ETAP
Validation Cases and Comparison Results

ETAP is Verified and Validated (V&V) against field results, real system measurements, published cases, other programs, and hand calculations in order to ensure its technical accuracy. Prior to each release, to encompass the V&V of new features and capabilities, the ETAP Test Group adds new test cases to the existing battery of scenarios. In addition, the Test Group re-runs all existing test cases, as part of our extensive and comprehensive V&V process.

In accordance with OTI's Quality Assurance Program, all procedures and activities related to the quality of ETAP software are subject to internal and external audits, including nuclear clients and ISO 9001:2000 certification assessments. Test cases are reviewed during the audit process.

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Comparison of Load Flow Results against a Published Example

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ETAP Load Flow

The ETAP V&V process for the Load Flow program has over 1500 test case scenarios that are run before each ETAP release. The following case samples are from the Load Flow Solutions & Methods category.

Load Flow Comparison Case # 1

Comparison of ETAP Load Flow Results against a Published Textbook Example

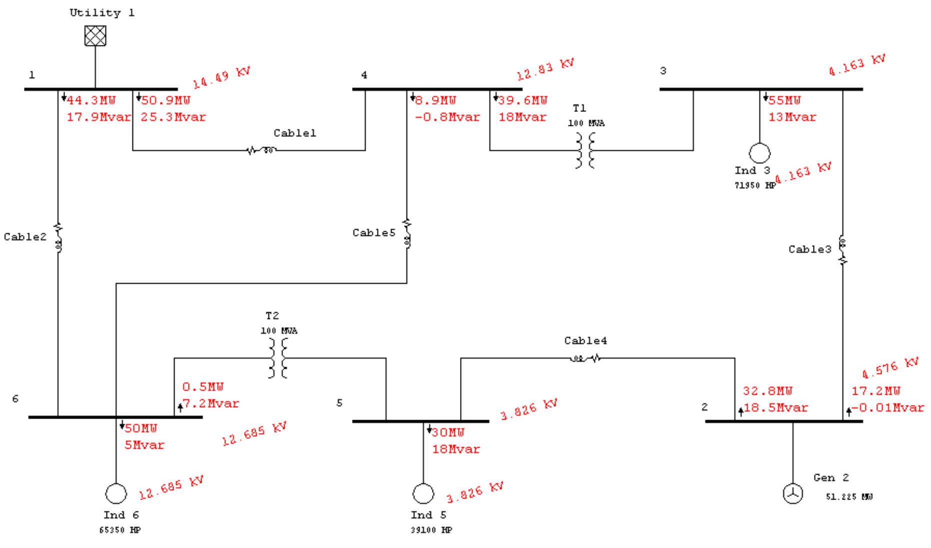
Excerpts from Validation Cases and Comparison Results (TCS-LF-006)

Highlights

- Comparison between ETAP Load Flow (LF) results against those published in the textbook "Computer Aided Power System Operation and Analysis" by R.N Dhar, page 89.
- Comparison of results for the Newton Rhapson Method.
- Comparison of results for the Accelerated Gauss Seidel Method.
- Comparison of results for the Fast Decoupled Method.
- Study includes generation, motor loads, transformers and cables.
- Considers line impedance and admittance.
- Comparisons are made against generation schedule, bus voltages and power flows in per-unit.
- The difference in the results is less than 1% for all bus voltages and power flows.

System Description

This is a six-bus system that is composed of lines, cables, transformers, generators and utility. The line impedance and charging effects are considered. The schedule of generation and loading for each bus were taken as described in Table 6.2 of the published example.



Comparison of Results

The following tables of comparison show the differences between ETAP Results and those published in the textbook example. Please notice that the percent difference for all branch flows and bus voltages is less than 1%.

COMPARISON BETWEEN ETAP AND REFERENCE FOR LOAD FLOW

BUS	REFERENCE		ETAP								
			AGS			NR			FD		
	% Mag.	Ang.	% Mag.	Ang.	% Diff Mag	% Mag.	Ang.	% Diff Mag	% Mag.	Ang.	% Diff Mag
1	105	0	105	0	**0.00**	105	0	**0.00**	105	0	**0.00**
2	110	-3.34	110	-3.3	**0.00**	110	-3.3	**0.00**	110	-3.3	**0.00**
3	100.08	-12.78	100.08	-12.8	**0.00**	100.08	-12.8	**0.00**	100.08	-12.8	**0.00**
4	92.98	-9.84	92.97	-9.8	**0.01**	92.97	-9.8	**0.01**	92.97	-9.8	**0.01**
5	91.98	-12.33	91.98	-12.3	**0.00**	91.98	-12.3	**0.00**	91.98	-12.3	**0.00**
6	91.92	-12.3	91.92	-12.2	**0.00**	91.92	-12.2	**0.00**	91.92	-12.2	**0.00**

Table 1: Bus Voltage Comparison for all three Load Flow methods against published results.

COMPARISON BETWEEN ETAP AND REFERENCE FOR LOAD FLOW

From BUS	To BUS	REFERENCE		ETAP											
				AGS				NR				FD			
		MW	Mvar	MW	Mvar	% Diff MW	%Diff Mvar	MW	Mvar	% Diff MW	%Diff Mvar	MW	Mvar	% Diff MW	%Diff Mvar
1	4	50.907	25.339	50.91	25.34	**-0.01**	**0.00**	50.91	25.34	-0.01	0.00	50.91	25.34	-0.01	0.00
1	6	44.3	17.913	44.3	17.92	**0.00**	**-0.04**	44.3	17.92	0.00	-0.04	44.3	17.92	0.00	-0.04
2	3	17.183	-0.01	17.18	-0.01	**0.02**	**0.00**	17.18	-0.01	0.02	0.00	17.18	-0.01	0.02	0.00
2	5	32.832	18.446	32.82	18.45	**0.04**	**-0.02**	32.82	18.45	0.04	-0.02	32.82	18.45	0.04	-0.02
3	2	-15.419	2.582	-15.42	2.57	**-0.01**	**0.46**	-15.42	2.57	-0.01	0.46	-15.42	2.57	-0.01	0.46
3	4	-39.58	-15.57	-39.58	-15.57	**0.00**	**-0.01**	-39.58	-15.57	0.00	-0.01	-39.59	-15.57	-0.03	-0.01
4	1	-48.497	-17.15	-48.5	-17.15	**-0.01**	**-0.02**	-48.5	-17.15	-0.01	-0.02	-48.5	-17.15	-0.01	-0.02
4	6	8.916	-0.824	8.92	-0.83	**-0.04**	**-0.73**	8.92	-0.83	-0.04	-0.73	8.92	-0.83	-0.04	-0.73

Table 2: Power Flow Comparison for all three Load Flow methods against published results.

Reference

1. “Computer Aided Power System Operation and Analysis,” R.N Dhar, page 89.
2. ETAP Load Flow V&V Documents, Case Number TCS-LF-006.

Load Flow Comparison Case # 2

Comparison of Load Flow Results against a Published Example

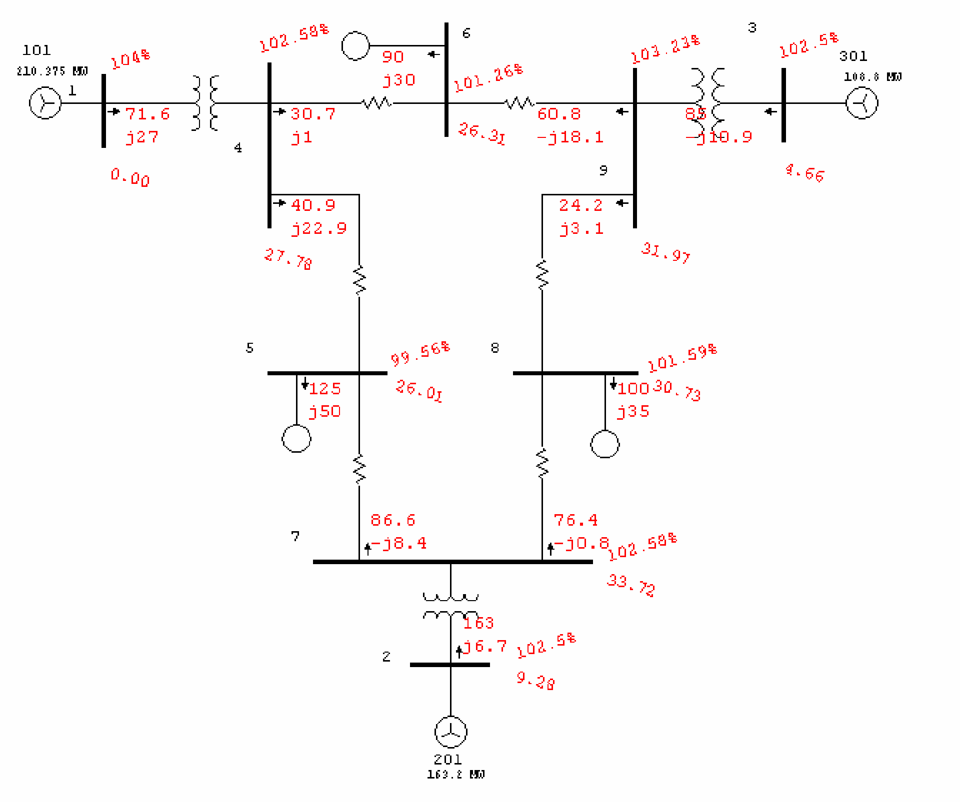
Excerpts from Validation Cases and Comparison Results (TCS-LF-008)

Highlights

- Comparison between ETAP Load Flow (LF) results against those published in the textbook “Power System Control and Stability” by P.M. Anderson and A.A. Fouad, page 38.
- Comparison of prefault load flow results (steady state initial load flow conditions for a Transient Stability Study).
- Nine bus system with multiple machines and generators.
- Simulation includes the three Load Flow methods.
- The difference in the results is less than 1% for all bus voltages and power flows.

System Description

This is a nine-bus system that is composed multiple machines including induction motors and synchronous generators.



Comparison of Results

The following tables of comparison show the differences between ETAP Results and those published in the textbook example. Please notice that the percent difference for all branch flows and bus voltages is less than 1%.

			ETAP								
BUS	REFERENCE		AGS			NR			FD		
#	% Mag.	Ang.	% Mag.	Ang.	**% Diff Mag**	% Mag.	Ang.	**% Diff Mag**	% Mag.	Ang.	**% Diff Mag**
1	104	0	104	0	**0.0**	104	0	**0.0**	104	0	**0.0**
2	102.5	9.3	102.5	9.3	**0.0**	102.5	9.3	**0.0**	102.5	9.3	**0.0**
3	102.5	4.7	102.5	4.7	**0.0**	102.5	4.7	**0.0**	102.5	4.7	**0.0**
4	102.6	27.8	102.58	27.8	**0.0**	102.58	27.8	**0.0**	102.58	27.8	**0.0**
5	99.6	26	99.56	26	**0.0**	99.56	26	**0.0**	99.56	26	**0.0**
6	101.3	26.3	101.26	26.3	**0.0**	101.26	26.3	**0.0**	101.26	26.3	**0.0**
7	102.6	33.7	102.58	33.7	**0.0**	102.58	33.7	**0.0**	102.58	33.7	**0.0**
8	101.6	30.7	101.59	30.7	**0.0**	101.59	30.7	**0.0**	101.59	30.7	**0.0**
9	103.2	32	103.23	32	**0.0**	103.23	32	**0.0**	103.23	32	**0.0**

Table 3: Comparison of ETAP Bus Voltage Results against those published in the Textbook Example.

From	To	**REFERENCE**		**ETAP**											
BUS	BUS			AGS				NR				FD			
#	#	MW	Mvar	MW	Mvar	**% Diff MW**	**%Diff Mvar**	MW	Mvar	**% Diff MW**	**%Diff Mvar**	MW	Mvar	**% Diff MW**	**%Diff Mvar**
1	4	71.6	27	71.64	27.05	**-0.1**	**-0.2**	71.64	27.05	**-0.1**	**-0.2**	71.64	27.05	**-0.1**	**-0.2**
2	7	163	6.7	163	6.65	**0.0**	**0.8**	163	6.65	**0.0**	**0.8**	163	6.65	**0.0**	**0.8**
3	9	85	-10.9	85	-10.86	**0.0**	**0.4**	85	-10.9	**0.0**	**0.4**	85	-10.86	**0.0**	**0.4**
4	5	40.9	22.9	40.49	22.89	**1.0**	**0.0**	40.49	22.89	**1.0**	**0.0**	40.49	22.89	**1.0**	**0.0**
4	6	30.7	1.03	30.7	1.03	**0.0**	**0.0**	30.7	1.03	**0.0**	**0.0**	30.7	1.03	**0.0**	**0.0**
6	9	-59.5	-13.5	-59.46	-13.46	**0.0**	**0.0**	-59.46	-13.5	**0.0**	**0.0**	-59.46	-13.46	**0.0**	**0.0**
7	5	86.6	-8.4	86.62	-8.38	**0.0**	**0.2**	86.62	-8.38	**0.0**	**0.2**	86.62	-8.38	**0.0**	**0.2**
7	8	76.4	-0.8	76.38	-0.8	**0.0**	**0.0**	76.38	-0.8	**0.0**	**0.0**	76.38	-0.8	**0.0**	**0.0**
8	9	-24.1	-24.3	-24.1	-24.3	**0.0**	**0.0**	-24.1	-24.3	**0.0**	**0.0**	-24.1	-24.3	**0.0**	**0.0**
9	8	24.2	3.12	24.18	3.12	**0.1**	**0.0**	24.18	3.12	**0.1**	**0.0**	24.18	3.12	**0.1**	**0.0**

Table 4: Comparison of ETAP LF Power Flows against published Textbook Results.

Reference

1. “Power System Control and Stability”, P.M. Anderson and A.A. Fouad, page 38.
2. ETAP Load Flow V&V Documents, Case Number TCS-LF-008.

Load Flow Comparison Case #3

Comparison of ETAP Load Flow Results against Published Textbook Examples

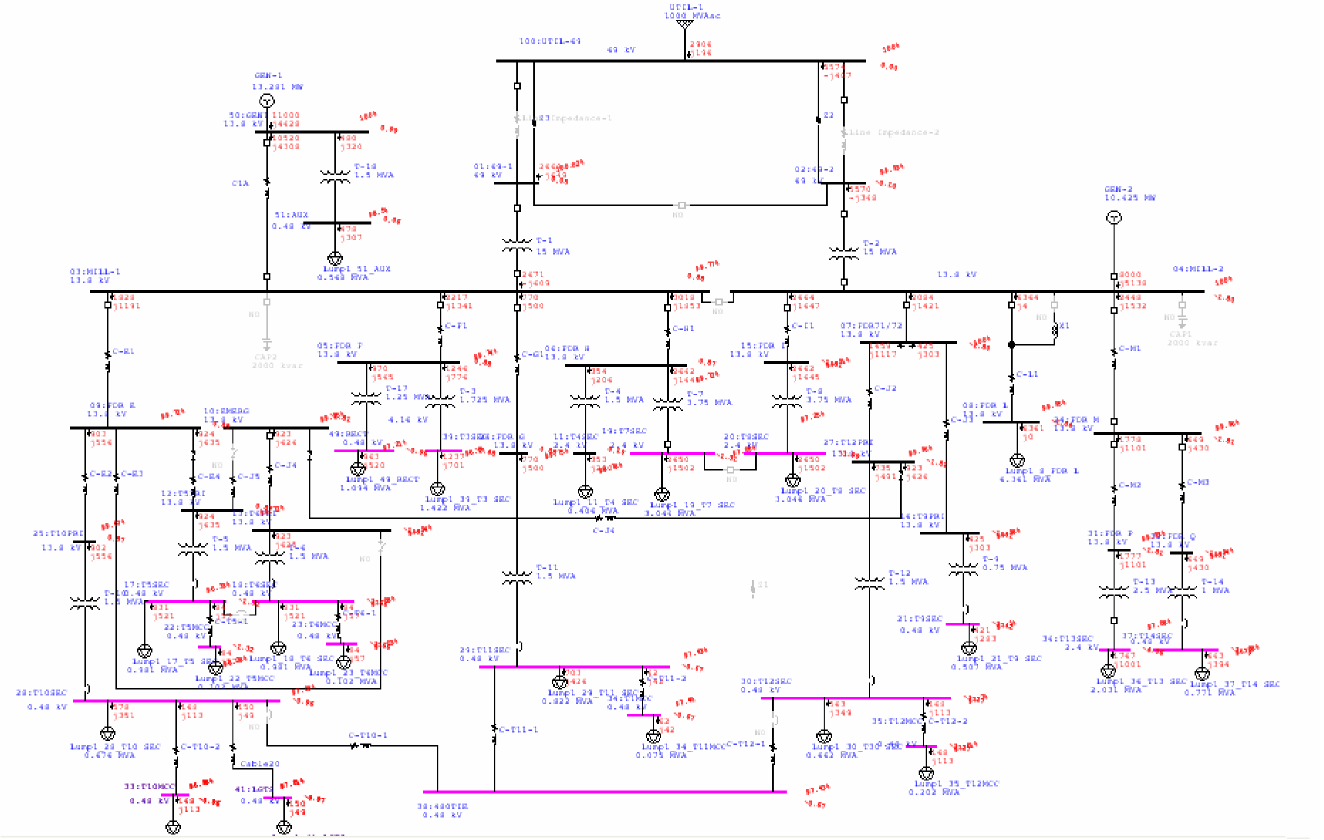
Excerpts from Validation Cases and Comparison Results (TCS-LF-150)

Highlights

- Comparison between ETAP Load Flow (LF) results against those published in IEEE Std. 399-1997, Brown Book, pages 151-161.
- Comparison of results for the Newton Rhapson Method, Accelerated Gauss-Seidel and Fast-Decoupled methods.
- Forty-four bus systems with multiple loads and generators and types of branches.
- Considers line impedance and admittance.
- Comparisons are made against bus voltage magnitude and angle and power flows (MW and Mvar flows).
- The difference in the results is less than 0.001% for all bus voltages and 0.34% for all power flows (for all three LF methods).

System Description

This is a forty-four bus system that is composed of lines, cables, transformers, generators, and a utility connection. The line impedance and charging effects are considered. The schedule of generation and loading for each bus was taken as described in Figures 6-5 through 6-7 of the published example. Only the base load flow case was compared in this test case.



Comparison of Results

The following tables of comparison show the differences between ETAP results and those published in the textbook example. The difference in the results is less than 0.001 % for all bus voltages and less than 0.34 % for all power flows (for all three LF methods).

Bus	Reference		ETAP		% Diff Mag.	% Diff Ang.
	% Mag	Ang(deg)	% Mag	Ang (deg)		
1: 69-1	100.02	0.1	100.02	0.1	0.00	0.00
2: 69-2	99.93	-0.1	99.93	-0.1	0.00	0.00
3: MILL-1	99.77	0.9	99.77	0.9	0.00	0.00
4: MILL-2	100	-1.8	100	-1.8	0.00	0.00
5: FDR F	99.74	0.9	99.74	0.9	0.00	0.00
6: FDR H	99.72	0.9	99.72	0.9	0.00	0.00
7: FDR 71/72	100	-1.8	100	-1.8	0.00	0.00
8: FDR L	99.95	-1.8	99.95	-1.8	0.00	0.00

Table 1: Bus Voltage Comparison for Load Flow method against published results

From Bus	To Bus	Reference		ETAP		% Diff	
		MW	Mvar	MW	Mvar	MW	Mvar
1: 69-1	**3: MILL-1**	-2.667	0.649	-2.669	0.649	0.07	0.00
3: MILL-1	**5: FDR F**	2.217	1.341	2.217	1.341	0.00	0.00
3: MILL-1	**50: Gen1**	-10.503	-4.277	-10.504	-4.277	0.01	0.00
4: MILL-2	**2: 69-2**	-5.562	0.534	-5.56	0.534	0.04	0.00
4: MILL-2	**24: FDR M**	2.445	1.530	2.448	1.532	0.12	0.13
5: FDR F	**39: T3 SEC**	1.246	0.776	1.246	0.776	0.00	0.00
5: FDR F	**49: RECT**	0.971	0.565	0.97	0.565	0.10	0.00
6: FDR H	**11: T4 SEC**	0.354	0.206	0.354	0.206	0.00	0.00
6: FDR H	**19: T7 SEC**	2.662	1.646	2.662	1.646	0.00	0.00
7: FDR 71/72	**16: T9 PRI**	0.425	0.304	0.425	0.303	0.00	0.33

Table 2: Power Flow Comparison for Load Flow method against published results

ETAP ANSI Short-Circuit

The ETAP V&V process for the ANSI Short-Circuit program has over 1700 test cases scenarios that are run before each ETAP release. The following cases are excerpts from the Short-Circuit ANSI 3-phase and unbalanced short-circuit results.

Short-Circuit ANSI Comparison Case # 1

Comparison of Short-Circuit Results against Hand Calculations based on Application Engineering Information

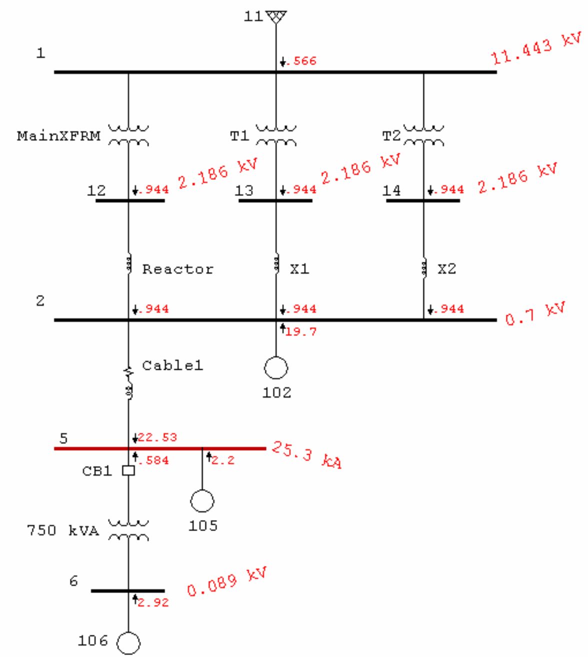
Excerpts from Validation Cases and Comparison Results (TCS-SC-005)

Highlights

- Comparison of ETAP 3-phase Short-Circuit results against hand calculations. The test case is based on a published power system from "Short-Circuit Current Calculations for industrial and Commercial Power Systems," published by General Electric, Section III, "Examples of AC Short-Circuit".
- Comparison of Momentary Short-circuit currents.
- Comparison of MF based on separate R&X networks per ANSI standards.
- Calculation of %V away from the faulted bus.

System Description

Typical industrial system with 5 MVA transformers, reactors, cables and induction motors. The available MVAsc rating of the utility is 250. X/R = 15. There is a lumped 19,900 HP of induction motor load at 2.4 kV and 800 HP at 0.480 kV.



Comparison of Results

The following tables of comparison show the differences between ETAP Results and those published in the General Electric document. Please notice that the maximum deviation in the results is about 1 %.

For a fault at Bus # 5	**Momentary Duty**			**Interrupting Duty**		
	Hand Calc	ETAP.	**% Diff**	Hand Calc	ETAP.	**% Diff**
Mom. Symm. Current (kA)	25.264	25.264	**0.0**	18.947	18.947	**0.0**
X/R (separate R&X networks)	4.106	4.100	**0.1**	5.578	5.600	**0.4**
MF (separate R&X networks)	1.197	1.197	**0.0**	-	-	**0.0**
I_{asy} (separate R/X networks)	30.243	30.243	**0.0**	-	-	**0.0**
MF (ANSI method)	1.600	1.600	**0.0**	-	-	
Contribution from Bus 2 (kA)	22.526	22.526	**0.0**	17.272	17.271	**0.0**
X/R from Bus 2	3.265	3.300	**1.0**	4.421	4.400	**0.5**
%V of Bus 2	29.155	29.160	**0.0**	22.354	22.350	**0.0**

Table 5: Comparison of ETAP SC 3-phase results against hand calculation results based on the Application Engineering document.

Reference

1. "Short-Circuit Current Calculations for industrial and Commercial Power Systems," General Electric, *Section III, Examples of AC Short-Circuit*.
2. ETAP Short Circuit ANSI V&V Documents, Case Number TCS-SC-005.

Short-Circuit ANSI Comparison Case # 2

Comparison of ETAP Unbalanced Short-Circuit Calculations against a Published Example

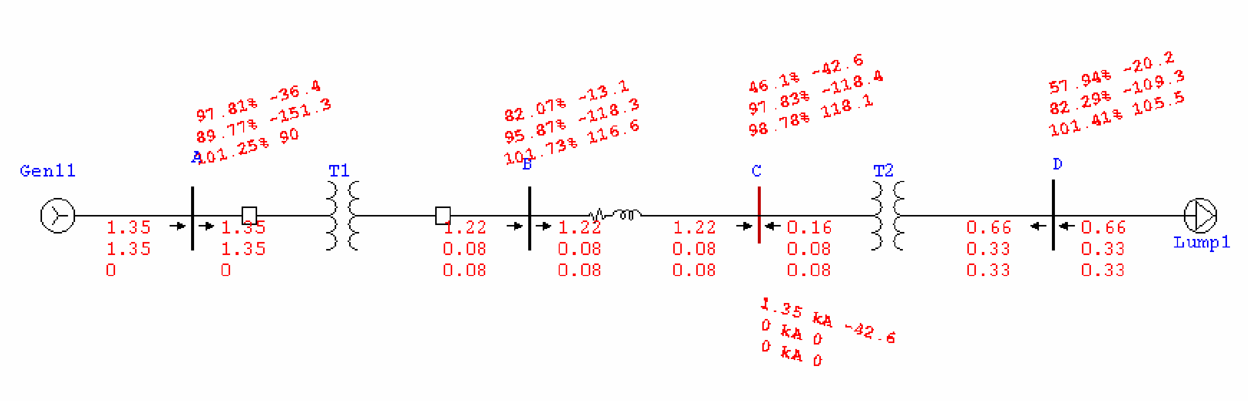
Excerpts from Validation Cases and Comparison Results (TCS-SC-105)

Highlights

- Comparison of ETAP unbalanced fault results against published results in “Faulted Power System Analysis” by Paul Anderson, 1973, page 38-40.
- Comparison of total fault current (I_A or $3*I_O$).
- Comparison of phase voltages (V_A, V_B and V_C).
- Comparison of sequence voltages (V_1, V_2, V_0).

System Description

This is a four-bus radial system that consists of a generator, transformer, transmission line, load transformer and load. The fault is located at Bus C. The generator is rated as 25MVA, 10 kV and its Subtransient Reactance is 12.5%.



Comparison of Results

The following tables of comparison show the differences between ETAP Results and those published in Paul Anderson’s book for an unbalanced LG fault. Please notice that the maximum deviation in the results is less than 0.5%.

	Example	ETAP	% Diff
Ia (3*Io) (kA)	1.35	1.35	**0.0**
Va (%)	46.02	46.1	**-0.2**
Vb (%)	98.08	97.83	**0.3**
Vc (%)	99.09	98.78	**0.3**
V1 (%)	77.42	77.53	**-0.1**
V2 (%)	25.61	25.5	**0.4**
V0 (%)	22.22	22.12	**0.5**

Table 6: Comparison of ETAP unbalanced fault results against textbook example

Reference

1. Faulted Power System Analysis” by Paul Anderson, 1973, pages 38-40.
2. ETAP Short Circuit ANSI V&V Documents, Case Number TCS-SC-105.

Short-Circuit ANSI Comparison Case # 3

Comparison of ETAP 3-Phase Duty Short-Circuit Calculations against Published IEEE Std 399-1997 Example

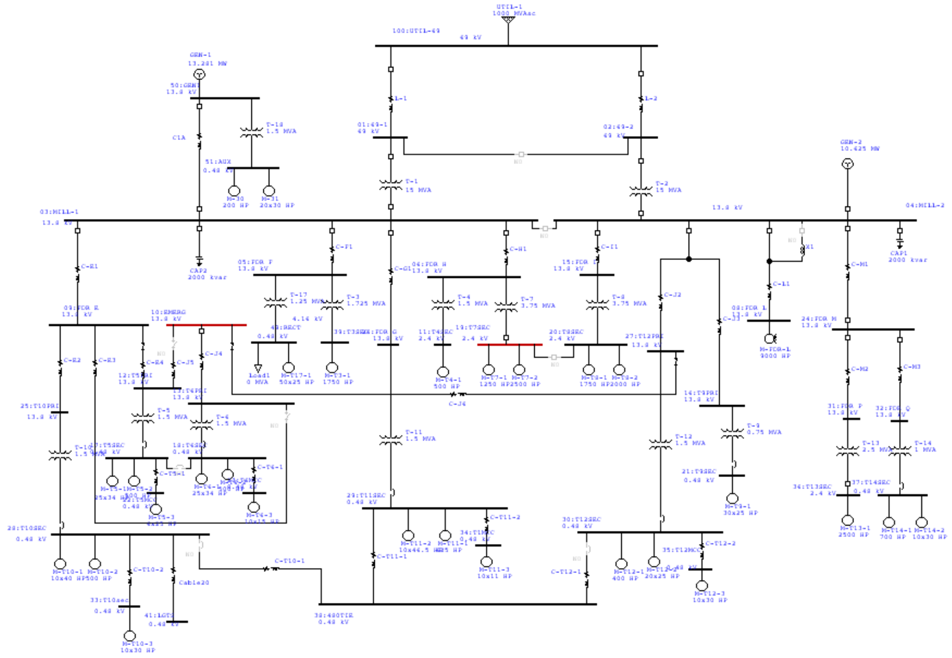
Excerpts from Validation Cases and Comparison Results (TCS-SC-162)

Highlights

- Comparison of ETAP 3-phase Duty Short-circuit results against a published 44-bus example from the IEEE Std. 399-1997, Section 7.7, pages 187-205.
- Comparison of Momentary fault currents.
- Comparison of Interrupting currents.
- Comparison of ANSI C37.010, C37.05 –1979 Multiplying factors.
- Comparison of calculated individual current contributions and calculated voltages away from the faulted bus.
- Comparison of motor contributions determined according to the Reactance Values specified in Table 7-2 of IEEE Std. 399-1997.
- Comparison of Asymmetrical currents.
- Comparison of Peak currents.
- Comparison of element per-unit impedance representation for motors, generators, cables and lines.

System Description

This is a 44 Bus system as modeled in ETAP. The system has a utility tie and in-plant generators. Both the utility tie and the generators are in service and supplying power to the plant. The system rotating-load is typical of a system operating near to full capacity. The system contains both induction and synchronous motors. The utility is operating at 69 kV and the generators at 13.8 kV. Several motors that are rated less than 50 HP are modeled as composite motors in ETAP. Medium size machines (rated higher than 50 Hp) are modeled individually.


UTIL-1
1000 MVAsc
100:UTIL-69
69 kV
GEN-1
13.281 MW
50:GEN1
13.8 kV
T-18
1.5 MVA
C1A
51:AUX
0.48 kV
M-30
200 HP
M-31
20x30 HP
L-1
L-2
01:69-1
69 kV
02:69-2
69 kV
NO
T-1
15 MVA
T-2
15 MVA
GEN-2
10.625 MW
03:MILL-1
13.8 kV
13.8 kV
04:MILL-2
CAP2
2000 kvar
CAP1
2000 kvar
X1
C-E1
C-F1
C-G1
C-H1
C-I1
C-J2
C-J3
C-L1
C-M1
05:FDR F
13.8 kV
06:FDR H
13.8 kV
15:FDR I
13.8 kV
08:FDR L
13.8 kV
24:FDR M
13.8 kV
M-FDR-L
9000 HP
09:FDR E
13.8 kV
10:EMERG
13.8 kV
T-17
1.25 MVA
T-3
1.725 MVA
4.16 kV
40:RECT
0.48 kV
T-4
1.5 MVA
T-7
3.75 MVA
T-8
3.75 MVA
11:T4SEC
2.4 kV
19:T7SEC
2.4 kV
20:T8SEC
2.4 kV
27:T12PRI
13.8 kV
Load1
0 MVA
M-T17-1
50x25 HP
M-T3-1
1750 HP
M-T4-1
500 HP
M-T7-1
1250 HP
M-T7-2
2500 HP
M-T8-1
1750 HP
M-T8-2
2000 HP
C-J6
C-E2
C-E3
C-E4
C-J5
C-J4
12:T5PRI
13.8 kV
13:T6PRI
13.8 kV
25:T10PRI
13.8 kV
T-5
1.5 MVA
T-6
1.5 MVA
T-10
1.5 MVA
17:T5SEC
0.48 kV
18:T6SEC
0.48 kV
C-T5-1
C-T6-1
M-T5-1
M-T5-2
25x34 HP
500 HP
22:T5MCC
0.48 kV
M-T5-3
4x25 HP
M-T6-1
25x34 HP
M-T6-3
10x15 HP
16:T9PRI
13.8 kV
T-9
0.75 MVA
21:T9SEC
0.48 kV
M-T9-1
30x25 HP
T-11
1.5 MVA
T-12
1.5 MVA
31:FDR P
13.8 kV
32:FDR Q
13.8 kV
C-M2
C-M3
T-13
2.5 MVA
T-14
1 MVA
36:T13SEC
2.4 kV
37:T14SEC
0.48 kV
M-T13-1
2500 HP
M-T14-1
700 HP
M-T14-2
10x30 HP
28:T10SEC
0.48 kV
29:T11SEC
0.48 kV
C-T11-2
34:T11MCC
0.48 kV
30:T12SEC
0.48 kV
C-T12-2
35:T12MCC
0.48 kV
M-T10-1
10x40 HP
M-T10-2
500 HP
C-T10-2
Cable20
C-T10-1
C-T11-1
M-T11-2
10x46.5 HP
M-T11-1
M-T11-3
10x11 HP
C-T12-1
M-T12-1
400 HP
M-T12-2
20x25 HP
M-T12-3
10x30 HP
33:T10sec
0.48 kV
41:LGTS
0.48 kV
M-T10-3
10x30 HP
38:480TIE
0.48 kV

Comparison of Results

The following tables of comparison show the differences between ETAP Results and those published in Tables 7-5 and 7-6 of IEEE Std. 399-1997. The result difference in all cases is less than or equal to 0.1%. Please note that the results have rounded-off and compared to the appropriate number of significant figures.

For a fault at Bus 19: T7SEC	IEEE Std 399-1997 Example	ETAP	% Diff
Prefault Voltage (kV)	2.4	2.4	**0.0**
Voltage to Ground (at fault location) (%)	0	0	**0.0**
Total Mom Fault Current (kA)	18.449	18.453	**0.0**
X/R ratio	13.7	13.7	**0.0**
Asymmetrical Momentary Current (kA)	27.765	27.762	**0.0**
Peak Current (kA)	46.879	46.838	**0.1**
Contribution from Bus 6:FDR-H2 (kA)	13.418	13.422	**0.0**
Voltage to Ground (at Bus 6) (%)	82	82	**0.0**
Contribution from Motor M-T7-1 (kA)	1.619	1.619	**0.0**
Contribution from Motor M-T7-2 (kA)	3.414	3.414	**0.0**

Table 7: Comparison of ETAP Momentary Short-circuit results against published IEEE Std 399-1997 Section 7.7 Example results for a fault at Bus 19: T7SEC.

For a fault at Bus 10: EMERG	IEEE Std 399-1997 Example	ETAP	% Diff
Prefault Voltage (kV)	13.8	13.8	**0.0**
Voltage to Ground (at fault location) (%)	0	0	**0.0**
Total Interrupting Fault Current (kA)	11.616	11.619	**0.0**
X/R ratio	8.95	8.94	**0.1**
MF (ANSI Std C37.010 1979)	1	1	**0.0**
Adjusted Asymmetrical Current (kA)	11.619	11.619	**0.0**
Contribution from Bus 13:T6 PRI (kA)	0.04	0.04	**0.0**
Voltage to Ground (at Bus 13) (%)	0.0	0.0	**0.0**
Contribution from Bus 27:T12 PRI (kA)	11.577	11.578	**0.0**
Voltage to Ground (at Bus 27) (%)	4.0	4.0	**0.0**

Table 8: Comparison of ETAP Interrupting Short-circuit results against published IEEE Std 399-1997 Section 7.7 Example results for a fault at Bus 10: EMERG.

Reference

1. IEEE Brown Book: IEEE Std. 399-1997, Section 7.7, page 187-205.
2. ETAP Short Circuit ANSI V&V Documents, Case Number TCS-SC-162.

ETAP IEC Short-Circuit

The ETAP V&V process for the IEC Short-Circuit program has over 1100 test case scenarios that are run before each ETAP release. The following cases are excerpts from the Short-Circuit IEC 3-phase and unbalanced short-circuit results.

Short-Circuit IEC Comparison Case # 1

Comparison of ETAP Short-Circuit IEC Calculations against Published Example

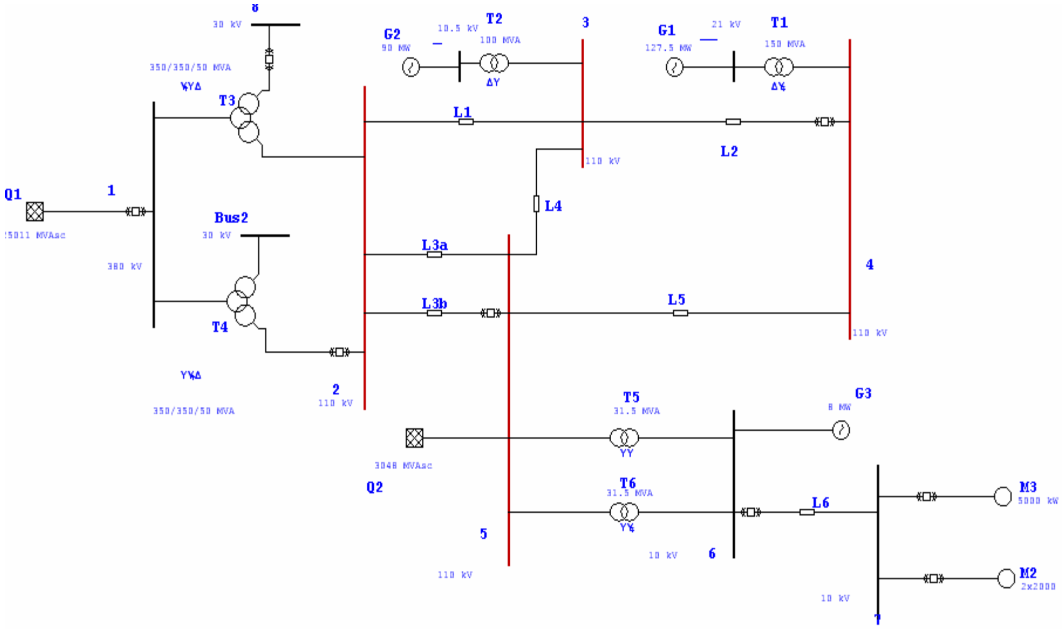
Excerpts from Validation Cases and Comparison Results (TCS-SCIEC-082)

Highlights

- Comparison of ETAP unbalanced fault results against published results in IEC Standard 60909-4 2000 Example 4.
- Compares system results for high and medium voltage systems.
- Compares the initial symmetrical current (I"k).
- Compares the peak current (Ip) for both method B and C.
- Compares the maximum steady state current value (Ik max).
- Compares both balanced 3-phase and unbalanced LG results.

System Description

This is 3-phase system operating at 50Hz. The Utility connection is operating at 380 kV. The utility connection transformers are two 350 MVA (primary winding rating) with 350 MVA 120 kV secondary and 50 MVA 30 kV tertiary windings. The system has two PowerStation units. One is operating at 21 kV and is rated for 150 MVA. The second unit is operating at 10.5 kV and is rated for 100 MVA.



Comparison of Results

The following tables of comparison show the differences between ETAP Results and those published in the IEC Standard example. Please note that the percent difference for the initial symmetrical current (I”k) is less than 0.002 % in most cases. The difference in the peak current values is less than 0.5% in most cases.

	IEC	**ETAP**		**IEC**	**ETAP**		**IEC**	**ETAP**		**IEC**	**ETAP**		**IEC**	**ETAP**	
Bus	**I"K (kA)**	**I"k**	**%Diff**	**Ip(b) (kA)**	**Ip(b)**	**%Diff**	**Ip©**	**Ip©**	**%Diff**	**Ib**	**Ib**	**%Diff**	**Ik (kA)**	**Ik**	**%Diff**
1	40.6447	40.6449	**0.0**	100.577	100.5783	**0.0**	100.568	100.576	**0.0**	40.645	40.64	**-0.0**	40.635	40.635	**0.0**
2	31.7831	31.7817	**-0.0**	80.8249	80.50905	**-0.4**	80.6079	80.6963	**0.1**	31.57	31.576	**0.0**	31.663	31.662	**-0.0**
3	19.673	19.6724	**-0.0**	45.8249	45.82378	**-0.0**	45.8111	45.9764	**0.4**	19.388	19.398	**0.0**	19.623	19.623	**-0.0**
4	16.2277	16.2273	**-0.0**	36.8041	36.80346	**-0.0**	36.8427	37.0397	**0.5**	16.017	16.015	**-0.0**	16.196	16.195	**-0.0**
5	33.1894	33.1873	**-0.0**	83.6266	83.62118	**-0.0**	83.4033	83.5906	**0.2**	32.795	32.807	**0.0**	32.997	32.995	**-0.0**
6	37.5629	37.5626	**-0.0**	99.191	99.19047	**-0.0**	98.1434	99.2752	**1.1**	34.028	34.166	**0.4**	34.356	34.356	**-0.0**
7	25.5895	25.5893	**-0.0**	59.094	59.09395	**0.0**	51.6899	51.8932	**0.4**	23.212	23.305	**0.4**	22.276	22.276	**0.0**
8	13.5778	13.5777	**-0.0**	36.9201	36.92002	**0.0**	36.9227	36.6847	**-0.6**	13.578	13.578	**0.0**	13.573	13.573	**-0.0**

Table 9: Comparison of ETAP 3-phase short-circuit IEC results against IEC Standard example for I”k, Ip and Ik.

	IEC	**ETAP**		**IEC**	**ETAP**	
Bus	**I"K LG**	**I"K LG**	**%Diff**	**Ip© LG**	**Ip© LG**	**%Diff**
2	15.9722	15.972	**-0.0**	40.5086	40.553	**0.1**
3	10.4106	10.41	**-0.0**	24.2424	24.33	**0.4**
4	9.0498	9.049	**-0.0**	20.5463	20.655	**0.5**
5	17.0452	17.045	**-0.0**	42.8337	42.931	**0.2**

Table 10: Comparison of ETAP unbalanced short-circuit IEC results against IEC Standard example for I”k and Ip.

Reference

1. IEC Standard 60909-4 2000, Example 4.
2. ETAP Short Circuit IEC V&V Documents, Case Number TCS-SCIEC-082.

ETAP Arc Flash Analysis

The ETAP V&V process for the Arc Flash program has over 900 test case scenarios that are run before each ETAP release. The following cases are excerpts from the Arc Flash V&V documentation.

Arc Flash Comparison Case # 1

Comparison of ETAP Arc Flash Results against hand calculated results based on IEEE Standards

Excerpts from Validation Cases and Comparison Results (TCS-SC-120)

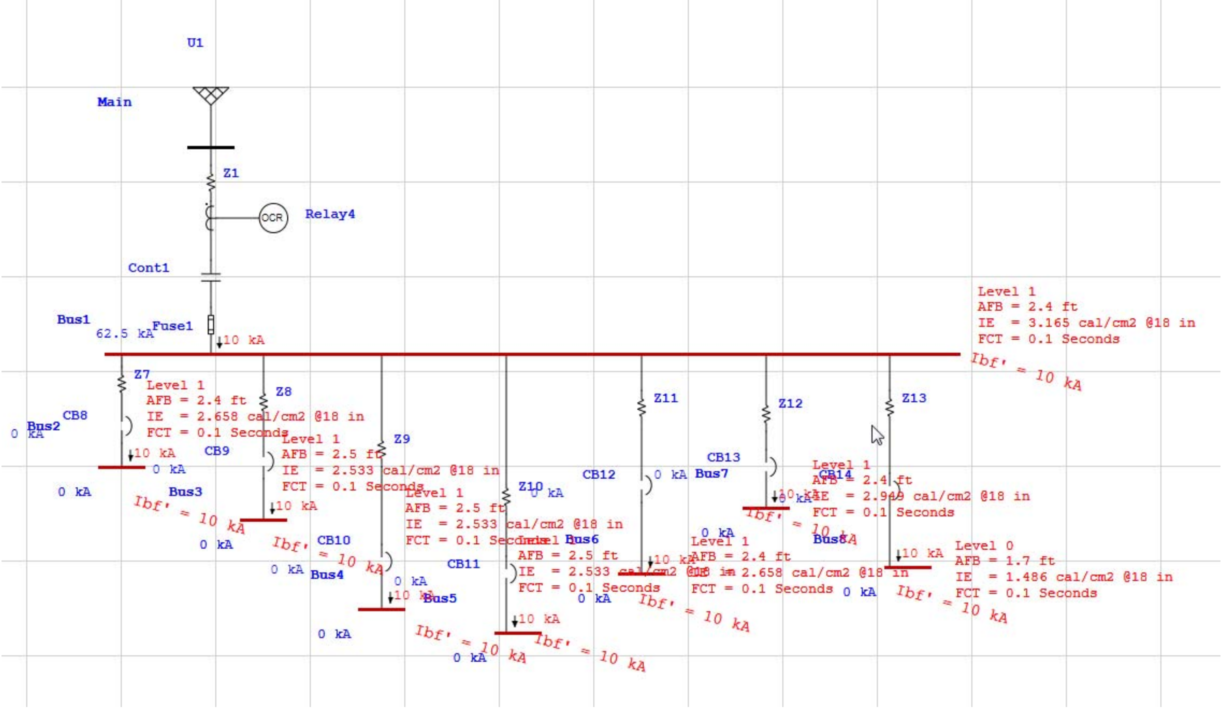
Highlights:

- Comparison of ETAP Arc-Flash analysis results against hand calculated results based on the equations listed in IEEE standard 1584 2002.
- The calculations include both open air and enclosed equipment
- The calculation results are within the specified range of validity of the IEEE 1584 Equations.
- The hand calculated results were developed based on a program developed in Matlab version 6.5.0 Release 13.0.1
- ETAP results and the Matlab hand calculated results have a percent difference less than 0.001% in all cases.

System Description:
The Arc-Flash calculation in ETAP for different bus voltages and input parameters was entered into different Buses in the program. Each bus had a different type of equipment as described in the IEEE standard. The following types of equipment were described for each bus at different voltage levels.

- MCC
- Switchgear
- Switchboard
- Switchrack
- Panelboard
- Cable Bus
- Open Air

Typical Gaps and X-factors were used for the calculation.
The Incident energy and the Flash Protection Boundary were calculated based on a Fault Clearing Time (arc fault clearing time) of 0.1 seconds.


U1
Main
Z1
Relay4
OCR
Cont1
Bus1
62.5 kA
Fuse1
10 kA
Level 1
AFB = 2.4 ft
IE = 3.165 cal/cm2 @18 in
FCT = 0.1 Seconds
Ibf' = 10 kA
Z7
Level 1
AFB = 2.4 ft
IE = 2.658 cal/cm2 @18 in
FCT = 0.1 Seconds
CB8
Bus2
0 kA
10 kA
0 kA
0 kA
Ibf' = 10 kA
Z8
CB9
Bus3
Level 1
AFB = 2.5 ft
IE = 2.533 cal/cm2 @18 in
FCT = 0.1 Seconds
10 kA
0 kA
Ibf' = 10 kA
Z9
CB10
Bus4
0 kA
Level 1
AFB = 2.5 ft
IE = 2.533 cal/cm2 @18 in
FCT = 0.1 Seconds
0 kA
10 kA
Bus5
0 kA
Ibf' = 10 kA
Z10
0 kA
CB11
Level 1
Bus6
AFB = 2.5 ft
IE = 2.533 cal/cm2 @18 in
FCT = 0.1 Seconds
10 kA
0 kA
0 kA
Ibf' = 10 kA
Z11
CB12
0 kA
Bus7
10 kA
0 kA
Level 1
AFB = 2.4 ft
IE = 2.658 cal/cm2 @18 in
FCT = 0.1 Seconds
Ibf' = 10 kA
Z12
CB13
10 kA
0 kA
Ibf' = 10 kA
Level 1
CB14
AFB = 2.4 ft
IE = 2.949 cal/cm2 @18 in
FCT = 0.1 Seconds
Bus8
Z13
10 kA
0 kA
Level 0
AFB = 1.7 ft
IE = 1.486 cal/cm2 @18 in
FCT = 0.1 Seconds
Ibf' = 10 kA

		Hand Calculated (Matlab)				ETAP results (Editors)				%Diff (Hand Calcs vs. ETAP)			
Bus ID	**Type**	**Ia (kA)**	**E (Cal/cm^2)**	**FPB (ft)**	**Level**	**Ia (kA)**	**E (Cal/cm^2)**	**FPB (ft)**	**Level**	**Ia %**	**E**	**FPB**	**Level**
Bus2	MCC	6.2952	2.6575	2.4412	1	6.29518	2.65848	2.43507	1	0.0	0.0	0.3	0.0
Bus3	Switchgear	6.2952	2.5319	2.4972	1	6.29518	2.53268	2.49017	1	0.0	0.0	0.3	0.0
Bus4	Switchboard	6.2952	2.5319	2.4972	1	6.29518	2.53268	2.49017	1	0.0	0.0	0.3	0.0
Bus5	Switchrack	6.2952	2.5319	2.4972	1	6.29518	2.53268	2.49017	1	0.0	0.0	0.3	0.0
Bus6	Panelboard	6.2952	2.6575	2.4412	1	6.29518	2.65848	2.43507	1	0.0	0.0	0.3	0.0
Bus7	Cable Bus	6.2952	2.9474	2.3557	1	6.29518	2.94864	2.35082	1	0.0	0.0	0.2	0.0
Bus8	Open Air	5.5336	1.4856	1.6724	0	5.53361	1.48623	1.66898	0	0.0	0.0	0.2	0.0
Bus10	MCC	14.4556	2.713	4.6449	1	14.45560	2.71354	4.62515	1	0.0	0.0	0.4	0.0
Bus11	Switchgear	14.4556	2.713	4.6449	1	14.45560	2.71354	4.62515	1	0.0	0.0	0.4	0.0
Bus12	Switchboard	14.4556	2.713	4.6449	1	14.45560	2.71354	4.62515	1	0.0	0.0	0.4	0.0
Bus13	Switchrack	14.4556	2.713	4.6449	1	14.45560	2.71354	4.62515	1	0.0	0.0	0.4	0.0
Bus14	Panelboard	14.4556	2.713	4.6449	1	14.45560	2.71354	4.62515	1	0.0	0.0	0.4	0.0
Bus15	Cable Bus	14.4556	2.7148	3.0145	1	14.45560	2.71596	3.00822	1	0.0	0.0	0.2	0.0
Bus16	Open Air	14.4556	1.573	2.2946	0	14.45560	1.57371	2.28986	0	0.0	0.0	0.2	0.0
Bus19	Cable Bus	23.8881	2.1736	4.0459	1	23.88808	2.17448	4.03754	1	0.0	0.0	0.2	0.0
Bus20	Open Air	23.8881	1.1923	3.0798	0	23.88808	1.19277	3.07338	0	0.0	0.0	0.2	0.0
Bus21	MCC	23.8881	2.9731	8.5052	1	23.88808	2.97367	8.46903	1	0.0	0.0	0.4	0.0
Bus22	Switchgear	23.8881	2.4898	8.5052	1	23.88808	2.49028	8.46903	1	0.0	0.0	0.4	0.0
Bus23	Switchboard	23.8881	3.294	8.5052	1	23.88808	3.29469	8.46903	1	0.0	0.0	0.4	0.0
Bus24	Switchrack	23.8881	4.2065	8.5052	2	23.88808	4.20738	8.46903	2	0.0	0.0	0.4	0.0
Bus25	Panelboard	23.8881	3.294	8.5052	1	23.88808	3.29469	8.46903	1	0.0	0.0	0.4	0.0
Bus26	Other	23.8881	2.1736	4.0459	1	23.88808	2.17448	4.03754	1	0.0	0.0	0.2	0.0
Bus37	Cable Bus	71.737	81.5412	33.0399	4	71.73701	81.56799	33.03988	4	0.0	0.0	0.0	0.0
Bus38	Open Air	71.737	36.2405	33.0399	4	71.73701	36.25244	33.03988	4	0.0	0.0	0.0	0.0
Bus39	MCC	71.737	18.7871	33.0399	3	71.73701	18.79327	33.03988	3	0.0	0.0	0.0	0.0
Bus40	Switchgear	71.737	13.0466	33.0399	3	71.73701	13.05088	33.03988	3	0.0	0.0	0.0	0.0
Bus41	Switchboard	71.737	81.5412	33.0399	4	71.73701	81.56799	33.03988	4	0.0	0.0	0.0	0.0
Bus42	Switchrack	71.737	23.7181	33.0399	3	71.73701	23.72587	33.03988	3	0.0	0.0	0.0	0.0
Bus43	Panelboard	71.737	92.7758	33.0399	4	71.73701	92.80625	33.03988	4	0.0	0.0	0.0	0.0
Bus44	Other	71.737	8.3498	33.0399	3	71.73701	8.35256	33.03988	3	0.0	0.0	0.0	0.0

Reference:

1. IEEE standard 1584 2002 Pages 4-13
2. ETAP Short Circuit ANSI V&V Documents, Case Number TCS-SC-120

Arc Flash Comparison Case # 2

Verification of ETAP Arc Flash NFPA 70E results against Hand Calculations

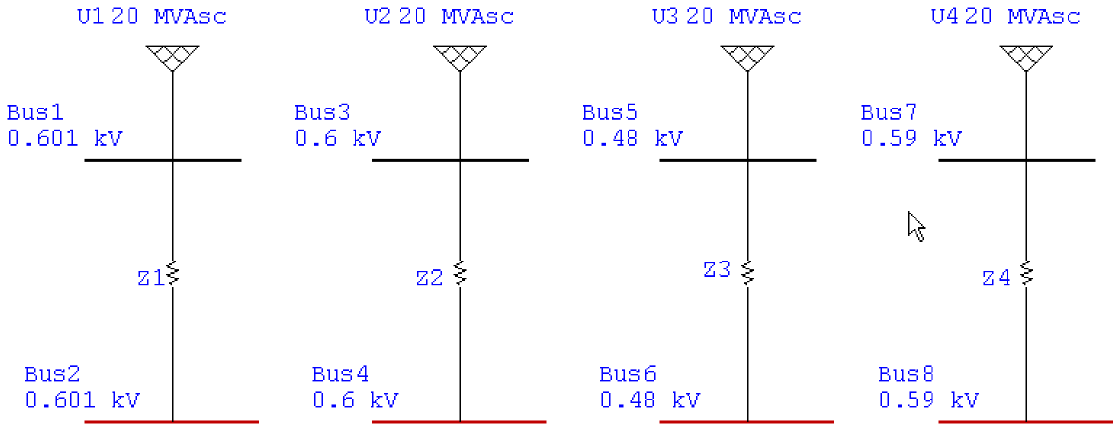
Excerpts from Validation Cases and Comparison Results (TCS-SC-157)

Highlights

- Comparison of ETAP Arc Flash results for Open-air Systems rated higher than 600 Volts against hand calculated values based on equations listed in Standard NFPA 70E 2004.
- The incident energy results and Flash Protection Boundaries have been determined based several working distances and Fault clearing times.
- The hand calculations were created based on the equations shown in the standard with the help of a calculation program called MathCAD Professional version 2000.
- In all cases, the percent difference between hand calculations and ETAP results is less than 1%.

System Description

The systems consist of multiple faulted buses that are configured to test all the situations that are related to a 600 Volt system. Each faulted bus tests a different situation, which includes open-air systems rated at 600 Volts, above or below. In all cases, the buses are energized by Power Grids.



The following is a sample of the MathCAD calculations for a fault at Bus2 based on ANSI short-circuit calculations.

For a fault at Bus2 (ANSI)

$$f := 60$$

$$t_a := \begin{pmatrix} 0.25 \\ 0.5 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 8 \\ 10 \\ 30 \\ 40 \\ 50 \\ 60 \\ 70 \\ 80 \\ 90 \\ 100 \\ 110 \\ 120 \end{pmatrix} \qquad V := \begin{pmatrix} 0.601 \\ 0.601 \\ 0.601 \\ 0.601 \\ 0.601 \\ 0.601 \\ 0.601 \\ 0.601 \\ 0.601 \\ 0.601 \\ 0.601 \\ 0.601 \\ 0.601 \\ 0.601 \\ 0.601 \\ 0.601 \\ 0.601 \\ 0.601 \\ 0.601 \end{pmatrix} \qquad F := \begin{pmatrix} 18.095 \\ 18.095 \\ 18.095 \\ 18.095 \\ 18.095 \\ 18.095 \\ 18.095 \\ 18.095 \\ 18.095 \\ 18.095 \\ 18.095 \\ 18.095 \\ 18.095 \\ 18.095 \\ 18.095 \\ 18.095 \\ 18.095 \\ 18.095 \\ 18.095 \end{pmatrix}$$

$$E_{18} := \overrightarrow{\left(\frac{793 \cdot F \cdot V \cdot \frac{t_a}{60}}{18^2}\right)} \qquad E_{24} := \overrightarrow{\left(\frac{793 \cdot F \cdot V \cdot \frac{t_a}{60}}{24^2}\right)} \qquad E_{30} := \overrightarrow{\left(\frac{793 \cdot F \cdot V \cdot \frac{t_a}{60}}{30^2}\right)} \qquad E_{36} := \overrightarrow{\left(\frac{793 \cdot F \cdot V \cdot \frac{t_a}{60}}{36^2}\right)}$$

$$E_{48} := \overrightarrow{\left(\frac{793 \cdot F \cdot V \cdot \frac{t_a}{f}}{48^2}\right)} \qquad FPB := \overrightarrow{\left[\left(2.65 \cdot \sqrt{3} \cdot V \cdot F \cdot \frac{t_a}{f}\right)^{0.5}\right]}$$

FPB =

	0
0	0.456
1	0.645
2	1.29
3	1.58
4	1.824
5	2.04
6	2.234
7	2.58
8	2.884
9	4.996
10	5.769
11	6.45
12	7.065
13	7.631
14	8.158
15	8.653
16	9.121
17	9.566
18	9.992
19	
20	

E_{18} =

	0
0	0.111
1	0.222
2	0.887
3	1.331
4	1.774
5	2.218
6	2.662
7	3.549
8	4.436
9	13.309
10	17.745
11	22.181
12	26.617
13	31.053
14	35.49
15	39.926
16	44.362
17	48.798
18	53.234
19	

E_{24} =

	0
0	0.062
1	0.125
2	0.499
3	0.749
4	0.998
5	1.248
6	1.497
7	1.996
8	2.495
9	7.486
10	9.981
11	12.477
12	14.972
13	17.467
14	19.963
15	22.458
16	24.954
17	27.449
18	29.944
19	

E_{30} =

	0
0	0.04
1	0.08
2	0.319
3	0.479
4	0.639
5	0.799
6	0.958
7	1.278
8	1.597
9	4.791
10	6.388
11	7.985
12	9.582
13	11.179
14	12.776
15	14.373
16	15.97
17	17.567
18	19.164
19	

E_{36} =

	0
0	0.028
1	0.055
2	0.222
3	0.333
4	0.444
5	0.555
6	0.665
7	0.887
8	1.109
9	3.327
10	4.436
11	5.545
12	6.654
13	7.763
14	8.872
15	9.981
16	11.09
17	12.2
18	13.309
19	

E_{48} =

	0
0	0.016
1	0.031
2	0.125
3	0.187
4	0.25
5	0.312
6	0.374
7	0.499
8	0.624
9	1.872
10	2.495
11	3.119
12	3.743
13	4.367
14	4.991
15	5.615
16	6.238
17	6.862
18	7.486
19	

Comparison of Results:

The following table of comparison shows the differences between ETAP Results and those calculated by Hand using the MathCAD program for the NFPA 70E Arc-Flash method. The difference in all cases is smaller than 1%.

	Hand Calculations						ETAP Results					
Arc duration		Incident Energy (Cal/cm^2)						Incident Energy (Cal/cm^2)				
Cycles	**FPB (ft)**	**18 in.**	**E24 in.**	**E30 in.**	**E36 in.**	**E48 in.**	**FPB (ft)**	**18 in.**	**E24 in.**	**E30 in.**	**E36 in.**	**E48 in.**
0.250	0.456	0.111	0.062	0.040	0.028	0.016	0.456	0.111	0.062	0.040	0.028	0.016
0.500	0.645	0.222	0.125	0.080	0.055	0.031	0.645	0.222	0.125	0.080	0.055	0.031
2.000	1.290	0.887	0.499	0.319	0.222	0.125	1.290	0.887	0.499	0.319	0.222	0.125
3.000	1.580	1.331	0.749	0.479	0.333	0.187	1.580	1.331	0.749	0.479	0.333	0.187
4.000	1.824	1.774	0.998	0.639	0.444	0.250	1.824	1.775	0.998	0.639	0.444	0.250
5.000	2.040	2.218	1.248	0.799	0.555	0.312	2.040	2.218	1.248	0.799	0.555	0.312
6.000	2.234	2.662	1.497	0.958	0.665	0.374	2.234	2.662	1.497	0.958	0.665	0.374
8.000	2.580	3.549	1.996	1.278	0.887	0.499	2.580	3.549	1.996	1.278	0.887	0.499
10.000	2.884	4.436	2.495	1.597	1.109	0.624	2.884	4.436	2.495	1.597	1.109	0.624
30.000	4.996	13.309	7.486	4.791	3.327	1.872	4.996	13.309	7.486	4.791	3.327	1.872
40.000	5.769	17.745	9.981	6.388	4.436	2.495	5.769	17.745	9.982	6.388	4.436	2.495
50.000	6.450	22.181	12.477	7.985	5.545	3.119	6.450	22.181	12.477	7.985	5.545	3.119
60.000	7.065	26.617	14.972	9.582	6.654	3.743	7.065	26.618	14.972	9.582	6.654	3.743
70.000	7.631	31.053	17.467	11.179	7.763	4.367	7.631	31.054	17.468	11.179	7.763	4.367
80.000	8.158	35.490	19.963	12.776	8.872	4.991	8.158	35.490	19.963	12.776	8.873	4.991
90.000	8.653	39.926	22.458	14.373	9.981	5.615	8.653	39.926	22.459	14.374	9.982	5.615
100.000	9.121	44.362	24.954	15.970	11.090	6.238	9.121	44.363	24.954	15.971	11.091	6.239
110.000	9.566	48.798	27.449	17.567	12.200	6.862	9.566	48.799	27.449	17.568	12.200	6.862

Table 1: ETAP Arc-Flash NFPA 70E Results and Hand Calculated results

Arc duration	% Difference between ETAP and Hand Calcs					
Cycles	**FPB (ft)**	**18 in.**	**E24 in.**	**E30 in.**	**E36 in.**	**E48 in.**
0.250	0.09%	0.18%	0.18%	0.18%	0.18%	0.18%
0.500	0.09%	0.18%	0.18%	0.18%	0.18%	0.18%
2.000	0.09%	0.18%	0.18%	0.18%	0.18%	0.18%
3.000	0.09%	0.18%	0.18%	0.18%	0.18%	0.18%
4.000	0.09%	0.18%	0.18%	0.18%	0.18%	0.18%
5.000	0.09%	0.18%	0.18%	0.18%	0.18%	0.18%
6.000	0.09%	0.18%	0.18%	0.18%	0.18%	0.18%
8.000	0.09%	0.18%	0.18%	0.18%	0.18%	0.18%
10.000	0.09%	0.18%	0.18%	0.18%	0.18%	0.18%
30.000	0.09%	0.18%	0.18%	0.18%	0.18%	0.18%
40.000	0.09%	0.18%	0.18%	0.18%	0.18%	0.18%
50.000	0.09%	0.18%	0.18%	0.18%	0.18%	0.18%
60.000	0.09%	0.18%	0.18%	0.18%	0.18%	0.18%
70.000	0.09%	0.18%	0.18%	0.18%	0.18%	0.18%
80.000	0.09%	0.18%	0.18%	0.18%	0.18%	0.18%
90.000	0.09%	0.18%	0.18%	0.18%	0.18%	0.18%
100.000	0.09%	0.18%	0.18%	0.18%	0.18%	0.18%
110.000	0.09%	0.18%	0.18%	0.18%	0.18%	0.18%
120.000	0.09%	0.18%	0.18%	0.18%	0.18%	0.18%

Table 2: Comparison of ETAP Arc-Flash results against Hand Calculated values based on Section D.7 of NFPA 70E 2004.

Reference

1. Standard NFPA 70E 2004 Section D.7
2. ETAP Short Circuit ANSI V&V Documents, Case Number TCS-SC-157.

ETAP Motor Acceleration Analysis

The ETAP V&V process for the Motor Acceleration program has over 1600 test case scenarios that are run before each ETAP release. The following cases are excerpts from the Motor Starting V&V documentation.

Motor Acceleration Comparison Case # 1

Comparison of ETAP Motor Acceleration with Torque Control Against Hand Calculated Results

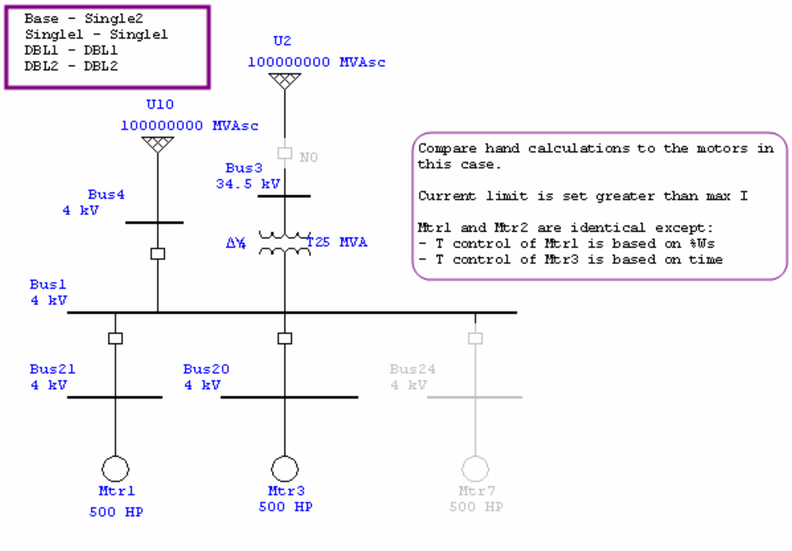
Excerpts from Validation Cases and Comparison Results (TCS-MS-149)

Highlights

- Comparison of ETAP Motor Acceleration results against Hand Calculations.
- Torque Control Solid-State Motor Starting Device is used to start the motor.
- Single1, Single2, Double1 and Double2 CKT models are used in the hand calculation.
- Motor is rated at 500 HP at 4 kV, RPM = 1800, %PF = 89.85 and %Eff = 94.14.
- The compared results include the motor Power Output, Reactive Power Input, Motor Current, Terminal Voltage and Power Factor at different Slip values.
- Hand Calculations were accomplished using MathCAD version 2000. The equations for the motor modeling were obtained from different sources.
- The same system was used for the different motor CKT models.

System Description

This is a 3-Phase system that consists of three induction motors. One of the induction motors at the 0.480 kV bus is being started at t = 0 sec. The CKT model parameters are as shown on the Model page. The motor being started is **50St100Ld-1**.



Base - Single2
Single1 - Single1
DBL1 - DBL1
DBL2 - DBL2

Compare hand calculations to the motors in this case.

Current limit is set greater than max I

Mtr1 and Mtr2 are identical except:
- T control of Mtr1 is based on %Ws
- T control of Mtr3 is based on time

The following is a sample of the hand calculations that were performed for each motor model.

Hand Calc's

Single2 Model:

$\mathrm{MotorkV} := 4$

$\mathrm{MotorMVA} := 0.4408$

$Z_B := \dfrac{\mathrm{MotorkV}^2}{\mathrm{MotorMVA}}$ $\quad Z_B = 36.29764$

$R_{2LR} := 0.0123 \cdot Z_B$ $\quad R_{2LR} = 0.44646$

$R_1 := 0.0383 \cdot Z_B$

$R_{2FL} := 0.0152 \cdot Z_B$ $\quad R_{2FL} = 0.55172$

$X_1 := 0.1029 \cdot Z_B$

$X_{2LR} := 0.093 \cdot Z_B$ $\quad X_{2LR} = 3.37568$

$Xm := 3.652 \cdot Z_B$

$X_{2FL} := 0.1167 \cdot Z_B$ $\quad X_{2FL} = 4.23593$

Find rated slip using trial and error until current (I1) is satisfied:

$s_{rated} := 0.0155022$

$R_2 := (R_{2FL} - R_{2LR}) \cdot (1 - s_{rated}) + R_{2LR}$ $\quad R_2 = 0.55009$

$X_2 := (X_{2FL} - X_{2LR}) \cdot (1 - s_{rated}) + X_{2LR}$ $\quad X_2 = 4.2226$

$$Zeq := R_1 + X_1 i + \left(\frac{1}{Xmi} + \frac{1}{\dfrac{R_2}{s_{rated}} + X_2 \cdot i} \right)^{-1}$$

$Zeq = 32.61631 + 15.92816i$

$$I_1 := \frac{\dfrac{\mathrm{MotorkV} \cdot 1000}{\sqrt{3}}}{|Zeq|}$$

$I_1 = 63.62373$

Calculate the relationship (K) between Pout and Pag to compensate for rotational losses:

$PF := \cos(\arg(Zeq))$ $\quad PF = 0.89858$

$P_{ag} := \sqrt{3} \cdot \mathrm{MotorkV} \cdot I_1 \cdot PF - \dfrac{(3 I_1{}^2 \cdot R_1)}{1000}$ $\quad P_{ag} = 379.20791$

$Pconv := (1 - s_{rated}) \cdot P_{ag}$ $\quad Pconv = 373.32935$

$Pout_{rated} := 500 \cdot 0.7457$ $\quad Pout_{rated} = 372.85$

$K_{ga} := \dfrac{P_{ag}}{Pout_{rated}}$ $\quad \boxed{K_{ga} = 1.01705}$

Comparison of Results

The following tables of comparisons illustrate the comparisons made between ETAP Motor Acceleration and the MathCAD hand calculations. Please note that in all cases, the % difference for all the compared parameters is less than 0.1%.

Single2 Model:

		Benchmark		ETAP		% Diff	
S (pu)	**t (s)**	**P (kW)**	**Q (kvar)**	**P (kW)**	**Q (kvar)**	**P (%)**	**Q (%)**
0.899978	0.876	7.45864	1558.67	7.45861	1558.58	**0.0**	**0.0**
0.699989	2.362	32.1615	1605.76	32.1615	1605.66	**0.0**	**0.0**
0.689957	2.416	35.0731	1634.12	35.0731	1634.02	**0.0**	**0.0**
0.670009	2.517	41.2157	1684.88	41.2158	1684.78	**0.0**	**0.0**
0.62994	2.722	47.4067	1647.67	47.4068	1647.57	**0.0**	**0.0**
0.55019	3.237	58.7214	1542.35	58.7214	1542.26	**0.0**	**0.0**
0.250022	4.417	332.613	1749.12	332.525	1749	**0.0**	**0.0**
0.013967	10	336.174	179.364	336.174	179.312	**0.0**	**0.0**

Double1 Model:

		Benchmark		ETAP		% Diff	
S(pu)	**t (s)**	**P (kW)**	**Q (kvar)**	**P (kW)**	**Q (kvar)**	**P (%)**	**Q (%)**
0.900043	1.369	5.59035	2332.06	5.59033	2332.38	**0.0**	**0.0**
0.749985	2.831	17.7119	2400.7	17.7119	2401.03	**0.0**	**0.0**
0.739948	2.911	18.7474	2405.82	18.7473	2406.15	**0.0**	**0.0**
0.720057	3.072	20.8734	2414.29	20.8734	2414.61	**0.0**	**0.0**
0.690032	3.331	23.6091	2389.87	23.6091	2390.19	**0.0**	**0.0**
0.619981	4.126	29.7549	2299.64	29.7549	2299.95	**0.0**	**0.0**
0.499961	5.21	73.4686	2829.61	73.4686	2829.61	**0.0**	**0.0**
0.249992	7.744	215.571	2794.31	215.571	2794.69	**0.0**	**0.0**
0.003514	10	344.09	168.2	344.09	168.321	**0.0**	**0.1**

Double2 Model:

		Benchmark		ETAP		% Diff	
S(pu)	**t (s)**	**P (kW)**	**Q (kvar)**	**P (kW)**	**Q (kvar)**	**P (%)**	**Q (%)**
0.89999	1.364	5.5933	1072.45	5.5933	1072.48	**0.0**	**0.0**
0.749945	2.82	17.716	1136.02	17.716	1136.06	**0.0**	**0.0**
0.739993	2.899	18.7427	1141.19	18.7426	1141.23	**0.0**	**0.0**
0.720021	3.06	20.8773	1151.11	20.8773	1151.15	**0.0**	**0.0**
0.689995	3.318	23.6125	1149.11	23.6126	1149.14	**0.0**	**0.0**
0.620011	4.109	29.7526	1132.15	29.7526	1132.19	**0.0**	**0.0**
0.499838	4.515	408.839	3357.97	408.84	3358.07	**0.0**	**0.0**
0.249964	4.677	578.276	2995.05	578.275	2995.15	**0.0**	**0.0**
0.003522	10	344.084	164.803	344.084	164.83	**0.0**	**0.0**

Table 14: Comparison of ETAP Motor Starting Results with a Torque Control Starting Device against Hand Calculations at various Motor Slip points.

Single1 Model:

		Benchmark		ETAP		% Diff	
S (pu)	t (s)	P (kW)	Q (kvar)	P (kW)	Q (kvar)	P (%)	Q (%)
0.900008	0.835	7.4564	1473.97	7.45639	1473.88	**0.0**	**0.0**
0.699987	2.252	32.1621	1555.32	32.162	1555.22	**0.0**	**0.0**
0.690051	2.303	35.0452	1585.36	35.0451	1585.26	**0.0**	**0.0**
0.66996	2.4	41.2247	1640.66	41.2247	1640.55	**0.0**	**0.0**
0.629982	2.595	47.4	1610.61	47.4	1610.5	**0.0**	**0.0**
0.550047	3.086	58.7177	1518.09	58.7177	1518	**0.0**	**0.0**
0.249183	3.67	1209.53	3005.72	1209.53	3005.72	**0.0**	**0.0**
0.01304	10	336.877	174.338	336.877	174.495	**0.0**	**0.1**

Table 15: Comparison of ETAP Motor Starting Results with a Torque Control Starting Device against Hand Calculations at various Motor Slip points.

Characteristic Model:

		Benchmark			
S (pu)	t (s)	V (%)	I (%)	PF (%)	Q (kvar)
0.900083	0.838	72.2158	359.635	25.803	1557.5
0.689961	2.354	76.409	373.631	27.883	1609.15
0.67999	2.407	77.88	380.351	28.024	1636.17
0.599963	2.822	78.7452	380.733	29.146	1633.47
0.500036	3.645	72.5149	344.736	31.038	1480.61
0.013515	10	99.9902	144.196	82.498	359.303

		ETAP			
S (pu)	t (s)	V (%)	I (%)	PF (%)	Q (kvar)
0.900083	0.838	72.2145	359.664	25.79	1557.54
0.689961	2.354	76.4068	373.627	27.872	1609.03
0.67999	2.407	77.8787	380.353	28.012	1636.07
0.599963	2.822	78.7406	380.735	29.14	1633.38
0.500036	3.645	72.5145	344.72	31.03	1480.44
0.013515	10	100.008	144.195	82.49391	359.351

		% Diff			
S (pu)	t (s)	V (%)	I (%)	PF (%)	Q (kvar)
0.900083	0.838	**-0.0**	**0.0**	**-0.1**	**0.0**
0.689961	2.354	**-0.0**	**-0.0**	**0.0**	**0.0**
0.67999	2.407	**-0.0**	**0.0**	**0.0**	**0.0**
0.599963	2.822	**-0.0**	**0.0**	**0.0**	**0.0**
0.500036	3.645	**-0.0**	**-0.0**	**0.0**	**0.0**
0.013515	10	**0.0**	**-0.0**	**0.0**	**0.0**

Table 16: Comparison of ETAP Motor Starting Results with a Torque Control Starting Device against Hand Calculations at various Motor Slip points.

Reference

1. ETAP Motor Acceleration V&V Documents, Case Number TCS-MS-149.

2. Motor Acceleration Comparison Case # 2

Comparison of ETAP Motor Acceleration Results Against Transient Stability

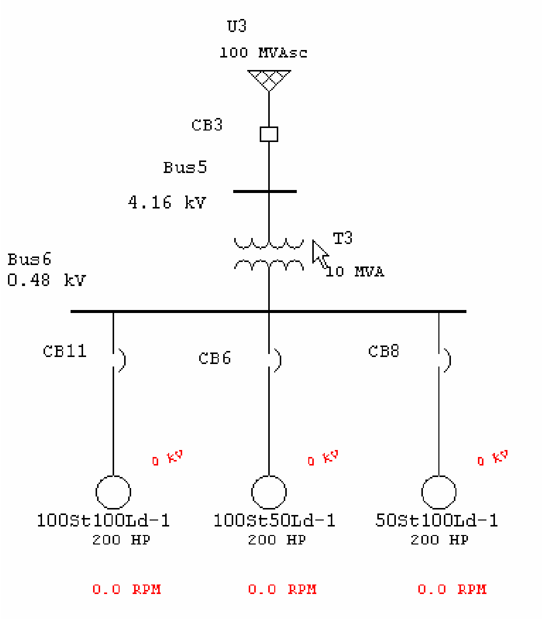
Excerpts from Validation Cases and Comparison Results (TCS-MS-083)

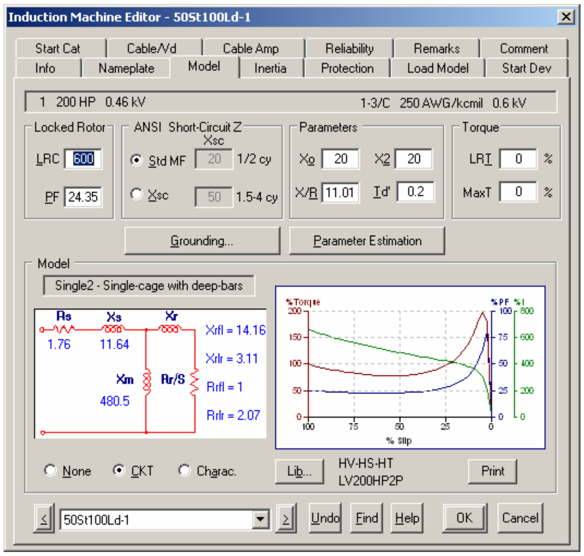
Highlights

- Comparison of ETAP Motor Acceleration results against Transient Stability results that have been validated against field measured data and hand calculations.
- Motor is rated at 200 HP at 0.46 kV. RPM = 1800. %PF = 91.71 and %Eff = 92.75.
- Motor CKT model is a Single (Single-cage with deep bars).
- The mechanical load model (Torque) is represented by the following polynomial equation T = 100 * ω (constant slope ramping load).
- The compared results include the motor current, motor real and reactive power demand and the motor slip. Please note that the Motor Starting study is able to predict the acceleration time very accurately.
- Refer to cases 1 to 5 published in http://www.etap.com/qa_tsvvcasedocs.htm for some TS validation results.

System Description

This is 3-Phase system that consists of three induction motors. One of the induction motors at the 0.480 kV bus is being started at t = 0 sec. The CKT model parameters are as shown on the Model page. The motor being started is **50St100Ld-1**.





Induction Machine Editor - 50St100Ld-1

1 200 HP 0.46 kV 1-3/C 250 AWG/kcmil 0.6 kV

Locked Rotor: LRC 600, PF 24.35

ANSI Short-Circuit Z, Xsc: ● Std MF 20 1/2 cy; ○ Xsc 50 1.5-4 cy

Parameters: Xo 20, X2 20, X/R 11.01, Id' 0.2

Torque: LRT 0 %, MaxT 0 %

Model: Single2 - Single-cage with deep-bars

Rs 1.76, Xs 11.64, Xm 480.5

Xrfl = 14.16
Xrlr = 3.11
Rrfl = 1
Rrlr = 2.07

○ None ● CKT ○ Charac.

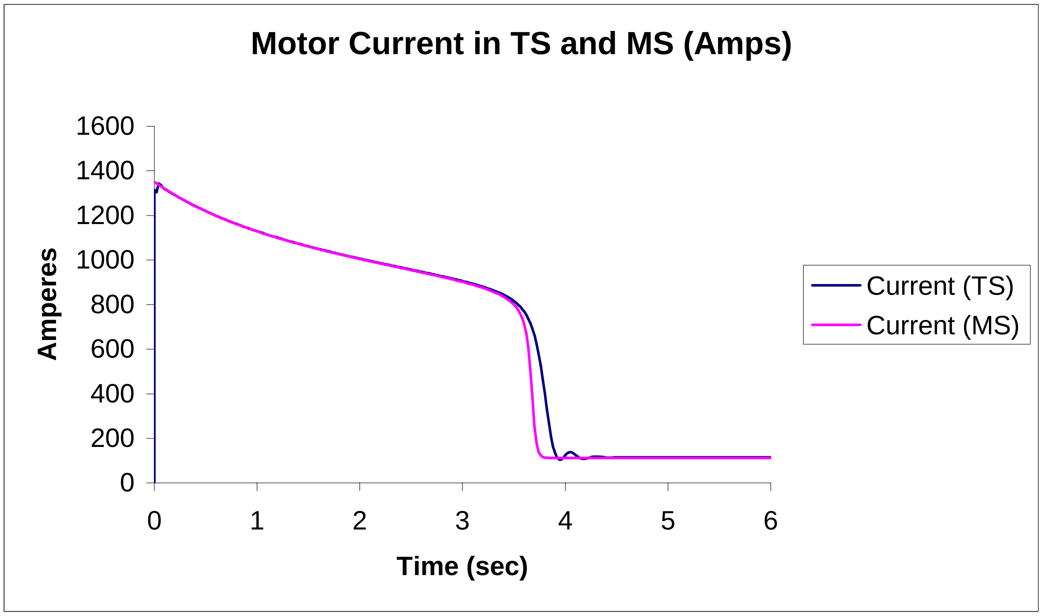
HV-HS-HT
LV200HP2P

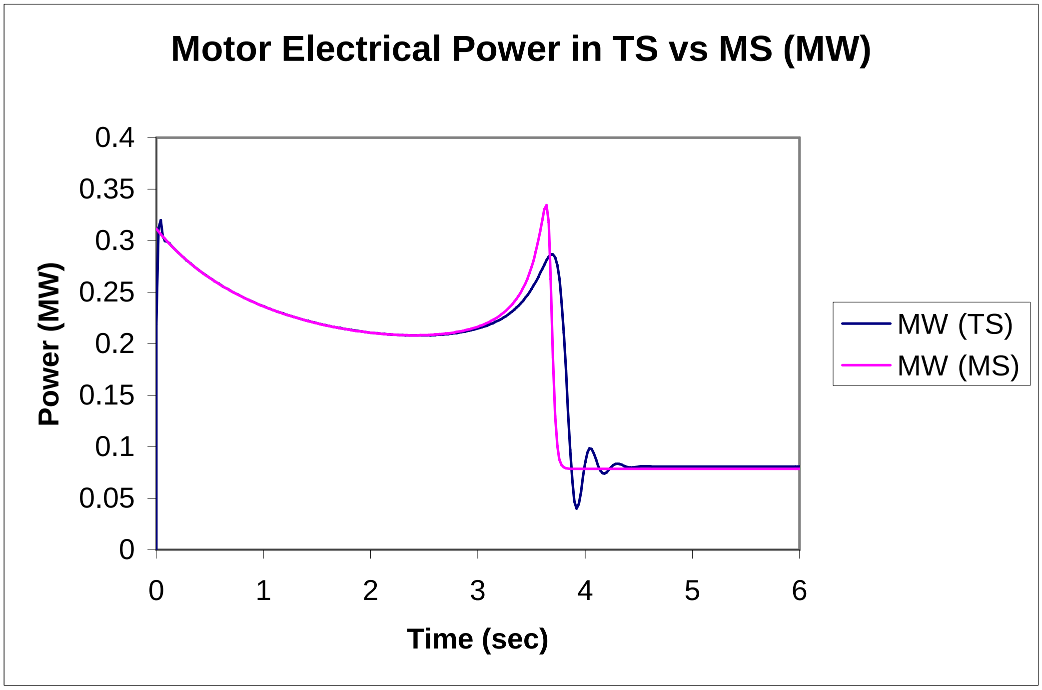
50St100Ld-1

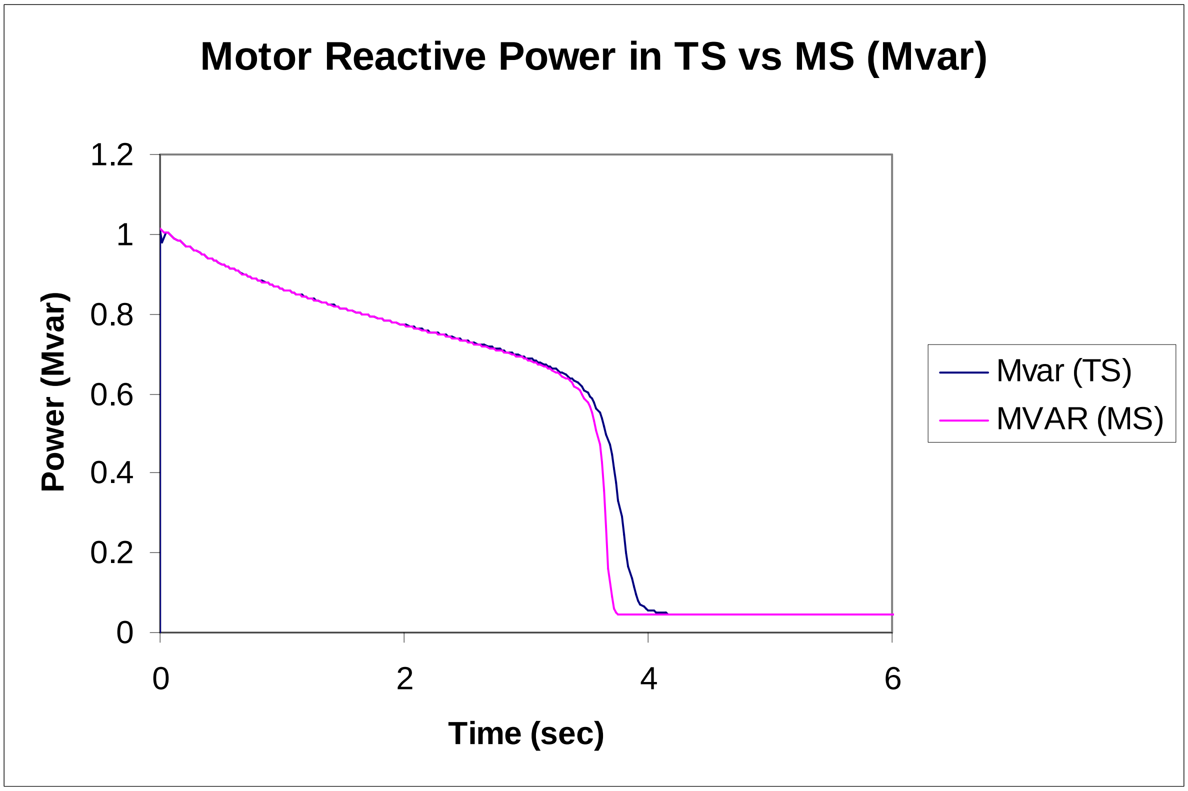
Comparison of Results

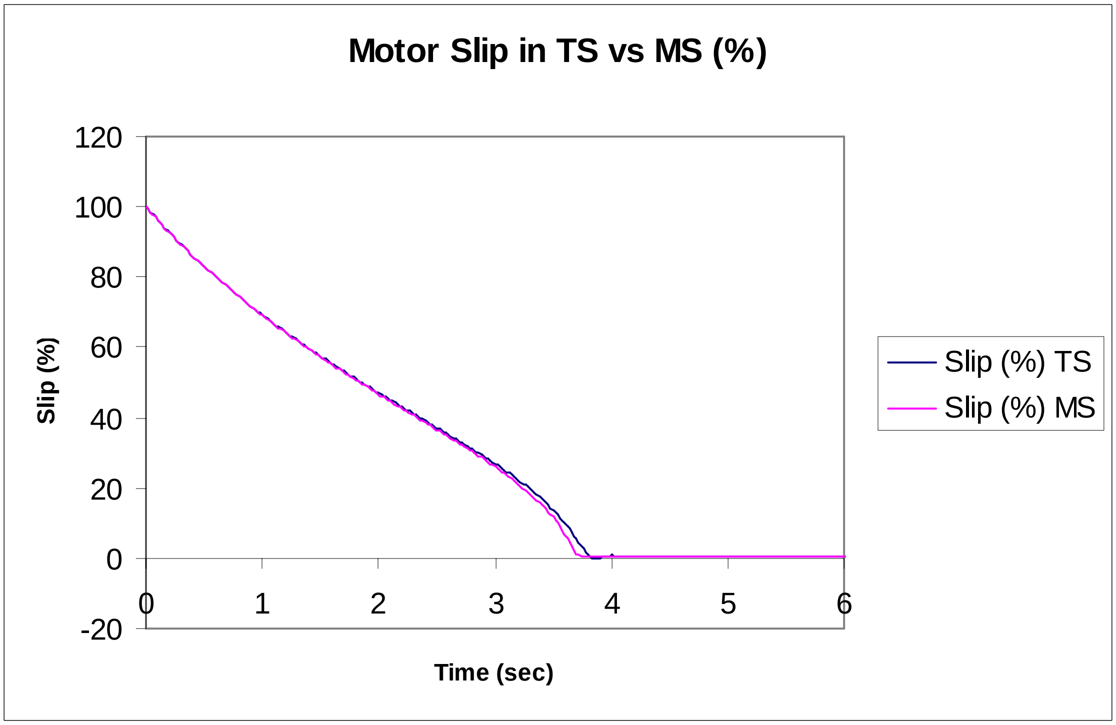
The following plots show the similarity between motor acceleration results obtained using ETAP Motor Acceleration and those obtained using ETAP Transient Stability. The TS model has been validated against hand calculations and field measured results as shown in the TS Verification & Validation Test Cases published on the ETAP Web site.

The compared plots are the Motor Current (Amps), Motor Electrical Power Demand (MW), Motor Reactive Power Demand (Mvar) and the Motor Slip (%).


Motor Current in TS and MS (Amps)
Amperes
1600
1400
1200
1000
800
600
400
200
0
0
1
2
3
4
5
6
Time (sec)
Current (TS)
Current (MS)


Motor Electrical Power in TS vs MS (MW)
Power (MW)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
1
2
3
4
5
6
Time (sec)
MW (TS)
MW (MS)





Reference

1. ETAP Motor Acceleration V&V Documents, Case Number TCS-MS-083.

ETAP Unbalanced Load Flow

The ETAP V&V process for the Unbalanced Load Flow program has over 550 test case scenarios that are run before each ETAP release. The following cases are excerpts from the Unbalanced Load Flow V&V documentation.

Unbalanced Load Flow Comparison Case # 1

Comparison of ETAP Unbalanced Load Flow Results against a Published IEEE 13-Bus Feeder System

Excerpts from Validation Cases and Comparison Results (TCS-ULF-002)

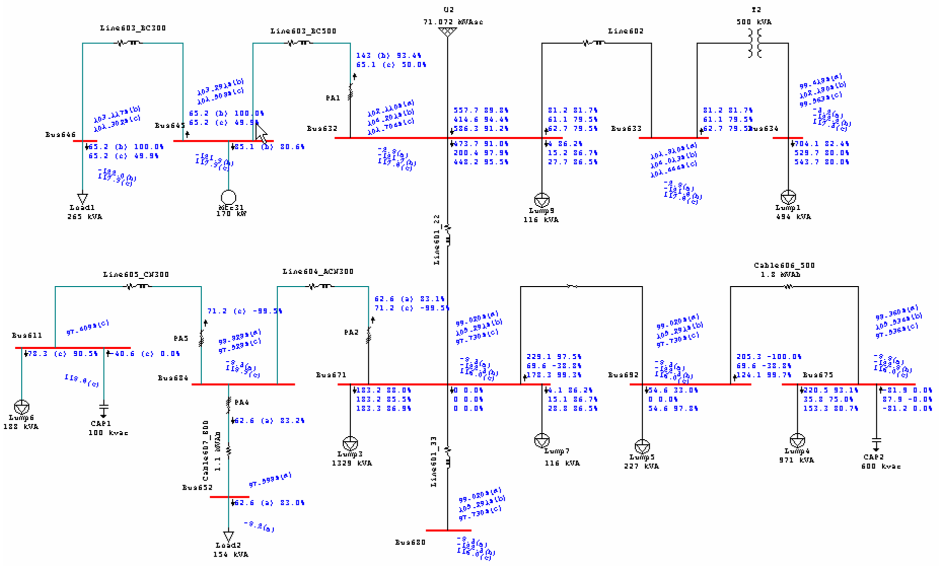
Highlights

- Comparison of ETAP Unbalanced Load Flow (ULF) results against those published in Radial Test Feeders - IEEE Distribution System Analysis Subcommittee for an IEEE 13-bus feeder system found on http://ewh.ieee.org/soc/pes/dsacom/testfeeders.html.
- Comparison of bus voltages and angles on each phase.
- Comparison of current flows and angles on each phase.
- The difference in the results is less than 1% for all bus voltages and power flows.

System Description

To model the unbalanced distribution thirteen-bus system found in the web site above, an equivalent system (as shown in Figure 1) was designed in ETAP with the following conditions:

1. This case covers only the portion below Node 632 due to the same ETAP transformer tap for three phases.
2. The portion above Node 632 is modeled using the internal impedances of the utility.
3. Cables are modeled using impedances.
4. The distributed load is modeled using two lumped loads at both line terminals.
5. The single phase load of constant current is modeled using an approximate lumped load.



Comparison of Results

The following tables of comparison show the differences between ETAP results and those published on the IEEE 13-bus feeder. Please notice that the percent difference for all branch flows and bus voltages is less than 1%. Any missing fields in the tables below were not provided in the IEEE benchmark results; however, the corresponding ETAP results have been included.

	Voltage (in per unit)								
	Phase A			**Phase B**			**Phase C**		
BUS	IEEE	ETAP	**% Diff**	IEEE	ETAP	**% Diff**	IEEE	ETAP	**% Diff**
632	1.021	1.021	**0.0**	1.042	1.042	**0.0**	1.017	1.017	**0.0**
633	1.018	1.018	**0.0**	1.04	1.04	**0.0**	1.015	1.014	**0.1**
634 (XF13)	0.994	0.994	**0.0**	1.022	1.022	**0.0**	0.996	0.996	**0.0**
645				1.033	1.032	**0.0**	1.015	1.015	**0.0**
646				1.031	1.031	**0.0**	1.013	1.013	**0.0**
671	0.99	0.989	**0.0**	1.053	1.053	**0.0**	0.978	0.976	**0.0**
680	0.99	0.989	**0.0**	1.053	1.053	**0.0**	0.978	0.976	**0.0**
684	0.988	0.987	**0.0**				0.976	0.974	**0.0**
611							0.974	0.972	**0.0**
652	0.982	0.981	**0.0**						
692	0.99	0.989	**0.0**	1.053	1.053	**0.0**	0.978	0.976	**0.0**
675	0.983	0.982	**0.0**	1.055	1.055	**0.0**	0.976	0.974	**0.0**

Table 17: Bus Voltage Magnitude Comparison

	Angle (in degrees)								
	Phase A			**Phase B**			**Phase C**		
BUS	IEEE	ETAP	**% Diff**	IEEE	ETAP	**% Diff**	IEEE	ETAP	**% Diff**
632	-2.49	-2.49	**0.0**	-121.7	-121.7	**0.0**	117.83	117.83	**0.0**
633	-2.56	-2.55	**0.4**	-121.8	-121.8	**0.01**	117.82	117.83	**0.01**
634 (XF13)	-3.23	-3.22	**0.0**	-122.2	-122.2	**0.0**	117.35	117.35	**0.0**
645				-121.9	-121.9	**0.0**	117.86	117.87	**0.0**
646				-122	-122	**0.0**	117.9	117.93	**0.0**
671	-5.3	-5.29		-122.3	-122.3	**0.0**	116.02	116.07	**0.0**
680	-5.3	-5.29		-122.3	-122.3	**0.0**	116.02	116.07	**0.0**
684	-5.32	-5.31					115.92	115.96	**0.0**
611							115.78	115.81	**0.0**
652	-5.25	-5.24	**0.0**						
692	-5.31	-5.29	**0.0**	-122.3	-122.3	**0.0**	116.02	116.07	**0.0**
675	-5.56	-5.55	**0.0**	-122.5	-122.5	0.0	116.03	116.08	**0.0**

Table 18: Bus Voltage Angle Comparison

To model the distributed load along node “Bus632” to node “Bus671”, the loading is equally connected at each end of the line segment (Line601_22), i.e. Lump9 and Lump7. Therefore, the current flows going from Bus632 to Bus671 and vice-versa are the following:

[1] 632-671: Phase A: 474.6 + 4 = 478.6
Phase B: 200.6 + 15.1 = 215.7
Phase C: 448.7+ 28.9 = 477.6

[2] 671 - 632 Phase A: 474.6 - 4.2 = 470.4
Phase B: 200.6 - 15.1 = 184.9
Phase C: 448.7 - 28.9 = 419.8

	Current Flow (Amps)								
	Phase A			Phase B			Phase C		
BUS	IEEE	ETAP	% Diff	IEEE	ETAP	% Diff	IEEE	ETAP	% Diff
611							71.2	71.2	**0.0**
632 - RG60	558.4			414.9			586.6		
-633	81.3	81.2	**0.2**	61.1	61.1	**0**	62.7	62.7	**0.0**
-645				143	143	**0**	65.2	65.1	**0.1**
[1] -671	478.2	478.1	**0**	215.1	215.6	**0.2**	475.5	475.9	**0.1**
633 - 632	81.3	81.3	**0.1**	61.1	61.1	**0**	62.7	62.7	**0.0**
-634	81.3	81.3	**0.1**	61.1	61.1	**0**	62.7	62.7	**0.0**
634 - 633	704.8	704.8	**0.0**	529.7	529.7	**0**	543.5	543.7	**0.0**
645-632				143	143	**0**	65.2	65.1	**0.1**
-646				65.2	65.1	**0.1**	65.2	65.1	**0.1**
646 - 645				65.2	65.1	**0.1**	65.2	65.1	**0.1**
652 - 684	63	63	**0.0**						
[2] 671 - 632	470.2	470	**0.0**	186.4	185.3	**0.6**	420.6	419.8	**0.2**
-680	0	0		0	0		0	0	
-684	63	63	**0.0**				71.2	71.2	**0.0**
-692	229.1	229.1	**0.0**	69.6	69.6	**0.0**	178.4	178.5	**0.1**
675 - 692	205.3	205.4	**0.0**	69.6	69.6	**0.0**	124.1	124.3	**0.1**
680 - 671	0	0		0	0		0	0	
684 - 671	63	63	**0.0**				71.2	71.2	**0.0**
-611							71.2	71.2	**0.0**
-652	63	63	**0.0**						
692 - 671	229.1	229.1	**0.0**	69.6	69.6	**0.0**	178.4	178.3	**0.1**
-675	205.3	205.4	**0.0**	69.6	69.6	**0.0**	124.1	124.1	**0.0**

Table 19: Current Flow Magnitude Comparison

Reference

1. IEEE Distribution System Analysis Subcommittee for an IEEE 13-bus feeder system found on http://ewh.ieee.org/soc/pes/dsacom/testfeeders.html.
2. ETAP Unbalanced Load Flow V&V Documents, Case Number TCS-ULF-002.

ETAP Harmonic Analysis

The ETAP V&V process for the Harmonic Analysis program has over 1300 test case scenarios that are run before each ETAP release. The following cases are excerpts from the Harmonic Analysis V&V documentation.

Harmonic Analysis Comparison Case # 1

Comparison of ETAP Harmonic Analysis Results Against IEEE Example

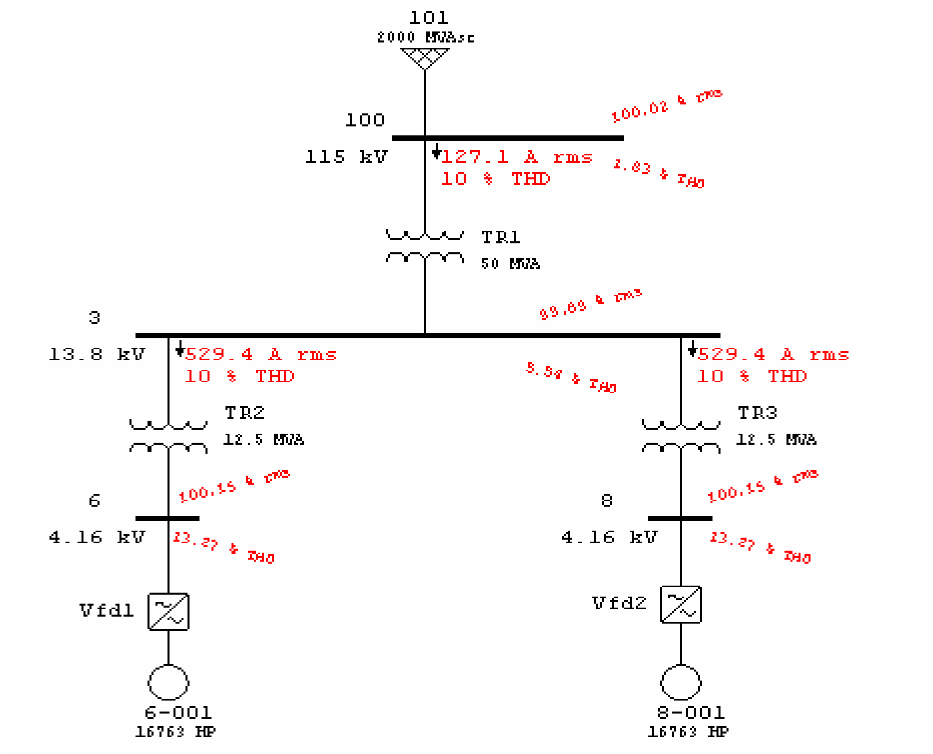
Excerpts from Validation Cases and Comparison Results (TCS-HA-001)

Highlights

- Comparison between ETAP Harmonic Analysis (HA) results against those published on IEEE Standard 519-1992 Example 13.1 page. 89-92.
- Comparison of Current Total and Individual Harmonic Distortion.
- Comparison of Voltage Total and Individual Harmonic Distortion.
- Comparison of voltage and current RMS, ASUM, THD, and TIF.

System Description

This is a large industrial plant system furnished at utility transmission voltage. The system is composed of multiple transformers, induction motors, variable frequency drives (as harmonic sources) and utility.



Comparison of Results

The following tables of comparison show the differences between ETAP results and those published in the textbook example. Please notice that the percent difference for all branch flows and bus voltages is less than 1%.

HARM ORDER	HARMONIC CURRENT (A) (from Bus 3 to Bus 100)			HARMONIC VOLTAGE (%) (Bus 100)		
	STD 519	ETAP	**% Diff**	STD 519	ETAP	**% Diff**
5	2.4	2.4	**0**	0.12	0.12	**0.0**
7	1.65	1.64	**0.0**	0.12	0.12	**0.0**
11	9.12	9.07	**0.1**	1	1	**0.0**
13	7.12	7.18	**-0.1**	0.92	0.93	**-0.0**
17	0.44	0.38	**0.1**	0.08	0.07	**0.0**
19	0.34	0.38	**-0.0**	0.06	0.06	**0.0**
23	2.51	2.52	**-0.0**	0.57	0.57	**0.0**
25	2	2.01	**-0.0**	0.5	0.5	**0.0**
29	0.17	0.13	**0.0**	0.05	0.05	**0.0**
31	0.15	0.13	**0.0**	0.05	0.05	**0.0**
35	1.37	1.39	**-0.0**	0.48	0.48	**0.0**

Table 20: Comparison between ETAP and IEEE STD 519 for Harmonic Load Flow

Note: 1. The harmonic currents listed in Table 13.1 of IEEE Std. 519, for the Static Power Converter (SPC) harmonic source have errors. The correct values used by ETAP are given below:

Harmonic	**PU Value**	**Harmonic**	**PU Value**	**Harmonic**	**PU Value**
1	1	19	0.0027	37	0.01
5	0.0192	23	0.02	41	0.0009
7	0.0132	25	0.016	43	0.0008
11	0.073	29	0.00136	47	0.008
13	0.057	31	0.0012	49	0.007
17	0.0035	35	0.011		

2. Errors results are given in absolute value due to small results values and insufficient number of digits.
3. ETAP gives branch harmonic currents in percentage of fundamental current.
4. The larger discrepancy in harmonic voltage values between the ETAP calculated and IEEE Std 519 values is due to insufficient number of digits in ETAP output. In the ETAP output, the harmonic voltage components are reported to second digit after the decimal point.

Below you can find tables of comparison between voltage and current on bus “100” and branch “TR1” for RMS, ASUM, THD, and TIF in ETAP against hand calculated values and reported errors for this comparison.

Parameter to be Compared	Hand Calculation (in MathCad)	ETAP	% Diff
RMS	100.02	100.02	**0.0**
ASUM	105.40	105.40	**0.0**
THD	1.83	1.83	**0.0**
TIF	108.35	108.44	**-0.1**

Table 21: Comparison on bus “100” for voltage RMS, ASUM, THD and TIF

Parameter to be compared	Hand Calculation (in MathCad)	ETAP	% Diff
RMS	126.63	127.05	**-0.3**
ASUM	156.62	157.16	**-0.3**
THD	9.99	10.00	**-0.1**
TIF	346.55	345.16	**0.4**

Table 22: Comparison on “TR1” for current RMS, ASUM, THD and TIF

Reference

1. IEEE Standard 519-1992 Example 13.1, page 89-92.
2. ETAP Harmonic Analysis V&V Documents, Case Number TCS-HA-001.

ETAP Transient Stability

The following test cases are specific to the Transient Stability program (including Generator Start-Up and User-Defined Dynamic Model modules) and are indicative of the type of tests performed for this analysis. Note that all of these cases indicate a very close correlation between ETAP simulated results and field measurements or other programs.

Transient Stability Comparison Case # 1

Generator Start-Up Simulation Comparison with Field Measurement Data

Excerpts from Validation Cases and Comparison Results (TCS-TS-143)

Highlights

- Comparison between the ETAP Transient Stability/Generator Start-Up simulation results and field measurement data
- Special study of the emergency generator start-up for a nuclear generation plant
- ETAP built-in frequency dependent synchronous generator, induction machine, and network models
- ETAP built-in IEEE Standard 2.1 synchronous machine model
- ETAP built-in hydro turbine and speed governor/gate control model, including water tunnel system
- ETAP built-in IEEE ST1D excitation and AVR model, including DC flashing and V/Hz switching control
- ETAP built-in double-cage induction machine model
- Multiple voltage levels, multiple substations, and multiple loads
- Comparisons include starting generator frequency, voltage, output current and power, starting motor voltage, current and input power
- Excellent correlation between ETAP simulation results and the field measurements data
- Accepted report by the client and NRC (Nuclear Regulation Commission)
- Published paper in IEEE IAS Transaction (see reference)

System Description

The studied hydro generation station shown in Figure 1 is a backup power source for a nuclear power generation plant. Under emergency conditions, hydro generators of the station must be started as a black start source to pick up the auxiliary loads of the nuclear generation plant. In this study, the generator is dynamically modeled with ETAP IEEE Standard 2.1 type. The Exciter/AVR and Turbine/Governor are modeled with ETAP built-in exciter STD1 type and governor HYDR type. The induction motors in the system are dynamically molded with ETAP double-cage independent bars type. The system including generator, motor, and network is flagged using frequency-dependent model.

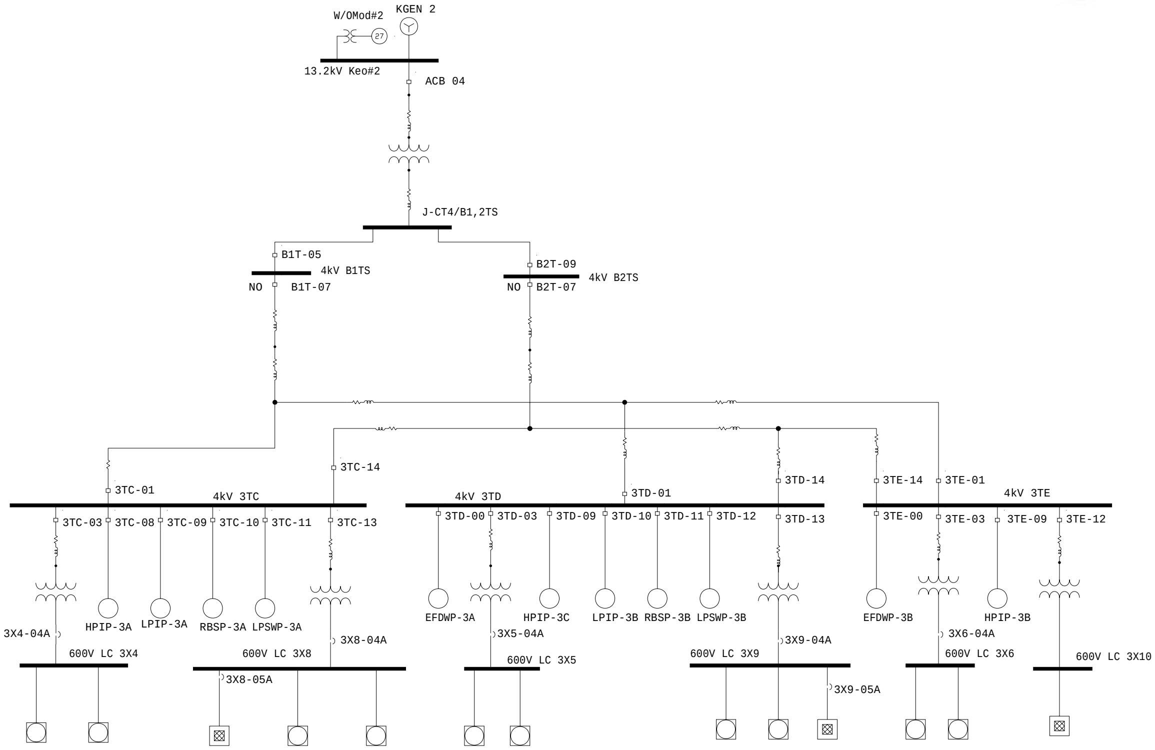


Fig. 1. Hydro Generation Station System One-Line Diagram

Simulation Events

The simulation events on the study are set up exactly the same as the site test procedures, which are as follows:

- Start generator, with the exciter running in field flushing mode and governor in start control mode, @ t = 0 second
- The voltage-per-hertz switch continuously checks the generator terminal V/Hz value
- Exciter will switch to AVR mode when it reaches 74% V/Hz
- The voltage relay checks the generator terminal voltage, if it reaches 76% V, it will trip to close the main feeder circuit breakers
- A sequence loading will follow by starting-up motors and adding loads by closing individual circuit breaker

Simulation Result Comparisons with the Site Measurement Data

The following plots (Figures 2 to 17) show some of the comparisons between the simulation results and field measurements for the starting generator and some starting induction motors.

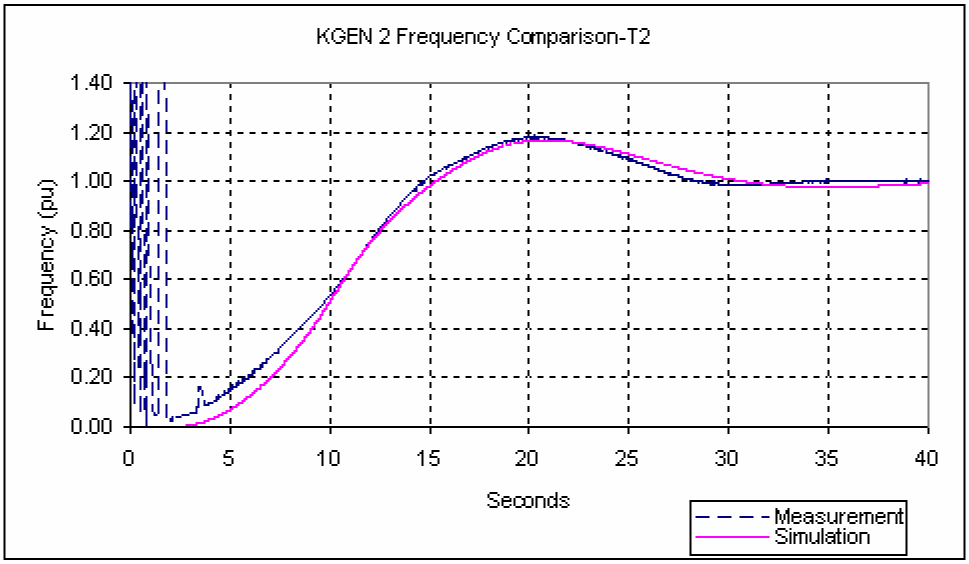


Fig. 2. Generator Frequency/Speed

In Figure 2, the measurement spikes at the start-up (up to 8 seconds) are noise related. The simulated result at the more critical portion of the curve (generator speed above 50% of its rated value) has a very close correlation with the field measurement data.

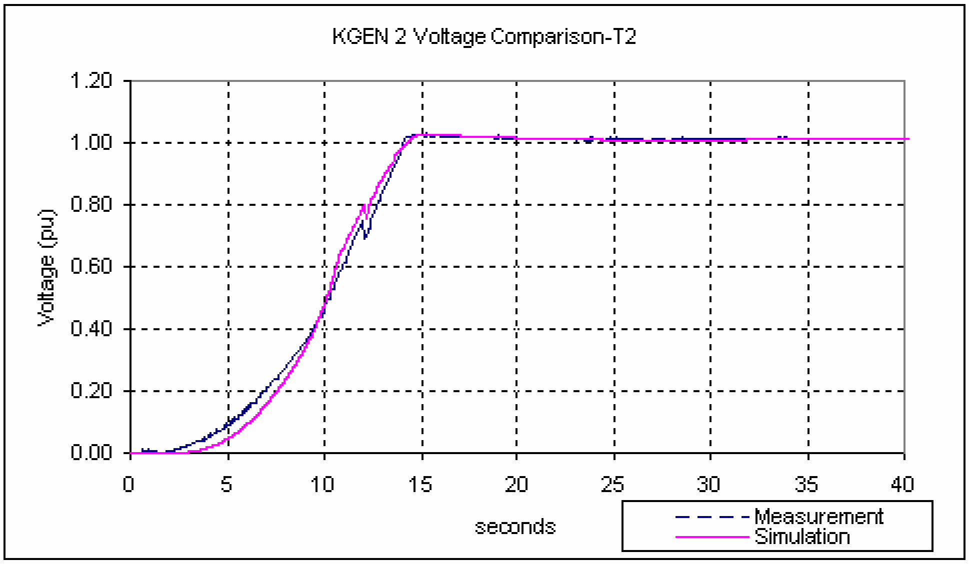


Fig. 3. Generator Terminal Voltage

Similar to the speed response, the generator voltage response in Figure 3 from the simulation also closely correlates the field measurement, in particular in the region more critical (voltage above 50% of its nominal value).

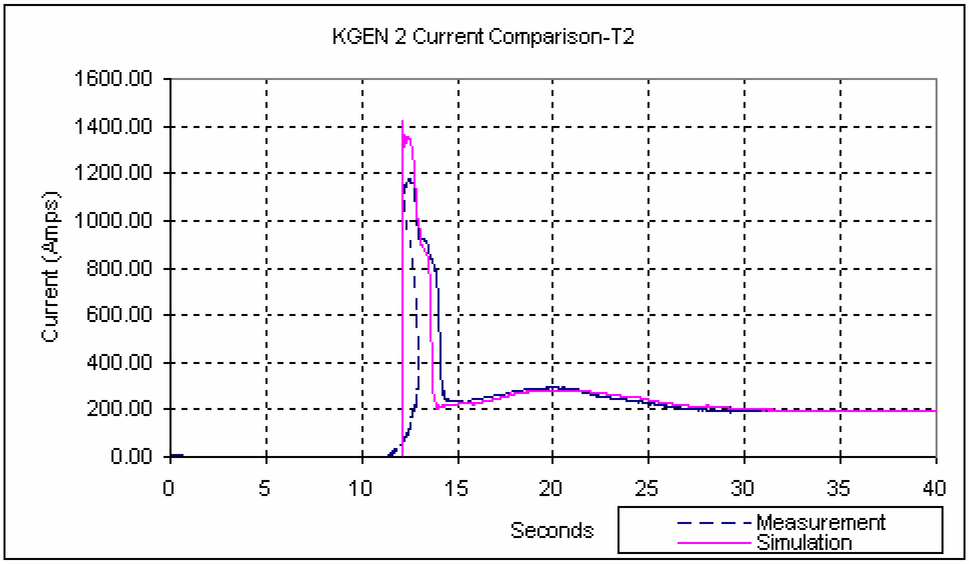


Fig. 4. Generator Current

The generator current from the ETAP simulation and the field measurement in Figure 4 shows almost identical results in the final settle down time and final values. The difference at the beginning (initial transient in the generator current) may be due to an error with the measuring device, i.e., difficulty with recording fast changing singles.

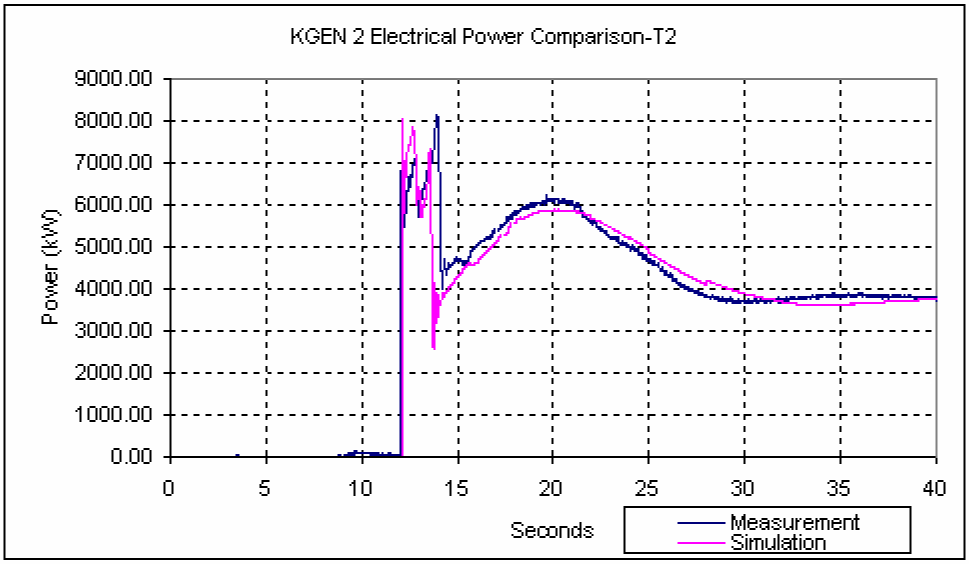


Fig. 5. Generator Electrical Power

The comparison for generator electrical power response in Figure 5 shows close correlation for the major parameters, including the peak of oscillation, settle down time, and final values. The difference in the initial high-speed transient is probably due to the responding time of the measuring equipment.

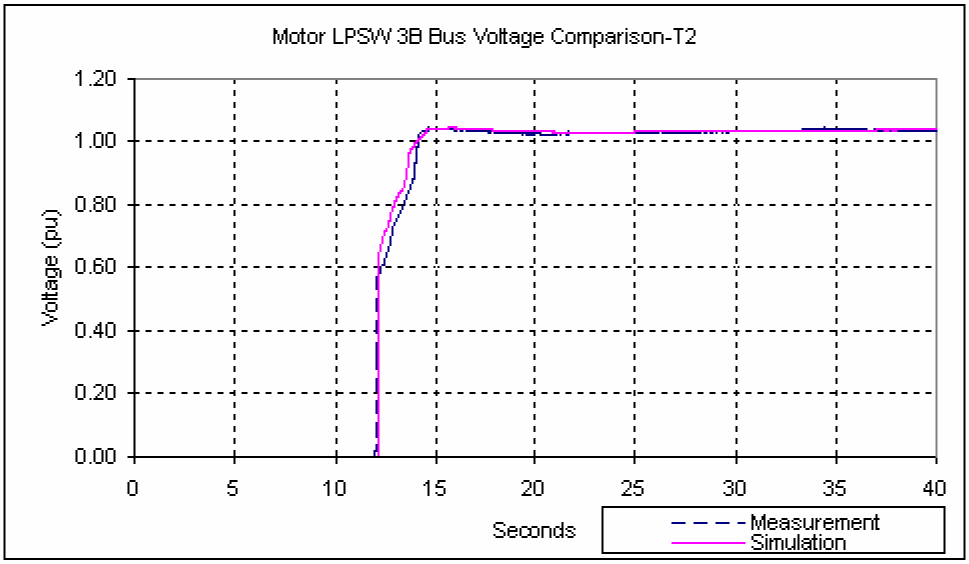


Fig. 6. Motor LPSW-3B Terminal Voltage

The motor voltage response for motor LPSW-3B in Figure 6 from the simulation very closely agrees to the measured data.

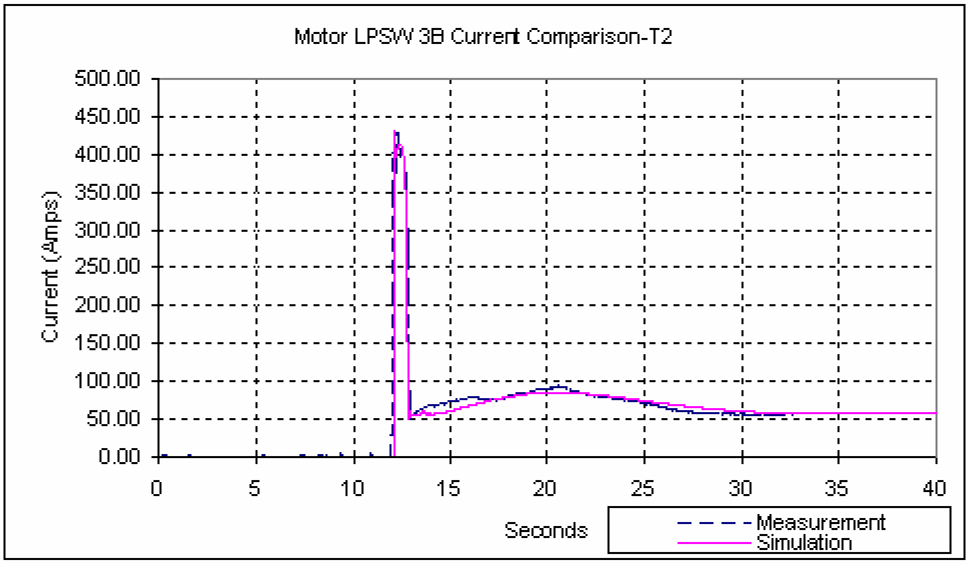


Fig. 7. Motor LPSW-3B Current

The motor current response for motor LPSW-3B in Figure 7 from the simulation also very closely agrees to the measured current curve.

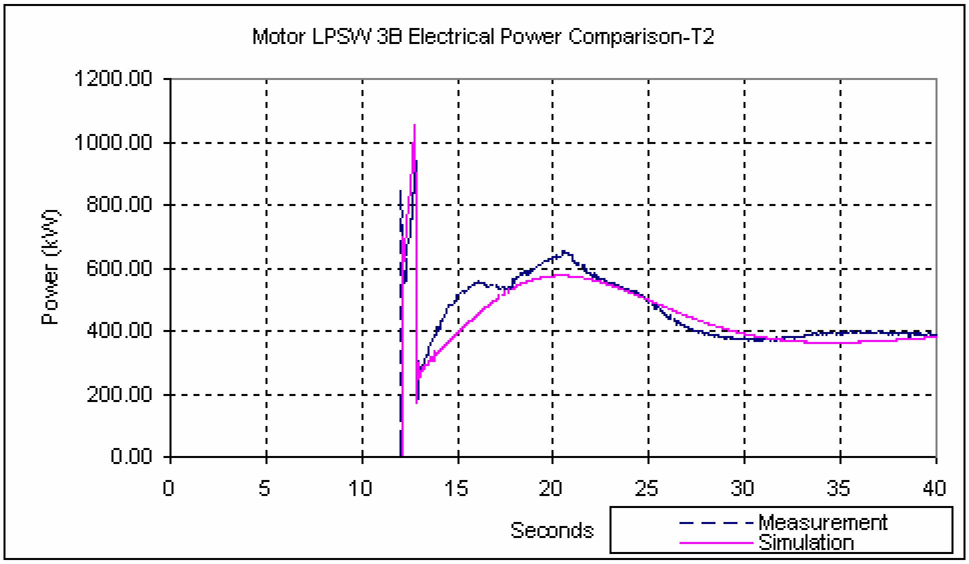


Fig. 8. Motor LPSW-3B Electrical Power

The motor electrical power response for motor LPSW-3B in Figure 8 from the simulation closely agrees to the measured electrical power curve. In particular, the motor starting time (duration of the inrush time) and the full load power both are identical between the simulation and the measurement.

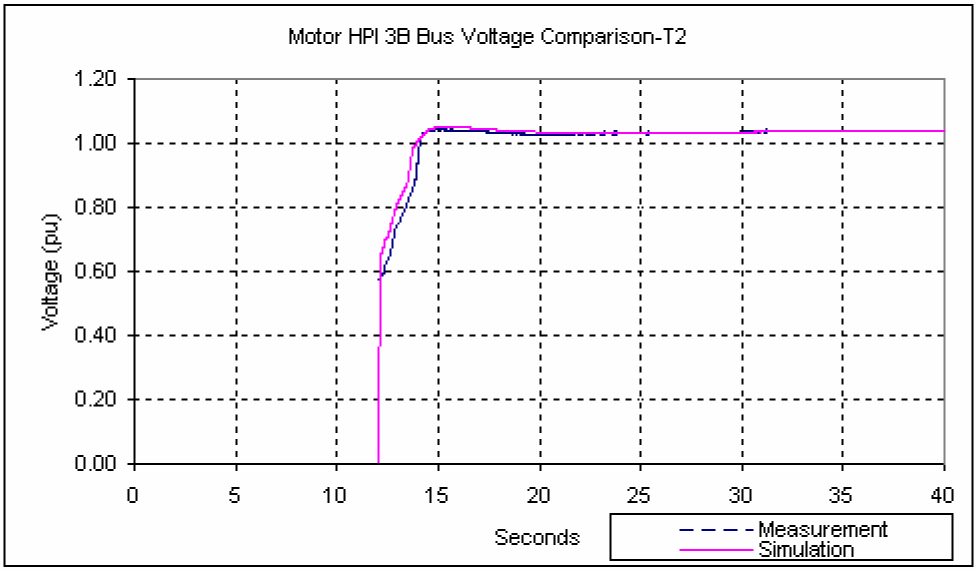


Fig. 9. Motor HPI-3B Terminal Voltage

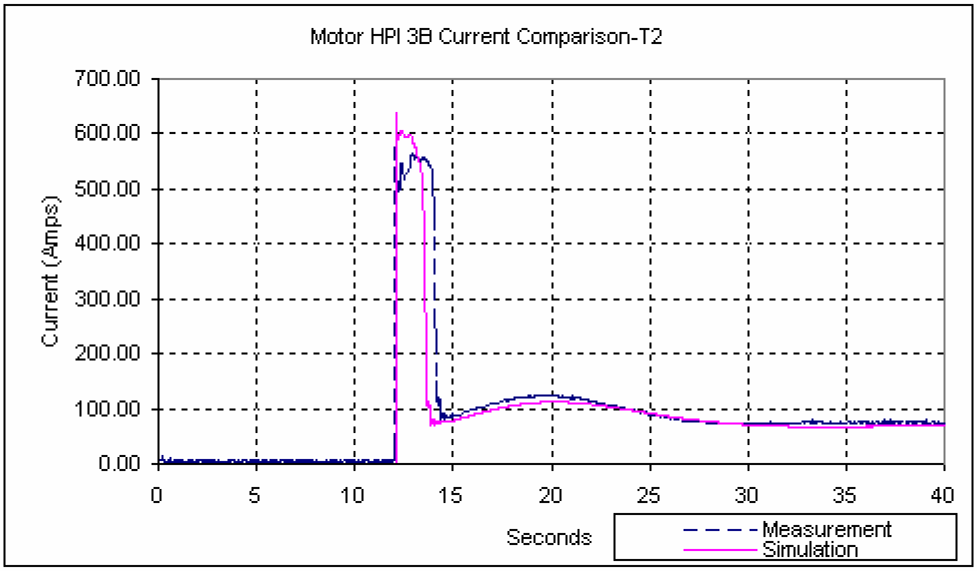


Fig. 10. Motor HPI-3B Current

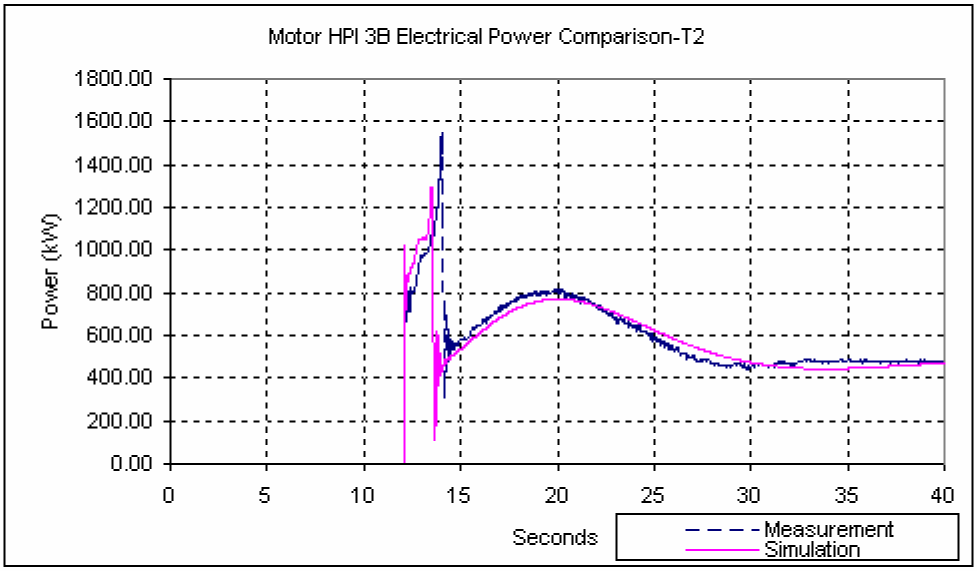


Fig. 11. Motor HPI-3B Electrical Power

Figures 9-11 show motor voltage, current, and electrical power comparison for motor HPI-3B. Simulation results also very closely agree to the measured data.

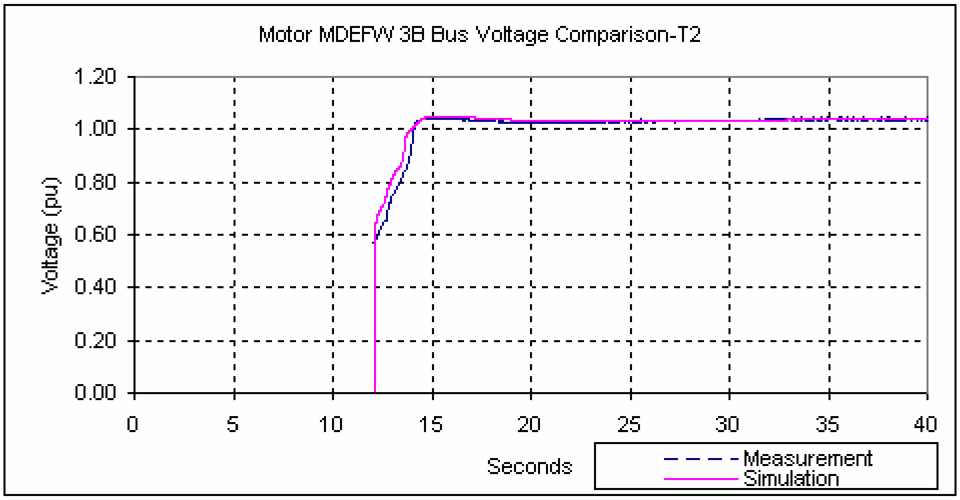


Fig. 12. Motor MDEFW-3B Terminal Voltage

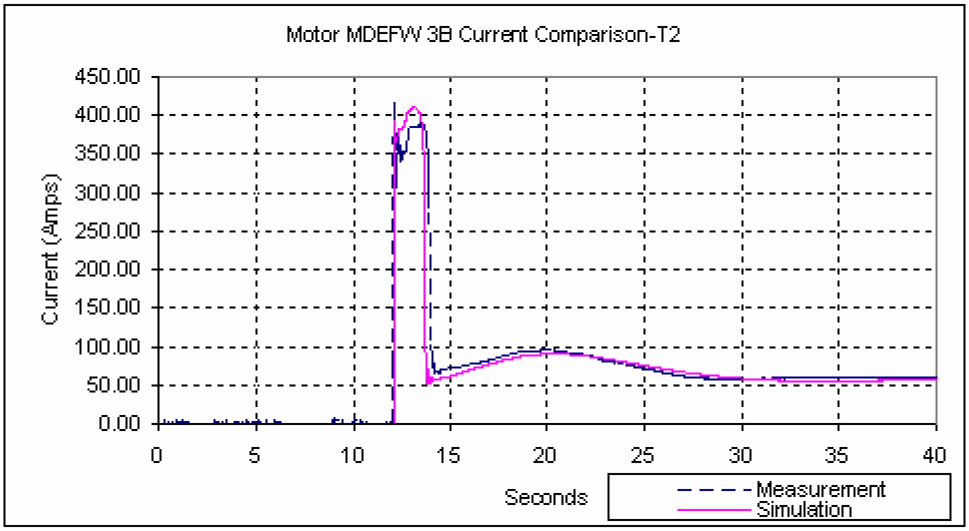


Fig. 13. Motor MDEFW-3B Current

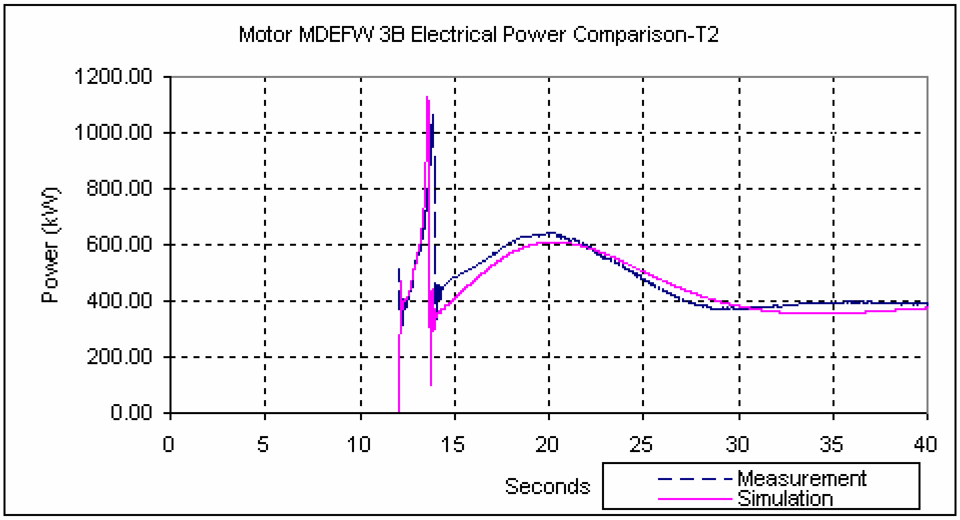


Fig. 14. Motor MDEFW-3B Electrical Power

Similar results and conclusions can be reached for another starting motor MDEFW-3B as seen in Figures 12-14.

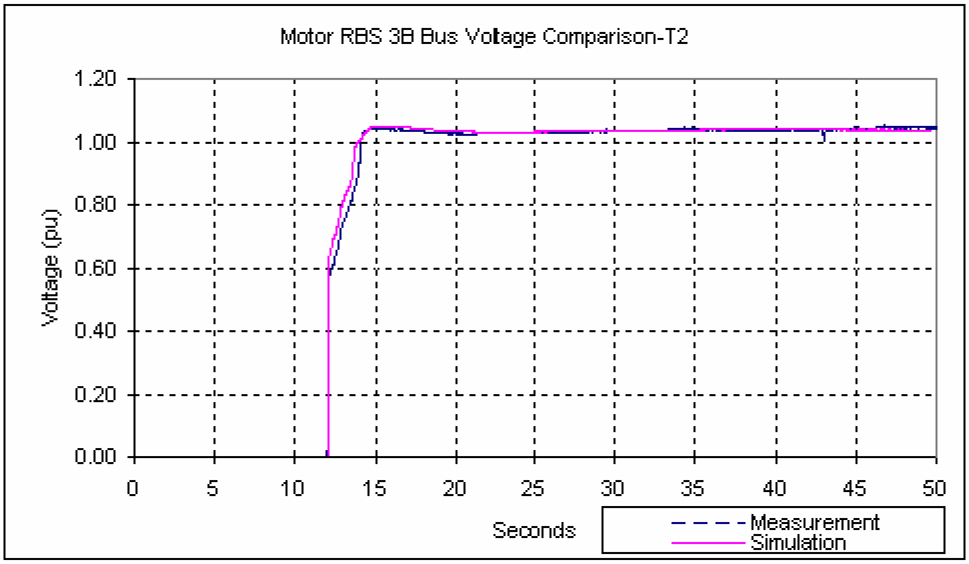


Fig. 15. Motor RBS-3B Terminal Voltage

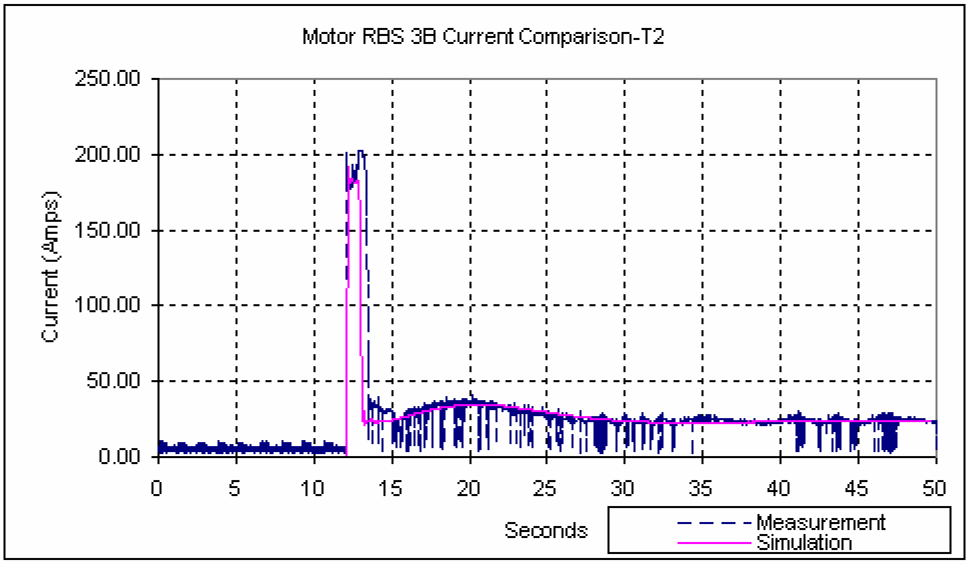


Fig. 16. Motor RBS-3B Current

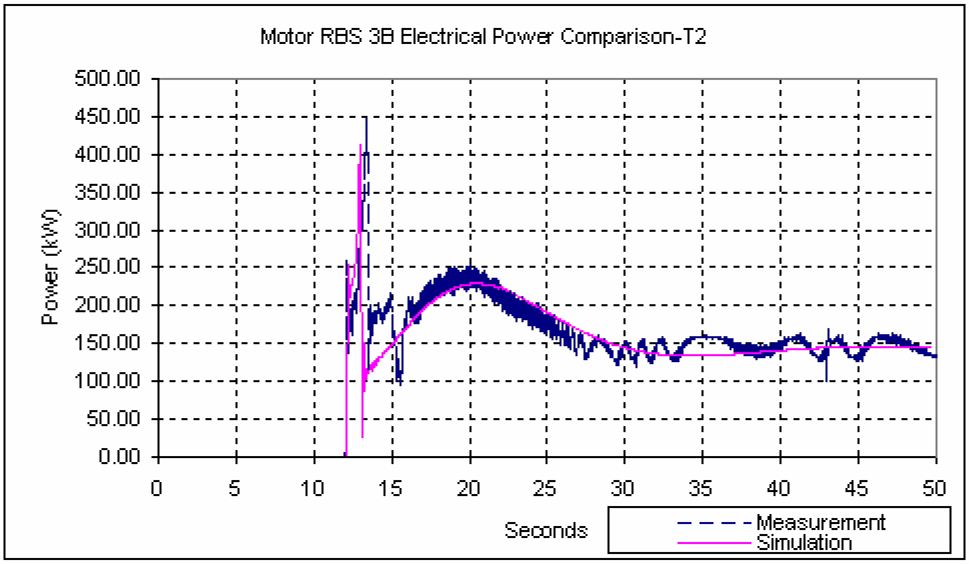


Fig. 17. Motor RBS-3B Electrical Power

The results and conclusions for comparison of the accelerating motor RBS-3B in Figures 15-17 are the same as for the other motors in the previous figures.

Conclusions

In this comparison case, a nuclear generation plant emergency backup generator start-up condition is studied. The actual generator start in the real system is performed and all the key variable responses are recorded. ETAP Transient Stability/Generator Start-Up program is used to simulate the real system and the results are compared to the field measurements. A close examination shows the ETAP simulation results closely correlate to all the field measurement data that have been compared. Note that some of the dynamic parameters for the generator and motors (including inertia constants and shaft damping constants) are estimated due to lack of actual data. These factors have direct effect on the motor acceleration times.

Reference

1. JJ Dai, Di Xiao, Farrokh Shokooh, Christopher Schaeffer, and Aldean Benge, "Emergency Generator Start-Up Study of a Hydro Turbine Unit for a Nuclear Generation Facility," IEEE Transactions on Industry Applications, Vol. 40, pp.1191-1199, September 2004.

2. ETAP Transient Stability V&V Documents, Case Number TCS-TS-143, 2005.

Transient Stability Comparison Case # 2

Synchronous Generator Response to a Fault Comparison with I.E.E Japan (IEEJ) Benchmark

Excerpts from Validation Cases and Comparison Results (TCS-TS-238)

Highlights

- Comparison between ETAP Transient Stability Simulation Results and I.E.E. Japan (IEEJ) Electrical Power System Standard Benchmark
- A 100 MW generator oscillation and stability with respect to a power grid
- Long transmission line network with large charging capacitance
- 3-phase fault in the middle of a transmission line
- ETAP built-in salient-pole subtransient synchronous machine model
- ETAP User-Defined Dynamic Model (UDM) for the IEEJ thermal and nuclear LPT-1 type turbine/governor model
- ETAP User-Defined Dynamic Model (UDM) for the IEEJ LAT-1 type excitation/AVR model
- Very close correlation between ETAP results and the benchmark
- Accepted and published results by IEEJ

System Description

The system to be modeled is an IEEJ Electrical Power System Standard Model (reference: 2001 National Convention Record I.E.E. Japan). This system includes a generator connected to a power system through transmission lines, as shown in Figure 1. The generator is rated in 100 MW and modeled in ETAP as a subtransient salient-pole type. IEEJ Thermal and Nuclear LPT-1 type Turbine/Governor model and IEEJ LAT-1 type Exciter/AVR model are used, and modeled using ETAP User-Defined Dynamic Model (UDM) module, as shown in Figures 2 and 3.

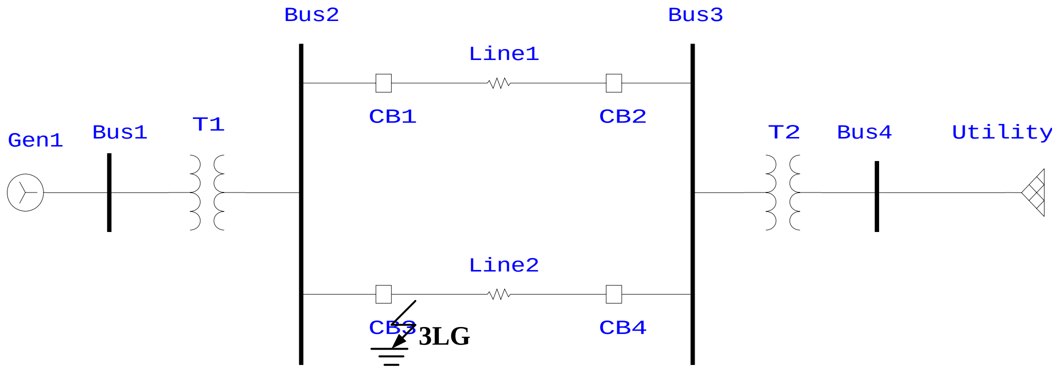


Fig. 1. IEEJ Electrical Power System Standard Benchmark

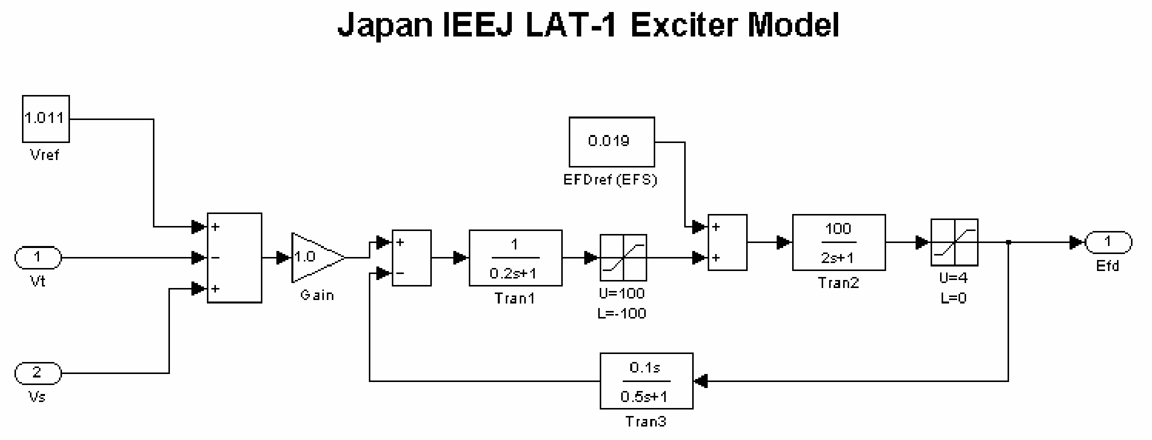


Fig. 2. ETAP UDM Model for IEEJ LAT-1 Type Exciter/AVR

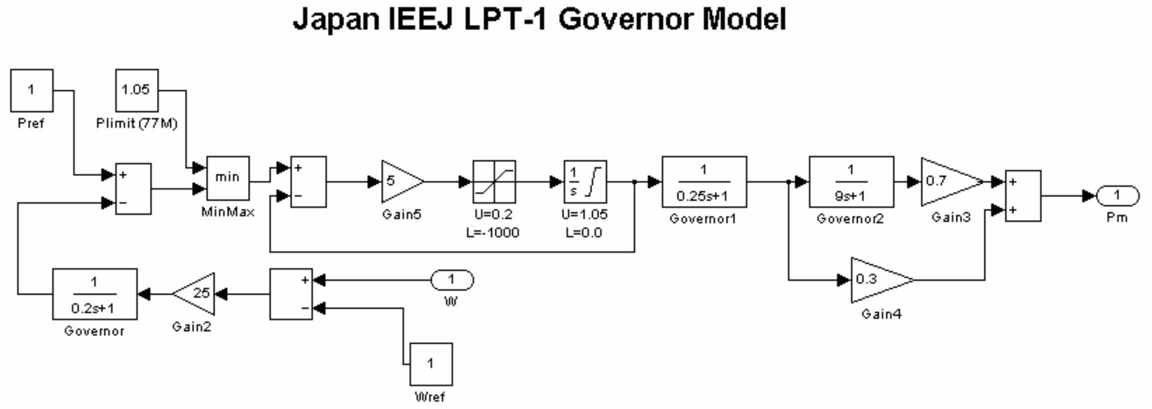


Fig. 3. ETAP UDM Model for IEEJ LPT-1 Type Turbine/Governor

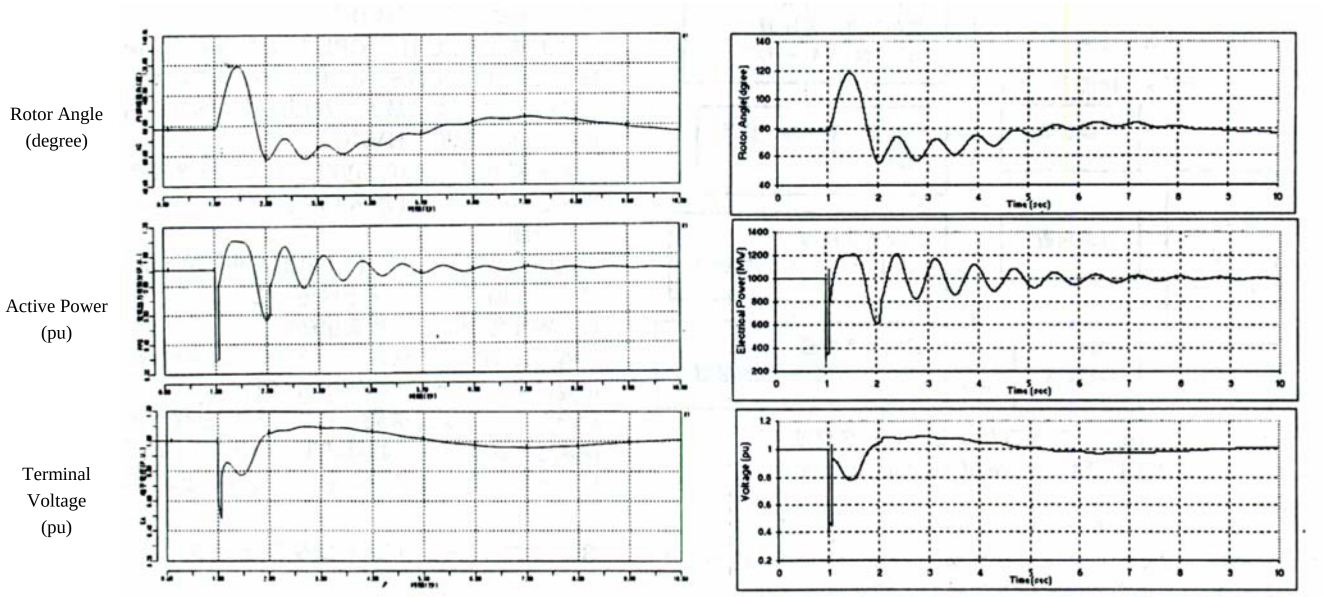
Simulation Events

The simulation events on this system are set up as follows:

- 3-phase fault on the middle of Line2 @ t = 1.00 second
- Clear fault and open CB3 and CB4 @ t = 1.07 second
- Re-close CB3 and CB4@ t = 2.07 second

Simulation Result Comparisons with IEEJ Y-Method

In this study, the generator rotor angle, electrical power, and terminal voltage response behaviors by ETAP simulation will be checked against those by IEEJ Y-Method. Comparison of the results is shown in Figure 4.



(a) IEEJ Y-Method **(b) ETAP**

Fig. 4. Result Comparison between IEEJ Y-Method and ETAP

As shown in the above figures, peak values, settle down time, final stable values, oscillation frequency, and general response curve shapes are sufficiently equal between the two programs for the generator rotor angle, active power, and terminal voltage. It is noted that the ETAP results show a slightly larger sub-oscillations than IEEJ Y-Method during the settle down time for the rotor angle and active power. This is due to the generator-damping coefficient used in the IEEJ Y-Method, which is not available and a typical value is used in the ETAP simulation.

Conclusions

As shown from the generator output response comparison curves, simulation results produced by Y-Method and ETAP are sufficiently equal to each other.

Reference

1. Hiroyuki Iki, et al, “Activities of ETAP PowerStation (User Group Japan) – Analysis and Simulation by ETAP PowerStation,” 2001 National Convention Record I.E.E. Japan (IEEJ), 2001.

2. IEEJ: Electrical Power System Standard Models, Technical Report No. 754, 1999.

3. ETAP Transient Stability V&V Documents, Test Case Number TCS-TS-238, 2005.

Transient Stability Comparison Case # 3

Post-Fault System Transient Response Comparison with Field Measurements from a Fault Recorder

Excerpts from Validation Cases and Comparison Results (TCS-TS-295)

Highlights

- Comparison between the ETAP Transient Stability simulation results and actual fault-recorder measurements before and after a three-phase fault in an industrial system
- A post-fault system transient response simulation study for a real industrial power system
- Simulation of 3-phase fault, followed by fault isolation and then a generator trip
- System includes multiple voltage levels, a power grid connection, on-site generators, motors, and lumped loads
- ETAP built-in round-rotor subtransient synchronous machine model
- ETAP built-in IEEE ST type turbine/governor model
- ETAP User-Defined Dynamic Model (UDM) for client excitation/AVR model
- ETAP Transient Stability simulation results compared to the filed fault recorded instantaneous waveforms including generator current and voltage, and a feeder fault current

System Description

The modeled system, shown in Figure 1, is an actual industrial power system located in Japan. This system has four generators, five large pumps, and one utility connection. All other loads are modeled as lumped loads. In this study, generators Gen-A, Gen-B, and Gen-C are out of service. Generator Gen-M is modeled in ETAP as a round-rotor type with ETAP IEEE Standard ST type Turbine/Governor model. The Exciter/AVR model, shown in Figure 2, was modeled with a User-Defined Dynamic Model (UDM).

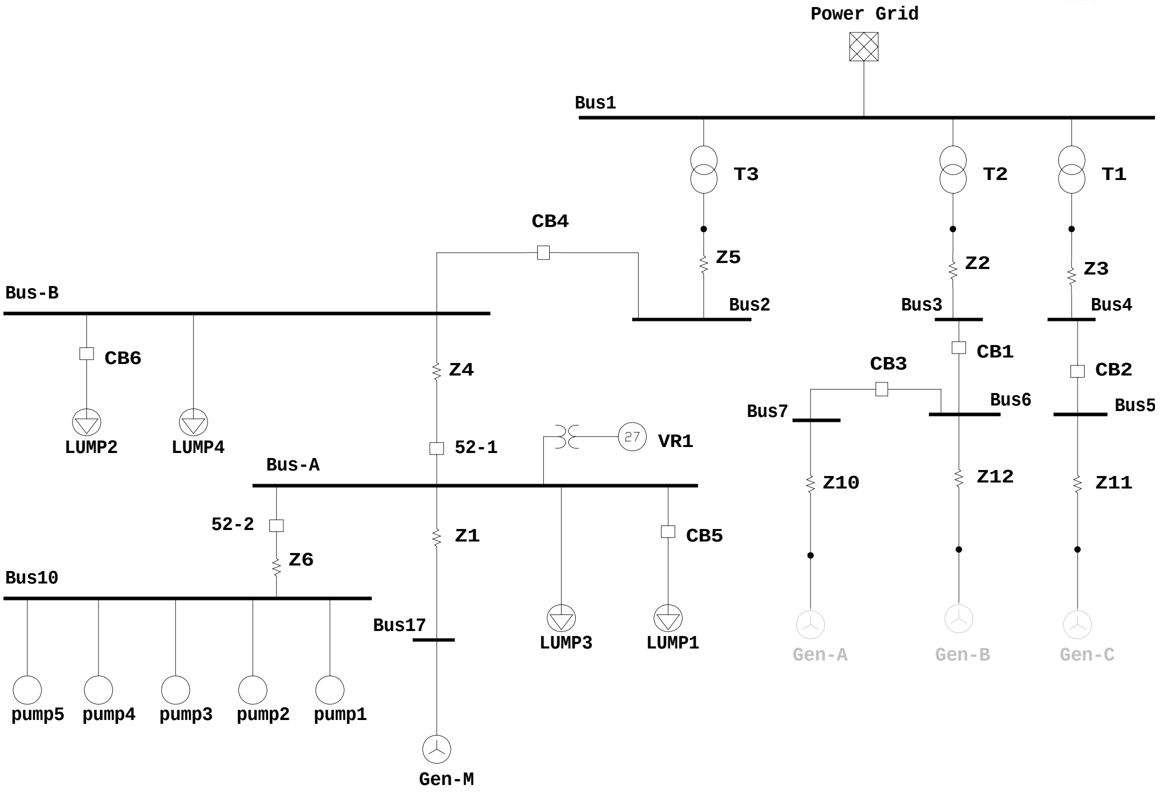


Fig. 1. Short-Circuit Fault Simulation Study System

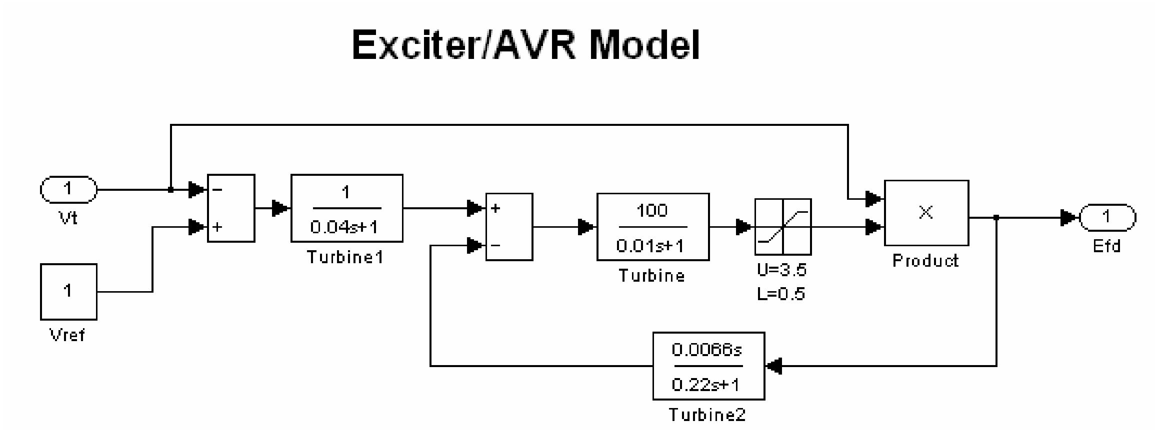


Fig. 2. ETAP User-Defined Dynamic Model (UDM) for Client Exciter/AVR Model

Simulation Events

The simulation events in this study are set the same as the recorded events from the fault recorder, which are as follows:

- 3-phase fault at Bus10 @ t = 0.12 second
- Open CB 52-2 @ t = 0.5 second
- Open CB 52-1 @ t = 0.92

Simulation Result Comparisons with the Field Measured Data

In this study, the instantaneous values of the generator current contribution to the fault and its terminal voltage, and the fault current from the feeder upstream to the fault (through CB 52-1) are compared against the field-measured data which is obtained from a digital fault recorder (DFR), as shown in Figure 3. For the comparison, RMS value results from ETAP are converted to the corresponding instantaneous values based on the RMS magnitude, frequency, and phase angles of the currents and voltages. The ETAP results are shown in Figures 4 and 6.

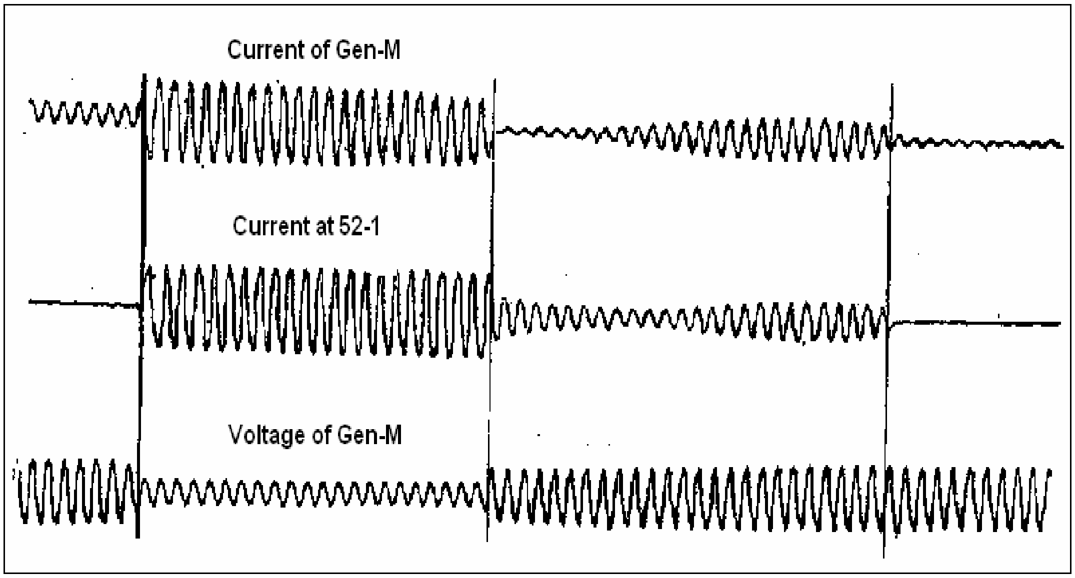


Fig. 3. Field Measurement Data from a Fault Recorder

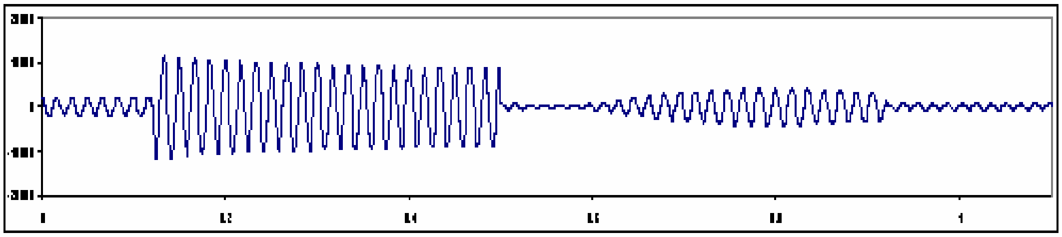


Fig. 4. Generator Gen-M Instantaneous Current by ETAP

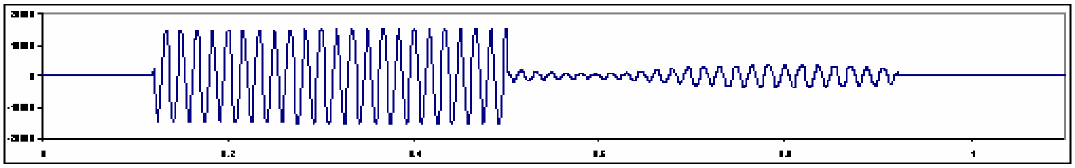


Fig. 5. CB 52-1 Instantaneous Current by ETAP

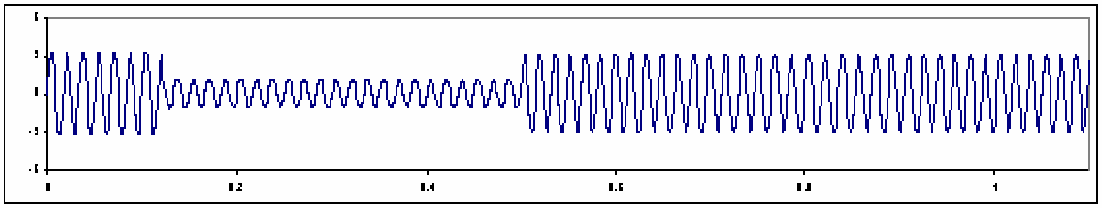


Fig. 6. Generator Gen-M Instantaneous Voltage by ETAP

From the comparison, the generator current and voltage responses as well as the feeder fault current response demonstrate a very close agreement with the field recorded data. A slight difference in generator and feeder currents during a short period of time immediately after opening CB 52-1 can be attributed to the fact that the actual model of the turbine/governor and parameters for the exciter/AVR model are not available and typical models and parameters are assumed in the ETAP simulation. Additionally, the pre-fault and post-fault loadings of the real system were not given and estimated loads are used for the simulation study.

Conclusions

As shown from the comparison plots, a very close agreement is clearly demonstrated between the ETAP Transient Stability simulation results and the field measurements for the generator voltage and current, and the feeder fault current.

Reference

1. ETAP Transient Stability V&V Documents, Case Number TCS-TS-295.

ETAP Transient Stability
Validation Cases and Comparison Results

Case No. 4
9-Bus Multi-Machine System Benchmark
ETAP TS V&V Case Number TCS-TS-126

Comparison with *Power System Control and Stability* by Anderson and Fouad

Highlights:

- Comparison between the ETAP Transient Stability simulation results and a 9-Bus Multi-Machine System Benchmark (*Power System Control and Stability* by Anderson and Fouad)
- Rotor angle stability study in a multi-machine transmission system
- 9-bus 3-machine benchmark system
- End of transmission line fault and fault isolation simulation
- Synchronous generator rotor angle post-fault response study
- ETAP built-in synchronous machine dynamic model
- ETAP built-in excitation/AVR model
- Comparison of generator relative and absolute rotor angle responses
- Nearly identical results in terms of the initial rotor angles, maximum rotor angles, oscillation frequency, and the overall curves of the rotor angle swing

1. System Description

A 9-bus 3-machine system transient stability study is applied in this validation case. The system is documented in *Power System Control and Stability* by Anderson and Fouad. The system includes three generator and three large equivalent loads connected in a meshed transmission network through transmission lines as shown in Figure 1. The generators are dynamically modeled with the classical equivalent model.

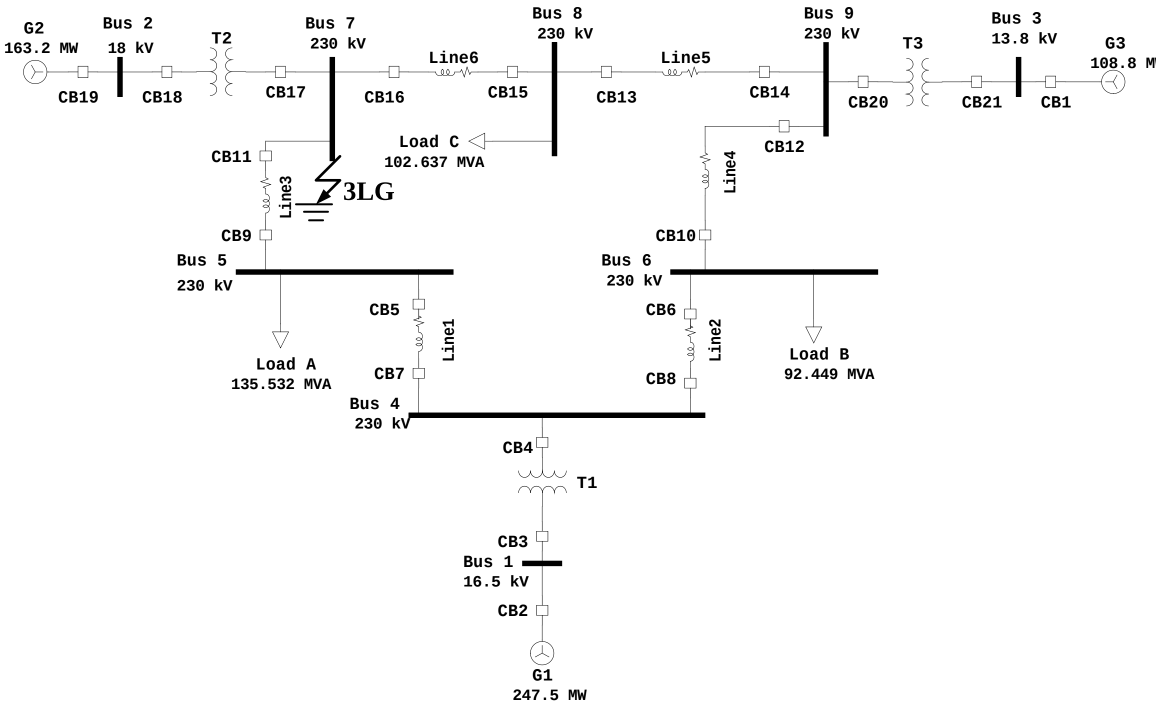


Fig. 1. 9-Bus Multi-Machine Benchmark System

2. Simulation Events

Simulation events for this system are set up as follows:

- 3-phase fault at the end of Line3 (near Bus7) @ t = 0
- Clear fault @ t = 0.083 second and open CB9 and CB11 @ t = 0.084 second

3. Simulation Result Comparisons with the 9-Bus Multi-Machine Benchmark System

In this study, the generator relative rotor angle and absolute rotor angle response behaviors will be investigated following the simulation events. The following plots (Figures 2-5) show the generator relative rotor angle and absolute rotor angle simulation results by ETAP and the 9-Bus Benchmark System as published in P*ower System Control and Stability* by Anderson and Fouad.

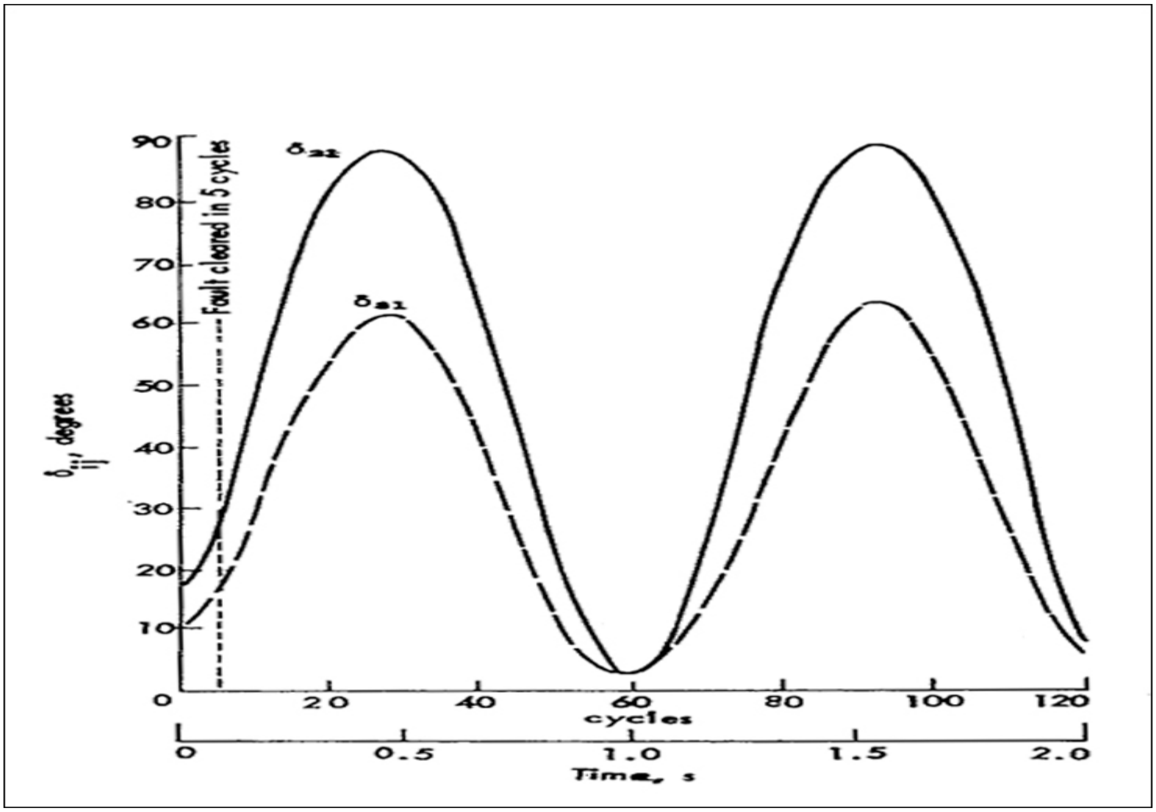


Fig. 2. Generator Relative Rotor Angle Responses for the 9-Bus Multi-Machine System

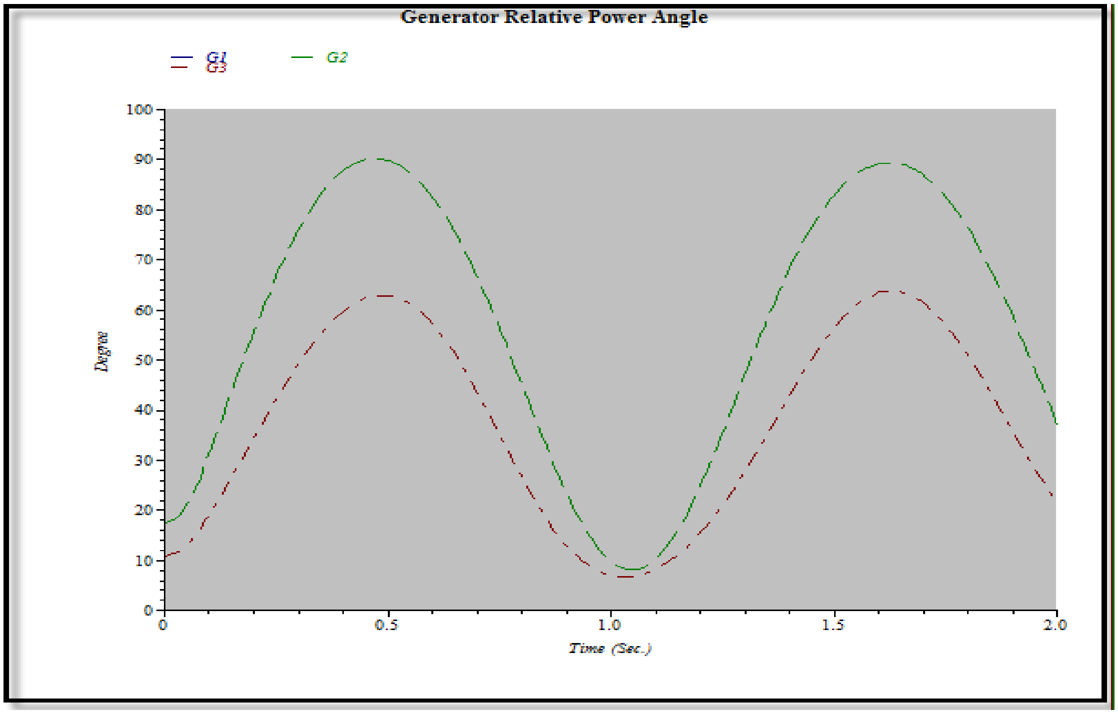


Fig. 3. Generator Relative Rotor Angle Responses by ETAP

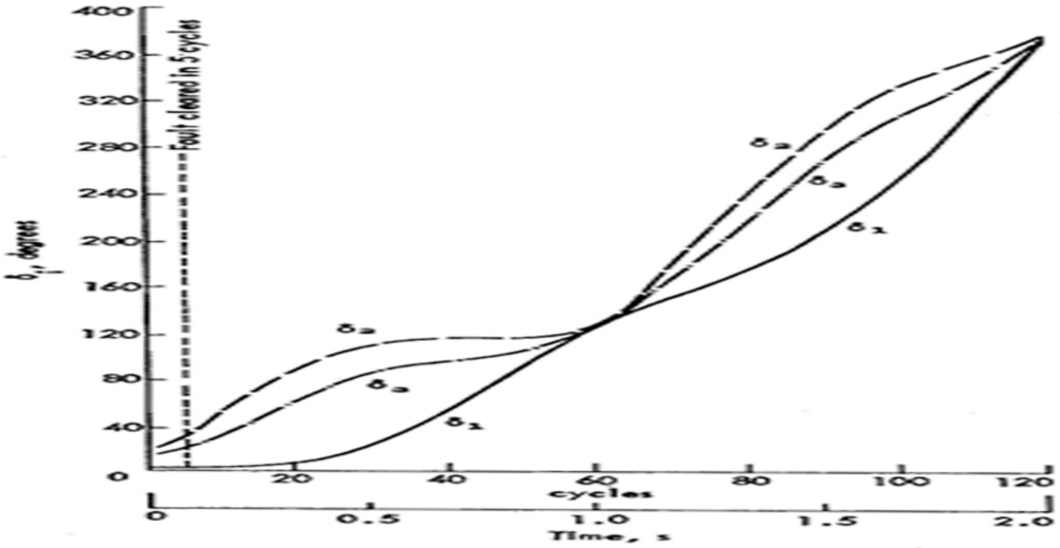


Fig. 4. Generator Absolute Rotor Angle Responses for the 9-Bus Multi-Machine System

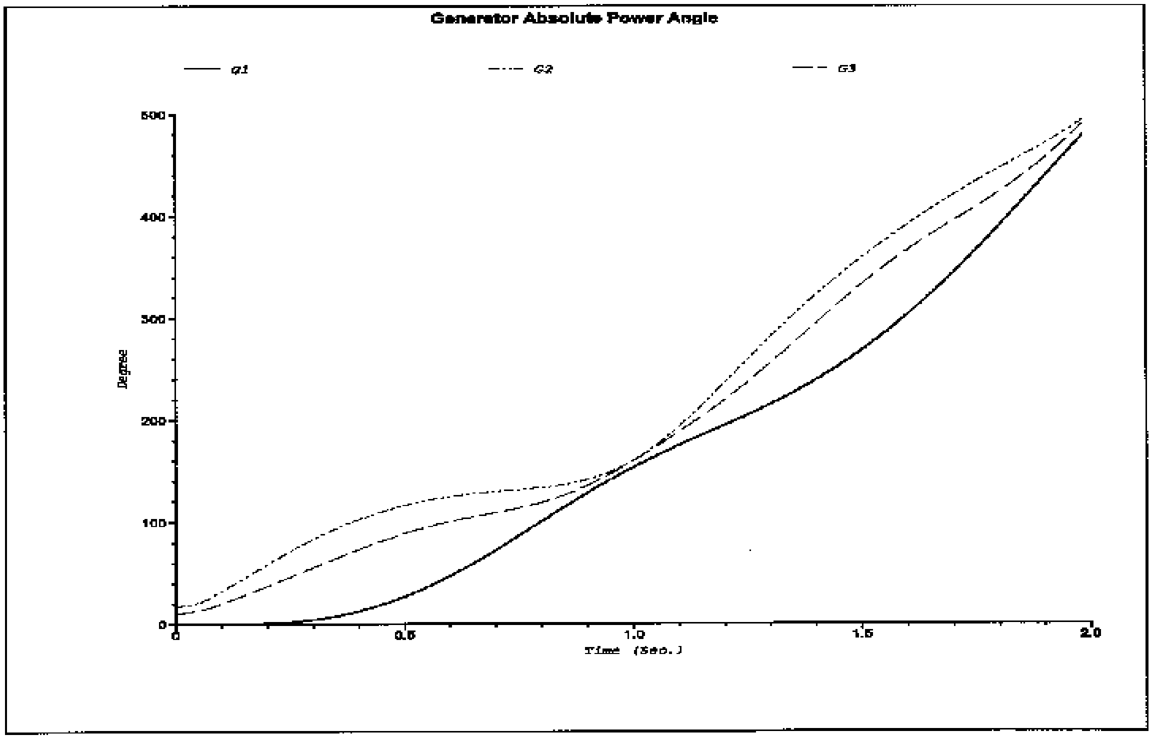


Fig. 5. Generator Absolute Rotor Angle Responses by ETAP

From the above figures, the initial generator relative rotor angles, relative rotor angle oscillation frequencies, maximum relative rotor angles, maximum absolute rotor angles, and the overall response curve shapes for both relative and absolute rotor angles are compared. Note that a very close correlation between ETAP results and the benchmark are noticed. The slight difference for G2 maximum relative rotor angle and the difference in the final values of the absolute angles may be due to the fact that the generator damping coefficients are not available in the publication and typical values are used in the ETAP simulation.

4. Conclusions

In this study, the ETAP Transient Stability generated simulation results for both the generator relative and absolute angle response behaviors, including their initial values, maximum values, oscillation frequencies, and overall shapes are all almost identical to the benchmark results.

Reference:

1. P.M. Anderson and A.A. Fouad, *Power System Control and Stability*, Vol. 1, The Iowa State University Press, Ames, Iowa, USA, 1977.

2. ETAP Transient Stability V&V Documents, Test Case Number TCS-TS-126, 2005.

Transient Stability Comparison Case # 5

Sequential Motor Dynamic Acceleration Simulation Comparison with PTI PSS/E Simulation Results

Excerpts from Validation Cases and Comparison Results (TCS-TS-181)

Highlights

- Comparison of simulation results between the ETAP Transient Stability simulation results and PTI PSS/E program
- Sequential motor dynamic acceleration study involving six motors
- An islanded system with no power grid support
- ETAP built-in salient-pole subtransient synchronous generator model
- ETAP built-in IEEE ST2 excitation/AVR model
- ETAP User-Defined Dynamic Model (UDM) for Woodward Diesel engine/governor model
- ETAP built-in double-cage induction machine model
- ETAP Transient Stability program simulation results compared to the PSS/E results
- Comparison includes generator real, reactive and mechanical power, exciter voltage, generator speed, and induction motor terminal voltage and slip
- Nearly identical results from ETAP and PSS/E

System Description

The system includes a generator and a group of induction motors as shown in Figure 1. The diesel unit generator is rated in 1.87 MW, and modeled in ETAP with Subtransient salient-pole type. Exciter/AVR is modeled with ETAP built-in IEEE Standard ST2 type, and Turbine/Governor is modeled with ETAP User-Defined Dynamic Model (UDM) Woodward Diesel type, shown in Figure 2. The induction motors ratings are ranged from 225 to 400 HP, and dynamically modeled with ETAP double-cage integrated bars type.

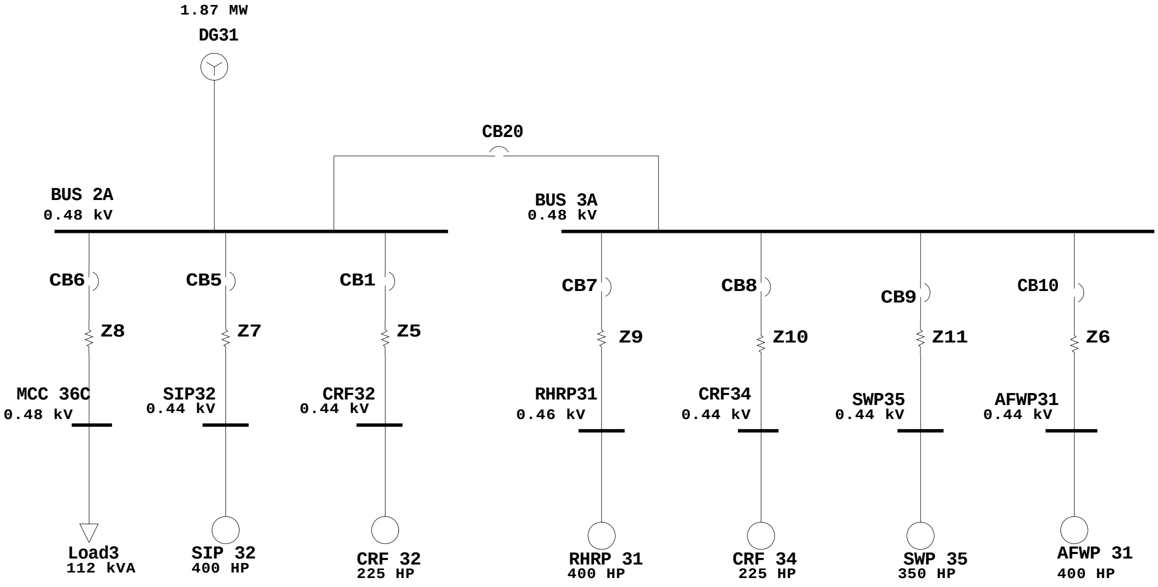


Fig. 1. Sequence Motor Dynamic Acceleration Simulation Study System

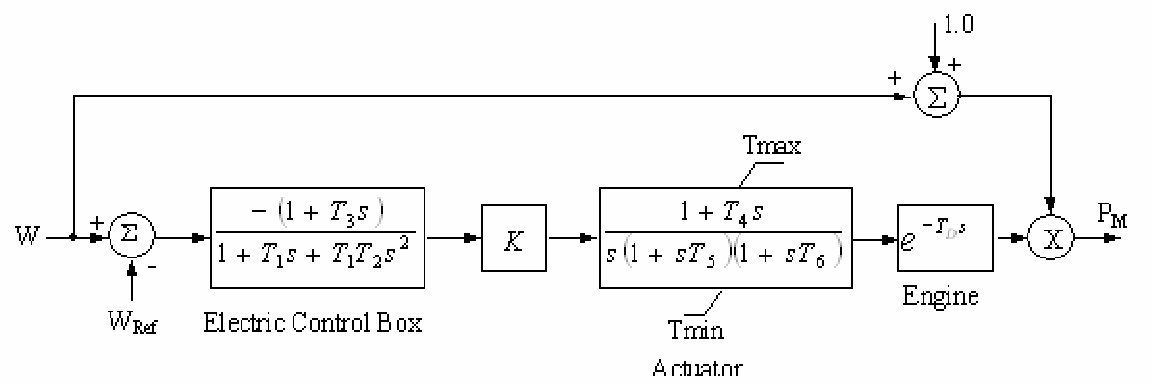


Fig. 2. ETAP UDM Woodward Diesel Turbine/Governor Model

Simulation Events

The simulation events on this system are scheduled to start-up one-by-one all six induction motors with 5 second intervals between each starting.

Simulation Result Comparisons with PTI PSS/E

In this study, the generator and motor simulation results, including generator real, reactive and mechanical power, generator speed deviation, exciter voltage, motor voltages and slips are compared with the results by PTI PSS/E. The following plots (Figures 3-10) show the result comparisons between ETAP and PSS/E.

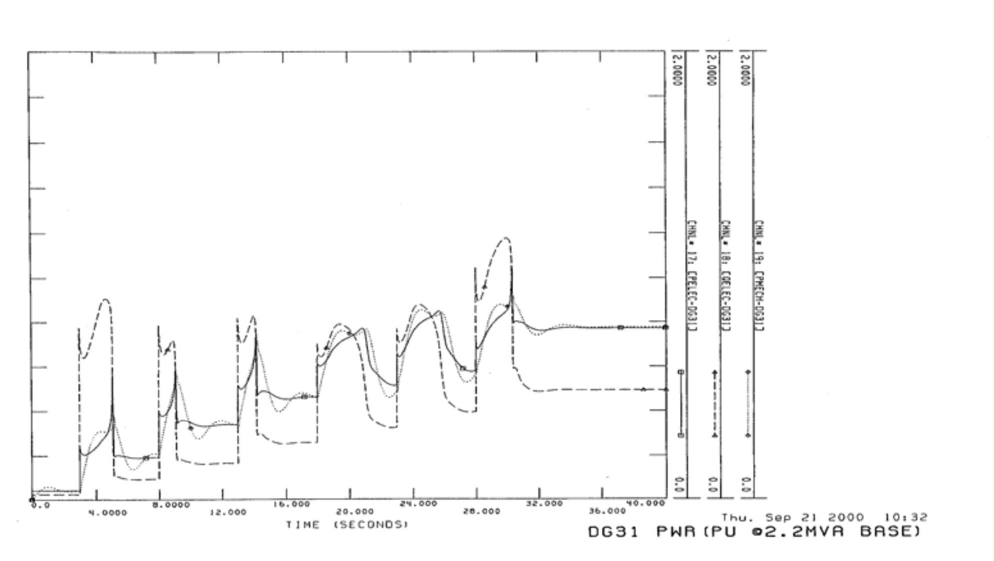


Fig. 3. Generator Real, Reactive, and Mechanical Power by PSS/E

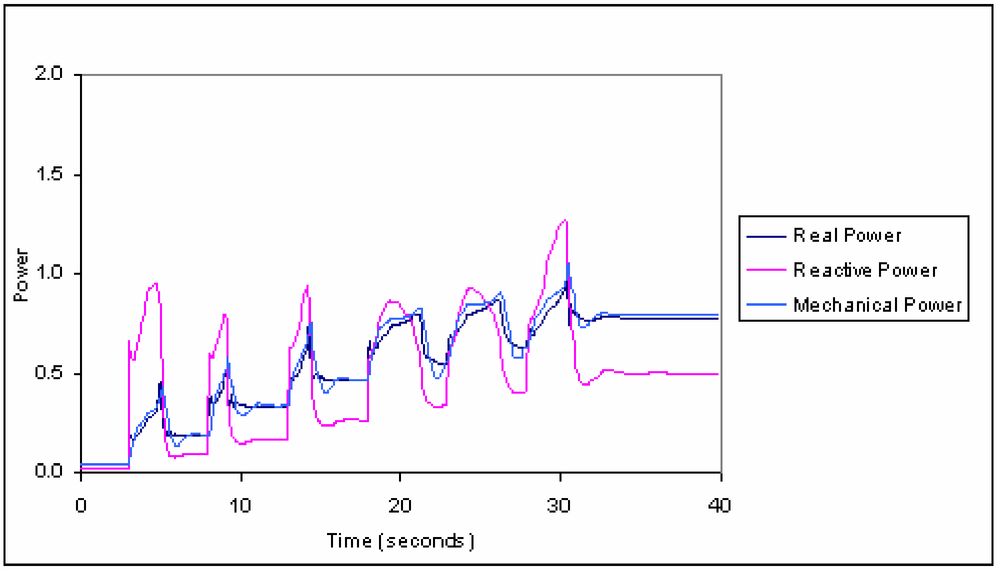


Fig. 4-1. Generator Real, Reactive, and Mechanical Power by ETAP

Simulation results for generator real and reactive power outputs and mechanical power input in Figures 3 and 4-1 show a very close agreement between the two simulations in terms of their peak values, final values, rising time, and overall response shapes. Note that the PSS/E results show a spike-like motor inrush in the generator reactive power curve at the beginning of each motor acceleration, which are not present in the ETAP results. In the ETAP simulation results, these motor inrush values are present for each individual motor reactive power demand (Figure 4-2), but not for the generator since the overall demand on the generator includes the combined effects of the starting motor inrush and the normal reactive power demand of all of the previously started motors, which are running.

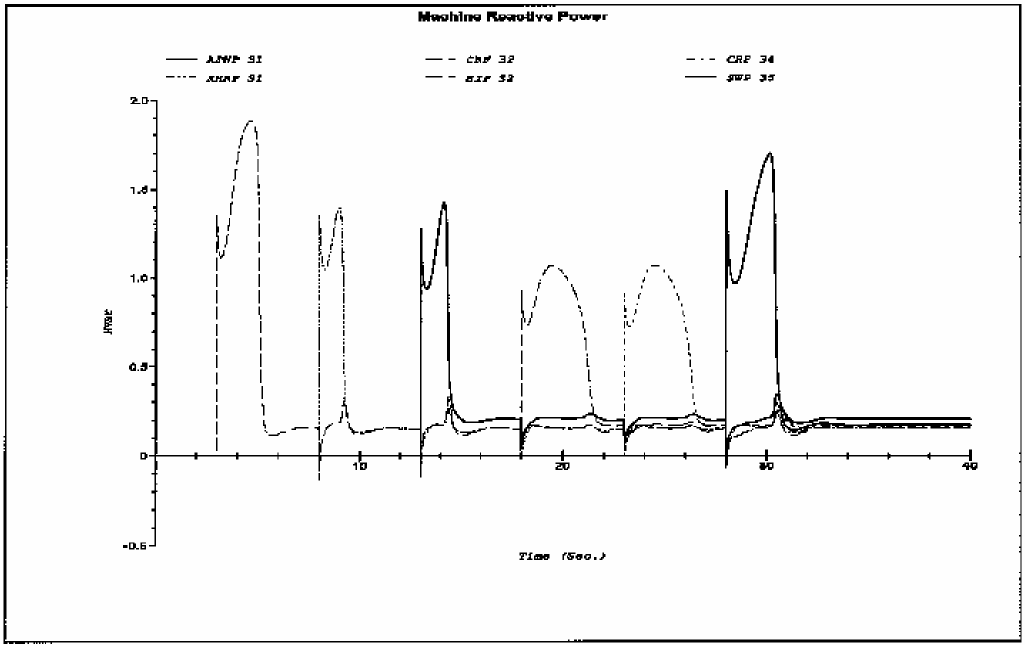


Fig. 4-2. Motor Reactive Power by ETAP

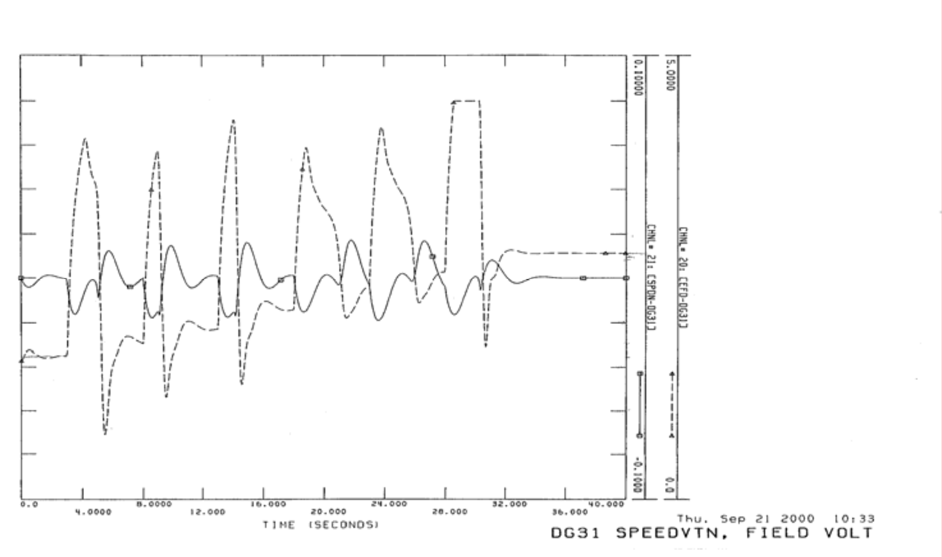


Fig. 5. Generator Exciter Voltage and Speed by PSS/E

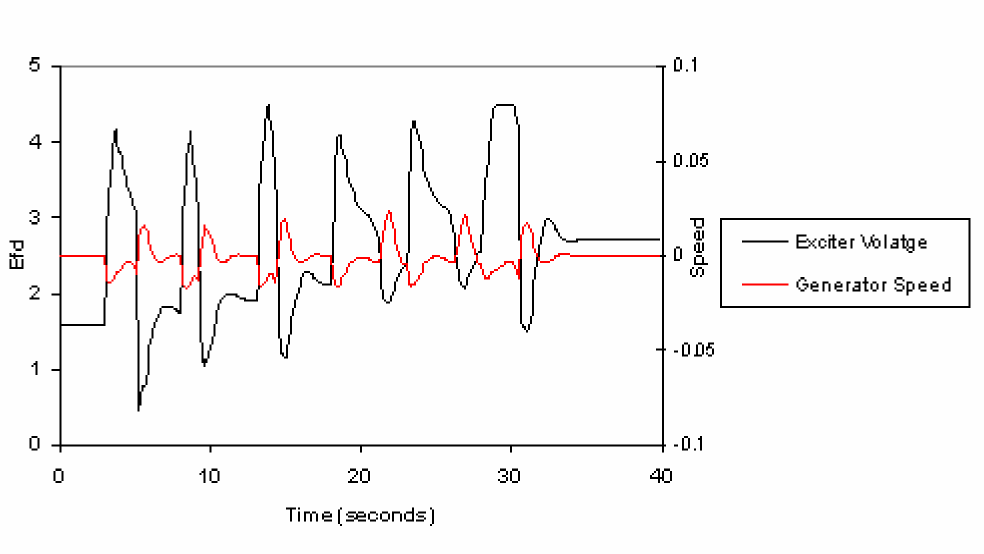


Fig. 6. Generator Exciter Voltage and Speed by ETAP

Figures 5 and 6 show a comparison for generator exciter voltage and speed responses. No significant difference is noticed between the two simulation results. It is pointed out that the initial load flow condition is not stable in the PSS/E simulation results.

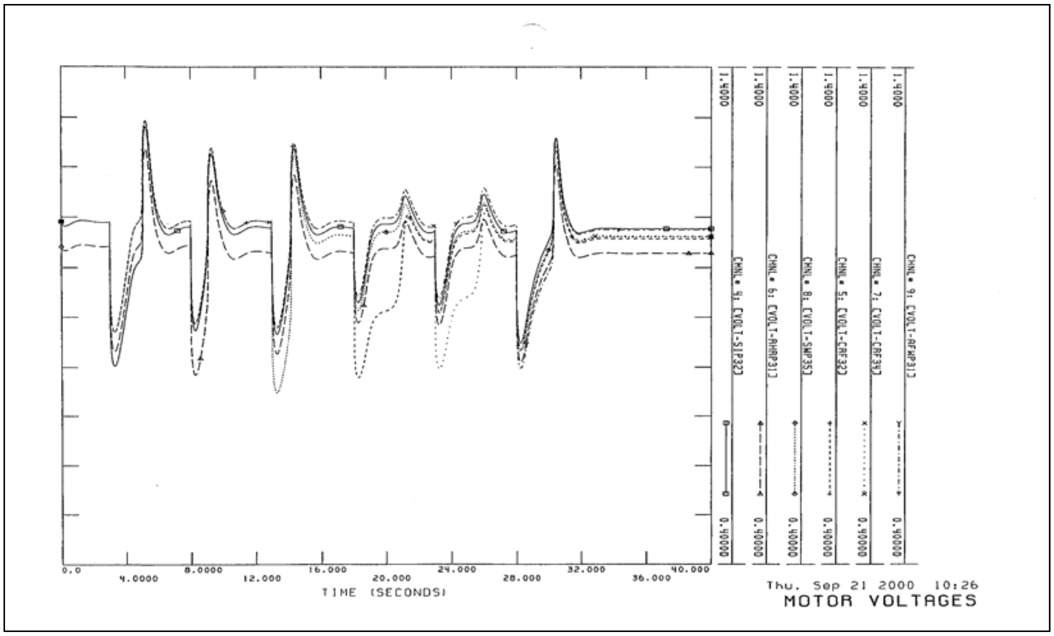


Fig. 7. Induction Motor Terminal Voltages by PSS/E

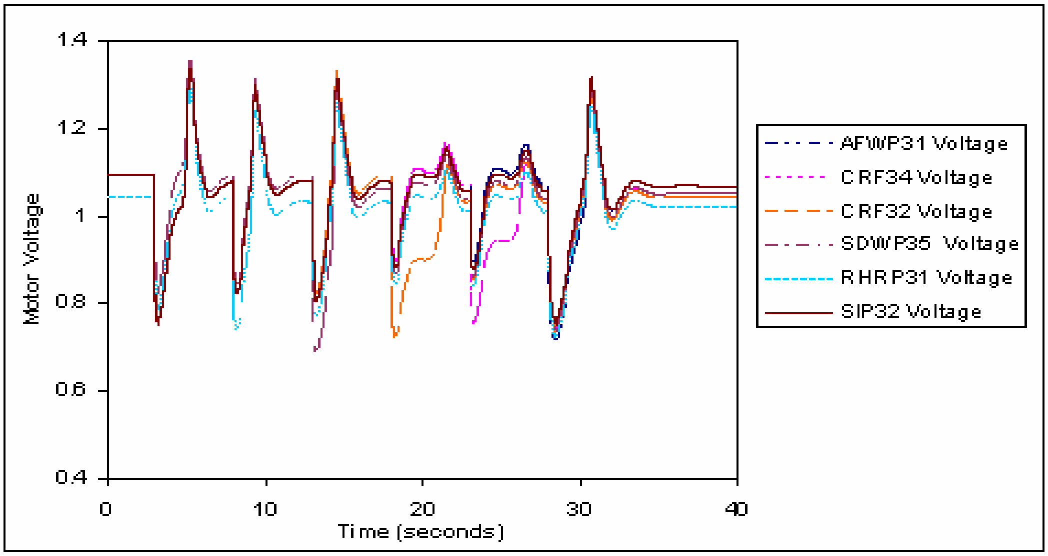


Fig. 8. Induction Motor Terminal Voltages by ETAP

The motor terminal voltage responses for all six accelerating motor buses display the same patterns and values in both simulation, shown in Figures 7 and 8.

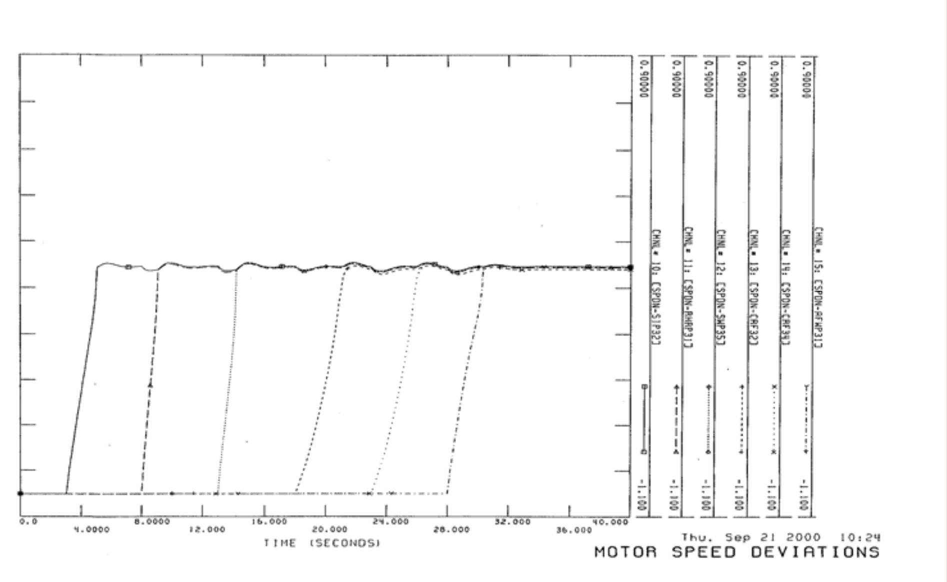


Fig. 9. Induction Motor Speed Slips by PSS/E

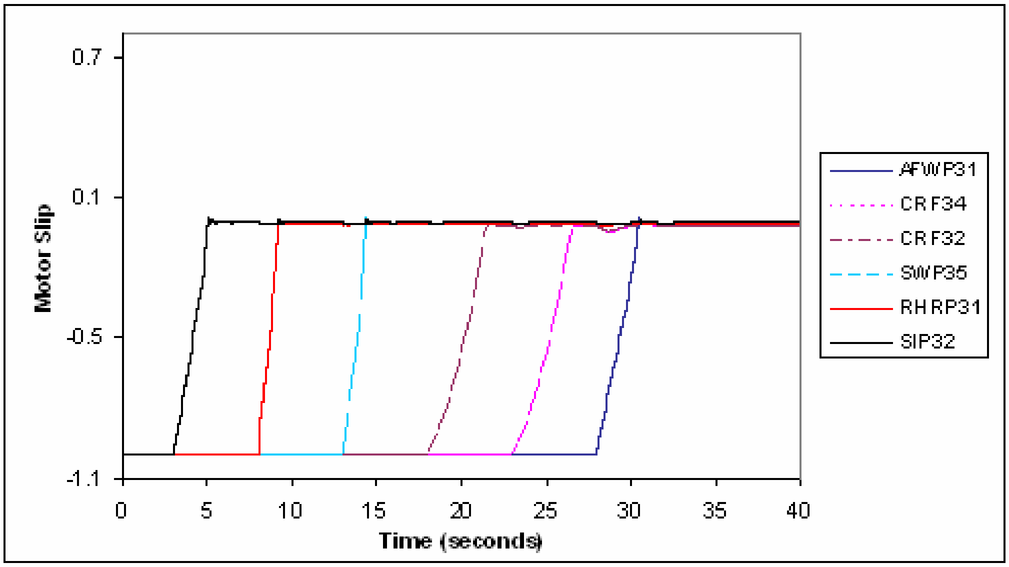


Fig. 10. Induction Motor Speed Slips by ETAP

The motor slip response curve comparison in Figures 9 and 10 shows the motor acceleration time and final slips for all six accelerating motors are almost identical. Note that the motor slip is defined here as (ωmtr - ωsys)/ ωsys, which is normally defined as (ωsys - ωmtr)/ ωsys.

Conclusions

A comprehensive comparison between ETAP and PSS/E results clearly show that both programs provide almost identical results.

Reference

1. ETAP Transient Stability V&V Documents, Test Case Number TCS-TS-181, 2005.