

*Pterra Consulting*

Course Notes C101-06 Rev 3.0

# WORKBOOK: Applications in Voltage Stability Course



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Name:

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The study of voltage stability is as timely a subject today as it has ever been. Changing use of system from energy market deregulation, few new transmission lines being built, the continual growth of demand and the entry of new forms of energy conversion from wind, solar, biomass, tides and other renewables make voltage stability an essential part of any power system planner, operator, market participant, designer, and analyst problem formulation. The consequences of blackout from voltage collapse, voltage-restricted transfers and dispatch, and the operation on the Voltage Ledge are real with significant cost impact.

This course is a study of voltage stability as applied to planning, operation, design and regulation of the power system. Very little of what this course covers exists only in theory. Practical issues of reactive reserve, allocation of compensation, sizing of dynamic resources and understanding the effect of various actions are what this course provides. From all this, the instructors hope that you will be better equipped to address voltage stability issues in your own work and field of interest or study.

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### 1.3. Reactive Power

This section is brief review on various concepts and terms relating to reactive power.

If instantaneous voltage and current are expressed as sinusoidal functions of time, then the instantaneous power is:

$$P(t) = \sqrt{V} \sqrt{I} [\cos\theta (1 - \cos(2\omega t)) - \sin\theta \sin(2\omega t)]$$

Where:  $\sqrt{V}$  &  $\sqrt{I}$  are R.M.S. or root-mean-square values.

Two components can be distinguished from the above equation: the component which is a cosine function and the component which is a sine function. These are **active power, P**, and **reactive power, Q**, respectively.

- For this course, we refer to reactive power with the shorthand terms: **Q** and **vars**.

The mean value of the active power is  $P = |V| |I| \cos\theta$ . The mean value of the reactive power is zero; however, the maximum value is taken into account for analysis purposes:  $Q = |V| |I| \sin\theta$ .

Both, the mean value of the active power and the maximum value of the reactive power are combined in a complex phasor that is called apparent power,  $S$ , where

$$S = P + jQ$$

$$S = VI^*$$

\* *conjugate*

**Power Factor** is the ratio of the active power  $P$  to the apparent power  $S$ . The power factor angle is usually represented by  $\theta$ . A load with a unity (1.00) power factor has zero power factor angle and has zero reactive power. A load with a power factor less than 1.00 draws more current. A load with zero power factor has a power

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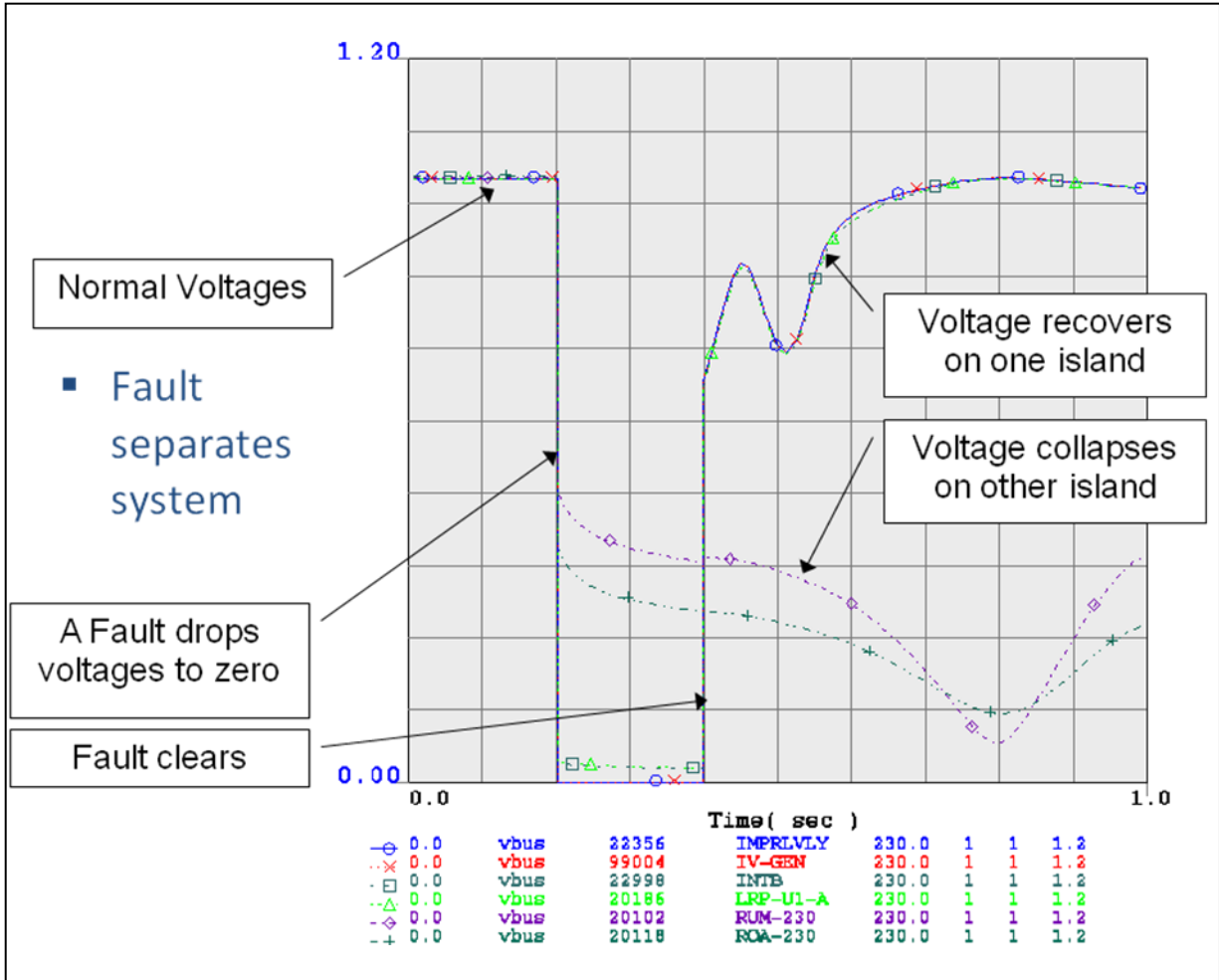
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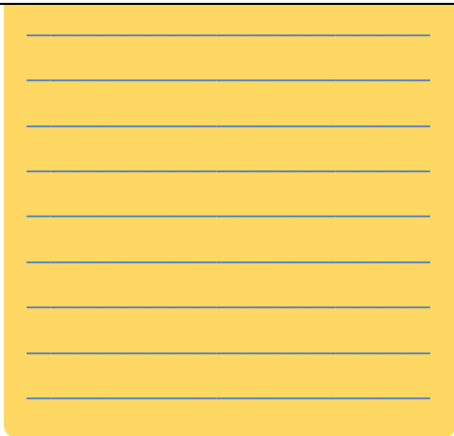




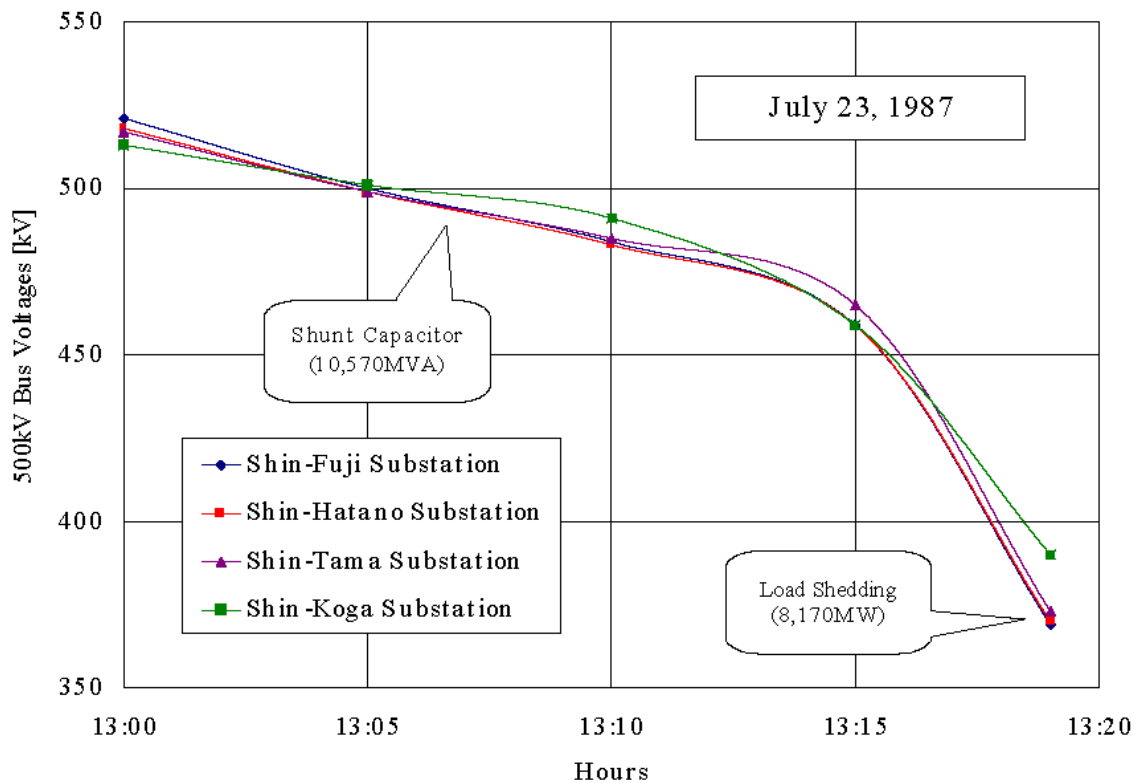
**Figure 1-1: Example of a fast voltage collapse.**

Voltage collapse can be classified by the cause, as follows:

- Static – occurs due to increasing load and power transfers. This is studied using nose curves and P-V curve analysis.



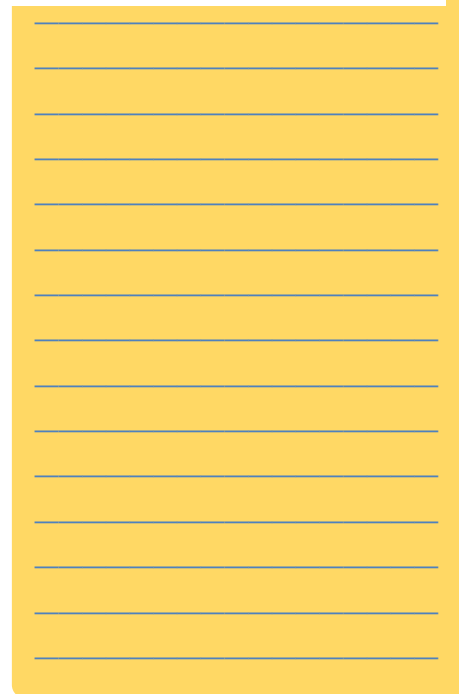
- Dynamic – occurs due to contingencies. This is studied using contingency analysis and dynamic simulation.



**Figure 1-2: Example of slow voltage collapse taken from Tokyo event of 1987 (Source: TEPCO)**

Voltage collapse can also be classified by onset, as follows:

- Fast - In the timeframe of milliseconds to seconds. This can be indistinguishable from angular instability. This type of collapse starts from a significant disturbance, such as a fault or generator failure. A large voltage drop causes motors to stall resulting in an increase in reactive power consumption. The lower voltage results in less reactive power from shunt capacitors.







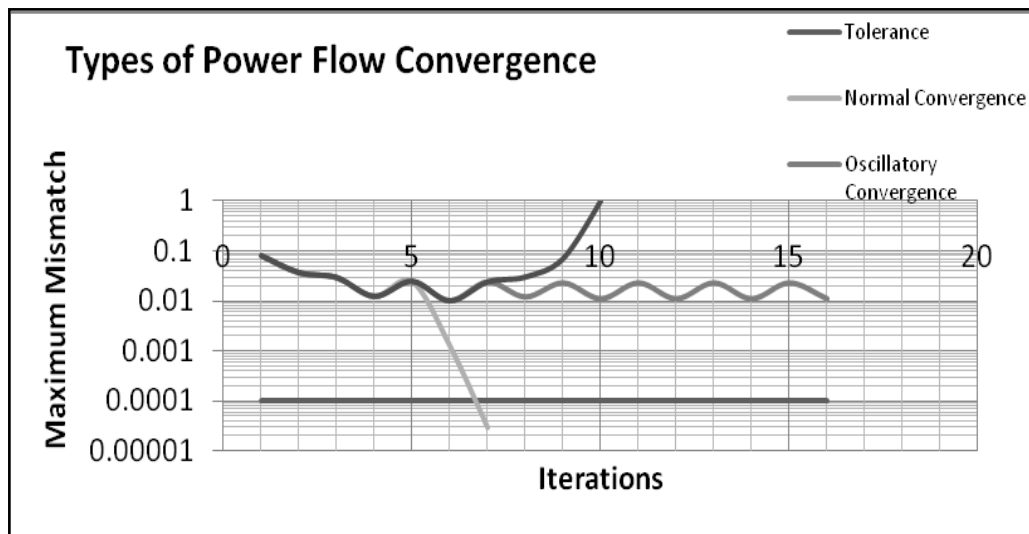


Figure 1-4

### 1.7. Dynamic Voltage Response of the Power System

The interconnected power system has inherent reactive reserves to respond to disturbances that may cause voltage instability. The reserves can be continuous such as provided by synchronous machines, or switched such as from capacitor banks.

The response of the system to a disturbance is reflected in the Voltage Response Curve (VRC). The form of the VRC indicates the level and type of reactive reserve the system has. An example VRC is given in Figure 1-5. VRC is unique to each system, being the result of a combination of the connected reactive resources and load composition.

Criteria define acceptable levels of response to maintain voltage stability. Dynamic response represented by the VRC is specific to each system, and the corresponding development of criteria has led to very specific regional criteria for voltage stability. Dynamic voltage criteria specify allowable voltages that the **power system**

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can withstand. The example in Figure 1-5 shows criteria that are specific to the Western Electricity Coordinating Council.

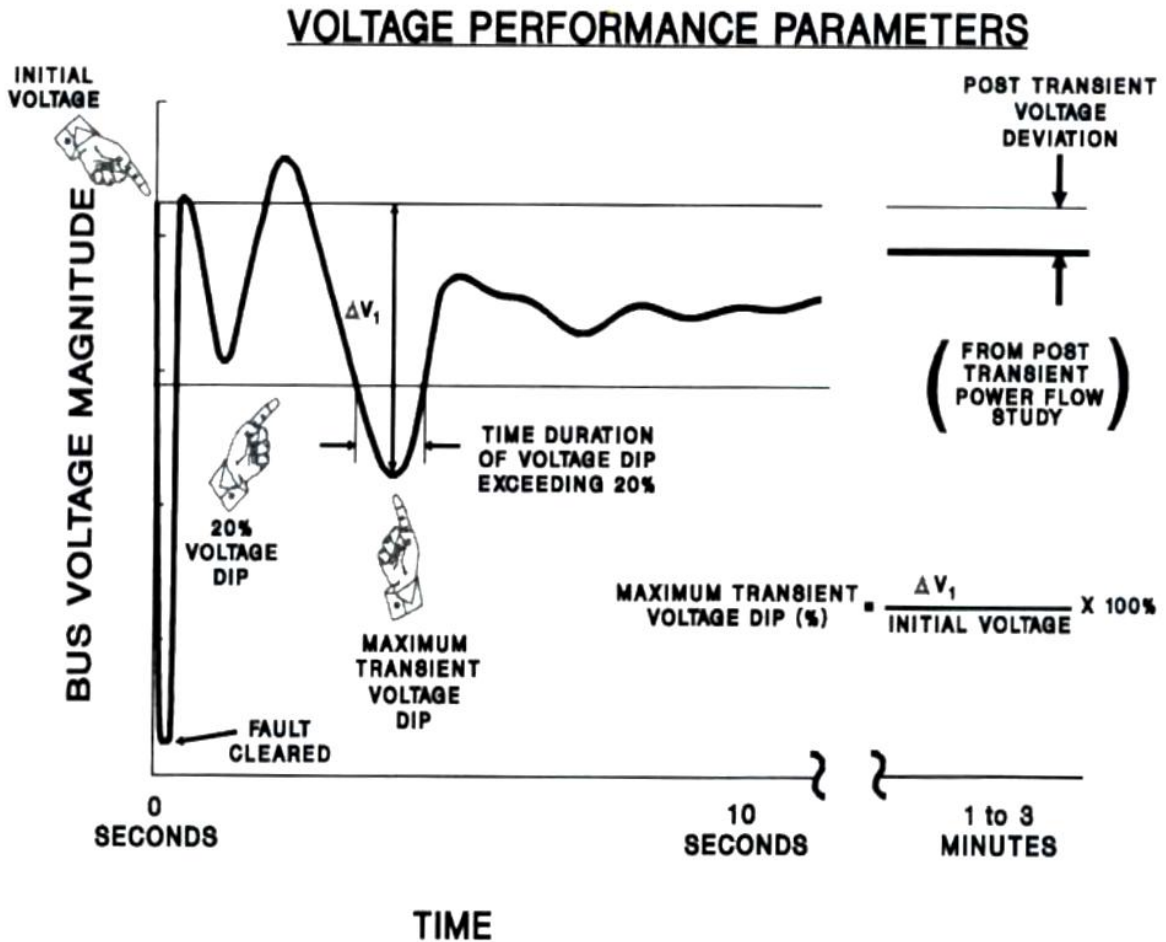
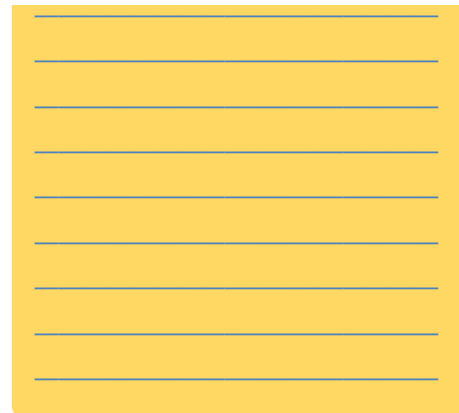


Figure 1-5: Dynamic response of the power system to disturbances (Source: WECC)

## 1.8. Composite System Response

The methodologies for analyzing voltage stability that exist today are best characterized as generation-transmission models; i.e., they are based on models that include generating and transmission







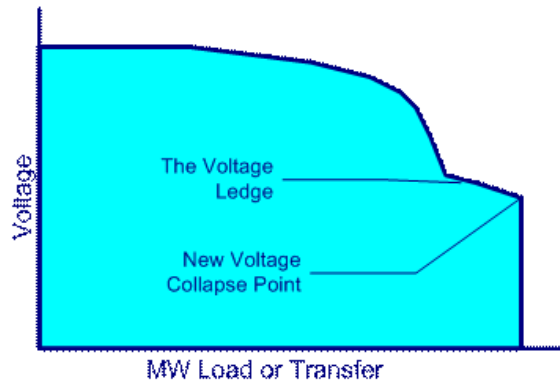


Figure 1-7: The Voltage Ledge as visualized from the P-V Curve.

When operators attempt to add reactive power to the region operating on the Voltage Ledge, the VARs may be absorbed without noticeable change in condition. Most of the significant phenomena occurs in the distribution system. The transmission system appears normal, and within voltage criteria.

### 1.10. The Rest of the Course

Hopefully, this introductory section has given you a flavor for what to expect in the rest of the course. The rest of this document is divided into the following sections:

- Analytical Methods
- Voltage Response of Equipment and Systems
- Voltage Response Criteria for Stability
- Countermeasures to Voltage Instability

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