Proposals for Cost Allocation of Regulated Reliability Solutions Associated with
NYCA LOLE Violations
(Methods “D” and “E”)

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Power Systems 101

Power Systems 101

- Real and Reactive Power
- Power Factor
- Generation
- Load
- Losses
- Thermal Limits
- Voltage Drop
- Bus Voltage Limits
- Capacitors

Real and Reactive Power

- Heating loads and incandescent lighting loads consume only Real Power (MW)
- Motors and transformers (and appliances and equipment including motors and transformers) consume both Real Power (MW) and Reactive Power (MVAr)
- The composite of both Real and Reactive Power is Apparent Power (MVA)

$$MVA = \sqrt{(MW)^2 + (MVAr)^2}$$

Power Factor

- **Power Factor is the ratio of Real Power to Apparent Power**

$$PF = (MW)/(MVA)$$

- **Unity Power Factor ... PF = 1.0**

  MW = MVA

  Thus MVAr = 0

Leading versus Lagging Power Factors		
	Leading	Lagging
Load	Producing VArs	Consuming VArs
Generator	Absorbing VArs	Producing VArs

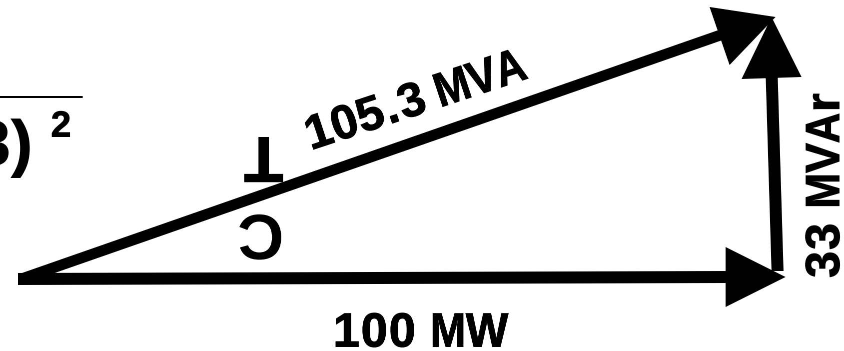
Power Factor Example

- Compute the Apparent Power and Power Factor associated with a Load of 100 MW and 33 MVAr

- Apparent Power ...

$$MVA = \sqrt{(100)^2 + (33)^2}$$

$$MVA = 105.3$$

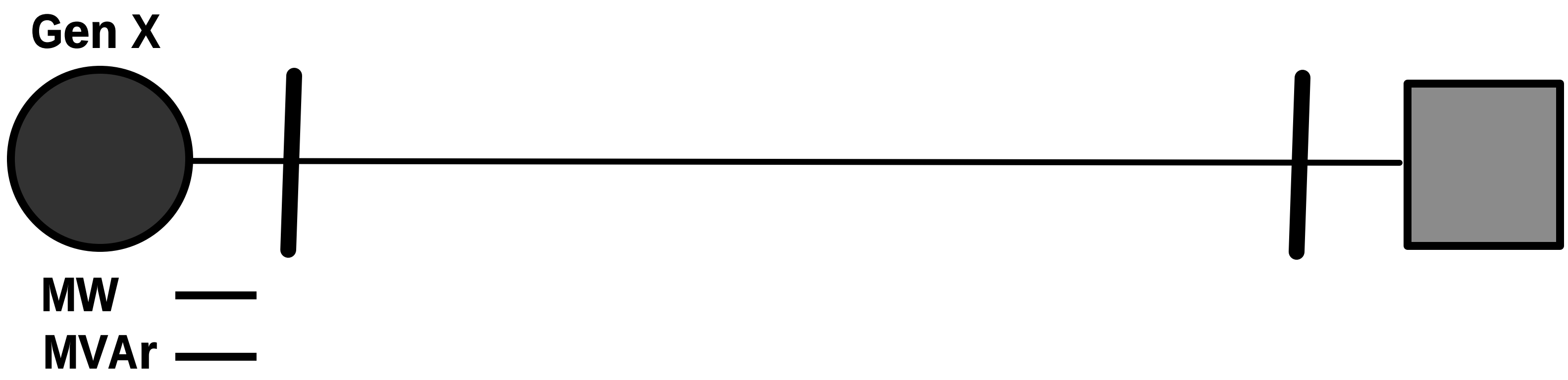


- Power Factor ...

$$PF = Cos\ T = (100)/(105.3)$$

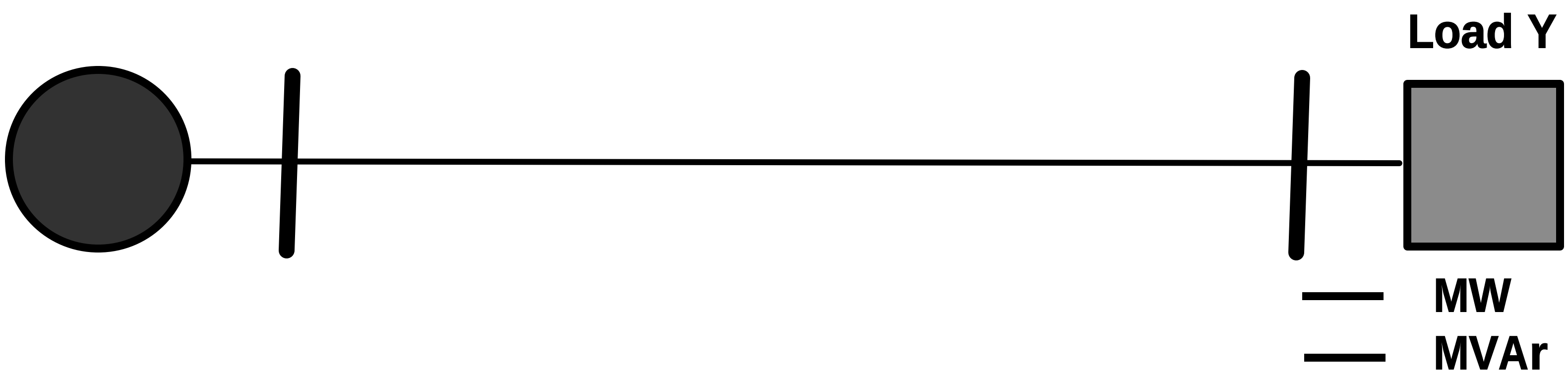
$$PF = 95.0\%$$

Generation



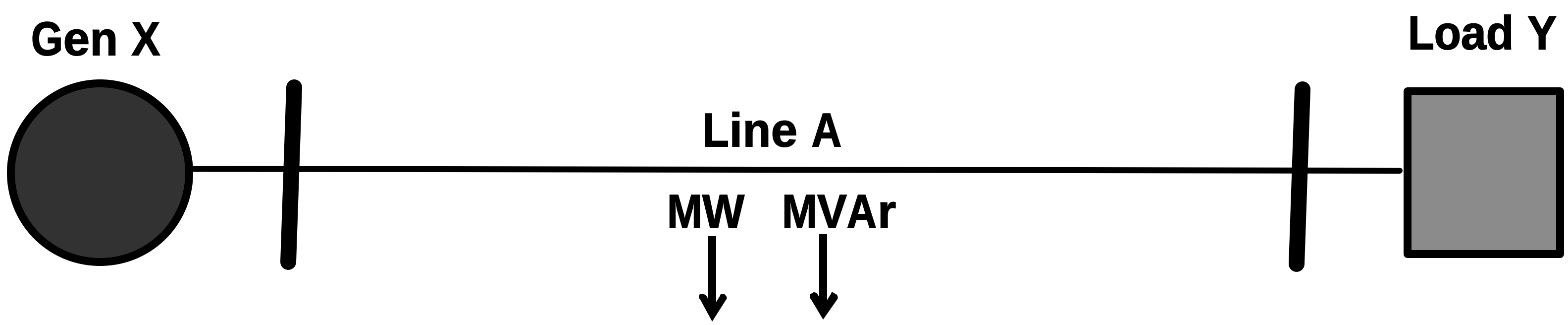
- Generator produces both Real (MW) and Reactive (MVAr) Power
- Generator may absorb Reactive Power instead of producing it if needed to reduce high voltage problems

Loads



- Load consumes both Real (MW) and Reactive (MVAr) Power
- Real and Reactive Power flow on transmission facilities from generators to serve loads results in losses and voltage drop on those transmission facilities

Losses on Transmission Facilities



- Transmission Facilities consume both Real (MW) and Reactive (MVAr) Power in the form of losses as a result of power flowing from Generators to Loads
- Real and Reactive Power Line losses vary exponentially with line flow ...
  - MW Line Losses result from both Real and Reactive Power flowing across Line Resistance
  - MVAr Line Losses result from both Real and Reactive Power flowing across Line Reactance
- Generator serves Real and Reactive Load *and* Losses

Transmission Thermal Rating

- Thermal ratings are invoked on transmission facilities to prevent ...
  - Equipment damage due to over-heating
  - Excessive sag in overhead lines
- Thermal Rating Categories
  - Summer vs. Winter
  - Normal (Continuous)
  - LTE (Long Term Emergency = 4 hrs per day)
  - STE (Short Term Emergency = 15 minutes)

Transmission Thermal Overloads

- **Thermal facilities can be overloaded by both Real (MW) and Reactive (MVAr) Power flow**
- **Strictly speaking, Thermal Ratings are based upon Current Ratings (Amperes)**
- **For simplicity ...**
  - **Current ratings are converted to MVA ratings using a presumed system voltage**
  - **Then MVA ratings are converted to MW ratings using a presumed Power Factor**
- **MW Ratings *may be overly optimistic* if either actual system voltages or power factors are lower than the presumed values**

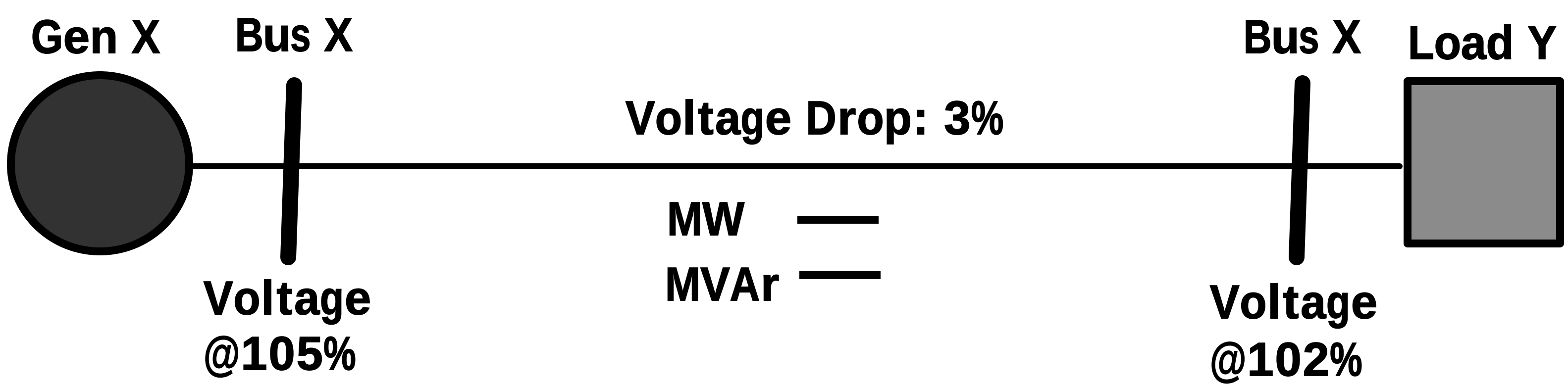
Bus Voltage Limits

- Bus is a termination or connection point for generators, loads and transmission facilities
- Each Bus has high and low voltage limits (as a % of the nominal voltage) for both pre-contingency and post-contingency conditions. For example …

Voltage Limits	Pre	Post
High	105%	105%
Low	100%	95%

- Note: Adhering to high voltage limit at one Bus may impinge on ability to adhere to low voltage limit at another Bus

Voltage Drop on Transmission Facilities



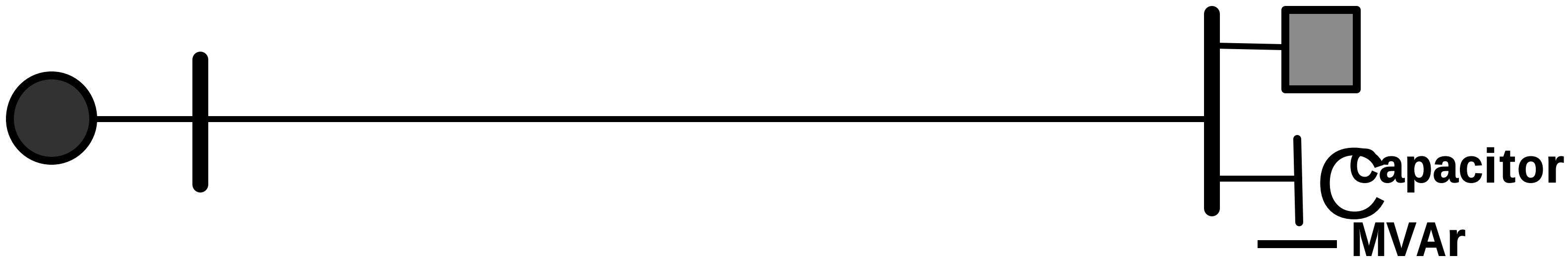
- Voltage drop occurs from Generators to Loads (Sources to Sinks) due to Real and Reactive Power flowing through the Resistance and Reactance of Transmission Facilities
- Voltage Drop varies proportionately with both Real (MW) and Reactive (MVAr) Power flow

Load Power Factors

- **Typically Load Factors during peak times are in the 90% to 95% range. For example ...**

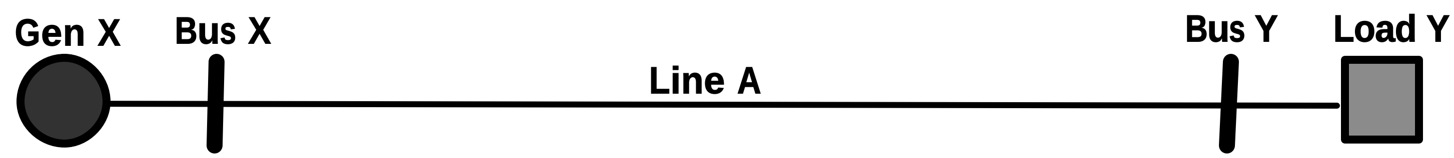
Load Power Factor (PF)	Real Load (MW)	Reactive Power (MVAr)	Total Apparent Power (MVA)
90%	1,000	484.3	1,111.1
95%	1,000	328.7	1,052.6

Capacitors



- Capacitors produce reactive power (MVAr) thereby *compensating* for reactive power consumed by loads
- When installed locally, capacitors reduce reactive power flows over transmission facilities from more remote sources which …
  - Reduces line losses
  - Reduces voltage drop
  - In the extreme: can produce voltage rise
- Underground cable and lightly loaded overhead transmission lines act as capacitors

Contributors to Reliability Violations



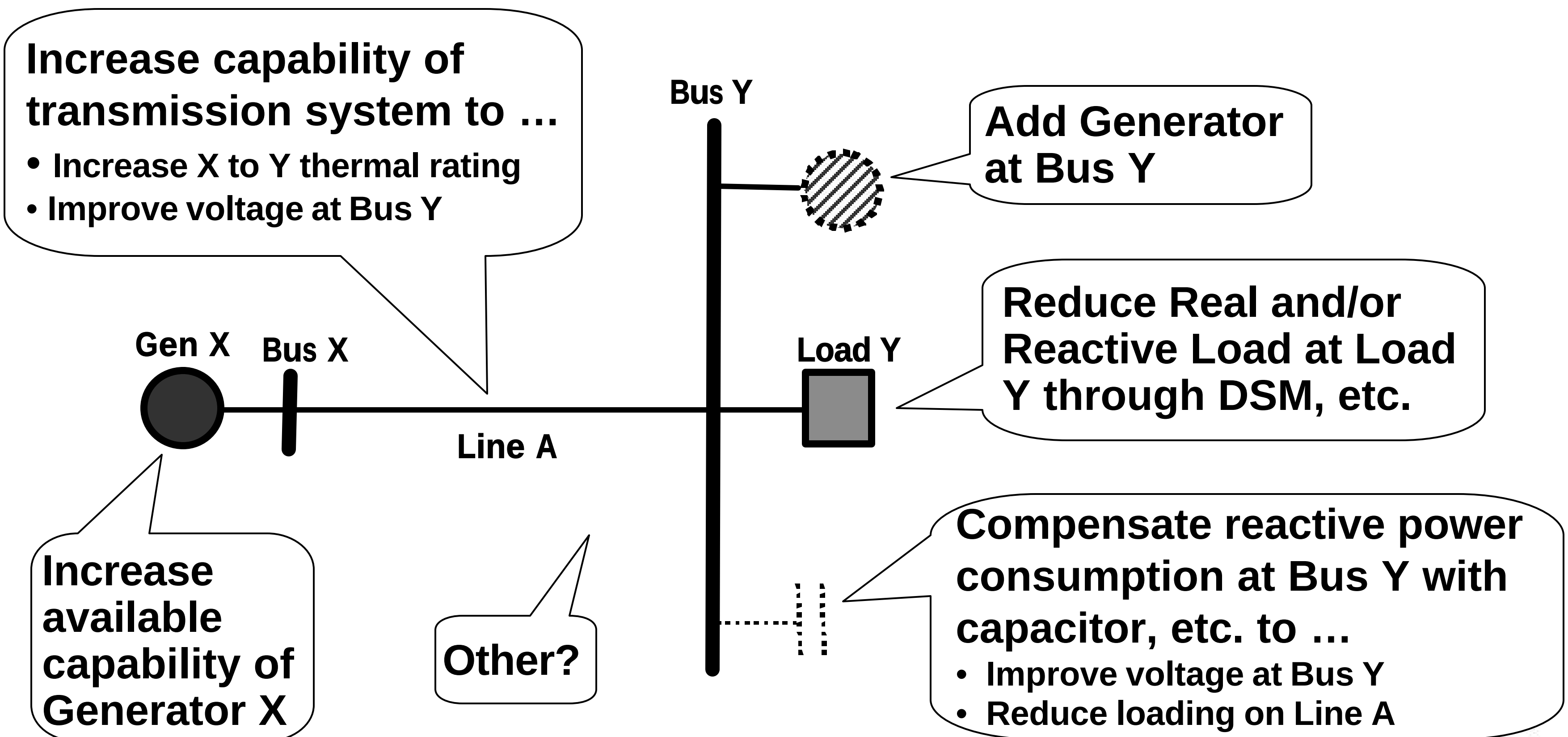
Inability to serve Load Y (i.e., having a detrimental impact on LOLE) can be contributed to by ...

- **Real and Reactive Power flowing to serve Load Y exceeding available capability of Generator X**
- **Real and Reactive Power flowing to serve Load Y exceeding thermal rating of Line A**
- **Real and Reactive Power flowing to serve Load Y results in excessive voltage drop from Bus X to Bus Y**

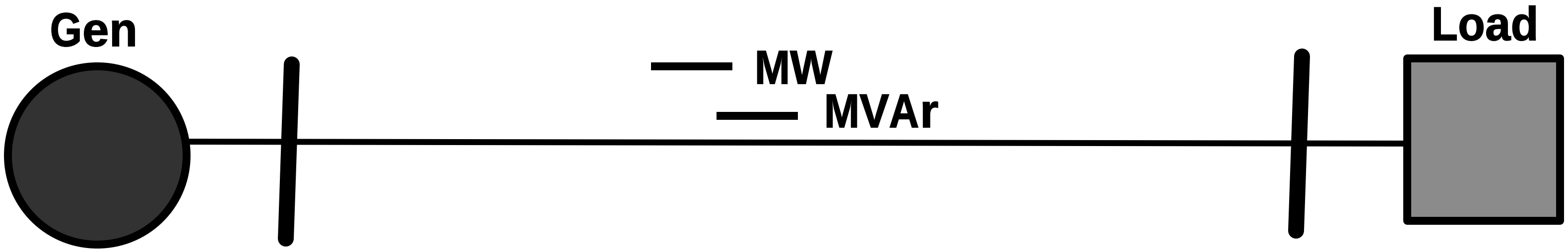
Both Real and Reactive Power flowing to serve loads contribute to reliability violations

Solutions to Reliability Violations

Depending upon circumstances, solutions to the inability to serve Load Y could include …



Observations



- Reliability Violations are contributed to by both Real and Reactive Power consumption (not necessarily on an equal impact basis)
- A Reliability Violation may be alleviated by
  - Reducing Real Power (MW) consumption
  - Reducing Reactive Power (MVAr) consumption
  - Increasing Real Power (MW) Production and/or Delivery
  - Increasing Reactive Power (MVAr) Production and/or Delivery

Cost Allocation

Cost Allocation Principles

1. **Load Decrements Can Determine Contribution**

   Decrementing loads at various locations is a legitimate way to ascertain which and to what degree individual loads contribute to a reliability violation.

2. **Loads Should be Decremented in MVA at Prevailing PF**

   Loads should be decremented simultaneously as both Real (MW) and Reactive (MVAr) Power using the applicable peak load Power Factors.

3. **Decrementing Only Real or Reactive Loads May Produce Misleading Results**

   Decrementing only one load component (i.e., either Real or Reactive loads, but not both simultaneously) to determine contribution to a reliability violation invokes an artificial and disproportional importance to the impact of that one component – when in fact both Real and Reactive Power components contribute to the reliability violation.

Principles (cont.)

4. **Non-Contributors to a Violation Should Not be Allocated Costs**

   A decremented load that does not help alleviate a reliability violation should not be assigned an allocation of costs for a solution because this shows it does not contribute to the violation.

5. **All Loads Contributing to a Violation Should Be Allocated Costs**

   All loads that contribute to a reliability violation should be allocated a portion of the cost of the solution even if one load can be decremented such that it can fully eliminate the violation, it should not be allocated 100% of the cost of a solution unless no other decremented load can help alleviate the violation.

6. **The Cost Allocation Method Should Not be Dependent Upon the Specific Solution**

   Various types of regulated solutions that meet a specific need (either fully or partially) should be cost allocated in the same way.

Principles (cont.)

7. **Loads that Contribute Proportionally More to a Violation (per MVA) Should Be Allocated Proportionately More Cost**

   A decremented load that is twice as effective (per MVA of load drop) as another decremented load in alleviating a violation should be allocated costs for the solution at a rate twice as high.

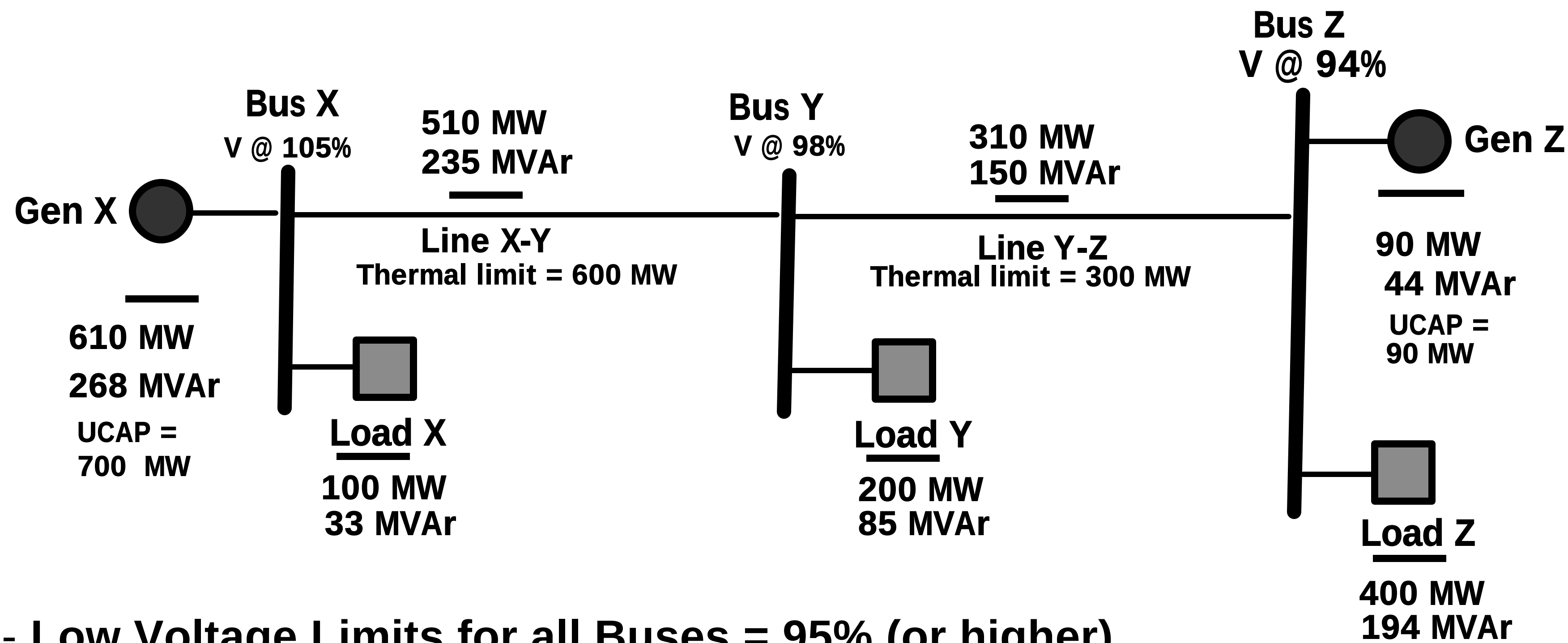
8. **A Larger Load that Contributes to a Violation Equally as a Smaller Load (per MVA) Should be Allocated Proportionately More Cost**

   If two decremented loads are equally effective (per MVA of load drop) in alleviating a violation, and one load is twice as large as the other, the larger load should be cost allocated twice as much.

9. **Cost Allocation Methods Should Be Similar for Various Violations**

   To the extend possible, cost allocation methods should be the same regardless of the type of violation that occurs.

Cost Allocation Example Diagram



- Low Voltage Limits for all Buses = 95% (or higher)
- Flows shown are those required to meet LOLE criteria of 0.1 or less
- Required flows result in Thermal Overload of Line Y-Z
- Required flows result in More Restrictive Low Voltage Violation at Bus Z
- Line Y-Z needs to be limited to 270 MW to maintain 95% voltage at Bus Z
- Resulting LOLE (honoring transmission and UCAP constraints) = 0.3

Methods "D" and "E"

- **Method "D"**
  - Decrement MVA loads individually in each sub-zone and then on a uniform basis for all sub-zones whose load decrement can improve LOLE
- **Method "E"**
  - Decrement MVAr loads individually in each sub-zone and then on a uniform basis for all sub-zones whose load decrement can alleviate Voltage Limits
  - Then decrement MW loads individually in each sub-zone and then on a uniform basis for all sub-zones whose load decrement can improve LOLE
- **Both Methods intended to …**
  - Accommodate the 9 aforementioned Cost Allocation Principles
  - Apply to NYCA LOLE violations (whether partially exacerbated by inter-zonal transfer limits or not)

Method “D” Cost Allocation Summary

- Decrement load in each sub-zone (uniformly across that sub-zone) on an MVA basis at that sub-zone’s prevailing power factor
- Determine sub-zone’s relative contribution based upon the degree to which its decremented load alleviates a violation (taking into account that load decrements may impact transfer limits)
- Allocate cost to each contributing sub-zone proportionally to the sub-zone’s relative load size and associated impact on the violation (similar to using a Generator Shift Factor)

Method "D" Example - Cost Allocation Computation

Method D				
LOLE Violation Cost Allocation Example				
Loads at Buses X, Y and Z pay on a proportional basis based upon their individual Real and Reactive Power (at prevailing Power Factors) impacts on LOLE				
Representative Values for Illustrative Purposes - Not Necessarily Actual				
	Bus X	**Bus Y**	**Bus Z**	**Total Area**
Coincident Peak Apparent Power Load (MVA)	105	217	445	767
Coincident Peak Real Load (MW)	100	200	400	700
Coincident Peak Reactive Load (MVAr)	33	85	194	312
As Found LOLE	0.30			
As Found Line Y-Z Limits (MW)	270 MW Voltage; 300 MW Thermal			
% Load Reduction in MVA Needed Alone	No Impact	32.0%	8.0%	--
MVA Load Reduction Needed on One Bus	No Impact	70	36	--
MW Load Reduction Needed on One Bus	No Impact	64	32	--
MVAr Load Reduction Needed on One Bus	No Impact	27	16	--
Resulting Line Y-Z Voltage Limit (MW) after Single Bus (Sub-Area) Load Reduction	No Impact	300	278	--
MVA Load Reduction Equivalent to the Impact of 1 MVA Reduction at Bus Z	No Impact	1.96	1.00	--
% Load Reduction Needed if Shared	No Impact	6.40%	6.40%	--
MVA Load Reduction Needed if Shared	No Impact	14	28	42
Resulting Line Y-Z Limits (MW) after Equally Shared MVA Load Reductions	310 MW Voltage; 300 MW Thermal			
MVA Load Reduction on an Equivalent Bus Z Load Reduction Impact Basis	-	7	28	36
Cost Allocation by Bus (Sub-Area) for a Regulated Solution	0.0%	20.0%	80.0%	100.0%
"% Load Reduction Needed Alone" is uniform load decrease solely at Bus X, Y or Z (at their own Power Factors) that is sufficient to reduce NYCA LOLE to less than 0.1.				
Based on above results, in terms of decreasing LOLE, a 1.96 MVA reduction at Bus Y equals a 1.0 MVA reduction at Bus Z (36 MVA needs to be reduced at Buz Z, or an equivalent amount at both Bus Y and Z)				
Total % Load Reduction needed if shared unifirmly is determined by solving for R where:				
(217 x R/1.96) + (445 x R) = 36; thus R = (36) / ((217 / 1.96) + 445) =			6.40%	

Method "D" Example - Results

- Buses are proxies for Sub-zones
- Decrementing MVA Load at Bus X has no impact on improving LOLE - therefore Bus X does not contribute to violation and is allocated no cost
- Each of the following load decrements improves LOLE to below 0.1 (in the process, they improve voltages at both Bus Y and Bus Z, and raise the X-Y voltage transfer limit):
  - 70 MVA at Bus Y (32.0% of its load)
  - 36 MVA at Bus Z (8.0% of its load)
  - 14 MVA at Bus Y and 28 MVA at Bus Z (6.40% of each)
- Bus Z is allocated 80.0% of the cost of the solution versus 20.0% for Bus Y because it contributes proportionately more to the violation in two ways:
  - A 1.0 MVA load drop on Bus Z is equivalent to a 1.96 MVA load drop on Bus Y (i.e., Bus Z load drops are more effective in alleviating the violation – consequently, Bus Z load contributes proportionately more to the violation)
  - Bus Z load is more than twice the level (205%) of Bus Y load, and therefore also contributes proportionately more to the violation

Method “E” Cost Allocation Summary

- If a Voltage Limit contributes to an LOLE > 0.1, decrement load in each sub-zone (uniformly across that sub-zone) on an MVAr basis
- Determine sub-zone’s relative contribution based upon the degree to which its decremented load alleviates a voltage violation (towards making a Thermal Limit the more restrictive)
- Allocate cost to each contributing sub-zone proportionally to the sub-zone’s relative load size and associated impact on the voltage violation (similar to using a Generator Shift Factor)
- If LOLE is still > 0.1 after Voltage Limit is eliminated, decrement loads in each sub-zone on a MW basis in a method parallel to above

Method "E" Example - Cost Allocation Computation

Method E - Part 1				
LOLE Violation Cost Allocation Example				
Loads at Buses X, Y and Z pay on a proportional basis based upon their individual Reactive Power Impacts on LOLE				
Representative Values for Illustrative Purposes - Not Necessarily Actual				
	Bus X	**Bus Y**	**Bus Z**	**Total Area**
Coincident Peak Apparent Power Load (MVA)	105	217	445	767
Coincident Peak Real Load (MW)	100	200	400	700
Coincident Peak Reactive Load (MVAr)	33	85	194	312
As Found LOLE	0.30			
As Found Volatge at Buz Z	94.1%			
As Found Line Y-Z Limits (MW)	270 MW Voltage; 300 MW Thermal			
% Load Reduction in MVAr on One Bus	100.0%	100.0%	20.0%	--
MVAr Load Reduction on One Bus	33	85	39	--
Resulting Bus Z Voltage	Unchanged	94.5%	94.5%	--
MVAr Load Reduction Equivalent to the Impact of 1 MVAr Reduction at Bus Z	No Impact	2.19	1.00	--
% Load Reduction in MVAr to Attain 95% Voltage at Bus Z	No Impact	Not Attainable	70.0%	
MVAr Load Reduction to Attain 95% at Bus Z	No Impact	" " "	136	--
% Load Redution in MVAr if Shared	No Impact	58.3%	58.3%	
MVAr Load Reduction Needed if Shared	No Impact	50	113	163
Resulting Line Y-Z Limits (MW) after Equally Shared MVAr Load Reductions	310 MW Voltage; 300 MW Thermal			
MVAr Load Reduction on an Equivalent Bus Z Load Reduction Impact Basis	-	23	113	136
Cost Allocation by Bus (Sub-Area) for a Regulated Solution	0.0%	16.7%	83.3%	100.0%
Resulting LOLE w New Limits	0.08			
"% Load Reduction Needed Alone" is uniform load decrease solely at Bus X, Y or Z (at their own Power Factors)				
Based on above results, in terms of improving voltage at Bus Z, a 2.19 MVAr reduction at Bus Y equals a 1.0 MVAr reduction at Bus Z				
Total % MVAr Load Reduction needed if shared unifirmly is determined by solving for R where:				
(85 x R/2.19) + (194 x R) = 136; thus R = (136) / ((85 / 2.19) + 194) =			58.3%	

Method “E” Example - Results

- Buses are proxies for Sub-zones
- Decrementing MVAr Load at Bus X has no impact on improving Bus Z Voltage – therefore Bus X does not contribute to violation and is allocated no cost
- Decrementing 100% of MVAr Load at Bus Y improves voltage at Bus Z from 94.1% to 94.5%. A 20% MVAr Load decrement at Bus Z has the same impact.
- Decrementing 70% of MVAr Load at Bus Z improves voltage at Bus Z to 95.0%
- Decrementing 58.3% of MVAr Load at both Bus Y and Bus Z also improves voltage at Bus Z to 95.0%
- Eliminating the Line Y-Z Voltage Limit improves the LOLE to less than 0.1
- Bus Z is allocated 83.3% of the cost of the solution versus 16.7% for Bus Y because it contributes proportionately more to the violation in two ways:
  - A 1.0 MVAr load drop on Bus Z is equivalent to a 2.19 MVAr load drop on Bus Y (i.e., Bus Z Reactive Power load drops are more effective in alleviating the violation – consequently, Bus Z load contributes proportionately more to the violation)
  - Bus Z MVAr load is more than twice the level of Bus Y MVAr load, and therefore also contributes proportionately more to the violation