Power System Security: Contingency Analysis

ECG 740

Background

- Power System Security involves practices designed to keep the system operating when components fail.
- Most power systems are operated such that any single initial failure event will not leave other components heavily overloaded.
- The above is referred to as the NERC (n-1) rule!, i.e., no single outage will result in flow or voltage violations.
- System security can be broken down into 3 major functions: a) system monitoring – Chap. 9, b) contingency analysis, Chap. 7, c) security-constrained OPF – Chap. 8.

Difference between reliability and security

Reliability of a power system refers to the probability of satisfactory operation over the long run. It denotes the ability to supply adequate electric service on a nearly continuous basis, with few interruptions over an extended time period. *(IEEE Paper on Terms & Definitions, 2004)*

Security is a time-varying attribute which can be judged by studying the performance of the power system under a particular set of conditions. Reliability, on the other hand, is a function of the time-average performance of the power system; it can only be judged by consideration of the system's behavior over an appreciable period of time.

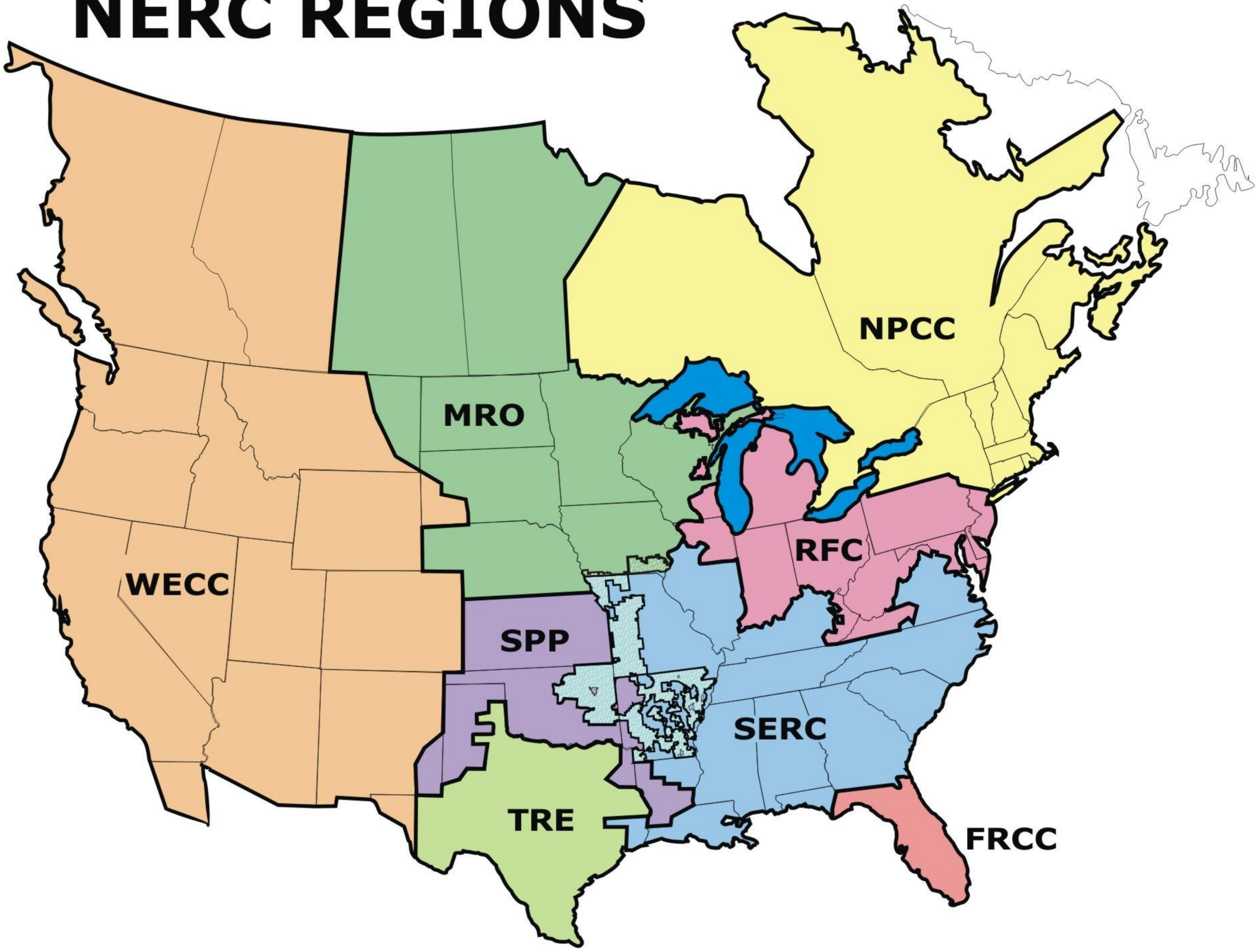
Requirements of Reliable Electric Power Service

- Steady-state and transient voltages and frequency must be held within close tolerances
- Steady-state flows must be within circuit limits
- Synchronous generators must be kept running in parallel with adequate capacity to meet the load demand
- Maintain "integrity" of bulk power network: avoid cascading outages

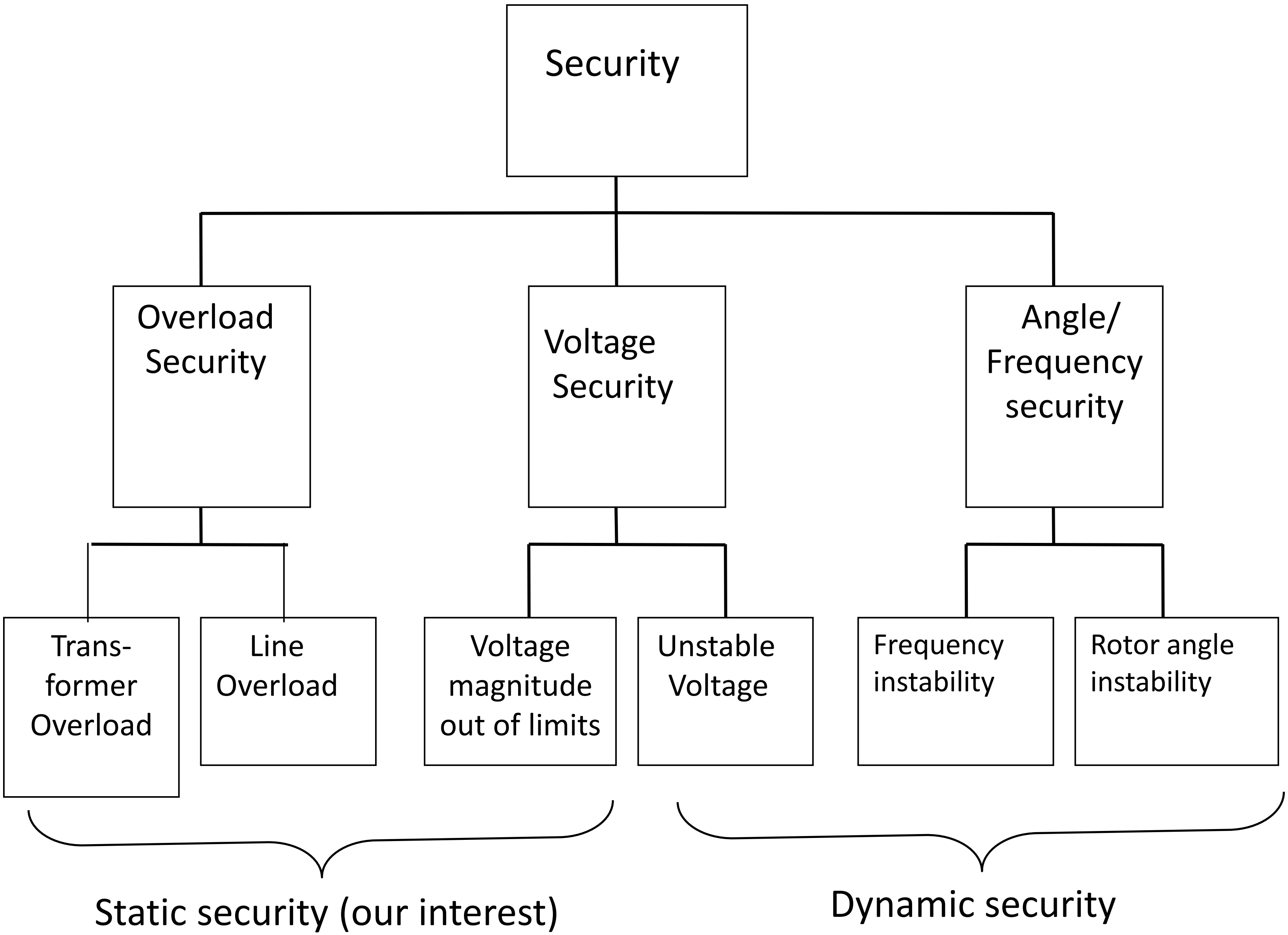
NERC, North American Electric Reliability Corporation:

Mission is to ensure reliability of the bulk power system in North America. They develop/enforce reliability standards; assess reliability annually via seasonal forecasts; monitor the bulk power system; evaluate users, owners, and operators for preparedness; and educate, train, and certify industry personnel. NERC is a self-regulated organization, subject to oversight by the U.S. Federal Energy Regulatory Commission

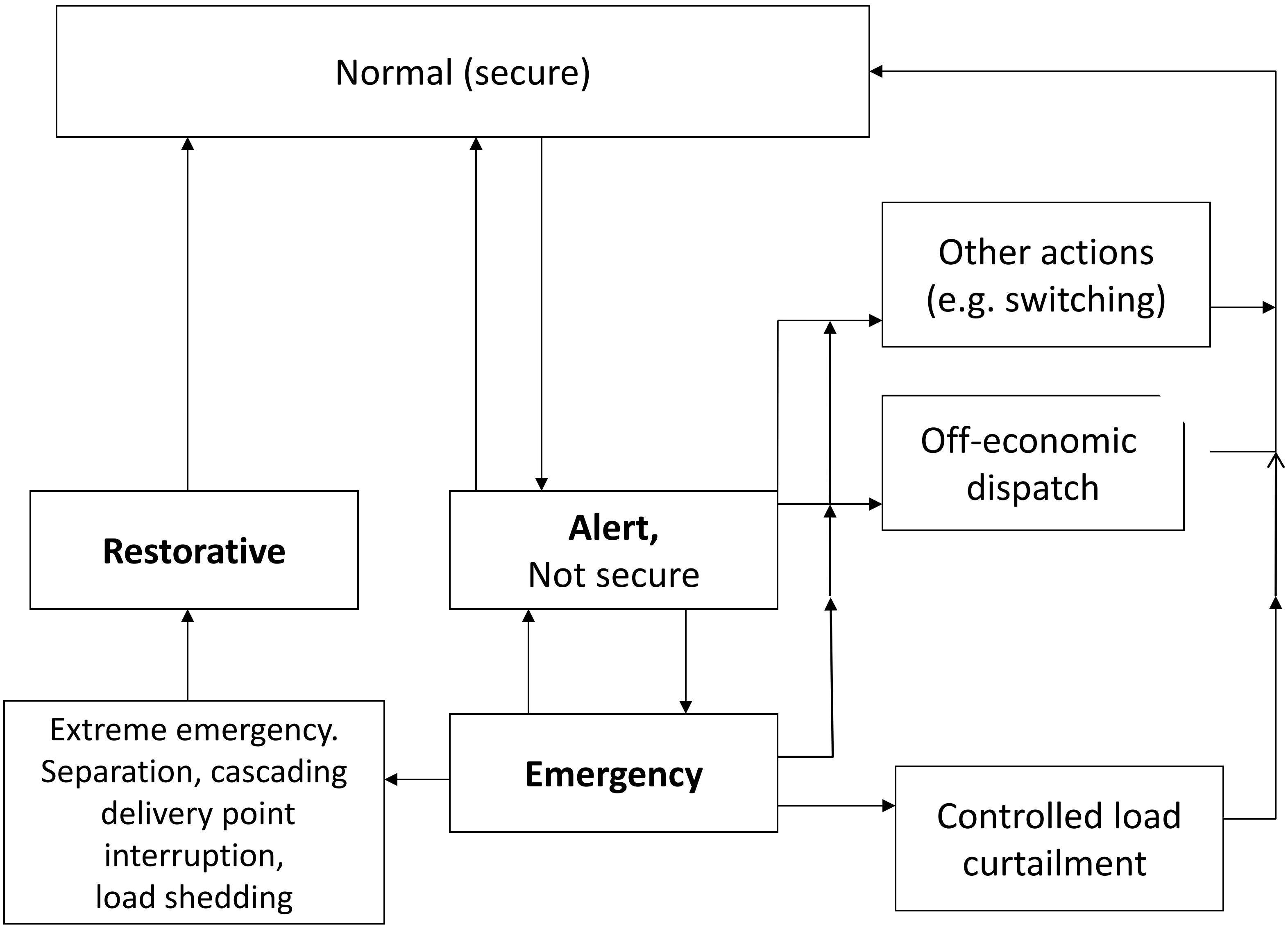
NERC REGIONS



An operator's view of "security"



Power system operational "States" & actions



Power system operational "States" & actions

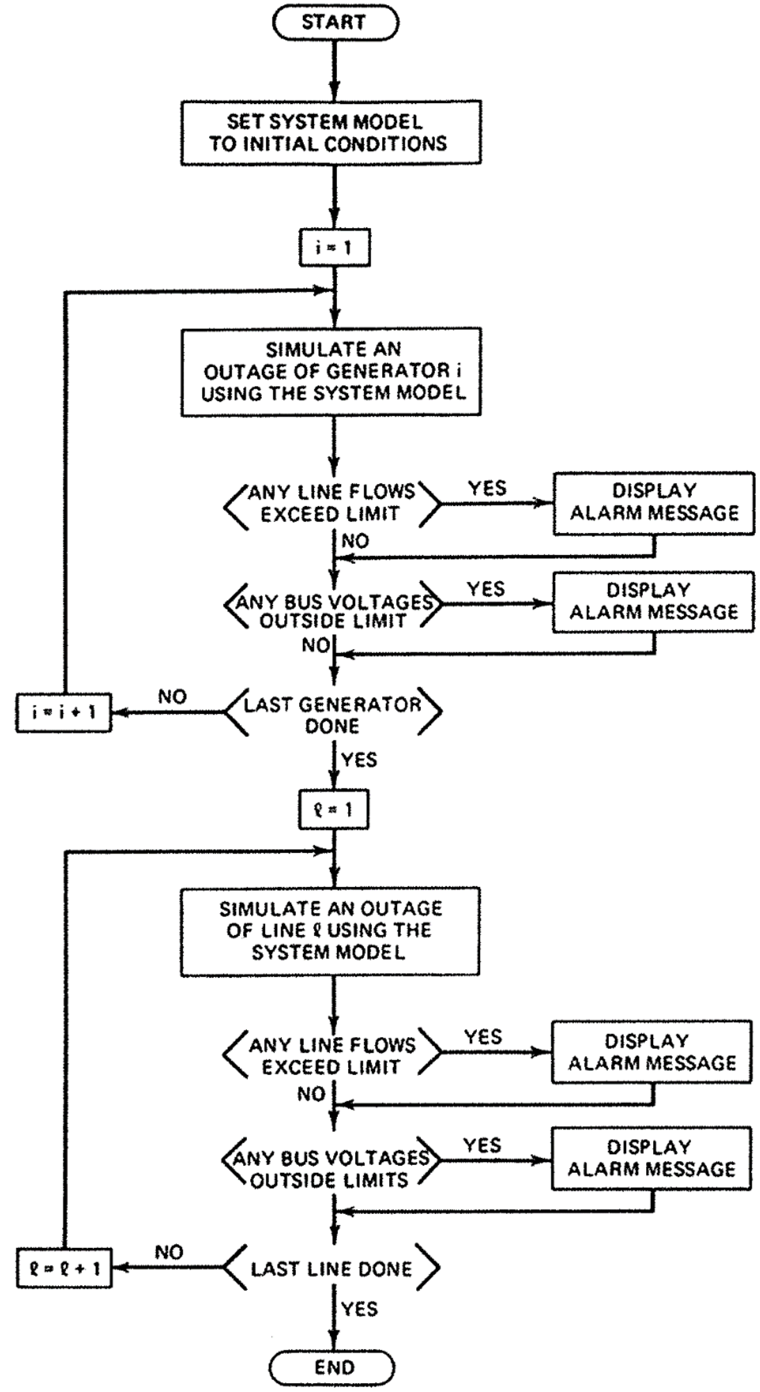
- For all **credible** contingencies, the system will, at worst transit from the normal state to the alert state, rather than to a more severe state such as the emergency state.
- If a system is operated according to a criteria, the system can transition from normal state to emergency state only for a non-credible (extreme) contingency.
- When the alert state is entered following a contingency, operators can take actions to return the system to the normal state, but such actions should not include load shedding.
- Load shedding should only be performed under emergencies.

Contingency Analysis

(Detection of Network Problems)

- **Generation outages:**
  - The initial imbalance will result in frequency drop which must be restored (Chap. 10).
  - Other generators must make up the loss of power from the outaged generator – must have sufficient spinning reserve.
  - Line flows and bus voltages will be altered – check for violations.
- **Transmission Outages**:
  - All flows in nearby lines and bus voltages will be affected.
  - The result can be line flow limit and/or voltage limit violations.
- **Other outages**
  - Bus outages
  - Loss of load

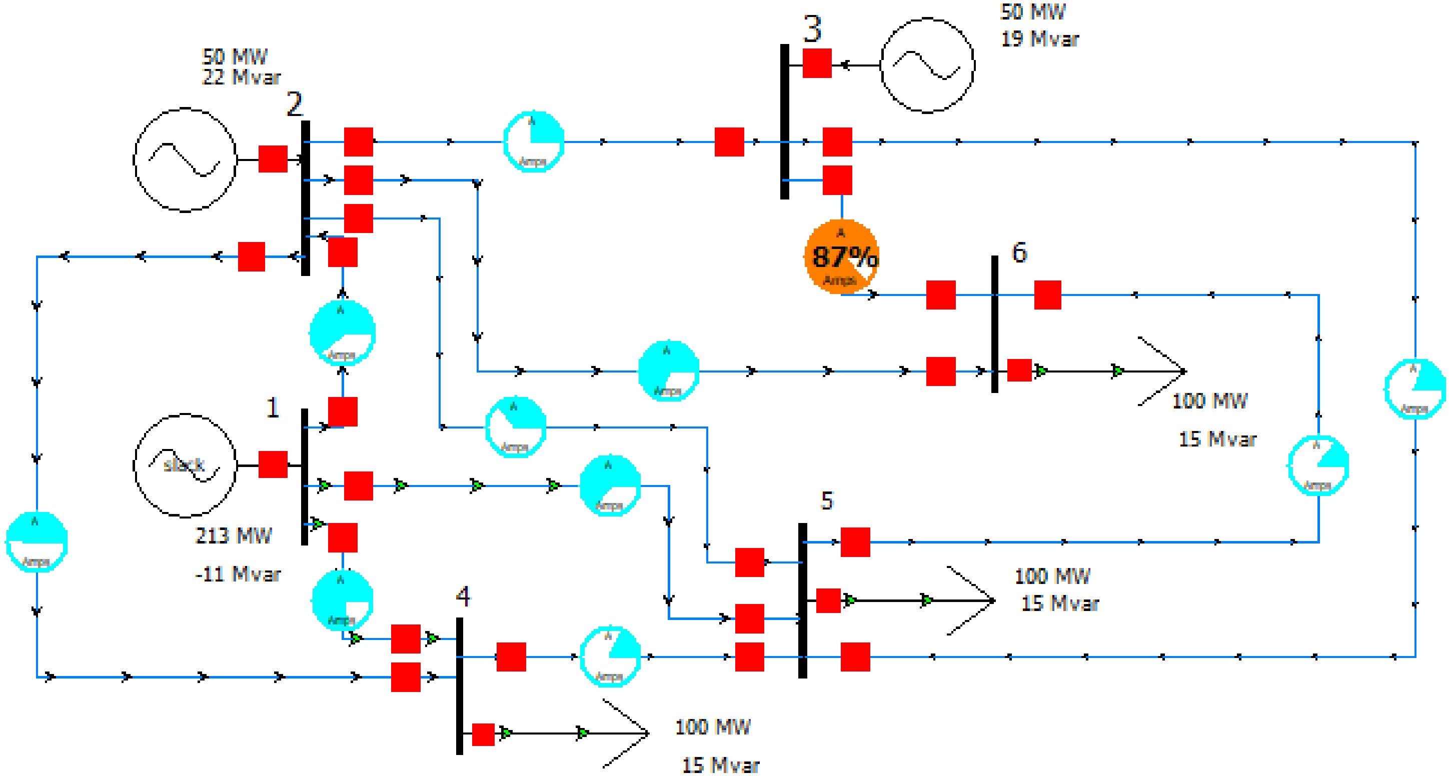
AC Power Flow Contingency Analysis Procedure (Fig. 7.2)



Example: Security analysis on 6-bus network using PowerWorld

- Base Case: (modified V_1 to 1.05pu)

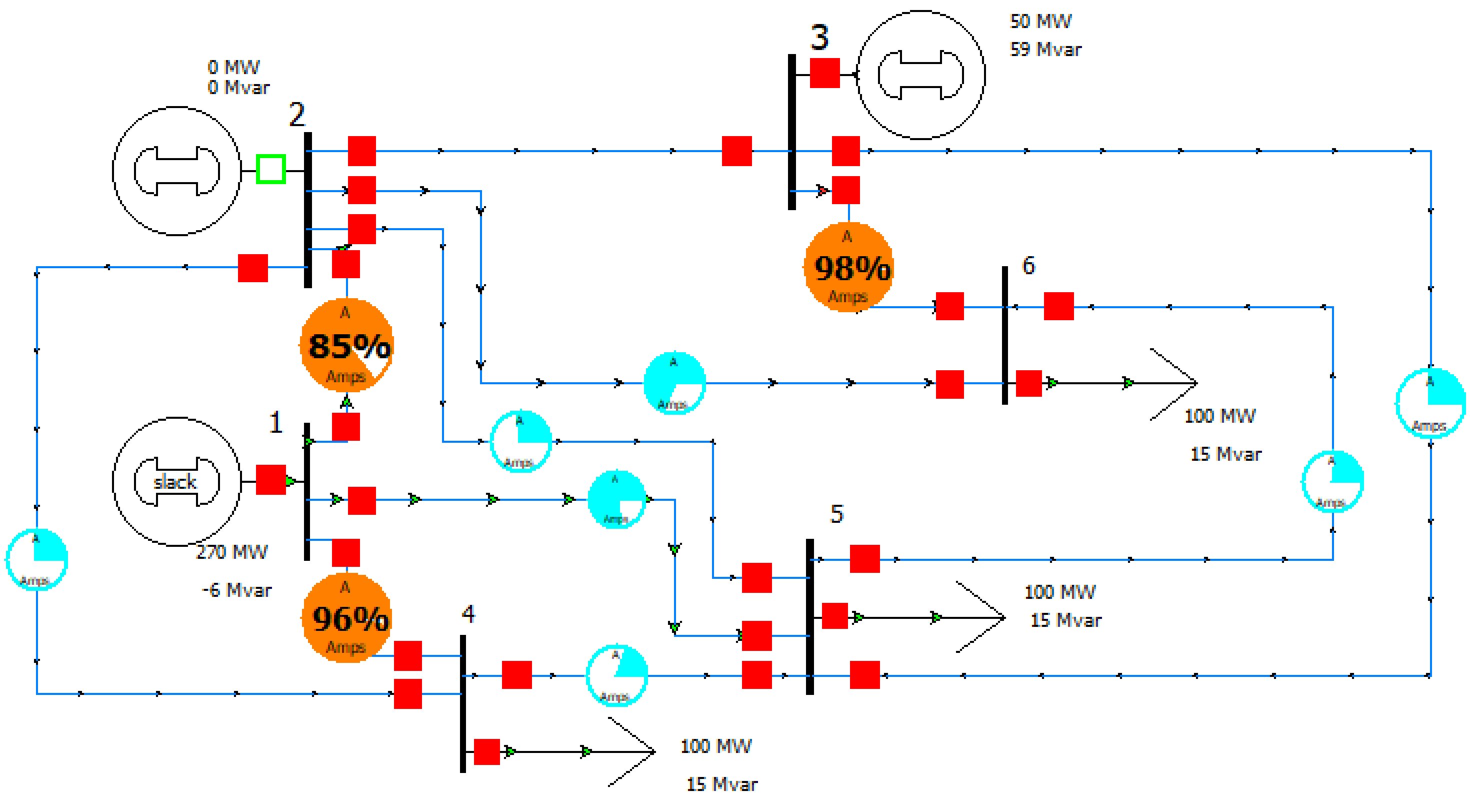
	PU Volt	Volt (kV)	Angle (Deg)
1	1.05000	241.500	0.00
2	1.05000	241.500	-7.84
3	1.05000	241.500	-9.83
4	1.02025	234.657	-8.92
5	1.01626	233.739	-11.07
6	1.02348	235.401	-12.41



Example: Security analysis on 6-bus network using PowerWorld

- Loss of Generator at Bus 2:

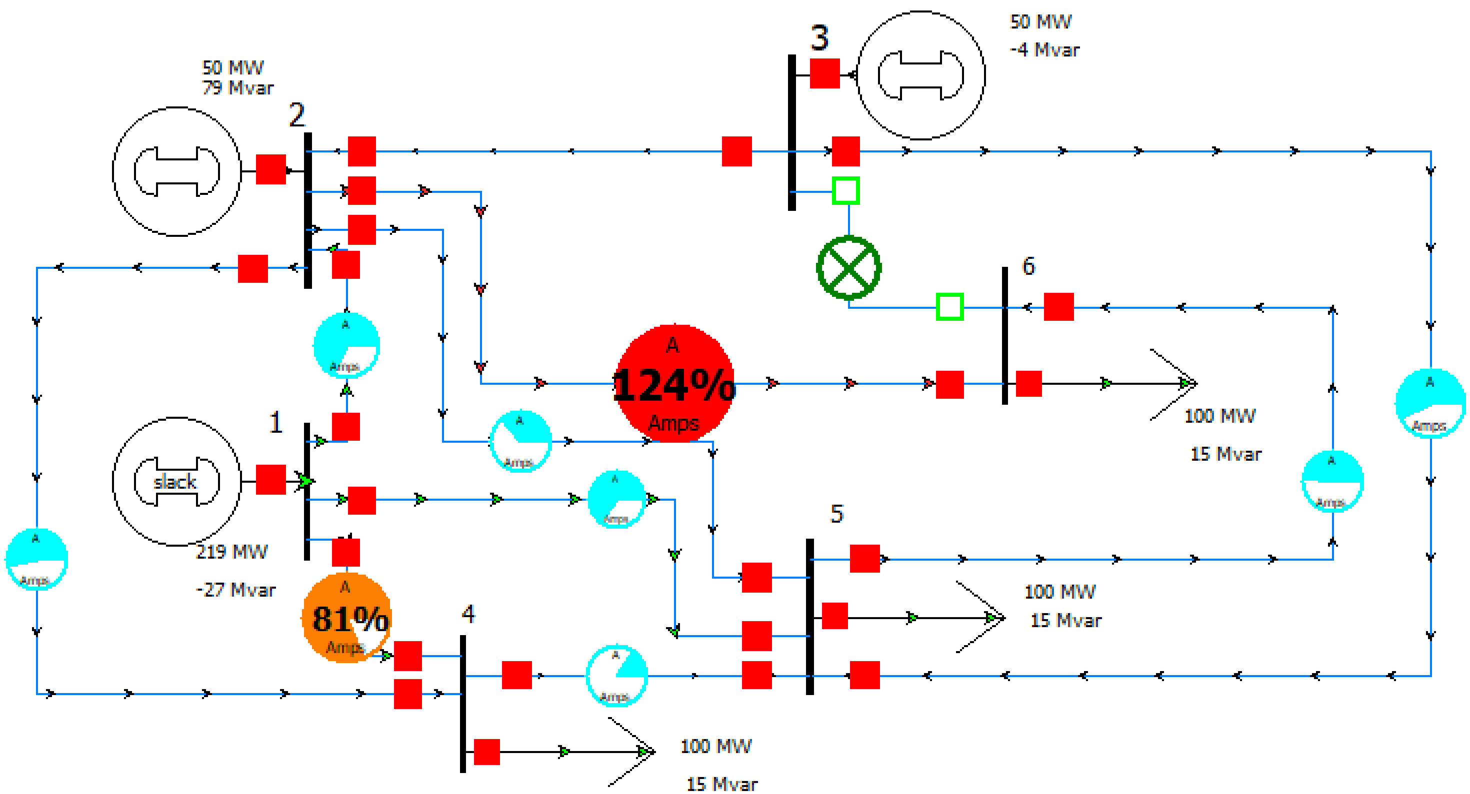
Name	Area Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)
1	1	230.00	1.05000	241.500	0.00
2	1	230.00	1.01238	232.848	-10.38
3	1	230.00	1.05000	241.500	-12.68
4	1	230.00	0.99653	229.203	-10.77
5	1	230.00	1.00072	230.166	-13.16
6	1	230.00	1.01004	232.310	-15.19



Example: Security analysis on 6-bus network using PowerWorld

- Loss of line 3-6:

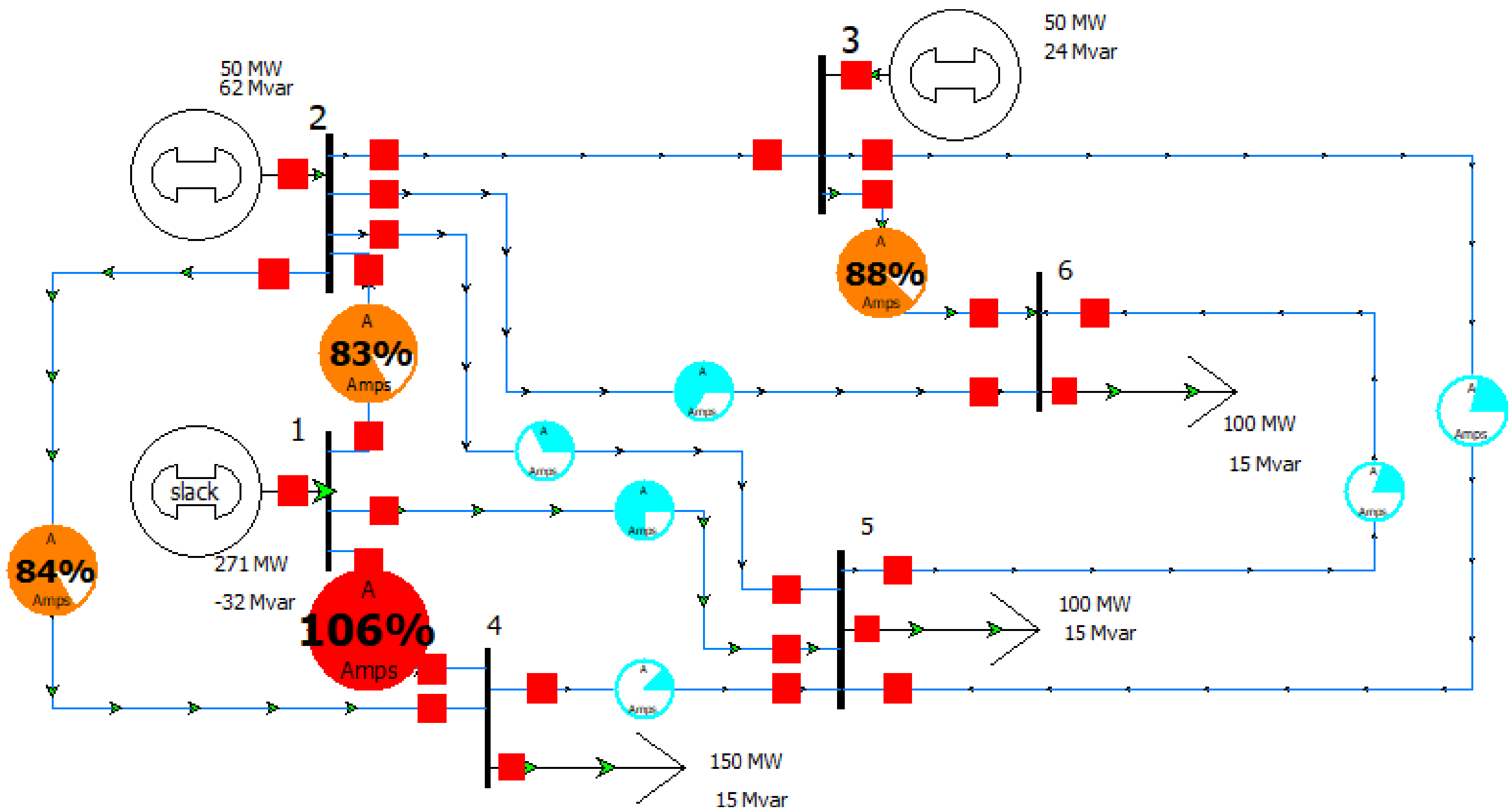
Name	Area Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	L
1	1	230.00	1.05000	241.500	0.00	
2	1	230.00	1.05000	241.501	-8.18	
3	1	230.00	1.05000	241.499	-6.27	
4	1	230.00	1.01813	234.170	-9.11	
5	1	230.00	1.00094	230.217	-11.04	
6	1	230.00	0.96809	222.660	-15.96	



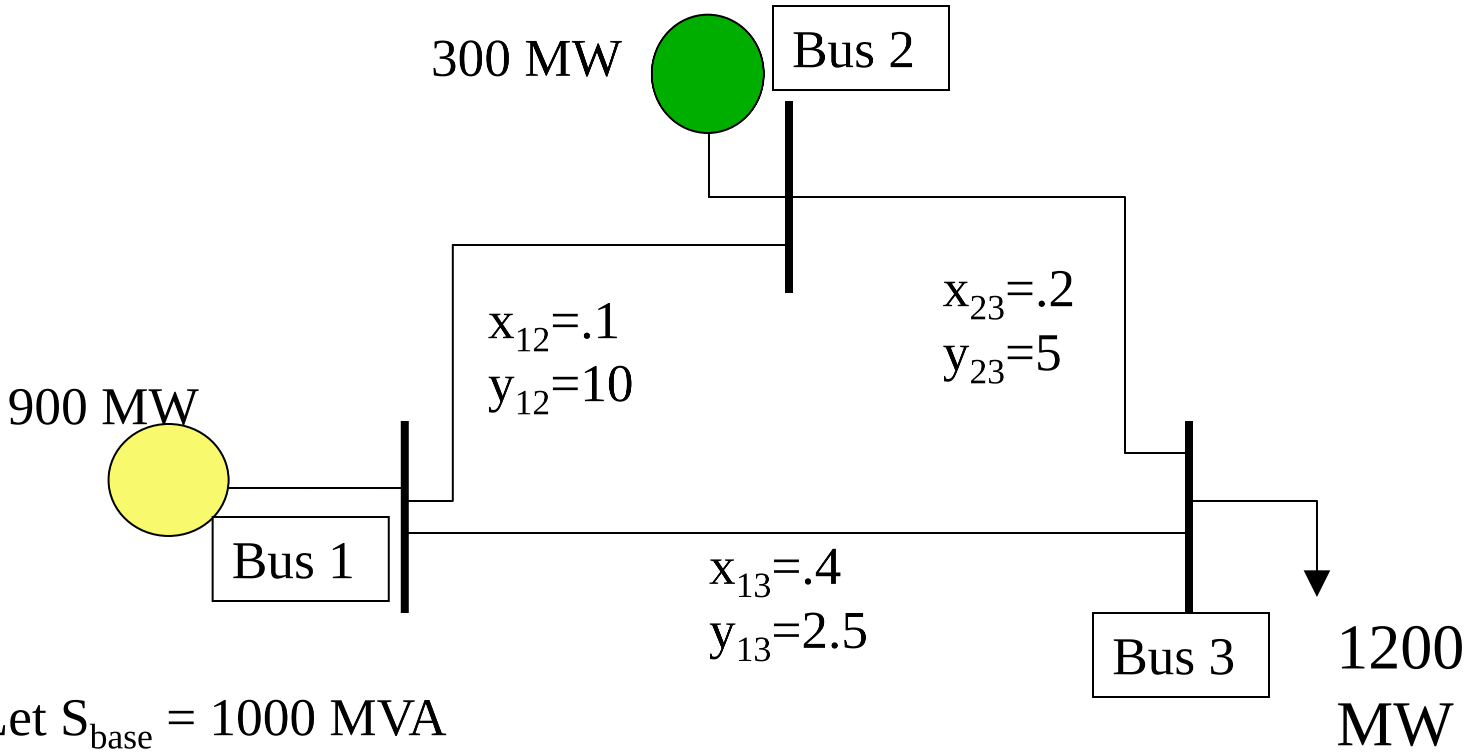
Example: Security analysis on 6-bus network using PowerWorld

- Increase load at bus 4 by 50%:

Name	Area Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)
1	1	230.00	1.05000	241.500	0.00
2	1	230.00	1.05000	241.500	-10.02
3	1	230.00	1.05000	241.500	-11.87
4	1	230.00	1.00581	231.336	-11.99
5	1	230.00	1.01368	233.147	-12.88
6	1	230.00	1.02305	235.302	-14.46



"DC" power flow in parallel paths



Let S_{base} = 1000 MVA

$$\begin{bmatrix} 15 & -5 \\ -5 & 7.5 \end{bmatrix} \begin{bmatrix} \theta_2 \\ \theta_3 \end{bmatrix} = \begin{bmatrix} .3 \\ -1.2 \end{bmatrix} \Rightarrow \begin{bmatrix} \theta_2 \\ \theta_3 \end{bmatrix} = \begin{bmatrix} .0857 & .0571 \\ .0571 & .1714 \end{bmatrix} \begin{bmatrix} .3 \\ -1.2 \end{bmatrix} = \begin{bmatrix} -.0428 \\ -.1885 \end{bmatrix}$$

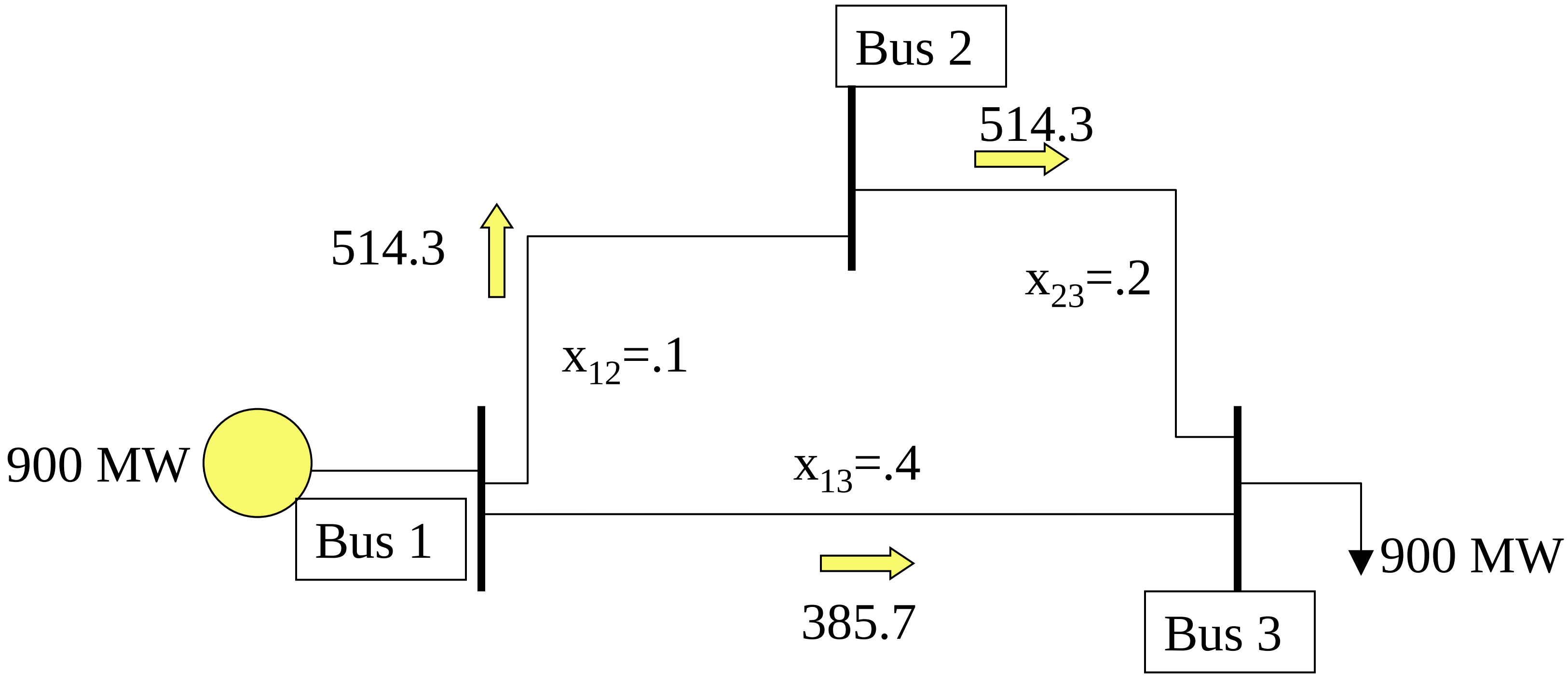
[B] $\qquad$ $[X] = [B]^{-1}$

$$P_{ij} = \frac{1}{x_{ij}}(\theta_i - \theta_j) \qquad \begin{bmatrix} P_{12} \\ P_{23} \\ P_{13} \end{bmatrix} = \begin{bmatrix} .428 \\ .728 \\ .472 \end{bmatrix} \text{pu} = \begin{bmatrix} 428 \\ 728 \\ 472 \end{bmatrix} \text{MW}$$

“DC” power flow in parallel paths

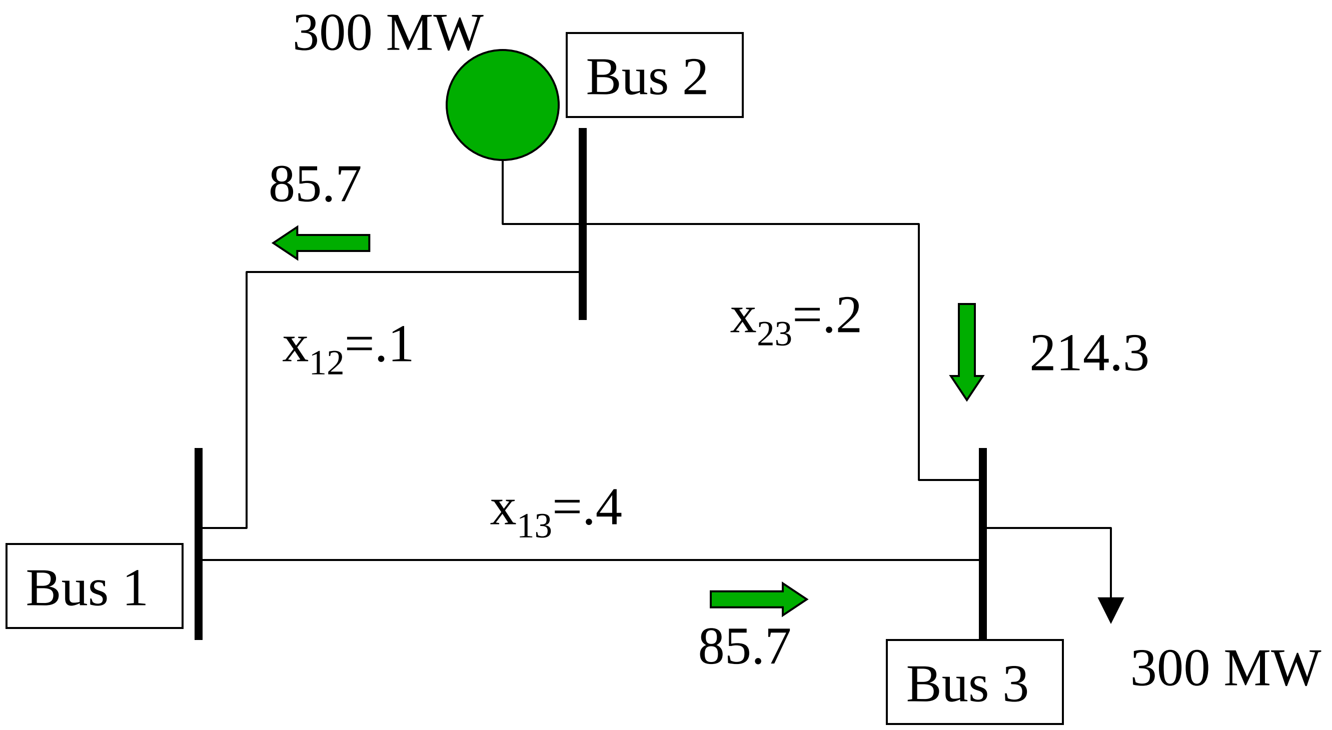
Treat power injections as currents sources and use superposition.

(a) 900 MW source acting alone:



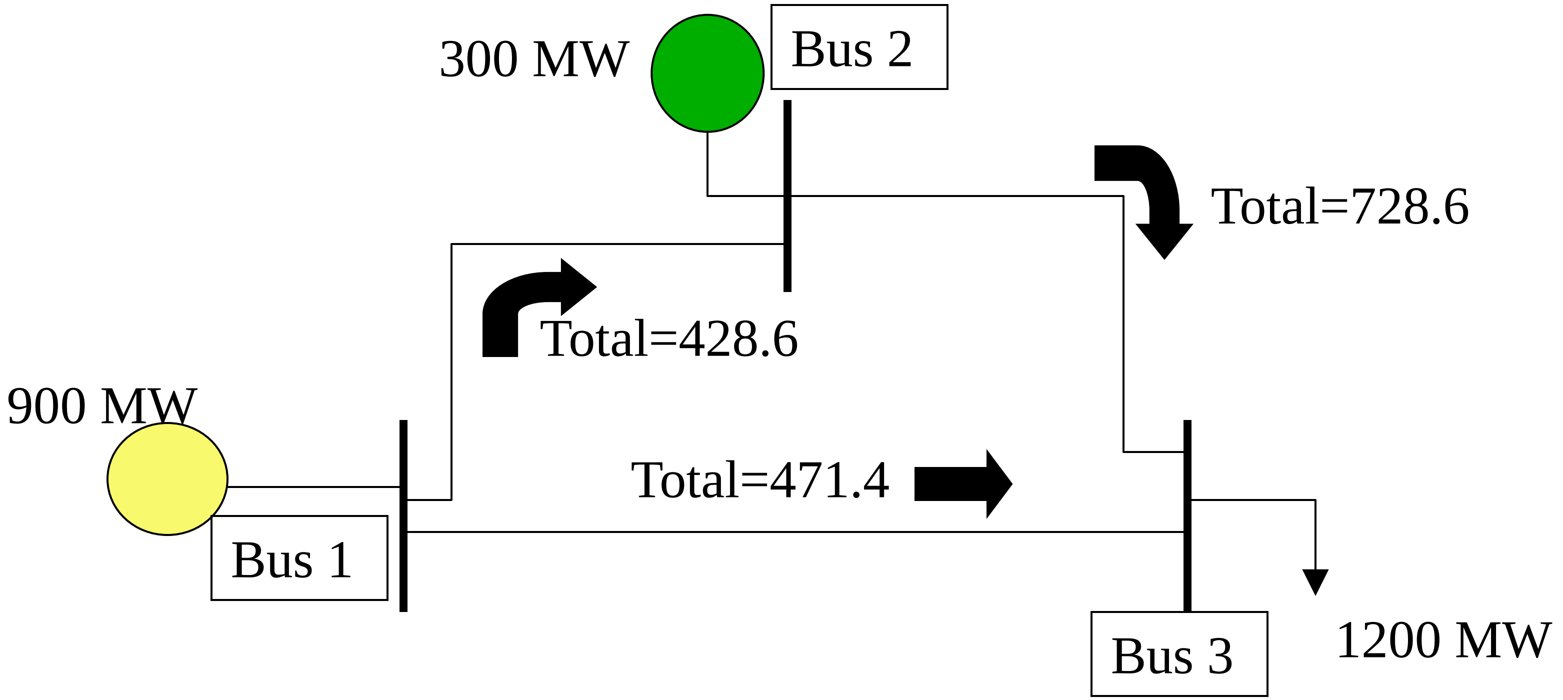
“DC” power flow in parallel paths

(b) 300 MW source acting alone:



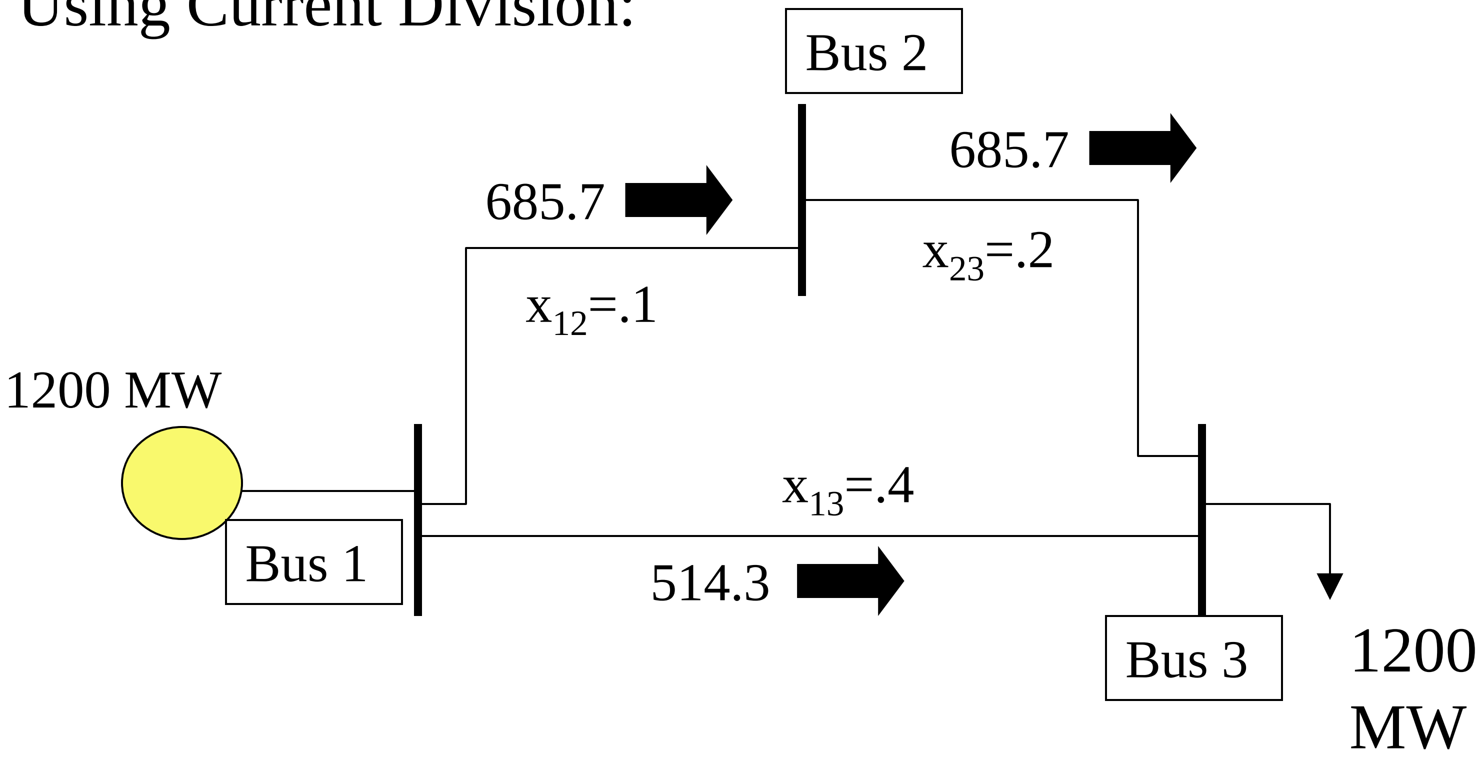
“DC” power flow in parallel paths

(c) Use Superposition



Generator loss @ Bus 2

Using Current Division:



Quick but Approximate Line Flows Using Linear Sensitivity factors

- Assume a power transfer $\Delta P_{s,r}$ from bus *s* (seller) to bus *r* (buyer). The fraction of this power Δf_l that ends up flowing on line *l* (located between bus *i* and bus *j*) is defined by the Power Transfer Distribution Factor (PTDF) of line *l*:

$$PTDF_{s,r,l} = \frac{\Delta f_l}{\Delta P_{s,r}}$$

- PTDF can be found by using linear "DC" power flow

$$PTDF_{s,r,l} = \frac{1}{x_l}(X_{is} - X_{ir} - X_{js} + X_{jr})$$

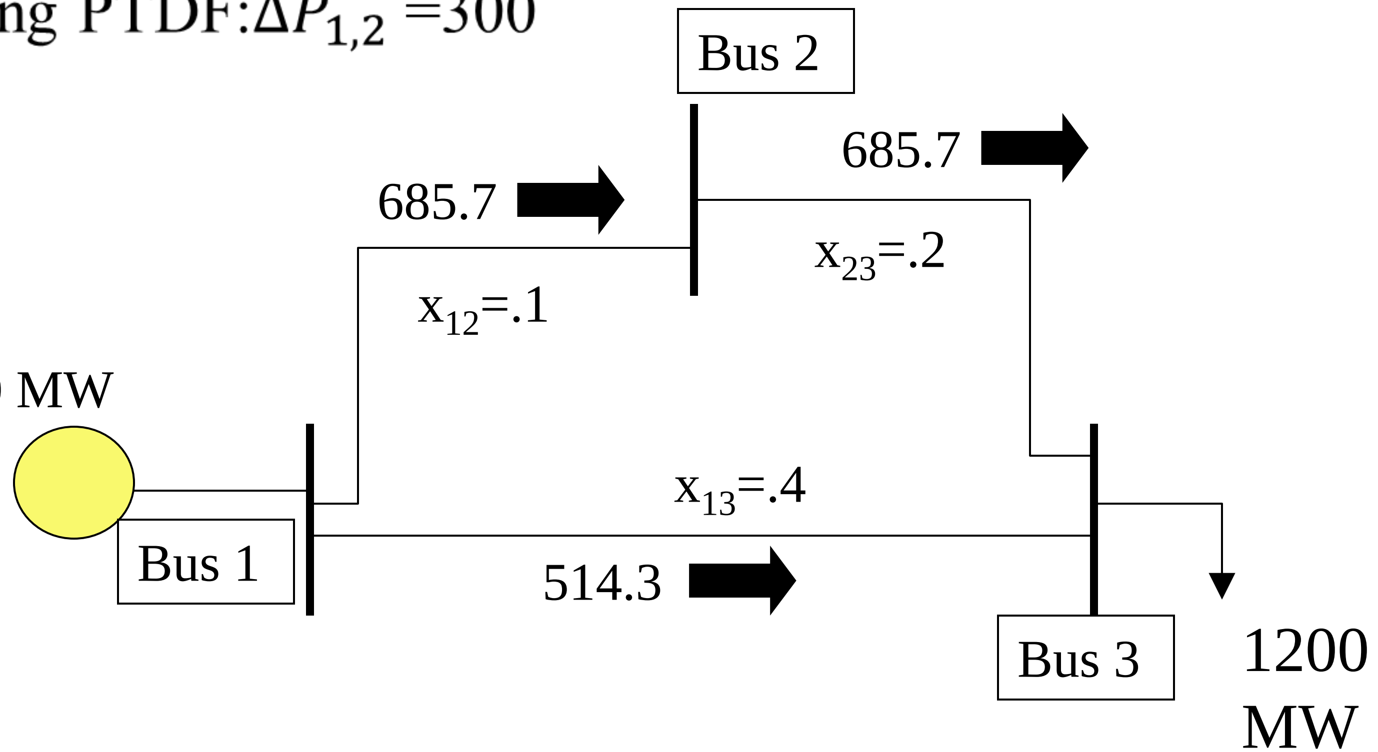
- Where x_l is the reactance of line *l*, and X_{mn} is the element of the reactance matrix (m^{th} row and n^{th} column),

$$[X] = [B]^{-1}$$

If one of the buses happens to be a reference bus, set the corresponding X elements in the equation above to zero.

Generator loss @ Bus 2

Using PTDF: $\Delta P_{1,2} = 300$



Line 2-3: l3

$PTDF_{1,2,l3} = \frac{1}{.2}(-X_{22}+X_{32}) = 5(-.0857+.0571) = -.143$ or -14.3% of 300 MW (i.e, -42.8 MW)

Hence The original line flow of 728.6 MW will be reduced to 685.7 MW.

Quick but Approximate Line Flows Using Linear Sensitivity factors

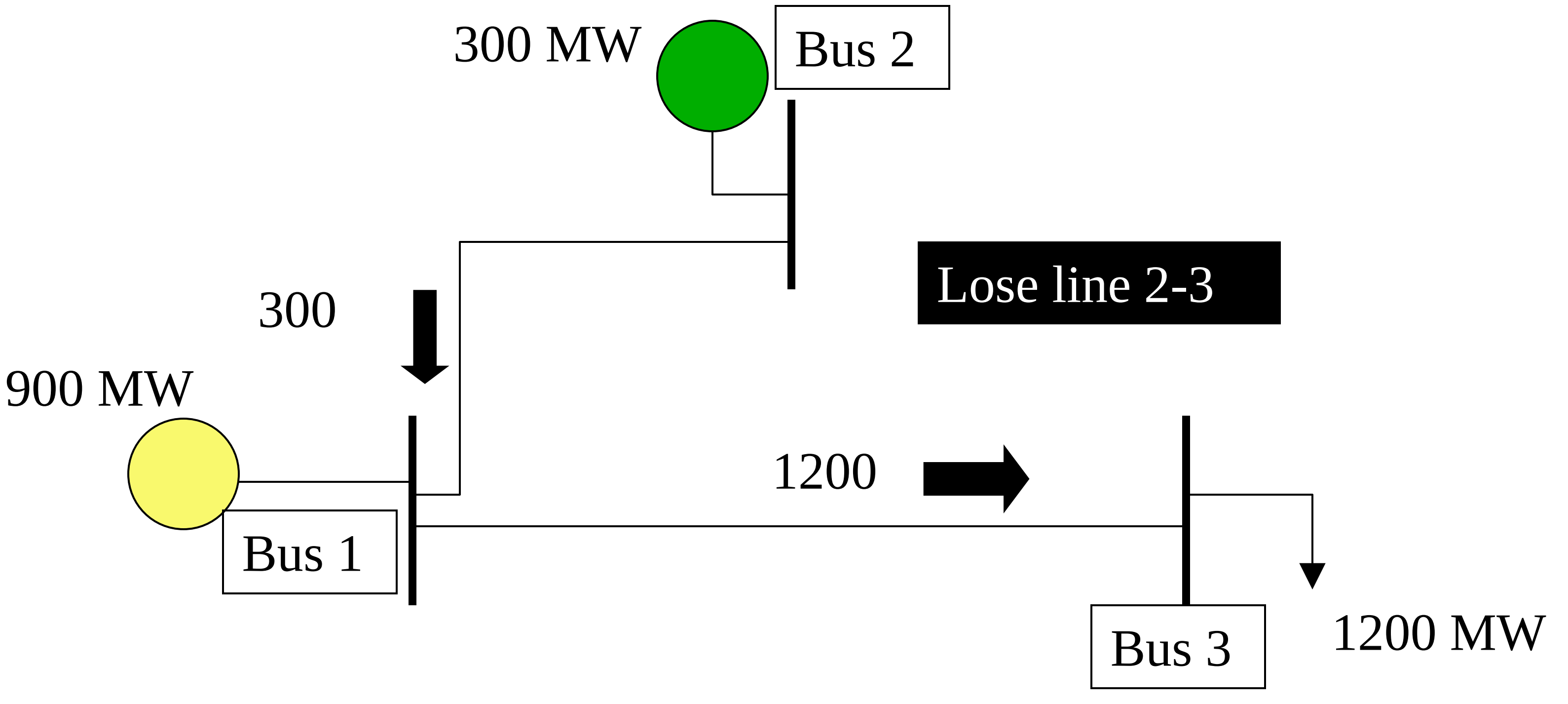
- Line Outage Distribution Factor (LODF) is applied for determining overloads when a transmission line is lost. It is defined by

$$LODF_{l,k} = \frac{\Delta f_l}{f_k^o}$$

- Where Δf_l is the % change in MW flow on line *l (from i to j)*, and f_k^o is the original flow on line *k (from n to m)* before it opened. LODF can be computed from the PTDFs of the lines as follows:

$$LODF_{l,k} = PTDF_{m,n,l} \frac{1}{1 - PTDF_{m.n,k}}$$

Line loss



Change of flow in line 1-2 due to loss of line 2-3:

$LODF_{l,k} = -1$

$\rightarrow \Delta f_l = -f_k^o = -728.6$ MW

$\rightarrow$ new flow $= 428.6 + (-728.6) = 300$ MW

Assignment:

- See PowerWorld video on contingency analysis https://www.powerworld.com/training/online-training/contingency-analysis
- Then conduct a full contingency analysis using PowerWorld on the 6-bus power system you modeled in Chapter 6.