Chapter 6

Contingency Analysis

Contingency analysis is an essential security function in power system planning and operation. This study analyzes and investigates responses of power system following the abnormal incidents. On the other hand, contingency analysis is a defensively study of power system providing the robustness of the system before unsafe situations arise.

Generally, scope of contingency study is bounded by the level of security requirement of the system that usually defined in planning stage. According to the "Regional Reliability Criteria" [27] published by North American Electric Reliability Council, as a minimum, power system in every regional council must be secured under n-1 contingency situations that means power system must be able to operate securely when a major facility is forced outage.

For more secure power system requirements, the system must be simulated by more severe situations such as the conditions of n-2 (2 facilities are forced outage) or n-3 contingency (3 facilities are forced outage). It is seen that security policy of utilities or power pool plays very important roles in confining contingency study since it determines the complexity of the study. For Thailand power system, n-1 contingency analysis is required as the representatives abnormal situations occur in the system. Details of n-1 contingency analysis are explained in this chapter.

Under the Available Transfer Capability point of view, contingency analysis gives representation of abnormal cases in the systems ranked by their severity since limitations between source and load in ATC interface may be determined by many factors. Existence of only one or a few facilities limitation violation based on standard security criteria during transient or steady state period will determine the value of available transfer capability of the entire system. Therefore, contingency study is an important procedure that may limit ATC values of the system even though loading conditions may be relative low compared to the security limits.

Different from reliability must-run units study, contingency analysis study is based on the simulation on the situations that major facility is forced outage from the system. Therefore, transient stability study is necessary to investigate the respond of the system after sudden changes of the system. In addition to acceptable system's states under steady state conditions, capability of the systems to remain stable during the transient period is also an important issue to affect maximum power transfer capability between ATC interfaces.

6.1 Basic Concept of Contingency Analysis

Generally, contingency analysis is a planning implementation of power system which usually be done off-line. Results from contingency analysis are considerably crucial for real-time ATC calculation since they give information regarding system

responds when unexpected severe upsets occur. These off-line results are still valid for real-time study as long as basic system configuration remains unchanged.

Since the contingency analysis plays an importance role in power system security analysis, this chapter will explain the basic concept of this defensive operation of power system. Because power system is immense, complex encompassing large geographical service areas, locations and severity of contingencies in the power system are unpredictable since they may be triggered by numerous random events at any time and any place. In order to protect power system from severe interruption of service, defensive actions is one of the competitive approaches to cope with these problems. Contingency analysis is a network problem detection method that can be performed through the investigation of simulated events which contingency situations occur accordance with the requirement of security level.

According to the above concept, a major technical difficulty of contingency analysis is determining the foreseeable size of the problem. A simple example shows that with a relatively small power system that contains 50 generators and 250 high voltage transmission lines, following contingency cases are generated from each requirement level.

N-1 contingency:

There are $\binom{50}{1}+\binom{250}{1}=300$ contingency cases need to be studied.

N-2 contingency:

There are $\binom{50}{2}+\binom{50}{1}\binom{250}{1}+\binom{250}{2}=1225+12500+31125=44850$ cases need to be studied

In each case, systems states prior and following the fault (voltage and current) and ability to remain in stable operation under transient period are necessary to be studied. Therefore, contingency analysis is a time-consuming process that requires lots of computation resources unless an appropriate technique is applied to downsize the problem.

In order to handle the above-mentioned problem, many methods such as modified AC powerflow, DC powerflow and contingency screening method have been proposed to speed up the calculation. Evaluating the advantages and disadvantages of these methods this dissertation employs the method that bases on the contingency screening method to investigate the problem. Reliability, accuracy and comprehensive results obtained from this approach are the major reasons behind this selection.

Regardless the technique that is employed in contingency analysis, the basic calculation processes is similar as described below.

6.1.1 Generation of contingency cases

This step creates sets of contingency cases that might significant enough to impact the normal system operation. The abnormal cases are directly depended on the required security level. For example, n-1 contingency analysis requires contingency cases generated from the situations that power system losses a major facility (usually represented by loss of generator or transmission line) and n-2 contingency analysis based on the situations that power system losses two major facilities. This step of calculation procedures is relatively straightforward. The detailed calculation and results will be shown in section 6.1.3 and 6.3 respectively.

6.1.2 Investigation of systems response

Investigation of systems response is the most time consuming process in contingency analysis because of the number of contingency cases and possible system states to be studied. During this process, amount of power flow in transmission lines, voltage magnitude at buses, and ability to remain stable of the system after disturbances are monitored in order to ensure the security of the system or prepare the information for screening processes. From this reason, calculation processes in this step have included both steady state and transient responds of the system

As mentioned, the technical challenge of this step is to speed up the calculation while the correctness of results is retained. According to the above concepts, three general techniques to evaluate the response of power system under abnormal situations are summarized as follows [75].

a) Study all possible cases with very fast algorithms:
   This strategy has been used many years in power industry to perform contingency analysis. Through this approach, all the cases in 6.1.1 are screened. The most commonly used algorithms are DC power flow, Fast Decoupled power flow (FDPF) or Linear Sensitivity method. These techniques are useful as long as the approximated results are acceptable since they disregard many factors to speed up the calculation.

b) Select only the important cases and perform detailed calculation:
   Different from the above mentioned method, this approach favors the complete calculation method such as AC power flow to obtain system's result rather than simplifying the calculation tool as shown in a). So as to obtain the satisfactory calculation speed, additional technique to discriminate risky cases from normal cases, contingency screening, such as performance index (PI) [33] is required in this approach. This dissertation uses this concept to propose a new performance index formula that considers both real and reactive power constraints. Detailed calculation of this method and contingency screening techniques will be explained in 6.3.

c) Study all possible cases in the system with the detailed calculation but speed up the calculation speed by enhancing computer capability:
This last approach gives the most complete results of contingency analysis since it employs detailed calculation on all possible cases in the systems. However, this is a costly method since it requires tremendous computational resources especially when this approach as applied to a large power system.

Base on the three methods explained before, three significant bottlenecks have to be overcome in contingency analysis. They are:

a) Place too many cases on the short list:
Most of this problem arises because power system planners need to ensure that they do not overlook any abnormal cases in the system by combining as many suspected cases or possible in the short list. This results in slower calculation speed since analysis procedures have to go through many unnecessarily cases. However, it is not a significant drawback and is acceptable if the available time is sufficient.

b) Skipping Cases
Skipping cases is the problem when the cases that may cause system security issues are overlooked by contingency screening processes. This error is more severe than the first case since it may lead to severe situation in the systems without warnings. In some situations, this error may cause major outages.

c) Incorrect or insufficient results
The selection of tool or technique to analyze system states in contingency study highly influences the quality of contingency analysis results. Fast calculation method will speed up the calculation processes but it may give less-accurate or incomplete results since it ignores or overlook some components in the system. A typical example of this issue is the implementation of DC load flow in contingency study. By this method, reactive components of power system are omitted from the calculation in order to speed up the calculation processes even though reactive power is considerably significant to power system under deregulated environment. Therefore, the trade-off of implementing DC powerflow in contingency analysis is the deficiency of voltage magnitude and voltage stability information.

6.1.3 Contingency Ranking and Selection

Contingency ranking and selection is the last step of the contingency analysis processes. In this process, studied cases are scored and ranked by comparing their operating point during the contingency period against system security criteria. Currently, many power utilities around the world trust in the performance index (PI) [75-76] technique and use this method to extract severe contingency cases. From this

method, each contingency case is scored and then ranked by comparing amount of power flow and thermal limits violations based on the following formula.

$$PI = \sum_{all\_branches(i)} \left(\frac{P_{flow\_i}}{P_i^{\max}} \right)^{2n} \quad (1)$$

Where

P_{flow_i} is amount of real power flow in transmission line i

$P_i^{\max}$ is amount of maximum rating of power flow in transmission line i (usually determined by transmission lines rating)

n is a large number giving clearly different of score when power flow in transmission line is less or greater than maximum rating

However, it is seen that performance index given by equation 1) may not provide adequate information of a power system under deregulated environment since it justifies performance index from the power flow in the system only. Therefore, this dissertation proposes a new formula to calculate the performance index based on both amount of power flow and voltage level as follows:

$$PI = \sum_{all\_branches(i)} \left(\frac{P_{flow\_i}}{P_i^{\max}} \right)^{2n_1} + \sum_{PQ\_buses(j)} \left(\frac{\left| |V_j| - 1 \right|}{0.5} \right)^{2n_2}$$

$$+ \sum_{PV\_buses(k)} \left(\left(|V_{k,spec}| - (V_{k,actual}) \right) * 100 \right)^{2n_3} \quad (2)$$

Where

P_{flow_i} is amount of real power flow in transmission line i

$P_i^{\max}$ is amount of maximum rating of power flow in transmission line i (usually determined by transmission lines rating)

V_j is voltage magnitude at load bus j

$V_{k,spec}$ is the specified voltage magnitude at voltage-controlled bus k

$V_{k,actual}$ is the actual voltage magnitude at voltage-controlled bus k

n_1 is a large number which will clearly give different scores when power flow in transmission line is less or greater than maximum rating

n_2 is a large number which will clearly give different scores when

voltage magnitude of load bus is less or greater than maximum rating

n_3 is a large number which will clearly give different scores when voltage magnitude of voltage-controlled bus is less or greater than maximum rating

According to the modified performance index formula given in equation (2), PI score is given by considering both amount of power flow and voltage level at load and generator buses. Constants n_1, n_2 and n_3 are usually assigned with different values in order to be able to trace the abnormal part in the system. This concept covers most of state quantities necessary to ensure security level of power system. Summary of contingency calculation processes are given as flowchart shown in figure 6-1.

6.2 Factors to be considered in contingency analysis

Contingency analysis considers several security factors similar to reliability must-run units study which has been explained in chapter 5. However, as explained earlier, these two calculations are dissimilar in details since they are based on different situations. For contingency analysis, the simulated cases are based on the assumption that major facilities in power system (normally represented by generators or transmission lines) are forced outage. Hence, contingency analysis must incorporate responds of power system during transient period. As the conclusion, factors to be considered in contingency analysis procedures are summarized below.

6.2.1 Pre fault conditions

First of all, it is important that base case conditions of the systems must not contain abnormal conditions prior to the contingency study. Generally, abnormal problems in base case might be eliminated by performing redispatch technique which reallocate generation scheduling. According to this concept, a test system must satisfy following reliability criteria at prefault conditions:

a) Voltage magnitude at load buses are lying within ± 5 % range from nominal voltage

b) Most of voltage level at voltage controlled buses are maintained at the rated voltage (specified voltage that normally slightly higher than load buses)

c) Amount of total power flow (MVA flow) in transmission lines do not exceed 90% of normal thermal ratings

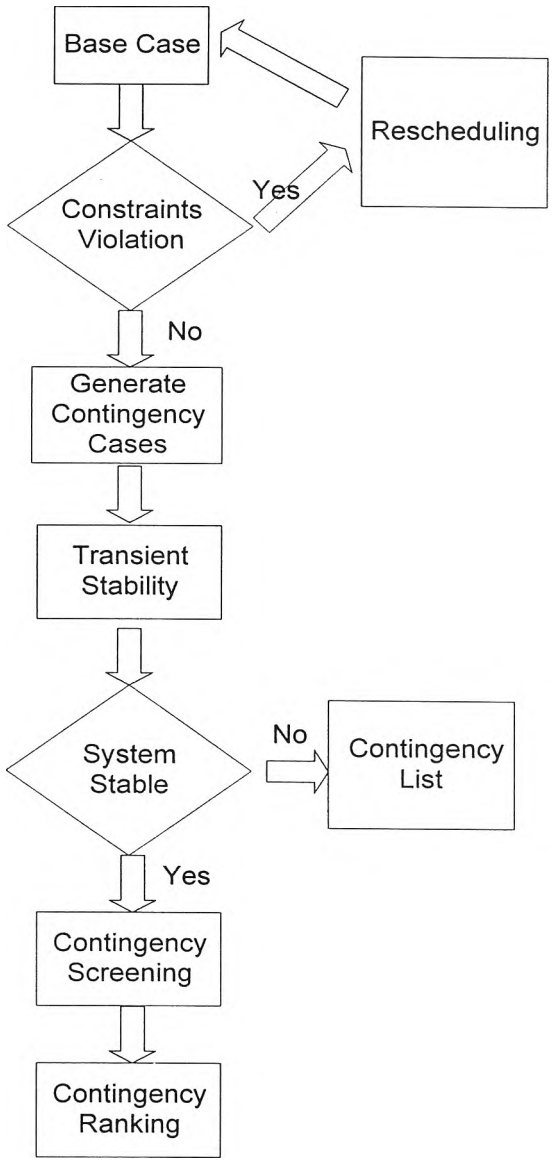

Figure 6-1. Flowchart of contingency analysis procedures

6.2.2 During fault conditions

Ability to remain stable operation is the main purpose of investigation process during this stage of study. When a major facility is assumed to have an outage as presented by three-phase fault at that location, power system is necessary to be evaluated with transient stability.

6.2.3 Post fault conditions

During the postfault period, similar to prefault and during fault conditions, power system must remain in secure operating conditions. Therefore, following reliability criteria must be satisfied so as to maintain reliability operating of the system.

e) Voltage magnitude at load buses are lying within ± 5 % of the nominal voltage

f) Voltage magnitude at voltage controlled buses are maintained within ± 5 % of the nominal voltage (voltage level are lying within emergency limits but it is acceptable if voltage controlled buses can not maintain voltage level at the specified values)

g) Amount of total power flow (MVA flow) in transmission lines do not exceed
emergency thermal ratings

h) Power system are secure to voltage collapse

6.3 Simulation Results

Since there are many steps in contingency analysis procedures, this section will present calculation results corresponding to each step of calculation processes as follows:

6.3.1 Generation of contingency cases

According to the requirements from ATC framework, the minimal contingency cases are generated by loss of single facility. In this report, the situations of a single contingency, the situations when a generator or transmission line is unavailable, caused by three-phase fault in the system are selected as the representatives of contingency cases. Information of generated contingency cases are given in table 6-1 and 6-2.

Table 6-1 Contingency cases created by loss of generation facility

No	Bus	Description (loss of)
1	1001	North Bangkok Unit 1
2	1002	North Bangkok Unit 2
3	1003	North Bangkok Unit 3
4	1011	South Bangkok Thermal Unit 1
5	1012	South Bangkok Thermal Unit 2
6	1013	South Bangkok Thermal Unit 3
7	1014	South Bangkok Thermal Unit 4
8	1015	South Bangkok Thermal Unit 5
9	1023	South Bangkok Combined Cycle Unit 1
10	1033	South Bangkok Combined Cycle Unit 2
11	2001	Chulabhorn Hydro Unit 1
12	2003	Sirindhorn Hydro Unit 1
13	2004	Sirindhorn Hydro Unit 2
14	2006	Ubolrattana Hydro Unit 1
15	2009	Nam Pung Hydro Unit 1
16	2023	Nam Phong Combined Cycle Unit 1
17	2026	Nam Phong Combined Cycle Unit 2
18	2051	Pak Num Hydro Unit 1
19	2052	Pak Num Hydro Unit 2
20	2053	Pak Num Hydro Unit 3
21	2054	Pak Num Hydro Unit 4
22	3001	Bang Lang Hydro Unit 1
23	3002	Bang Lang Hydro Unit 2
24	3003	Bang Lang Hydro Unit 3
25	3011	Khanom Thermal Unit 1 (EGCO)
26	3012	Khanom Thermal Unit 2 (EGCO)
27	3015	Khanom Combined Cycle Unit 1 (EGCO)
28	3061	Surat Thani Thermal Unit 1
29	4001	Bhumibol Hydro Unit 1
30	4002	Bhumibol Hydro Unit 2
31	4011	Sirikit Hydro Unit 1
32	4012	Sirikit Hydro Unit 2
33	4031	Lan Krabu Gas Turbine Unit 1
34	4032	Lan Krabu Gas Turbine Unit 2
35	4033	Lan Krabu Gas Turbine Unit 3
36	4035	Lan Krabu Gas Turbine Unit 5
37	4036	Lan Krabu Gas Turbine Unit 6
38	4037	Lan Krabu Gas Turbine Unit 7
39	4038	Lan Krabu Gas Turbine Unit 8
40	4041	Mae Moh Thermal Unit 1
41	4044	Mae Moh Thermal Unit 4
42	4045	Mae Moh Thermal Unit 5

Table 6-1 Contingency cases created by loss of generation facility (cont)

No	Bus	Description (loss of)
43	4047	Mae Moh Thermal Unit 7
44	4048	Mae Moh Thermal Unit 8
45	4049	Mae Moh Thermal Unit 9
46	4050	Mae Moh Thermal Unit 10
47	4052	Mae Moh Thermal Unit 12
48	4053	Mae Moh Thermal Unit 13
49	5001	Wang Noi Combined Cycle Unit 1
50	5002	Wang Noi Combined Cycle Unit 2
51	5005	Wang Noi Combined Cycle Unit 3
52	5051	Gulf Cogeneration Unit 1 (SPP)
53	5052	Rojana Power Unit 1 (SPP)
54	6001	Bang Pakong Thermal Unit 1
55	6002	Bang Pakong Thermal Unit 2
56	6003	Bang Pakong Thermal Unit 3
57	6004	Bang Pakong Thermal Unit 4
58	6011	Bang Pakong Combined Cycle Unit 1
59	6012	Bang Pakong Combined Cycle Unit 2
60	6013	Bang Pakong Combined Cycle Unit 3
61	6014	Bang Pakong Combined Cycle Unit 4
62	6028	Kiridharn Hydro Unit 1
63	6031	The Cogeneration Gas Unit 1 (SPP)
64	6032	The Cogeneration Gas Unit 2 (SPP)
65	6033	The Cogeneration Coal Unit 1 (SPP)
66	6034	The Cogeneration Coal Unit 2 (SPP)
67	6041	Rayong Combined Cycle Unit 1 (EGCO)
68	6043	Rayong Combined Cycle Unit 2 (EGCO)
69	6044	Rayong Combined Cycle Unit 3 (EGCO)
70	6048	Thai Power Supply (SPP)
71	6051	Rayong Combined Cycle Unit 4 (EGCO)
72	6064	National Petrochemicals (SPP)
73	6065	Tuntex Petrochemicals (SPP)
74	6066	Industrial Power Unit 1 (SPP)
75	6067	Industrial Power Unit 2 (SPP)
76	6068	Thai Oil Power (SPP)
77	6069	Bangkok Cogeneration Company (SPP)
78	6075	Amata-EGCO Power (SPP)
79	6078	Sahacogen (SPP)
80	6081	National Power Supply Unit 1 (SPP)
81	6082	National Power Supply Unit 2 (SPP)
82	6090	MTP Cogeneration Unit 1 (SPP)
83	6091	MTP Cogeneration Unit 2 (SPP)
84	7001	Srinagarind Hydro Unit 1

Table 6-1 Contingency cases created by loss of generation facility (cont)

No	Bus	Description (loss of)
85	7002	Srinagarind Hydro Unit 2
86	7003	Srinagarind Hydro Unit 3
87	7006	Tha Thung Na Hydro Unit 1
88	7007	Tha Thung Na Hydro Unit 2
89	7011	Khao Laem Hydro Unit 1
90	7012	Khao Laem Hydro Unit 2
91	7013	Khao Laem Hydro Unit 3
92	7031	Kaeng Krachan Hydro Unit 1
93	7099	Bang Saphan (IPP)

Table 6-2 Contingency cases created by loss of transmission facility

No	From	To	Description of outage
1	1709	1792	Transmission line between bus 1709 and 1792 circuit 1
2	1202	1801	Transmission line between bus 1202 and 1801 circuit 1
3	1203	1801	Transmission line between bus 1203 and 1801 circuit 1
4	1203	1802	Transmission line between bus 1203 and 1802 circuit 1
5	1204	1803	Transmission line between bus 1204 and 1803 circuit 1
6	1204	1803	Transmission line between bus 1204 and 1803 circuit 2
7	1802	1803	Transmission line between bus 1802 and 1803 circuit 1
8	1204	1804	Transmission line between bus 1202 and 1801 circuit 1
9	1805	1806	Transmission line between bus 1805 and 1806 circuit 1
10	1805	1806	Transmission line between bus 1805 and 1806 circuit 2
11	1805	1806	Transmission line between bus 1805 and 1806 circuit 3
12	1806	1807	Transmission line between bus 1806 and 1807 circuit 1
13	1806	1807	Transmission line between bus 1806 and 1807 circuit 2
14	1807	1808	Transmission line between bus 1807 and 1808 circuit 1
15	1803	1811	Transmission line between bus 1803 and 1811 circuit 1
16	1803	1811	Transmission line between bus 1803 and 1811 circuit 2
17	1804	1811	Transmission line between bus 1804 and 1811 circuit 1
18	1810	1811	Transmission line between bus 1810 and 1811 circuit 1
19	1804	1813	Transmission line between bus 1804 and 1813 circuit 1
20	1804	1813	Transmission line between bus 1804 and 1813 circuit 2
21	1805	1813	Transmission line between bus 1805 and 1813 circuit 1
22	1204	1815	Transmission line between bus 1204 and 1815 circuit 1
23	1803	1830	Transmission line between bus 1803 and 1830 circuit 1
24	1803	1830	Transmission line between bus 1803 and 1830 circuit 2
25	1802	1834	Transmission line between bus 1802 and 1834 circuit 1
26	1803	1834	Transmission line between bus 1803 and 1834 circuit 1
27	1202	1835	Transmission line between bus 1202 and 1835 circuit 1
28	1802	1835	Transmission line between bus 1802 and 1835 circuit 1
29	1809	1835	Transmission line between bus 1802 and 1835 circuit 1

Table 6-2 Contingency cases created by loss of transmission facility (cont)

No	From	To	Description of outage
30	2714	2228	Transmission line between bus 2714 and 2228 circuit 1
31	2715	2230	Transmission line between bus 2715 and 2230 circuit 1
32	2717	2233	Transmission line between bus 2717 and 2233 circuit 1
33	2725	2243	Transmission line between bus 2725 and 2243 circuit 1
34	2747	2253	Transmission line between bus 2747 and 2253 circuit 1
35	2747	2253	Transmission line between bus 2747 and 2253 circuit 1
36	2735	2270	Transmission line between bus 2735 and 2270 circuit 1
37	2738	2275	Transmission line between bus 2738 and 2275 circuit 1
38	2738	2275	Transmission line between bus 2738 and 2275 circuit 2
39	2740	2280	Transmission line between bus 2740 and 2280 circuit 1
40	2740	2280	Transmission line between bus 2740 and 2280 circuit 2
41	2701	2702	Transmission line between bus 2701 and 2702 circuit 1
42	2702	2703	Transmission line between bus 2702 and 2703 circuit 1
43	2703	2704	Transmission line between bus 2703 and 2704 circuit 1
44	2703	2704	Transmission line between bus 2703 and 2704 circuit 2
45	2703	2705	Transmission line between bus 2703 and 2705 circuit 1
46	2703	2705	Transmission line between bus 2703 and 2705 circuit 2
47	2704	2705	Transmission line between bus 2704 and 2705 circuit 1
48	2705	2706	Transmission line between bus 2705 and 2706 circuit 1
49	2705	2707	Transmission line between bus 2705 and 2707 circuit 1
50	2704	2708	Transmission line between bus 2704 and 2708 circuit 2
51	2704	2709	Transmission line between bus 2704 and 2709 circuit 1
52	2709	2710	Transmission line between bus 2709 and 2710 circuit 2
53	2703	2711	Transmission line between bus 2703 and 2711 circuit 1
54	2708	2712	Transmission line between bus 2708 and 2712 circuit 1
55	2709	2712	Transmission line between bus 2709 and 2712 circuit 1
56	2711	2712	Transmission line between bus 2711 and 2712 circuit 1
57	2712	2713	Transmission line between bus 2712 and 2713 circuit 1
58	2712	2713	Transmission line between bus 2712 and 2713 circuit 2
59	2713	2714	Transmission line between bus 2713 and 2714 circuit 1
60	2713	2714	Transmission line between bus 2713 and 2714 circuit 2
61	2714	2716	Transmission line between bus 2714 and 2716 circuit 1
62	2714	2716	Transmission line between bus 2714 and 2716 circuit 2
63	2715	2716	Transmission line between bus 2715 and 2716 circuit 1
64	2716	2717	Transmission line between bus 2716 and 2717 circuit 2
65	2712	2718	Transmission line between bus 2712 and 2718 circuit 1
66	2714	2718	Transmission line between bus 2714 and 2718 circuit 1
67	2716	2718	Transmission line between bus 2716 and 2718 circuit 1
68	2716	2719	Transmission line between bus 2716 and 2719 circuit 1
69	2716	2719	Transmission line between bus 2716 and 2719 circuit 1
70	2716	2720	Transmission line between bus 2716 and 2720 circuit 1
71	2719	2720	Transmission line between bus 2719 and 2720 circuit 1

Table 6-2 Contingency cases created by loss of transmission facility (cont)

No	From	To	Description of outage
72	2719	2721	Transmission line between bus 2719 and 2721 circuit 1
73	2720	2722	Transmission line between bus 2720 and 2722 circuit 1
74	2720	2722	Transmission line between bus 2720 and 2722 circuit 2
75	2721	2722	Transmission line between bus 2721 and 2722 circuit 1
76	2721	2722	Transmission line between bus 2721 and 2722 circuit 2
77	2721	2723	Transmission line between bus 2721 and 2723 circuit 1
78	2721	2723	Transmission line between bus 2721 and 2723 circuit 1
79	2722	2724	Transmission line between bus 2722 and 2724 circuit 1
80	2722	2724	Transmission line between bus 2722 and 2724 circuit 2
81	2719	2725	Transmission line between bus 2719 and 2725 circuit 1
82	2719	2725	Transmission line between bus 2719 and 2725 circuit 2
83	2725	2726	Transmission line between bus 2725 and 2726 circuit 1
84	2712	2728	Transmission line between bus 2712 and 2728 circuit 1
85	2727	2728	Transmission line between bus 2727 and 2728 circuit 1
86	2712	2729	Transmission line between bus 2712 and 2729 circuit 2
87	2712	2730	Transmission line between bus 2712 and 2730 circuit 1
88	2712	2730	Transmission line between bus 2712 and 2730 circuit 2
89	2729	2730	Transmission line between bus 2729 and 2730 circuit 1
90	2730	2731	Transmission line between bus 2730 and 2731 circuit 1
91	2730	2731	Transmission line between bus 2730 and 2731 circuit 2
92	2730	2732	Transmission line between bus 2730 and 2732 circuit 1
93	2730	2732	Transmission line between bus 2730 and 2732 circuit 2
94	2730	2733	Transmission line between bus 2730 and 2733 circuit 1
95	2730	2733	Transmission line between bus 2730 and 2733 circuit 2
96	2732	2733	Transmission line between bus 2732 and 2733 circuit 1
97	2732	2734	Transmission line between bus 2732 and 2734 circuit 1
98	2734	2735	Transmission line between bus 2734 and 2735 circuit 2
99	2732	2736	Transmission line between bus 2732 and 2736 circuit 1
100	2733	2737	Transmission line between bus 2733 and 2737 circuit 2
101	2737	2738	Transmission line between bus 2737 and 2738 circuit 1
102	2737	2738	Transmission line between bus 2737 and 2738 circuit 1
103	2733	2739	Transmission line between bus 2733 and 2739 circuit 1
104	2737	2739	Transmission line between bus 2737 and 2739 circuit 1
105	2737	2739	Transmission line between bus 2737 and 2739 circuit 2
106	2739	2740	Transmission line between bus 2739 and 2740 circuit 1
107	2739	2740	Transmission line between bus 2739 and 2740 circuit 2
108	2714	2741	Transmission line between bus 2714 and 2741 circuit 1
109	2739	2741	Transmission line between bus 2739 and 2741 circuit 1
110	2739	2741	Transmission line between bus 2739 and 2741 circuit 2
111	2739	2741	Transmission line between bus 2739 and 2741 circuit 3
112	2739	2741	Transmission line between bus 2739 and 2741 circuit 4
113	2741	2742	Transmission line between bus 2741 and 2742 circuit 1

Table 6-2 Contingency cases created by loss of transmission facility (cont)

No	From	To	Description of outage
114	2741	2742	Transmission line between bus 2741 and 2742 circuit 2
115	2714	2743	Transmission line between bus 2714 and 2743 circuit 1
116	2742	2743	Transmission line between bus 2742 and 2743 circuit 1
117	2742	2743	Transmission line between bus 2742 and 2743 circuit 2
118	2701	2745	Transmission line between bus 2701 and 2745 circuit 1
119	2703	2745	Transmission line between bus 2703 and 2745 circuit 1
120	2741	2747	Transmission line between bus 2741 and 2747 circuit 1
121	2741	2747	Transmission line between bus 2741 and 2747 circuit 2
122	2741	2751	Transmission line between bus 2741 and 2751 circuit 2
123	2741	2751	Transmission line between bus 2741 and 2751 circuit 2
124	2744	2751	Transmission line between bus 2744 and 2751 circuit 2
125	2741	2751	Transmission line between bus 2741 and 2751 circuit 1
126	2741	2751	Transmission line between bus 2741 and 2751 circuit 1
127	2744	2751	Transmission line between bus 2744 and 2751 circuit 1
128	2801	2802	Transmission line between bus 2801 and 2802 circuit 1
129	2801	2802	Transmission line between bus 2801 and 2802 circuit 2
130	2801	2802	Transmission line between bus 2801 and 2802 circuit 3
131	2801	2802	Transmission line between bus 2801 and 2802 circuit 4
132	2802	2803	Transmission line between bus 2802 and 2803 circuit 1
133	2802	2803	Transmission line between bus 2802 and 2803 circuit 2
134	2802	2803	Transmission line between bus 2802 and 2803 circuit 3
135	2802	2803	Transmission line between bus 2802 and 2803 circuit 4
136	2803	2804	Transmission line between bus 2803 and 2804 circuit 2
137	2803	2804	Transmission line between bus 2803 and 2804 circuit 1
138	2803	2804	Transmission line between bus 2803 and 2804 circuit 2
139	2803	2804	Transmission line between bus 2803 and 2804 circuit 3
140	2803	2805	Transmission line between bus 2803 and 2805 circuit 1
141	2803	2805	Transmission line between bus 2803 and 2805 circuit 2
142	2803	2805	Transmission line between bus 2803 and 2805 circuit 3
143	2803	2805	Transmission line between bus 2803 and 2805 circuit 4
144	2803	2806	Transmission line between bus 2803 and 2806 circuit 1
145	2803	2806	Transmission line between bus 2803 and 2806 circuit 2
146	2803	2806	Transmission line between bus 2803 and 2806 circuit 3
147	2803	2806	Transmission line between bus 2803 and 2806 circuit 4
148	2723	2888	Transmission line between bus 2723 and 2888 circuit 1
149	3203	3204	Transmission line between bus 3203 and 3204 circuit 1
150	3201	3701	Transmission line between bus 3201 and 3701 circuit 1
151	3202	3701	Transmission line between bus 3202 and 3701 circuit 1
152	3201	3702	Transmission line between bus 3201 and 3702 circuit 1
153	3201	3703	Transmission line between bus 3201 and 3703 circuit 1
154	3202	3703	Transmission line between bus 3202 and 3703 circuit 1
155	3703	3704	Transmission line between bus 3703 and 3704 circuit 1

Table 6-2 Contingency cases created by loss of transmission facility (cont)

No	From	To	Description of outage
156	3703	3707	Transmission line between bus 3703 and 3707 circuit 1
157	3706	3707	Transmission line between bus 3706 and 3707 circuit 1
158	3705	3708	Transmission line between bus 3705 and 3708 circuit 1
159	3705	3708	Transmission line between bus 3705 and 3708 circuit 2
160	3705	3708	Transmission line between bus 3705 and 3708 circuit 3
161	3705	3708	Transmission line between bus 3705 and 3708 circuit 4
162	3707	3708	Transmission line between bus 3707 and 3708 circuit 1
163	3708	3709	Transmission line between bus 3708 and 3709 circuit 1
164	3708	3709	Transmission line between bus 3708 and 3709 circuit 1
165	3709	3710	Transmission line between bus 3709 and 3710 circuit 1
166	3708	3711	Transmission line between bus 3708 and 3711 circuit 1
167	3711	3712	Transmission line between bus 3711 and 3712 circuit 1
168	3712	3713	Transmission line between bus 3712 and 3713 circuit 1
169	3713	3714	Transmission line between bus 3713 and 3714 circuit 1
170	3713	3714	Transmission line between bus 3713 and 3714 circuit 2
171	3703	3715	Transmission line between bus 3703 and 3715 circuit 1
172	3203	3717	Transmission line between bus 3203 and 3717 circuit 1
173	3712	3717	Transmission line between bus 3712 and 3717 circuit 1
174	3717	3719	Transmission line between bus 3717 and 3719 circuit 1
175	3719	3720	Transmission line between bus 3719 and 3720 circuit 1
176	3719	3720	Transmission line between bus 3719 and 3720 circuit 2
177	3720	3721	Transmission line between bus 3720 and 3721 circuit 1
178	3720	3721	Transmission line between bus 3720 and 3721 circuit 2
179	3719	3722	Transmission line between bus 3719 and 3722 circuit 1
180	3723	3724	Transmission line between bus 3723 and 3724 circuit 1
181	3720	3725	Transmission line between bus 3720 and 3725 circuit 1
182	3720	3725	Transmission line between bus 3720 and 3725 circuit 2
183	3723	3725	Transmission line between bus 3723 and 3725 circuit 1
184	3723	3726	Transmission line between bus 3723 and 3726 circuit 1
185	3723	3726	Transmission line between bus 3723 and 3726 circuit 2
186	3720	3728	Transmission line between bus 3720 and 3728 circuit 1
187	3724	3734	Transmission line between bus 3724 and 3734 circuit 1
188	3714	3736	Transmission line between bus 3714 and 3736 circuit 1
189	3714	3736	Transmission line between bus 3714 and 3736 circuit 2
190	3203	3746	Transmission line between bus 3203 and 3746 circuit 1
191	3801	3802	Transmission line between bus 3801 and 3802 circuit 1
192	3801	3802	Transmission line between bus 3801 and 3802 circuit 2
193	3802	3803	Transmission line between bus 3802 and 3803 circuit 1
194	3802	3803	Transmission line between bus 3802 and 3803 circuit 2
195	3803	3804	Transmission line between bus 3803 and 3804 circuit 1
196	3803	3804	Transmission line between bus 3803 and 3804 circuit 2
197	3804	3805	Transmission line between bus 3804 and 3805 circuit 1

Table 6-2 Contingency cases created by loss of transmission facility (cont)

No	From	To	Description of outage
198	3804	3805	Transmission line between bus 3804 and 3805 circuit 2
199	3805	3806	Transmission line between bus 3804 and 3806 circuit 1
200	3805	3806	Transmission line between bus 3804 and 3806 circuit 2
201	3806	3846	Transmission line between bus 3806 and 3846 circuit 1
202	3806	3846	Transmission line between bus 3806 and 3846 circuit 2
203	4441	4440	Transmission line between bus 4441 and 4440 circuit 1
204	4804	4440	Transmission line between bus 4804 and 4440 circuit 1
205	4441	4442	Transmission line between bus 4441 and 4442 circuit 1
206	4804	4442	Transmission line between bus 4804 and 4442 circuit 1
207	4442	4443	Transmission line between bus 4442 and 4443 circuit 1
208	4441	4444	Transmission line between bus 4441 and 4444 circuit 1
209	4804	4444	Transmission line between bus 4804 and 4444 circuit 1
210	4444	4445	Transmission line between bus 4444 and 4445 circuit 1
211	4441	4446	Transmission line between bus 4441 and 4446 circuit 1
212	4441	4447	Transmission line between bus 4441 and 4447 circuit 1
213	4441	4448	Transmission line between bus 4441 and 4448 circuit 1
214	4441	4449	Transmission line between bus 4441 and 4449 circuit 1
215	4441	4450	Transmission line between bus 4441 and 4450 circuit 1
216	4441	4451	Transmission line between bus 4441 and 4451 circuit 1
217	4701	4702	Transmission line between bus 4701 and 4702 circuit 1
218	4702	4703	Transmission line between bus 4702 and 4703 circuit 1
219	4702	4704	Transmission line between bus 4702 and 4704 circuit 1
220	4702	4705	Transmission line between bus 4702 and 4705 circuit 1
221	4705	4706	Transmission line between bus 4705 and 4706 circuit 1
222	4706	4707	Transmission line between bus 4706 and 4707 circuit 1
223	4707	4708	Transmission line between bus 4707 and 4708 circuit 1
224	4708	4709	Transmission line between bus 4708 and 4709 circuit 1
225	4709	4710	Transmission line between bus 4709 and 4710 circuit 1
226	4711	4712	Transmission line between bus 4711 and 4712 circuit 1
227	4711	4712	Transmission line between bus 4711 and 4712 circuit 2
228	4712	4713	Transmission line between bus 4712 and 4713 circuit 1
229	4712	4713	Transmission line between bus 4712 and 4713 circuit 2
230	4713	4714	Transmission line between bus 4713 and 4414 circuit 1
231	4715	4716	Transmission line between bus 4715 and 4416 circuit 1
232	4715	4716	Transmission line between bus 4715 and 4716 circuit 2
233	4715	4717	Transmission line between bus 4715 and 4717 circuit 1
234	4715	4717	Transmission line between bus 4715 and 4717 circuit 2
235	4717	4718	Transmission line between bus 4717 and 4718 circuit 1
236	4716	4719	Transmission line between bus 4716 and 4719 circuit 1
237	4716	4720	Transmission line between bus 4716 and 4720 circuit 1
238	4719	4720	Transmission line between bus 4719 and 4720 circuit 1
239	4720	4721	Transmission line between bus 4720 and 4721 circuit 1

Table 6-2 Contingency cases created by loss of transmission facility (cont)

No	From	To	Description of outage
240	4720	4723	Transmission line between bus 4720 and 4723 circuit 1
241	4720	4723	Transmission line between bus 4720 and 4723 circuit 2
242	4722	4724	Transmission line between bus 4722 and 4724 circuit 1
243	4715	4725	Transmission line between bus 4715 and 4725 circuit 1
244	4715	4725	Transmission line between bus 4715 and 4725 circuit 2
245	4720	4727	Transmission line between bus 4720 and 4727 circuit 2
246	4706	4730	Transmission line between bus 4706 and 4430 circuit 1
247	4707	4730	Transmission line between bus 4707 and 4430 circuit 1
248	4701	4731	Transmission line between bus 4701 and 4731 circuit 1
249	4716	4732	Transmission line between bus 4716 and 4732 circuit 1
250	4727	4733	Transmission line between bus 4727 and 4733 circuit 1
251	4732	4733	Transmission line between bus 4732 and 4733 circuit 1
252	4722	4734	Transmission line between bus 4722 and 4734 circuit 1
253	4722	4734	Transmission line between bus 4723 and 4734 circuit 2
254	4723	4734	Transmission line between bus 4723 and 4734 circuit 1
255	4723	4734	Transmission line between bus 4723 and 4734 circuit 2
256	4705	4742	Transmission line between bus 4705 and 4742 circuit 1
257	4712	4742	Transmission line between bus 4712 and 4742 circuit 1
258	4741	4743	Transmission line between bus 4741 and 4743 circuit 1
259	4741	4744	Transmission line between bus 4741 and 4744 circuit 1
260	4744	4751	Transmission line between bus 4744 and 4751 circuit 1
261	4751	4752	Transmission line between bus 4751 and 4752 circuit 1
262	4718	4754	Transmission line between bus 4718 and 4454 circuit 1
263	4718	4755	Transmission line between bus 4718 and 4455 circuit 1
264	4752	4756	Transmission line between bus 4752 and 4756 circuit 1
265	4752	4757	Transmission line between bus 4752 and 4757 circuit 1
266	4731	4777	Transmission line between bus 4731 and 4777 circuit 1
267	4732	4777	Transmission line between bus 4732 and 4777 circuit 1
268	4751	4788	Transmission line between bus 4751 and 4788 circuit 1
269	4752	4788	Transmission line between bus 4752 and 4788 circuit 1
270	4713	4790	Transmission line between bus 4713 and 4790 circuit 1
271	4715	4790	Transmission line between bus 4715 and 4790 circuit 1
272	4713	4791	Transmission line between bus 4713 and 4791 circuit 1
273	4715	4791	Transmission line between bus 4715 and 4791 circuit 1
274	4718	4799	Transmission line between bus 4718 and 4799 circuit 1
275	4718	4799	Transmission line between bus 4718 and 4799 circuit 2
276	4801	4802	Transmission line between bus 4801 and 4802 circuit 1
277	4801	4803	Transmission line between bus 4801 and 4803 circuit 1
278	4801	4803	Transmission line between bus 4801 and 4803 circuit 1
279	4802	4803	Transmission line between bus 4802 and 4803 circuit 1
280	2802	4804	Transmission line between bus 2802 and 4804 circuit 1
281	2802	4804	Transmission line between bus 2802 and 4804 circuit 2

Table 6-2 Contingency cases created by loss of transmission facility (cont)

No	From	To	Description of outage
282	2802	4804	Transmission line between bus 2802 and 4804 circuit 3
283	2802	4804	Transmission line between bus 2802 and 4804 circuit 4
284	4803	4804	Transmission line between bus 4803 and 4804 circuit 1
285	4803	4804	Transmission line between bus 4803 and 4804 circuit 2
286	4803	4806	Transmission line between bus 4803 and 4806 circuit 1
287	4803	4806	Transmission line between bus 4803 and 4806 circuit 2
288	4805	4806	Transmission line between bus 4805 and 4806 circuit 1
289	4805	4806	Transmission line between bus 4805 and 4806 circuit 2
290	2803	4807	Transmission line between bus 2803 and 4807 circuit 1
291	2803	4807	Transmission line between bus 2803 and 4807 circuit 2
292	2803	4807	Transmission line between bus 2803 and 4807 circuit 3
293	2803	4807	Transmission line between bus 2803 and 4807 circuit 4
294	4806	4807	Transmission line between bus 4806 and 4807 circuit 1
295	4806	4807	Transmission line between bus 4806 and 4807 circuit 2
296	4806	4808	Transmission line between bus 4806 and 4808 circuit 1
297	4806	4808	Transmission line between bus 4806 and 4808 circuit 2
298	4808	4812	Transmission line between bus 4808 and 4812 circuit 1
299	4808	4812	Transmission line between bus 4808 and 4812 circuit 2
300	5708	5051	Transmission line between bus 5708 and 5051 circuit 1
301	1810	5201	Transmission line between bus 1810 and 5201 circuit 1
302	5701	5703	Transmission line between bus 5701 and 5703 circuit 1
303	5701	5703	Transmission line between bus 5701 and 5703 circuit 2
304	5701	5703	Transmission line between bus 5701 and 5703 circuit 3
305	5702	5703	Transmission line between bus 5702 and 5703 circuit 1
306	5703	5704	Transmission line between bus 5703 and 5704 circuit 1
307	5703	5705	Transmission line between bus 5703 and 5705 circuit 1
308	5703	5705	Transmission line between bus 5703 and 5705 circuit 2
309	5703	5706	Transmission line between bus 5703 and 5706 circuit 1
310	5703	5707	Transmission line between bus 5703 and 5707 circuit 1
311	2701	5708	Transmission line between bus 2701 and 5708 circuit 1
312	2701	5708	Transmission line between bus 2701 and 5708 circuit 2
313	5705	5708	Transmission line between bus 5705 and 5708 circuit 1
314	5705	5708	Transmission line between bus 5705 and 5708 circuit 2
315	5708	5709	Transmission line between bus 5708 and 5709 circuit 1
316	5703	5710	Transmission line between bus 5703 and 5710 circuit 1
317	5705	5710	Transmission line between bus 5705 and 5710 circuit 1
318	5705	5710	Transmission line between bus 5705 and 5710 circuit 2
319	5710	5711	Transmission line between bus 5710 and 5711 circuit 1
320	5703	5712	Transmission line between bus 5703 and 5712 circuit 1
321	5712	5713	Transmission line between bus 5712 and 5713 circuit 1
322	5712	5713	Transmission line between bus 5712 and 5713 circuit 2
323	5713	5714	Transmission line between bus 5713 and 5714 circuit 1

Table 6-2 Contingency cases created by loss of transmission facility (cont)

No	From	To	Description of outage
324	5712	5715	Transmission line between bus 5712 and 5715 circuit 1
325	5712	5716	Transmission line between bus 5712 and 5716 circuit 1
326	5712	5717	Transmission line between bus 5712 and 5717 circuit 1
327	5712	5717	Transmission line between bus 5712 and 5717 circuit 2
328	5717	5718	Transmission line between bus 5717 and 5718 circuit 1
329	5717	5718	Transmission line between bus 5717 and 5718 circuit 2
330	5718	5719	Transmission line between bus 5718 and 5719 circuit 1
331	5718	5719	Transmission line between bus 5718 and 5719 circuit 2
332	4751	5720	Transmission line between bus 4751 and 5720 circuit 1
333	5701	5720	Transmission line between bus 5701 and 5720 circuit 1
334	5720	5721	Transmission line between bus 5720 and 5721 circuit 1
335	1709	5722	Transmission line between bus 1709 and 5722 circuit 1
336	4804	5801	Transmission line between bus 4804 and 5801 circuit 1
337	4804	5801	Transmission line between bus 4804 and 5801 circuit 2
338	1808	5802	Transmission line between bus 1808 and 5802 circuit 1
339	1808	5802	Transmission line between bus 1808 and 5802 circuit 2
340	4803	5802	Transmission line between bus 4803 and 5802 circuit 1
341	4803	5802	Transmission line between bus 4803 and 5802 circuit 2
342	2801	5803	Transmission line between bus 5718 and 5803 circuit 1
343	2801	5803	Transmission line between bus 4751 and 5803 circuit 2
344	2801	5803	Transmission line between bus 5701 and 5803 circuit 3
345	2801	5803	Transmission line between bus 2801 and 5803 circuit 4
346	5801	5804	Transmission line between bus 5801 and 5804 circuit 1
347	5801	5804	Transmission line between bus 5801 and 5804 circuit 1
348	4804	5805	Transmission line between bus 4804 and 5805 circuit 1
349	4804	5805	Transmission line between bus 4804 and 5805 circuit 2
350	5802	5805	Transmission line between bus 5802 and 5805 circuit 1
351	5802	5805	Transmission line between bus 5802 and 5805 circuit 2
352	5803	5805	Transmission line between bus 5803 and 5805 circuit 1
353	5803	5805	Transmission line between bus 5803 and 5805 circuit 2
354	1809	5806	Transmission line between bus 1809 and 5806 circuit 1
355	1809	5806	Transmission line between bus 1809 and 5806 circuit 2
356	1809	5806	Transmission line between bus 1809 and 5806 circuit 3
357	1809	5806	Transmission line between bus 1809 and 5806 circuit 4
358	5804	5806	Transmission line between bus 5804 and 5806 circuit 1
359	5804	5806	Transmission line between bus 5804 and 5806 circuit 2
360	1908	5906	Transmission line between bus 1908 and 5906 circuit 1
361	1908	5906	Transmission line between bus 1908 and 5906 circuit 2
362	4447	5906	Transmission line between bus 4447 and 5906 circuit 1
363	4450	5906	Transmission line between bus 4450 and 5906 circuit 1
364	5906	6650	Transmission line between bus 5906 and 6650 circuit 1
365	6650	6661	Transmission line between bus 6650 and 6661 circuit 1

Table 6-2 Contingency cases created by loss of transmission facility (cont)

No	From	To	Description of outage
366	1815	6662	Transmission line between bus 1815 and 6662 circuit 1
367	6661	6662	Transmission line between bus 6661 and 6662 circuit 1
368	6662	6663	Transmission line between bus 6662 and 6663 circuit 1
369	1810	6664	Transmission line between bus 1810 and 6664 circuit 1
370	6661	6664	Transmission line between bus 6661 and 6664 circuit 1
371	6664	6665	Transmission line between bus 6664 and 6665 circuit 1
372	4446	6666	Transmission line between bus 4446 and 6666 circuit 1
373	6661	6666	Transmission line between bus 6661 and 6666 circuit 1
374	5906	6667	Transmission line between bus 5906 and 6667 circuit 1
375	6661	6667	Transmission line between bus 6661 and 6667 circuit 1
376	6702	6703	Transmission line between bus 6702 and 6703 circuit 1
377	6702	6705	Transmission line between bus 6702 and 6705 circuit 1
378	6702	6705	Transmission line between bus 6702 and 6705 circuit 2
379	6705	6706	Transmission line between bus 6705 and 6706 circuit 1
380	6705	6706	Transmission line between bus 6705 and 6706 circuit 2
381	6706	6707	Transmission line between bus 6706 and 6707 circuit 1
382	6707	6708	Transmission line between bus 6707 and 6708 circuit 1
383	6707	6709	Transmission line between bus 6707 and 6709 circuit 1
384	6707	6709	Transmission line between bus 6707 and 6709 circuit 2
385	6709	6710	Transmission line between bus 6709 and 6710 circuit 1
386	6709	6710	Transmission line between bus 6709 and 6710 circuit 2
387	6711	6712	Transmission line between bus 6711 and 6712 circuit 1
388	6711	6713	Transmission line between bus 6711 and 6713 circuit 1
389	6713	6714	Transmission line between bus 6713 and 6714 circuit 1
390	6713	6714	Transmission line between bus 6713 and 6714 circuit 1
391	6713	6715	Transmission line between bus 6713 and 6715 circuit 1
392	6713	6715	Transmission line between bus 6713 and 6715 circuit 2
393	6714	6716	Transmission line between bus 6714 and 6716 circuit 1
394	6714	6716	Transmission line between bus 6714 and 6716 circuit 1
395	6715	6716	Transmission line between bus 6715 and 6716 circuit 2
396	6714	6717	Transmission line between bus 6614 and 6617 circuit 1
397	6714	6717	Transmission line between bus 6714 and 6717 circuit 1
398	6716	6717	Transmission line between bus 6716 and 6717 circuit 2
399	6717	6718	Transmission line between bus 6717 and 6618 circuit 1
400	6710	6719	Transmission line between bus 6710 and 6719 circuit 1
401	6711	6719	Transmission line between bus 6711 and 6719 circuit 2
402	6709	6722	Transmission line between bus 6709 and 6722 circuit 1
403	6703	6727	Transmission line between bus 6703 and 6727 circuit 2
404	6704	6727	Transmission line between bus 6604 and 6627 circuit 1
405	6726	6727	Transmission line between bus 6726 and 6727 circuit 1
406	6726	6727	Transmission line between bus 6726 and 6727 circuit 2
407	6717	6731	Transmission line between bus 6717 and 6731 circuit 1

Table 6-2 Contingency cases created by loss of transmission facility (cont)

No	From	To	Description of outage
408	6727	6744	Transmission line between bus 6727 and 6744 circuit 1
409	6727	6744	Transmission line between bus 6727 and 6744 circuit 2
410	6713	6752	Transmission line between bus 6713 and 6752 circuit 1
411	6713	6752	Transmission line between bus 6713 and 6752 circuit 2
412	6714	6770	Transmission line between bus 6714 and 6770 circuit 1
413	6714	6770	Transmission line between bus 6714 and 6770 circuit 2
414	1804	6801	Transmission line between bus 1804 and 6801 circuit 1
415	1804	6801	Transmission line between bus 1804 and 6801 circuit 2
416	6802	6804	Transmission line between bus 6802 and 6804 circuit 1
417	6802	6804	Transmission line between bus 6802 and 6804 circuit 2
418	6802	6806	Transmission line between bus 6802 and 6806 circuit 1
419	6802	6806	Transmission line between bus 6802 and 6806 circuit 2
420	6804	6806	Transmission line between bus 6804 and 6806 circuit 1
421	6804	6806	Transmission line between bus 6804 and 6806 circuit 2
422	6804	6807	Transmission line between bus 6804 and 6807 circuit 1
423	6804	6807	Transmission line between bus 6804 and 6807 circuit 2
424	1809	6808	Transmission line between bus 1809 and 6808 circuit 1
425	1809	6808	Transmission line between bus 1809 and 6808 circuit 2
426	6801	6808	Transmission line between bus 6801 and 6808 circuit 1
427	6801	6808	Transmission line between bus 6801 and 6808 circuit 2
428	6807	6809	Transmission line between bus 6807 and 6809 circuit 1
429	6804	6853	Transmission line between bus 6804 and 6853 circuit 1
430	6804	6853	Transmission line between bus 6804 and 6853 circuit 2
431	1204	6891	Transmission line between bus 1204 and 6891 circuit 1
432	1810	6891	Transmission line between bus 1810 and 6891 circuit 1
433	1811	6891	Transmission line between bus 1811 and 6891 circuit 1
434	1815	6891	Transmission line between bus 1815 and 6891 circuit 1
435	6802	6891	Transmission line between bus 6802 and 6891 circuit 1
436	6802	6891	Transmission line between bus 6802 and 6891 circuit 2
437	6802	6891	Transmission line between bus 6802 and 6891 circuit 3
438	6802	6891	Transmission line between bus 6802 and 6891 circuit 4
439	6812	6891	Transmission line between bus 6812 and 6891 circuit 1
440	6812	6891	Transmission line between bus 6812 and 6891 circuit 2
441	7201	7701	Transmission line between bus 7201 and 7701 circuit 1
442	7202	7701	Transmission line between bus 7202 and 7701 circuit 1
443	7201	7703	Transmission line between bus 7201 and 7703 circuit 1
444	7202	7703	Transmission line between bus 7202 and 7703 circuit 1
445	7702	7703	Transmission line between bus 7702 and 7703 circuit 2
446	7701	7704	Transmission line between bus 7701 and 7704 circuit 1
447	7701	7704	Transmission line between bus 7701 and 7704 circuit 2
448	7701	7705	Transmission line between bus 7701 and 7705 circuit 2
449	7706	7707	Transmission line between bus 7706 and 7707 circuit 1

Table 6-2 Contingency cases created by loss of transmission facility (cont)

No	From	To	Description of outage
450	7706	7708	Transmission line between bus 7706 and 7708 circuit 1
451	7707	7708	Transmission line between bus 7707 and 7708 circuit 1
452	7707	7708	Transmission line between bus 7707 and 7708 circuit 2
453	7708	7709	Transmission line between bus 7708 and 7709 circuit 1
454	7708	7710	Transmission line between bus 7708 and 7710 circuit 1
455	7710	7711	Transmission line between bus 7710 and 7711 circuit 1
456	7711	7712	Transmission line between bus 7711 and 7712 circuit 1
457	7712	7713	Transmission line between bus 7712 and 7713 circuit 1
458	7705	7714	Transmission line between bus 7705 and 7714 circuit 1
459	7707	7714	Transmission line between bus 7707 and 7714 circuit 1
460	7714	7715	Transmission line between bus 7714 and 7715 circuit 1
461	7714	7715	Transmission line between bus 7714 and 7715 circuit 2
462	7715	7716	Transmission line between bus 7715 and 7716 circuit 1
463	7715	7716	Transmission line between bus 7715 and 7716 circuit 1
464	7716	7717	Transmission line between bus 7716 and 7717 circuit 1
465	7717	7718	Transmission line between bus 7707 and 7718 circuit 1
466	3701	7720	Transmission line between bus 3701 and 7720 circuit 1
467	3701	7720	Transmission line between bus 3701 and 7720 circuit 1
468	7719	7720	Transmission line between bus 7719 and 7720 circuit 1
469	7702	7725	Transmission line between bus 7702 and 7725 circuit 1
470	7703	7725	Transmission line between bus 7703 and 7725 circuit 1
471	7702	7726	Transmission line between bus 7702 and 7726 circuit 1
472	7702	7726	Transmission line between bus 7702 and 7726 circuit 2
473	7706	7726	Transmission line between bus 7706 and 7726 circuit 1
474	7706	7726	Transmission line between bus 7706 and 7726 circuit 2
475	7717	7728	Transmission line between bus 7717 and 7728 circuit 1
476	7719	7728	Transmission line between bus 7719 and 7728 circuit 1
477	1808	7801	Transmission line between bus 1808 and 7801 circuit 1
478	1808	7801	Transmission line between bus 1808 and 7801 circuit 2
479	7204	7802	Transmission line between bus 7204 and 7802 circuit 1
480	7801	7802	Transmission line between bus 7801 and 7802 circuit 1
481	7801	7802	Transmission line between bus 7801 and 7802 circuit 2
482	7203	7803	Transmission line between bus 7203 and 7803 circuit 1
483	7205	7803	Transmission line between bus 7205 and 7803 circuit 1
484	7801	7804	Transmission line between bus 7801 and 7804 circuit 1
485	7801	7804	Transmission line between bus 7801 and 7804 circuit 2
486	7801	7804	Transmission line between bus 7801 and 7804 circuit 3
487	7801	7804	Transmission line between bus 7801 and 7804 circuit 4
488	7804	7806	Transmission line between bus 7804 and 7806 circuit 1
489	7804	7806	Transmission line between bus 7804 and 7806 circuit 2
490	7802	7807	Transmission line between bus 7802 and 7807 circuit 1
491	7802	7807	Transmission line between bus 7802 and 7807 circuit 2

Table 6-2 Contingency cases created by loss of transmission facility (cont)

No	From	To	Description of outage
492	7203	7812	Transmission line between bus 7203 and 7812 circuit 1
493	7204	7812	Transmission line between bus 7204 and 7812 circuit 1
494	7205	7812	Transmission line between bus 7205 and 7812 circuit 1
495	7802	7813	Transmission line between bus 7802 and 7813 circuit 1
496	7812	7813	Transmission line between bus 7812 and 7813 circuit 1
497	1806	7816	Transmission line between bus 1806 and 7816 circuit 1
498	1807	7816	Transmission line between bus 1807 and 7816 circuit 1
499	3802	7829	Transmission line between bus 3802 and 7829 circuit 1
500	3802	7829	Transmission line between bus 3802 and 7829 circuit 2
501	7803	7829	Transmission line between bus 7803 and 7829 circuit 1
502	7803	7829	Transmission line between bus 7803 and 7829 circuit 2
503	2810	8000	Transmission line between bus 2810 and 8000 circuit 1
504	2810	8000	Transmission line between bus 2810 and 8000 circuit 2
505	8000	8001	Transmission line between bus 8000 and 8001 circuit 1
506	8000	8001	Transmission line between bus 8000 and 8001 circuit 2
507	2732	8734	Transmission line between bus 2732 and 8734 circuit 1
508	2733	8734	Transmission line between bus 2733 and 8734 circuit 1
509	2736	8734	Transmission line between bus 2736 and 8734 circuit 1
510	2736	8734	Transmission line between bus 2736 and 8734 circuit 2
511	8734	8735	Transmission line between bus 8734 and 8735 circuit 1
512	8734	8735	Transmission line between bus 8734 and 8735 circuit 2
513	8734	8735	Transmission line between bus 8734 and 8735 circuit 3
514	4808	8882	Transmission line between bus 4808 and 8882 circuit 1
515	8881	8882	Transmission line between bus 8881 and 8882 circuit 1
516	8882	8883	Transmission line between bus 8882 and 8883 circuit 1
517	4449	8884	Transmission line between bus 4449 and 8884 circuit 1
518	8881	8884	Transmission line between bus 8881 and 8884 circuit 1
519	4448	8885	Transmission line between bus 4448 and 8885 circuit 1
520	8881	8885	Transmission line between bus 8881 and 8885 circuit 1
521	4451	8886	Transmission line between bus 4451 and 8886 circuit 1
522	8881	8886	Transmission line between bus 8881 and 8886 circuit 1

6.3.2 Constraints violation for base case

There are no constraints violations detected in base case of this study. Voltage level in both load buses and voltage-controlled buses lie within acceptable range as well as amount of power flow in transmission lines. Therefore, it is not necessary to apply redispatching technique to mitigate the problems in the system.

6.3.3 Transient Stability Study

Since many contingency cases are generated for n-1 reliability criteria of Thailand power system (522 cases for transmission lines outage and 93 cases for generator outage), transient stability study are performed and the simulation results of

all cases will be given in appendix B. According to the transient stability results, Thailand power system is strong enough to remain stable in all cases of transient stability within the clearing time of 0.15 second after fault is applied. This is contributed by two factors. Firstly, due to economic crisis in 1997, as seen from amount of peak demand in the systems sharply plunge from 16,000 MW to 13,000 MW, facilities in the system are operated in less stress conditions than the former expectation. This also strengthens the system indirectly. Secondly, since generation facilities in Thailand power system are usually composed of many small generation units attached to the same bus as well as transmission systems are usually connected in loop, the system is relatively strong during transient period of n-1 contingency analysis.

6.3.4 Contingency Screening and Ranking

Based on the results given in the above calculation, contingency analysis result of each case is scored according to their results compared to security criteria as mentioned above. There are 35 cases have significantly different score compare to other cases in the study. Table 6-3 gives the results of these contingency cases and their corresponding score

Table 6-3. Significant contingency cases from contingency analysis program

No	Cont. No.	Score		
		Thermal limit	PQ buses	PV buses
1	48	8.8998	0.0000	5912.1205
2	49	8.8998	0.0000	5912.1205
3	101	8.8997	0.0000	5912.1205
4	102	10.1815	0.0000	5912.1205
5	113	10.1815	0.0000	5912.1205
6	114	9.7450	0.0000	5912.1205
7	115	9.7588	0.0000	5912.1205
8	116	9.8515	0.0000	5912.1205
9	240	9.8515	0.0000	5912.1205
10	276	7.9740	0.0000	5912.1205
11	279	12.3629	0.0000	5913.8360
12	280	12.4755	0.0000	5914.9225
13	303	8.9003	0.0000	5912.1205
14	317	8.8997	0.0000	5912.1205

Table 6-3. Significant contingency cases from contingency analysis program (cont.)

No	Cont. No.	Score		
		Thermal limit	PQ buses	PV buses
15	335	9.7589	0.0000	5912.1205
16	336	9.7589	0.0000	5912.1205
17	343	8.8998	0.0000	5912.1205
18	344	8.8998	0.0000	5912.1205
19	345	8.8998	0.0000	5912.1205
20	349	8.8998	0.0000	5912.1205
21	361	8.8998	0.0000	5912.1205
22	363	10.8271	0.0000	5912.1205
23	364	9.7954	0.0000	5912.1205
24	469	9.7954	0.0000	5912.1205
25	471	9.7954	0.0000	5912.1205
26	598	9.7954	0.0000	5912.1205
27	599	10.9975	0.0000	5912.1205
28	603	11.2840	0.0000	5912.1205
29	611	10.1265	0.0000	5912.1205
30	612	10.1265	0.0000	5912.1205
31	617	10.0747	0.0000	5912.1205
32	618	10.0747	0.0000	5912.1205
33	625	9.9150	0.0000	5912.1205
34	626	9.9150	0.0000	5912.1205

It is seen that it is relatively difficult to determine the most insecure case among the contingency cases given in table 6. Therefore, it is reasonable to take all of these cases into consideration as non-secure operating conditions. However, thermal limits violation is an important factor to be considered in Thailand power system since it is varied among cases. In addition, it is likely to be the existing character of Thailand system to have many voltage-controlled buses (PV bus) operated at the maximum reactive power limit even though voltage magnitude is lying in the satisfactory region all over the system. Therefore, if the security issues are compared, thermal limit violation should take precedence in determining security level in Thailand power system.

6.4 Employing Contingency Study in ATC calculation

Including the entire processes of contingency analysis in ATC calculation procedures seem to be the most comprehensive method providing complete information for ATC calculation. However, unless the system is equipped with the high-speed computer and efficient algorithm, this technique may not appropriate for real-time ATC calculation since contingency study will require additional computation time to precede its processes. Therefore, different from next hour ATC

procedures currently using in power industry, a special consideration must be applied to incorporate contingency analysis in real-time ATC calculation.

Considering from the contingency study procedures and results given in this dissertation, number of studied cases and the topics need to be studied in contingency are two major factors delaying the entire processes. For example, comparing to ATC calculation, contingency study obligates to 44,850 cases for n-1 contingency while ATC calculation covers only less than 300 cases for every platform of transactions. This example clearly illustrates the major dissimilar in size of problem that leads to computation time needed in each study.

Hence, this dissertation proposes four strategies to cope with this technical difficulty for real-time analysis as the following.

6.4.1 Enhance Calculation Capability

This method insists to perform full-range contingency analysis in real-time ATC calculation. Therefore, investment in hardware, computers and real-time information interfaces are necessary to maintain acceptable computation time for real-time ATC calculation. In addition to centralized ATC calculation, distributed ATC calculation using many high-performance computers sharing calculation burden is a good solution for this approach.

6.4.2 Compensate the Contingency Study with TRM:

This alternative will not include contingency analysis in real-time ATC calculation but employs other ATC calculation procedures to compensate with contingency study due to the above difficulty.

By this concept, slightly more transmission capability is reserved than normal TRM in real-time ATC calculation. Since the purpose of TRM is to abide with uncertainties in power system that may include contingency, reserving an amount of transfer capability as TRM should be possible and equivalent to contingency analysis.

Beside, transmission system is normally equipped with protection equipment to rescue the system from abnormal conditions. Fault in power system is the primary thing to be considered in protection system design. Therefore, even though TRM fails to prevent the system from contingency situations, protective equipment will definitely recover the system from the severe situation as a standard corrective control scheme.

6.4.3 Compromises off-line contingency analysis with real-time ATC:

This technique still relies on contingency study but favors the off-line study than combining contingency study in real-time ATC procedures. Due to the fact that contingency study results depend on power system configuration, load and generation conditions, following observation and assumptions can be applied to employ the off-line contingency study results in real-time ATC calculation.

A good example of this application is an attempt to minimize number of cases of contingency analysis by eliminating unnecessary cases. By this approach, contingency study program will be run for the base case to obtain the contingency ranking list. Due to the fact that contingency ranking list contains many cases having "zero" or "close to zero" score that is significantly differ from risky cases, these cases will not brought into consideration if system condition is not substantially changed.

6.4.3.1 Configuration of power system:

Unless new construction or destruction of transmission lines, commissioning or decommissioning of generation units are applied to the system configuration of power system is considered "unchanged". Therefore, the power development plan (PDP) of utilities must be consulted in a regular basis. Contingency study is required to be redone if any change in power system configuration is taken place.

6.4.3.2 Load and generation conditions:

Basically, electric utilities perform load forecasting study in a regular time frame to anticipate the future customer as well as planning the PDP. For that reason, seasonally and annually load in power system is automatically available through this source of information following by the contingency studies in accordance with this information.

This dissertation prefers the second approach to combine contingency study in real-time calculation since the first approach seem to be too risky in evaluating significant standard for highly competitive and nonlinear market such as power system. Consequently, contingency study will be study in off-line approach and its results will be used in real-time ATC study. In order to minimize the error, even though power system configuration is still intact, contingency study is highly recommended to recalculate every season to follow up behavior of the customers.

6.5 Conclusion

Contingency analysis is an important procedure to handle the unexpected abnormal situations in the power system during the operation stage. The technical challenge of contingency analysis is how to develop a smart method to select the unsafe cases from thousands of normal cases.

Many techniques have been developed to solve this technical challenge of contingency analysis by modifying the calculation algorithm or reducing number of cases to be studied. However, this dissertation trusts the AC power flow method and transient stability study as the main tools to diagnose abnormal situations in the systems because of the complete results that are required for security analysis. Furthermore, insecure contingency cases are chosen from normal contingency cases by a new performance index to generate the security of the system.

Contingency analysis results obtained from the calculation procedures show that there are 34 contingency cases are significantly hazard in Thailand power system as seen from the modified performance index given in section 6.4. Due to the complication of the calculation, this dissertation employs off-line contingency study results to the real-time ATC calculation. However, it is recommended to recalculate contingency analysis again for any power system when system configurations or loading conditions in the system changed. These factors may greatly affect contingency analysis results in any power system.