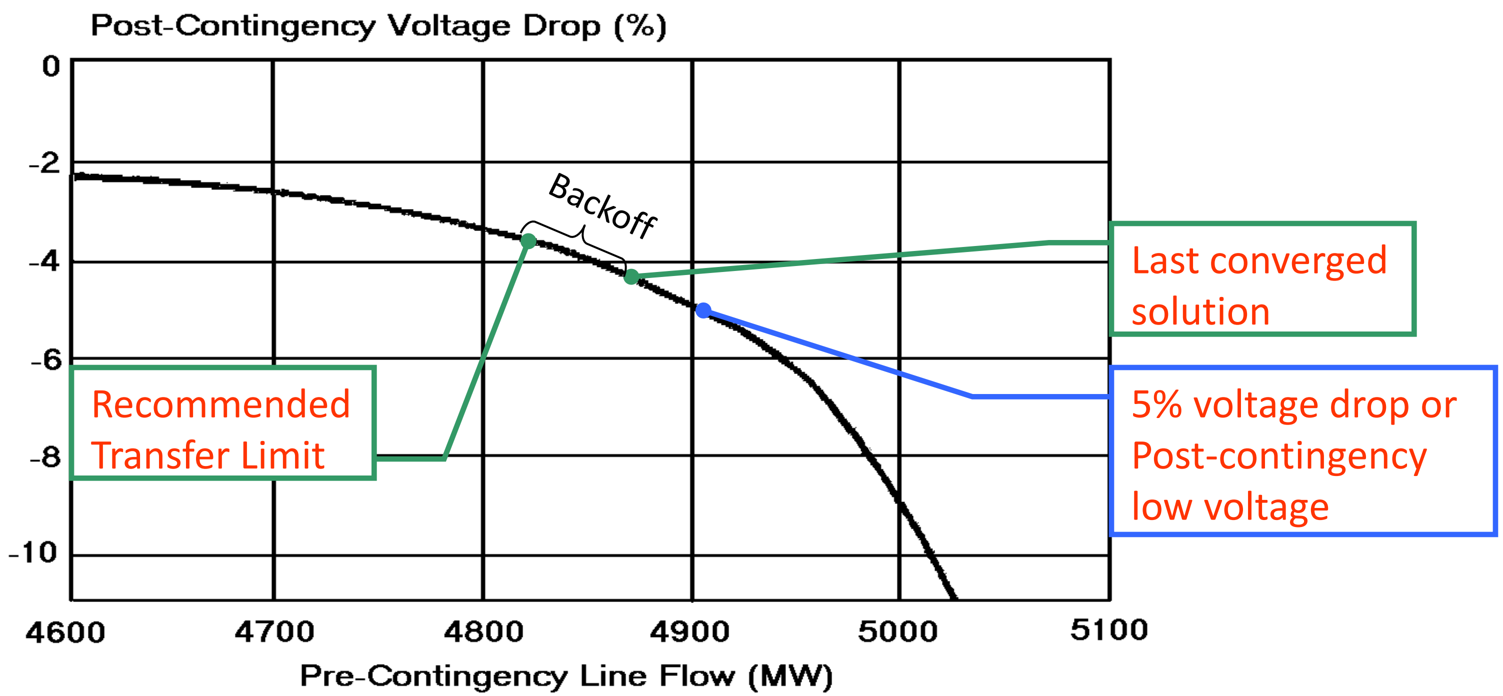
What are the IROLs in the PJM footprint?

- Determination of Reactive Transfer Limit

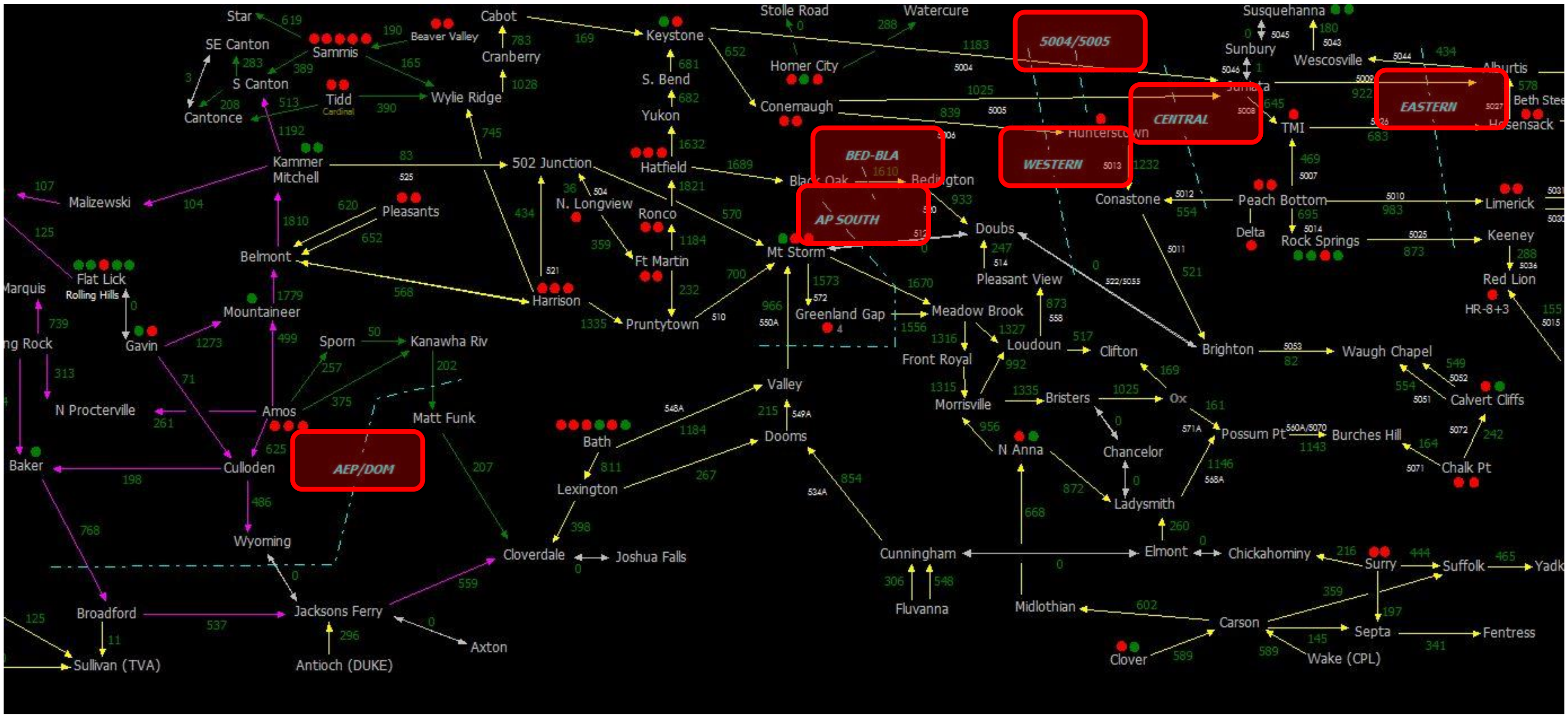


What are the IROLs in the PJM footprint?

- Determination of Reactive Transfer Limit

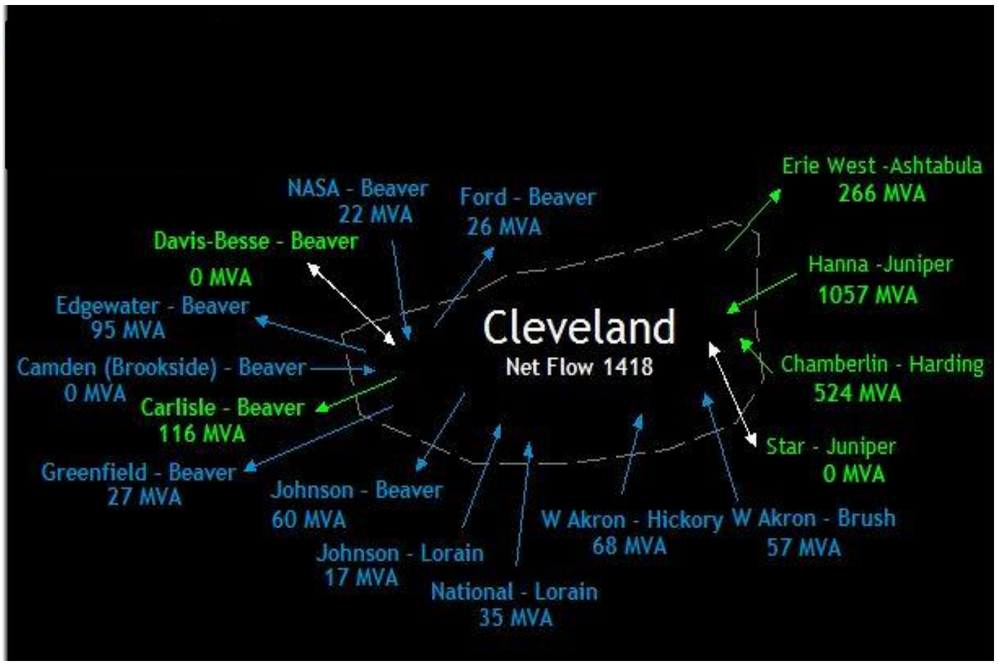


What are the IROLs in the PJM footprint?



What are the IROLs in the PJM footprint?

- Cleveland Interface

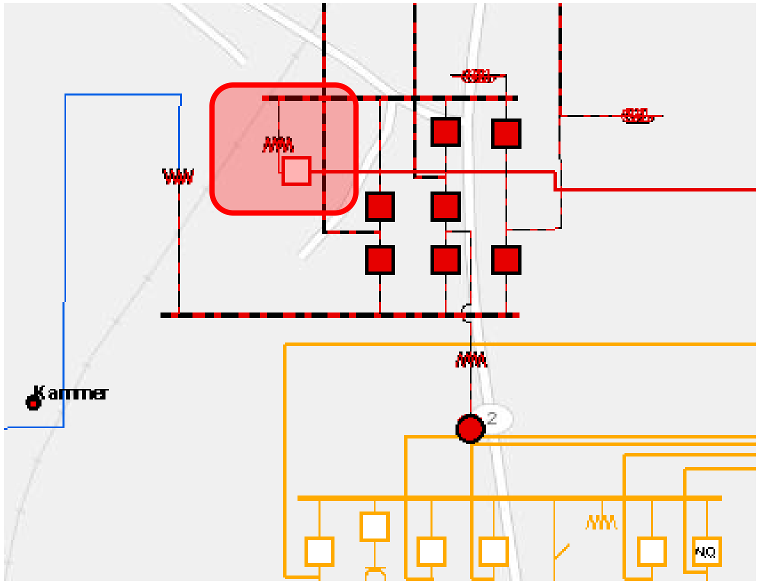


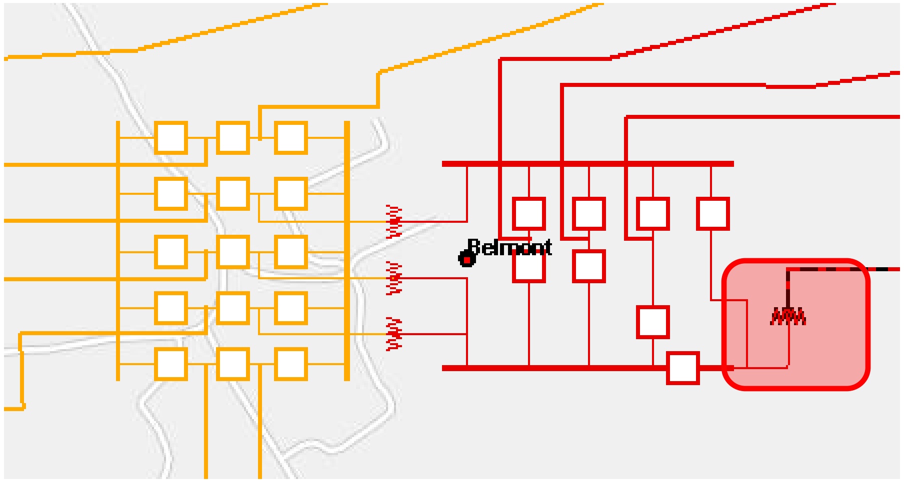
- ComEd Interface

Station	Voltage	Name		Station	Voltage	Name
STJOHNS	345 KV	CRE-STJ1		TAZEWEL2	345 KV	93505
DUMONT2	765 KV	DUM-WIL1		SHEFFILD	345 KV	STA-SHE1
LATHAM	345 KV	2102 3		ROCK CRE	345 KV	0405
BROKAW	345 KV	BRO-PON		SUB 91	345 KV	0401 1
SUB 39	345 KV	39-QC-1		17WOLFLK	138 KV	STA-17W1
PADDOCK	345 KV	17102		KEWANEE	138 KV	BTIE Z1
ROCKDAL3	345 KV	17101		OGLESBY	138 KV	7713 3
17ROXANA	138 KV	STA-17R1		EDWARDS	138 KV	7423
ARCADIAN	345 KV	2222		MARSEILE	138 KV	6102 4
PLEAS PR	345 KV	2221		HENNEPIN	138 KV	6101 4
PAWNEE	345 KV	2106		LAKEVIE2	138 KV	28201
NO PANA	345 KV	2105		1352	138 KV	1352 1
TAZEWEL2	345 KV	0304		ALBANY	138 KV	13219
SHEFFILD	345 KV	BUR-SHE1		LANESVL	345 KV	2101 1
MUNSTER2	345 KV	BUR-MUN1		OLIVE	345 KV	OLI-UNI1

What are the IROLs in the PJM footprint?

- Thermal Limit Interfaces
  - Kammer 765/500 kV Transformer
  - Belmont #5 765/500 kV Transformer





IROL Load Shed Procedure

- When an IROL limit has been exceeded for 5 minutes or longer a **Manual Load Dump Warning** should be issued via the All-Call in order to prepare Transmission dispatchers/LSEs to curtail load
- When an IROL limit has been exceeded for 25 minutes or longer a **Manual Load Dump Action** should be issued via the All-Call allowing Transmission dispatchers/LSEs to curtail load within 5 minutes to return flows below the IROL limit

IROL Load Shed Procedure

- Purpose of the IROL Manual Load Dump:
  - Provide loading relief on IROL facilities as a last step
  - Prevent exceeding an IROL Limit for 30 minutes (IROL Violation)
  - Quickly act to mitigate IROL facilities in accordance with operating procedures
  - PJM Transmission Operations Manual (M03)
    - Section 2: Thermal Operating Guidelines
    - Section 3: Voltage & Stability Operating Guidelines
  - PJM Emergency Operations Manual (M13)
    - Section 5: Transmission Security Emergencies

IROL Load Shed Procedure

- IROL Manual Load Dump Warning
  - PJM issues an IROL Manual Load Dump Warning via the PJM All-Call System when the IROL Limit has been exceeded for **5 minutes** or longer in order to prepare Transmission dispatchers/LSEs to curtail load
  - The purpose is to **PREPARE** Transmission dispatchers/LSEs to curtail load within 5 minutes to return flows below the IROL Limit

IROLs and SOLs

- IROL Manual Load Dump Warning
  - Transmission dispatchers / LSEs
    - Promptly review IROL Manual Load Dump Allocation Table (Attachment N, M - 13) in preparation of Manual Load Dump once an IROL Manual Load Dump Warning has been implemented
    - To determine your required amount of Load Shed, determine your company multiplier for that IROL
    - Multiply the amount of relief requested by PJM by your multiplier to determine your company's load shed amount
    - Validate Load Dump Plan, Identifying critical or priority load(s)
    - **PREPARE** to shed load

IROL Load Shed Procedure

- IROL Manual Load Dump Action
  - PJM issues an IROL Manual Load Dump Action via the PJM All-Call System when the IROL Limit has been exceeded for **25 minutes or longer**
  - PJM dispatch:
    - Notifies PJM management
    - Public information personnel, and members
    - Other Control Areas through the RCIS
    - Notifies DOE, FEMA, and NERC
    - Notifies FERC via the FERC Division of Reliability’s electronic pager system

IROL Load Shed Procedure

- IROL Manual Load Dump Action
  - Transmission dispatchers/LSEs
    - Promptly **(within 5 minutes)** shed an amount of load equal to or in excess of the amount requested by PJM dispatcher in accordance with Attachment N, but consider/recognize priority/critical load
      - A Grey Box on Attachment N indicates your company has no responsibility to shed load for that IROL
    - Notify governmental agencies, as applicable
    - Maintain the requested amount of load relief until the load dump order is cancelled

IROL Load Shed Procedure

Attachment N: IROL Load Dump Tables

IROL	East	Central	5004/05	West	AP South	Bed-BO	AEP/DOM	CLVLND	Belmont	Kammer	ComEd
TO Zone	Multiplier	Multiplier	Multiplier	Multiplier	Multiplier	Multiplier	Multiplier	Multiplier	Multiplier	Multiplier	Multiplier
DPL	0.21	0.16	0.40	0.18					0.45	0.41	
DPL-Dover	0.01	0.01	0.02	0.01					0.03	0.02	
DPL-DEMEC	0.02	0.01	0.03	0.02					0.04	0.04	
DPL-Easton	0.00	0.00	0.01	0.00					0.01	0.01	
DPL-ODEC	0.05	0.04	0.10	0.05					0.12	0.11	
AE	0.14	0.11	0.27	0.12					0.30	0.28	
AE-Vineland	0.01	0.01	0.02	0.01					0.02	0.02	
PS	0.59	0.46	1.10	0.49					1.25	1.13	
RECO	0.02	0.02	0.04	0.02					0.04	0.04	
PE	0.60	0.47	1.12	0.50					1.28	1.16	
JC	0.32	0.25	0.60	0.27					0.68	0.62	
PL		0.51	1.23	0.55					1.39	1.27	
UGI		0.01	0.03	0.01					0.04	0.03	
ME		0.18	0.43	0.19					0.49	0.44	
PN									0.56	0.51	
BC				0.44	0.93	3.98	1.48		1.12	1.02	
PEP				0.35	0.75	3.20	1.19		0.90	0.82	
PEP-SMECO				0.05	0.10	0.44	0.17		0.13	0.11	
AP									1.60	1.45	
Dom					2.91	4.10	4.62		1.54	2.99	
Dom-NCEMC					0.26	1.11	0.41		0.31	0.28	
DOM-ODEC					0.05	0.19	0.07		0.05	0.05	
DLCO											
AEP							1.00				
Dayton											
FE								0.93			
CPP								0.07			
ComEd											1.00
DEOK											
EKPC											

IROL Load Shed Procedure

- Example IROL Load Shed Request –
  - PJM announces an IROL Load Shed Warning for 350 MW of Relief on the Western Transfer IROL
  - Your company is Public Service (PS)
  - You consult Attachment N and determine that your company Multiplier for the Western Transfer IROL is 0.49

IROL Load Shed Procedure

Attachment N: IROL Load Dump Tables

IROL	East	Central	5004/05	West	AP South	Bed-BO	AEP/DOM	CLVLND	Belmont	Kammer	ComEd
TO Zone	Multiplier	Multiplier	Multiplier	Multiplier	Multiplier	Multiplier	Multiplier	Multiplier	Multiplier	Multiplier	Multiplier
DPL	0.21	0.16	0.40	0.18					0.45	0.41	
DPL-Dover	0.01	0.01	0.02	0.01					0.03	0.02	
DPL-DEMEC	0.02	0.01	0.03	0.02					0.04	0.04	
DPL-Easton	0.00	0.00	0.01	0.00					0.01	0.01	
DPL-ODEC	0.05	0.04	0.10	0.05					0.12	0.11	
AE	0.14	0.11	0.27	0.12					0.30	0.28	
AE-Vineland	0.01	0.01	0.02	0.01					0.02	0.02	
PS	0.59	0.46	1.10	0.49					1.25	1.13	
RECO	0.02	0.02	0.04	0.02					0.04	0.04	
PE	0.60	0.47	1.12	0.50					1.28	1.16	
JC	0.32	0.25	0.60	0.27					0.68	0.62	
PL		0.51	1.23	0.55					1.39	1.27	
UGI		0.01	0.03	0.01					0.04	0.03	
ME		0.18	0.43	0.19					0.49	0.44	
PN									0.56	0.51	
BC				0.44	0.93	3.98	1.48		1.12	1.02	
PEP				0.35	0.75	3.20	1.19		0.90	0.82	
PEP-SMECO				0.05	0.10	0.44	0.17		0.13	0.11	
AP									1.60	1.45	
Dom					2.91	4.10	4.62		1.54	2.99	
Dom-NCEMC					0.26	1.11	0.41		0.31	0.28	
DOM-ODEC					0.05	0.19	0.07		0.05	0.05	
DLCO											
AEP							1.00				
Dayton											
FE								0.93			
CPP								0.07			
ComEd											1.00
DEOK											
EKPC											

IROL Load Shed Procedure

- Example IROL Load Shed Request –
  - You multiply the amount of PJM requested relief (350 MW) by your company multiplier (0.49) to get your required Loadshed amount
    - 350 X 0.49 = 171.5 MW
  - You identify where in your Zone that load will be shed
  - If/When PJM issues the IROL Load Shed Action, you would shed at least 171.5 MW within 5 minutes and keep that amount of load off the system until PJM gives you the OK to restore the load
    - Rotating load is OK so long as the minimum shed is at least 171.5 MW

Post Contingency Local Load Relief Warning

Purpose of PCLLRWs

From PJM Manual, M-13, Emergency Operations

> "The purpose of the Post Contingency Local Load Relief Warning is to provide advance notice to a transmission owner(s) of the potential for manual load dump in their area(s). It is issued after all other means of transmission constraint control have been exhausted OR until sufficient generation is on-line to control the constraint within designated limits and timelines as identified in PJM Manual 3 Transmission Operations, Section 2 – Thermal Operating Guidelines"

Post-Contingency Load Dump Limit Exceedance Analysis

- As indicated, a PCLLRW is issued after all other means of transmission constraint control have been exhausted or until sufficient generation is on-line to control the constraint within designated limits and timelines
- If post-contingency flows were to exceed the 15 minute Load Dump rating, there is a concern that the facility may trip before actions can be taken to reduce the flow within limits
- To prepare for this potential N-2 (initial contingency plus the overloaded facility) and prevent a cascade
    - Does not matter if this is an MP-1 or MP-2 facility

Post-Contingency Load Dump Limit Exceedance Analysis

- As stated in PRC-023 R1.2 and R1.11, transmission line relays and transformer overload protection relays are set so they do not operate at or below 115% of the facility's highest emergency rating
- For PJM facilities, the highest rating is the Load Dump rating
- Therefore PJM will perform the following analysis for any facility that reaches or exceeds 115% of its Load Dump Limit:
  - If a facility approaches 115% of its Load Dump limit, the PJM Operator will study the loss of the contingency element and the overloaded facility

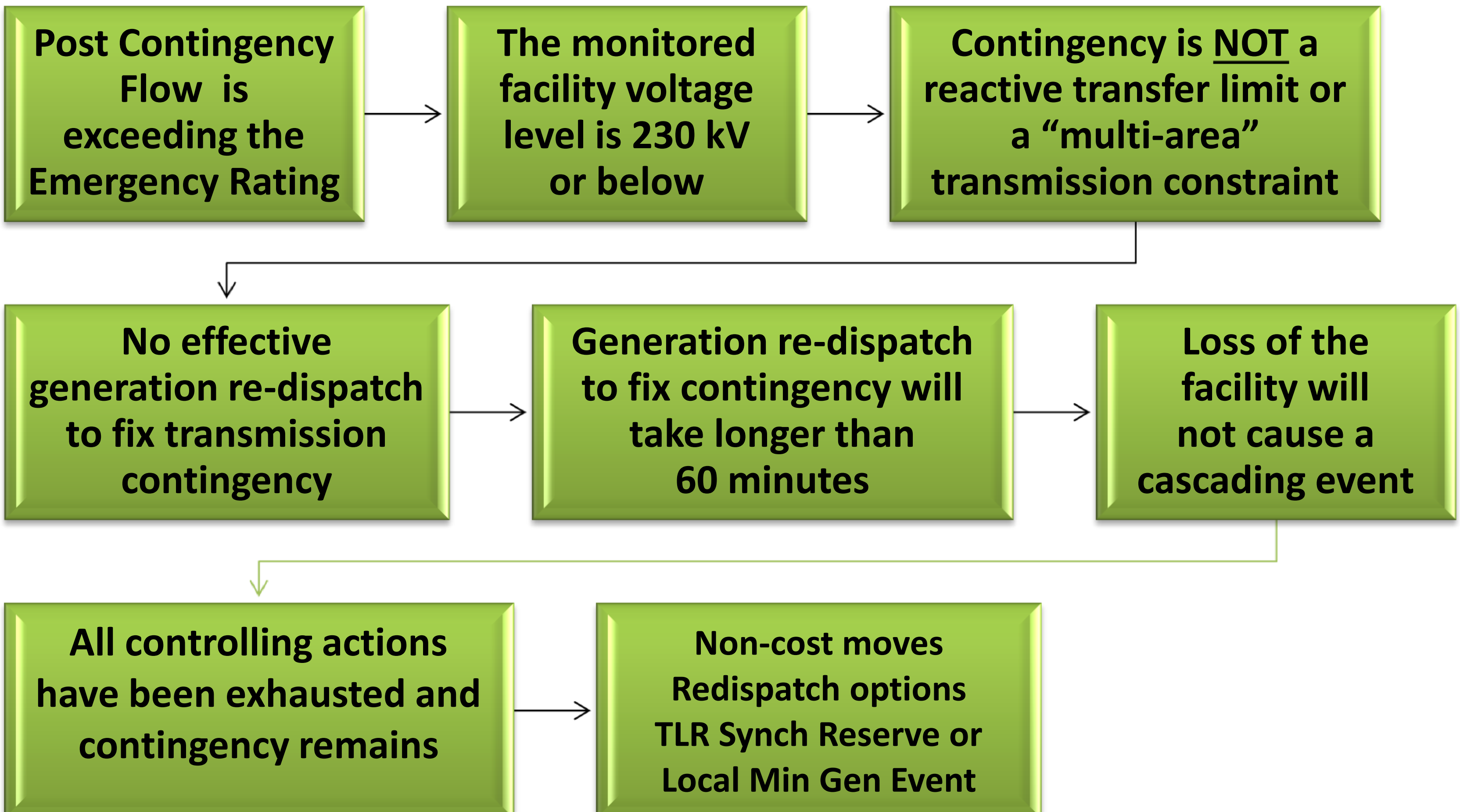
Post-Contingency Load Dump Limit Exceedance Analysis

- If the study results indicate no additional facilities will be overloaded over 115% of their Load Dump limit, this is determined to be a localized event and no additional pre-contingency actions will be taken
- If the study results in an additional facility(s) over 115% of its Load Dump rating, the operator will continue the analysis to also trip the additional circuits
  - This analysis will be performed tripping a maximum of 5 facilities
- If the study indicates either a non-converged case OR continues to show facilities exceeding 115% of their Load Dump limits, this will be considered a potential cascade situation

Post-Contingency Load Dump Limit Exceedance Analysis

- The results with the Transmission Owner and direct pre-contingency Load Shed
  - **Note:** Load Shed will be directed in the amount needed to maintain the post contingency flow below 115% of the Load Dump limit on the original contingency within 30 minutes of the detection of the potential cascade situation
- If the analysis at any point results in a valid non-converged contingency indicating a potential cascade the PJM Operator will review the results with the TO and direct pre-contingency Load Shed within 30 minutes to mitigate the potential cascading situation

When to issue a PCLLRW



Implementation of PCLLRW

- PJM Actions:
  - Discuss with affected TO
    - Contingency flows
    - Ratings
    - Possible switching solutions (pre and post contingency)
  - Perform all possible controlling actions including
    - Off-cost operation
    - Transmission Loading Relief (TLR)
    - Hydro adjustment
    - MISO Market to Market Redispatch
    - 100% Synch Reserve or Local Min Gen

Implementation of PCLLRW

- PJM Actions (cont.)
  - Determine desired flow on affected facility
    - Post-contingency flow < LTE rating
  - Issue PCLLRW
    - Communicate verbally to affected TO(s)
    - Post on Emergency Procedure Posting Application
      - Include area affected, desired flow, any post-contingency switching, generation reductions or load transfer options
    - Email load dfax report to affected TO(s)

Implementation of PCLLRW

- PJM Actions (cont.)
  - Discuss with TO where and how much load will be shed if needed
  - Establish mutual awareness with appropriate TO of the need to address the post-contingency actions with minimal delay
  - Direct load shed should contingency occur
  - Cancel PCLLRW when appropriate
    - Post-contingency flow drops below LTE rating and is not expected to reappear in the near future
    - Notify TO prior to canceling PCLLRW
    - Cancel in Emergency Procedure application
    - Log

Implementation of PCLLRW

- Member Actions:
  - Discuss with PJM amount of load to be shed to return flow below emergency rating
  - Monitor expected post-contingency flows and adjust load dump strategy as appropriate
  - Advise appropriate stations and key personnel
    - Staff substations as necessary if load shed can't be accomplished via SCADA
  - Review load dump procedures and prepare to dump load in amount requested when directed by PJM
  - Prepare to implement post-contingency switching options, manual generation trip or SCADA load transfer
    - Prepare to implement load shedding if above fails
  - Notify PJM if post-contingency flow drops below LTE limit and PCLLRW has not yet been cancelled

Expressed Concerns about PCLLRWs

- Why call a PCLLRW, if the TO and PJM can agree on a post-contingency switching solution that avoids the potential for load shedding?
  - PJM needs to have a documented method for conveying the post-contingency overload concern to the TO, to ensure clear communications of the potential reliability threat

Posting of PCLLRWs

Emergency Messages (11/28/2012 15:25:10)

Region(s): PJM - RTO, NICA - Control Area, PJMCA - Control Area, Mid-Atlantic - Region

Message Type: NERC EEA 3, New, Non-Market Post Contingency Local L, Post Contingency Local Load Relief W

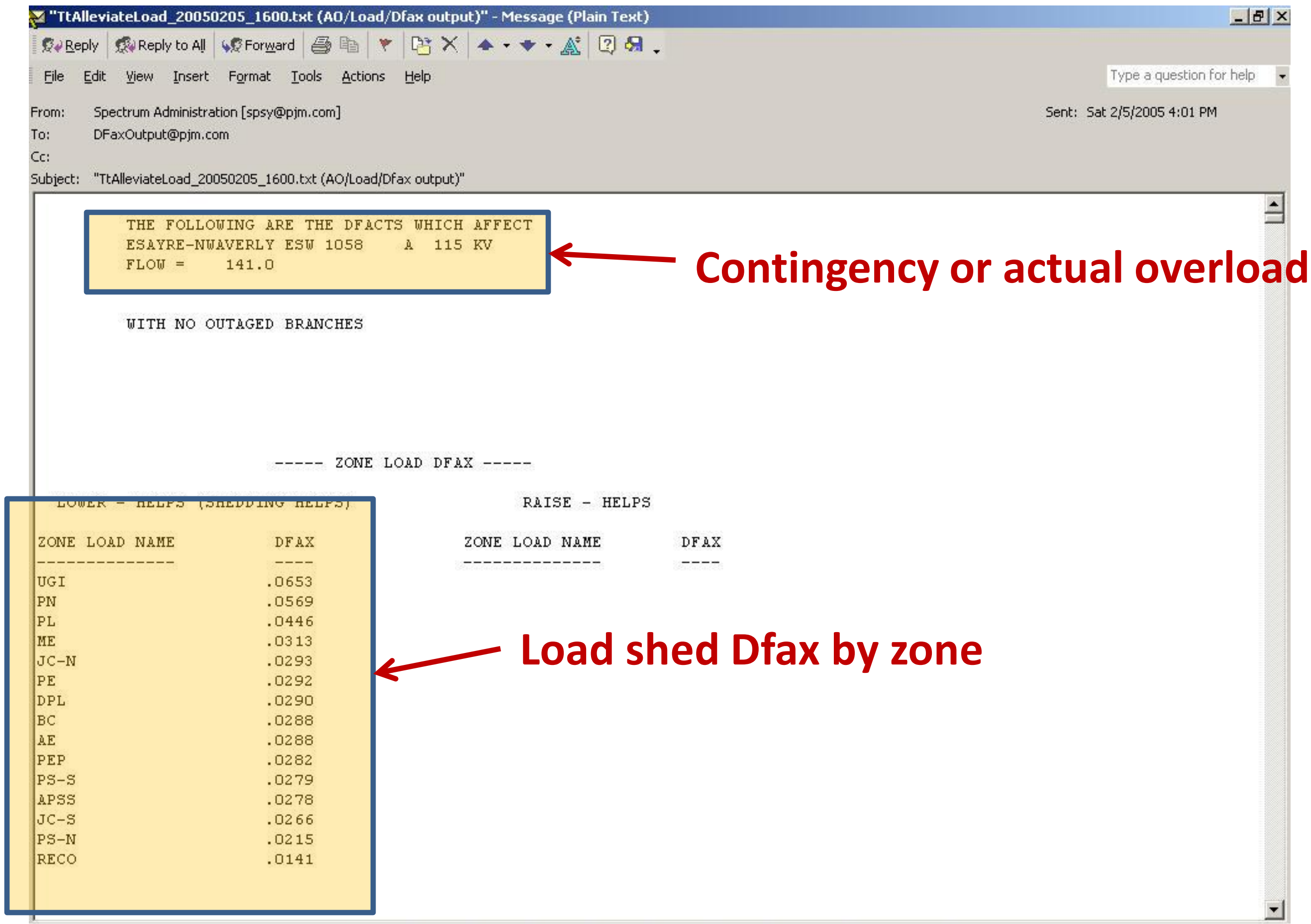
From: To: Active Only: Last 2 Days: Last 2 Days or Active: Flowgate Number: PJM Drills: Include

Apply Filter Reset Filter

Msg. ID	Msg. Type	Posting Timestamp	Region/Area	Emergency Message	Cancellation Timestamp
80140	Post Contingency Local Load Relief Warning	11/28/2012 07:22	AEP - Control Zone	As of 07:20 a Post Contingency Local Load Relief Warning to maintain Circleville at 189 MVA in the AEP area has been issued for Transmission Contingency Control. Additional Comments: L/O 138KV line Mulberry-Waverly	11/28/2012 10:30
80119	Post Contingency Local Load Relief Warning	11/27/2012 20:40	Mid-Atlantic - Region	As of 20:35 a Post Contingency Local Load Relief Warning to maintain Shawnee at 212 KV in the FE (ME) area has been issued for Transmission Contingency Control. Additional Comments: Low voltage at Shawnee l/o Kittatiny-Bushkill	11/27/2012 22:12
80099	Post Contingency Local Load Relief Warning	11/26/2012 18:24	ATSI - Control Zone	As of 18:20 a Post Contingency Local Load Relief Warning to maintain Ashtubula #8 TR at 435 MVA in the ATSI area has been issued for Transmission Contingency Control. For post contingency overload of Ashtubula #8 TR for loss of Perry - East lake 345 kV Line	11/26/2012 19:12

Download

Example PCLLRW E-mail Report



"TtAlleviateLoad_20050205_1600.txt (AO/Load/Dfax output)" - Message (Plain Text)

Reply | Reply to All | Forward

File Edit View Insert Format Tools Actions Help

Type a question for help

From: Spectrum Administration [spsy@pjm.com]

Sent: Sat 2/5/2005 4:01 PM

To: DFaxOutput@pjm.com

Cc:

Subject: "TtAlleviateLoad_20050205_1600.txt (AO/Load/Dfax output)"

```
THE FOLLOWING ARE THE DFACTS WHICH AFFECT
ESAYRE-NWAVERLY ESW 1058     A  115 KV
FLOW =    141.0

WITH NO OUTAGED BRANCHES

                  ----- ZONE LOAD DFAX -----

 LOWER - HELPS (SHEDDING HELPS)                       RAISE - HELPS

ZONE LOAD NAME             DFAX            ZONE LOAD NAME       DFAX
--------------             ----            --------------       ----
UGI                       .0653
PN                        .0569
PL                        .0446
ME                        .0313
JC-N                      .0293
PE                        .0292
DPL                       .0290
BC                        .0288
AE                        .0288
PEP                       .0282
PS-S                      .0279
APSS                      .0278
JC-S                      .0266
PS-N                      .0215
RECO                      .0141
```

Example PCLLRW E-mail Report

Total Bus Load

30% load shed Cumulative effect on constraint

100% load shed Cumulative effect on constraint

"TtAlleviateLoad_20050205_1600.txt (AO/Load/Dfax output)" - Message (Plain Text)

Reply | Reply to All | Forward

File Edit View Insert Format Tools Actions Help

Type a question for help

From: Spectrum Administration [spsy@pjm.com]

Sent: Sat 2/5/2005 4:01 PM

To: DFaxOutput@pjm.com

Cc:

Subject: "TtAlleviateLoad_20050205_1600.txt (AO/Load/Dfax output)"

----- LOAD DFAX (PJM) -----

LOWER - HELPS (SHEDDING HELPS)

ZONE	STATION	NAME	DFAX	LOAD MW	30% SHED (CUM_LOAD_MW,		100% SHED CUM_RELIEVED_MW)	
PN	ESAYRE	#3 TX	.6061	24	7	4	24	14
PN	ESAYRE	#1&2 T	.6061	21	13	8	46	28
PN	ETOWANDA	1 TX	.2586	23	20	10	69	34
PN	ETOWANDA	5 TX	.2586	27	29	12	97	41
PN	ETOWANDA	2 TX	.2586	22	36	14	120	47
PN	STROY	1 TX	.2233	5	37	14	126	48
PN	STROY	2 TX	.2233	5	39	14	132	49
PN	MANS PN	WELLSB	.1963	2	40	15	134	50
PN	BLOSSBUR	BLOSB	.1963	9	43	15	144	52
PN	MANS PN	TROY	.1963	1	43	15	145	52
PN	TOWERHIL	NO1 TX	.1963	3	44	15	149	53
PN	WARD	1 BANK	.1963	5	46	16	155	54
PN	NILESVAL	WLSBR2	.1788	9	49	16	164	56
PN	OSCEOLA	1 TX	.1788	9	52	17	174	57
PN	NILESVAL	WLSBR1	.1788	9	54	17	183	59
PN	GROVER	LOAD1	.1682	22	61	18	206	63
PN	SABINSVI	WELLBR	.1569	2	62	19	208	63
PN	SABINSVI	OSCEOL	.1569	7	64	19	215	64
PN	MEHOOPAN	2PG	.1557	11	68	19	227	66
PN	MEHOOPAN	C3	.1557	18	73	20	246	69
PN	MEHOOPAN	C4	.1557	18	79	21	265	72
PN	NMESHOPP	2 TX	.1557	6	81	22	271	73
PN	NMESHOPP	1 TX	.1557	17	86	22	289	76
PN	MEHOOPAN	1PG	.1557	12	90	23	301	78
PN	MEHOOPAN	5PG	.1557	11	94	23	313	79
PN	GOLD	NO.1 T	.1375	3	95	24	317	80
PN	OXBOW	ONE	.1213	8	97	24	325	81
APSS	LOBO	1TX	.1185	-2	98	24	328	81
APSS	POTTER	115LD1	.1121	6	100	24	334	82
APSS	POTTER	115LD2	.1121	9	103	25	343	83

Load Dfax by bus

Example PCLLRW E-mail Report

Exact load shed locations to be determined by TO as long as total relief is achieved

Example: Contingency flow is 162 MVA with an Emergency limit of 150 MVA. How much load needs to be shed to control this contingency?

File Edit View Insert Format Tools Actions Help

Type a question for help

From: Spectrum Administration [spsy@pjm.com]

Sent: Sat 2/5/2005 4:01 PM

To: DFaxOutput@pjm.com

Cc:

Subject: "TtAlleviateLoad_20050205_1600.txt (AO/Load/Dfax output)"

----- LOAD DFAX (PJM) -----

LOWER - HELPS (SHEDDING HELPS)

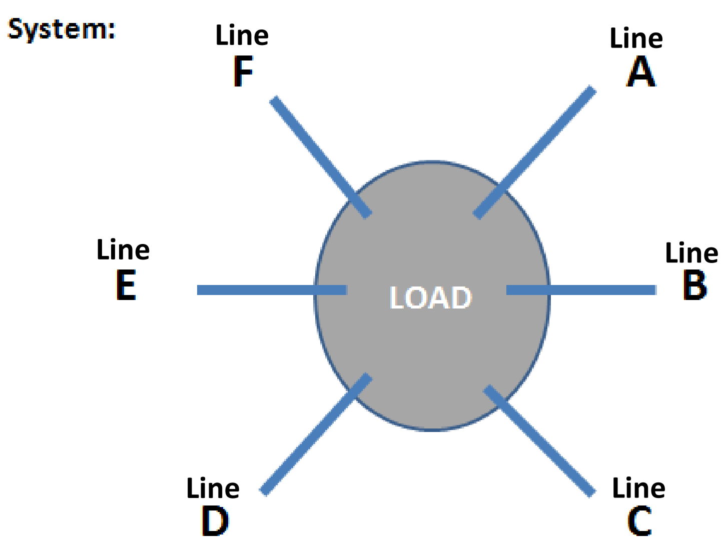
ZONE	STATION	NAME	DFAX	LOAD MW	30% SHED (CUM_LOAD_MW,		100% SHED CUM_RELIEVED_MW)	
PN	ESAYRE	#3 TX	.6061	24	7	4	24	14
PN	ESAYRE	#1&2 T	.6061	21	13	8	46	28
PN	ETOWANDA	1 TX	.2586	23	20	10	69	34
PN	ETOWANDA	5 TX	.2586	27	29	12	97	41
PN	ETOWANDA	2 TX	.2586	22	36	14	120	47
PN	STROY	1 TX	.2233	5	37	14	126	48
PN	STROY	2 TX	.2233	5	39	14	132	49
PN	MANS PN	WELLSB	.1963	2	40	15	134	50
PN	BLOSSBUR	BLOSB	.1963	9	43	15	144	52
PN	MANS PN	TROY	.1963	1	43	15	145	52
PN	TOWERHIL	NO1 TX	.1963	3	44	15	149	53
PN	WARD	1 BANK	.1963	5	46	16	155	54
PN	NILESVAL	WLSBR2	.1788	9	49	16	164	56
PN	OSCEOLA	1 TX	.1788	9	52	17	174	57
PN	NILESVAL	WLSBR1	.1788	9	54	17	183	59
PN	GROVER	LOAD1	.1682	22	61	18	206	63
PN	SABINSVI	WELLBR	.1569	2	62	19	208	63
PN	SABINSVI	OSCEOL	.1569	7	64	19	215	64
PN	MEHOOPAN	2PG	.1557	11	68	19	227	66
PN	MEHOOPAN	C3	.1557	18	73	20	246	69
PN	MEHOOPAN	C4	.1557	18	79	21	265	72
PN	NMESHOPP	2 TX	.1557	6	81	22	271	73
PN	NMESHOPP	1 TX	.1557	17	86	22	289	76
PN	MEHOOPAN	1PG	.1557	12	90	23	301	78
PN	MEHOOPAN	5PG	.1557	11	94	23	313	79
PN	GOLD	NO.1 T	.1375	3	95	24	317	80
PN	OXBOW	ONE	.1213	8	97	24	325	81
APSS	LOBO	1TX	.1185	-2	98	24	328	81
APSS	POTTER	115LD1	.1121	6	100	24	334	82
APSS	POTTER	115LD2	.1121	9	103	25	343	83

Shedding all 24 MW at East Sayre #3 Tx will provide 14 MW of relief

Shedding 29 MW from the four transformers will provide 12 MW of relief

PJM's N-2 Analysis Procedure

- **Exercise 1:**
  - Use this diagram and chart to assist in answering questions in the following scenario



Generic System Line Ratings				
Line	Loading	Normal	Emergency	Load Dump
A	80	120	150	180
B	62	65	70	80
C	66	85	95	100
D	73	105	110	130
E	80	160	175	205
F	89	310	350	400

PJM's N-2 Analysis Procedure

- **Exercise 1:**
  Results of Security Analysis (SA) indicates the following contingency:
  On the loss of Line F
  Line B will go to 94 MVA (118% of LD rating)

  There is no generation that helps with this contingency

  The TO confirms there are no other options available (switching, cutting out load, etc.)

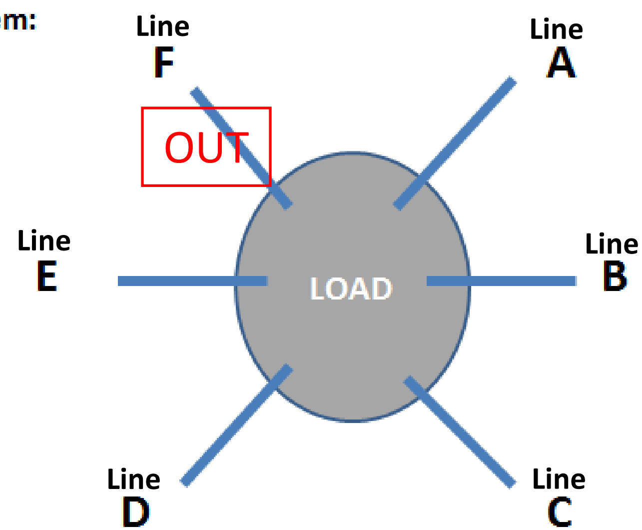
- **What is your next action?**

PJM's N-2 Analysis Procedure

Results of Security Analysis (SA) indicates the following contingency:
On the loss of Line F, Line B will go to 94 MVA (118% of LD rating)
What action, if any, should be taken?

- ☐ Issue a PCLLRW for 25 MVA of relief on Line B for loss of Line F this is not a potential cascading problem
- ☑ Run a Study with Line F and Line B out of Service to determine if this may be a cascading potential problem
- ☐ Issue a Pre-Contingency Manual Load Shed for 25 MVA of relief on Line B based on the Initial SA solution for the loss of Line F, this is a cascading problem
- ☐ Issue a Pre-Contingency Manual Load Shed for 15 MVA of relief on Line B based on the Initial SA solution for the loss of Line F, this is a cascading problem

System:



Generic System Line Ratings				
Line	Loading	Normal	Emergency	Load Dump
A	89	120	150	180
B	94	65	70	80
C	83	85	95	100
D	79	105	110	130
E	105	160	175	205
F	0	310	350	400

PJM's N-2 Analysis Procedure

- **Exercise 1:**
  You run a study for the loss of Lines F and B

  On the loss of Lines F and B Study results indicate the following:

  Line C will go to 102 MVA (102% of Load Dump rating)

  There is no generation that helps with this contingency

  The TO confirms there are no other options available

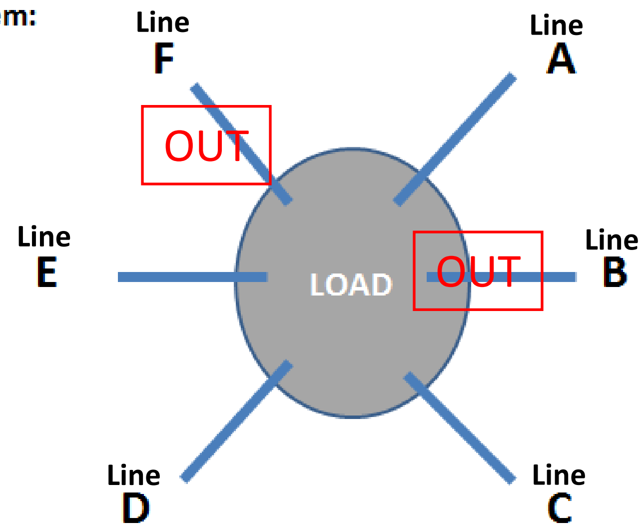
- **What is your next action?**

PJM's N-2 Analysis Procedure

On the loss of Lines F and B Study results indicate the following :
Line C will go to 102 MVA (102% of LD rating)
What action, if any, should be taken?

- ☑ Issue a PCLLRW for the Loss of Lines F and B for 7 MVA relief on Line C, this is not a potential cascading problem
- ☐ Run a Study with Lines F, B and C out of Service to determine if this may be a cascading potential problem
- ☐ Issue a Pre-Contingency Manual Load Shed for 14 MVA of relief based on the Initial SA solution for the loss of Line F, this is a cascading problem
- ☐ Issue a Pre-Contingency Manual Load Shed for 7 MVA of relief based on the Study solution for the loss of Line F and B, this is a cascading problem

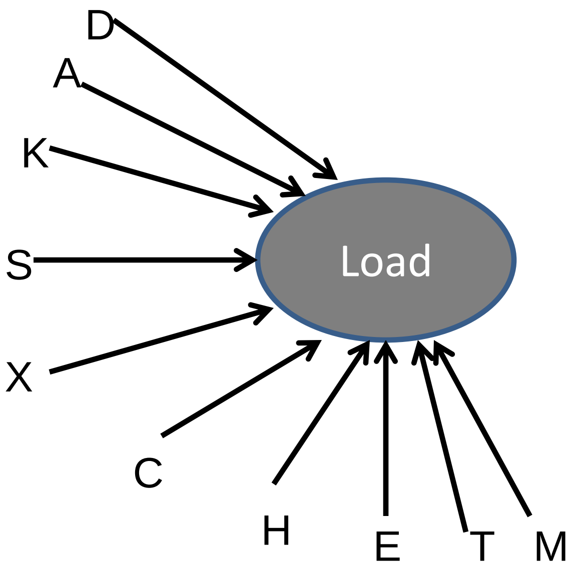
System:



Generic System Line Ratings				
Line	Loading	Normal	Emergency	Load Dump
A	108	120	150	180
B	0	65	70	80
C	102	85	95	100
D	97	105	110	130
E	143	160	175	205
F	0	310	350	400

PJM's N-2 Analysis Procedure

- **Exercise 2:**
  - Use this diagram and chart to assist in answering questions in the following scenario



Generic System Line Ratings				
Line	**Loading**	**Normal**	**Emergency**	**Load Dump**
A	**92**	**120**	**150**	**160**
C	**64**	**65**	**70**	**80**
D	**73**	**85**	**95**	**105**
E	**79**	**105**	**110**	**120**
H	**95**	**160**	**175**	**185**
K	**126**	**310**	**350**	**370**
M	**74**	**95**	**105**	**115**
S	**56**	**75**	**80**	**90**
T	**109**	**145**	**160**	**170**
X	**122**	**310**	**350**	**370**

PJM's N-2 Analysis Procedure

- **Exercise 2:**
  Results of Security Analysis (SA) indicates the following contingency:
  On the loss of Line K
  Line C will go to 94 MVA (118% of Load Dump rating)

  There is no generation that helps with this contingency

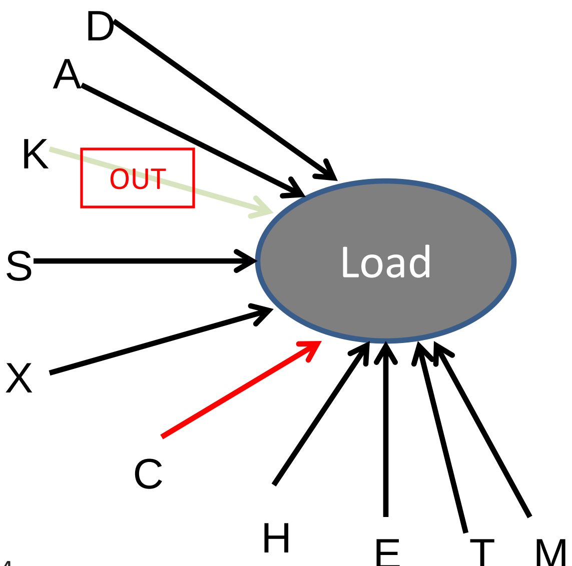
  The TO confirms there are no other options available (switching, cutting out load, etc.)

- **What is your next action?**

PJM's N-2 Analysis Procedure

Results of Security Analysis (SA) indicates the following contingency:
On the loss of Line K Line C will go to 94 MVA (118% of LD rating)
What action, if any, should be taken?

- ☐ Issue a PCLLRW for 25 MVA of relief on Line C for loss of Line K this is not a potential cascading problem
- ☐ Issue a Pre-Contingency Manual Load Shed for 25 MVA of relief on Line C based on the Initial SA solution for the loss of Line K, this is a cascading problem
- ☑ Run a Study with Line K and Line C out of Service to determine if this may be a cascading potential problem
- ☐ Issue a Pre-Contingency Manual Load Shed for 3 MVA of relief on Line C based on the Initial SA solution for the loss of Line K, this is a cascading problem



Generic System Line Ratings				
Line	Loading	Normal	Emergency	Load Dump
A	98	120	150	160
C	94	65	70	80
D	81	85	95	105
E	86	105	110	120
H	105	160	175	185
K	0	310	350	370
M	86	95	105	115
S	74	75	80	90
T	118	145	160	170
X	148	310	350	370

PJM's N-2 Analysis Procedure

- **Exercise 2:**
  You run a study for the loss of Lines K and C

  On the loss of Lines K and C Study results indicate the following:

  Line S will go to 106 MVA (118% of Load Dump rating)

  There is no generation that helps with this contingency

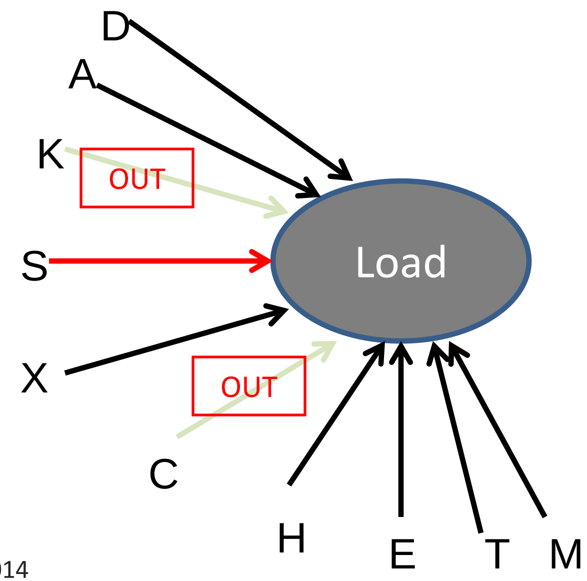
  The TO confirms there are no other options available

- **What is your next action?**

PJM's N-2 Analysis Procedure

On the loss of Lines K and C Study results indicate the following :
Line S will go to 106 MVA (118% of LD rating)
What action, if any, should be taken?

- ☐ Issue a PCLLRW for 25 MVA of relief on Line S for loss of Lines K and C this is not a potential cascading problem
- ☑ Run a Study with Lines K, C and S out of Service to determine if this may be a cascading potential problem
- ☐ Issue a Pre-Contingency Manual Load Shed for 3 MVA of relief on Line S based on the Study results for the loss of Lines K and C, this is a cascading problem
- ☐ Issue a Pre-Contingency Manual Load Shed for 25 MVA of relief on Line C based on the Initial SA solution for the loss of Line K, this is a cascading problem



Generic System Line Ratings				
Line	**Loading**	**Normal**	**Emergency**	**Load Dump**
A	101	120	150	160
C	0	65	70	80
D	86	85	95	105
E	91	105	110	120
H	113	160	175	185
K	0	310	350	370
M	92	95	105	115
S	106	75	80	90
T	123	145	160	170
X	178	310	350	370

PJM's N-2 Analysis Procedure

- **Exercise 2:**
  You run a study for the loss of Lines K, C and S

  On the loss of Lines K, C and S Study results indicate the following:

  Line D will go to 124 MVA (118% of Load Dump rating)

  There is no generation that helps with this contingency

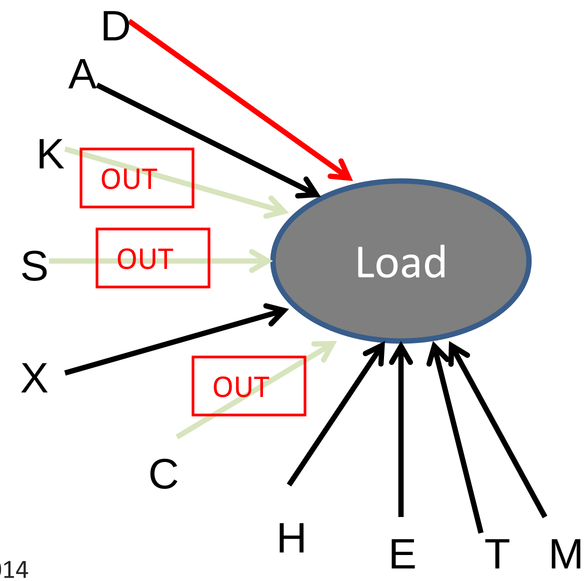
  The TO confirms there are no other options available

- **What is your next action?**

PJM's N-2 Analysis Procedure

On the loss of Lines K, C and S Study results indicate the following :
Line D will go to 124 MVA (118% of LD rating)
What action, if any, should be taken?

- [x] Run a Study with Lines K, C, S and D out of Service to determine if this may be a cascading potential problem
- [ ] Issue a Pre-Contingency Manual Load Shed for 3 MVA of relief on Line C based on the Initial SA solution for the loss of Line K, this is a cascading problem
- [ ] Issue a Pre-Contingency Manual Load Shed for 10 MVA of relief on Line D based on the Study results for the loss of Lines K, C, and S this is a cascading problem
- [ ] Issue a PCLLRW for 10 MVA of relief on Line D based on the Study results for the loss of Lines K, C, and S, this is NOT a cascading problem



Generic System Line Ratings

Line	Loading	Normal	Emergency	Load Dump
A	112	120	150	160
C	0	65	70	80
D	124	85	95	105
E	96	105	110	120
H	129	160	175	185
K	0	310	350	370
M	96	95	105	115
S	0	75	80	90
T	131	145	160	170
X	202	310	350	370

PJM's N-2 Analysis Procedure

- **Exercise 2:**
  You run a study for the loss of Lines K, C, S and D

  On the loss of Lines K, C, S and D Study results indicate the following:

  Line M will go to 138 MVA (120% of Load Dump rating)
  Line E will go to 111 MVA (101% of the Emergency rating)

  There is no generation that helps with this contingency

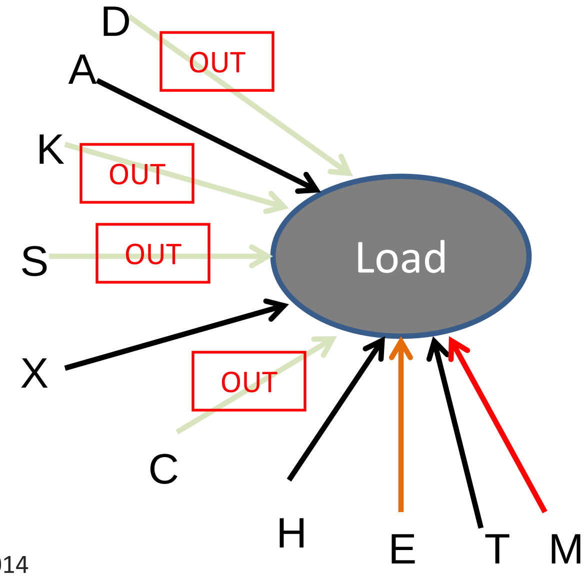
  The TO confirms there are no other options available

- **What is your next action?**

PJM's N-2 Analysis Procedure

On the loss of Lines K, C, S and D Study results indicate the following :
Line M will go to 138 MVA (120% of LD rating), Line E will go to 111 MVA (101% of Emergency rating)
What action, if any, should be taken?

- ☐ Issue a PCLLRW for 7 MVA of relief on Line M based on the Study results for the loss of Line D, this is NOT a cascading problem
- ☐ Issue a Pre-Contingency Manual Load Shed for 3 MVA of relief on Line C based on the Initial SA solution for the loss of Line K, this is a cascading problem
- ☐ Issue a Pre-Contingency Manual Load Shed for 7 MVA of relief on Line M based on the Study results for the loss of Lines K, C, S, and D, this is a cascading problem
- ☑ Run a Study with Lines K, C, S, D and M out of Service to determine if this may be a cascading potential problem



Generic System Line Ratings				
Line	**Loading**	**Normal**	**Emergency**	**Load Dump**
A	126	120	150	160
C	0	65	70	80
D	0	85	95	105
E	111	105	110	120
H	154	160	175	185
K	0	310	350	370
M	138	95	105	115
S	0	75	80	90
T	147	145	160	170
X	214	310	350	370

PJM's N-2 Analysis Procedure

- **Exercise 2:**
  You run a study for the loss of Lines K, C, S, D and M

  On the loss of Lines K, C, S, D and M Study results indicate the following:

  Line E will go to 148 MVA (123% of Load Dump rating)
  Line A will go to 152 MVA (101% of the Emergency rating)
  Line H will go to 176 MVA (101% of the Emergency rating)
  Line T will go to 168 MVA (105% of the Emergency rating)

  There is no generation that helps with this contingency

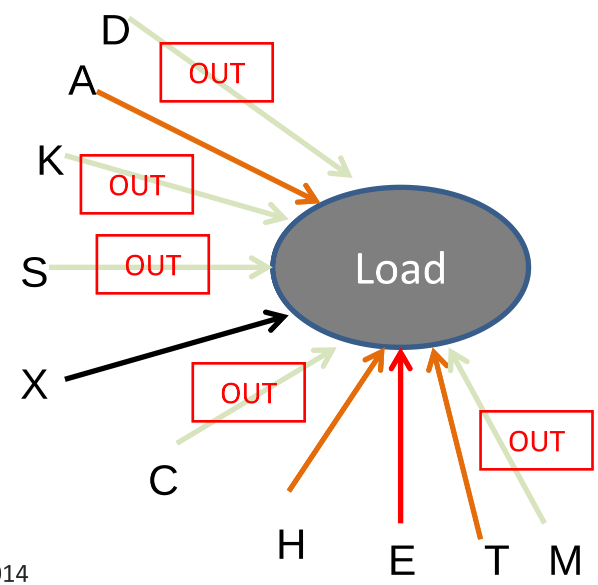
  The TO confirms there are no other options available

- **What is your next action?**

PJM's N-2 Analysis Procedure

On the loss of Lines K, C, S, D and M Study results indicate the following :
Line E will go to 148 MVA (123% of LD rating), Line A to 152 MVA (101% of Emergency rating)
Line H to 111 MVA (101% of Emergency rating) Line T to 168 MVA (105% of Emergency rating)
What action, if any, should be taken?

- [ ] Run a Study with Lines K, C, S, D, M and E out of Service to determine if this may be a cascading potential problem
- [x] Issue a Pre-Contingency Manual Load Shed for 3 MVA of relief on Line C based on the Initial SA solution for the loss of Line K, this is a cascading problem
- [ ] Issue a Pre-Contingency Manual Load Shed for 11 MVA of relief on Line E based on the Study results for the loss of Lines K, C, S, D, and M, this is a cascading problem
- [ ] Issue a PCLLRW for 11 MVA of relief on Line E based on the Study results for the loss of Lines K, C, S, D, and M, this is NOT a cascading problem



Generic System Line Ratings				
Line	**Loading**	**Normal**	**Emergency**	**Load Dump**
A	152	120	150	160
C	0	65	70	80
D	0	85	95	105
E	148	105	110	120
H	176	160	175	185
K	0	310	350	370
M	0	95	105	115
S	0	75	80	90
T	168	145	160	170
X	246	310	350	370

Manual Load Shed Determination Procedure

For a facility exceeding its LD, STE or LTE rating, PJM and TO operators should utilize the following steps:

- ***Step 1***: Contact between PJM and TO should be made immediately. In particular for a facility exceeding its LD rating, there is minimal time for delay outside the initial recognition of the event
- ***Step 2***: Compare RT flows to state estimator flows
  - If there are no discrepancies, move to Step 3
  - For any discrepancies:
    - If the reason for the discrepancies is not immediately obvious, PJM and TO shall agree upon the most conservative values
    - If the reason is immediately obvious and the facility is not in an overload condition
  - PJM and TO should work together to resolve the discrepancy, log it and cease Load Shed Determination Procedure

Manual Load Shed Determination Procedure

- ***Step 3****:* Compare LD and Emergency ratings (LTE and STE, if both are provided) between PJM and TO
  - If there are no rating discrepancies, move on to Step 4
  - For any discrepancies:
    - If the reason for the discrepancies is NOT immediately obvious, PJM and TO shall agree upon the most conservative/lowest values
    - If the reason is immediately obvious and the facility is not in an overload condition
  - PJM and TO should work together as needed to resolve the discrepancy, log it and cease Load Shed Determination Procedure

Manual Load Shed Determination Procedure

- ***Step 4****:* Switching and Generation option
  - For a LD rating overload, there are only 3 options available to alleviate:
    - A reclose attempt on the facility that tripped to cause the violation
    - Pre-studied switching solution
    - And/or Generation Re-dispatch (if generation can move fast enough)
  - If pre-studied switching solution or generation re-dispatch is not available, go to *Step 5*

Note:
A *Pre-Studied Switching Solution* must be …
- A switching that had been agreed upon by both the TO and PJM which:
  - Had been studied prior to the initiating event for present Load Dump overload
  - The study should have accurately reflected the initiating event and present system topology for the area presently experiencing the Load Dump overload
  - The switching solution CANNOT place any other facility into a Normal Rating overload

Manual Load Shed Determination Procedure

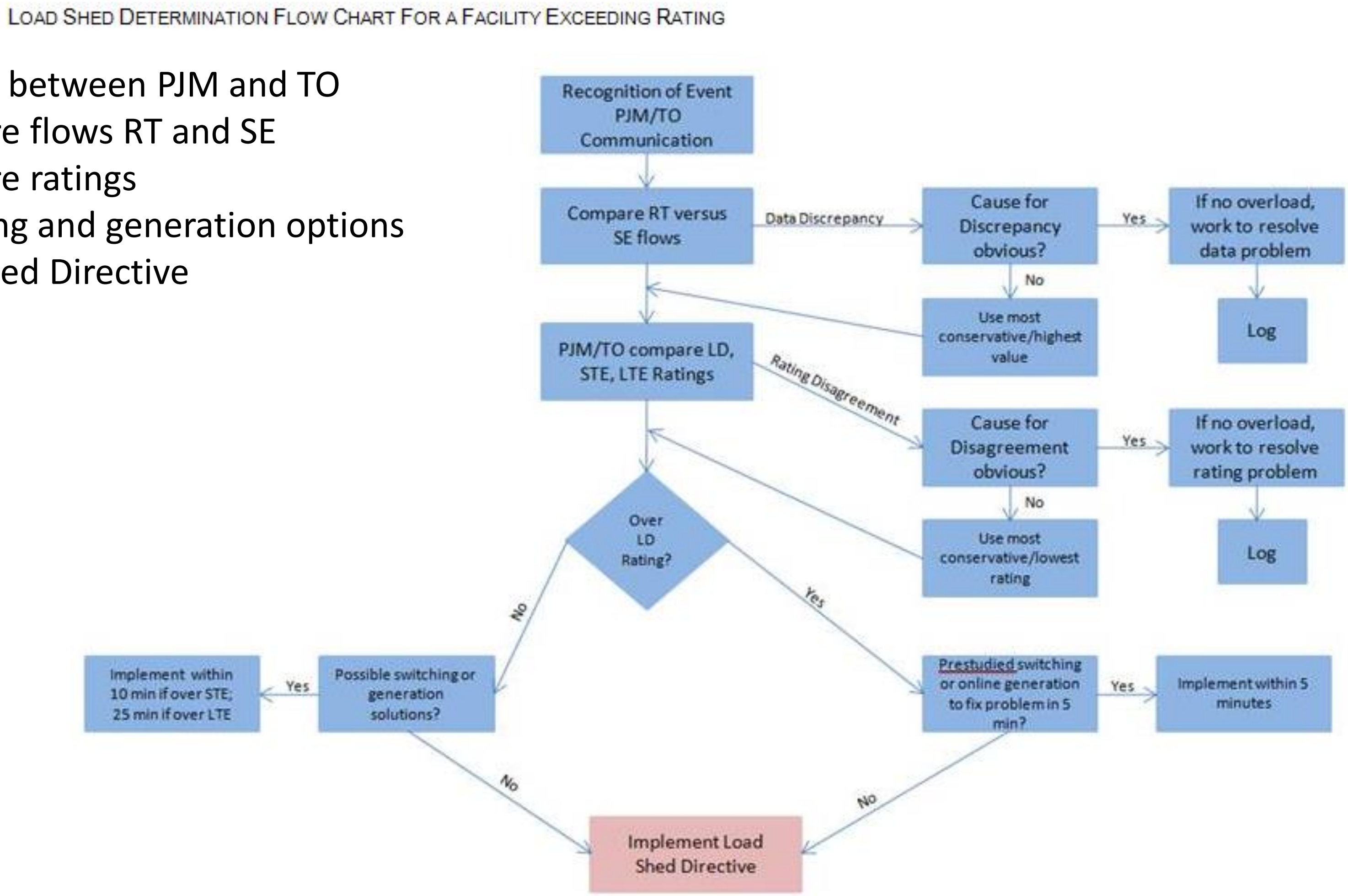
For an Emergency (LTE or STE) overload:

- Operators may have time to study Switching Solutions and/or Generation Re-dispatch
- Once an Emergency rating overload is 5 minutes away from becoming a violation (see bullets below) and if a switching solution and/or re-dispatch is not expected to relieve the overload in the next 5 minutes, go to *Step 5*
- For STE<>LTE
  - 10 minutes after a facility exceeds its STE rating (15 minutes to alleviate from the time of the initial overload)
  - Within "X" minus 5 minutes after a facility exceeds its LTE rating, yet remains below its STE rating

- ***Step 5***: Commence **Load Shed Directive** immediately and without delay

Flow Chart

1. Contact between PJM and TO
2. Compare flows RT and SE
3. Compare ratings
4. Switching and generation options
5. Load Shed Directive



Manual Load Shed Determination Procedure

- After completion of the **Load Shed Determination Procedure**,
- Both parties should be in agreement as to the extent of the overload and need to alleviate
- Keywords:
  - ***Overloaded Facility***: Facility in an Overload of either its EM or LD rating, using End A and End B names as well as applicable voltage(s)
  - ***Facility Flow***: Value, in MVA, for the agreed upon flow across the Overloaded Facility as determined in **Step 2** of the Load Shed Determination Procedure
  - ***Rating***: Rating for the Overloaded Facility which is presently being exceeded (LD, STE or LTE)
  - ***Overload Time***: Initial time, in military -- Eastern Prevailing Time, the Overloaded Facility's Flow began exceeding its Overloaded Rating

Manual Load Shed Determination Procedure

- Keywords (cont.)
  - ***Desired Flow*** : If rating being exceeded is the LD rating, Desired Flow would be the nearest Emergency rating (STE or LTE). If the rating being exceeded is either the STE or LTE rating, the Desired Flow would be the Emergency rating (STE or LTE)
  - ***Load Shed Area***: If an overloaded facility is overloaded with flow from End A to End B, then End B would be the applicable Load Shed Area. If an overloaded facility is overloaded with flow from End B to End A, then End A would be the applicable Load Shed Area

Note: The amount of load shed required in a *Load Shed Area* is typically dependent upon the amount of load under SCADA control in the *Load Shed Area*. As such, the TO may have to shed a substantial amount of load that significantly reduces the flow across the *Overloaded Facility* (sometimes well below the NL rating on said facility) due to limited SCADA control.

However, this is the desired effect, to protect the *Overloaded Facility*. If significant load shed is required, the TO should shed the load first to protect the facility… then, in coordination with PJM, fine-tune the load shed afterwards with the help of additional TO personnel (substation, switchman, etc.)

Manual Load Shed Determination Procedure

- The following is meant to be a template script for issuance of a Load Shed Directive
- The Script should be readily available to both PJM and TO operators as a reference
- The intent of the script is for familiarity and easy recognition of the gravity of the situation
- Both operators should take special note that the tone of the Directive is meant to be formal, clear and specific
- At the beginning, during and at the completion of the Directive, there should be no ambiguity as to what is taking place or what needs to be done to alleviate the situation. As such, no extraneous conversation outside of the directive should take place either during the Directive or at the end of the Directive
- **If at any time during the issuance of the Directive, either party becomes distracted for any reason, they should cancel the order and commence from the beginning**

Example Script

Keywords:

- ***PJM Operator***: John Doe
- ***TO Company***: XYZ Energy
- ***TO Operator***: A.J. Jones
- ***Present Time***: 1208
- ***Overloaded Facility:*** Victorstation 345/138kV #2 Transformer (which is presently overloaded with flow from the 345kV high side down to the 138kV low side)
- ***Facility Flow*** : 705 MVA
- ***Rating***: LD rating. (650 MVA)
- ***Overload Time***: 1206
- ***Desired Flow***: 590 MVA LTE/STE rating
- ***Load Shed Area***: Victorstation 138kV and below

Script Verbiage

PJM Operator:

- “This is PJM Dispatcher John Doe with a Load Shed Directive”
- “As of 1208, the Victorstation 345/138kV #2 Transformer is determined to be exceeding its Load Dump rating of 650 MVA and is presently loaded at 705 MVA. The facility has been exceeding its Load Dump rating since 1206”

TO Operator:

- “I agree that as of 1208, the Victorstation 345/138kV #2 Transformer is determined to be exceeding its Load Dump rating of 650 MVA and is presently loaded at 705 MVA. I also agree that the facility has been exceeding its Load Dump rating since 1206”

PJM Operator:

- That is correct

Script Verbiage

PJM Operator:

- "At this time PJM is initiating a Load Shed Directive to reduce the flow across the Victorstation 345/138kV #2 Transformer to a level not to exceed 590 MVA. XYZ Energy should commence load shed in the Victorstation 138kV and below area immediately"

TO Operator:

- "I agree that a Load Shed Directive has been ordered to immediately commence load shed in the Victorstation 138kV and below area with the intent to reduce the flow across the Victorstation 345/138kV #2 Transformer down to a flow that does not exceed 590 MVA"

PJM Operator:

- That is correct
- "Please call me back to confirm once the load shed is completed"

Sample “Load Shed” call between PJM and AEP

Post Contingency Congestion Management Program

Post-Contingency Congestion Management Program

- Post-contingency Congestion Management Program
  - Background
    - PJM analysis indicates that probability of contingent facility tripping during an off-cost event is less than .05%
    - Prudent to operate to a higher pre-contingency threshold (i.e. 30 minute rating) in areas
      - If switching of quick-start generation is available to eliminate an actual overload should contingent facility tripping occur
    - Implemented as pilot program in 2003 with 5 facilities in Conectiv
      - Congestion costs reduced by more than $2,000,000.00
      - No contingencies occurred

Post-Contingency Congestion Management Program

- Post-contingency Congestion Management Program
  - Criteria
    - Outage of contingent facility must not cause a cascading outage
    - EHV facilities not included in the program
    - Transmission owner will have an established short-term emergency rating (normally 30 minutes)
    - Facilities must have more than 1 quick-start CT or diesel to eliminate the contingency should it occur
      - 120% of necessary generation to obtain required relief from 30 minute rating to normal rating must be demonstrated
      - Generation must have history of being on-line and loaded within 30 minutes 85% of the time
        - Non-winter months only for generation solutions (switching solutions can be used year-round)
      - Condensers will be brought on-line for control once a contingency flow reaches the 4-hour emergency rating

Post-Contingency Congestion Management Program

- Post-contingency Congestion Management Program
  - Criteria
    - TO may utilize switching procedures to control for these facilities
      - Must be studied and approved by PJM
      - Must be implemented via SCADA control
      - Must also have ability to dump sufficient load via SCADA if switching procedure can not be implemented
      - Switching procedures may be implemented pre-contingency once contingency flow exceeds the 30-minute rating and all generation has been called

Post-Contingency Congestion Management Program

- Post-contingency Congestion Management Program
  - Switching Solutions
    - On a pre-contingency basis off-cost operations will commence once simulated contingency flow, using *Guide Implemented* contingency definitions reaches the <u>Long-term emergency rating</u>
    - On a pre-contingency basis off-cost operations will commence once simulated contingency flow, using the *Guide Failed* contingency definitions approaches the <u>Load Dump Rating</u>
    - In the event of a contingent facility tripping, the appropriate guide scheme will be used to ensure flow drops below the Long-term emergency rating. Generation redispatch, if needed, will be used to bring the flow below the normal rating

Post-Contingency Congestion Management Program

- Post-contingency Congestion Management Program
  - Roles/Responsibilities
    - PJM
      - Analysis/approval for facilities in program
      - Publish facilities in Manual M-03, Transmission Operations
      - Operate facility to Short-term rating provided by Trans Owner
    - Transmission Owner
      - Review/comment/challenge/add to facility list
      - Supply 30 minute rating
    - Generation Owner
      - Operate generation in accordance with PJM instruction

Post-Contingency Congestion Management Program

- Post-contingency Congestion Management Program
  - List of facilities is in Transmission Operations Manual 3, Appendix E

Transmission Loading Relief (TLR)

Transmission Loading Relief Procedure (TLR)

- NERC TLR
  - Transmission Loading Relief is a NERC procedure that is used to safely and effectively reduce flow on a transmission element on the bulk power system
  - Used in the Eastern Interconnection
  - Respects transmission service reservation priorities
  - Mitigates potential or actual Operational Security Limit violations

Transmission Loading Relief Procedure (TLR)

- PJM TLR Definition:
  - The PJM procedure includes the NERC procedure but incorporates the generation re-dispatch as a means for managing congestion much earlier in the process

Transmission Loading Relief Procedure (TLR)

- PJM TLR Procedure
  - Step 1 - Implement all non-cost measures to control transmission flows
  - Step 2 - Curtail transactions with transmission service in PJM that are “not willing to pay through congestion”
  - Step 3 - Adjust output of generators off-cost to alleviate overloads
  - Step 4 - Re-dispatches to the fullest extent possible, not including Maximum Emergency Generation, then initiates the NERC TLR procedure as a last resort

Transmission Loading Relief Procedure (TLR)

- PJM TLR Procedure
  - Step 5 - PJM curtails external transmission customers not willing to pay through congestion and charges other external customers willing to pay for the cost of congestion
  - Step 6 - PJM curtails transmission customers willing to pay through congestion (and no longer charges those curtailed for congestion) in Priority order

Transmission Loading Relief Procedure (TLR)

NERC TLR Procedure Levels

TLR Levels 1 - Notification

TLR Level 2 - Hold Interchange Transactions

TLR Level 3a - Reallocation Non-firm Point-to-Point

TLR Level 3b - Curtailment Non-firm Point-to-Point

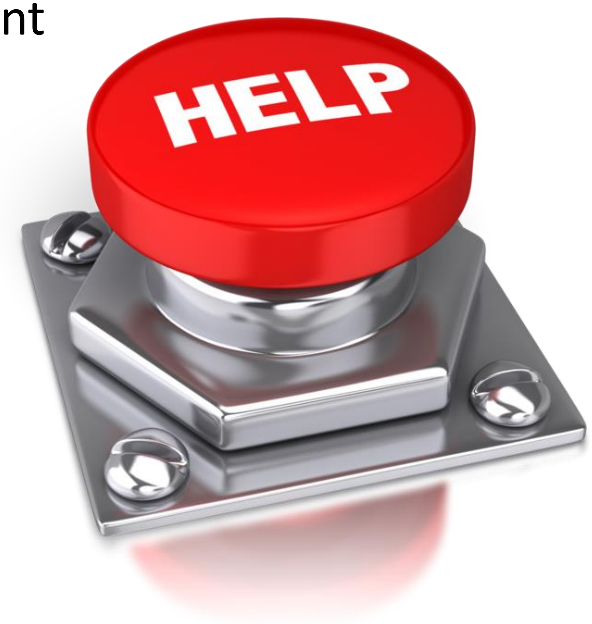
TLR Level 4 - Reconfiguration

TLR Level 5a - Reallocation Firm Point-to-Point

TLR Level 5 b - Curtailment Firm

TLR Level 6 - Emergency Procedure

TLR Level 0 - TLR Concluded



Transmission Loading Relief Procedure (TLR)

Transmission Service Priorities

Priority 0	NX - Next -hour Market Service
Priority 1	NS - Service over secondary receipt and delivery points
Priority 2	NH - Hourly Service
Priority 3	ND - Daily Service
Priority 4	NW - Weekly Service
Priority 5	NM - Monthly Service
Priority 6	NN - Network Integration Transmission Service from sources not designated as network resources
Priority 7	F - Firm point to point Trans Service and Network Integration Transmission Service from designated resources

Transmission Loading Relief Procedure (TLR)

- Other concepts you need to know:
  - Power Flow Model
  - Flowgates
  - Transfer Distribution Factors
  - NERC E-Tags
  - Transmission Service Priorities
  - IDC (Interchange Distribution Calculator)

Transmission Loading Relief Procedure (TLR)

- **Power Flow Model**
  - Models the actual configuration of the Eastern Interconnection
  - Contains Generator & Transmission status
  - Created once every hour
  - Can be updated three times an hour
  - Reliability Coordinators are responsible for updating the model

Transmission Loading Relief Procedure (TLR)

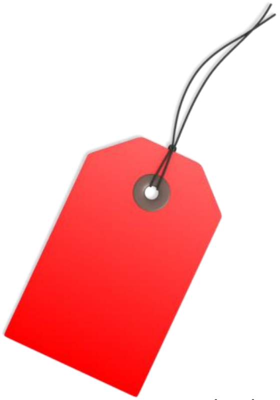
- **FLOWGATES**
  - A flowgate is a boundary between two parts of a transmission system across which there **may** be congestion
  - Flowgates may cut across a number of circuits and because they "cut" across circuits, they are known as CUT SETS
  - The key characteristic of a flowgate is that it has a well defined limit of power that can flow across it
  - A flowgate may have thermal, voltage, phase angle and/or stability limitations

Transmission Loading Relief Procedure (TLR)

- Transfer Distribution Factors
  - Transfer Distribution Factors represent the impact of an interchange transaction between one control area to another control area on a given flowgate
  - There are two types of Transfer Distribution Factors (TDF) calculated
    - Power Transfer Distribution Factors (PTDF) - These factors are calculated to consider the effect of a transaction on a flowgate
    - Outage Transfer Distribution Factor (OTDF) - These factors are calculated to consider the effect of a transaction on a flowgate after an outage of another facility

Transmission Loading Relief Procedure (TLR)

- **NERC E-TAGS**
  - Provide a tag name to determine the Source and Sink Control Areas
  - Provides OASIS information to determine priority
  - Provides the energy profile to determine MW flow
  - Each E-TAG will have Transfer Distribution Factor assigned by the IDC per individual flowgate
  - Only Interchange Transactions with a TDF of 5% or greater are subject to TLR Curtailments



Transmission Loading Relief Procedure (TLR)

- **Interchange Distribution Calculator (IDC)**
  - Primary tool used for NERC TLR
  - Calculates Transfer Distribution Factors (TDF) for specific flowgates
  - Uses an updated power flow model of the Eastern Interconnection
  - Obtains interchange transaction data from NERC E-Tags
  - Provides TLR Level notification
  - Creates Curtailment report for specific flowgates

Constraint Management Mitigation Procedure

Constraint Management Mitigation Procedure

- Purpose
  - Allows for BRIEF deviations from thermal operating criteria to accommodate switching
    - Results in maintaining system integrity by keeping lines/facilities in service during these short term excursions
    - Reduces the occurrence of unnecessary off-cost operation
    - Normal Limits can be exceeded briefly without damaging equipment due to the lengthy thermal time constants for heat build-up in equipment
      - Supported by Equipment Engineers

Constraint Management Mitigation Procedure

- Requirements
  - Pre-agreement by PJM OPD, PJM Dispatch and TO Dispatch (and anyone else who is involved)
    - If the above parties are not in agreement on the use of this procedure, the procedure should not be utilized
  - Planned event MUST be pre-studied on a case by case basis
    - Each operation or use of this procedure should be documented and logged

Constraint Management Mitigation Procedure

- Requirements (cont.)
  - PJM will **NOT** allow actual operation over the Emergency thermal rating on an actual basis for ANY period of time
    - Operation over the normal rating will be tolerated for up to 5 minutes (with an approved “back-out” plan)
  - PJM will **NOT** allow operation over the Load Dump rating on a post-contingency basis for ANY period of time
    - Operation over the Emergency Rating on a post-contingency basis will be tolerated for up to 5 minutes (with an approved “back-out” plan

Constraint Management Mitigation Procedure

- Requirements (cont.)
  - Planned event (overload) should take no longer than 5 minutes
  - "Back-out" plan must be in place to alleviate the overload should event be extended due to unexpected circumstances

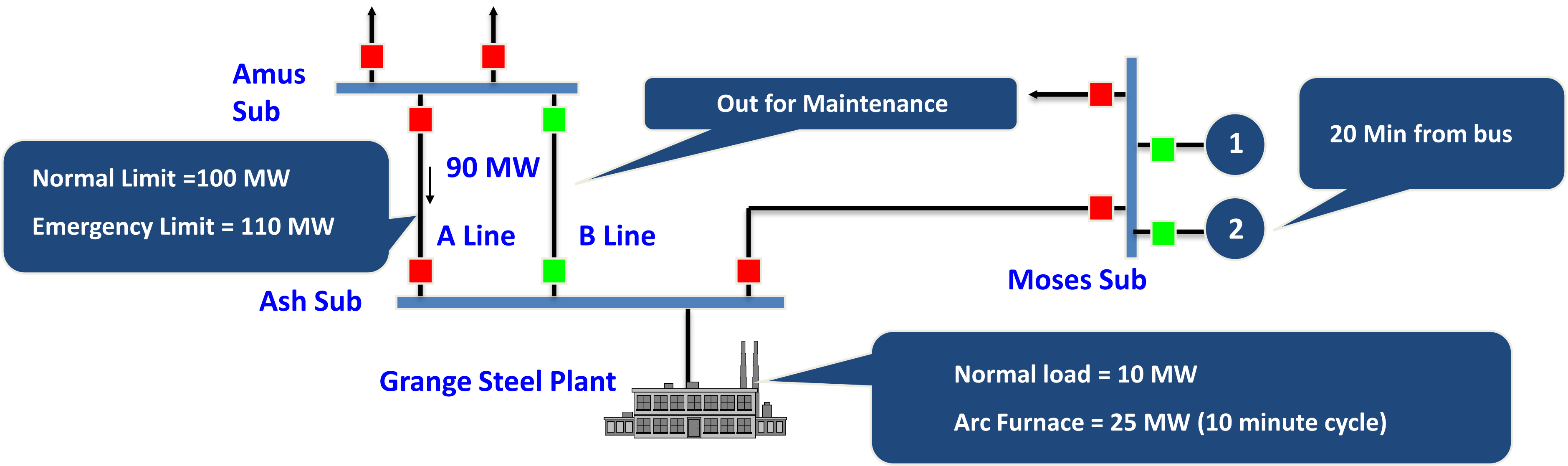
Constraint Management Mitigation Procedure

- Back-out Plan
  - Must be agreed to by all parties
  - Must not impact other members
  - <u>Must return overloaded facility within limits in **15 minutes or less** from the start of the outage</u>
  - Must have sufficient redundancy
    - SCADA and physical control
    - Variety of options
      - Multiple CTs
  - Must be pre-studied and studied for actual system conditions

Constraint Management Mitigation Procedure

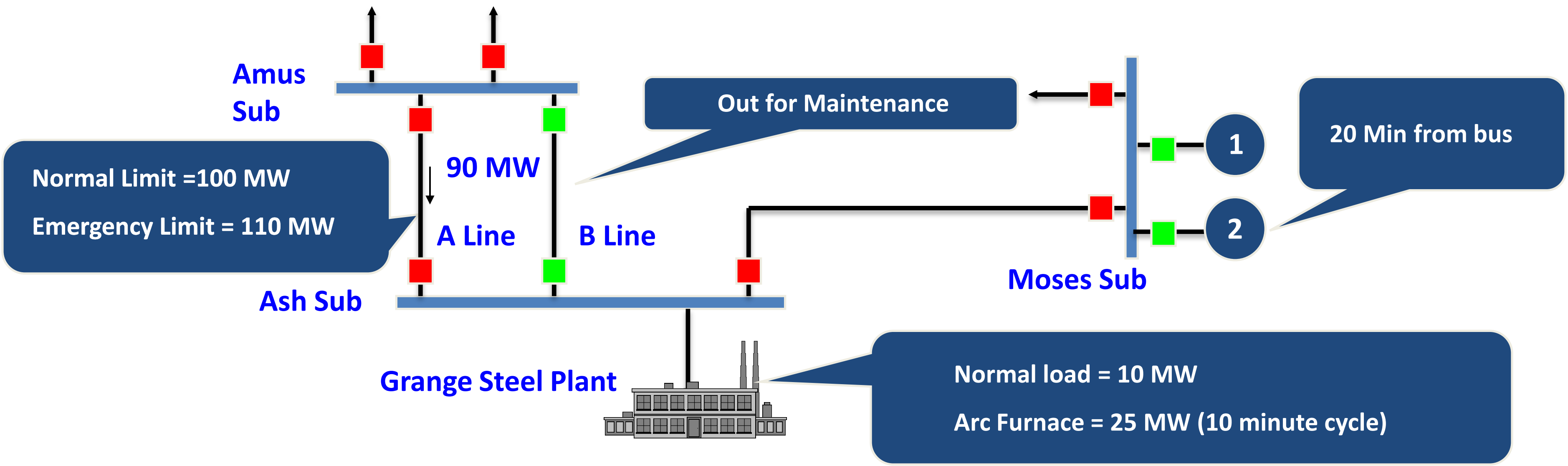
- General
  - Communication and Coordination are the keys to success of this procedure
    - PJM<-> TO,   TO<-> Field
  - All personnel must be in place and ready to implement “Back-out” plan if it becomes necessary
  - No safety or standard switching procedures should be violated in implementing the back out plan
  - ALL requirements of this procedure must be met to allow for the application of this procedure
  - This procedure is an option available to the TO and may not be applicable for all situations

Constraint Management Mitigation Procedure



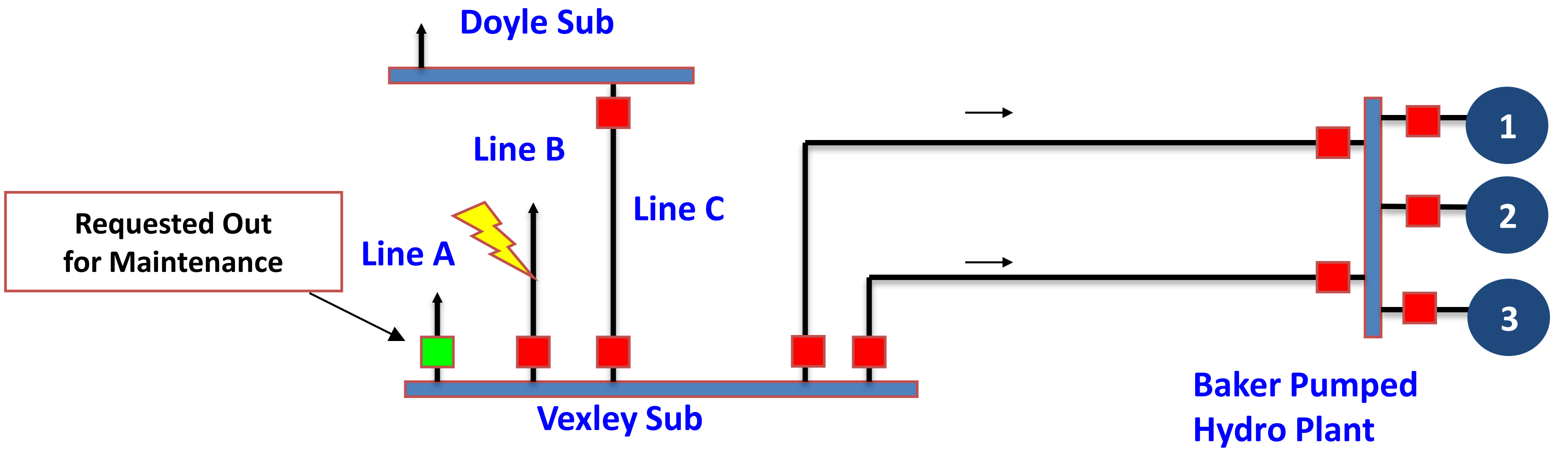
PAL Power wants to take out line Amus – Ash B Line for maintenance. If the Grange Steel Plant arc furnace is on, the load on the A Line increases to 115 MW. PAL Power says that these furnaces generally only run for a 10 minute cycle, then the loading will return to under the 100 MW limit. They have a "back-out" plan in case the arc furnace stays on longer than expected, running the Moses CTs will reduce the A Line flow under the 100 MW limit

Constraint Management Mitigation Procedure



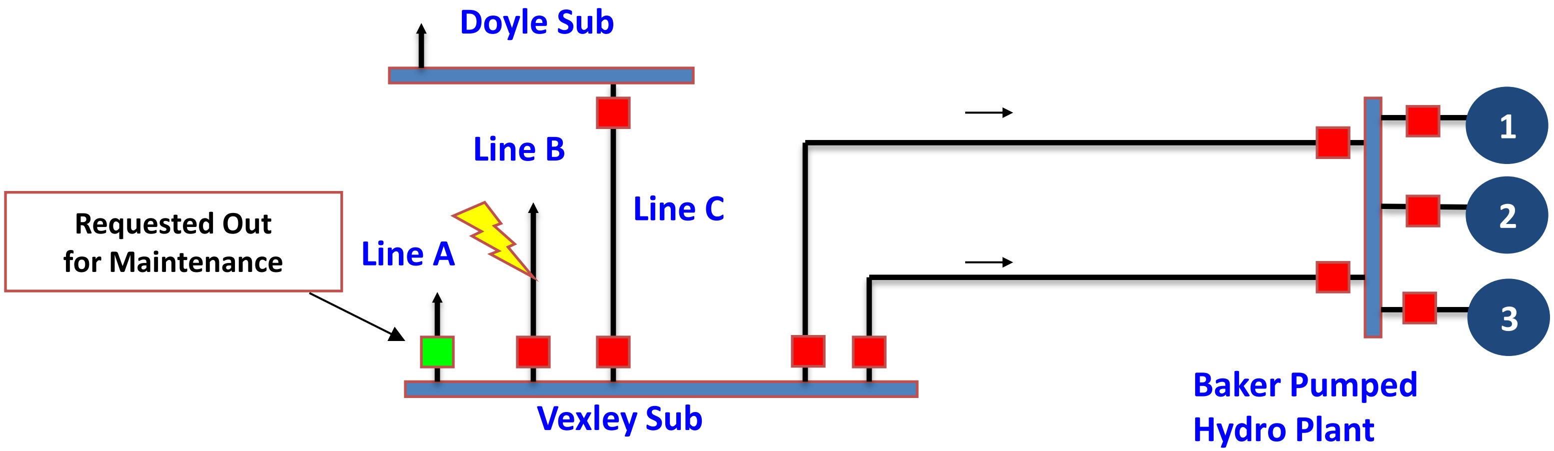
- **This action is <u>NOT</u> a candidate for the Constraint Management Mitigation Procedure for the following reasons:**
  - **The Emergency limit on A Line can not be exceeded for any length of time**
  - **In this example the Emergency limit would be exceeded for at least 10 minutes**
- **The Moses CTs are 20 minutes from the bus**
  - **The "back-out" plan must alleviate the overload within 15 minutes**

Constraint Management Mitigation Procedure



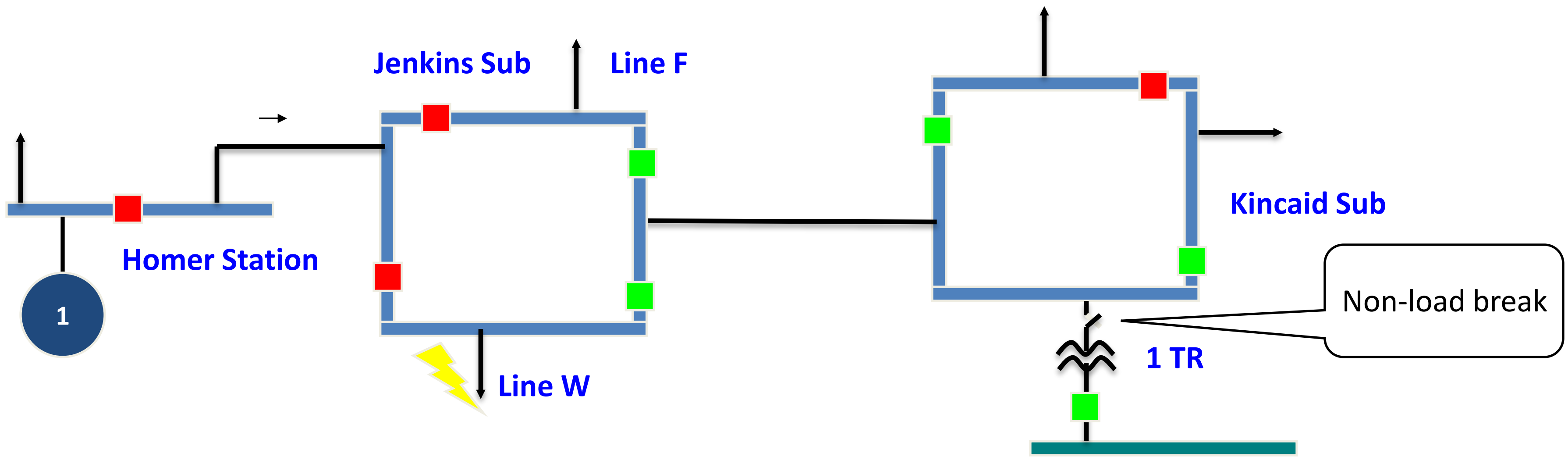
PAL Power wants to take out Line A for 1 week for maintenance. If all 3 pumps are on at the Baker Pumped Hydro Plant, a contingency exists on Line C for the loss of Line B (with Line A out of service). This contingency is over the emergency rating on Line C (on a contingency basis) but under the Load Dump Rating. PAL Power has a "back-out" plan of dumping one of the three pumps at Baker Pumped Hydro Plant (which they own) to bring the loading on Line C back under the normal rating in within 10 minutes

Constraint Management Mitigation Procedure



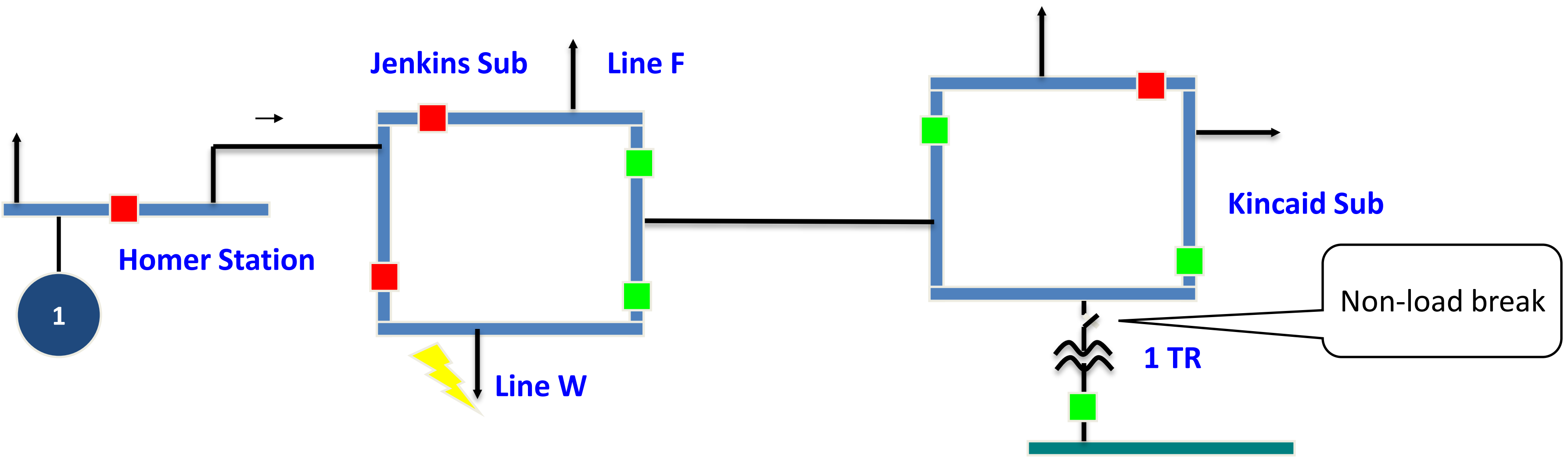
- **This action is <u>NOT</u> a candidate for the Constraint Management Mitigation Procedure for the following reason:**
  - **The Contingency on Line C will exist for more than 5 minutes**
- **The Constraint Management Mitigation Procedure allows for operation over the applicable Emergency Rating on a post contingency basis for up to 5 minutes only**

Constraint Management Mitigation Procedure



PAL Power wants to take out 1 TR at Kincaid Sub for maintenance. The high side disconnect of the transformer is non-load break and must be operated de-energized. This will entail switching out the Jenkins – Kincaid line to open the disconnect. The Jenkins – Kincaid line can then be switched back into service. However, while the Jenkins – Kincaid line is off, studies indicate Line F will be over emergency rating (under Load Dump) for the loss of Line W. The back-out plan is to open the bus tie CB at Homer Station to alleviate the contingency if necessary. This plan has been studied and will alleviate the contingency immediately upon opening the tie CB. Personnel are in place at all three substations for the switching and it is anticipated that the disconnect can be opened in less than 5 minutes. All those affected by this plan have been notified and are in agreement with the plan

Constraint Management Mitigation Procedure



- **This action IS a candidate for the Constraint Management Mitigation Procedure for the following reasons:**
  - **The contingency on Line F for the loss of Line W is only expected to last for less than 5 minutes**
  - **The contingency on Line F is over the Emergency Rating but UNDER the Load Dump Rating**
- **The Back-out plan will relieve the contingency in a total time of under 15 minutes. The back-out plan was approved by all parties and studied thoroughly**

Voltage Operating Criteria

Voltage Limits

- Definition
  - A high and/or low limit placed on voltage to avoid damage to equipment and maintain power system voltage levels at a reliable level
- Determination of Voltage Limits
  - Established by equipment manufacturers
  - Affected Equipment
    - Motors
    - Transformers
    - Generators
    - Loads
    - Capacitors

Voltage Limits

- Determination of Voltage Limits (cont.)
  - System voltage limits
    - Maintain system reliability
      - High voltage limit protects equipment from damage
      - Low voltage limit protects system from voltage instability and equipment damage
    - ANSI Standards provide basis for voltage schedules
      - 97.5% - 105.0% Normal
      - 95.0% - 105.8% Emergency
      - These limits are for customer voltage

Voltage Limits

- Consequences of deviations from voltage limits
  - Low voltage
    - Dim lights
    - Slow heating of heating devices
    - Difficulty starting motors
    - Overheating/damage to motors
  - High voltage
    - Light bulb life decreased
    - Electronic devices life decreased

Voltage Limits

PJM Baseline Voltage Limits									
Limit	**765 kV**	**500 kV**	**345 kV**	**230 kV**	**161 kV**	**138 kV**	**115 kV**	**69 kV**	**34 kV**
High	803.2 (1.05)	550.0 (1.10)	362.0 (1.05)	242.0 (1.05)	169.0 (1.05)	145.0 (1.05)	121.0 (1.05)	72.5 (1.05)	37.4 (1.10)
Normal Low	726.8 (.95)	500.0 (1.00)	328.0 (.95)	219.0 (.95)	153.0 (.95)	131.0 (.95)	109.0 (.95)	65.5 (.95)	31.3 (.92)
Emergency Low*	703.8 (.92)	485.0 (.97)	317.0 (.92)	212.0 (.92)	148.0 (.92)	127.0 (.92)	106.0 (.92)	63.5 (.92)	30.6 (.90)
Load Dump*	688.5 (.90)	475.0 (.95)	310.0 (.90)	207.0 (.90)	145.0 (.90)	124.0 (.90)	103.0 (.90)	62.0 (.90)	0.0
Voltage Drop Warning*	5.0%	2.5%	4.0-6.0%	4.0-6.0%	4.0-6.0%	4.0-6.0%	4.0-6.0%	4.0-6.0%	5.0%
Voltage Drop Violation**	8.0-10.0%	5.0-8.0%**	5.0-8.0%	5.0-8.0%	5.0-10.0%	5.0-10.0%	5.0-10.0%	5.0-10.0%	8.0%

* Refer to PJM Manual for Emergency Procedures (M-13)

** The voltage drop violation percentage may vary dependent on PJM analysis.

Exhibit 3: PJM Base Line Voltage Limits

Voltage Limits

- Transmission Owners may specify bus-specific voltage limits
  - Submit limit in writing to PJM, Manager Operations Planning
  - PJM will evaluate these limits for reasonableness
  - PJM will return confirmation of new limits to SOS representative when limits are in EMS
  - PJM will forward new limits to System Planning for use in future planning studies
  - Provided engineering justification exists, PJM allows member company to set more restrictive voltage limits
    Manual M-03, Attachment C for details

Detection of Voltage Problems

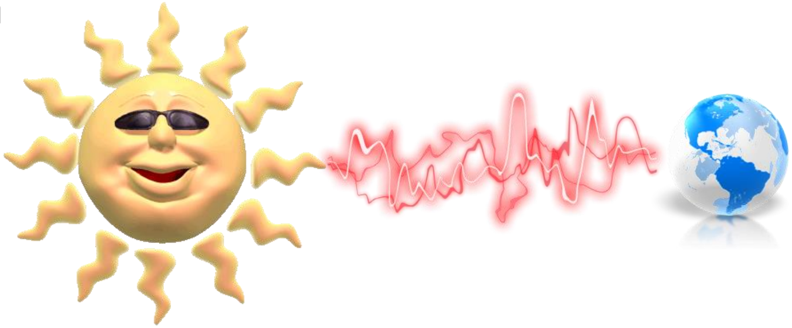
- Observe Critical Bus Voltages
  - Where do problems appear first?
- Observe Voltages in an Area
  - Determine if deviation is on a single bus or over an area on the system
- Observe Voltage Alarms
- Monitoring Sources
  - EMS, Mapboard, Trend Reports, Field Reports, Customer Complaints
  - Monitor voltages, limits, alarms, and MVAR flow

VAR Sources and Sinks

- Voltage Control Means MVAR Control
  - Control of voltage and reactive power are inseparable!
    - MVAR sources support or hold up voltages
      - Capacitors
      - Generators / Synchronous Condensers
      - Static VAR Compensators
      - System Capacitance
    - MVAR sinks pull down voltages
      - Reactors
      - Generators / Synchronous Condensers
      - Loads
      - Mvar Losses
      - Static VAR Compensators

Causes of Low Voltage

- Due to excessive VAR loading
  - Usually seen as voltage drop in an area rather than a single bus
- Due to voltage regulation malfunction
  - Generator voltage regulator may fail
  - Transformer tap hang-up
  - Usually seen as voltage decrease at a single bus
  - May result in an imbalance in MVAR flows or circulating MVAR
- Due to Geo-Magnetic Disturbance
  - Increased VAR requirement in system
    - Var absorption by EHV transformers

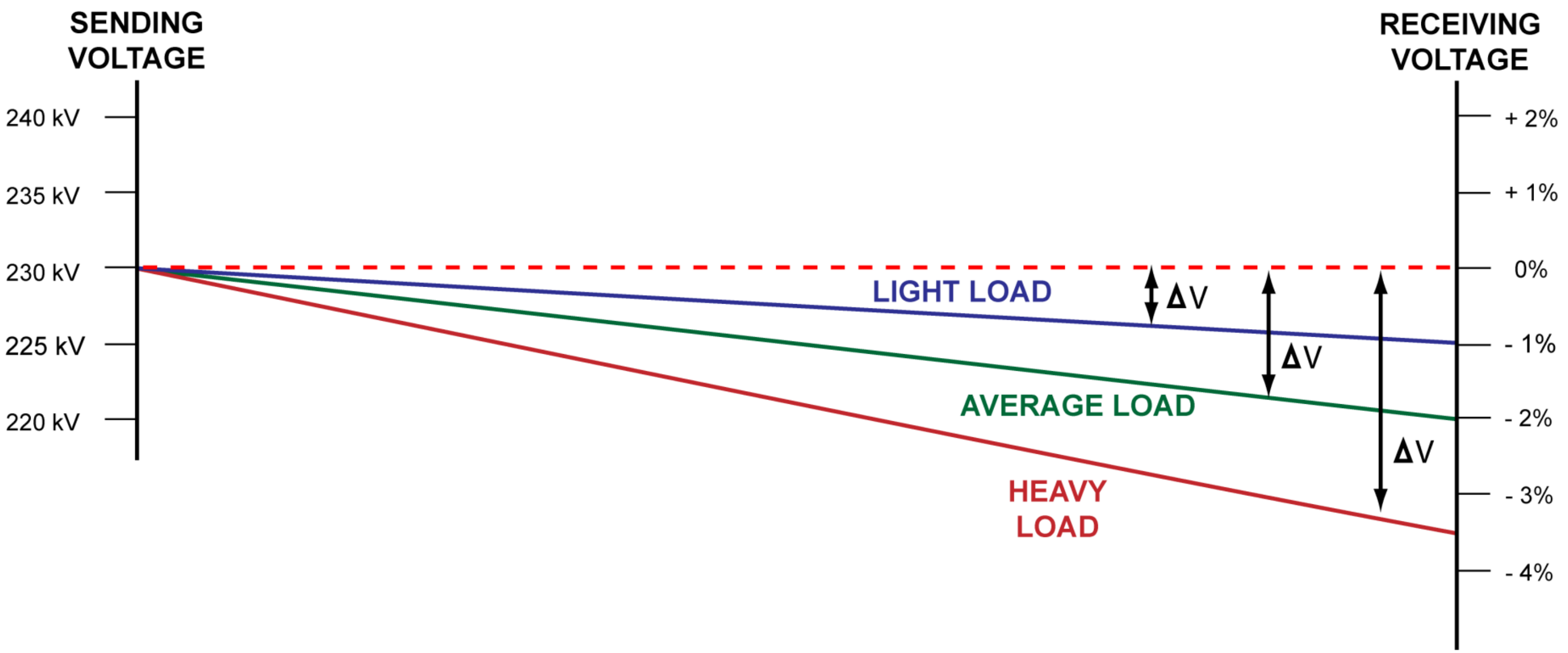


Causes of High Voltage

- Due to light load
  - Caused by excess line capacitance
  - Voltage rise in area rather than a single bus
- Due to switching in a line with high capacitive charging current
  - Reactive supplied by charging of line
- Also caused by:
  - Voltage regulation malfunction
  - Excess VAR sources on system

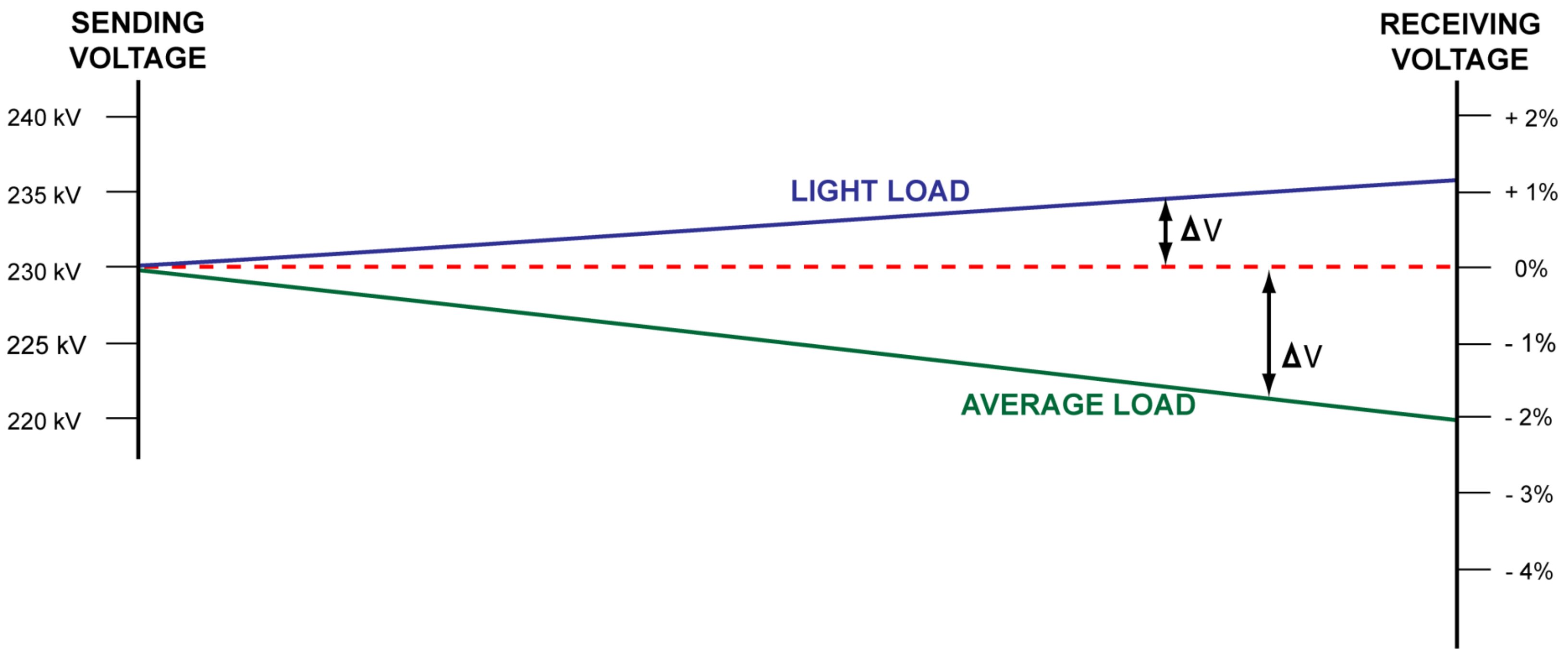
System Voltage Characteristics

- Results
  - Result is constantly changing voltage profile



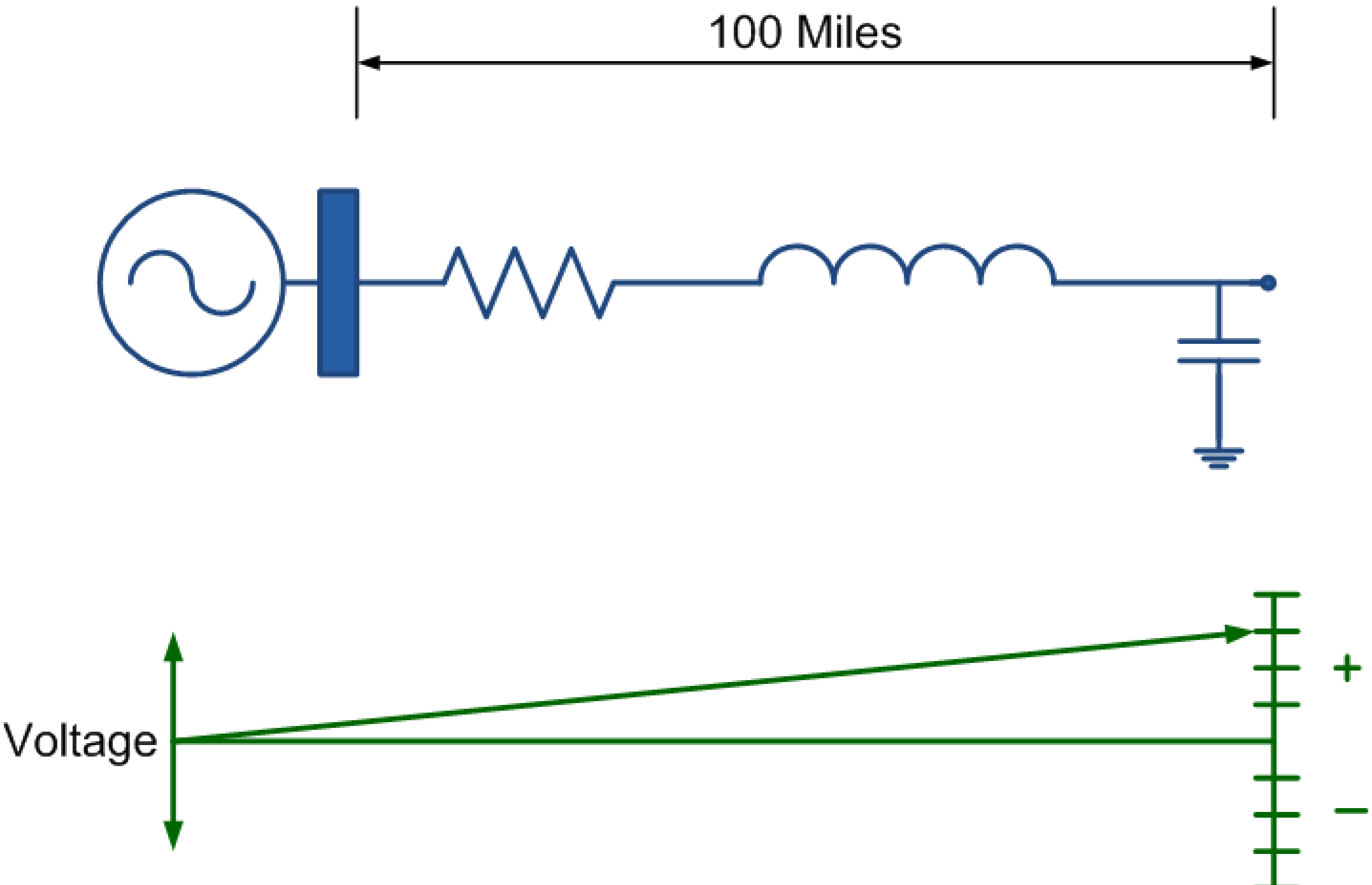
System Voltage Characteristics

- Results
  - For light loads, voltage can rise due to low losses and line capacitance



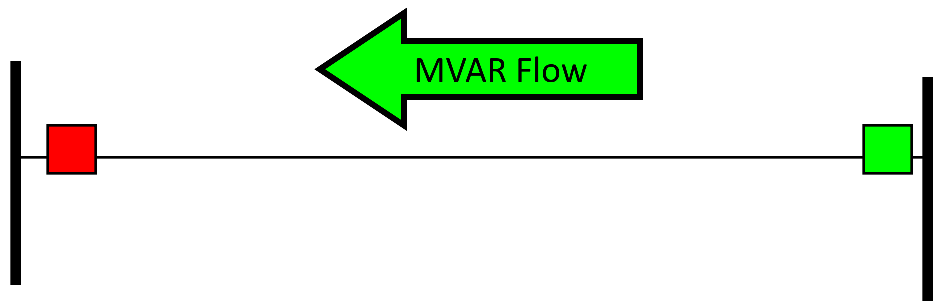
VARs From Transmission Lines

- Line open at one end



VARs From Transmission Lines

- Switching Operations
  - Open one end
    - Provides VARs to closed end of line due to line capacitance



VARs From Transmission Lines

- VARs supplied by charging of line

MVARs Supplied by Lines and Cables		
Voltage	Transmission Line	Transmission Cable
765 kV	4.6 MVAR/Mile	
500 kV	1.7 MVAR/Mile	
345 kV	0.8 MVAR/Mile	15–30 MVAR/Mile
230 kV	0.3 MVAR/Mile	5-15 MVAR/Mile
115 kV	0.1 MVAR/Mile	2-7 MVAR/Mile

VARs From 500kV Transmission Lines

The attached chart contains Open Circuit Terminal Voltage Control information. Open Circuit Terminal Voltage Control												
				Closed Terminal Voltage (V2)								
				500 kV (1.0 pu)			525 kV (1.05 pu)			550 kV (1.1 pu)		
From Bus — To Bus	**Line Number**	**Mileage**	**Closed End Voltage Increase At Switching**	**Chrg MVAR (Q-Base)**	**V1**	**V1 Incr**	**Chrg MVAR**	**V1**	**V1 Chrg**	**Chrg MVAR**	**V1**	**V1 Incr**
Keystone - S. Bend	5001 / 513	2		0.4	500.0	0.0	0.4	525.0	0.0	0.4	550.0	0.0
Keystone - Cabot	5002	27	0.5	49.1	500.8	0.8	54.1	525.8	0.8	59.4	550.8	0.8
Keystone - Conemaugh	5003	29	0.6	42.1	500.8	0.8	46.4	525.9	0.9	50.9	550.9	0.9
Keystone - Juniata	5004	118	3.1	196.7	514.7	14.7	216.9	540.4	15.4	238.0	566.1	16.1
Conemaugh - Juniata	5005	121	4.9	201.2	515.4	15.4	221.8	541.1	16.1	243.5	566.9	16.9
Conemaugh - Hunterstown	5006	112	4.2	186.3	513.2	13.2	205.4	538.8	13.8	225.4	564.5	14.5
Peach Bottom - TMI	5007	42	0.8	67.2	501.8	1.8	74.1	526.9	1.9	81.3	552.0	2.0
Juniata - TMI	5008	44	2.6	73.1	502.0	2.0	80.6	527.1	2.1	88.5	552.2	2.2
Juniata - Alburtis	5009	88	3.7	146.7	508.0	8.0	161.7	533.4	8.4	177.5	558.8	8.8
Peach Bottom-Limerick	5010	57	1.9	98.4	503.4	3.4	108.4	528.5	3.5	119.0	553.7	3.7
Conastone - Brighton	5011	77	3.0	112.6	506.1	6.1	124.2	531.4	6.4	136.3	556.7	6.7
Conastone - Peach Bottom	5012	16	1.4	27.4	500.3	0.3	30.2	525.3	0.3	33.2	550.3	0.3
Hunterstown - Conastone	5013	40	1.7	73.2	501.6	1.6	80.7	526.7	1.7	88.6	551.8	1.8
Peach Bottom – Rock Springs	5014	34	2.2	59.1	501.2	1.2	65.1	526.3	1.3	71.5	551.3	1.3

Attachment B - Transmission Operation Manual

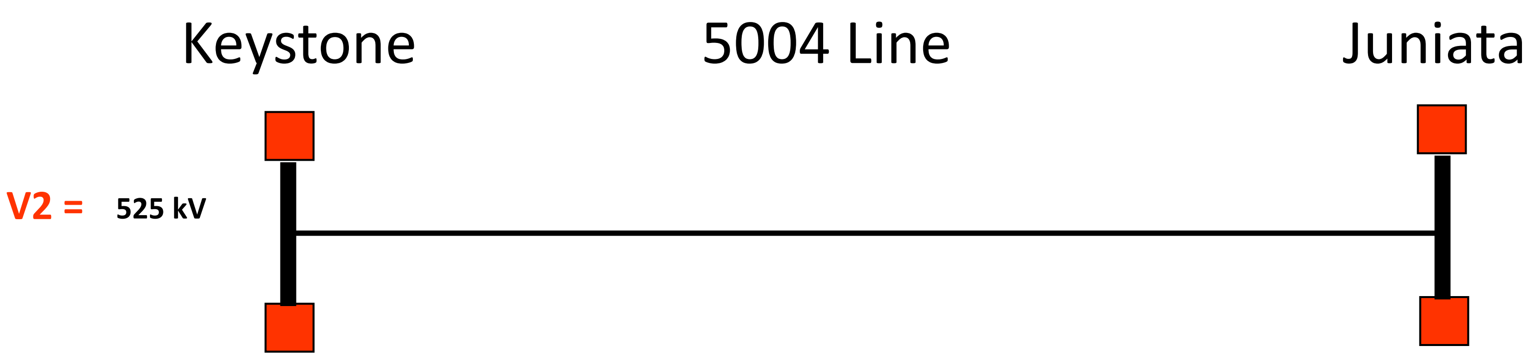
VARs From 765kV Transmission Lines

The attached chart contains Open Circuit Terminal Voltage Control information. Open Circuit Terminal Voltage Control													
				Closed Terminal Voltage (V2)									
				765 kV (1.0 pu)			790 kV (1.03 pu)			815 kV (1.07 pu)			
From Bus - To Bus	Line Number	Mileage	Closed End Voltage Increase @ switching	Chrg MVAR (Q-Base)	V1	V1 Incr	Chrg MVAR (Q-Base)	V1	V1 Incr	Chrg MVAR (Q-Base)	V1	V1 Incr
23 Collins - 112 Wilton Center	11216	27.4		137.5	766.3	1.3	146.6	791.3	1.3	156.0	816.3	1.3
23 Collins - 167 Plano	2315	34.5		173.3	766.9	1.9	184.8	792.0	2.0	196.7	817.0	2.0
Amos - Culloden		15		76.4	765.4	0.4	81.5	790.5	0.5	86.8	815.5	0.5
Amos – Mountaineer		46		218.5	768.6	3.6	233.1	793.7	3.7	248.0	818.8	3.8
Amos - N. Proctorville		32		150.0	766.7	1.7	160.0	791.7	1.7	170.2	816.8	1.8
Axton - Jacksons Ferry		73		337.3	773.5	8.5	359.7	798.8	8.8	382.9	824.0	9.0
Baker – Broadford		125		590.8	790.8	25.8	630.1	816.6	26.6	670.6	842.4	27.4
Baker - Hanging Rock		31		140.8	766.5	1.5	150.1	791.6	1.6	159.8	816.6	1.6
Belmont - Kammer		49		220.8	768.8	3.8	235.5	793.9	3.9	250.7	819.0	4.0
Belmont – Mountaineer		66		312.1	772.4	7.4	332.8	797.6	7.6	354.2	822.8	7.8
Broadford - Jacksons Ferry		49		227.0	768.9	3.9	242.1	794.0	4.0	257.7	819.2	4.2
Cloverdale - Jacksons Ferry		65		303.2	771.9	6.9	323.4	797.2	7.2	344.2	822.4	7.4
Cloverdale - Joshua Falls		57		266.6	770.3	5.3	284.3	795.5	5.5	302.6	820.7	5.7

Attachment B - Transmission Operation Manual

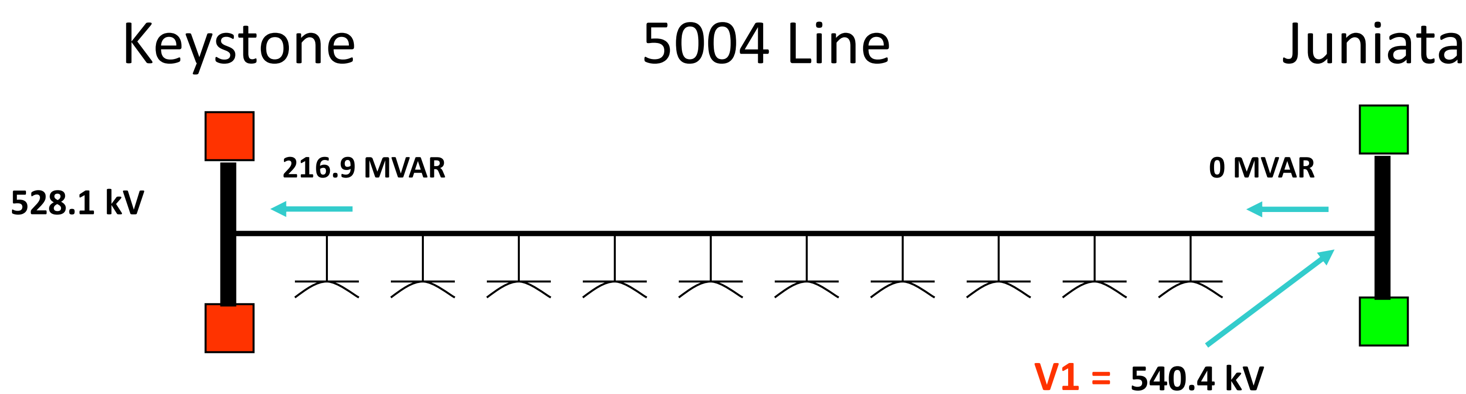
VARs From Transmission Lines

Open Circuit Terminal Voltage Control												
				Closed Terminal Voltage (V2)								
				500 kV (1.0 pu)			525 kV (1.05 pu)			550 kV (1.1 pu)		
From Bus — To Bus	Line Number	Mileage	Closed End Voltage Increase At Switching	Chrg MVAR (Q-Base)	V1	V1 Incr	Chrg MVAR	V1	V1 Chrg	Chrg MVAR	V1	V1 Incr
Keystone-Yukon	5001	39	0.9	70.8	501.6	1.6	78.1	526.7	1.7	85.7	551.7	1.7
Keystone-Cabot	5002	27	0.5	49.1	500.8	0.8	54.1	525.8	0.8	59.4	550.8	0.8
Keystone-Conemaugh	5003	29	0.6	42.1	500.8	0.8	46.4	525.9	0.9	50.9	550.9	0.9
KEYSTONE-JUNIATA	**5004**	**118**	**3.1**	**196.5**	**514.5**	**14.5**	**216.9**	**540.4**	**15.4**	**238.0**	**566.1**	**16.1**



VARs From Transmission Lines

Open Circuit Terminal Voltage Control												
				Closed Terminal Voltage (V2)								
				500 kV (1.0 pu)			525 kV (1.05 pu)			550 kV (1.1 pu)		
From Bus — To Bus	Line Number	Mileage	Closed End Voltage Increase At Switching	Chrg MVAR (Q-Base)	V1	V1 Incr	Chrg MVAR	V1	V1 Chrg	Chrg MVAR	V1	V1 Incr
Keystone-Yukon	5001	39	0.9	70.8	501.6	1.6	78.1	526.7	1.7	85.7	551.7	1.7
Keystone-Cabot	5002	27	0.5	49.1	500.8	0.8	54.1	525.8	0.8	59.4	550.8	0.8
Keystone-Conemaugh	5003	29	0.6	42.1	500.8	0.8	46.4	525.9	0.9	50.9	550.9	0.9
KEYSTONE-JUNIATA	5004	118	3.1	196.5	514.5	14.5	216.9	540.4	15.4	238.0	566.1	16.1



Open Circuit Terminal Voltage Exercise

The attached chart contains Open Circuit Terminal Voltage Control information. Open Circuit Terminal Voltage Control												
				Closed Terminal Voltage (V2)								
				500 kV (1.0 pu)			525 kV (1.05 pu)			550 kV (1.1 pu)		
From Bus — To Bus	Line Number	Mileage	Closed End Voltage Increase At Switching	Chrg MVAR (Q-Base)	V1	V1 Incr	Chrg MVAR	V1	V1 Chrg	Chrg MVAR	V1	V1 Incr
Keystone - S. Bend	5001 / 513	2		0.4	500.0	0.0	0.4	525.0	0.0	0.4	550.0	0.0
Keystone - Cabot	5002	27	0.5	49.1	500.8	0.8	54.1	525.8	0.8	59.4	550.8	0.8
Keystone - Conemaugh	5003	29	0.6	42.1	500.8	0.8	46.4	525.9	0.9	50.9	550.9	0.9
Keystone - Juniata	5004	118	3.1	196.7	514.7	14.7	216.9	540.4	15.4	238.0	566.1	16.1
Conemaugh - Juniata	5005	121	4.9	201.2	515.4	15.4	221.8	541.1	16.1	243.5	566.9	16.9
Conemaugh - Hunterstown	5006	112	4.2	186.3	513.2	13.2	205.4	538.8	13.8	225.4	564.5	14.5
Peach Bottom - TMI	5007	42	0.8	67.2	501.8	1.8	74.1	526.9	1.9	81.3	552.0	2.0
Juniata - TMI	5008	44	2.6	73.1	502.0	2.0	80.6	527.1	2.1	88.5	552.2	2.2
Juniata - Alburtis	5009	88	3.7	146.7	508.0	8.0	161.7	533.4	8.4	177.5	558.8	8.8
Peach Bottom-Limerick	5010	57	1.9	98.4	503.4	3.4	108.4	528.5	3.5	119.0	553.7	3.7
Conastone - Brighton	5011	77	3.0	112.6	506.1	6.1	124.2	531.4	6.4	136.3	556.7	6.7
Conastone - Peach	5012	16	1.4	27.4	500.3	0.3	30.2	525.3	0.3	33.2	550.3	0.3

We're ready to switch the Conemaugh-Juniata 500 kV Line back into service by energizing the line at the Conemaugh Substation. The current bus voltage at Conemaugh is 525 kV.

What will the bus voltage be after the line is first energized at Conemaugh?

- **529.9 kV**

What would the open end voltage be at Juniata?

- **541.1 kV**

Open Circuit Terminal Voltage Exercise

The attached chart contains Open Circuit Terminal Voltage Control information. Open Circuit Terminal Voltage Control												
				Closed Terminal Voltage (V2)								
				765 kV (1.0 pu)			790 kV (1.03 pu)			815 kV (1.07 pu)		
From Bus - To Bus	**Line Number**	**Mileage**	**Closed End Voltage Increase @ switching**	**Chrg MVAR (Q-Base)**	**V1**	**V1 Incr**	**Chrg MVAR (Q-Base)**	**V1**	**V1 Incr**	**Chrg MVAR (Q-Base)**	**V1**	**V1 Incr**
23 Collins - 112 Wilton Center	11216	27.4		137.5	766.3	1.3	146.6	791.3	1.3	156.0	816.3	1.3
23 Collins - 167 Plano	2315	34.5		173.3	766.9	1.9	184.8	792.0	2.0	196.7	817.0	2.0
Amos - Culloden		15		76.4	765.4	0.4	81.5	790.5	0.5	86.8	815.5	0.5
Amos – Mountaineer		46		218.5	768.6	3.6	233.1	793.7	3.7	248.0	818.8	3.8
Amos - N. Proctorville		32		150.0	766.7	1.7	160.0	791.7	1.7	170.2	816.8	1.8
Axton - Jacksons Ferry		73		337.3	773.5	8.5	359.7	798.8	8.8	382.9	824.0	9.0
Baker – Broadford		125		590.8	790.8	25.8	630.1	816.6	26.6	670.6	842.4	27.4
Baker - Hanging Rock		31		140.8	766.5	1.5	150.1	791.6	1.6	159.8	816.6	1.6
Belmont - Kammer		49		220.8	768.8	3.8	235.5	793.9	3.9	250.7	819.0	4.0
Belmont – Mountaineer		66		312.1	772.4	7.4	332.8	797.6	7.6	354.2	822.8	7.8

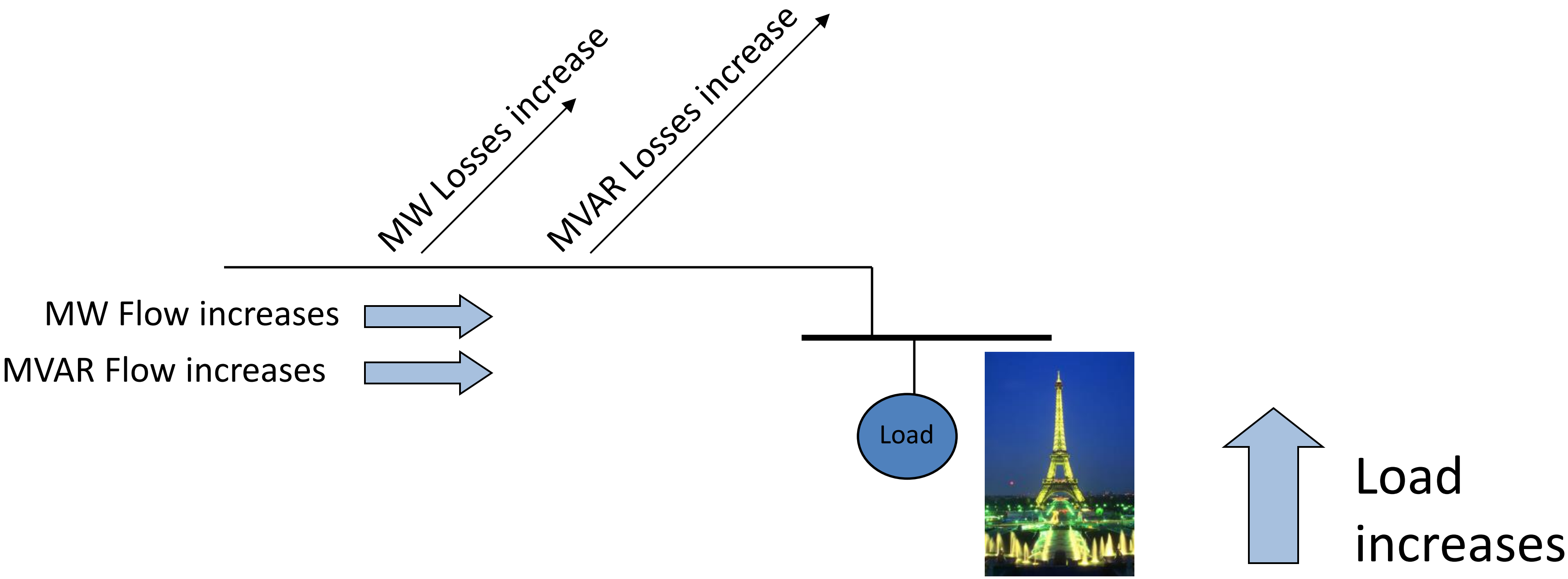
We’re ready to switch the Baker-Broadford 765 kV Line back into service by energizing the line at the Baker Substation. The current bus voltage at Baker is 790 kV.

What would the open end voltage be at Broadford?

- **816.6 kV**

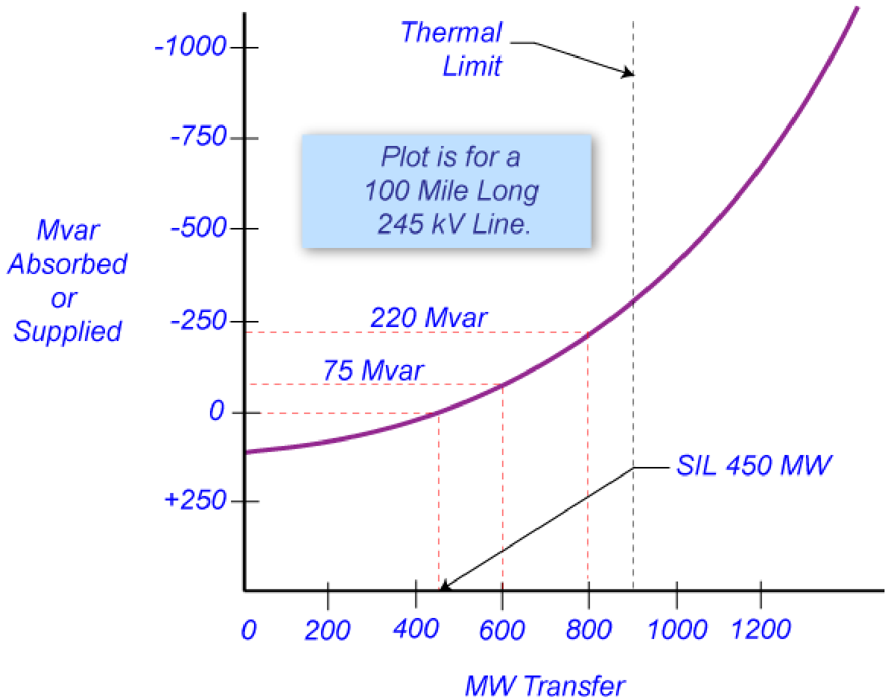
VARs From Transmission Lines

- Line connected to load
  - Power (MW) losses increase with load
  - Reactive (MVAR) losses increase with load



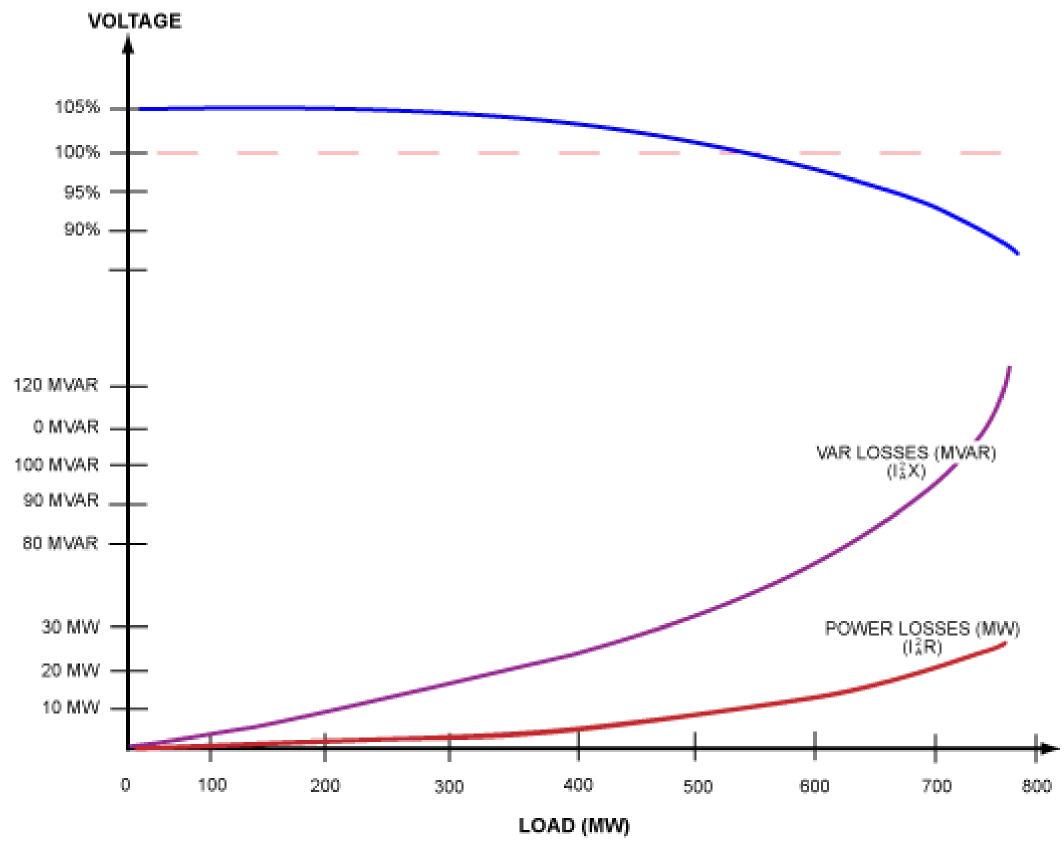
VARs From Transmission Lines

- Surge Impedance Loading
  - Loading point where VAR losses on a line equal VARs generated by line



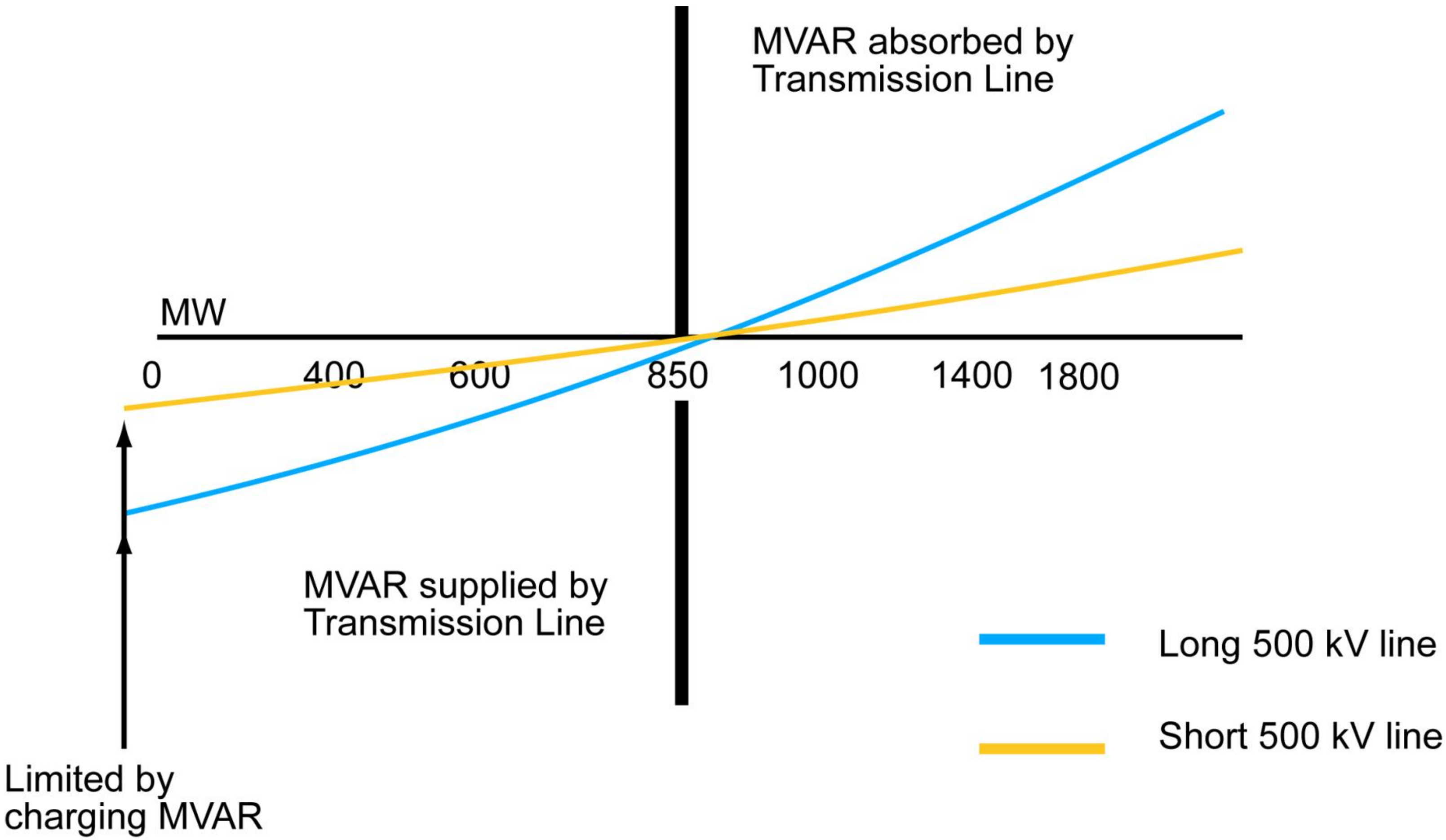
VARs From Transmission Lines

- Surge Impedance Loading
  - 765 kV = 2100 MW
  - 500 kV = 850 MW
  - 345 kV = 400 MW
  - 230 kV = 135 MW



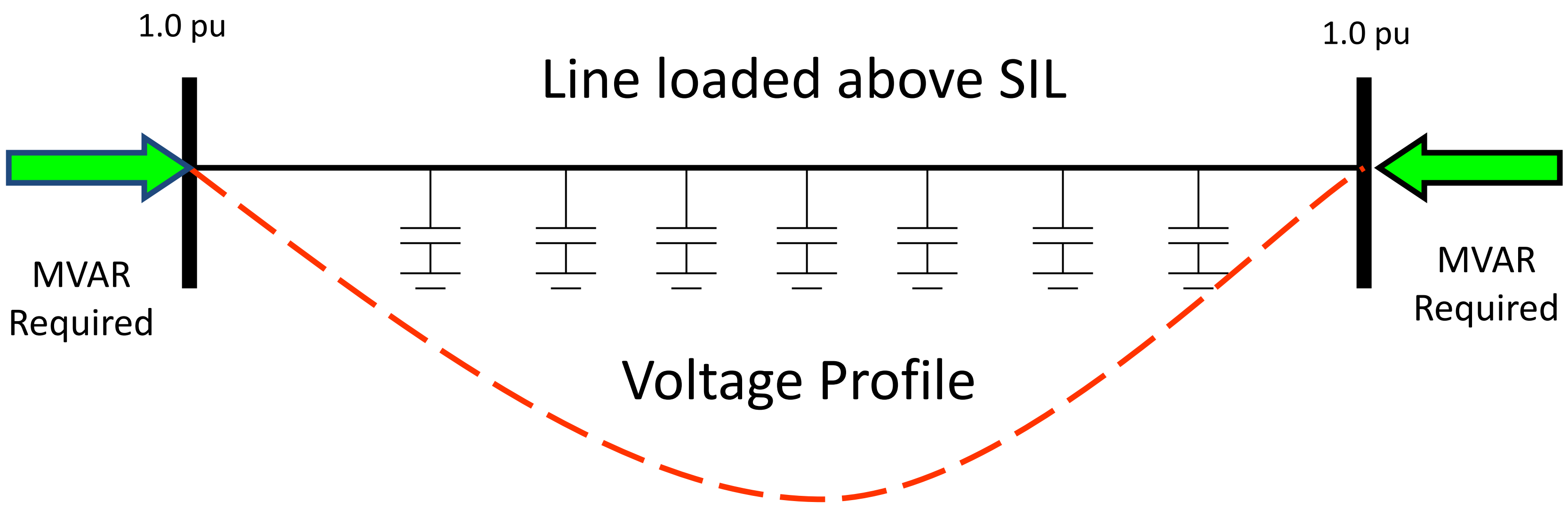
LINE LOSSES AND VOLTAGE DROP

VARs From Transmission Lines



Surge Impedance Loading Example

VARs From Transmission Lines

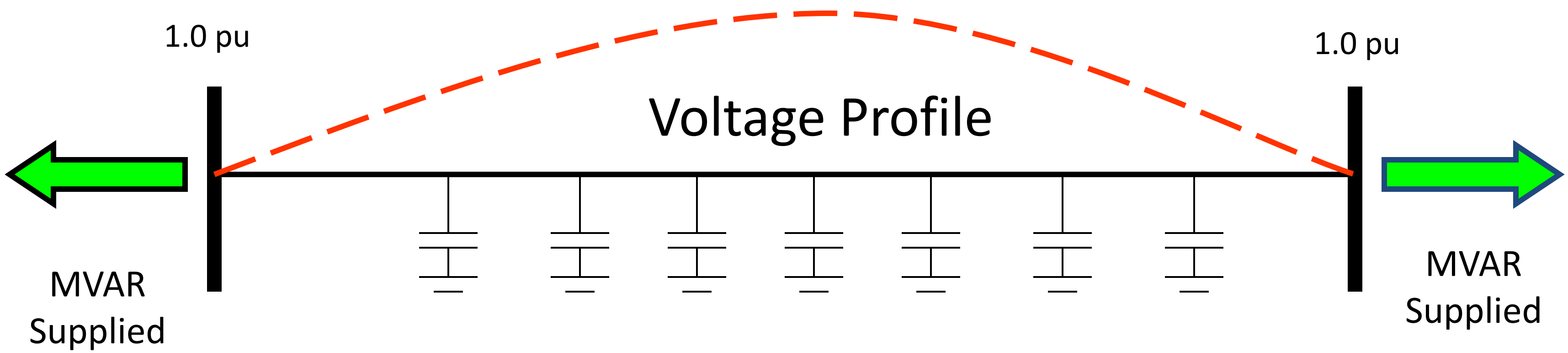


As line loading increases:

Reactive losses <u>increase</u> proportional to I^2

Reactive supply <u>decreases</u> proportional to V^2

VARs From Transmission Lines



Line loaded below SIL

As line loading decreases:

Reactive losses <u>decrease</u> proportional to I^2

Reactive supply <u>increases</u> proportional to V^2

Voltage Operating Criteria

Legend
Non-Cost
Off-Cost
Load Shedding

Voltage Limit Exceeded	If Actual voltage limits are violated	Time to correct (minutes)
High Voltage	Use all effective non-cost and off-cost actions	Immediate
Normal Low	Use all effective non-cost actions, off-cost actions and emergency procedures except load dump	15 minutes
Emergency Low	All of the above plus, shed load if voltages are decaying	5 minutes
Load Dump Low	All of the above plus, shed load if analysis indicates the potential for a voltage collapse	Immediate
Transfer Limit Warning Point (95%)	Use all effective non-cost actions. Prepare for off-cost actions. Prepare for emergency procedures except load dump	Not applicable
Transfer Limit	All of the above, plus shed load if analysis indicates the potential for a voltage collapse	15 minutes or less depending on the severity

Voltage Operating Criteria

Legend
Non-Cost
Off-Cost
Load Shedding

Voltage Limit Exceeded	If post contingency simulated voltage limits are violated	Time to correct (minutes)
High Voltage	Use all effective non-cost actions	30 minutes
Normal Low	Use all effective non-cost actions	Not applicable
Emergency	Use all effective non-cost actions, off-cost actions, and emergency procedures except load dump	15 minutes
Load Dump Low	All of the above plus, shed load if analysis indicates the potential for a voltage collapse	5 minutes
Voltage Drop Warning	Use all effective non-cost actions	Not applicable
Voltage Drop Violation	All effective non-cost and off-cost actions plus, shed load if analysis indicates the potential for a voltage collapse	15 minutes

Non-Cost Responses to Voltage Violations

- Switch capacitors in/out of service
- Switch reactors out/in to service
- Adjust output of Static Var Compensators
- Adjust generator excitation
- Adjust transformer tap position
- Switch lines or cables out of service
  - Pre-studied for high voltage control

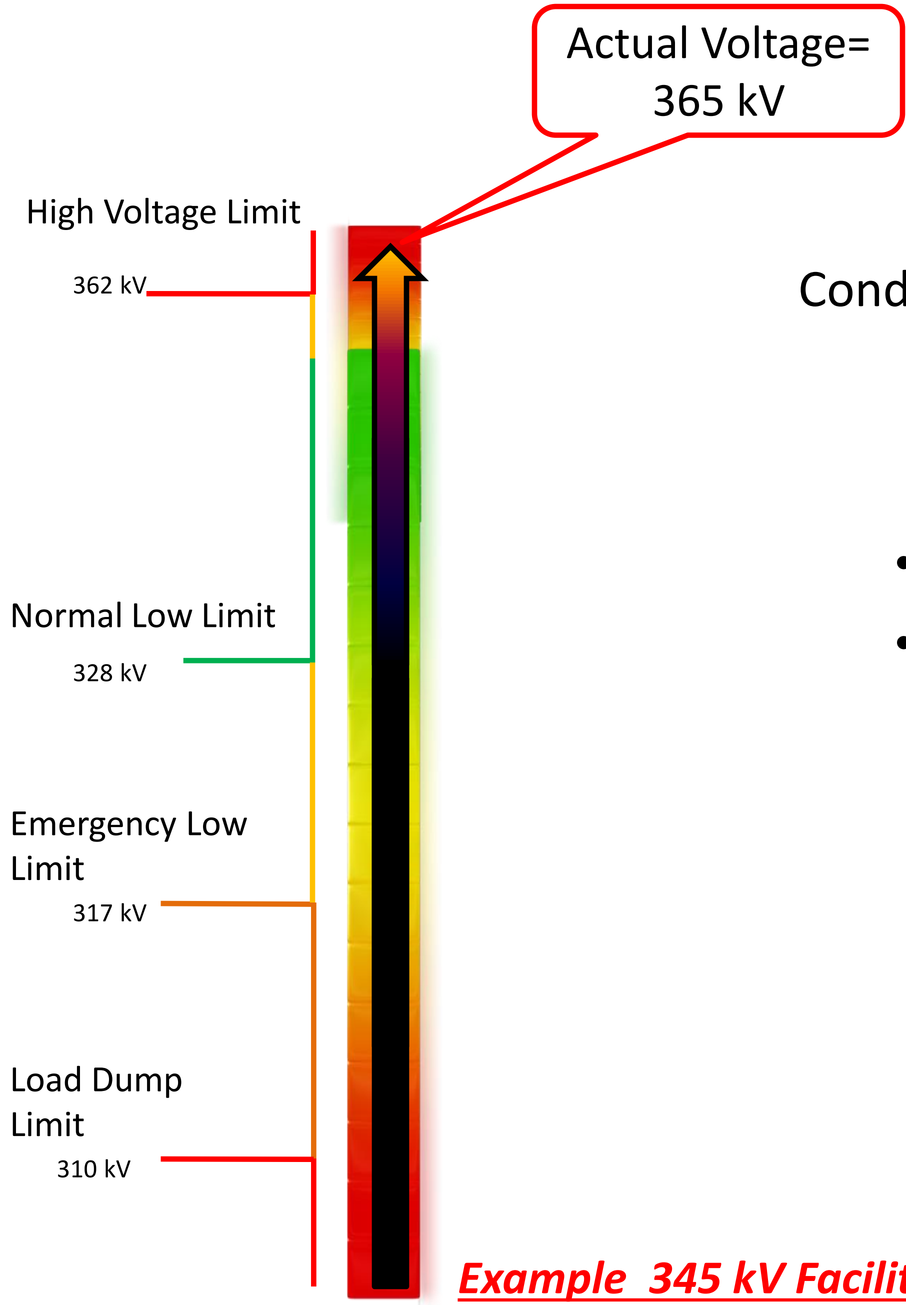
Off-Cost Responses to Voltage Violations

- Curtail Non-firm transactions NOT willing to pay congestion prior to redispatch of generation
- Redispatch generation
- Dispatch synchronous condensers
- Initiate ALL Emergency Procedures EXCEPT Load Shed
    - Including Manual Load Dump Warning

Load Shedding Responses to Voltage Violations

- Determine if load shedding is required
  - All other control actions have been exhausted
  - Under emergency low or load dump low voltage limit on an actual basis or Reactive Transfer Limit to avoid voltage collapse
  - Under load dump low voltage limit or voltage drop violation limit on contingency basis if analysis indicates potential for voltage collapse
- Determine amount of load shed necessary
- Shed load proportional among Native Load customers, Network customers and firm point-point service

Corrective Actions

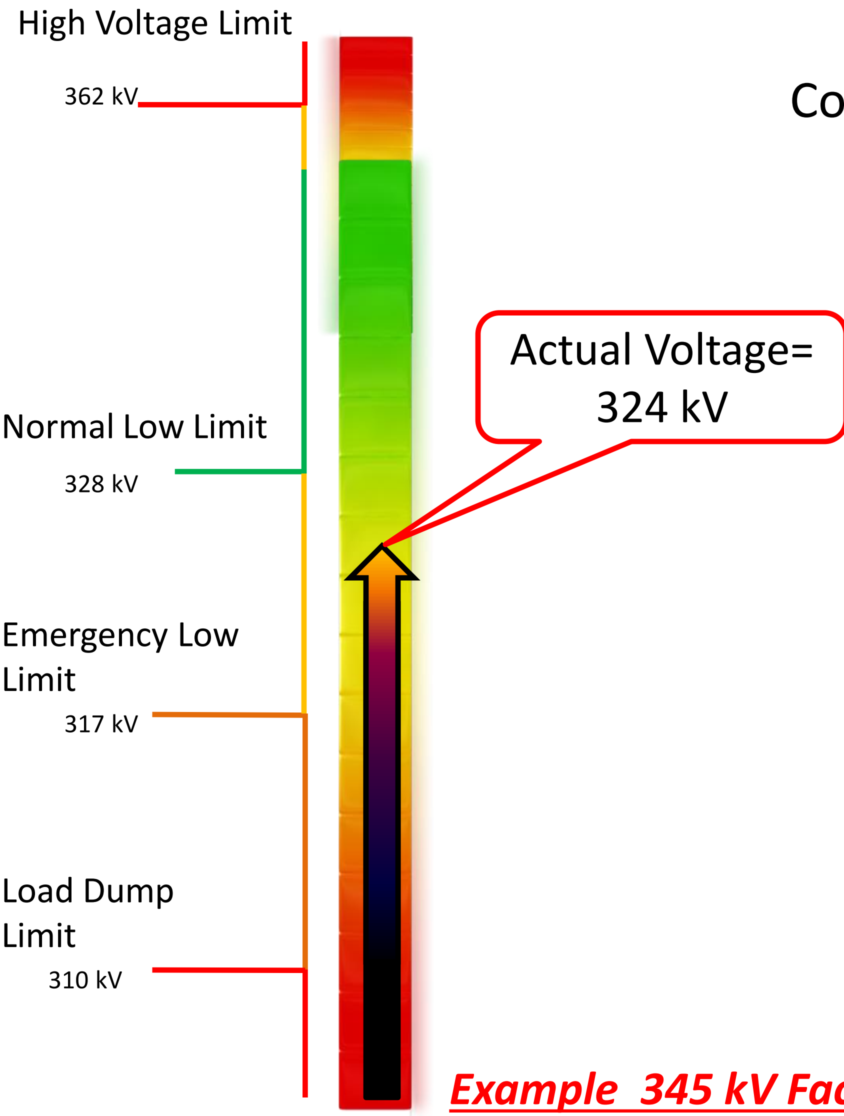


Condition: Actual Voltage exceeds High Voltage limit

- Time to correct - Immediate
- Corrective Actions include:
  - Capacitor/Reactor switching
  - Tap changer adjustment
  - Generator/synchronous condenser excitation adjustment
  - Switching lines/cables out of service*
    (*Facilities 500 kV & Above)
  - Off-cost generation adjustments

Example 345 kV Facility

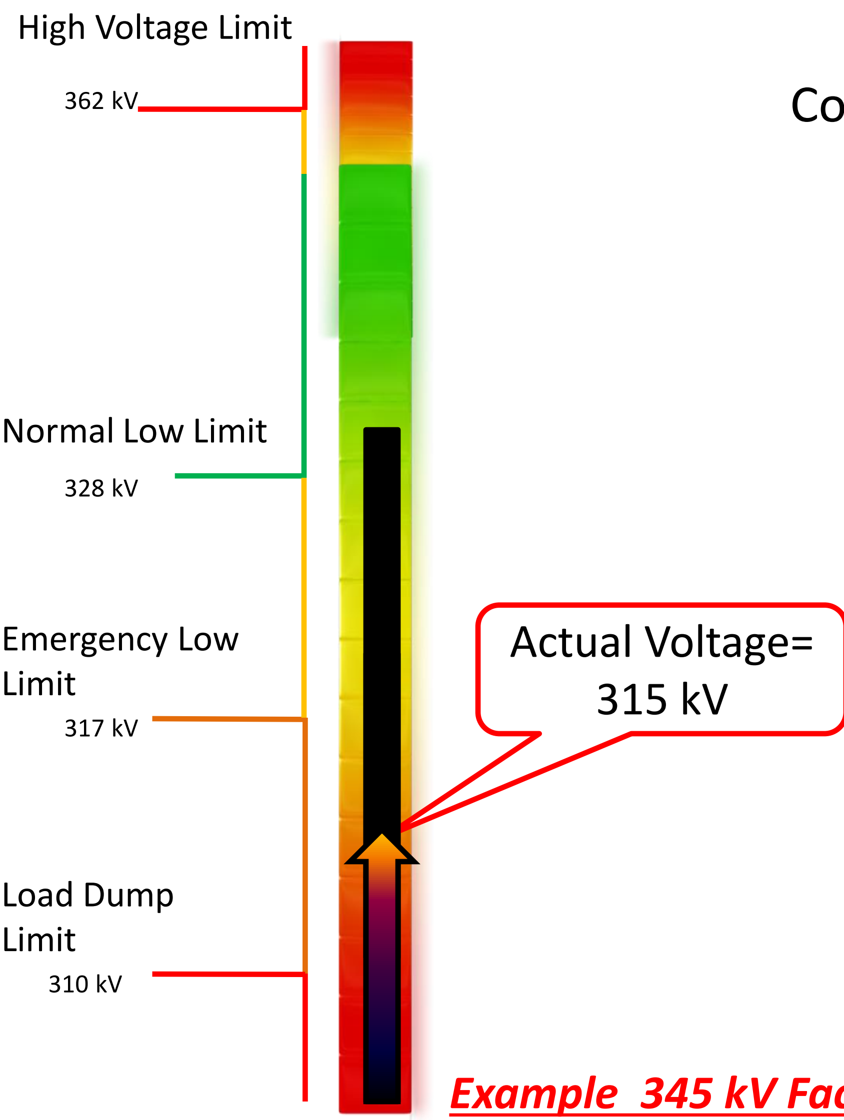
Corrective Actions



Example 345 kV Facility

Condition: Actual Voltage is <u>less than</u> Normal Voltage limit but <u>greater than</u> Emergency Low Voltage limit

- Time to correct - 15 minutes
- Corrective Actions include:
  Non-cost actions
    - Capacitor switching
    - Generator excitation adjustment
    - Tap changer adjustment
- Off-cost generation adjustment
- All emergency procedures <u>EXCEPT</u> load dump

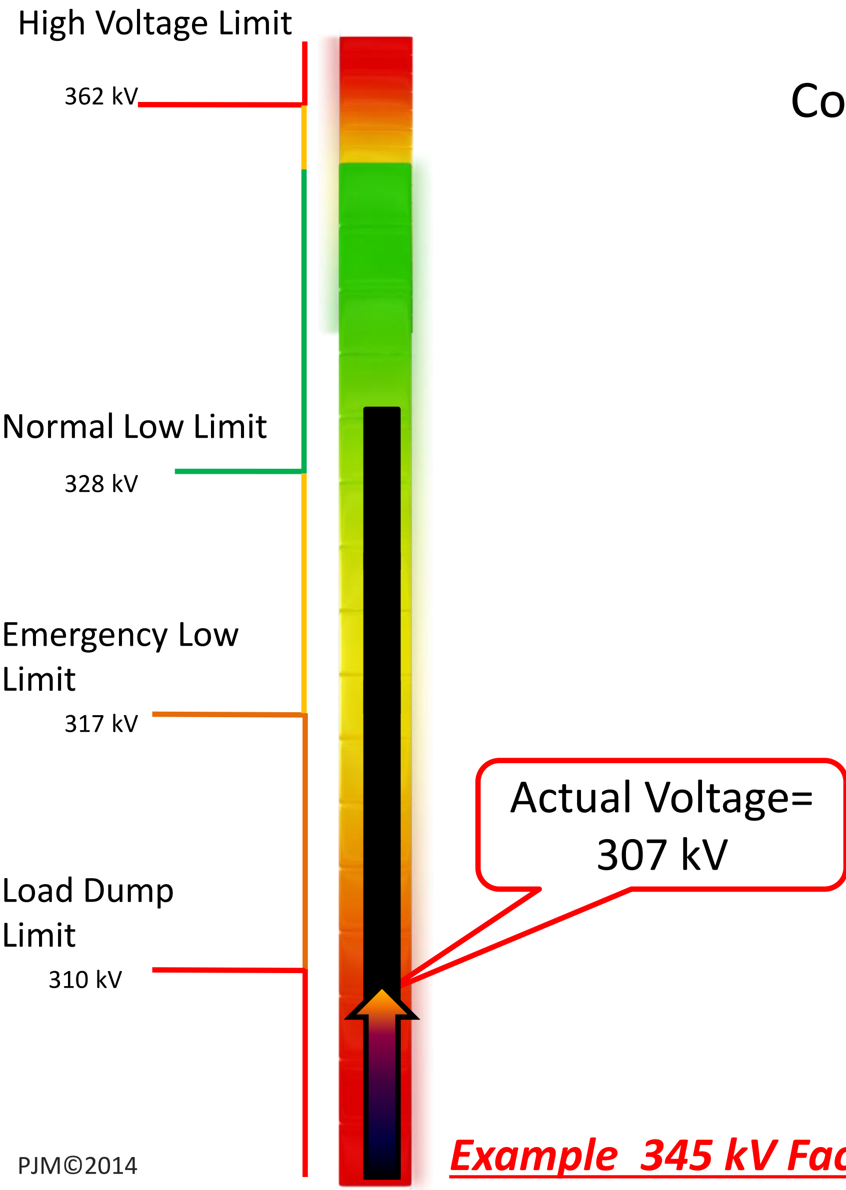


Example 345 kV Facility

Condition: Actual Voltage is <u>less than</u> Emergency Low Voltage limit but <u>greater than</u> Load Dump Low Voltage limit

- Time to correct - 5 minutes
- Corrective Actions include:
  - Non-cost actions
    - See previous slide
  - Off-cost generation adjustment
  - All emergency procedures
  - If voltages are decaying to Load Dump limit, shed load to return voltages to Normal Low

Corrective Actions

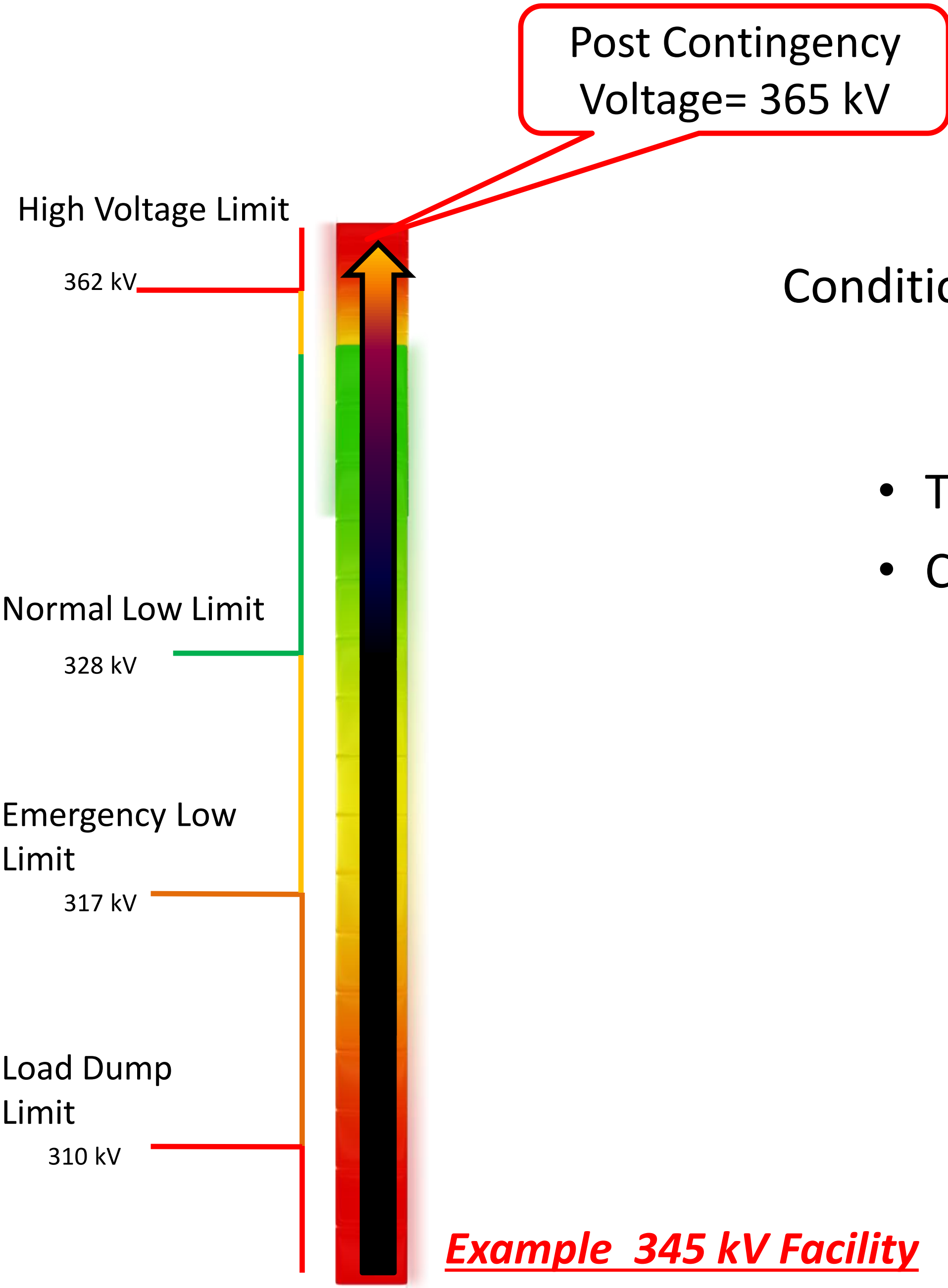


Example 345 kV Facility

Condition: Actual Voltage <u>less than</u> Load Dump Low Voltage limit

- Time to correct - Immediate
- Corrective Actions include:
  - Non-cost actions
  - Off-cost generation adjustment
  - All emergency procedures
  - If voltages are at or below Load Dump limit, shed load to return voltages to Normal Low limit

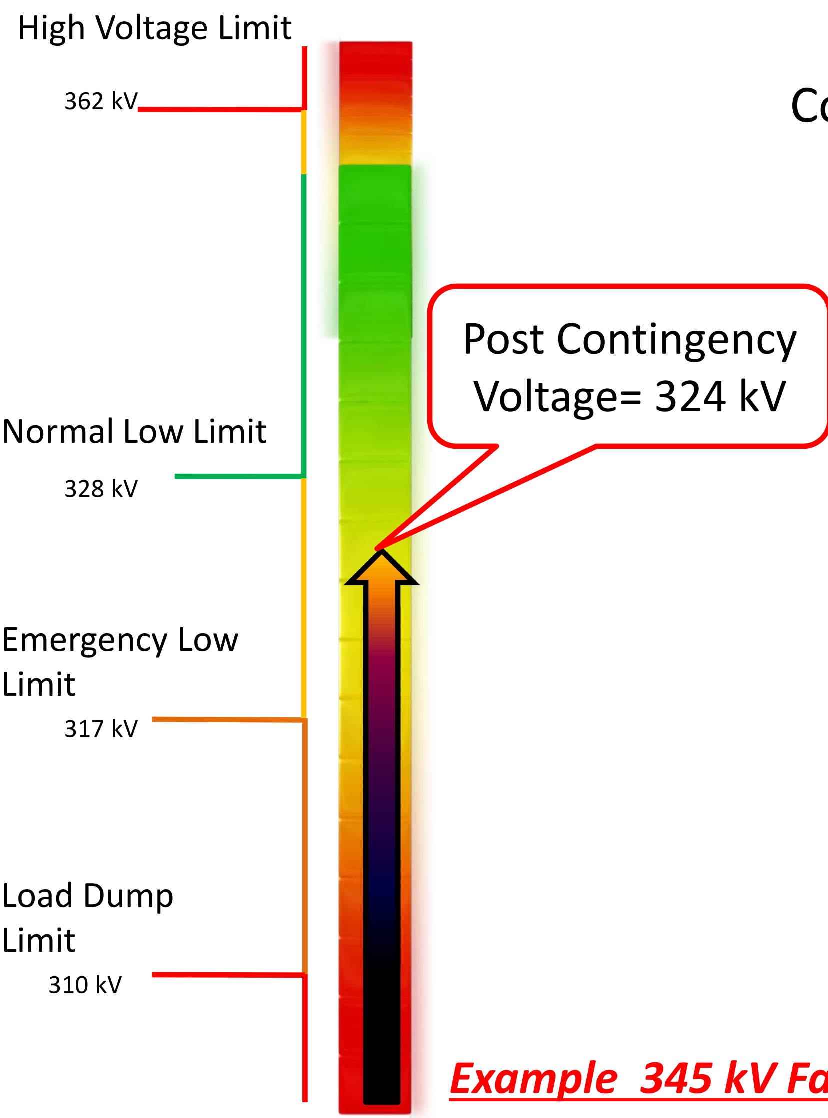
Corrective Actions



Condition: Post-contingency Voltage <u>exceeds</u> High Voltage limit

- Time to correct - 30 minutes
- Corrective Actions include:
  - Capacitor/Reactor switching
  - Tap changer adjustment
  - Generator/synchronous condenser excitation adjustment
  - Switching lines/cables out of service (*Facilities 500 kV & Above)
  - Off-cost generation adjustments

Corrective Actions

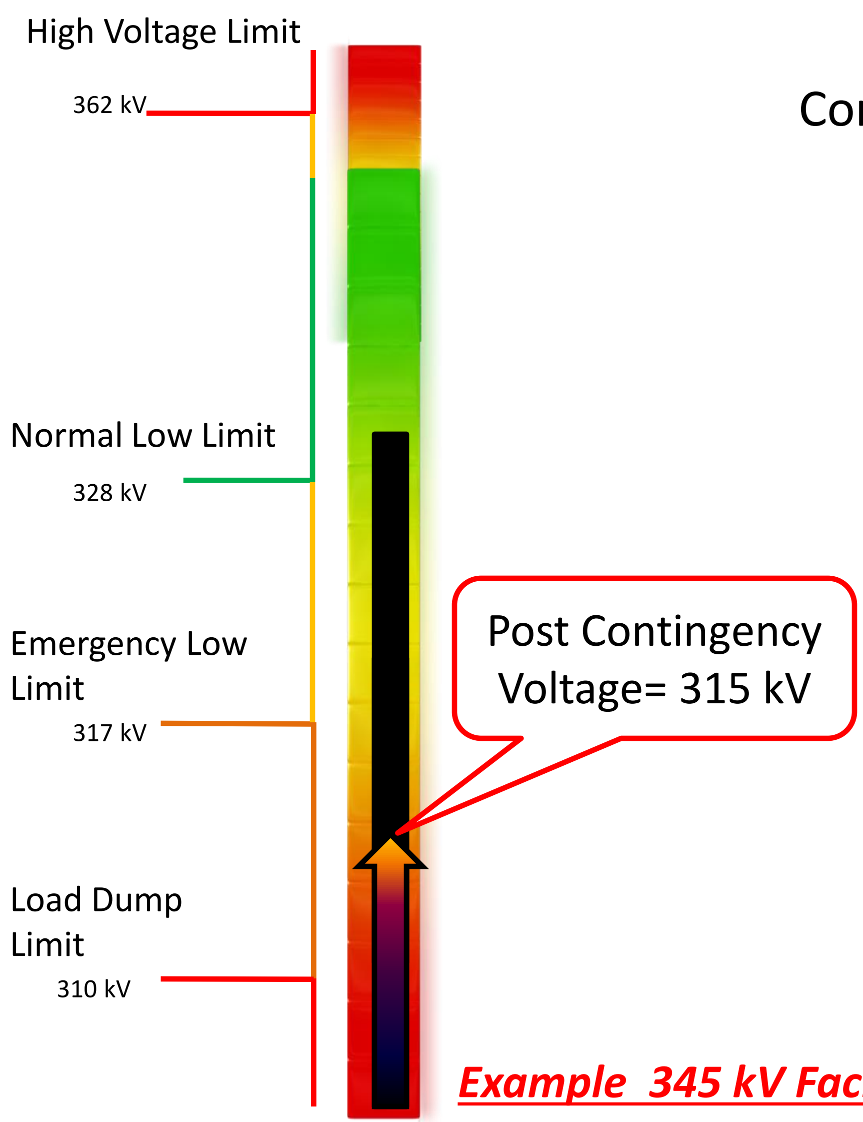


Example 345 kV Facility

Condition: Post-contingency Voltage <u>less than</u> Normal Low Voltage limit but <u>greater than</u> Emergency Low Voltage limit

- Time to correct - Not Applicable
- Corrective Actions include:
  - Non-cost actions only
  - This situation is considered a Trend and should be monitored, however, no off-cost measures will be taken to correct

Corrective Actions

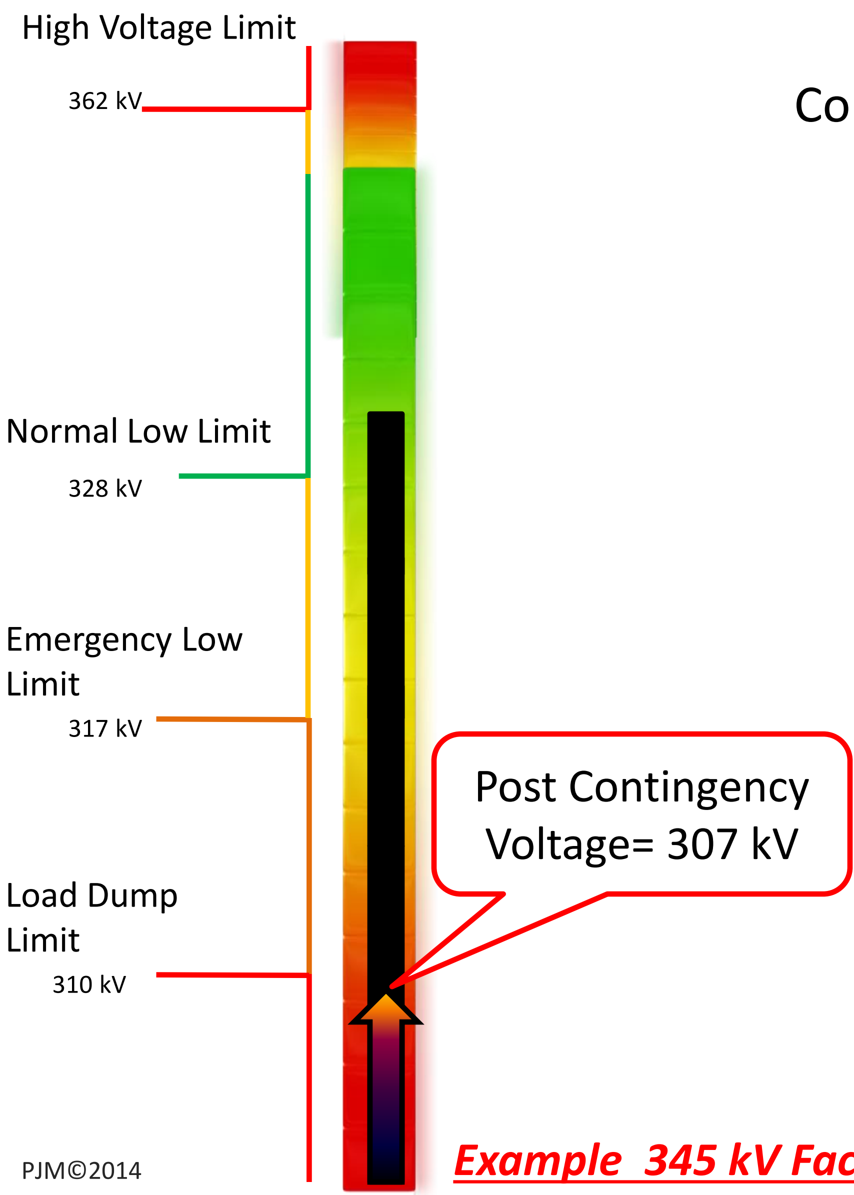


Condition: Post-contingency Voltage less than Emergency Low Voltage Limit but greater than Load Dump Low Voltage Limit

- Time to correct - 15 Minutes
- Corrective Actions include:
  - Non-cost actions
  - Off-cost generation adjustment
  - All emergency procedures EXCEPT load dump

Example 345 kV Facility

Corrective Actions

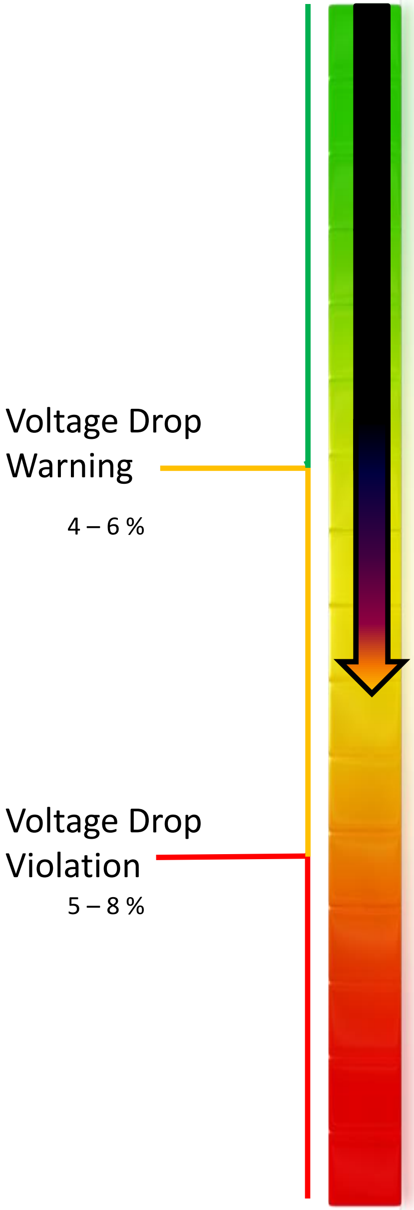


Example 345 kV Facility

Condition: Post-contingency Voltage <u>less than</u> Load Dump Low Voltage Limit

- Time to correct - 5 Minutes
- Corrective Actions include:
  - Non-cost actions
  - Off-cost generation adjustment
  - All emergency procedures
  - Shed load pre-contingency if necessary to avoid voltage collapse (System wide problem)

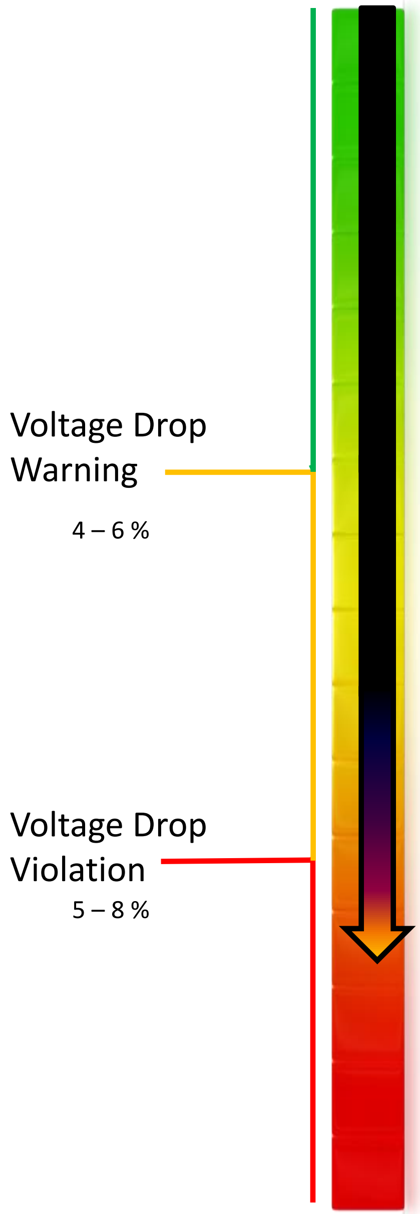
Corrective Actions



Condition: Post-contingency Voltage Drop (%) exceeds Voltage Drop Warning but is less than Voltage Drop Violation

- Time to correct - N/A
- Corrective Actions include:
  Non-cost actions only
  - This situation is considered a Trend and should be monitored, however, no off-cost measures will be taken to correct

Example 345 kV Facility



Condition: Post-contingency Voltage Drop (%) exceeds Voltage Drop Violation

- Time to correct - 15 Minutes
- Corrective Actions include:
  - Non-cost actions
  - Off-cost generation adjustment
  - All emergency procedures
  - Shed load pre-contingency if necessary to avoid voltage collapse

Example 345 kV Facility

Voltage Schedules

- NERC Standard VAR-001:
  - R4 – Each Transmission Owner shall specify a voltage or Reactive Power schedule at the interconnection between the generator facility and the Transmission Owner's facilities to be maintained by each generator. The Transmission Owner shall provide the voltage or Reactive Power schedule to the associated Generator Operator and direct the Generator Operator to comply with the schedule in automatic voltage control mode (AVR in service and controlling voltage)

Voltage Schedules

- Voltage Schedules
  - PJM requires the following subset of generators to follow voltage schedules:
    - Generators that aggregate to 75 MVA or greater that are connected to a common bus
    - Black start generators
    - Any other GO/GOPs that request a voltage schedule

PJM Default Generator Voltage Schedules								
Voltage Level (kV)	**765**	**500**	**345**	**230**	**138**	**115**	**69**	**66**
Schedule (kV)	760.0	525.0	350.0	235.0	139.5	117.0	70.0	67.0
Bandwidth (+/- kV)	+/-10.0	+/- 8.0	+/- 7.0	+/- 4.0	+/- 3.5	+/- 3.0	+/- 2.0	+/- 1.5

Voltage Schedules

- PJM:
  - Requires generators that fall within defined criteria to follow a voltage schedule
  - Will define exception criteria
    - Reactive and Power Factor Schedules are considered as exceptions
  - Requires PJM Transmission Owners to notify generators is writing of TO voltage schedules or PJM default schedule
- Transmission Owners:
  - Should notify generators located within their zone of TO voltage schedule
  - If the TO does not provide a TO voltage schedule to a generator in their zone they must notify PJM and PJM will notify generator in writing of PJM default voltage schedule

Maintaining Voltage Schedules

- PJM:
  - May elect to deviate from default voltage schedules based on load levels, transfer patterns, transmission or generation outages, or as required to honor pre-/post-contingency voltage limits or to maximize transfer capability based on PJM Security Analysis
  - Has the responsibility and authority to direct generators to increase or decrease MVAR output as well as direct the switching of reactive control devices to maintain voltages as system conditions dictate
  - Has the exclusive authority to request a generator to adjust voltage schedules if such a direction adversely impact the units MW output

Maintaining Voltage Schedules

- Transmission Owners:
  - May supply voltage schedules and a low and high bandwidth
  - Are required to coordinate voltage schedules, as well as adjustments to voltage schedules with PJM Dispatch. PJM Dispatch will approve/deny adjustments based on PJM EMS Security Analysis results
  - Have the authority to direct generators to adjust voltage schedules after coordinating with PJM Dispatch

Voltage Control with Generators

Voltage Control Background

- Generator is a Major Source of MVAR
  - VAR supply controlled by field excitation
  - VARs don’t travel well
    - Use units electrically close to the voltage problem
- Response to Generator Excitation Changes
  - Voltage at output of generator controlled by voltage regulator
    - Normally on automatic control (NERC Standard VAR-002)
      - If voltage regulator is out of service, eDART ticket is required
      - Can be manually controlled

Adjustments in Generation to Control Voltage

- Response to Generator Excitation Changes
- Voltage regulator controls excitation
    - Output voltage decreases
        - Voltage regulator senses decrease --> Excitation increased by voltage regulator --> VAR generation increases --> Output voltage increases (VAR flow on transmission line increases)
    - Output voltage increases
        - Voltage regulator senses increase --> Excitation decreased by voltage regulator --> VAR generation decreases --> Output voltage decreases (VAR flow on transmission line decreases)
    - Power (MW) output not affected by excitation

Generator Automatic Voltage Regulator Status

- Per NERC Standard VAR-002-2b
  - R3. Each Generator Operator shall notify its associated Transmision Operator as soon as practical, but within 30 minutes of any of the following:
    - R3.1. A status or capability change on any generator Reactive Power resource, including the status of each automatic voltage regulator and power system stabilizer and the expected duration of the change in status or capability
    - R3.2. A status or capability change on any other Reactive Power resources under the Generator Operator's control and the expected duration of the change in status or capability
- Reporting of AVR status and Reactive Capability changes accomplished via eDART generator reporting

Adjustments in Generation to Control Voltage

- Effect of Adjusting MVAR Output of a Single Generator with Radial Load
  - Increase in excitation
    - MVAR output increases
    - Voltage profile shifts upward
    - Results in voltage increase at generator output and at load bus
    - Effect is reduced further from generator due to MVAR losses on line

Adjustments in Generation to Control Voltage

- Effect of Adjusting MVAR Output of a Single Generator with Radial Load
  - Decrease in excitation
    - MVAR output decreases
    - Voltage profile shifts downward
    - Results in voltage decrease at generator output and at load bus

Adjustments in Generation to Control Voltage

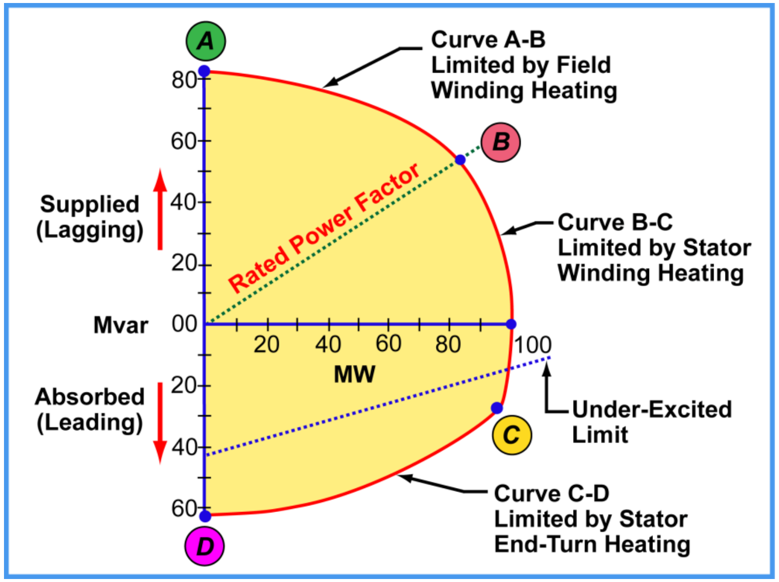
- Adjustments of Multiple Units at Single Station
  - Coordinate shifts of multiple units together
  - Otherwise, voltage regulators of other units may increase or decrease excitation to compensate for desired change
    - Results in unwanted VAR flow
  - Result of not adjusting all units
    - Voltage does not change as planned
    - Units may shift to absorbing VARs
    - Units may become under or over-excited

Adjustments in Generation to Control Voltage

- Adjustments in an Interconnected System
  - More complicated due to VAR flows
  - Voltage response
    - Increased VAR supply in local area will cause voltage rise in that area
    - Amount of voltage rise is diminished by VAR flow out of that area
    - Voltage rise is largest near VAR supply
      - Gradually decreases further from VAR supply
      - At some distance and beyond, no voltage effect will be see

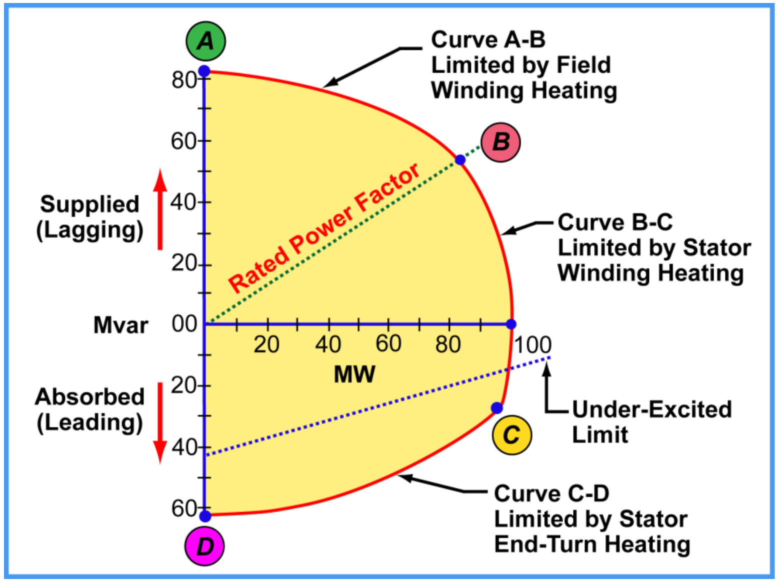
Restrictions and Limitations

- Generating Unit
  - Unit Over-excitation
    - Limit on field heating, limits MVAR generation
    - Rotor overheating is I2R heating caused by dc current overexcitation



Restrictions and Limitations

- Generating Unit
  - Unit Under-excitation
    - Limit on end turn heating
    - Unit instability
      - Field strength too weak, unit goes unstable
      - Area Stability, Salem, PS South



Restrictions and Limitations

- Generating Unit
  - MVAR output limited by D-curve
  - May be limited by auxiliary bus voltage limits
  - Voltage regulator limits
    - Voltage regulator operates only within designed voltage limits
    - Designed to limit amount of MVARs that can be generated
  - Power factor limits
    - Units are limited to operating within certain pf limits
  - MW tradeoff
    - Above certain MVAR output, MW must be traded to get additional MVAR output

Restrictions and Limitations

- Power System
  - Must coordinate shifts in generation to obtain desired MVAR flows and voltage adjustments
  - Should coordinate generation voltage adjustments with switchable sources (capacitors and reactors)
  - Do not remove all VAR reserve from a generating unit

Capacitors and Reactors

Capacitors or Reactors

- Peak Loads
  - Maximum load period cause large voltage drops across system due to heavy MVAR flow
  - Maximum VAR loading degrades voltage support
  - System voltages are lowered
  - Voltages most affected near VAR loads
  - Voltages can be improved by increasing VAR supply as close as possible to loads
    - Switch reactors out of service
    - Switch capacitors into service

Capacitors or Reactors

- Light Load Periods
  - Real power flows are minimized
  - Fixed capacitors and system capacitance dominate
  - System voltages rise
  - Customer voltages may exceed upper limits
  - Voltages can be lowered by adding VAR sinks to the system
    - Switch capacitors out of service
    - Switch reactors into service

Effects On The System

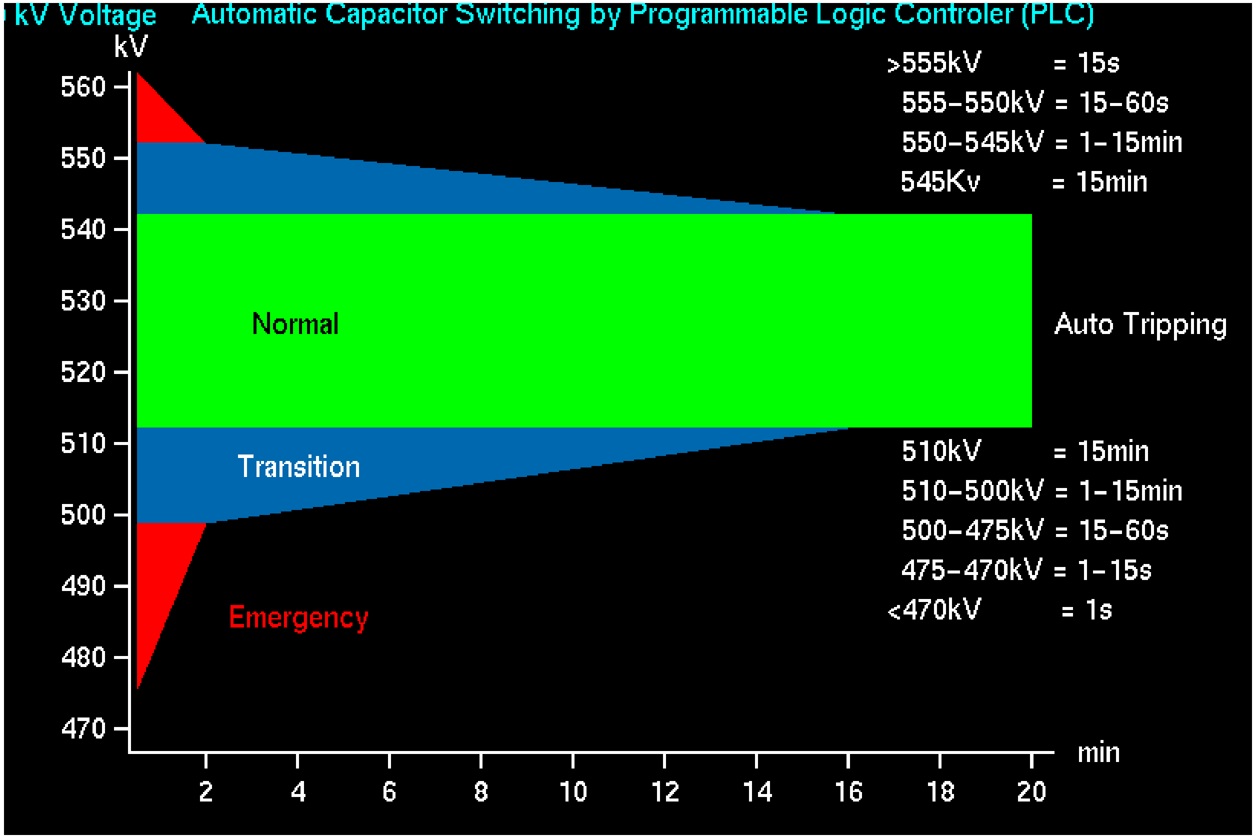
- Capacitors
  - Supply VARS
  - Locating capacitors near the load has two effects
    - Reduces system VAR flow to the load
      - Reduces line loading
      - Reduces voltage drops due to IX component
    - Provides additional VARs to the system which causes voltage to rise

Capacitor Switching Philosophy

- PJM, in coordination with the TOs, attempts to minimize capacitor switching when possible
- Switching of reactive resources 230 kV and above must be done at the direction of TOP
  - Automatic capacitor switching capability on facilities 230 kV and above must be documented in Manual 3, Section 3
  - Switching of reactive devices connected to 138 kV and below may be done without notifying PJM
    - However TOs should evaluate the impact of adding and removing reactive devices as well as adjusting LTCs so as not to violate any voltage limits

Automatic Switching of Capacitors

- Programmable Logic Controller



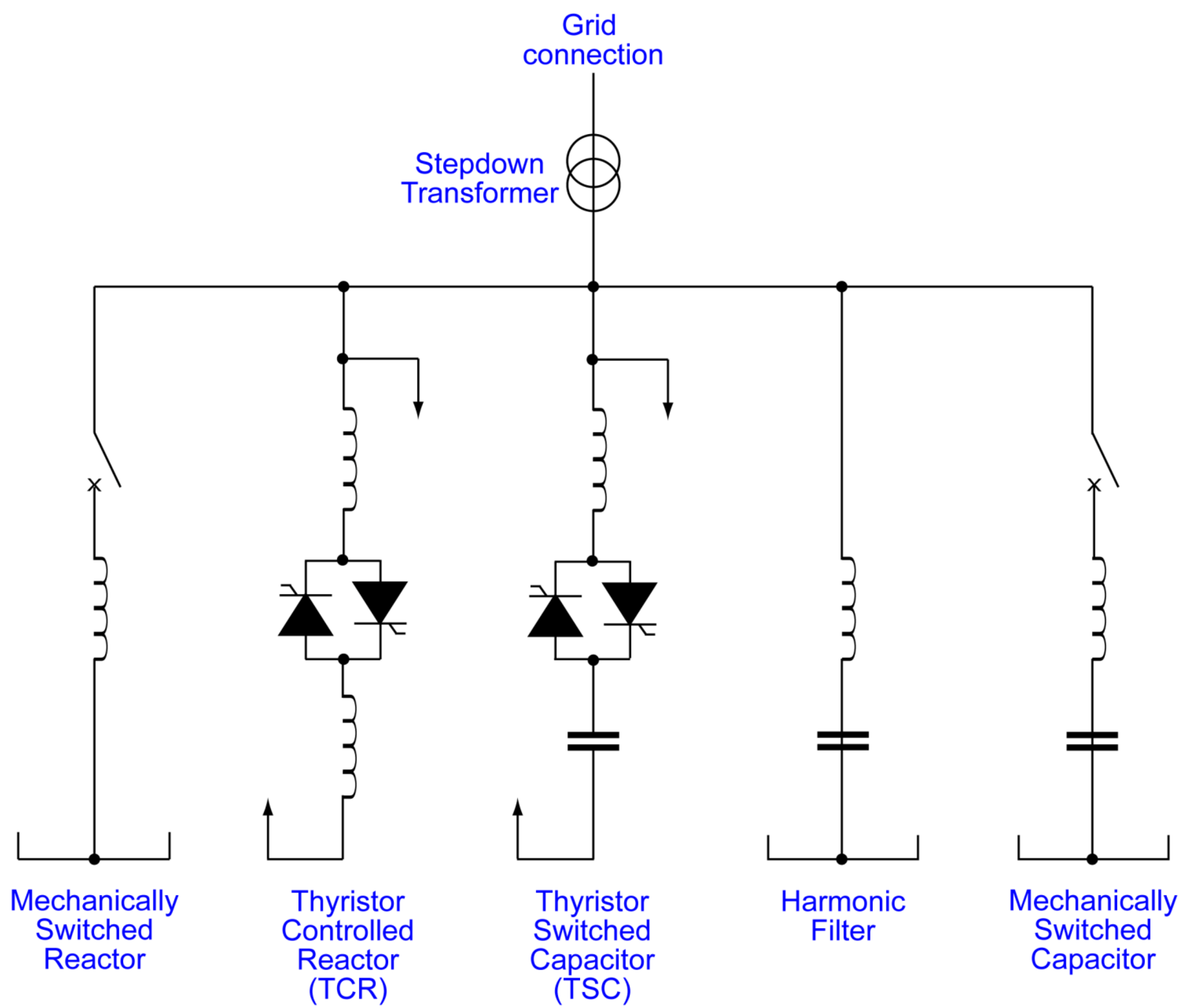
Effects On The System

- Reactors
  - Reactors serve as VAR sinks
    - Absorb VARs from the system
    - Cause voltage to decrease
  - Placed on transmission system
    - Most effective when close to VAR sources
      - End of transmission cables
    - Prevent unnecessary VAR flows

Effects On The System

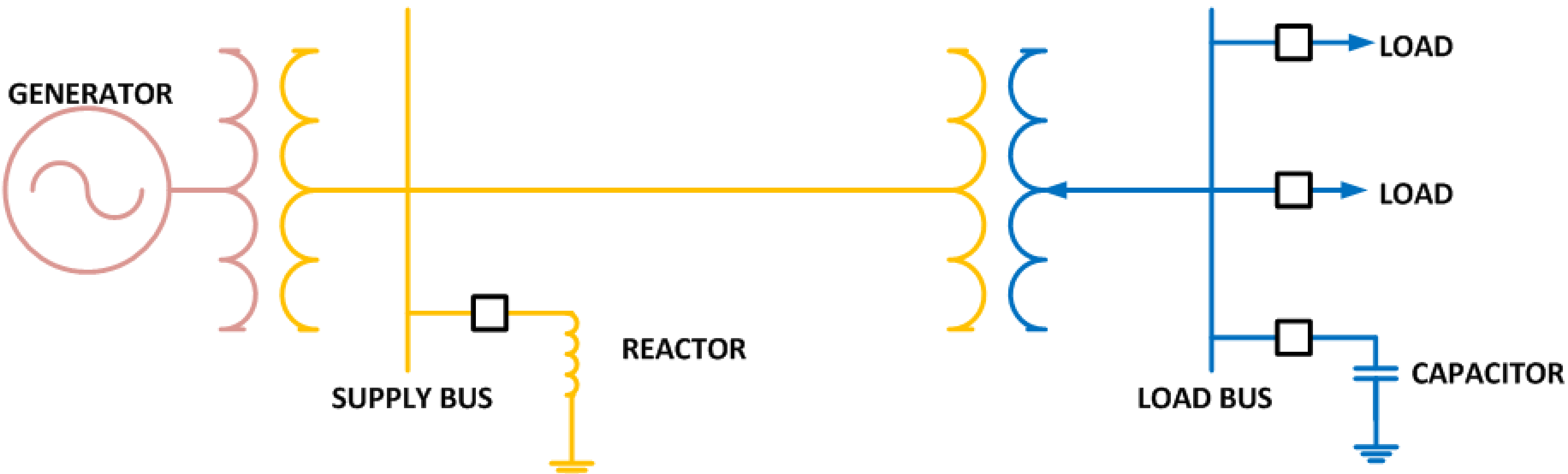
- Static Var Controllers
  - Capacitors and reactors in combination
  - Capacitors/Reactors in series with thyristors
  - Thyristors control reactive to system, to control voltage within preset band width

Effects On The System



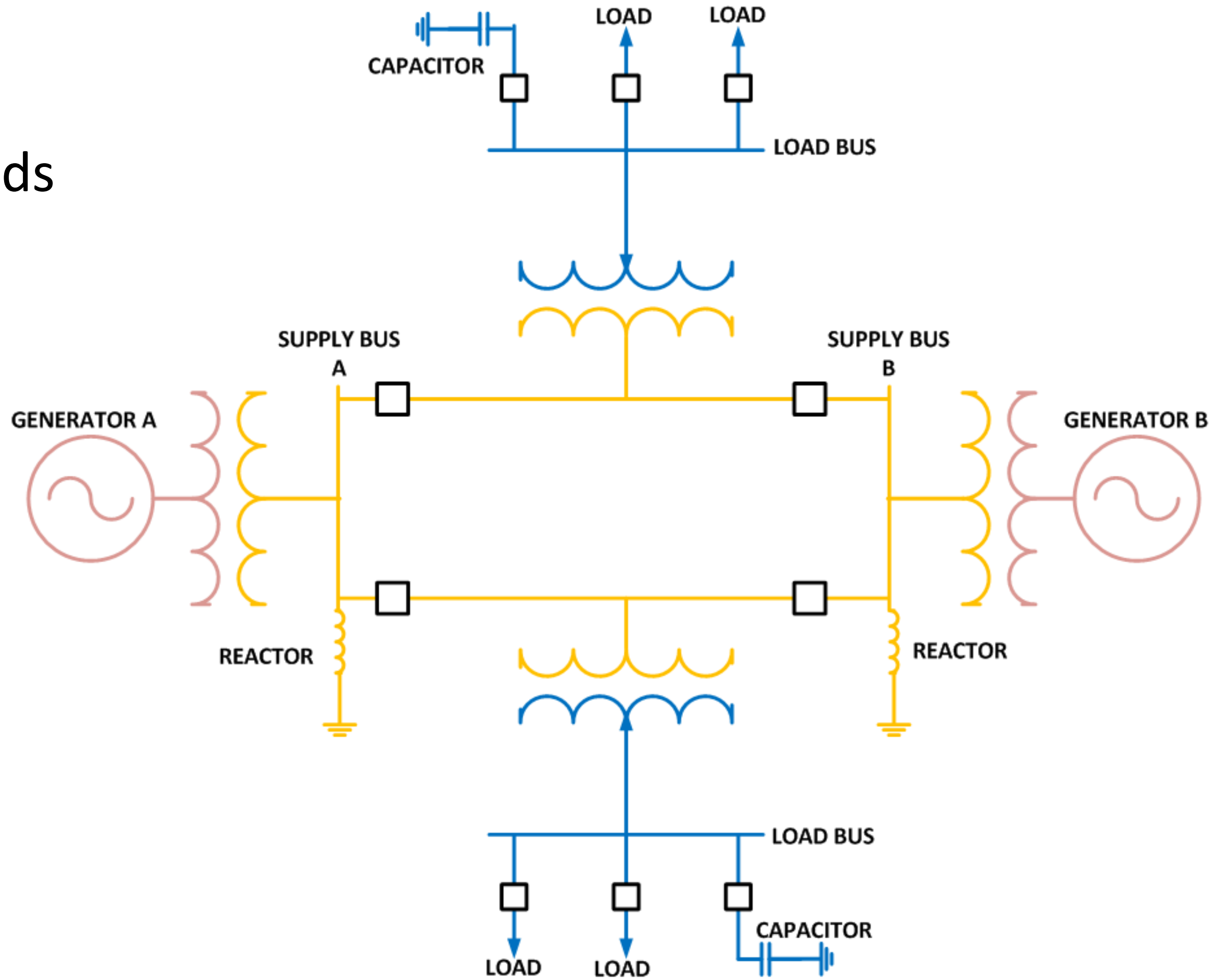
Effects On The System

- Radial Load
  - Voltage Control
    - Switch capacitor in/out of service
    - Switch reactor in/out of service
    - Change Tap Position
    - Adjust Generation



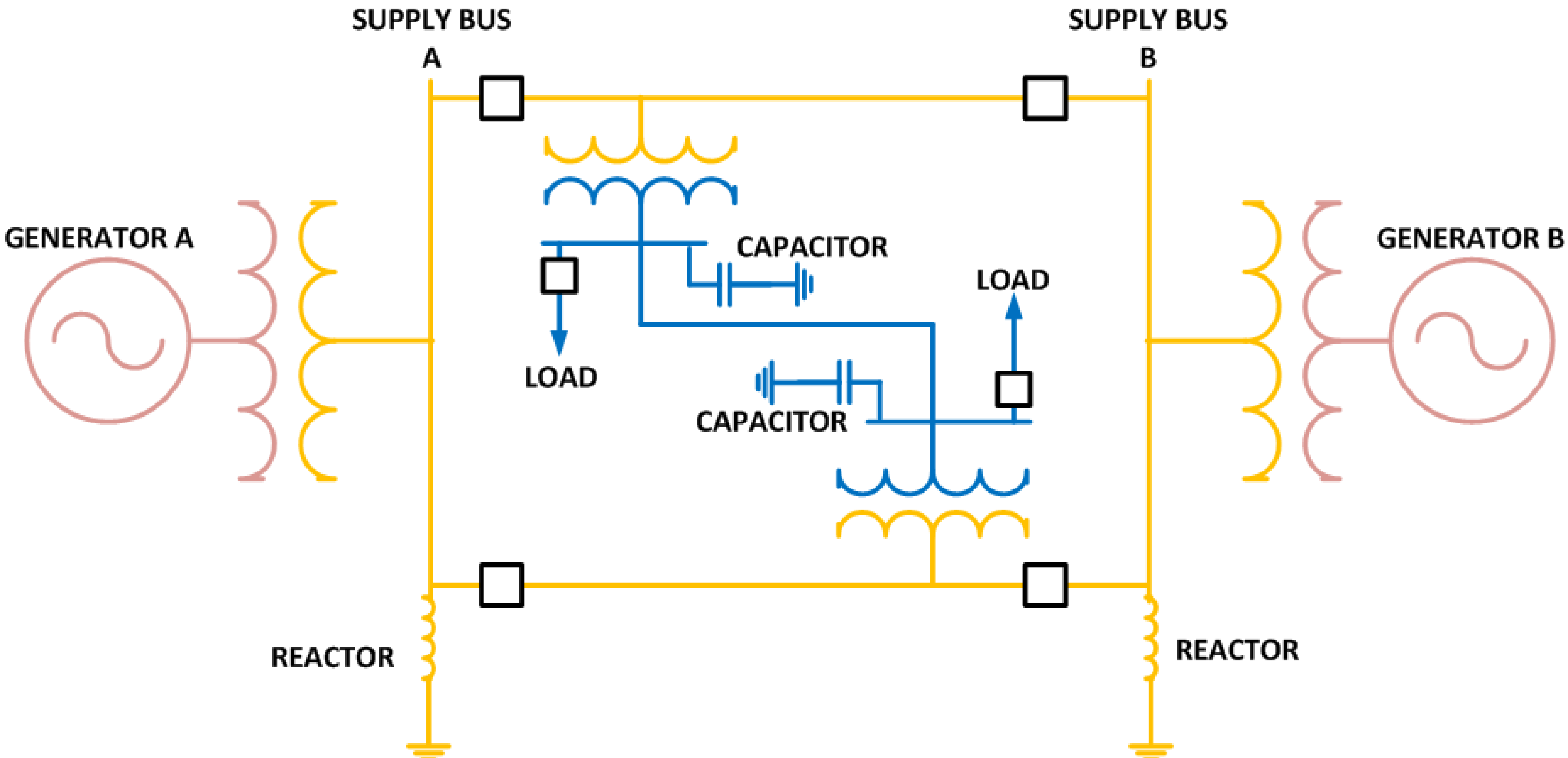
Effects On The System

- Loop system
  with radial loads



Effects On The System

- Interconnected Loop Systems



Limitations and Restrictions

- Switching Schedules
  - Many capacitors and reactors are switched by schedule
    - Fixed capacitors and reactors
    - Time switched
    - Load switched
    - kVAR load switched
    - Voltage switched
    - Manual switched
    - Programmable Logic Controller (PLC)

Limitations and Restrictions

- Capacitor is Less Effective as Voltage Decreases
  - MVAR output proportional to square of voltage
  - When needed most, capacitors provide the least support

$$MVAR\ Output = MVAR_{Rated}\left(\frac{V_{Actual}}{V_{Rated}}\right)^2$$

Limitations and Restrictions

- As an example, if a 100 Mvar capacitor (rated 100 Mvar at 345 kV) is energized at 340 kV the capacitor output is:

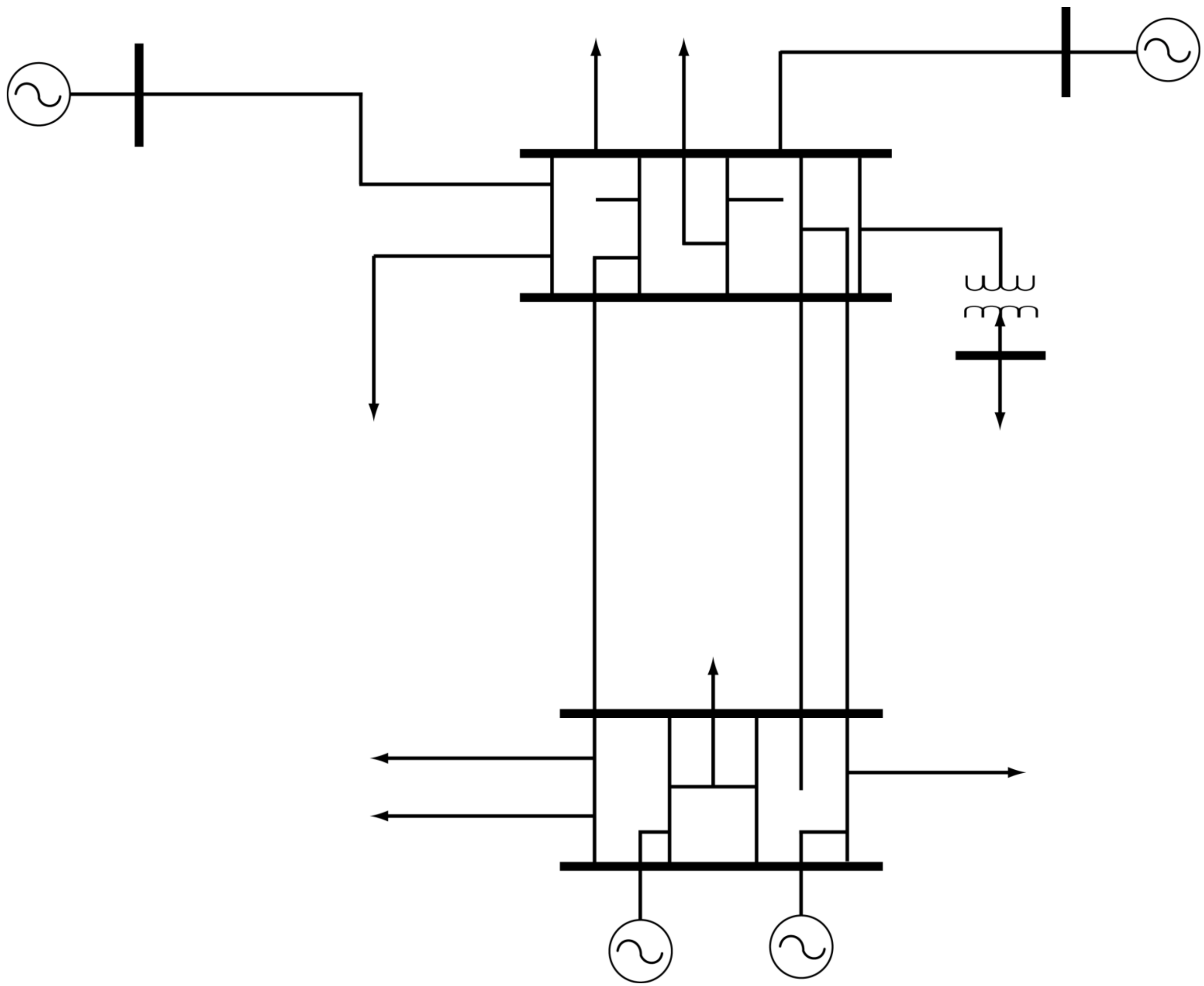
$$MVAR\ Output = 100\ MVAR\left(\frac{340\ kV}{345\ kV}\right)^2 = 97\ \text{MVAR}$$

Transformer Load Tap Changer Operations

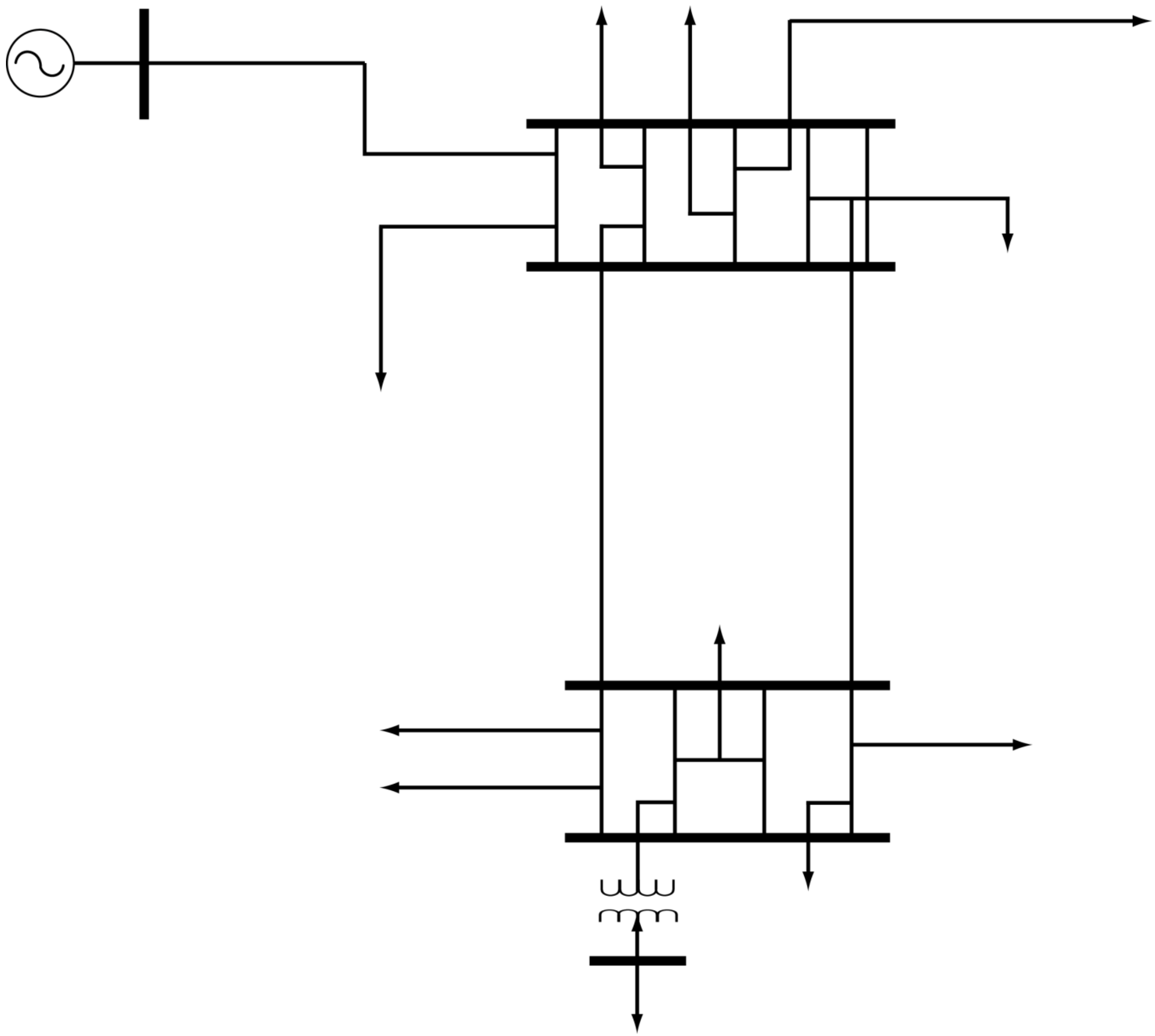
Voltage Control with LTCs

- Load Tap Changer (LTC) or Tap Changer Under Load (TCUL) Operation:
  - Weak Bus vs. Strong
  - If a transformer is connected to a “weak” reactive power source, it will not be effective in controlling the voltage on the other winding
  - When it “pulls” VARs from the primary, the primary voltage drops
  - This offsets any gains that might have been made to the secondary voltage

Strong Bus Example



Weak Bus Example

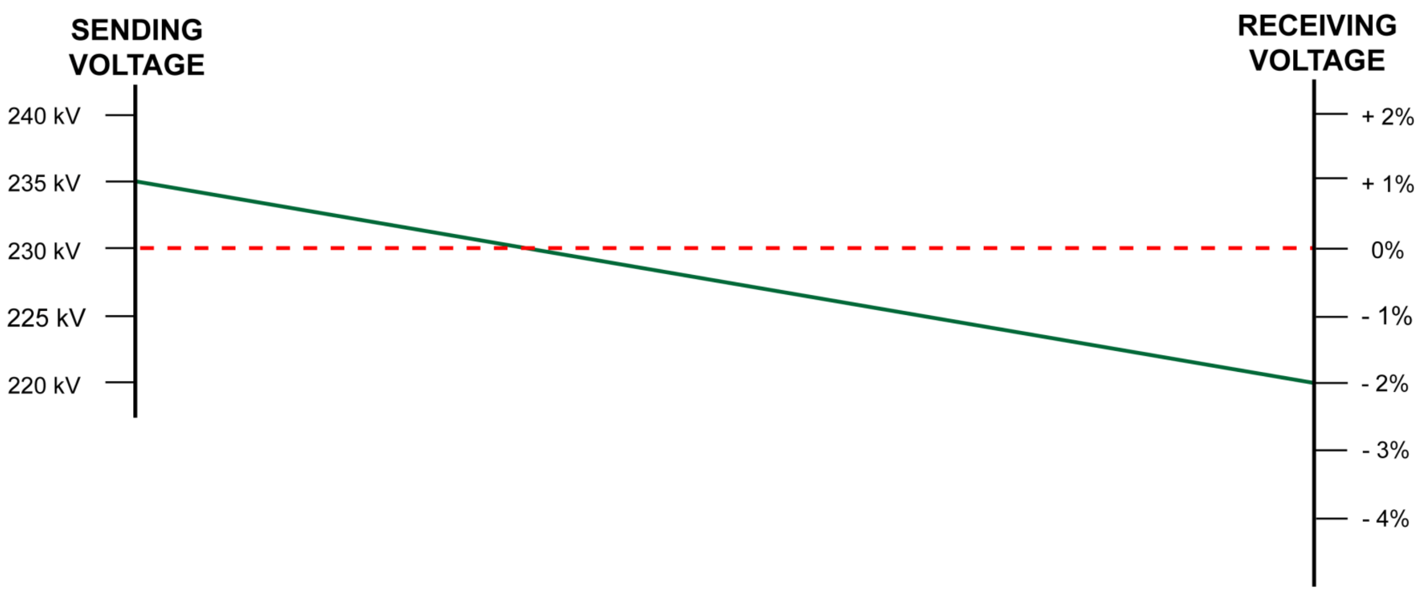


Tap Change Operation

- Maintain System Voltage Profile
  - Transformer tap changers act as VAR shovels
  - Adjust voltage on both sides of transformer
  - Most adjustments to maintain constant voltage at sub-transmission and distribution levels are accomplished by automatic load tap changing
- Correct Voltages Which Exceed Limits
- Reduce Undesirable MVAR Flow
  - VAR flow control within a power system
  - Adjust VAR flow through a transformer
    - Reduce losses

Effects of Tap Change Operation on the Power System

- Effect on Transmission Line Voltage Profile
  - If tap position is referenced to the low side voltage:
    - Voltage profile shifts upward when tap is raised
    - Voltage profile shifts downward when tap is lowered
    - Percent shift of tap position results in equal shift in percent voltage at transformer terminals

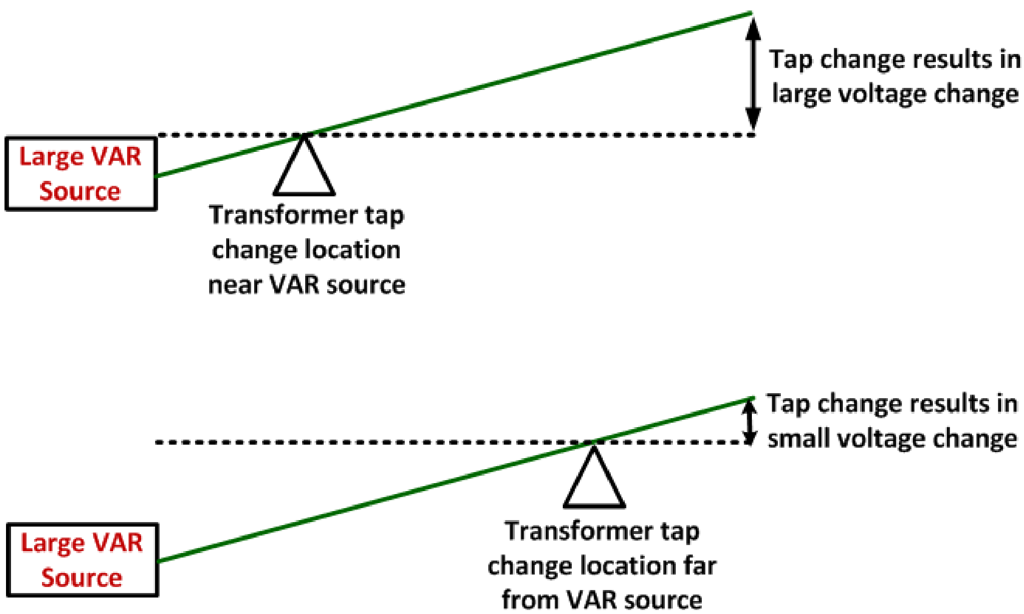


Effects of Tap Change Operation on the Power System

- Effect of Location of Transformer on System Voltages
  - Effect of tap change is determined by how close transformer is to VAR sources and VAR loads
  - Magnitude of voltage change determined by:
    - Distance of tap changer from VAR source or VAR load
      - Tap change will have greater effect near source and less effect away from source
    - Magnitude of VAR source or VAR load

Effects of Tap Change Operation on the Power System

- Effect of Location of Transformer on System Voltages



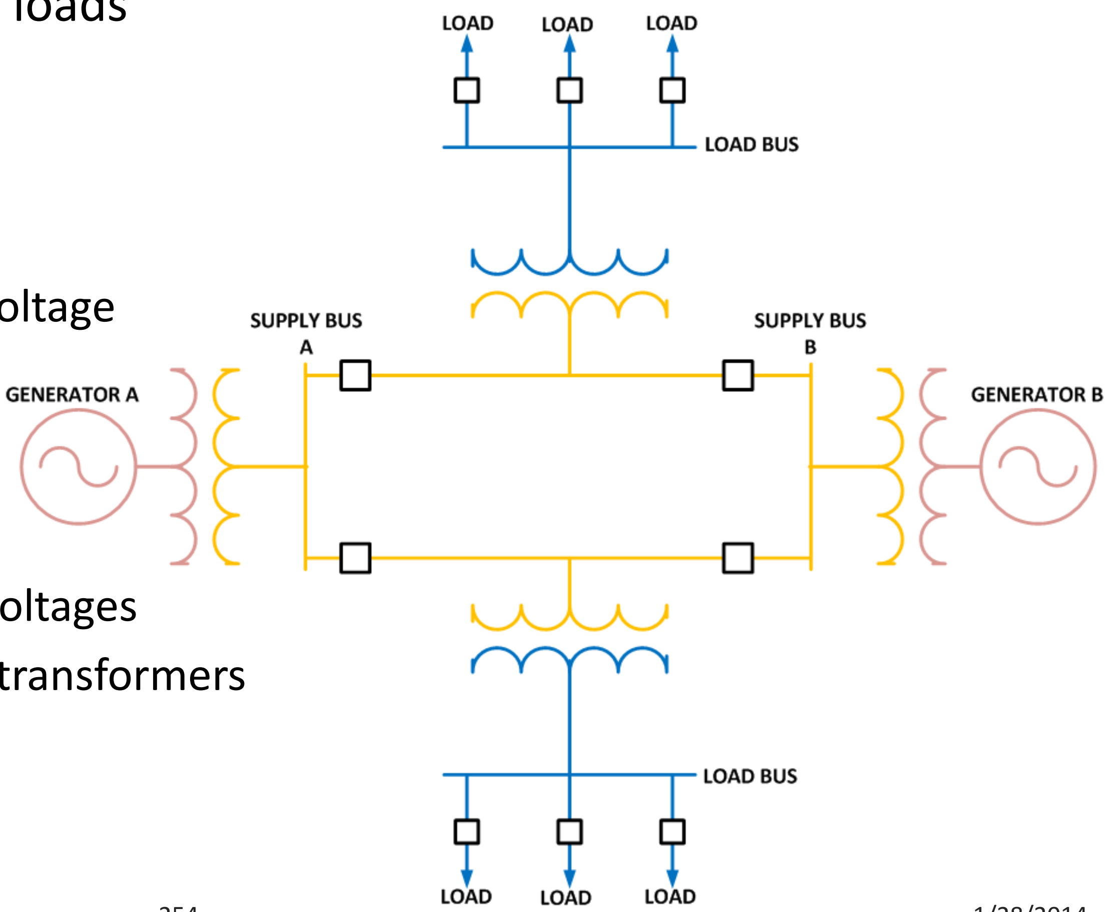
Effects of Tap Change Operation on the Power System

- Voltage and MVAR Flow Relationship as a Function of Tap Position
  - Voltage Profile varies with both tap position and VAR flow on transmission line
- Transformer Tap Changes in Various Configurations
  - Radial loads

    - No TCUL Available
      - Regulate supply bus voltage
    - TCUL Available
      - Regulate supply bus voltage
      - Change taps on TCUL transformer

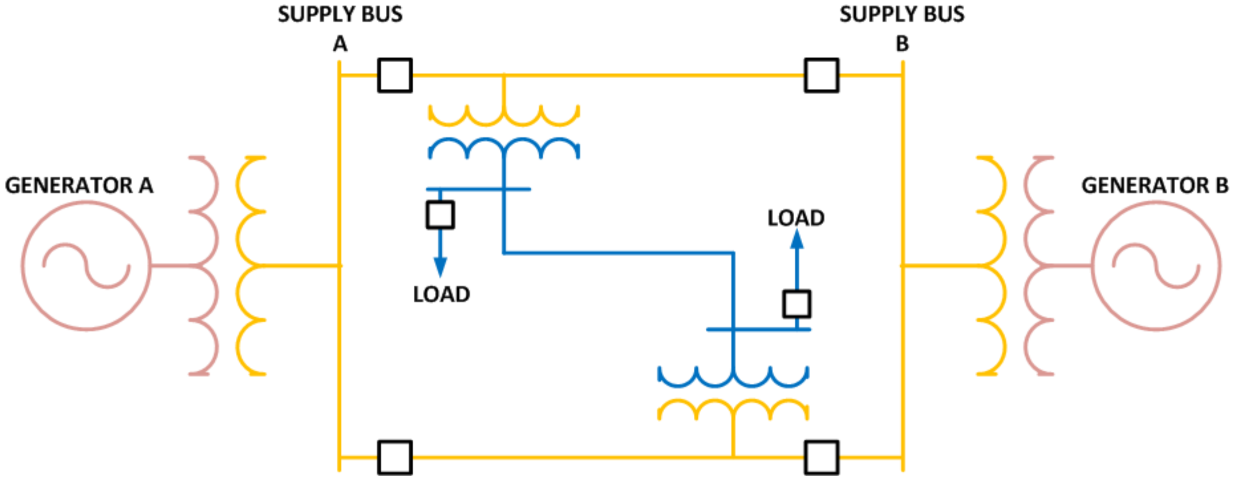
Effects of Tap Change Operation on the Power System

- Transformer Tap Changes in Various Configurations
  - Loop system with radial loads
  - No TCUL Available
    - Regulate supply bus voltage
  - TCUL Available
    - Regulate Supply bus voltages
    - Change taps on TCUL transformers



Effects of Tap Change Operation on the Power System

- Transformer Tap Changes in Various Configurations
  - Interconnected loop systems
  - No TCUL Available
    - Regulate supply bus voltages
  - TCUL Available
    - Regulate supply bus voltages
    - Change taps on TCUL transformers

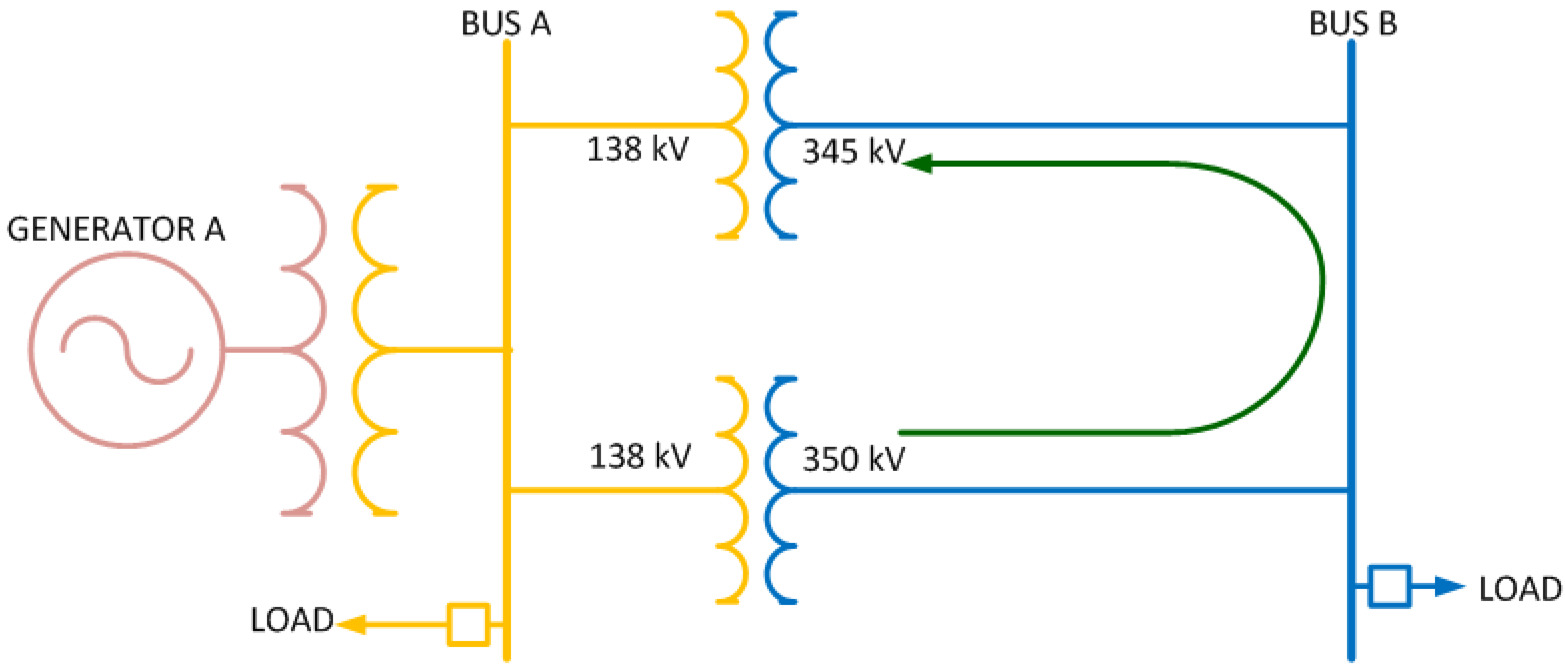


Restrictions and Limitations

- Effect on Interconnected Voltages
  - On interconnected system, changing voltage at one location will also affect interconnected voltages
  - Cannot adjust single individual voltage due to interconnected nature of system
    - Generally must change all taps into an area to achieve the desired effect on the voltage
  - Must observe effects of a tap change on surrounding voltages close to tap change and coordinate tap moves

Restrictions and Limitations

- Unwanted VAR Flows
  - Shifting voltages can cause unwanted VAR flows



Restrictions and Limitations

- Summary of Restrictions and Limitations
  - Use voltage schedule to determine need to change voltage
  - Coordinate tap changes
    - Transformers in parallel must be balanced to prevent unwanted VAR flows
    - Change of one voltage must be coordinated with interconnected voltages

PAR Operation to adjust voltage

- Phase Angle Regulators (PARs) change the power system phase angle at their location, allowing power flows to be regulated
  - All though they don’t directly control voltage, they can have an impact on the voltage profile in the area they are located
  - If you increase the flow on parallel lines by adjusting the tap of a PAR, those lines will consume more reactive power to support the increased MW flow
  - This could lead to a decrease in voltage in the area of those flows if there are not any local reactive resources

Reactive Resource Outages

- The Transmission Owners are responsible for reporting outages on all facilities contained within the Transmission Facilities List Database
  - These lists include reactive resources and can be found on PJMs website at the following link:
    - http://www.pjm.com/markets-and-operations/transmission-service/transmission-facilities.aspx
  - In addition to complete outages, if a capacitor bank's rated MVAR capability has been significantly changed, this should also be communicated to PJM for modeling purposes as well as updated in the Transmission Owner's EMS model

Generator Reactive Testing

Generator Reactive Testing

- NERC Standard MOD-025
  - Purpose - To ensure accurate information on generator gross and net Reactive Power capability is available for steady-state models used to assess Bulk Electric System reliability
    - R1 - The Regional Reliability Organization shall establish and maintain procedures to address verification of generator gross and net Reactive Power capability

Generator Reactive Testing

- Reactive capability testing is necessary to improve transmission system reliability by accurately determining generator reactive capability on a regular basis
- Testing of units is intended to demonstrate reactive capabilities for those conditions where reactive reserves would be required
- Testing should be coordinated between all affected parties to minimize impact on system conditions

Generator Reactive Testing

- PJM Generator Reactive Capability Testing
  - All units greater than 70 MW must be tested for reactive capability
  - All units designated as Black-Start must complete testing
  - Testing is required once very 5 years
  - Units less than 70 MW should still verify capability on a regular basis and report any changes via eDART

Generator Reactive Testing

Test Requirements

Unit Type	Required Testing	Exception Criteria
Nuclear	Lagging Test	Documented Exception to Lagging based on impact to System Reliability
Black Start Near-term Steam	Lagging Test Leading Test	Not Applicable
All Other	Lagging Test 0 MVAR Test	Documented Exception to Lagging test based on impact to System Reliability

Note: Near- term Steam units are defined as steam units with a hot start plus (+) notification time of less than 8 hours. The list of units is maintained by PJM and located in Transmission Owners Restoration Plan

Generator Reactive Testing

- Test Window
  - Testing targeted between May 1 and September 30
  - Testing generally Monday – Friday between 0900–1100, Eastern time
  - Required testing period for over-excitation is 1 hour, under-excitation capability recorded as soon as a limit is met

Generator Reactive Testing

- Test Scheduling
  - Generation Owners schedule their units during testing period
  - Tests scheduled through eDART by submitting a MVAR test ticket by noon 3 business days prior to test
    - Allows testing to be incorporated into the day-ahead studies

Generator Reactive Testing

- Study Process
  - PJM and TO perform studies to determine impact of testing on system.
    - Studies done day(s) ahead and 30 minutes prior to test
  - If studies indicate actual or post-contingency violations that can't be mitigated, test will be rescheduled
  - Voltage schedule changes may be needed to accommodate testing

Generator Reactive Testing

- Communication and Coordination
  - MOC
    - Schedules tests via eDART
    - Contacts PJM three hours prior to start of test to initiate study process
    - Coordinate and implement mitigations steps, exit strategy as required
  - TO
    - Communicate concerns found during study process to PJM
    - Coordinate and implement mitigation steps, exit strategy as required

Generator Reactive Testing

- Communication and Coordination (cont.)
  - PJM
    - Directs and coordinates all communications for test scheduling and actual testing process
    - Communication between MOC and TO channeled through PJM Dispatch
    - Coordinate and implement mitigations steps and exit strategy with MOC and TO as required

Generator Reactive Testing

- Exit Strategy
  - Reactive Capability testing cannot place system in unacceptable state
    - Each test will be studied and approved on case by case basis
    - All mitigation steps are to be agreed upon and coordinated will all parties

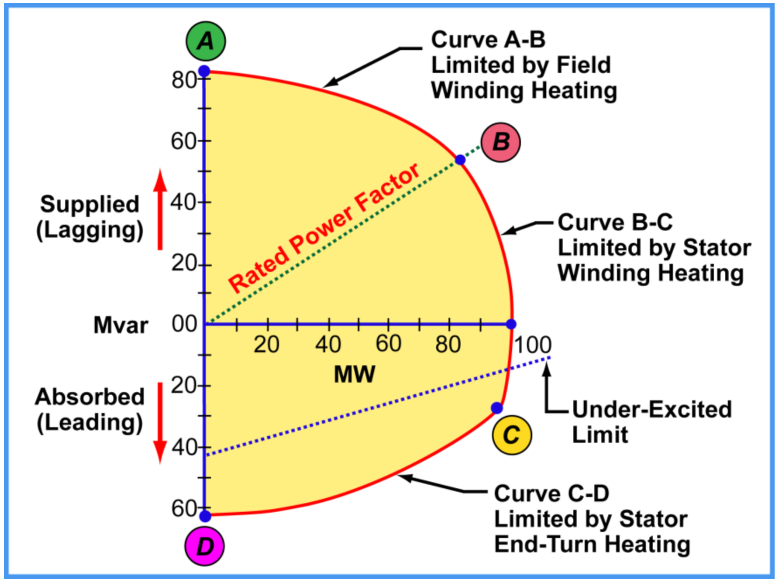
Generator Reactive Testing

- Results Reporting
  - MOC
    - Submit all required testing results to PJM within 10 working days
    - Test results submitted on "PJM Leading and/or Lagging Test Form R"
  - PJM
    - Provide feedback to Generation Owners on status of their test results
    - Also provide test results to appropriate TO
    - Conduct periodic audits of test results and provide results to OC and SOS

Reactive Capability Changes and Reporting

Generator Reactive Reporting

- Reactive Capability (or “D”) Curves
  - Generators Report "Continuous Unit Reactive Capability Curve"
    - Realistic usable capability sustainable during continuous unit operation
    - Should be based on actual operating experience (or testing)
    - Takes into consideration any normal unit or plant restrictions at 95 degrees F ambient or above



Generator Reactive Reporting

- Reactive Capability (or “D”) Curves
  - Sufficient number of curve points must be provided
    - Min of 2
    - Max of 8
  - Limits specified as measured at the low side of the step up transformer
    - Excludes any station service load fed off the terminal bus

Generator Reactive Reporting

- Reactive Capability (or “D”) Curves
  - Semi annual Reviews
    - Generator Owners required to review Capability and update any changes in eDART
      - Pre-Summer - During month of April
      - Pre-Winter - During month of October
    - Transmission Owners and PJM to review D-Curve changes in eDART and update respective EMS systems
      - Pre-Summer – During month of May
      - Pre-Winter – During month of November

Generator Reactive Reporting

- Reactive Capability (or "D") Curves
  - Permanent Updates
    - Generator must notify PJM and TO
      - via eDART ticket
      - Check "New Default" field on ticket
    - EMS Updates
      - PJM and TOs act on notifications, updating generator reactive capability in Security Programs

Generator Reactive Reporting

- Reactive Capability (or "D") Curves
  - Real-Time Updates
    - Generator must notify PJM and TO
      - via eDART ticket
      - AND via phone call
    - EMS Updates
      - PJM and TOs act on notifications, updating generator reactive capability in Security Programs

Questions?

Disclaimer:

PJM has made all efforts possible to accurately document all information in this presentation. The information seen here does not supersede the PJM Operating Agreement or the PJM Tariff both of which can be found by accessing: http://www.pjm.com/documents/agreements/pjm-agreements.aspx

For additional detailed information on any of the topics discussed, please refer to the appropriate PJM manual which can be found by accessing: http://www.pjm.com/documents/manuals.aspx

Resources and References

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