IEEE 9 Bus System Example

Version: R0

Date: 23/10/2017

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REVISION HISTORY

Revision	Author		Approved	Description
	Name	Date		
R0	JP Bérard	23 Oct 2017		

CONTENTS

1. IEEE 9 BUS SYSTEM EXAMPLE

1.1. Summary

This example consists of a modified version of the well-known Western System Coordinating Council (WSCC) 9 bus test case as presented in [1]. This benchmark model contains three synchronous machines with built-in voltage and speed regulators, three two-winding transformers, six constant parameters lines and three loads.

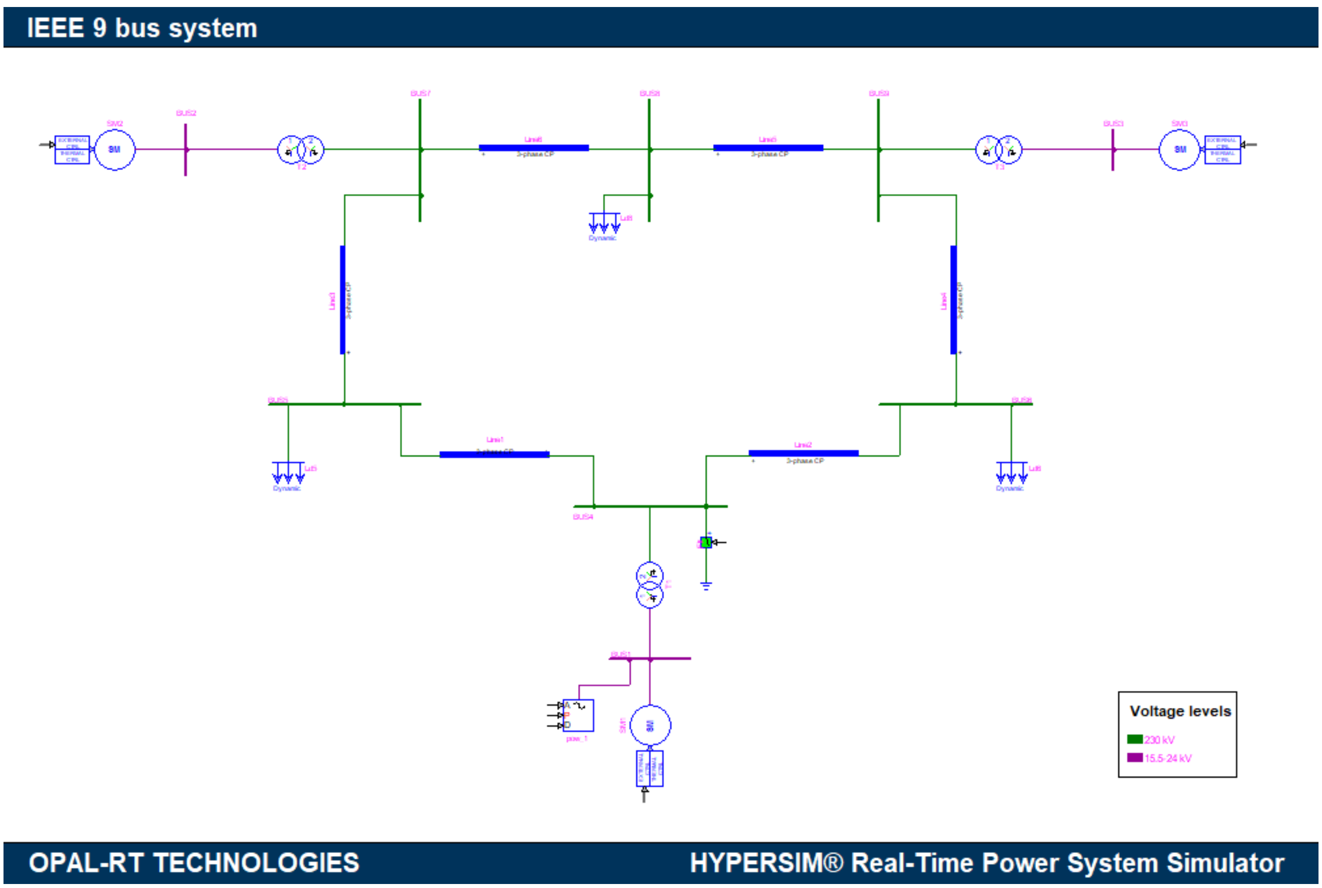

Figure 1 Schematic of the IEEE 9 Bus System

1.2. Components Parameters

1.2.1. Generators

Table 1 Synchronous machine parameters

	SM1	SM2	SM3
Nominal Power (MVA)	512	270	125
Nominal Voltage (kV RMS L-L)	24	18	15.5
Xd (pu)	1.7	1.7	1.22
X'd (pu)	0.27	0.256	0.174
X''d (pu)	0.2	0.185	0.134
T'do (s)	3.8	4.8	8.97
T''do (s)	0.01	0.01	0.033
Xq (pu)	1.65	1.62	1.16
X'q (pu)	0.47	0.245	0.25
X''q (pu)	0.2	0.185	0.134
T'qo (s)	0.48	0.5	0.5
T''qo (s)	0.0007	0.0007	0.07
Ra (pu)	0.004	0.0016	0.004
Xl (pu)	0.16	0.155	0.0078
S(1.0)	0.09	0.125	0.1026
S(1.2)	0.4	0.45	0.432
H (s)	2.6312	4.1296	4.768
D (pu)	2	2	2

Table 2 Exciter parameters

	SM1	SM2	SM3
Kp	5.3	5.3	5.3
Ka	200	30	25
Kf	0.0635	0.05	0.108
Tr (s)	0	0	0.06
Ta (s)	0.395	0.4	0.2
Tf (s)	1	1.3	0.35
Vt min (pu)	0.1	0.1	0.1
Vt max (pu)	100	100	100
Vr min (pu)	-3.84	-4.59	-3
Vr max (pu)	3.84	4.59	3

1.2.2. Transformers

Table 3 Transformer parameters

	T1	T2	T3
Nominal primary voltage (kV RMS L-L)	24	18	15.5
Nominal secondary voltage (kV RMS L-L)	230	230	230
R1 (pu)	1.00E-10	1.00E-10	1.00E-10
L1 (pu)	2.88E-02	3.13E-02	2.93E-02
R2 (pu)	1.00E-10	1.00E-10	1.00E-10
L2 (pu)	2.88E-02	3.13E-02	2.93E-02
Rm (pu)	5.00E+03	5.00E+03	5.00E+03
Lm (pu)	5.00E+03	5.00E+03	5.00E+03

1.2.3. Lines

Table 4 CP line parameters

Line		Length (km)	R0 (Ω/km)	L0 (H/km)	C0 (F/km)	R1 (Ω/km)	L1 (H/km)	C1 (F/km)
From	To							
4	5	89.93	5.88E-01	3.98E-03	5.89E-09	5.88E-02	1.33E-03	9.81E-09
4	6	97.336	9.24E-01	3.98E-03	4.88E-09	9.24E-02	1.33E-03	8.14E-09
5	7	170.338	9.94E-01	3.98E-03	5.41E-09	9.94E-02	1.33E-03	9.01E-09
6	9	179.86	1.15E+00	3.98E-03	5.99E-09	1.15E-01	1.33E-03	9.98E-09
7	8	76.176	5.90E-01	3.98E-03	5.89E-09	5.90E-02	1.33E-03	9.81E-09
8	9	106.646	5.90E-01	3.98E-03	5.90E-09	5.90E-02	1.33E-03	9.83E-09

1.2.4. Loads

Table 5 Load parameters

	Load5	Load6	Load8
Nominal Active Power (MW)	125	90	100
Nominal Reactive Power (MVar)	50	30	35

1.3. MODEL VALIDATION

1.3.1. LOAD FLOW

The model is validated by comparing the load flow results from HYPERSIM R6.0.11.o505 and a PSS®E version of the benchmark published on the Internet [2]. This validation was done first by using equivalent voltage sources at BUS 1, BUS 2 and BUS 3 and then using synchronous machines. Tables 6 to 8 present the comparison.

Table 6 - Load flow results comparison, bus voltages

	PSSE		HYPERSIM							
			Voltage Sources				Synchronous Machines			
	Mag (pu)	*Ang (deg)*	*Mag (pu)*	*ΔMag (pu)*	*Ang(deg)*	*ΔAng(deg)*	*Mag (pu)*	*ΔMag (pu)*	*Ang(deg)*	*ΔAng(deg)*
BUS1	1.04	0.00	1.04	0.00	0.00	0.00	1.04	0.00	0.00	0.00
BUS2	1.03	9.28	1.03	0.00	9.21	-0.07	1.03	0.00	9.21	-0.07
BUS3	1.03	4.66	1.03	0.00	4.60	-0.06	1.03	0.00	4.60	-0.06
BUS4	1.03	-2.22	1.03	0.00	-2.22	0.00	1.03	0.00	-2.22	0.00
BUS5	1.00	-3.99	1.00	0.00	-3.99	0.00	1.00	0.00	-3.99	0.00
BUS6	1.01	-3.69	1.01	0.00	-3.69	0.00	1.01	0.00	-3.69	0.00
BUS7	1.03	3.72	1.03	0.00	3.65	-0.07	1.03	0.00	3.65	-0.07
BUS8	1.02	0.73	1.02	0.00	0.67	-0.06	1.02	0.00	0.67	-0.06
BUS9	1.03	1.97	1.03	0.00	1.90	-0.07	1.03	0.00	1.90	-0.07

Table 7 - Load flow results comparison, lines

		PSSE		HYPERSIM							
				Voltage Sources				Synchronous Machines			
From	*To*	*P (pu)*	*Q (pu)*	*P (pu)*	*ΔP (pu)*	*Q(pu)*	*ΔQ(pu)*	*P (pu)*	*ΔP (pu)*	*Q(pu)*	*ΔQ(pu)*
BUS4	**BUS5**	0.41	0.23	0.41	0.00	0.23	0.00	0.41	0.00	0.23	0.00
BUS4	**BUS6**	0.31	0.01	0.31	0.00	0.01	0.00	0.31	0.00	0.01	0.00
BUS5	**BUS7**	0.84	0.11	0.84	0.00	0.11	0.00	0.84	0.00	0.12	0.00
BUS6	**BUS9**	0.59	0.13	0.59	0.00	0.14	0.00	0.59	0.00	0.14	0.00
BUS7	**BUS8**	0.76	0.01	0.76	0.00	0.01	0.00	0.76	0.00	0.01	0.00
BUS8	**BUS9**	0.24	0.24	0.24	0.00	0.24	0.00	0.24	0.00	0.24	0.00

Table 8 - Load flow results comparison, sources

	PSSE		HYPERSIM							
			Voltage Sources				Synchronous Machines			
To	*P (pu)*	*Q (pu)*	*P (pu)*	*ΔP (pu)*	*Q(pu)*	*ΔQ(pu)*	*P (pu)*	*ΔP (pu)*	*Q(pu)*	*ΔQ(pu)*
BUS5	0.72	0.27	0.72	0.00	0.27	0.00	0.72	0.00	0.27	0.00
BUS6	1.63	0.07	1.63	0.00	0.07	0.00	1.64	0.01	0.07	0.00
BUS7	0.85	-0.11	0.85	0.00	-0.11	0.00	0.85	0.00	-0.11	0.00

1.3.2. STEADY-STATE

The steady-state bus voltage magnitudes, active and reactive powers in the lines and at the sources are compared to the load flow values to validate that the system stabilizes at the same operating point when the time domain simulation is started and ran. The results are shown in Figures 2 to 4 and can be compared to Tables 6 to 8. Relative errors are presented in Tables 9 to 11.

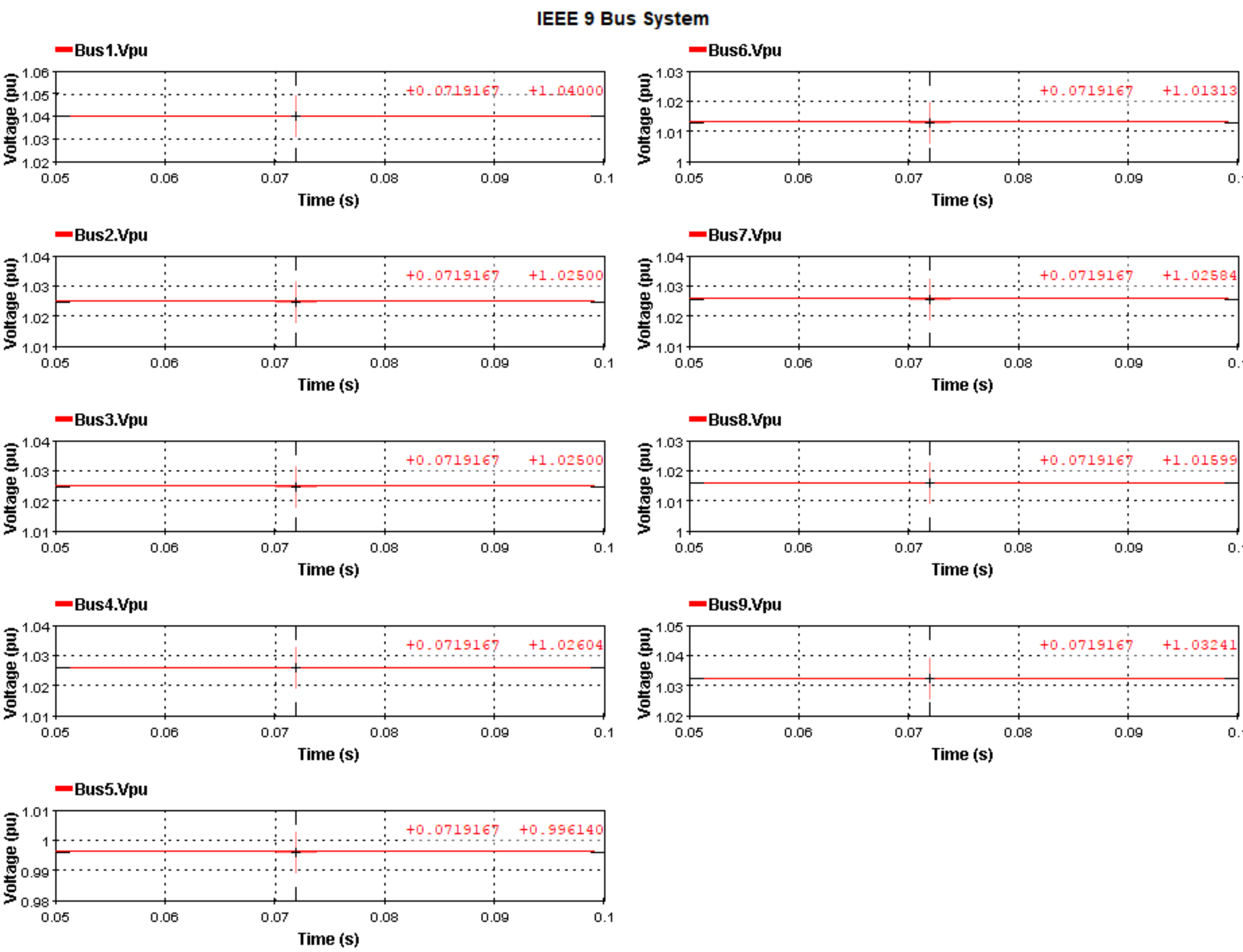

Figure 2 - Steady-state bus voltages

Table 9 - Bus voltages, steady-state vs load flow

	PSSE	HYPERSIM Steady-state values	
	Mag (pu)	*Mag (pu)*	*ΔMag (pu)*
BUS1	1.040	1.040	0.000
BUS2	1.025	1.025	0.000
BUS3	1.025	1.025	0.000
BUS4	1.026	1.026	0.000
BUS5	0.996	0.996	0.000
BUS6	1.013	1.013	0.000
BUS7	1.026	1.026	0.000
BUS8	1.016	1.016	0.000
BUS9	1.032	1.032	0.000

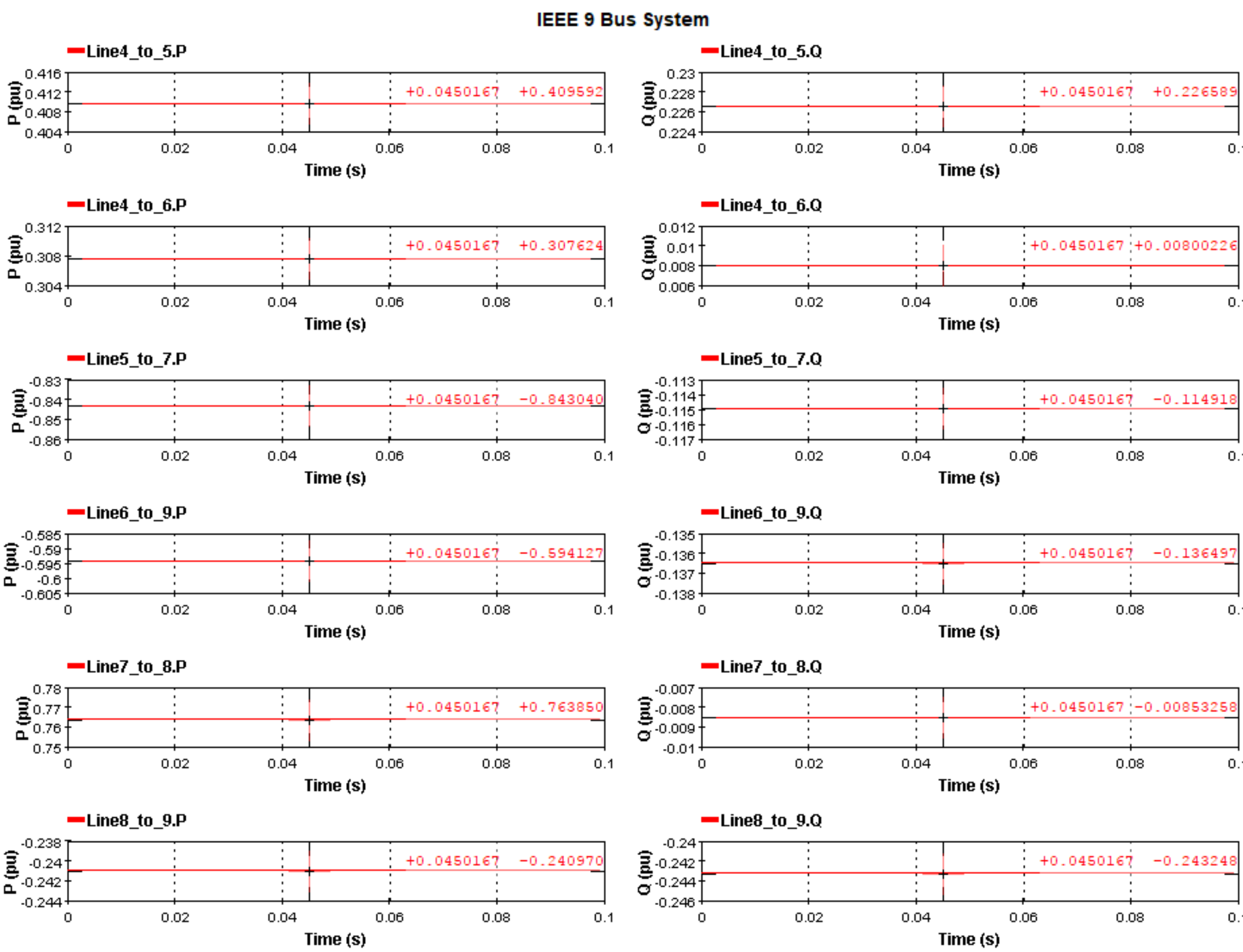

Figure 3 – Steady-state lines P&Q

Table 10 - Lines P&Q, steady-state vs load flow

		PSSE		HYPERSIM Steady-state values			
From	*To*	*P (pu)*	*Q (pu)*	*P (pu)*	*ΔP (pu)*	*Q(pu)*	*ΔQ(pu)*
BUS4	**BUS5**	0.41	0.23	0.41	0.00	0.23	0.00
BUS4	**BUS6**	0.31	0.01	0.31	0.00	0.01	0.00
BUS5	**BUS7**	0.84	0.11	0.84	0.00	0.11	0.00
BUS6	**BUS9**	0.59	0.13	0.59	0.00	0.14	0.00
BUS7	**BUS8**	0.76	0.01	0.76	0.00	0.01	0.00
BUS8	**BUS9**	0.24	0.24	0.24	0.00	0.24	0.00

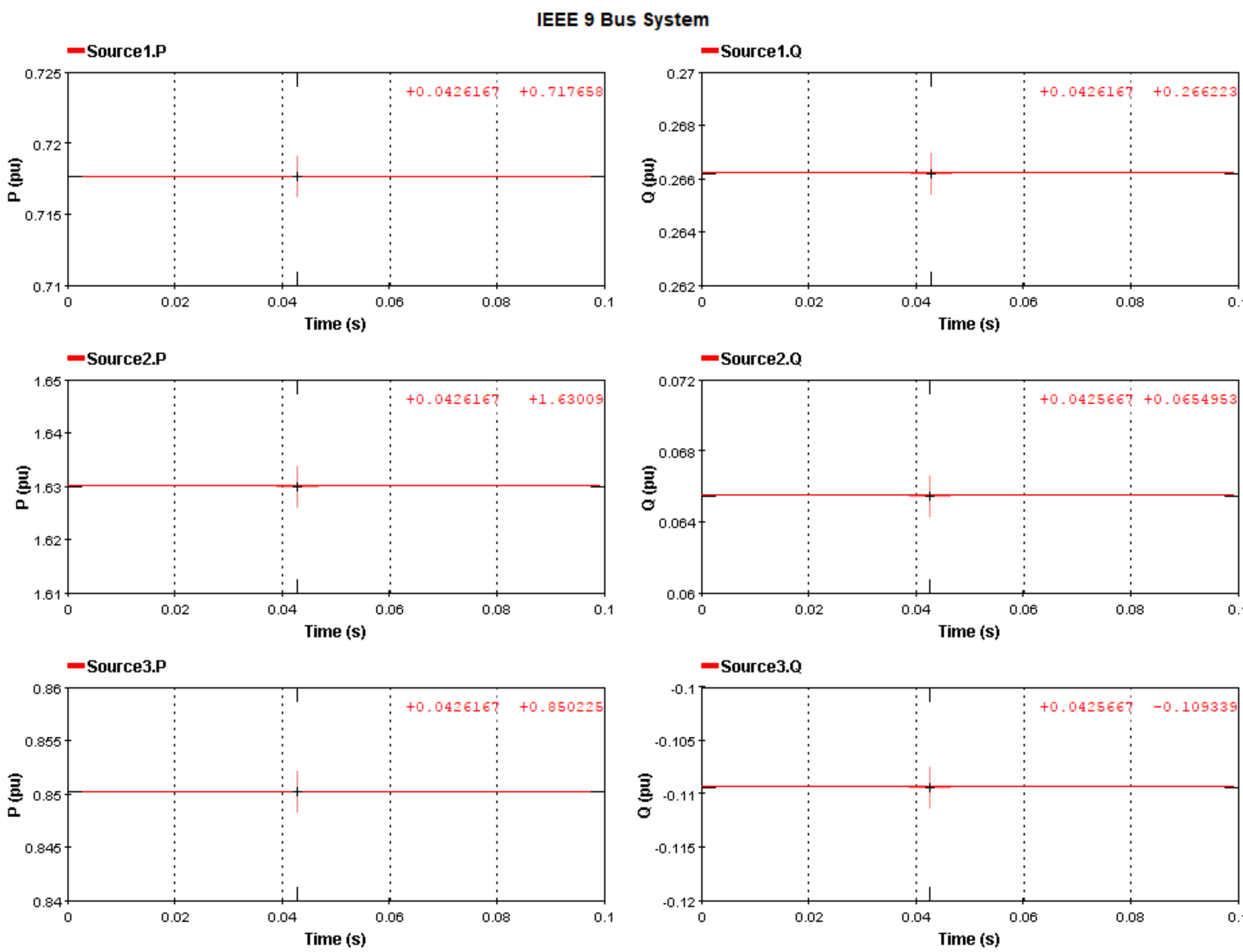

Figure 4 - Steady-state sources P&Q

Table 11 - Sources P&Q, steady-state vs load flow

	PSSE		HYPERSIM Steady-state values			
To	*P (pu)*	*Q (pu)*	*P (pu)*	*ΔP (pu)*	*Q(pu)*	*ΔQ(pu)*
BUS5	0.72	0.27	0.72	0.00	0.27	0.00
BUS6	1.63	0.07	1.63	0.00	0.07	0.00
BUS7	0.85	-0.11	0.85	0.00	-0.11	0.00

1.3.3. Transient Response

The HYPERSIM model with voltage sources is compared to a modified version of the benchmark done in PSCAD, which is publicly available on the Internet [3]. The PSCAD model was modified to reflect the HYPERSIM components parameters as shown in Tables 1 through 5. A 3-phase-to-ground fault with Rfault=1mΩ is applied on Bus4 at t=2.6s. Voltages and currents at different points in the system are compared by superimposing the simulation results. It can be observed from Figures 5 and 6 that the steady-state and transient results from both software agree with each other.

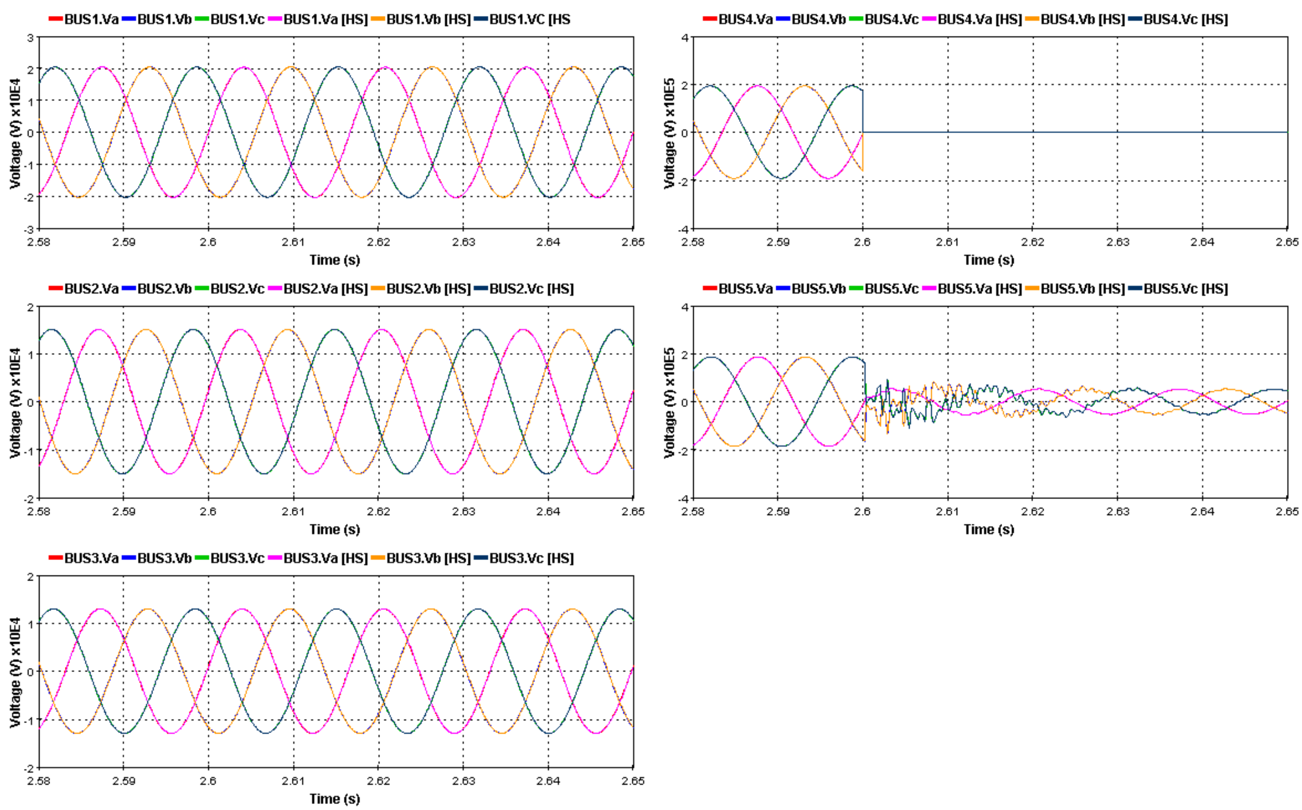

Figure 5 - Bus voltages during 3LG fault, PSCAD vs HYPERSIM

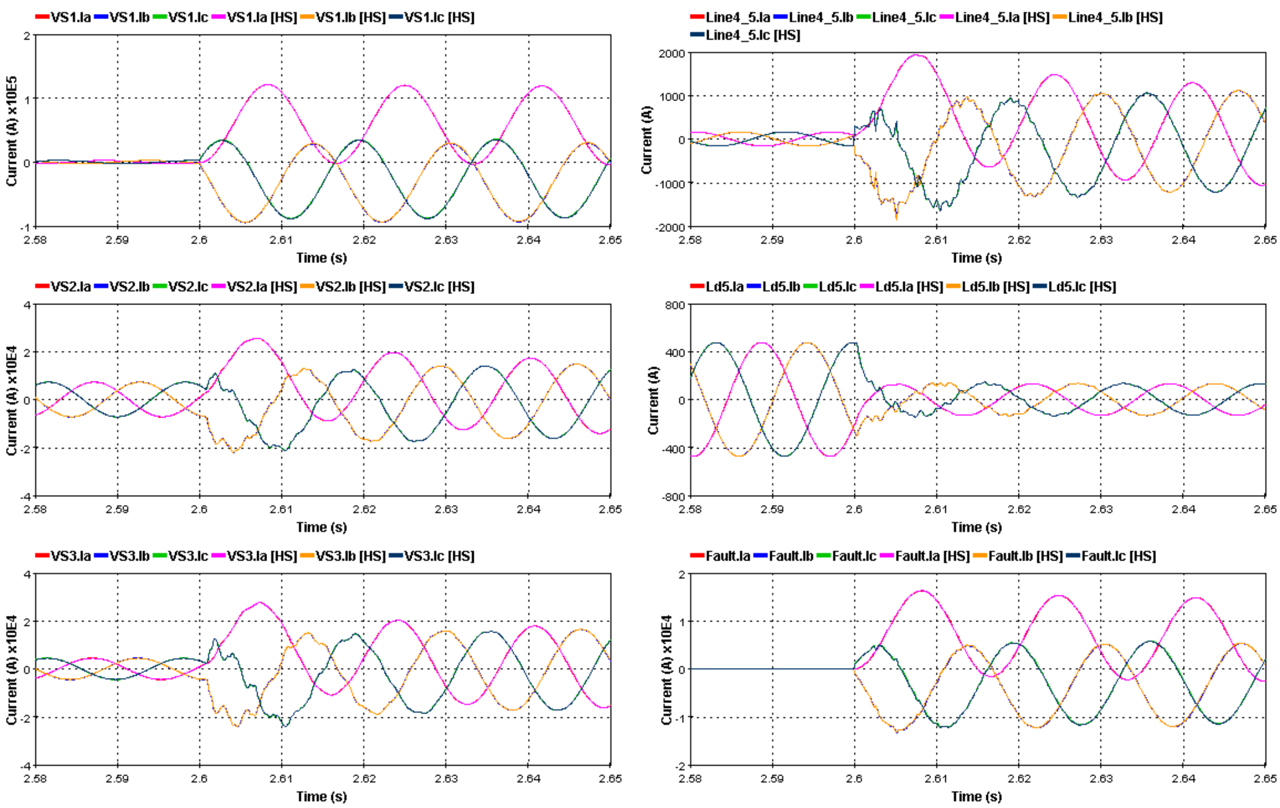

Figure 6 - Currents during 3LG fault, PSCAD vs HYPERSIM

1.4. REFERENCES

[1] KIOS Centre for Intelligent Systems & Networks. 2013. IEEE 9-bus modified test system. [ONLINE] Available at: http://www.kios.ucy.ac.cy/testsystems/index.php/dynamic-ieee-test-systems/ieee-9-bus-modified-test-system.

[2] Harrys Kon. 2016. WSCC 9-Bus System. [ONLINE] Available at: https://harryskon.com/2016/02/28/wscc-9-bus-system/.

[3] Manitoba HVDC Research Center. 2015. IEEE Test Systems. [ONLINE] Available at: http://forum.hvdc.ca/1598644/IEEE-Test-Systems.

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23/10/2017