On Voltage Stability Solutions

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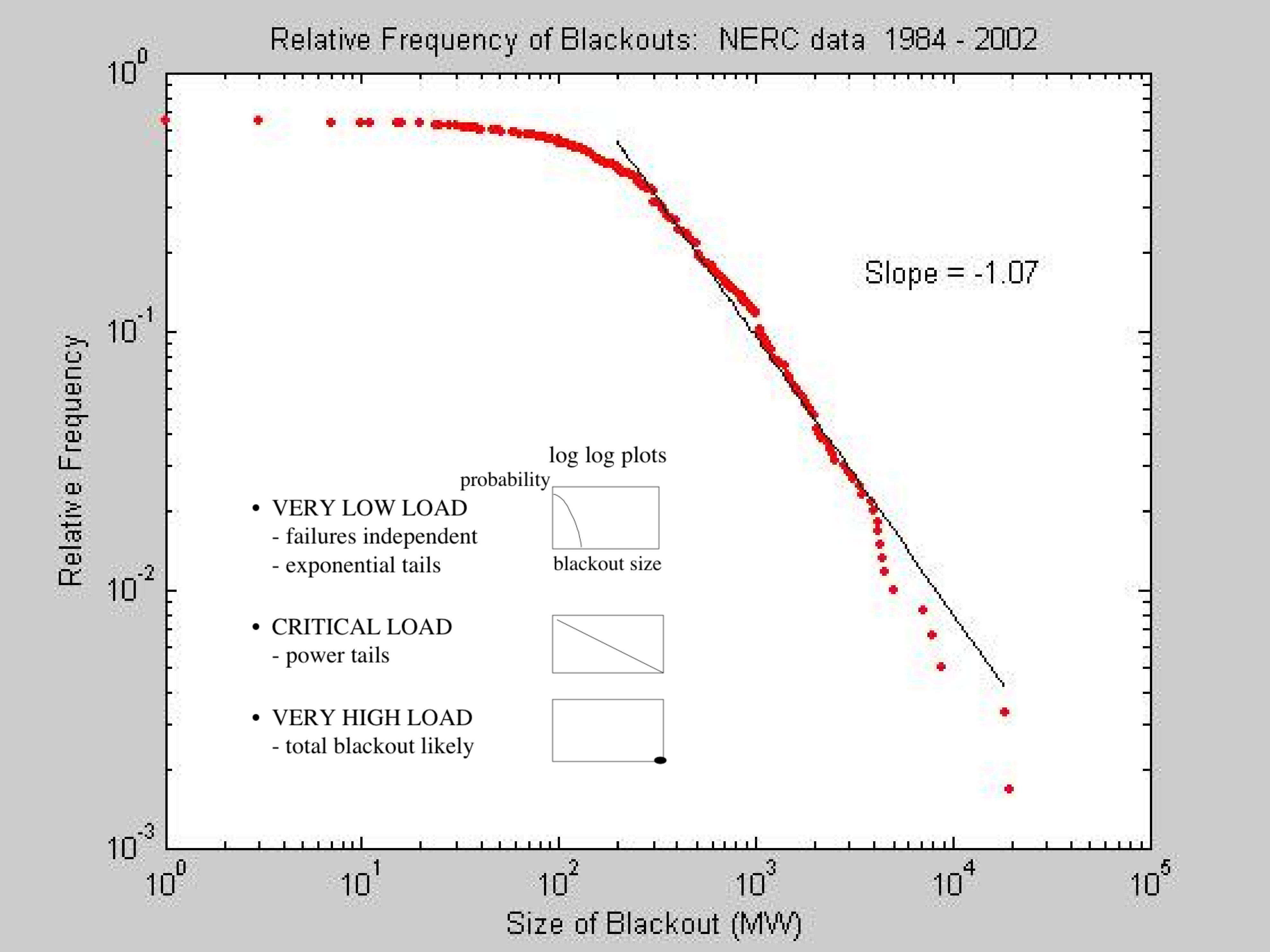
Motivation: Incidence of Large Power System Disturbances

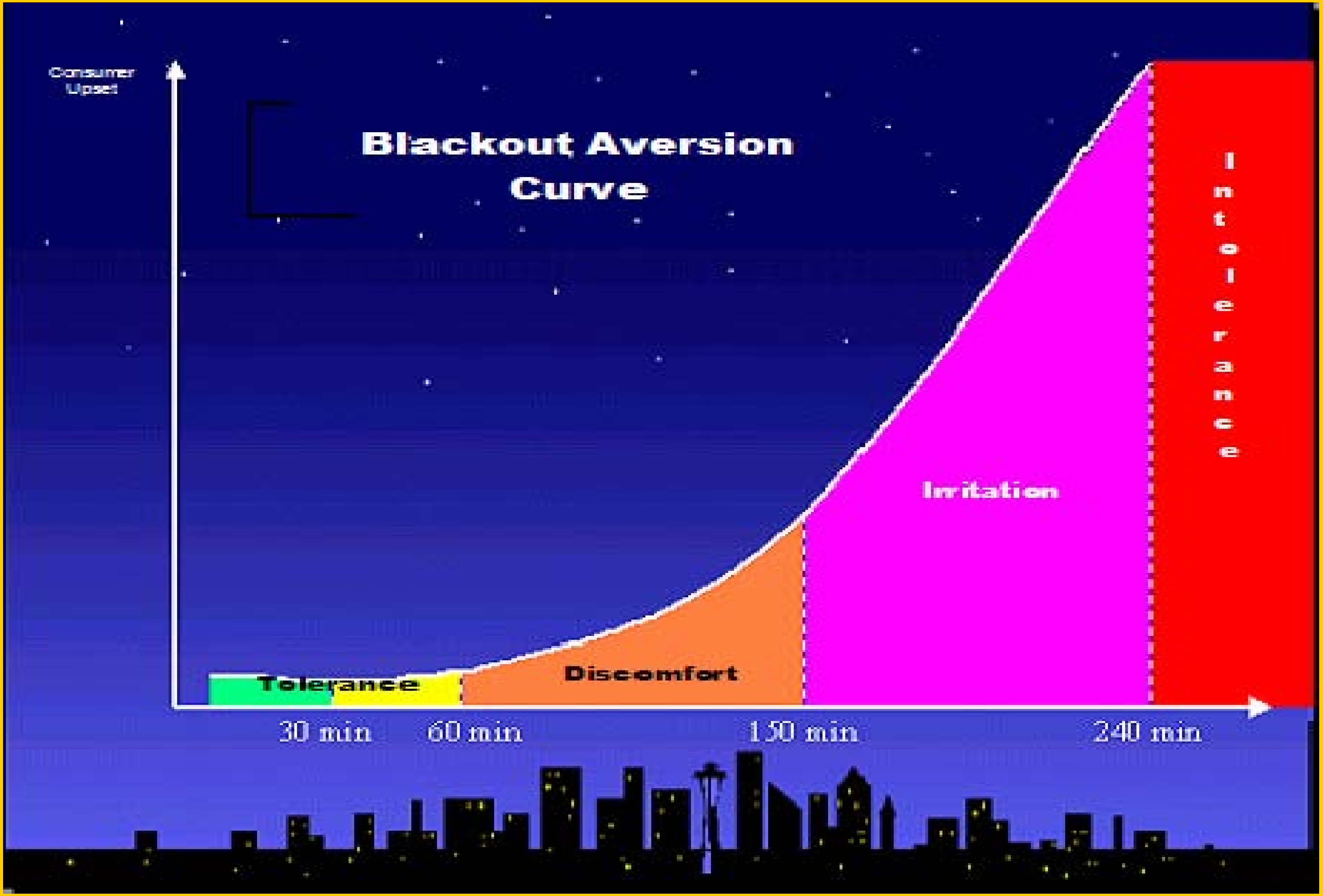
- NERC (and Other) Data Indicate Some Regularity in Occurrence of Large Disturbances

- Complex Protection Schemes are Becoming Increasingly Common Tools for Mitigation of Such Disturbances



Source: http://www.people.cornell.edu/pages/khs7/research/journal.htm

Customer Aversion to Energy Disruptions



Linearization of Power Flow Equation

$$g(\xi, V, \lambda) = 0$$

$$g_{\xi}\, d\xi + g_{V}\, dV + g_{\lambda}\, d\lambda = 0$$

$$\begin{bmatrix} A_1 & A_2 \\ A_3 & A_4 \end{bmatrix} \begin{bmatrix} d\xi \\ dV \end{bmatrix} = -\begin{bmatrix} g_{1_\lambda} \\ g_{2_\lambda} \end{bmatrix} d\lambda$$

Voltage Collapse

$$\begin{bmatrix} A_1 & A_2 \\ A_3 & A_4 \end{bmatrix} \begin{bmatrix} d\xi \\ dV \end{bmatrix} = -\begin{bmatrix} g_{1_\lambda} \\ g_{2_\lambda} \end{bmatrix} d\lambda$$

SMALL LOAD INCREASE

+

NEAR SINGULAR JACOBIAN MATRIX

=

VERY LARGE VOLTAGE (OR ANGLE) GRADIENTS

Example: Voltage Stability

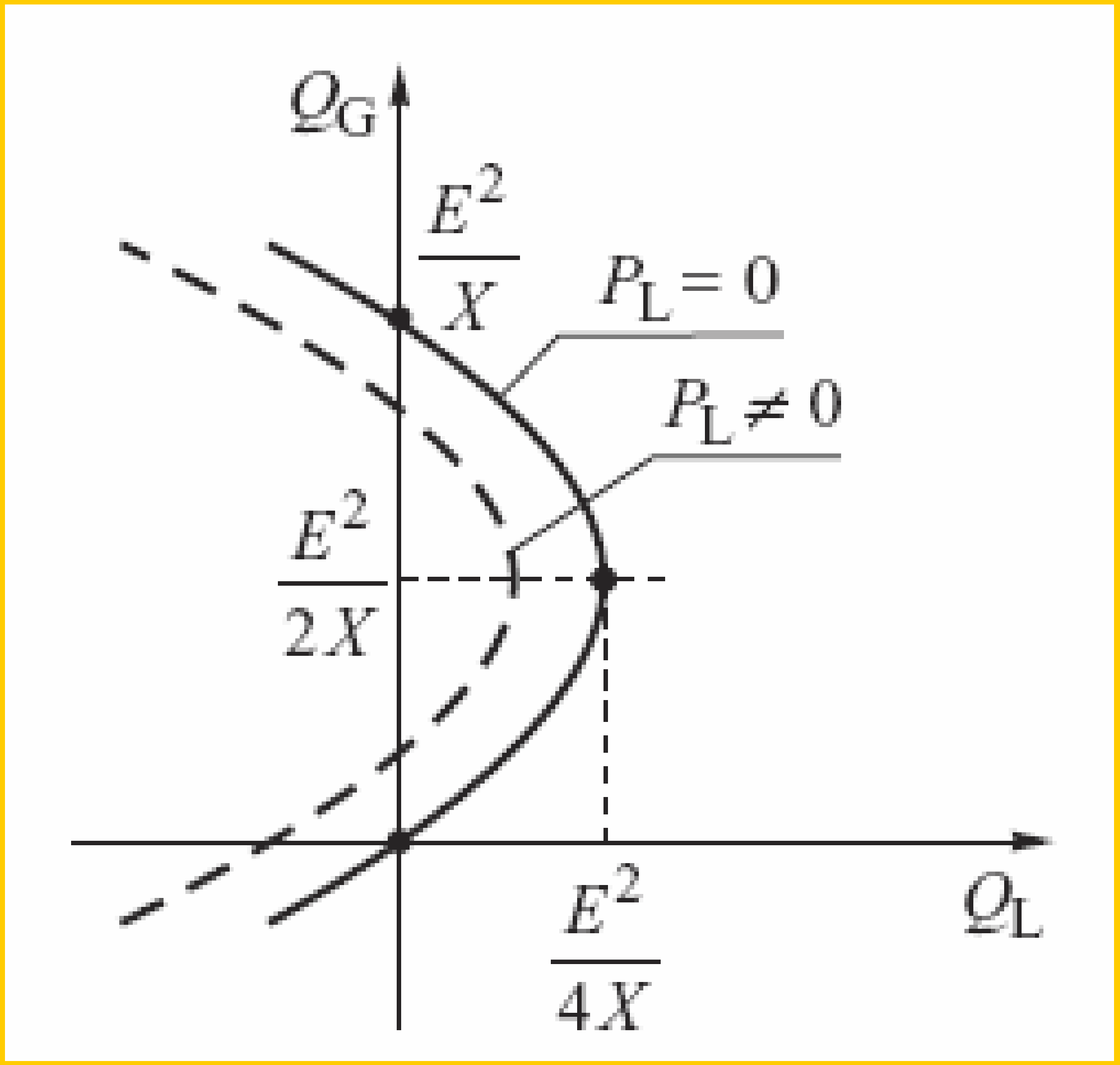
The image cannot be displayed. Your computer may not have enough memory to open the image, or the image may have been corrupted. Restart your computer, and then open the file again. If the red x still appears, you may have to delete the image and then insert it again.

dQ_G/dQ_L Criterion

$$Q_G(V) = \frac{E^2}{X} - \frac{EV}{X}\cos\delta$$

$$Q_G^2(V) - \frac{E^2}{X}Q_G(V) + P_L^2(V) + \frac{E^2}{X}Q_L(V) = 0$$

$$Q_L(V) = -\frac{Q_G^2(V)}{\frac{E^2}{X}} + Q_G(\mathrm{V}) - \frac{P_L^2(V)}{\frac{E^2}{X}}.$$



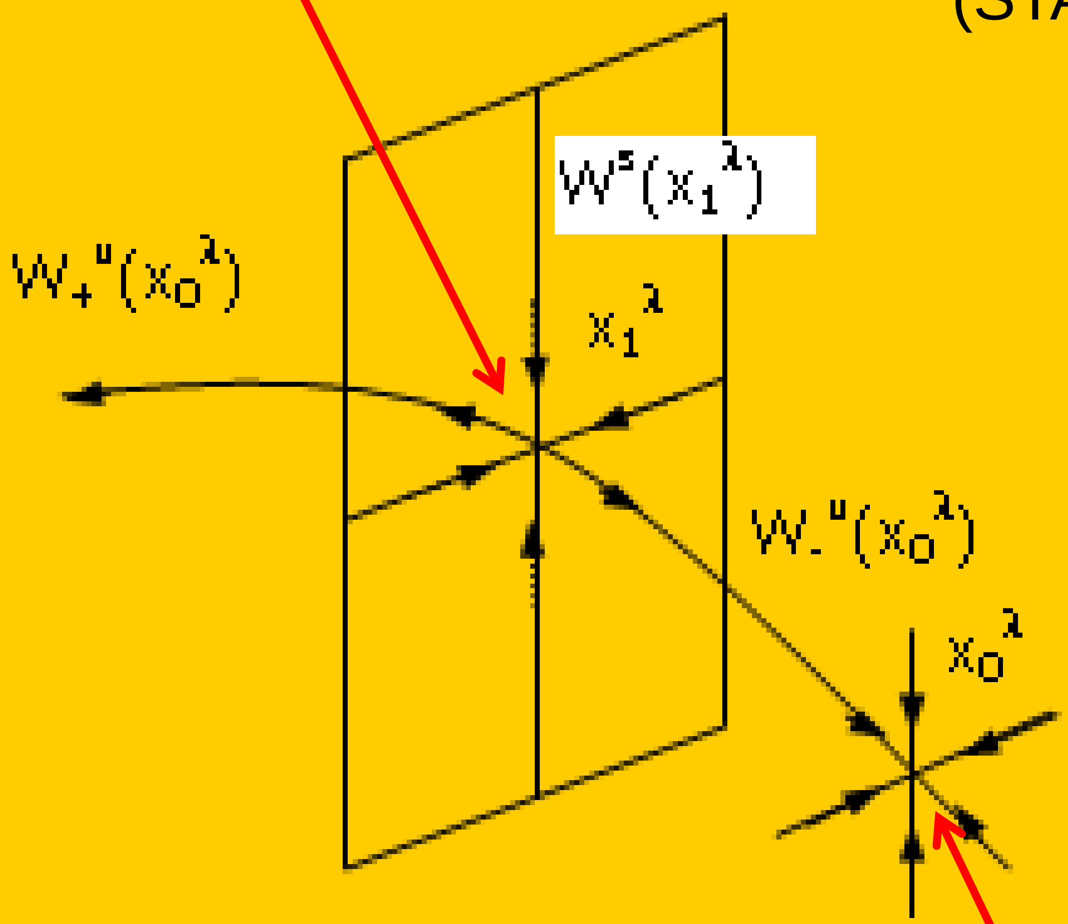
System Stability → $$\frac{dQ_G}{dQ_L} > 0$$

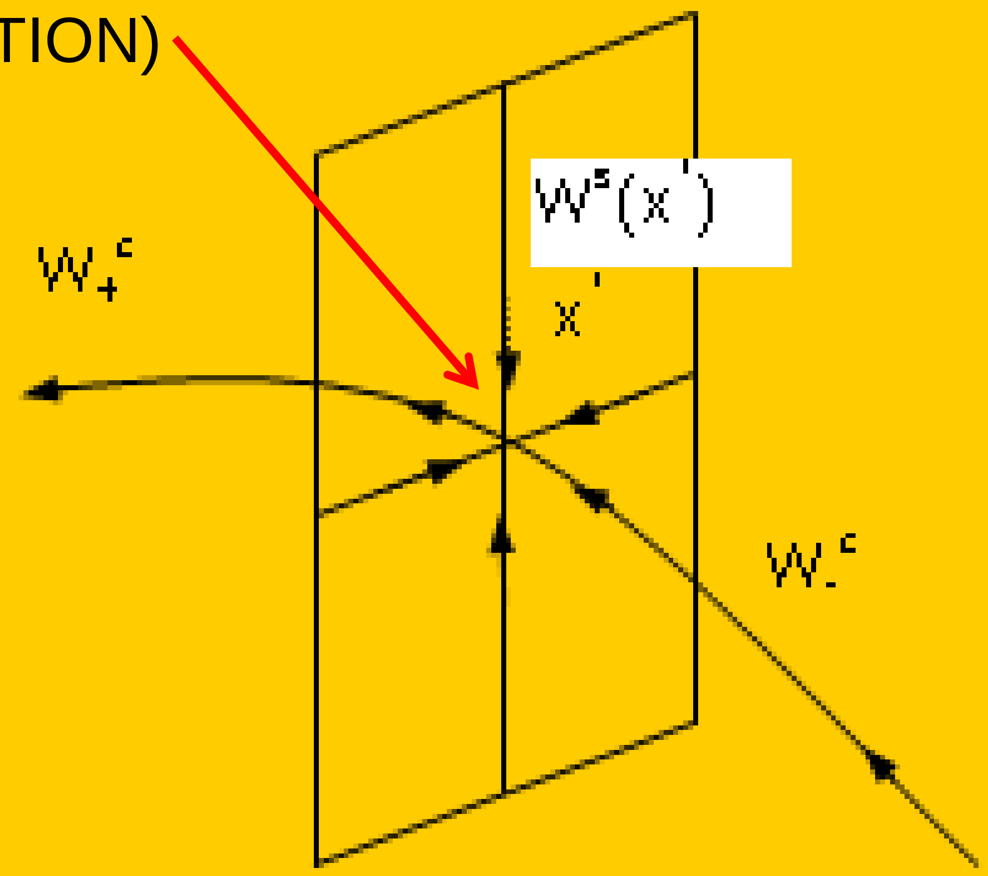
Source: Machovsky, Bialek, Bumby, “Power System Dynamics”, John Wiley, 2008

Static Bifurcation Model

UNDER HEAVY LOAD
OR FOLLOWING A SEVERE
CONTINGENCY, BOTH
EQUILIBRIA COALESCE
INTO A SINGLE POINT
(STATIC BIFURCATION)

UNSTABLE EQUILIBRIUM





STABLE EQUILIBRIUM

Planning Options for Prevention of VC

	Cost ($)	Time to Implement
Additional Generation	Tens to Hundred Millions	Years
Additional Transmission Lines	Tens to Hundred Millions	Over 10 years
Dynamic Reactive Power (e.g. FACTS)	Tens of Millions	1~ 3 years
Comprehensive Load Shedding Scheme **Is it really an option???**	Few Millions (depending on requirements and complexity)	1-2 years

Source: Jean-Marie Gagnon, Damir Novosel

Tools Against Voltage Instability

- Generation Redispatch
- Demand Side Management
- Control of Tap Changers
- Reactive Power Support
  - Switched Sources
  - Dynamic Sources
- Distribution Voltage Control
- Rolling Brownouts
- UF Load Shedding
- UV Load Shedding
- Adaptive UV Load Shedding
- Wide-Area Analysis Based Load Shedding

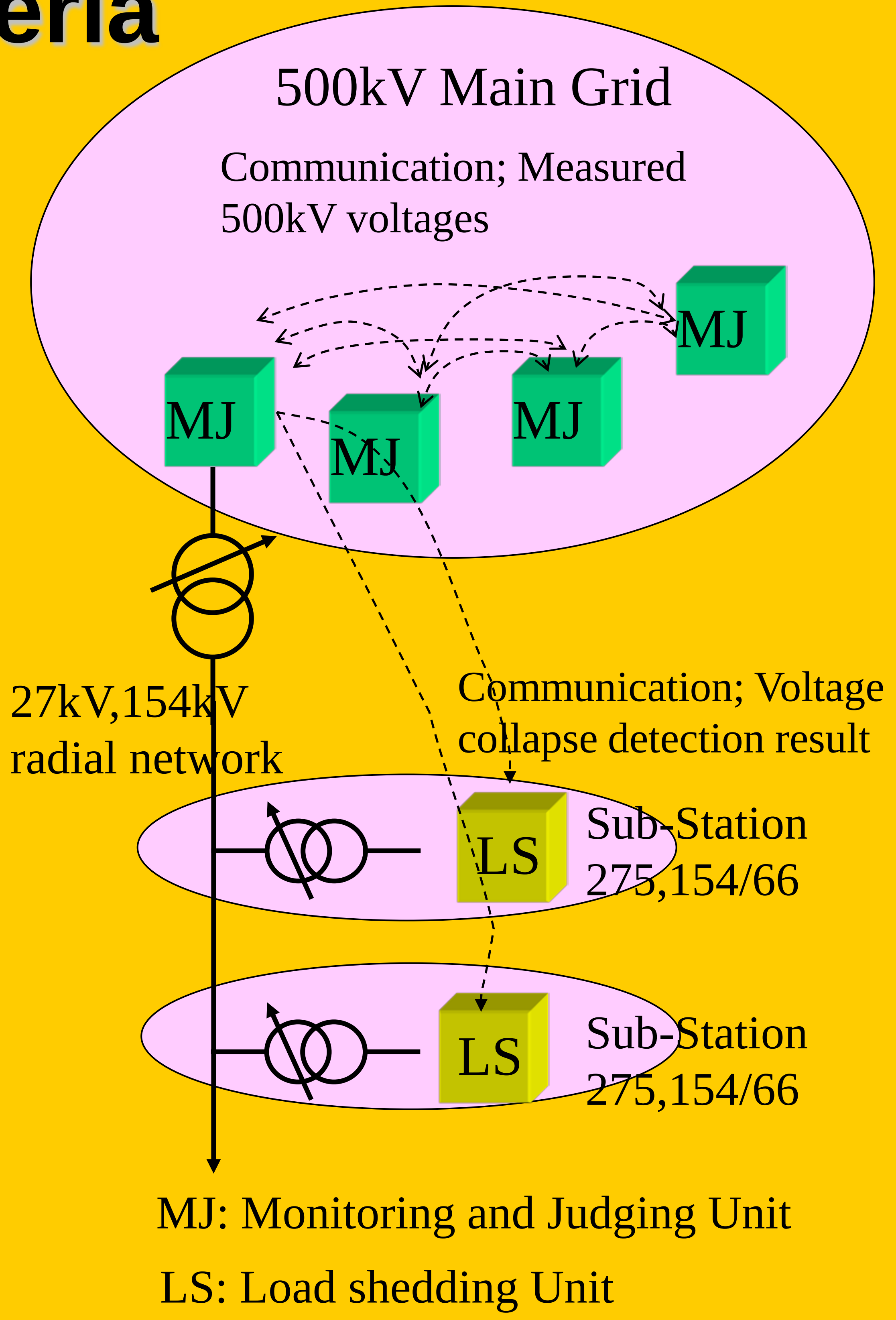
Emergency Controls

- **Tap Blocking:** deactivation of tap action
- **Tap Reversing:** controlling the primary voltage
- **Tap Locking:** deactivating tap to a chosen value
- **Voltage Reduction:** lowering distribution voltage
- **Load Shedding:** rejection of a percentage of load

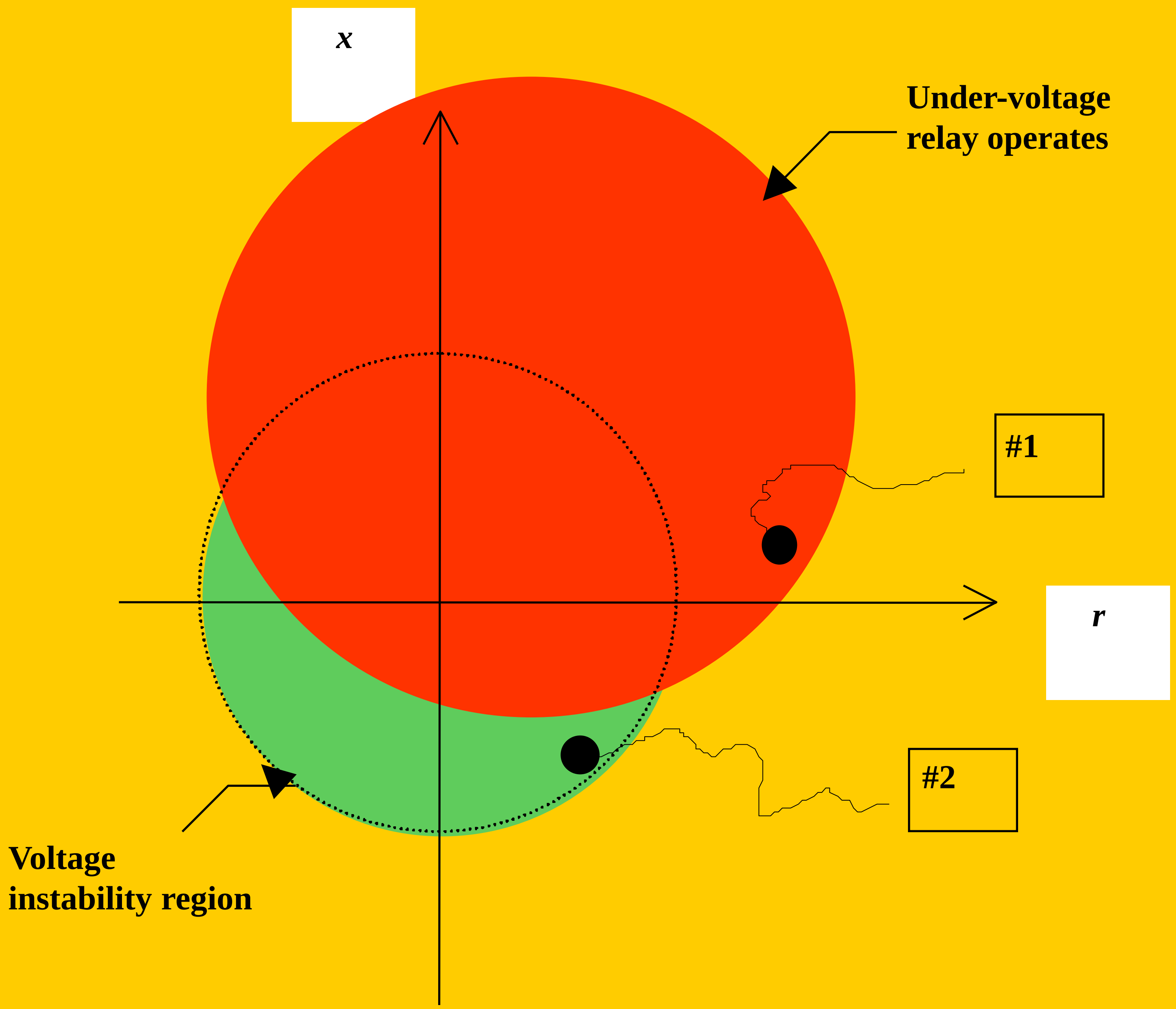
Source: "Comparison and Combination of Emergency Control Methods for Voltage Stability", Vournas, IEEE PES GM 2004

TEPCO UVLS Criteria

- UVLS installed to prevent cascading following severe contingencies like multiple outages during extreme weather and heavy load (outside planning and operation criteria)
- 500kV voltages measured
- Based on 3 out of 4 decision making logic to avoid unwanted operation
- Decisions are transferred to substation protection terminals



Under-voltage load shedding



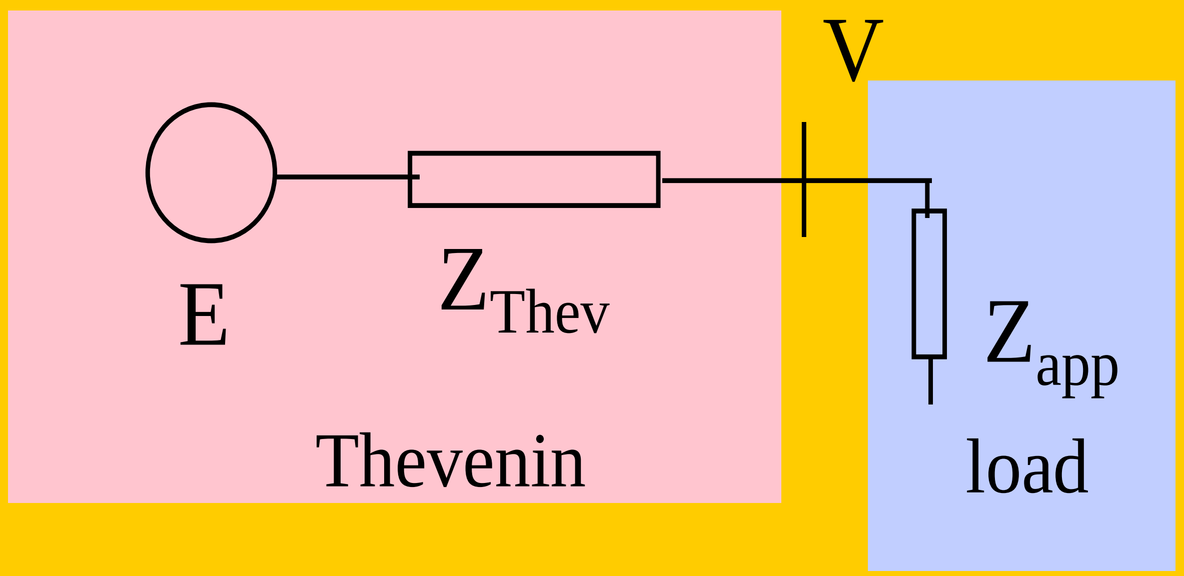
Issues with voltage as an indicator of voltage instability:

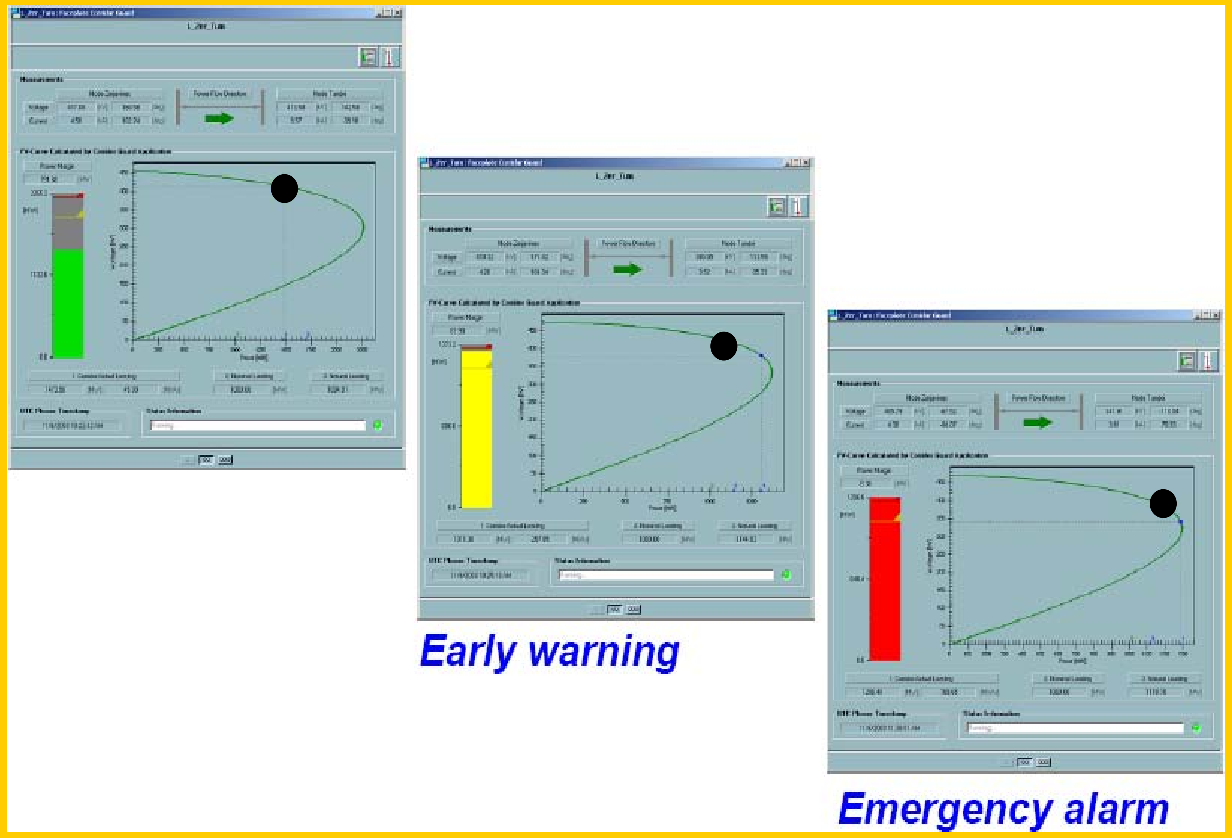
#1: UV relay trips unnecessarily

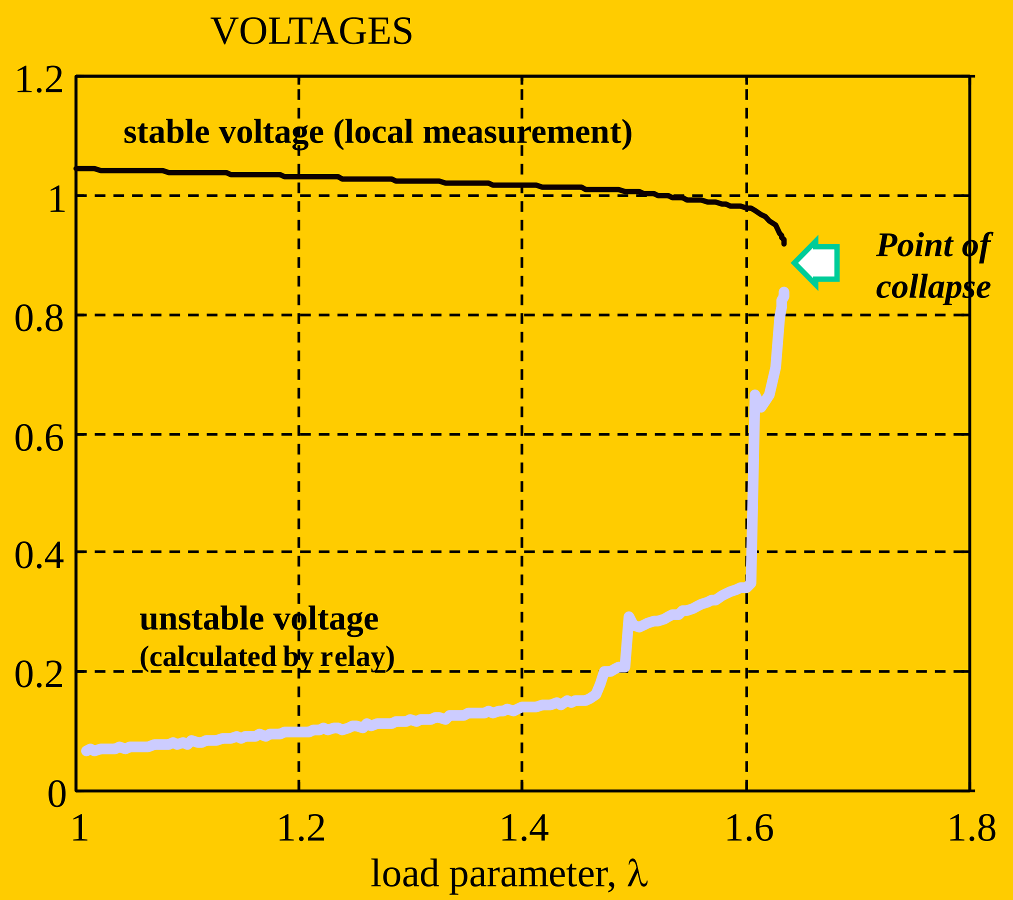
#2: UV relay fails to trip

Voltage Instability Predictor*

- Maximal power transfer ⇔ $|Z_{app}| = |Z_{Thev}|$ is point of collapse
- Measuring the proximity to instability - improvement to UV LS
- Corridor version: Two PMUs on the both side of the line
  - More accurate Thevenin equivalent

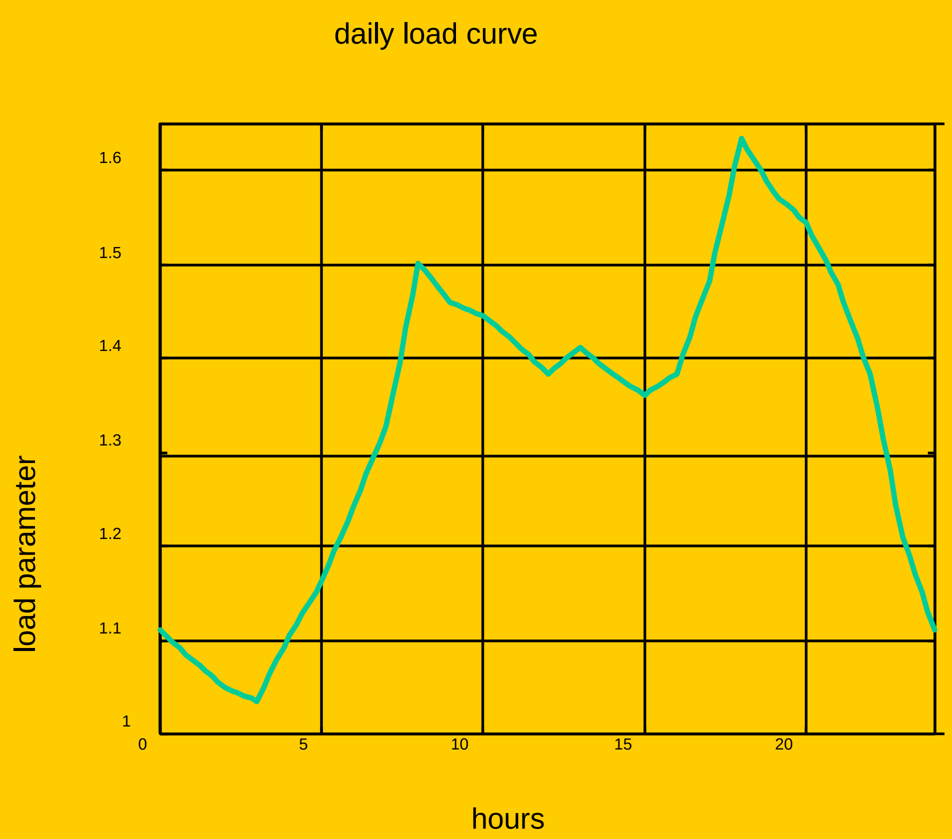




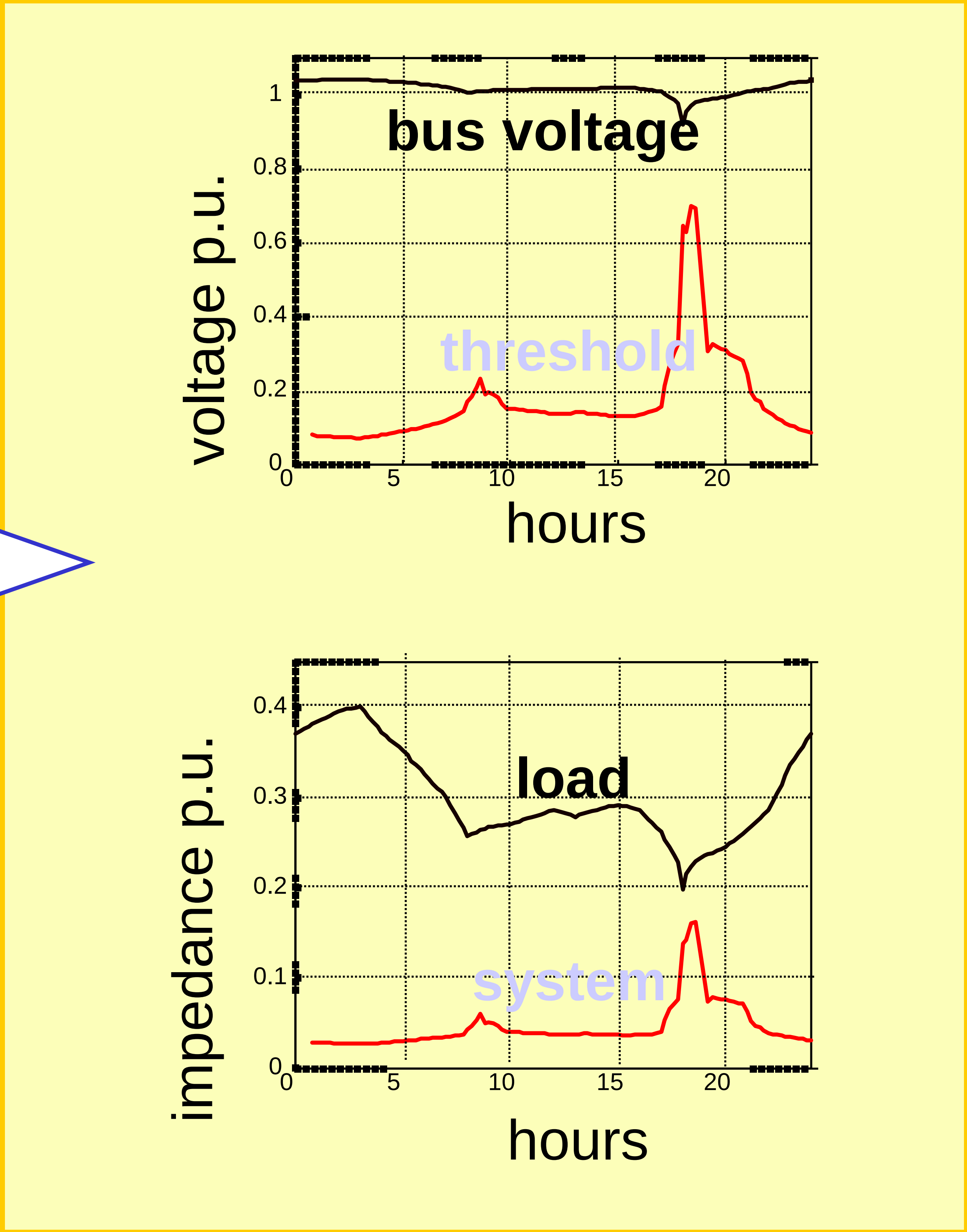


* K. Vu and D. Novosel, "Voltage Instability Predictor (VIP) - Method and System for Performing Adaptive Control to Improve Voltage Stability in Power Systems," US Patent No. 6,219,591, April 2001.

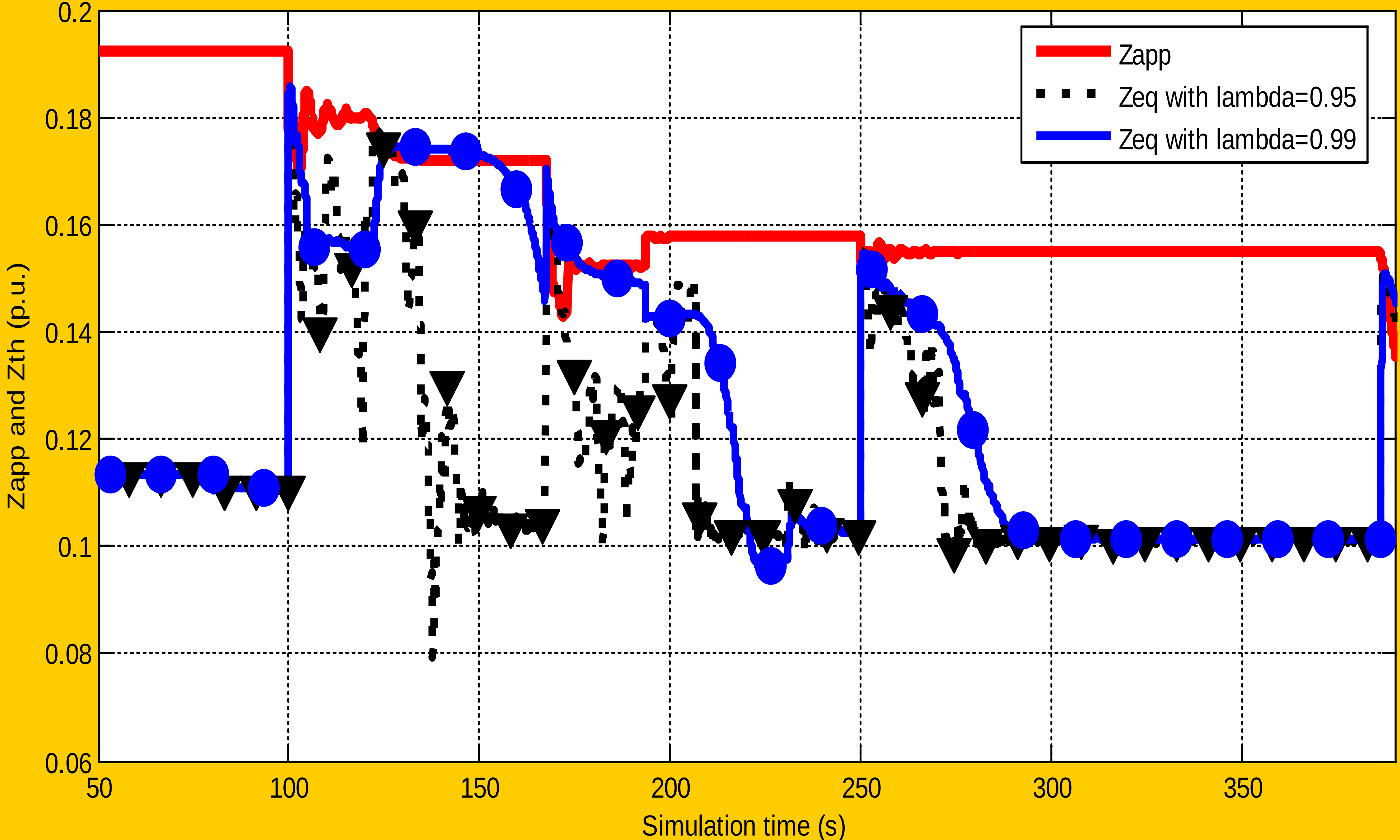
Monitoring Instability---Example 2



On-line monitoring



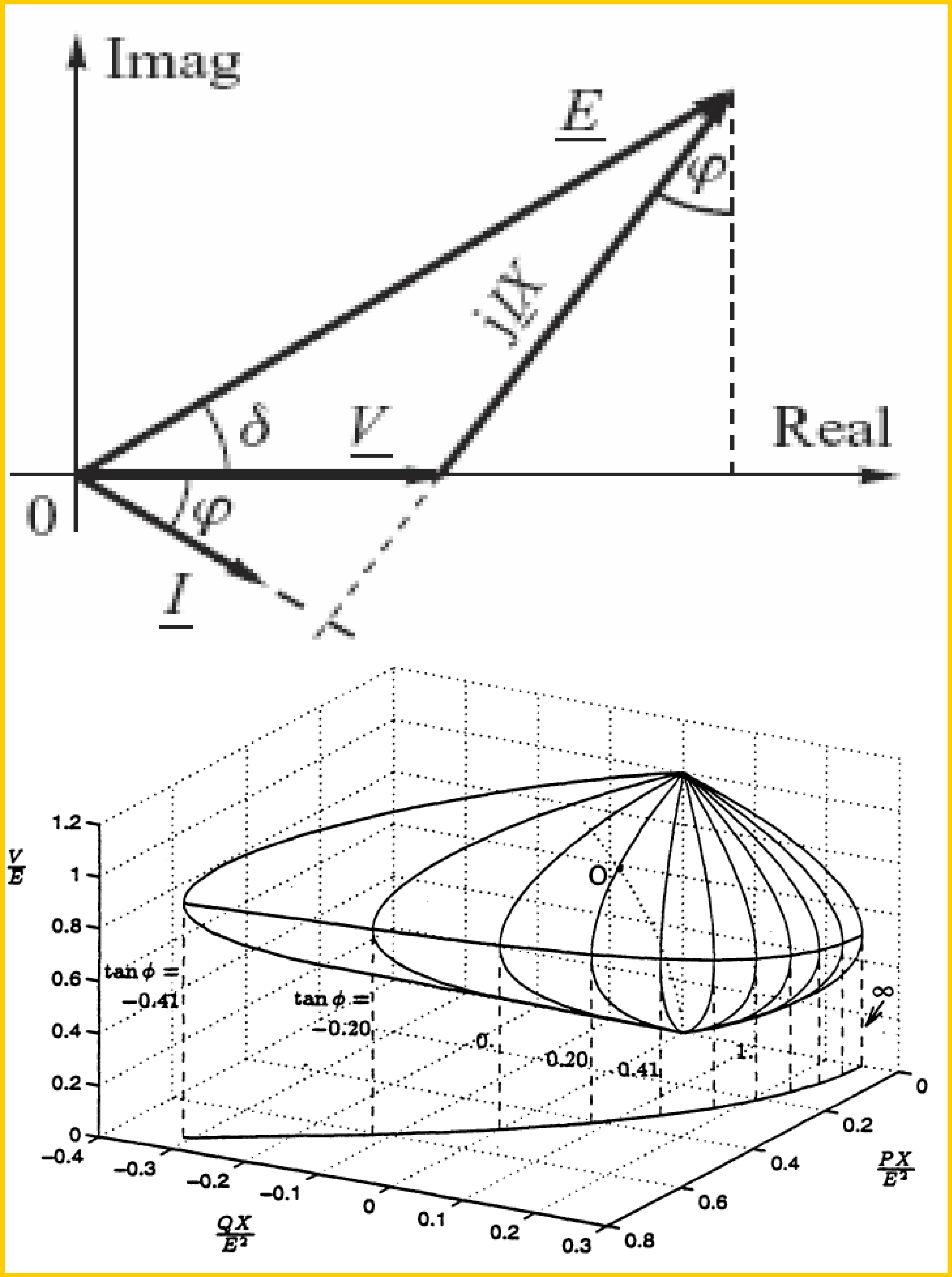
Tracking Performance on Tap Changes Near Voltage Collapse Region

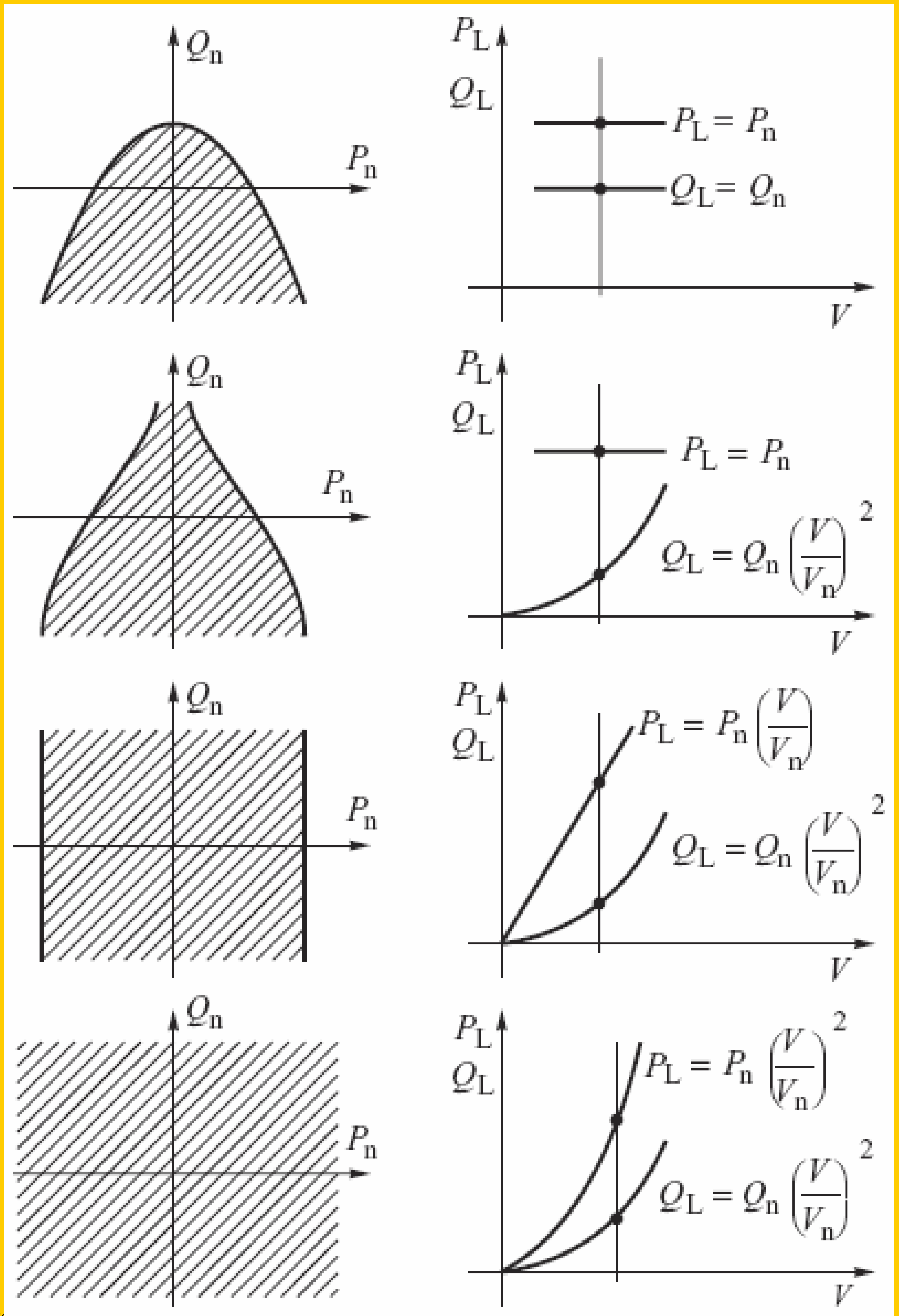


Conclusions

- Balanced approach to fixing the system as a whole by implementing various planning, operations, and maintenance measures to reduce probability of future outages
  - Weigh the costs, performance and risks associated with each measure
- A comprehensive defense plan using SIPSs significantly increases system reliability
- Use of local techniques may create a tradeoff with accurate solutions, but represents a fallback position for the situations when communication network fails or other circumstances prevent normal (or fast enough) operation of the SIPS
- Additional research is needed to get the most out of local measurement based techniques

Stability Area and Load Characteristics





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VIP Tracking Performance