L41 - Voltage Stability

System may be Swing (transient)

Stable, but Voltage Collapses
L41 will focus on

- WECC document (LINK @ end of L40 notes)
- PV curves
- QV curves
Swing Eq

\[ P = \frac{1}{2} m g x + P_{\text{max}} \sin \theta \]
voltage stability margins must be available to all WECC members for the resulting margins to be recognized.

A full P-V curve (see Figure 8.1) can be produced by two methods. The first is by increasing the loads in the study region and increasing external generation. The second is by increasing flows across an interface (i.e., shifting generation from the receiving region to the external region). External areas that are resource constrained are permitted the use of a fictitious generator, solely for the purpose of establishing power margin. Good engineering judgment should be used in placing such a generator, and the generator should not supply reactive power. The following procedures cover these two methods of stressing a region to generate a complete P-V curve from low loads or low interface flows to high loads or high interface flows, respectively. Separate procedures are also provided and are to be used when the primary analysis method is V-Q and P-V checks are needed to ensure that the power margin is met.

The procedure for full P-V curve development, P-V tests, and determination of real power margin are discussed in the following sections 8.1, 8.2, 8.3, 8.4, and 8.5.

8.1 Full P-V Curve Development (Load Increase Methodology)

The following methodology which should be followed for development of a full P-V curve for studies involving load areas is described below.

1. Choose a region as the study area wherein load will be incrementally increased. This could be a region that is suspected or known to be susceptible to voltage collapse and can be as large or as small as necessary. The quantities that will be varied are internal load, at a constant power factor, and external generation.

2. Model the loads in the study area initially at a level of approximately 20% of the expected peak load. This will provide the full benefit of P-V analysis, with the development of the P-V curve at levels below the operating points for which problems could be anticipated. Generation external to the study area should be reduced to match the scaled down load levels in the study area. As loads are scaled up in the study area, the effects of increased load requirements on the study region's voltage profile will be captured.
3. Set the internal study area generation to a constant level of the on-line units. The real power output of the internal generators should remain unchanged during the P-V analysis. The reactive power capability of each of the generating units should represent the unit's capability, and the reactive power output of each unit should be allowed to adjust as the P-V analysis progresses. Voltage collapse will occur in the study region after the VAR capability in the study region is depleted.

4. Choose the bus or buses in the study area at which the voltages will be monitored as the power transfers into the study area are increased. As an initial investigation of a region for voltage instability, the engineer should select several buses to monitor. The monitored voltages are the y-axis data of a P-V curve. See sections 7 and 8 regarding methods of identifying buses to monitor.

5. Determine (a) if the x-axis data will be load or interface flows, and (b) if the units will be MW or MVA (see Figure 8.1). If an interface path is used, it should be defined in a manner that measures all imports to the receiving region. A partial interface definition that allows imports into the receiving region over an unmonitored branch is incomplete. Choosing the x-axis to be study area load in MW is a good starting point.
6. Choose the system condition to be simulated. The system condition should be represented before internal loads and external generation are scaled up to develop the P-V data. A pre-contingency P-V analysis of the system provides an indication of the maximum capability of the study region to serve load. Simulating contingencies based on the performance levels of Table 1 are required to assure compliance with the voltage stability margins and provide information regarding the steady-state operating point that will occur after the contingency.

7. Solve the initial power flow case representing a low receiving area load for the performance level being studied using the post-transient methodology described in Section 6.

8. Record the bus voltages at the monitored buses, and the load level or interface transfer level at which the power flow case was solved.

9. Scale loads and external generation up to match the load increase. The load increases can be larger at lower load levels than at higher load levels, which are near the point of collapse. Ensure that loads are scaled up in the neighboring systems if they have similar climatic or geographic characteristics to the system under study. Initially, a load increase equal to the starting load level in the study region should be effective. If the power flow case fails to converge to a solution after a load increase, return to the last solved case, and scale up the loads by one-half or one-fourth of the previous attempt.

NOTE: When the load level reaches the starting load level, for the next 5% load increase, only automatic and manual adjustments, which would occur within 30 minutes, are allowed for increasing the load. These adjustments include generation dispatch, tap changer and phase shifter adjustments, switching of devices, etc.

10. The results of the P-V analysis could indicate that the voltage profile of a region is significantly lower than acceptable operating conditions at the point-of-collapse. In such cases, the limit of the system could be determined by other voltage criteria, such as post-transient voltage deviation or the lower limit of acceptable operating voltage. However, in some receiving regions, typically regions with a high degree of shunt compensation, the point-of-collapse will occur at or near bus voltages that appear acceptable. For these cases, the system should be designed with some operating margin from the point of collapse.
"P" in PV curve may be

- Load Area
- Inter Area
- Internal Path
"p" is NOT:

- RADIAL SYSTEM
- LOCAL "SMALL"
Adding shunt capacitors tends to "MASK" voltage stability risk.
QV or VQ curves

Reactive determined by Voltage

- OR -

Voltage determined by Reactive?
Figure 7.1 - V-Q Curve
In powerflow add condenser (svc) to a bus

Set V, solve, measure Q

\[ P = 0, \quad Q = 0, \quad B U S \ A \]
SWITCHED SHUNTS CREATE A FAMILY OF CURVES.
Table 1

WSCC VOLTAGE STABILITY CRITERIA (*)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Any element such as: One Generator One Circuit One Transformer One Reactive Power Source One DC Monopole</td>
<td>≥ 5%</td>
<td>Worst Case Scenario (8)</td>
</tr>
<tr>
<td>B</td>
<td>Bus Section</td>
<td>≥ 2.5%</td>
<td>50% of Margin Requirement in Level A</td>
</tr>
<tr>
<td>C</td>
<td>Any combination of two elements such as: A Line and a Generator A Line and a Reactive Power Source Two Generators Two Circuits Two Transformers Two Reactive Power Sources DC Bipole</td>
<td>≥ 2.5%</td>
<td>50% of Margin Requirement in Level A</td>
</tr>
<tr>
<td>D</td>
<td>Any combination of three or more elements such as: Three or More Circuits on ROW Entire Substation Entire Plant Including Switchyard</td>
<td>&gt; 0</td>
<td>&gt; 0</td>
</tr>
</tbody>
</table>

(1) This table applies equally to the system with all elements in service and the system with one element removed and the system readjusted (see Section 2.2).

(2) For application of this criteria within a member system, controlled load shedding is allowed to meet Performance Level A (see Section 2.2 for a description of provisions for application of this criteria within a member system).

(3) The list of element outages in each Performance Level is not intended to be different than the Disturbance Performance Table in the WECC Reliability Criteria. Additional element outages have been added to this table to show more examples of contingencies. Determination of credibility for contingencies for each Performance Level is based on the definitions used in the existing WECC Reliability Criteria.

(4) Margin for N-0 (base case) conditions must be greater than the margin for Performance Level A.

(5) Maximum operating point on the P axis must have a MW margin equal to or greater than the values in this table as measured from the nose point of the P-V curve for each Performance Level.

(6) Post-transient analysis techniques shall be utilized in applying the criteria.

(7) Each member system should consider, as appropriate, the uncertainties in Section 2.3 to determine the required margin for its system.

(8) The most reactive deficient bus must have adequate reactive power margin for the worst single contingency to satisfy either of the following conditions, whichever is worse: (i) a 5% increase beyond maximum forecasted loads or (ii) a 5% increase beyond maximum allowable interface flows. The worst single contingency is the one that causes the largest decrease in the reactive power margin.

(*) Table 1 is an excerpt from the WSOC Reliability Criteria for Transmission System Planning in effect at the time of this document's approval. The most current version of the Council's Table of Allowable Effects on Other Systems should be referred to when conducting studies.
WHAT IS 5% P?

- 5% of PEAK INTERFACE FLOW

- 5% of 1 in 2 load PEAK LOAD Day = 50% chance of exceeding this year
LEVEL "A" Q MARGIN
WORST CASE SCENARIO?

- Limiting Contingency
- Plot QV Curve
University of Idaho

- Increase Base Flow 5%
- PLOT 2nd QV Curve
- NOTE CHANGE
Figure 7.2 - V-Q Curve Test for Determination of Reactive Power Margin

Therefore, the total required margin is 300 MVAR for the worst single contingency without system adjustments. This implies that after a system experiences an N-1 contingency, at least 300 MVAR of margin must be available. The system is clearly deficient in reactive power and has a potential to collapse. After installing reactive power support, the V-Q curves must be reproduced to provide the necessary positive margin as shown in Figure 7.3. The margin covers the worst single contingency and a 5% load forecast or interface flow uncertainty. If capacitors are added to provide the required margin, an adequate amount must be added to take into account the relationship between the capacitor output and square of the voltage applied to the capacitors. For example, if the required margin of 300 MVAR is at a voltage collapse point of 0.9 pu, about 370 (300/0.9² = 370) MVAR of capacitors would be needed to provide the margin.
LEVEL Margin

Margin for contingency

N+5% load

N-1
Figure 7.3 - Required Reactive Power Margin

No tests are needed to determine the required MVAR margin for Performance Levels B through D. The amount of required margin for Performance Levels B through D is determined by multiplying the amount of margin determined for Performance Level A by the appropriate factor as shown in Table 1. For example, if the required reactive power reserve for Performance Level A is determined to be 300 MVAR, the required reactive power reserve for Performance Level B would be 50% of 300 MVAR, or 150 MVAR.

As indicated in Section 2.2, the criteria in Table 1 apply equally to the system with all elements in service as well as the system with one element removed and the system readjusted. An example will be given to illustrate this situation. Suppose a nearby generator is out of service for the example described above. Furthermore, suppose that the system adjustments required to displace the lost generation consist of dispatching a distant generator with no other changes to the system. The distant generator cannot provide reactive power support to the critical bus under study. Since the reactive power support from the generator which is out of
Margin should be greater than

Other considerations on next page
2.3 Consideration of Uncertainties for Establishment of the Voltage Stability Criteria

Table 1 specifies the minimum required margins for each member system. Prior to applying Table 1, the member system should consider, as appropriate, the uncertainties a-r [28] listed below. These uncertainties relate to unknowns in data, equipment performance, and network conditions. This list will be modified as member systems gain experience in applying Table 1 and identify new uncertainties or agree that some uncertainties are already included in Table 1.

(a) Customer real and reactive power demand greater than forecasted
(b) Approximations in studies (Planning and Operations)
(c) Outages not routinely studied on the member system
(d) Outages not routinely studied on neighboring systems
(e) Unit trips following major disturbances
(f) Lower voltage line trips following major disturbances
(g) Variations on neighboring system dispatch
(h) Large and variable reactive exchanges with neighboring systems
(i) More restrictive reactive power constraints on neighboring system generators than planned
(j) Variations in load characteristics, especially in load power factors
(k) Risk of the next major event during a 30-minute adjustment period
(l) Not being able to readjust adequately to get back to a secure state
(m) Increases in major path flows following major contingencies due to various factors such as on-system undervoltage load shedding
(n) On-system reactive resources not responding
(o) Excitation limiters responding prematurely
(p) Possible RAS failure
(q) Prior outages of system facilities
(r) More restrictive reactive power constraints on internal generators than planned.

The RRWG further recommends that member systems consider the consequences of a voltage collapse in determining the amount of required margin in the study area.

The BPA Blue Ribbon Panel report (see Appendix F) states that:

"The Panel is not convinced that a study margin is sufficient if key generators are at their reactive limits. However, the studies presented indicated margin existed on a number of key generators."
Role of you count on short term
May use static

Dynamic Best

Statistic vs Dynamic
UNDER VOLTAGE LOAD
SHEDDING

- DESIGN SPECIFIC TO AREA
- NO NEED FOR A UNIFORM PLAN (REGION/WIDE)
• TRANSIENT VOLTAGE DIP

• FAULTS
DYNAMIC VARS ARE CRITICAL
AVRs MUST BE IN VOLTAGE CONTROL FOR MAX VOLTAGE STABILITY