# Reactive Power Control in a Competitive Market

Mo-Shing Chen Rasool Kenarangui

Energy Systems Research Center
Electrical Engineering Department
University of Texas at Arlington
Box 19048, Arlington, Texas 76019-0048

## 1. Introduction

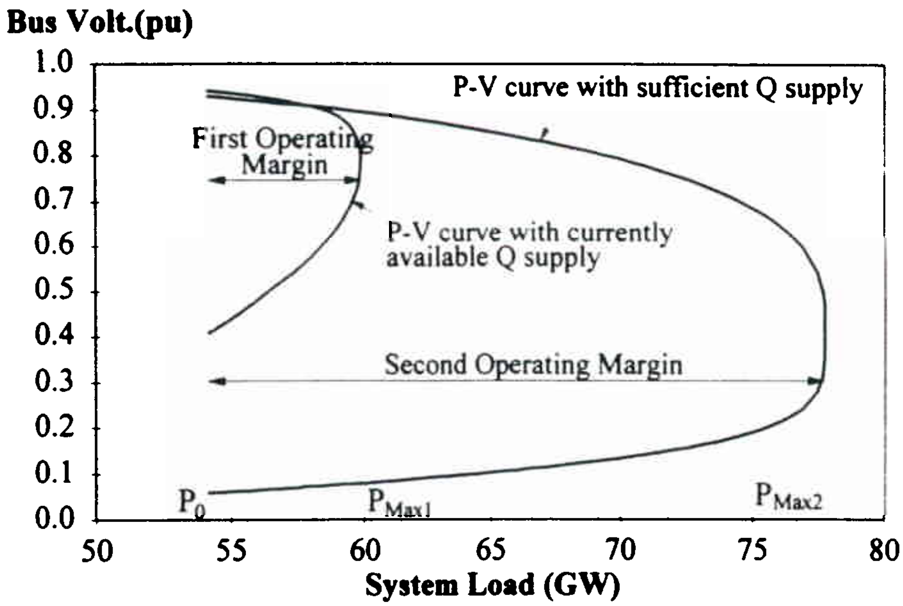
Quite a high percentage of power system blackouts reported over the years were categorized as voltage instability. The phenomena of voltage collapse were described in several literature. Time frame of voltage collapse could be less than a second, seconds, minutes, or even longer than half hour. A very severe and critical contingency could cause a heavily stressed system blackout in a moment. Most of voltage collapse cases occurred after the system had experienced several cascading events, which could last seconds, minutes or even longer.

This summer there were several times of voltage dips in the north Texas area due to generator outages. Though the ERCOT system survived these incidents, some questions raised among those who worried about the security of ERCOT system, such as

- How large the operating margin was for the pre- and post-generator outage contingency on those voltage dip days?
- Can the system service the same generator outages if there was line outage, scheduled out or forced out, during that period of voltage dip?
- If several high-pollution power plants in the DFW area retire and the reduced power supply is imported from other areas, how much effects that could cause in terms of operating margins? Can the system survive similar generator outage after the retirement of the high-pollution units?
- How much the new transmission lines that are under construction or proposed in the north Texas can benefit the voltage stability of ERCOT system?
- Are there any other measures, instead of building new transmission line, that possibly improve the operating margin and relieve the transmission congestion problems?
- The renewable energy sources will play a more important role in energy supply in the near future. The effect of the renewable sources to the power system security is largely dependent on the design of dynamic reactive sources. What is the effect of renewable energy sources to the voltage stability in the ERCOT system?

## 2. Reactive Power and P-V Curve

There can be two types of P-V curves depending on the reactive power resources of a power system. The first type is based on the existing reactive power resources and the second one is based on the assumption of sufficient reactive power resources. The following figure illustrates these two types of P-V curves.




Based on two types of P-V curve, one can define two operating margins for a power system: the first operating margin and the second operating margin. The following are our definitions:

**First Operating Margin**: The operating margin obtained from the P-V curve by load flow solutions which simulate the currently available reactive sources. The first operating margin is usually expressed in percentage and obtained by:

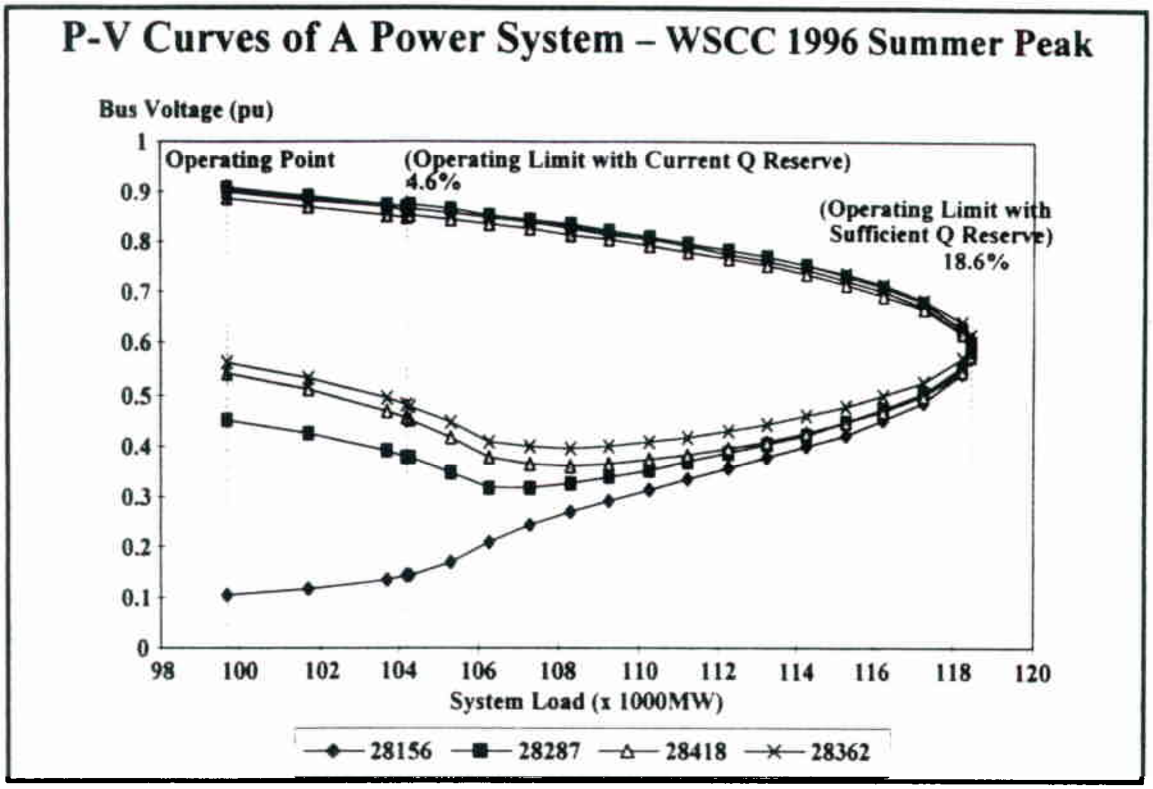
$$\frac{P_{Max1} - P_0}{P_0} \times 100\%$$

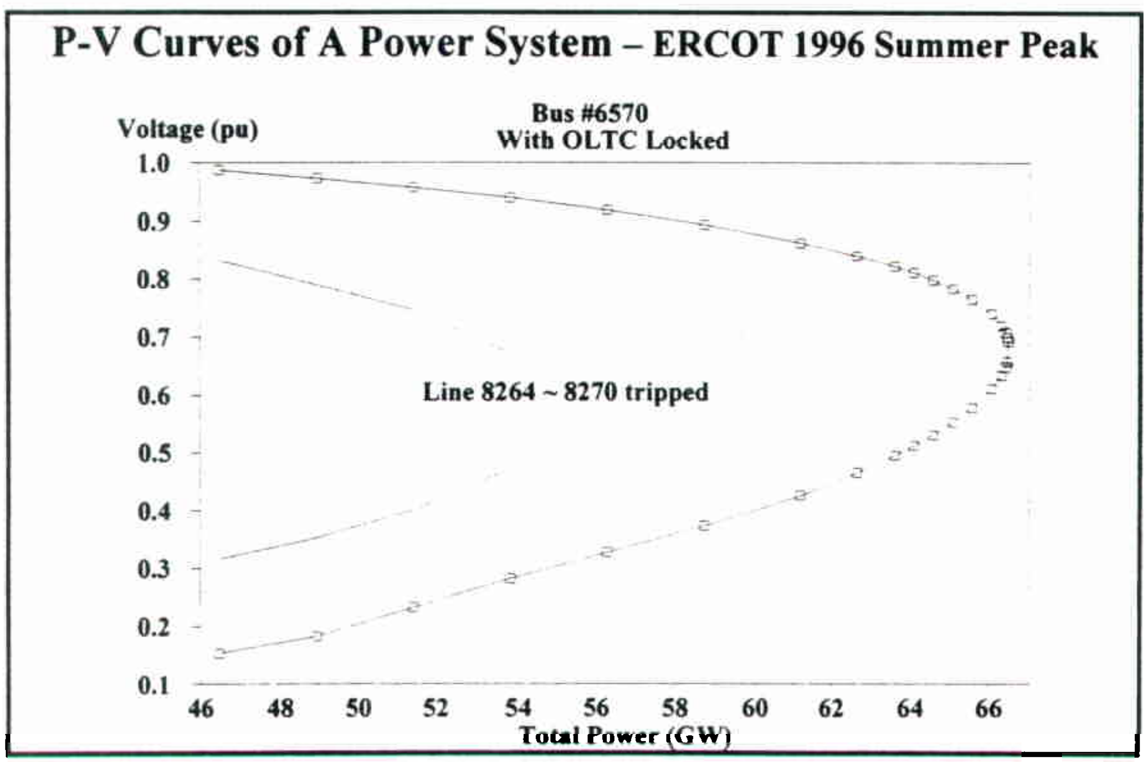
**Second Operating Margin**: The operating margin obtained from the P-V curve by load flow solutions which set the reactive power limit of every generator to the ± infinity. The second operating margin is representative of a power system with sufficient regulating reactive sources such as synchronous condensers, SVC, or must-run generating units. The percentage second operating margin is obtained by:

$$\frac{P_{Max2} - P_0}{P_0} \times 100\%$$

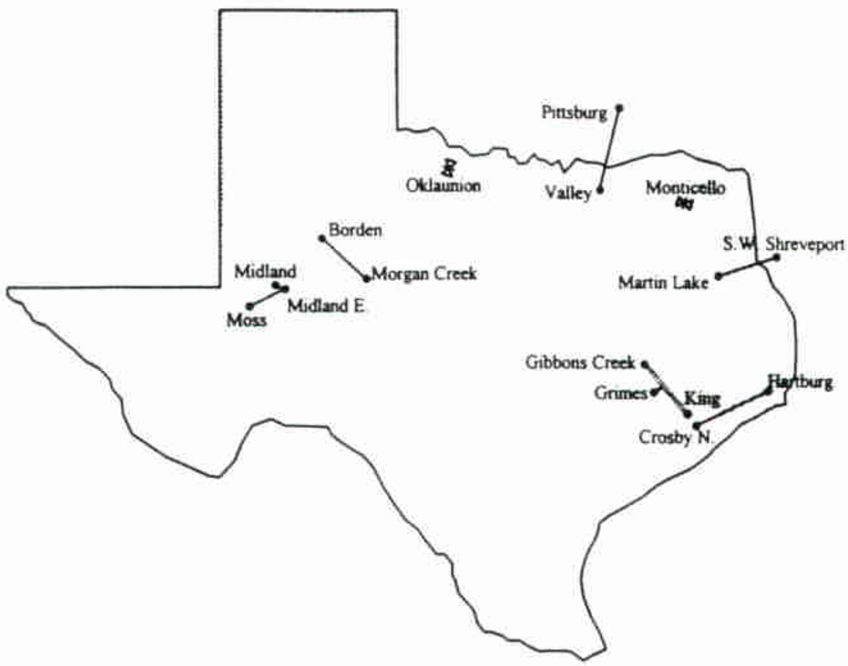
The first operating margin is the current system margin which the system operators should pay attention to. The second operating margin is the ideal margin of plenty reactive sources. The difference between two margins represents the room that the system security can be improved by means of proper reactive power compensation.

3. ESRC's Research on Voltage Stability



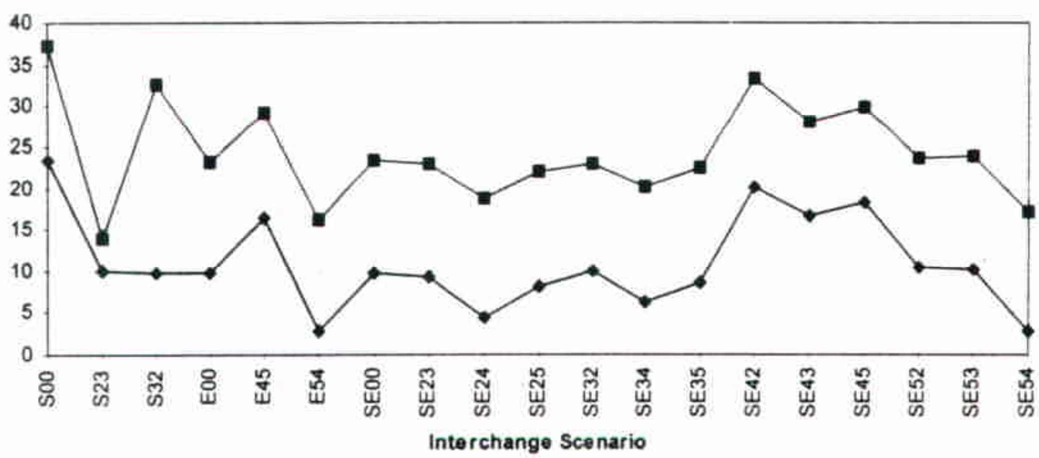



## ESRC Research On ERCOT Voltage Stability (1998)




## ESRC Research On ERCOT Voltage Stability (1998)

The operating margins for different power transfer scenarios




Area Code:

2 – South SPP, 3 – North SPP, 4 – South ERCOT, 5 – North ERCOT

4. Weak Buses and Weak Areas of a Power System

In a power system there always have weak buses and weak areas from the voltage stability point of view. The weak areas might vary with base cases and contingencies. Tables 1 and 2 list the major weak areas for a power system. The entries that are marked with "--" are the non-convergent or not-applicable cases. The weak buses within Areas A, B and F are shown in the figures on the next page.

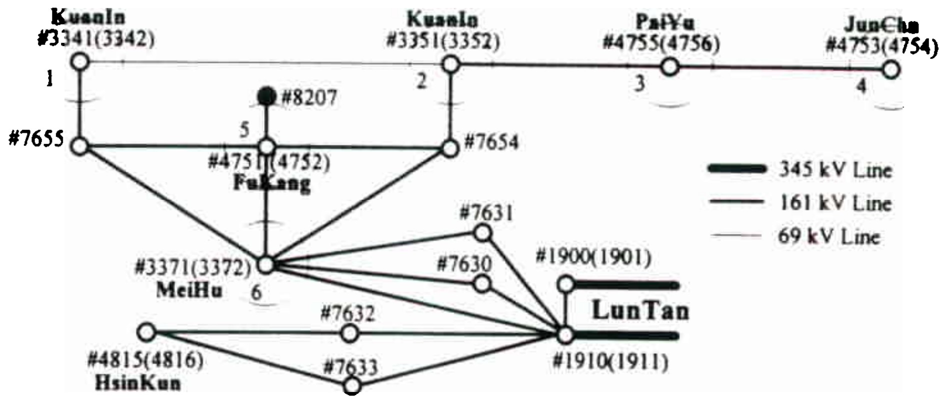
Table 1 Major weak areas for double contingencies

| Case | 1-1 | 1-2 | 1-3 | 1-4 | 1-5 | 1-6 | 1-7 | 1-8 | 2-1 | 2-2 | 2-3 | 2-4 | 2-5 | 2-6 | 2-7 | 2-8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Base Case | A | A | A | A | A | A | A | A, C | A, F | A, F | B, A | A,B,F | A | A | A | D,C,A |
| Cont. #2 | A | A | -- | -- | A | A | A | A,C,D | A | A | -- | -- | A | A | -- | D, G |
| Cont. #8 | A | A | -- | -- | A | A | A | -- | -- | -- | -- | -- | A, B | A, B | -- | -- |
| Cont. #12 | A | A | -- | -- | A | A | A | C,A,D | A | A, F | -- | -- | A | A | A | D, G |
| Cont. #13 | A | A | -- | -- | A | A | A | A, C | A | A | -- | -- | A | A | A | D, G |
| Cont. #15 | A | A | -- | -- | A | A | A | A,C,D | A, F | A, F | -- | -- | A | A | A | D, G |
| Cont. #16 | A | A | -- | -- | A | A | A | A, C | A | A | -- | -- | A | A | -- | D, G |
| Cont. #17 | A | A | -- | -- | A | A | A | A, C | A | A | -- | -- | A | A | A | D, G |
| Cont. #18 | A | A | -- | -- | A | A | A | -- | A, F | A, F | -- | -- | -- | -- | -- | -- |
| Cont. #23 | A | A | -- | -- | A | A | A | A, C | A | A | -- | -- | A | A | A | D, G |
| Cont. #27 | A | A | -- | -- | A | A | A | A, C | A | A | -- | -- | A | A | A | C, A |

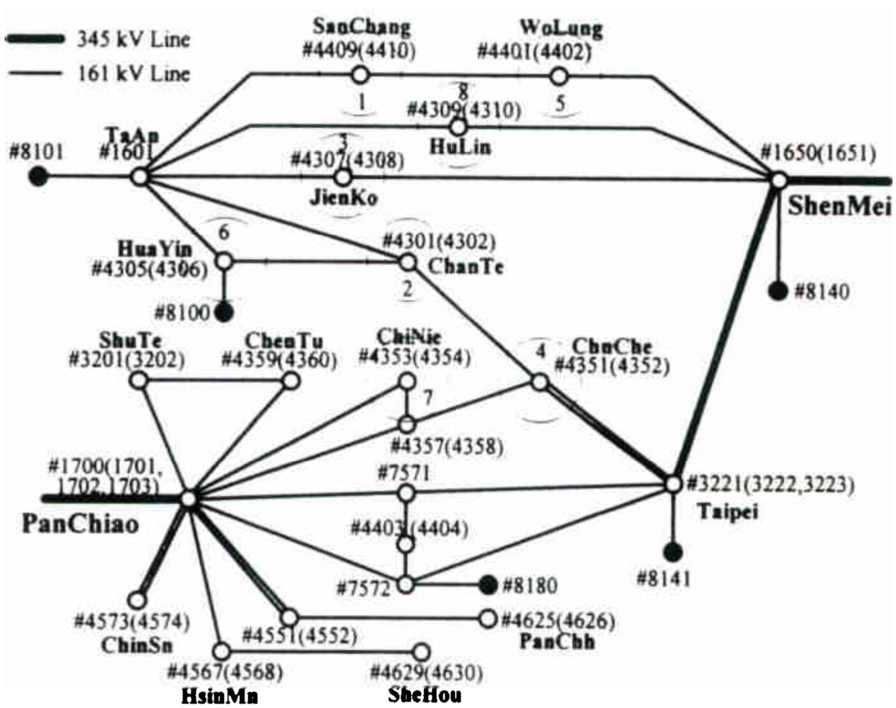
Table 2 Major weak areas for single contingencies

| Case | 1-1 | 1-2 | 1-3 | 1-4 | 1-5 | 1-6 | 1-7 | 1-8 | 2-1 | 2-2 | 2-3 | 2-4 | 2-5 | 2-6 | 2-7 | 2-8 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cont. #2 | A | A | A | A | A | A | A | A, C | A, F | A, F | A,B,F | A,B,F | A, F | A, F | A | D, G |
| Cont. #3 | A | A | A | A | A | A | A | A, C | A, F | A, F | B | B, A | A | A | A | D, G |
| Cont. #4 | A | A | A | A | A | A | A | A, C | A, F | A, F | B | -- | A | A | A | D, G |
| Cont. #5 | A | A | A | A | A | A | A | C, A | A, F | A, F | A,B,F | A,B,F | A | A, F | A | D, G |
| Cont. #12 | A | A | A | A | A | A | A | A | A | A | A,B,F | A,B,F | A | A | A | A, D |
| Cont. #37 | A | A | A | A | A | A | A | A, C | A, F | A, F | A,B,F | B,A,F | A, F | A, F | A | D, A |
| Cont. #41 | A | A | A | A | A | A | A | A, C | A | A | B, A | B, A | A | A | A | D,C,A |
| Cont. #42 | A | A | A | A | A | A | A | A, C | A | A | A,B,F | B, A | A | A | A | D,C,A |
| Cont. #45 | A | A | A | A | A | A | A | A, C | A | A | B, A | B, A | A | A | A | D,C,A |
| Cont. #78 | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Cont. #79 | A | A | A | A | A | A | A | A | A | A | A, B | A | A | A | A | A |

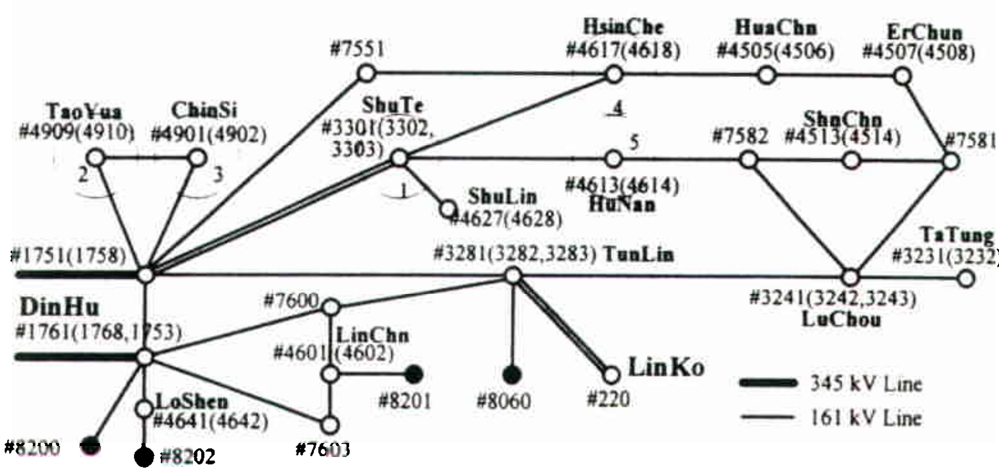
Weak Area A




Weak Area B




Weak Area F



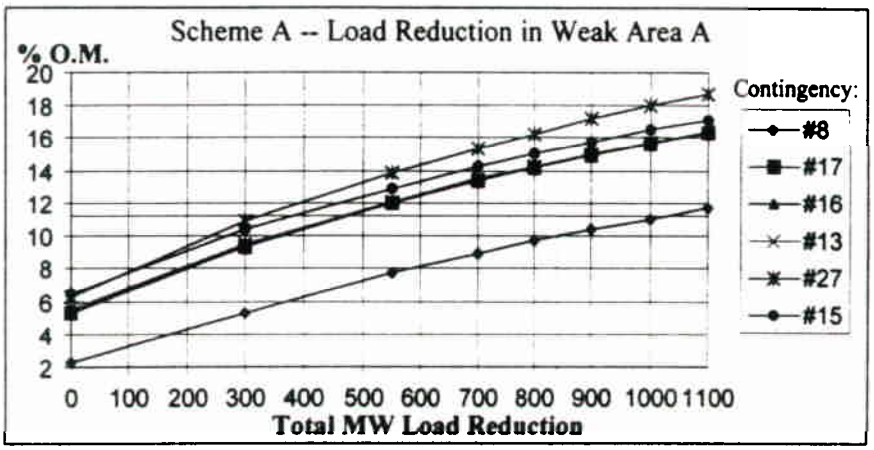
In addition to dynamic reactive power compensation, load reduction is an effective way to improve the system operating margin. Table 3 list the detailed schemes of load reduction. The effectiveness in the operating margin improvements is listed in Table 4 and also shown in the two figures followed.

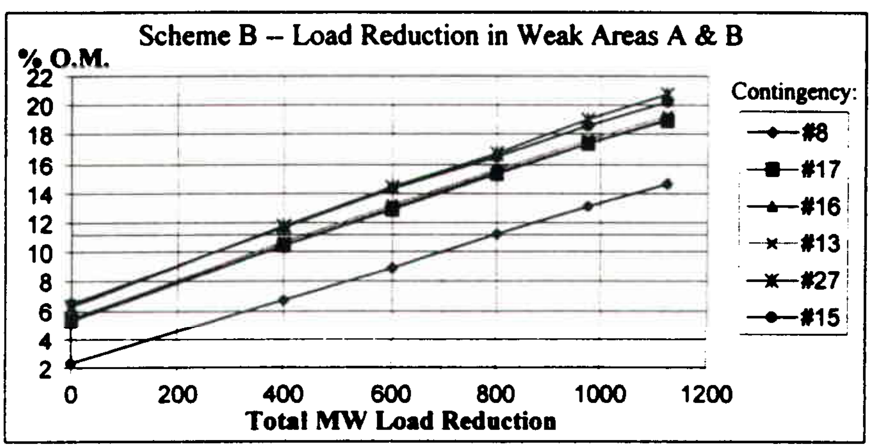
Table 3 MW load reduction arrangement

| Arrangement | Base Case | Load Reduction in Weak Area A (Scheme A) | | | | | | | | Load Reduction in Weak Areas A & B (Scheme B) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Bus | LS 1 | LS 2 | LS 3 | LS 4 | LS 5 | LS 6 | LS 7 | Bus | LS 1 | LS 2 | LS 3 | LS 4 | LS 5 | LS 6 | LS 7 |
| | | #3342 | 50 | 100 | 150 | 200 | 250 | 300 | 350 | #3342 | 50 | 75 | 100 | 125 | 150 | | |
| | | #3352 | 50 | 100 | 150 | 150 | 150 | 150 | 150 | #3352 | 50 | 75 | 100 | 125 | 150 | | |
| | 1-1 | #3372 | 50 | 100 | 150 | 200 | 250 | 300 | 350 | #4756 | 50 | 75 | 100 | 125 | 125 | | |
| | 1-2 | #4752 | 50 | 100 | 100 | 100 | 100 | 100 | 100 | #3372 | 50 | 75 | 100 | 125 | 150 | | |
| A | 1-3 | #4754 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | #4410 | 50 | 75 | 100 | 125 | 150 | | |
| | 1-4 | #4756 | 50 | 100 | 100 | 100 | 100 | 100 | 100 | #4302 | 50 | 75 | 100 | 125 | 150 | | |
| | | | | | | | | | | #4308 | 50 | 75 | 100 | 100 | 100 | | |
| | | | | | | | | | | #4352 | 50 | 75 | 100 | 125 | 150 | | |
| | | Total | 300 | 550 | 700 | 800 | 900 | 1000 | 1100 | Total | 400 | 600 | 800 | 975 | 1125 | | |
| | | #3342 | 50 | 100 | 150 | 200 | 250 | 300 | | #3342 | 50 | 75 | 100 | 125 | 150 | | |
| | | #3352 | 50 | 100 | 150 | 150 | 150 | 150 | | #3352 | 50 | 75 | 100 | 125 | 150 | | |
| | | #3372 | 50 | 100 | 150 | 200 | 250 | 300 | | #4756 | 50 | 75 | 100 | 125 | 125 | | |
| | 1-5 | #4752 | 50 | 100 | 100 | 100 | 100 | 100 | | #3372 | 50 | 75 | 100 | 125 | 150 | | |
| B | 1-6 | #4754 | 50 | 50 | 50 | 50 | 50 | 50 | | #4410 | 50 | 75 | 100 | 125 | 150 | | |
| | | #4756 | 50 | 100 | 100 | 100 | 100 | 100 | | #4302 | 50 | 75 | 100 | 125 | 150 | | |
| | | | | | | | | | | #4308 | 50 | 75 | 100 | 100 | 100 | | |
| | | | | | | | | | | #4352 | 50 | 75 | 100 | 125 | 150 | | |
| | | Total | 300 | 550 | 700 | 800 | 900 | 1000 | | Total | 400 | 600 | 800 | 975 | 1125 | | |
| | | #3342 | 50 | 75 | 100 | 125 | 150 | 200 | | #3342 | 25 | 50 | 75 | 100 | | | |
| | | #3372 | 50 | 75 | 100 | 125 | 150 | 200 | | #3372 | 25 | 50 | 75 | 100 | | | |
| | 1-7 | #4756 | 50 | 75 | 100 | 100 | 100 | 100 | | #4756 | 25 | 50 | 75 | 90 | | | |
| C | 1-8 | | | | | | | | | #3733 | 25 | 50 | 70 | 70 | | | |
| | | | | | | | | | | #3682 | 25 | 50 | 75 | 100 | | | |
| | | | | | | | | | | #3792 | 25 | 50 | 75 | 100 | | | |
| | | Total | 150 | 225 | 300 | 350 | 400 | 500 | | Total | 150 | 300 | 445 | 560 | | | |
| | | #3342 | 50 | 75 | 100 | 125 | 150 | 200 | 250 | #3342 | 50 | 75 | 100 | 125 | 150 | 175 | 200 |
| | | #3352 | 50 | 75 | 100 | 125 | 150 | 150 | 150 | #3352 | 50 | 75 | 100 | 125 | 150 | 150 | 150 |
| | 2-1 | #4756 | 50 | 75 | 100 | 125 | 125 | 125 | 125 | #4756 | 50 | 75 | 100 | 125 | 125 | 125 | 125 |
| D | 2-2 | | | | | | | | | #4410 | 50 | 75 | 100 | 125 | 150 | 170 | 170 |
| | 2-3 | | | | | | | | | #4302 | 50 | 75 | 100 | 125 | 150 | 150 | 150 |
| | 2-4 | | | | | | | | | #4308 | 50 | 75 | 100 | 100 | 100 | 100 | 100 |
| | | | | | | | | | | #4352 | 50 | 75 | 100 | 125 | 150 | 175 | 200 |
| | | Total | 150 | 225 | 300 | 375 | 425 | 475 | 525 | Total | 350 | 525 | 700 | 850 | 975 | 1045 | 1095 |
| | | #3342 | 50 | 75 | 100 | 125 | 150 | 200 | 250 | #3342 | 50 | 75 | 100 | 125 | 150 | 175 | |
| | | #3352 | 50 | 75 | 100 | 125 | 150 | 170 | 170 | #3352 | 50 | 75 | 100 | 125 | 150 | 150 | |
| | 2-5 | #4756 | 50 | 75 | 100 | 120 | 120 | 120 | 120 | #4756 | 50 | 75 | 100 | 120 | 120 | 120 | |
| E | 2-6 | | | | | | | | | #4410 | 50 | 75 | 100 | 125 | 150 | 150 | |
| | | | | | | | | | | #4302 | 50 | 75 | 100 | 125 | 125 | 125 | |
| | | | | | | | | | | #4308 | 50 | 75 | 90 | 90 | 90 | 90 | |
| | | | | | | | | | | #4352 | 50 | 75 | 100 | 125 | 150 | 175 | |
| | | Total | 150 | 225 | 300 | 370 | 420 | 490 | 540 | Total | 350 | 525 | 690 | 835 | 935 | 985 | |
| | | #3342 | 50 | 75 | 100 | 125 | 150 | 200 | | #3342 | 25 | 50 | 75 | 100 | | | |
| | | #3372 | 50 | 75 | 100 | 125 | 150 | 200 | | #3372 | 25 | 50 | 75 | 100 | | | |
| | 2-7 | #4756 | 50 | 75 | 100 | 100 | 100 | 100 | | #4756 | 25 | 50 | 75 | 100 | | | |
| F | 2-8 | | | | | | | | | #3322 | 25 | 50 | 75 | 100 | | | |
| | | | | | | | | | | #3362 | 25 | 50 | 75 | 100 | | | |
| | | | | | | | | | | #3682 | 25 | 50 | 75 | 100 | | | |
| | | Total | 150 | 225 | 300 | 350 | 400 | 500 | | Total | 150 | 300 | 450 | 600 | | | |

Table 4 Effectiveness of load reduction for selected contingencies

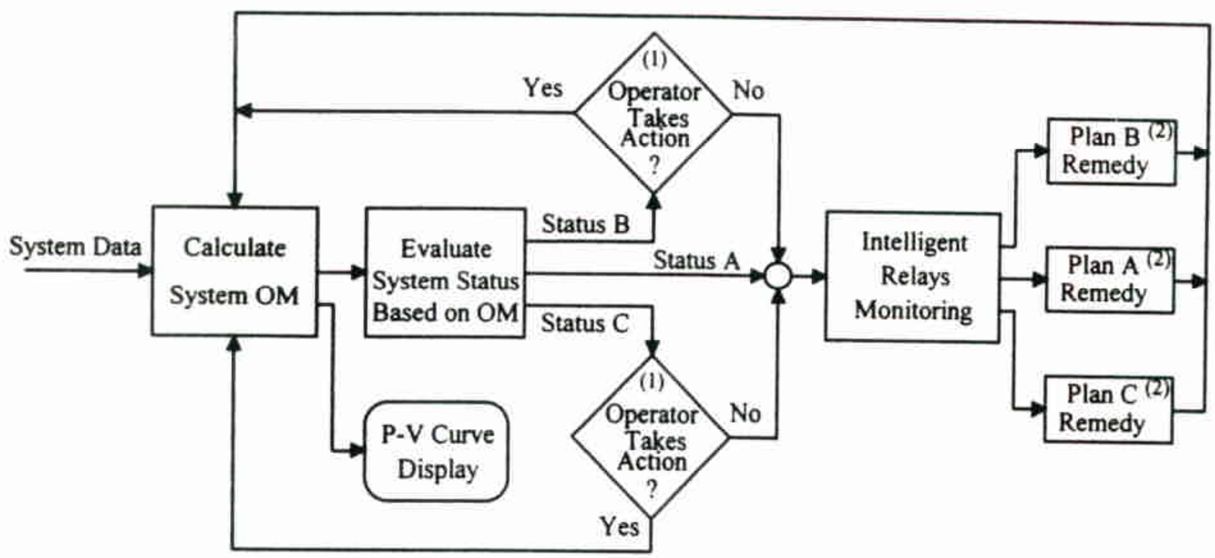
| Base Case | Base Case OM(%) | System Load (MW) Base Case | System Load (MW) After Max. Load Red. | Arrange-ment | Effective. of Load Reduction in Weak Area A (Scheme A) (Percentage Point) | (MW) | Effective. of Load Reduction in Weak Areas A & B (Scheme B) (Percentage Point) | (MW) |
|---|---|---|---|---|---|---|---|---|
| 1-1 | 11.19 | 25681 | 24581/24556 | A | 0.85 ~ 1.14 | 209 ~ 280 | 1.09 ~ 1.29 | 268 ~ 317 |
| 1-2 | 11.13 | 25681 | 24581/24556 | A | 0.85 ~ 1.13 | 209 ~ 278 | 1.09 ~ 1.29 | 268 ~ 317 |
| 1-3 | 2.75 | 25681 | 24581/24556 | A | 0.69 ~ 0.81 | 170 ~ 199 | 0.93 ~ 1.01 | 228 ~ 248 |
| 1-4 | 2.56 | 25681 | 24581/24556 | A | 0.68 ~ 0.80 | 167 ~ 196 | 0.89 ~ 0.99 | 219 ~ 243 |
| 1-5 | 17.06 | 23065 | 22065/21940 | B | 1.10 ~ 1.53 | 243 ~ 338 | 1.34 ~ 1.62 | 294 ~ 355 |
| 1-6 | 17.06 | 23065 | 22065/21940 | B | 0.90 ~ 1.33 | 199 ~ 293 | 1.15 ~ 1.47 | 252 ~ 323 |
| 1-7 | 51.94 | 12555 | 12055/11995 | C | 1.89 ~ 2.97 | 228 ~ 358 | 1.90 ~ 2.39 | 228 ~ 287 |
| 1-8 | 36.88 | 12555 | 12055/11995 | C | 1.53 ~ 1.72 | 184 ~ 207 | 1.52 ~ 1.45 | 182 ~ 174 |
| 2-1 | 7.06 | 27903 | 27378/26808 | D | 0.59 ~ 0.83 | 162 ~ 227 | 0.84 ~ 0.89 | 225 ~ 239 |
| 2-2 | 6.88 | 27903 | 27378/26808 | D | 0.59 ~ 0.84 | 162 ~ 230 | 0.83 ~ 0.88 | 223 ~ 236 |
| 2-3 | 2.88 | 27903 | 27378/26808 | D | 0.47 ~ 0.59 | 129 ~ 162 | 0.78 ~ 0.86 | 209 ~ 231 |
| 2-4 | 2.69 | 27903 | 27378/26808 | D | 0.49 ~ 0.63 | 135 ~ 172 | 0.77 ~ 0.88 | 206 ~ 236 |
| 2-5 | 13.19 | 25122 | 24582/24137 | E | 0.72 ~ 0.91 | 177 ~ 224 | 1.03 ~ 1.09 | 249 ~ 263 |
| 2-6 | 13.13 | 25122 | 24582/24137 | E | 0.72 ~ 0.91 | 177 ~ 224 | 1.02 ~ 1.09 | 246 ~ 263 |
| 2-7 | 53.13 | 14147 | 13647/13547 | F | 1.90 ~ 2.92 | 259 ~ 399 | 2.11 ~ 2.92 | 286 ~ 396 |
| 2-8 | 38.00 | 14147 | 13647/13547 | F | 1.29 ~ 1.34 | 176 ~ 183 | 1.24 ~ 1.30 | 168 ~ 174 |



5. Reactive Power Design in System Operating and System Planning

## Conceptual Design of An Intelligent System to Prevent Voltage Collapse




Note: (1) **Preventive actions include Redispatch, Shedding interruptible loads, Shedding weak bus loads, etc.**

(2) **Plans A, B, C remedies**

For planning purpose

## Intelligent System to Prevent Voltage Collapse – Used as a Planning Tool