Journal of KIEE., 11(1), 55-61 (2001) **55**

A Contingency Screening Algorithm Using SIME for Transient Stability Assessment of the KEPCO System

J. Lee, B. Lee, S.-H. Kwon, H.-K. Nam, T. Ahn, J.-B. Choo and K. Yi

Abstract - SIME(SIngle Machine Equivalent) method has been recognized as a useful tool to determine transient stability of power systems. In this paper, SIME method is used to develop the KEPCO transient stability assessment (TSA) tool. A new screening algorithm that can be implemented in SIME method is proposed. The salient feature of the proposed screening algorithm is as follows. First, critical generators are identified by a new index in the early stage of the time domain simulation. Thus, computational time required to find OMIB(One Machine Infinite Bus) can be reduced significantly. Second, clustering critical machines can be performed even in very stable cases. It enables to be avoid extra calculation of time trajectory that is needed in SIME for classifying the stable cases. This algorithm is applied to the fast TSA of the KEPCO system in the year of 2010.

Keywords - Contingency Screening, Transient Stability Assessment(TSA), SIngle Machine Equivalent(SIME), Direct Method, KEPCO System

Abbreviations:

TSA	: Transient Stability Assessment
SIME	: SIngle Machine Equivalent
OMIB	: One Machine Infinite Bus
CCT	: Critical Clearing Time
CT	: Clearing Time
AI	: Angle Increment
TSDS	: Time Synchronized Data acquisition System
NEMS	: New Energy Management System

1. Introduction

In recent years, power systems have been operated under more stressed conditions close to stability limits. Under these circumstances, the transient stability assessment (TSA) has become more important for secure operation. The TSA requires evaluating transient stability of numerous contingencies within short periods. Therefore, the screening algorithm that filters out very stable cases in advance has been adopted as a key function in the TSA [1,2].

For contingency screening in the TSA, various methods have been developed [2-6]. Recently, the hybrid method that combines the direct method and time simulation method has been recognized to be useful for contingency screening. Moreover, the hybrid method has an advantage in terms of modeling flexibility. The SIME method is a hybrid method utilizing a time-domain simulation technique in conjunction with equal area criterion [7,8]. In this paper, SIME method is used to develop the KEPCO TSA tool. The KEPCO protection systems are normally operated in the range of 3 to 6 cycles when a fault occurs. Although the time required for backup protection is considered, the maximum fault duration is assumed within 12 cycles. As observed in any practical system, for most contingencies the KEPCO system is usually stable in terms of first swing stability for the duration of the fault. However, since SIME method takes a longer simulation time to determine the result in stable cases, the fast screening algorithm for filtering stable contingencies is needed in developing the KEPCO TSA tool. In this paper, a new approach that can be adopted to SIME for fast screening very stable contingencies is developed and implemented in the KEPCO TSA tool.

For screening stable cases in SIME method, a new generator grouping index is proposed to identify critical generators, even in very stable cases, so that one machine infinite bus (OMIB) can be obtained. Therefore, for very stable cases, it is possible to evaluate the stability by using the trajectory of equivalent OMIB. Adopting this screening algorithm, computational time is significantly reduced.

In this paper, section 2 describes the proposed screening algorithm with a new index. A current KEPCO TSA environment is introduced in Section 3. In Section 4, the proposed algorithm is applied to the KEPCO system in the year of 2010.

Manuscript received: Dec. 27, 2000 Accepted: Jan. 30, 2001.

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2. Screening Algorithm

In this paper, the hierarchical screening algorithm for fast transient stability assessment of power systems is proposed. This screening algorithm consists of two steps. The first step is the main feature of the proposed algorithm and second step is SIME algorithm that was established before. The first step process is shown in Fig. 1.

First, for a given contingency in the reduced order equivalent system, time domain simulation is performed until the observation time. The generators are divided into two groups with a new index and the simulation results are transformed into the trajectory of equivalent OMIB. If the trajectory reaches a stable or unstable point, the simulation is terminated. Otherwise, the simulation will be continued. Most of the stable contingencies are discarded through the first step process.

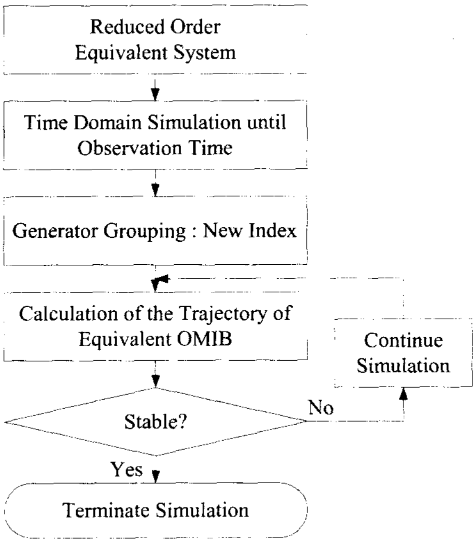


Fig. 1 First step process

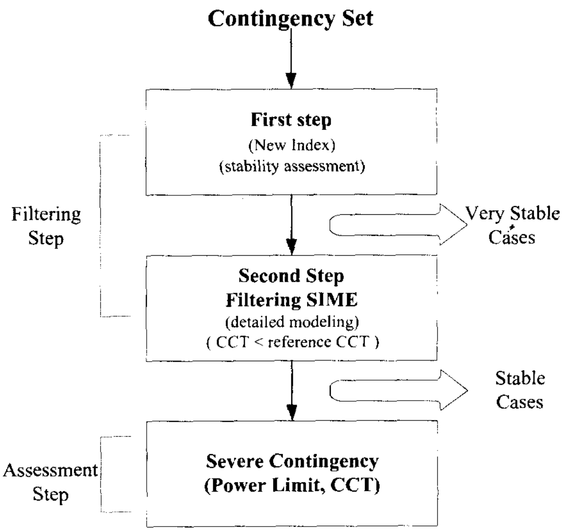


Fig. 2 Whole screening algorithm

In the second step process that consists of the established SIME algorithm, the selected contingency set that estimates unstable cases in the first step is simulated. The stability limit (power limit or CCT (Critical Clearing Time)) assessment through the first and the second step process is shown in Fig. 2. The details will be explained in sequence.

2.1 A New Index for the Generator Grouping

In the above mentioned algorithm, a gap criterion is generally used to separate the critical machines in the first step. The gap criterion defines the relevant cluster of machines to be made up of the machines classified above the maximum angle gap, i.e. the maximum angular difference between successive machines [7,8]. The generator grouping by using the gap criterion is shown in Fig. 3. As shown in Fig 3, the relative angles of the machines are divided conspicuously into critical machines and non-critical machines.

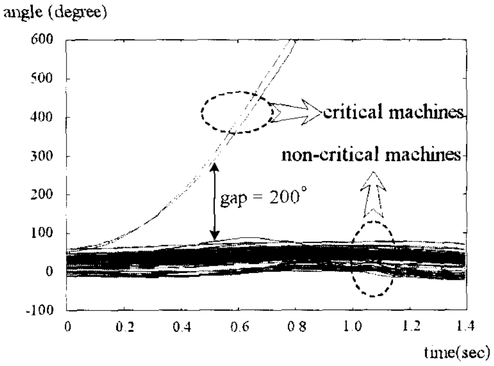


Fig. 3 Generator grouping by using the gap criterion

However, in most of the stable cases, the angle difference between critical and non-critical machines may not be distinct that reults in taking much computational time. In this work, a new generator grouping index (AI) is used .

The angle increment (AI) is the index that represents the increment of the rotor angle of the generator with respect to the mean value for all generators during a period after the fault clearing. The angle increment is defined as follows.

$$AI_i = (\delta_{oi} - \delta_{ci}) - \frac{\sum_{i=1}^{n}(\delta_{oi} - \delta_{ci})}{n} \qquad (1)$$

where δ_{oi} : generator rotor angle at observation time
δ_{ci} : generator rotor angle at fault clearing time
n : Number of generators

In this equation, the first term $(\delta_{oi} - \delta_{ci})$ indicates the angle increment at the generator i and the second term $\sum_{i=1}^{n}(\delta_{oi} - \delta_{ci})/n$ indicates the mean value of the angle increment for all generators.

The generators that are accelerated faster than others have positive angle increments. The generators with positive angle increments are sorted in decreasing order of the angle increment, and the generators above the maximum gap of angle increments are selected as critical machines. The other generators compose another group. The process of these generator grouping is shown in Fig. 4.

The important advantage of this method is that it enables the generator to be grouped more quickly whether the contingency is stable or unstable.

In this grouping method, the selection of the grouping time is important because the groups are distinguished by the grouping time. For the exact generator grouping, the effect of faults on the system must be fully considered. In this paper, the grouping time is selected 18cycles after the fault is cleared.

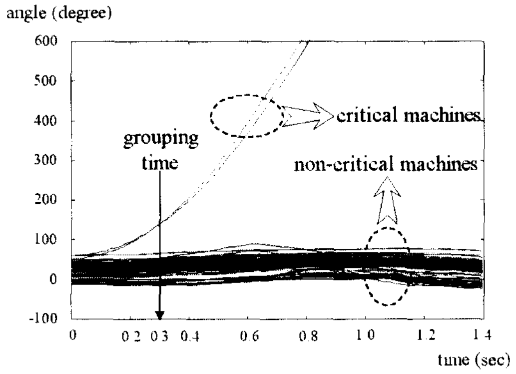


Fig. 4 Generator grouping by AI index

2.2 Stability Evaluation

The simulation results of the two generator groups are transformed into the trajectories of the two equivalent generators and further reduced to the trajectory of equivalent OMIB. This process has been useful for determining the transient stability of the bulk power system quickly and efficiently [7,8].

The stability of the contingency is evaluated by checking the behavior of the OMIB trajectory. Post-fault trajectory is checked in every time step whether it reaches a stable or unstable point. If the post-fault trajectory reaches a stable or unstable point, the simulation is terminated. Otherwise, the simulation will be continued. The stability rules using the time trajectory of equivalent OMIB are described below. The time trajectory of angle swing curves and power-angle OMIB curve are showed in Fig 5, corresponding to each case.

2.2.1 *Stable case*

The return time t_r is defined as the point at which the rotor angle starts to decrease. At this point, the speed is zero and the accelerating power is negative.

$$\omega(t_r) = 0, \qquad P_a(t_r) < 0 \tag{2}$$

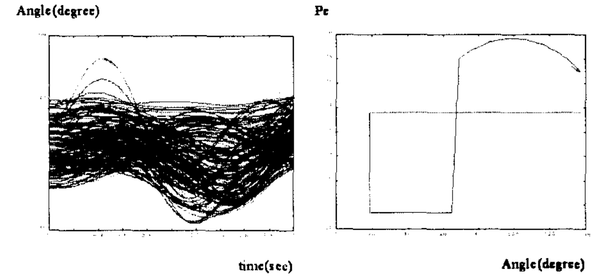
2.2.2 *Unstable case*

The unstable time t_u is defined as the point at which the electrical power starts to be lower than the mechanical power. At this point, the trajectory of equivalent OMIB meets the following conditions.

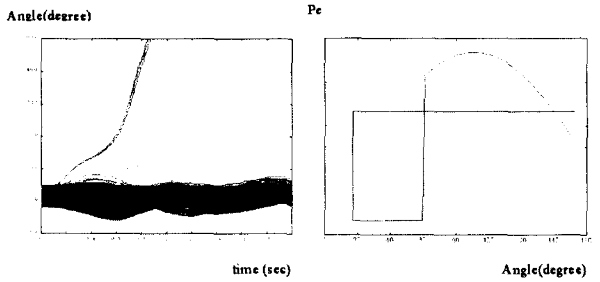
$$P_a(t_u) = 0, \qquad \frac{dP_a}{dt}\bigg|_{t=t_u} > 0 \tag{3}$$

2.2.3 *Very unstable case*

It corresponds to the case where an accelerating power has only positive values even after fault clearing. In this case, the very unstable time t_{vu} is defined as the point at which the accelerating power starts to increase.



(a) Stable case



(b) Unstable case

Fig. 5 Angle Swing Curves and Power-Angle OMIB Curve

3. Application of The On-line TSA

In this section, the feature of KEPCO TSA environment is introduced. As shown in Fig. 6, it mainly consists of master server and two client PCs. The master server handles real time data, which are collected from the TSDS (Time Synchronized Data acquisition System). In addition to TSDS, the KEPCO NEMS (New Energy Management System) database is linked to the master server to provide auxiliary system data. The TSDS sends the real time data with a definite sampling time to the master server. The NEMS database is updated every few seconds. Based on these data, the master server provides system condition to the TSA client PC. At the moment, the TSA is designed to

Table 1 Test Result (first step)

Case No.	Fault Location	Critical Generators Group (AI index)	Step-out Generators From Simulation	Stability Evaluation Results
1	5150-5100	94 95 96 97	-	Stable
2	5100-5010	94 95 96 97	-	Stable
3	5150-5600	94 95 96 97	-	Stable
4	5600-5450	94 95 96 97 100 101 102 103 125 126 134 135	-	Stable
5	5151-5500	98 99	-	Stable
6	5500-5700	123	-	Stable
7	5500-8450	123	-	Stable
8	7150-7300	184 185 186 187	184 185 186 187	Very unstable
9	7300-7600	184 185 186 187	-	Stable
10	10150-10250	261 262 263 264 265 266	261 262 263 264 265 266	Unstable
11	10150-10600	261 262 263 264 265 266	261 262 263 264 265 266	Unstable
12	10150-10700	261 262 263 264 265 266	261 262 263 264 265 266	Unstable
13	10400-7900	192 193	-	Stable
14	7900-7100	190 191 192 193 198 199 200 201 202 203 206 207 208 209 210 211 212 213 214	190 191 192 193 198 199 200 201 202 203 206 207 208 209 210 211 212 213 214	Very Unstable
15	7900-7250	192 193 198 199 200 201 202 203	192 193 198 199 200 201 202 203	Unstable
16	10401-10301	194 195 196 197	194 195 196 197	Very Unstable
17	10301-8800	194 195 196 197 267 270	-	Stable

monitor the first swing stability every 15 minutes for the pre-selected 50 contingencies.

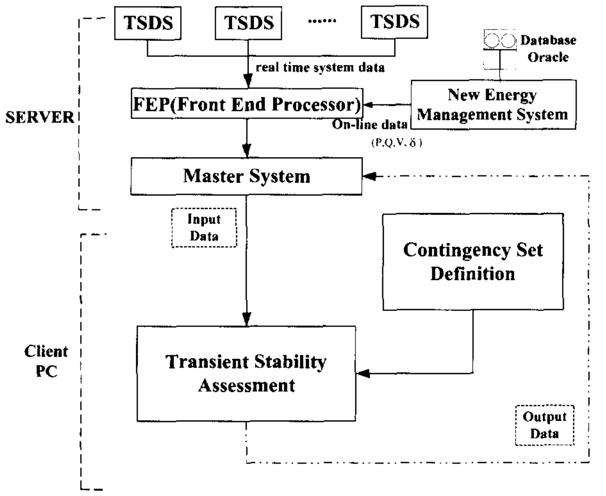


Fig. 6 The Configuration of KEPCO on-line TSA

4. Test Results

In this section, the interim results of KEPCO stability analysis by using the TSA algorithm currently being implemented is applied to the KEPCO system of the year of 2010. The numerical simulation in this section aims to demonstrate the fast screening algorithm in conjunction with SIME method described in the preceding section. The peak load demand perspective of the KEPCO system is 62,191MW and the scale of the system is 1208 buses, 2594 lines, 486 transformers, and 272 generators. Fig. 7 shows the simplified configuration of the test system that includes major generating power plant and 345kV transmission lines.

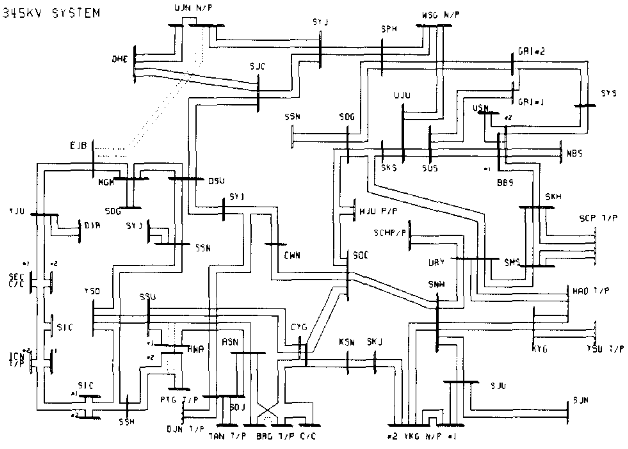


Fig. 7 Simplified configuration of the KEPCO system in the year of 2010.

4.1 Simulation Conditions

The conditions for the numerical simulations are as follows:

- Simulation time (Integration time): 5.0(sec)
- Integration step size: 0.0083(sec)
- Fault location: 345kV lines in the vicinity of the important power station
- Fault type: 3 phase line-to-ground

- Fault duration time: 0.2(sec)
- Numbers of cases: 17

4.2 Results

In the test, the generator grouping is performed at the 18th cycle after fault clearing. Table 1 shows the test results. Column 2 shows the fault location, column 3 and 4 show the critical generators group and step-out generators from simulation respectively. And stability evaluation results from the proposed method are shown in column 5. Comparing column 3 with column 4, the proposed grouping method gave correct grouping results for all unstable cases.

The simulation time for every case is shown in Table 2. For each case, the integration time takes less than 1 second.

Comparing to SIME that requires at least two simulations for generator grouping and stability evaluation, the proposed method reduced the computational time significantly.

The above results show that the proposed method can evaluate the stability of a large number of contingencies at high speed with reliable accuracy. In this test, unstable cases take the major part of the tested contingencies, because severe contingencies were selected intentionally for the test. However, in practice, considering most of the contingencies are greatly stable cases, it can be said that the proposed method is adequate to a fast contingency screening filter.

Table 2 Simulation Time (first step)

Case	Fault Location	t_r	t_u	t_{vu}	Simulation Time
No.	Bus No.- Bus No.	Sec	sec	sec	sec
1	5150-5100	0.5167	-	-	0.5167
2	5100-5010	0.4333	-	-	0.5000
3	5150-5600	0.5167	-	-	0.5167
4	5600-5450	0.4000	-	-	0.5000
5	5151-5500	0.4583	-	-	0.5000
6	5500-5700	0.3583	-	-	0.5000
7	5500-8450	0.3583	-	-	0.5000
8	7150-7300	-	-	0.3000	0.5000
9	7300-7600	0.3917	-	-	0.5000
10	10150-10250	-	0.3833	-	0.5000
11	10150-10600	-	0.3667	-	0.5000
12	10150-10700	-	0.3583	-	0.5000
13	10400-7900	0.4333	-	-	0.5000
14	7900-7100	-	-	0.3500	0.5000
15	7900-7250	-	0.3750	-	0.5000
16	10401-10301	-	0.3583	-	0.5000
17	10301-8800	0.4083	-		0.5000

In the first step, 10 stable cases are screened out and 7 unstable contingencies are selected for the detailed transient stability analysis. In the second step, the selected contingencies are simulated for calculating the stability limit. And using the simulation result, the unstable margins corresponding to the selected contingencies are computed. After the stability level (CT) adjustment, the simulation of each contingency is implemented again, and the second unstable margin is computed to acquire the critical clearing time. Using the pair of relevant margins, the stability limit (CCT) corresponding to margin=0 is calculated by using linear extrapolation.

Since the stable margin is usually calculated by using the approximated unstable time, the margin is not accurate. Therefore, in this simulation only unstable margin is used. If the simulation result using the adjusted second stability level is stable, stability level is adjusted again for obtaining the unstable margin. The result of the second step is shown in table 3.

Table 3 Test Results (second step)

Case	Fault Location	Iter	CT	Margin	CCT	
No.	Bus No.- Bus No.	No.	sec	*(rad/sec)*^{2}	sec	cycle
8	7150-7300	1	0.2000	-340.3778	-	-
		2	0.1833	-224.6248	0.1509	9.05
		3	0.1667	-112.5475	0.1500	9.00
		4	0.1500	Stable	-	-
		5	0.1583	-55.1160	**0.1502**	**9.01**
10	10150-10250	1	0.2000	-197.5087	-	-
		2	0.1833	stable	-	-
		3	0.1917	-78.1470	**0.1863**	**11.18**
11	10150-10600	1	0.2000	-255.5384	-	-
		2	0.1833	-34.5814	**0.1807**	**10.84**
		3	0.1667	stable	-	-
12	10150-10700	1	0.2000	-290.2743	-	-
		2	0.1833	-75.5262	**0.1774**	**10.64**
		3	0.1667	stable	-	-
14	7900-7100	1	0.2000	-515.2667	-	-
		2	0.1833	-324.5195	0.1549	9.29
		3	0.1667	-199.0814	0.1404	8.42
		4	0.1417	-8.9797	**0.1405**	**8.43**
15	7900-7250	1	0.2000	-386.4453	-	-
		2	0.1833	-161.0885	0.1714	10.28
		3	0.1667	-0.1079	**0.1667**	**10.00**
16	10401-10301	1	0.2000	-223.1707	-	-
		2	0.1833	-92.7251	0.1714	10.28
		3	0.1667	stable	-	-
		4	0.1750	-30.6772	**0.1709**	**10.25**

Table 4 Ranking of contingencies

Ranking	Case	Fault Location	CCT	
No.	No.	Bus No.- Bus No.	sec	cycle
1	14	7900-7100	0.1405	8.43
2	8	7150-7300	0.1502	9.01
3	15	7900-7250	0.1667	10.00
4	16	10401-10301	0.1709	10.25
5	12	10150-10700	0.1774	10.64
6	11	10150-10600	0.1807	10.84
8	10	10150-10250	0.1863	11.18

In table 3, the search for CCTs that are presented as bold type numbers at each case may rely on iterative procedure obtained by using linear extrapolation. The CCTs of the case number 8 and the case number 14 are smaller than that of other case number. It shows that instability of the case number 8 and the case number 14 is more severe than other cases. The results of this stability evaluation matches well with the results of the first step result in table 2.

According to the results, the ranking of contingencies is shown in table 4.

5. Conclusion

New transient stability evaluation method for fast contingency screening is proposed in this paper. This method can evaluate the first-swing stability of a large number of contingencies in a short time with reliable accuracy. The salient features in this paper are as follows:

- Generator grouping by using a new index: The proposed generator grouping method can identify critical generators even in very stable cases. Thus, the computational time for stability evaluation of stable cases can be reduced significantly.
- Early simulation termination: Using the trajectory of equivalent OMIB as a stability criterion, the simulation can be terminated as soon as the result is determined to be stable or unstable. This can save considerable computation time.

The test results on the KEPCO system show that the proposed method can be adopted as a contingency screening function for the TSA of the KEPCO system.

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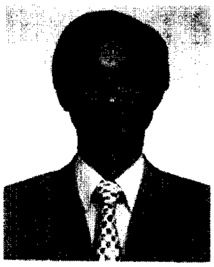

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