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Transient Stability Test Systems for Direct Stability Methods

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TRANSIENT STABILITY TEST SYSTEMS
FOR DIRECT STABILITY METHODS

IEEE COMMITTEE REPORT

PREPARED BY THE IEEE STABILITY TEST SYSTEMS
TASK FORCE OF THE DYNAMIC SYSTEM PERFORMANCE SUBCOMMITTEE

Chairman: V. Vittal

ABSTRACT

The aim of this paper is to present a standard set of power system data with benchmark results against which direct stability techniques to assess transient stability could be compared and tested.

The test systems have been selected to display a wide range of dynamic characteristics to provide a robust test of the efficacy and accuracy of the various analytical techniques to analyze transient stability. Transient stability test system data and benchmark results obtained from two commercially available time domain stability analysis packages are presented in this paper.

I. INTRODUCTION

Modern day power systems exhibit a wide range of complex dynamic behavior. Analysis of such phenomena requires the development of new analytical tools and a variety of applications of conventional time domain simulations. In order to determine the efficacy of the different techniques, they need to be compared using a common system with available benchmark results.

In recent years, several analytical approaches dealing with direct methods for transient stability assessment have been proposed. In some cases, the approaches have been applied to small sample test systems which are not very realistic. Furthermore, in order to provide a relative comparison of the various proposed techniques, there is a need for testing these methods on a realistic system with benchmark results obtained from conventional time domain analysis. This paper addresses such a need. It provides system data for two realistic test systems and provides benchmark transient stability results using two different commercially available time simulation packages. The packages used are the EPRI-Extended Transient/Mid-Term Stability Program (ETMSP) and PTI-Power System Simulation/E Program (PSS/E).

The two systems have been carefully chosen to display a wide range of dynamic characteristics: i) operating conditions are specified for which these systems display a plant mode of instability where the plant close to the disturbance loses synchronism with the rest of the system; ii) a complex mode of instability where a number of plants are electrically close to each other along a river, and a disturbance close to these plants results in all of them being severely disturbed; iii) an inter-area mode of instability where an entire area separates from another area following a disturbance. This wide range of dynamic response is specifically intended to provide a robust test of the efficacy and accuracy of the various analytical techniques. The benchmark testing has been conducted using three phase faults. Two different kinds of stability limits are provided: i) plant generation limits, and ii) critical clearing time. These limits are obtained using i) the classical power system model, and ii) the two axis machine model with exciters. In all the benchmark tests, the loads are represented as constant impedances.

II. TEST SYSTEMS

Two test systems are used to provide the benchmark results: a 17-generator, 162-bus equivalent of the network of the State of Iowa, and a 50-generator, 145-bus system.

17-Generator System

Figure 1 shows the major 345 kV lines in the 17-generator system. The system has several generating plants along the banks of the Missouri River. These are shown in the left hand side of Figure 1. The electrical proximity of these plants results in a very complex and interesting dynamic behavior of the system. For a three phase fault close to these plants, a large number of plants are severely disturbed resulting in a complex mode of disturbance.

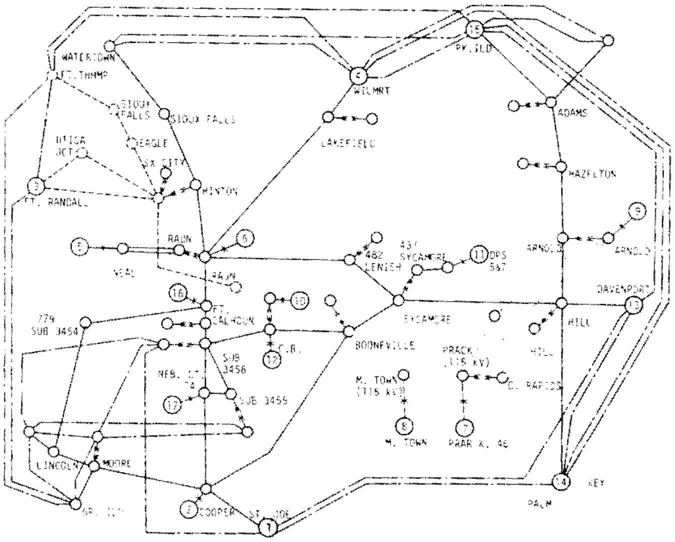


Fig. 1. 17-generator test system: major high voltage lines

Only the classical model data is provided for this system. The machine data is given in Table 1 on a 100 MVA base. The network data is provided in IEEE COMMON FORMAT for power flow exchange [1]. See Section IV for information to obtain the network data on a magnetic diskette.

Table 1. 17-Generator System Machine Data

Power Flow Bus Number	Generator Parameters[a]	
	H (s)	x'_d (pu)
3	100.00	0.004
6	34.56	0.0437
15	80.00	0.0100
27	80.00	0.0500
73	16.79	0.0507
76	32.49	0.0206
99	6.65	0.1131
101	2.66	0.3115
108	29.60	0.0535
114	5.00	0.1770
118	11.31	0.1049
121	19.79	0.0297
124	200.00	0.0020
125	200.00	0.0020
126	100.00	0.0040
130	28.60	0.0559
131	20.66	0.0544

[a] On 100 MVA Base.

50-Generator System

The 50-generator system demonstrates a wide range of dynamic characteristics at different loading levels. For the base case loading level provided in the network data, a three phase fault results in a simple plant mode of instability, where the plant close to the disturbance loses synchronism with the rest of the system. Shifting the generation at two generators and subjecting the system to the identical disturbance as in the plant mode case, results in an inter-area mode of separation where a large area separates from the rest of the system.

Benchmark cases are provided for: i) the classical model representation, and ii) for six machines represented by the two-axis model and equipped with Type AC-4 [2] exciters. Table 2 provides the machine data for the 50-generator system on a 100 MVA base. The six generators with the two-axis representation are placed at the top of the table. Table 3 provides the Type AC-4 exciter data for these six generators.

Table 2. 50-Generator System Machine Data

Power Flow Bus Number	Generator Parameters[a]									
	H (s)	x'_d (pu)	x'_q (pu)	x_d (pu)	x_q (pu)	x_l (pu)	S (1.0)	S (1.2)	τ'_{do} (s)	τ'_{qo} (s)
93	115.0366	0.024	0.03655	0.09842	0.09673	0.01237	0.0654	0.5743	8.50	1.24
104	73.8528	0.0122	0.0144	0.1016	0.0982	0.0081	0.2100	0.5500	10.00	1.50
105	84.3915	0.0208	0.03149	0.1144	0.1092	0.01102	0.1300	0.4096	6.61	1.50
106	56.261	0.03118	0.0472	0.17165	0.16377	0.01653	0.1300	0.4096	6.61	1.50
110	115.05	0.024	0.03655	0.09842	0.09673	0.01237	0.0654	0.5743	8.50	1.24
111	73.8528	0.0122	0.0144	0.1016	0.0982	0.0081	0.2100	0.5500	10.00	1.50
60	1.41	0.4769								
67	52.1796	0.0213								
79	6.65	0.1292								
80	1.2857	0.6648								
82	2.115	0.5291								
89	20.5602	0.0585								
90	0.7628	1.600								
91	1.6848	0.3718								
94	17.3424	0.0839								
95	5.4662	0.1619								
96	2.1216	0.4824								
97	5.4912	0.2125								
98	13.96	0.0795								
99	17.108	0.1146								
100	7.56	0.1386								
101	12.2844	0.0924								
102	78.4366	0.0135								
103	8.16	0.1063								
108	30.432	0.0248								
109	2.6622	0.2029								
112	12.2844	0.0924								
115	97.33	0.0024								
116	105.50	0.0022								
117	102.16	0.0017								
118	162.74	0.0014								
119	348.22	0.0002								
121	116.54	0.0017								
122	39.24	0.0089								
124	116.86	0.0017								
128	503.87	0.0001								
130	230.90	0.0010								
131	1101.72	0.0001								
132	120.35	0.0016								
134	802.12	0.0003								
135	232.63	0.0008								
136	2018.17	0.0001								
137	469.32	0.0004								
139	2210.20	0.0001								
140	899.19	0.0003								
141	1474.22	0.0001								
142	950.80	0.0003								
143	204.30	0.0023								
144	443.22	0.0004								
145	518.08	0.0018								

[a] On 100 MVA Base

Table 3. 50-Generator System Exciter Data

Power Flow Bus Number	K_A	τ_A	τ_C	τ_B	$E_{FD_{MAX}}$	$E_{FD_{MIN}}$
93	185.0	0.020	1	1	8.89	-2.00
104	253.0	0.015	1	1	8.86	-7.00
105	54.63	0.468	1	1	7.38	0.0
106	54.63	0.468	1	1	7.38	0.0
110	185.0	0.020	1	1	8.89	-2.0
111	253.0	0.015	1	1	8.86	-7.0

III. BENCHMARK TESTS

17-Generator System

Fault Specification

Three phase fault at Bus #75 cleared by opening line between Bus #75 - Buse #9.

This benchmark test on the 17-generator system consists of determining the critical clearing time. The specified fault results in a complex mode of disturbance. Seven generators close to the fault are severely disturbed. In the critical case, however, only one generator loses synchronism with respect to the rest of the system as shown in Figure 2 obtained from the ETMSP package. The benchmark results using the ETMSP and PSS/E packages are given in Table 4.

Table 4. 17-Generator System: Critical Clearing Time

Clearing Time In Seconds	Stability Classification By ETMSP	Stability Classification By PSS/E
0.352	Stable	Stable
0.354	Unstable	Stable
0.356	Unstable	Unstable

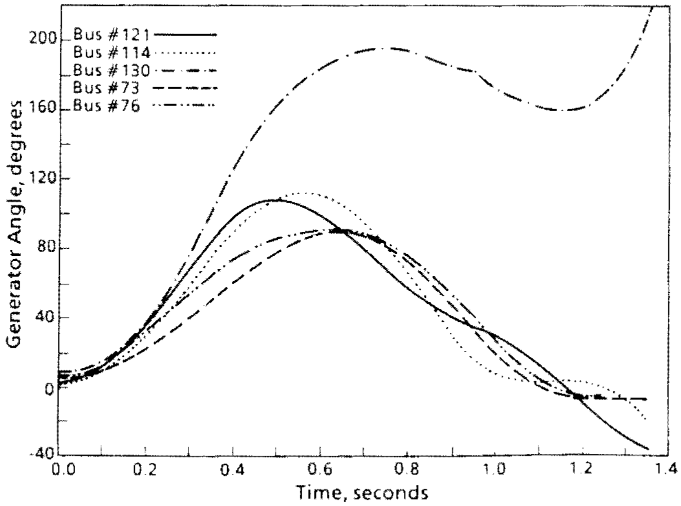


Fig. 2. 17-generator test system:
fault cleared at 0.354 seconds

50-Generator System

Fault Specification

Three phase fault at Bus #7 cleared by opening line between Bus #7 - Bus #6.

Classical Machine Model

In this set of tests all the 50-generators are represented by the classical machine model. Two types of stability limits are determined: i) plant generation limits, and ii) critical clearing time. Two different dynamic characteristics are also studied: i) plant mode of instability, where the plant closest to the disturbance loses synchronism with the rest of the system, and ii) inter-area mode of instability, where an entire area separates from the rest of the system.

Plant Mode Cases

Power Flow Features: The base case power flow provided in the diskette represents the operating condition for the plant mode analysis. It is characterized by the generation at Bus #93 and Bus #110, being set at 700 MW each.

Plant Generation Limit: In this analysis, the specified fault is always cleared at 0.108 s. The stability limit is determined by changing the generation equally at Bus #104 and Bus #111, which are two generators at a plant. The stability limit is calculated in terms of the sum of generation at the above generators. In obtaining new power flow solutions different from the base case provided on the diskette, the generation at Bus #104 and Bus #111 is 'changed' in equal steps and the slack Bus #145 absorbs all the change.

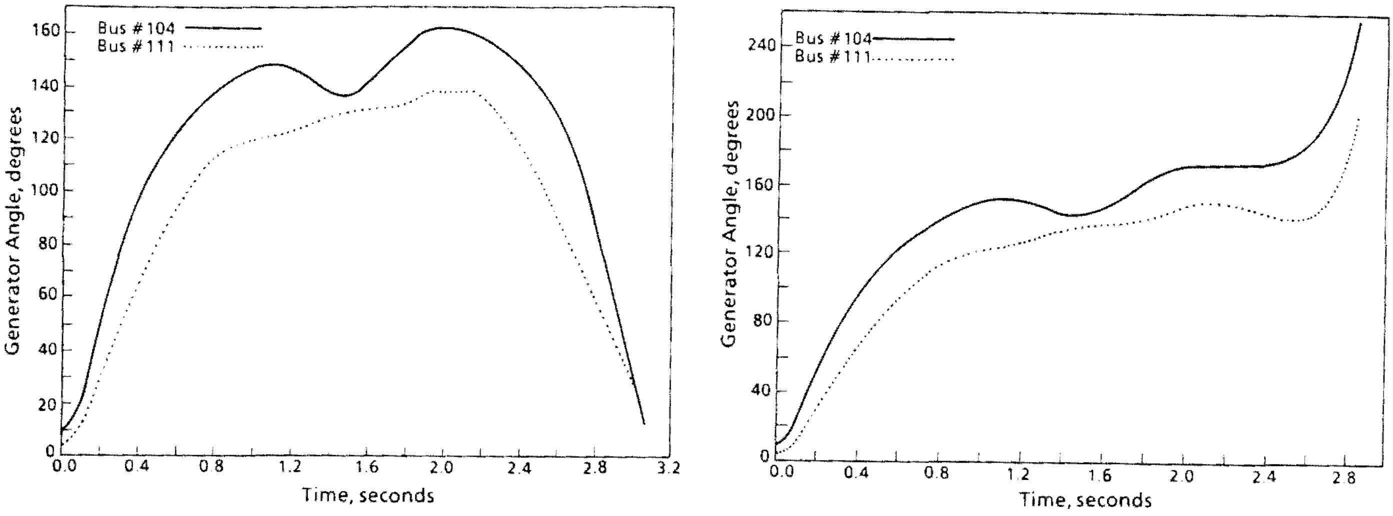
The plant generation limits obtained using the two packages are given in Table 5.

Table 5. 50-Generator System: Plant Generation Limit
Classical Generator Model
Fixed Fault Clearing time = 0.108 s
Plant Mode

Sum of Generation At Bus #104 and Bus #111	Stability Classification By ETMSP	Stability Classification By PSS/E
4000 MW	Stable	Stable
4010 MW	Unstable	Unstable

The rotor angle plots for the generators at Bus #104 and Bus #111 with respect to the generator at Bus #145 using the ETMSP package for the stable and unstable cases are given in Figure 3.

Critical Clearing Time: In this analysis, the base case power flow provided in the diskette is used and the clearing time varied to obtain the critical clearing time. Table 6 shows the results of this analysis obtained using the ETMSP and PSS/E packages.



a) Stable case

b) Unstable case

Fig. 3. 50-generator test system:
classical mode, plant mode

Table 6. 50-Generator System: Critical Clearing Time
Classical Generator Model
Total Generation at Bus #104 and Bus #110 = 4000 MW
Plant Mode

Clearing Time in Seconds	Stability Classification By ETMSP	Stability Classification By PSS/E
0.1080	Stable	Stable
0.1085	Unstable	Unstable

Table 7. 50-Generator System: Plant Generation Limit
Classical Generator Model
Fixed Fault Clearing Time = 0.108 s
Inter-Area Mode

Sum of Generation At Bus #104 and Bus #111	Stability Classification By ETMSP	Stability Classification By PSS/E
3540 MW	Stable	Stable
3550 MW	Unstable	Unstable

INTER-AREA MODE CASE

Power Flow Features: The base case power flow provided in the diskette has to be altered to obtain the initial conditions for the inter-area mode phenomenon. The power flow is solved by setting the generation at Bus #93 and Bus #110 to 1580 MW each and allowing the slack Bus #145 to account for the change.

Plant Generation Limit: In this analysis the specified fault is always cleared at 0.108 s. The stability limit is obtained by changing the generation in equal increments at Bus #104 and Bus #111, which are two generators at the same plant. The stability limit is calculated in terms of the sum of the generation at the above generators.

The plant generation limits obtained using the two stability packages are given in Table 7. In the critically unstable case, 29 generators separate from the rest of the system. The rotor angle plots from the ETMSP package of a few generators with respect to the generator at Bus #145 is given in Figure 4.

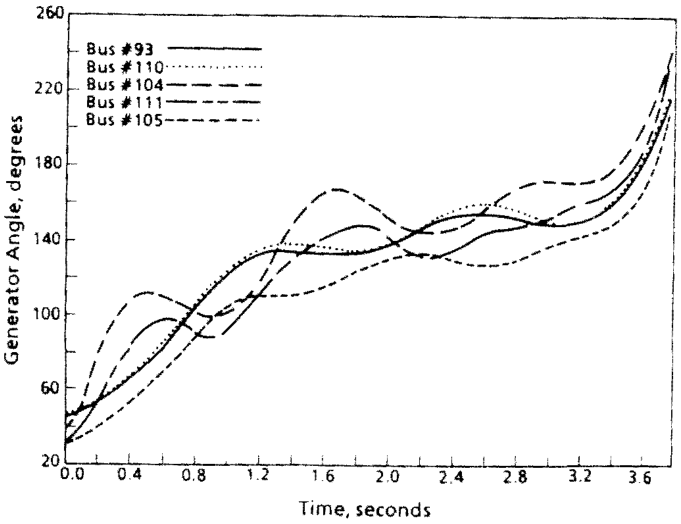


Fig. 4. 50-generator test system:
classical model, inter-area mode

Detailed Machine Model

In this set of tests, six generators in the 50-generator system are represented by the two-axis model [3, pg 138], and equipped with Type AC-4 [2] exciters. The detailed machine data is given in Table 2 and the exciter data is given in Table 3. The same fault considered for the classical machine model cases is analyzed. Only the plant mode case is studied, and both plant generation limit and critical clearing time are obtained.

Plant Generation Limit: The same fault considered in the classical machine model case is analyzed. The stability limit is calculated in terms of the sum of the generation of the generators located at Bus #104 and Bus #111. The change cases of the power flow are obtained as described earlier. The results of the test are shown in Table 8.

The difference in results between the two packages is attributed to the differences in the representation of the machine model and the exciter model in the two packages.

Critical Clearing Time: The two critically stable cases from the ETMSP and PSS/E packages are analyzed to obtain the critical clearing time. These results are presented in Table 9.

Table 8. 50-Generator System: Plant Generation Limit
Detailed Generator Model
Fixed Fault Clearing Time = 0.108 s
Plant Mode

Sum of Generation at Bus #104 and Bus #111	Stability Classification By ETMSP	Stability Classification By PSS/E
4250 MW	Stable	Stable
4260 MW	Stable	Unstable
4270 MW	Stable	Unstable
4280 MW	Unstable	Unstable

Table 9. 50-Generator System: Critical Clearing Time
Detained Generator Model
Plant Mode

ETMSP Results Output of Bus #104 and Bus #111 = 4270 MW		PSS/E Results Output of Bus #104 and Bus #111 = 4250 MW	
Clearing Time (s)	Stability Classification	Clearing Time(s)	Stability Classification
0.1090	Stable	0.11	Stable
0.1095	Unstable	0.12	Unstable

IV. NETWORK DATA

The network power flow data can be obtained by sending a pre-paid request to the following address:

Iowa State University Computation Center
Reference and Supplies Office
195 Durham Center
Iowa State University
Ames, IA 50011

The data can be requested on either a 3-1/2" or 5-1/4" double density MSDOS formatted diskette.

The diskette is currently priced as follows, any change in pricing will be indicated to the user when the order is placed.

Diskette	→	US $	12.00
Tax	→	US $	0.60
U.S. Shipping	→	US $	2.00
Overseas Shipping	→	US $	7.00

All international orders must be paid for using an international money order in U.S. dollars.

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