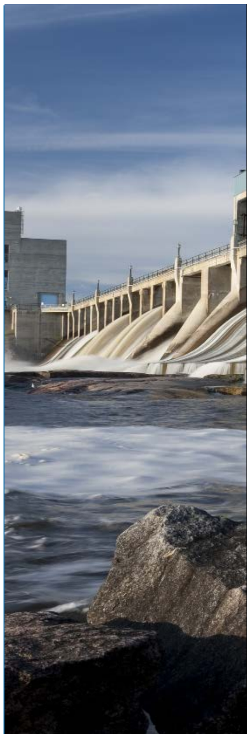

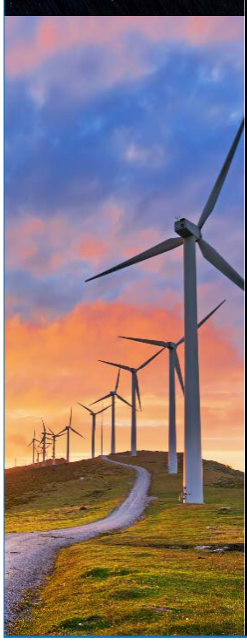

IEEE 39 Bus Power System

RTDS Technologies

Contents

1. CASE INFORMATION

Case Name	IEEE 39 Bus Power System
Location	RSCAD\Example Cases\Benchmark Systems
Revision Date	01 – November, 2022
Created by	Arunprasanth Sakthivel
Target	PB5, NovaCor
Minimum Hardware	1 x NovaCor Chassis with at least 3 enabled core 1 x PB5 based rack with at least 5 PB5 cards
Keywords	Generator, Exciter, Governor, Fault, Transmission line
Purpose	To provide an RSCAD model of the IEEE 39 bus power system

2. INTRODUCTION

IEEE 39-Bus system is a reduced equivalent of the New England test system (NETS). Figure 1 shows the one-line diagram of the test system [1].

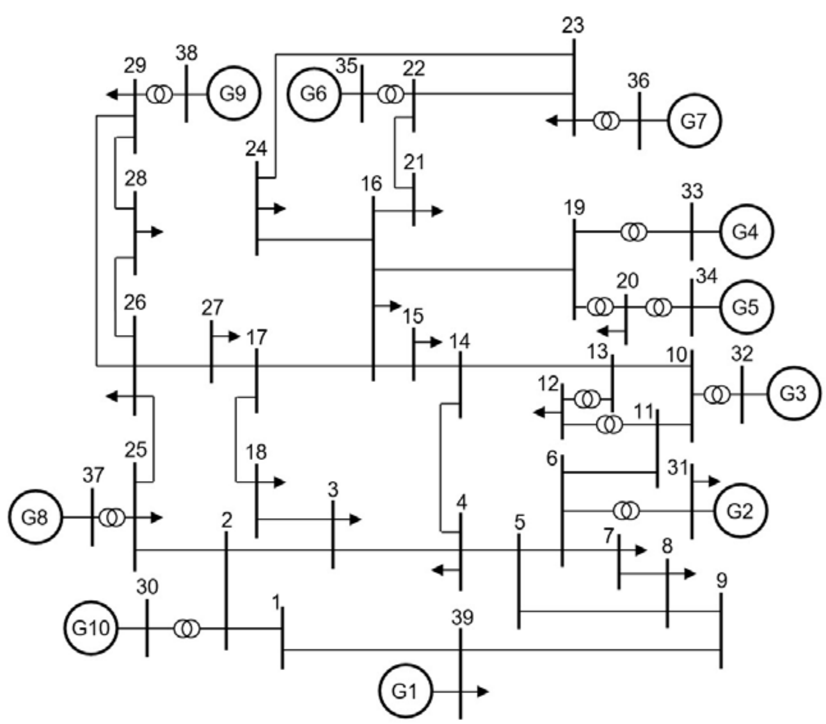

Figure 1 : One-Line Diagram of IEEE 39 Bus Power System [1]

The data pertaining to the system are given in Section 3. The power flow results from RSCAD® and PSS®E are compared in Section 4 to show that a close match can be achieved. Section 5 lists references related to the data and models used in the system.

3. SYSTEM MODELLING

The power flow data of the system are taken from [1]. It was assumed that the branch data provided in [1] is compensated for long line effects. The transmission lines in RSCAD simulation case are modelled using Bergeron model, which is simulated using distributed line parameters. However, since the lines in the system are not too long, the long line compensation was not removed when using the branch data in RSCAD case.

NOTE: The transmission lines in RSCAD case have been configured to read data from the tlines file located in the case folder. If required, tline data input files (.tli) of all transmission lines can be found inside the 'Tline Files' folder.

Table 1 Bus Data

BUS	Type	|V| (pu)	P_{GEN} (MW)	P_{LOAD} (MW)	Q_{LOAD} (MVAr)
1	P-Q	-	-	0	0
2	P-Q	-	-	0	0
3	P-Q	-	-	322	2.4
4	P-Q	-	-	500	184
5	P-Q	-	-	0	0
6	P-Q	-	-	0	0
7	P-Q	-	-	233.8	84
8	P-Q	-	-	522	176
9	P-Q	-	-	0	0
10	P-Q	-	-	0	0
11	P-Q	-	-	0	0

12	P-Q	-	-	7.5	88
13	P-Q	-	-	0	0
14	P-Q	-	-	0	0
15	P-Q	-	-	320	153
16	P-Q	-	-	329	32.3
17	P-Q	-	-	0	0
18	P-Q	-	-	158	30
19	P-Q	-	-	0	0
20	P-Q	-	-	628	103
21	P-Q	-	-	274	115
22	P-Q	-	-	0	0
23	P-Q	-	-	247.5	84.6
24	P-Q	-	-	308.6	-92
25	P-Q	-	-	224	47.2
26	P-Q	-	-	139	17
27	P-Q	-	-	281	75.5
28	P-Q	-	-	206	27.6
29	P-Q	-	-	283.5	26.9
30	P-V	1.0475	250	0	0
31	SLACK	0.9820	-	9.2	4.6
32	P-V	0.9831	650	0	0
33	P-V	0.9972	632	0	0

34	P-V	1.0123	508	0	0
35	P-V	1.0493	650	0	0
36	P-V	1.0635	560	0	0
37	P-V	1.0278	540	0	0
38	P-V	1.0265	830	0	0
39	P-V	1.0300	1000	1104	250

Table 2 Branch Data

From BUS	To BUS	R (pu)	X (pu)	B (pu)
1	2	0.0035	0.0411	0.6987
1	39	0.0010	0.0250	0.7500
2	3	0.0013	0.0151	0.2572
2	25	0.0070	0.0086	0.1460
3	4	0.0013	0.0213	0.2214
3	18	0.0011	0.0133	0.2138
4	5	0.0008	0.0128	0.1342
4	14	0.0008	0.0129	0.1382
5	6	0.0002	0.0026	0.0434
5	8	0.0008	0.0112	0.1476
6	7	0.0006	0.0092	0.1130
6	11	0.0007	0.0082	0.1389
7	8	0.0004	0.0046	0.0780

8	9	0.0023	0.0363	0.3804
9	39	0.0010	0.0250	1.2000
10	11	0.0004	0.0043	0.0729
10	13	0.0004	0.0043	0.0729
13	14	0.0009	0.0101	0.1723
14	15	0.0018	0.0217	0.3660
15	16	0.0009	0.0094	0.1710
16	17	0.0007	0.0089	0.1342
16	19	0.0016	0.0195	0.3040
16	21	0.0008	0.0135	0.2548
16	24	0.0003	0.0059	0.0680
17	18	0.0007	0.0082	0.1319
17	27	0.0013	0.0173	0.3216
21	22	0.0008	0.0140	0.2565
22	23	0.0006	0.0096	0.1846
23	24	0.0022	0.0350	0.3610
25	26	0.0032	0.0323	0.5130
26	27	0.0014	0.0147	0.2396
26	28	0.0043	0.0474	0.7802
26	29	0.0057	0.0625	1.0290
28	29	0.0014	0.0151	0.2490

Table 3 Transformer Data

From BUS	To BUS	R (pu)	X (pu)	Tap Ratio[1]
12	11	0.0016	0.0435	1.006
12	13	0.0016	0.0435	1.006
6	31	0	0.0250	1.070
10	32	0	0.0200	1.070
19	33	0.0007	0.0142	1.070
20	34	0.0009	0.0180	1.009
22	35	0	0.0143	1.025
23	36	0.0005	0.0272	1.000
25	37	0.0006	0.0232	1.025
2	30	0	0.0181	1.025
29	38	0.0008	0.0156	1.025
19	20	0.0007	0.0138	1.060

The dynamic data available in [1] is not sufficient to model the generators for detailed EMT simulation studies. Therefore, the missing data such as sub-transient data were taken from [2]. The exciter data provided in [1] correspond to the 'IEEE Type 1' excitation system. The generator data in [1] fall in the typical data range of thermal generating units [3]. Therefore, the 'TGOV' type thermal governor is used.

Modifications:

- The synchronous machine model in RSCAD have minimum value settings for generator parameters to ensure the numerical stability. Therefore, the data in [1] were converted from 100 MVA to 1000 MVA to satisfy the above limits.
- Generator-1 represents the aggregation of the power system connected to BUS-39 and is supplied with constant field voltage and constant mechanical torque.

[1] Tap ratio is set to the from bus side of the transformer

- The Tqo' parameter of Generator-10 was given as 0 in [1] and this must be a typing mistake. Therefore, a value of 1.5 s is used.
- To satisfy the condition, Xq' ≥ Xd' for typical data [3], the Xq' of Generator-10 given in [1] was modified as 0.031 pu (100 MVA base).
- To satisfy the condition, Xa < Xq" < Xd' for typical data [3], the Xd" and Xq" of Generator-1 in [2] were modified as 0.005 pu (on 100 MVA base).
- To satisfy the condition for typical data [3], the Xd" and Xq" of Generator-5 in [2] were modified as 0.09 pu (on 100 MVA base).

Table 4 Generator Data-1 (1000 MVA base)

GEN	BUS	Xa (pu)	Xd (pu)	Xd' (pu)	Xd" (pu)	Xq (pu)	Xq' (pu)	Xq" (pu)
1	39	0.03	0.2	0.06	0.05	0.19	0.08	0.05
2	31	0.035	2.95	0.697	0.5	2.82	1.7	0.5
3	32	0.304	2.495	0.531	0.45	2.37	0.876	0.45
4	33	0.295	2.62	0.436	0.35	2.58	1.66	0.35
5	34	0.54	6.7	1.32	0.99	6.2	1.66	0.99
6	35	0.224	2.54	0.5	0.4	2.41	0.814	0.4
7	36	0.322	2.95	0.49	0.4	2.92	1.86	0.4
8	37	0.28	2.9	0.57	0.45	2.8	0.911	0.45
9	38	0.298	2.106	0.57	0.45	2.05	0.587	0.45
10	30	0.125	1	0.31	0.25	0.69	0.3	0.25

Table 5 Generator Data-2 (1000 MVA base)

GEN	BUS	Ra (pu)[2]	Tdo' (s)	Tdo" (s)	Tqo' (s)	Tqo" (s)	H (s)	D(pu/pu)
1	39	0.000125	7.0	0.05	0.7	0.06	50	0
2	31	0.000125	6.56	0.05	1.5	0.06	3.03	0
3	32	0.000125	5.7	0.05	1.5	0.06	3.58	0
4	33	0.000125	5.69	0.05	1.5	0.06	2.86	0
5	34	0.000125	5.4	0.05	0.44	0.06	2.6	0
6	35	0.000125	7.3	0.05	0.4	0.06	3.48	0
7	36	0.000125	5.66	0.05	1.5	0.06	2.64	0
8	37	0.000125	6.7	0.05	0.41	0.06	2.43	0
9	38	0.000125	4.79	0.05	1.96	0.06	3.45	0
10	30	0.000125	10.2	0.05	1.5	0.06	4.2	0

Table 6 Exciter data-1 (IEEE Type T1)

GEN	KA	TA	VRmin	VRmax	KE	TE	KF	TF
2	6.2	0.05	-1	1	-0.6330	0.4050	0.0570	0.5000
3	5.0	0.06	-1	1	-0.0198	0.5000	0.0800	1.0000
4	5.0	0.06	-1	1	-0.0525	0.5000	0.0800	1.0000
5	40.0	0.02	-10	10	1.0000	0.7850	0.0300	1.0000
6	5.0	0.02	-1	1	-0.0419	0.4710	0.7540	1.2460
7	40.0	0.02	-6.5	6.5	1.0000	0.7300	0.0300	1.0000
8	5.0	0.02	-1	1	-0.0470	0.5280	0.0854	1.2600
9	40.0	0.02	-10.5	10.5	1.0000	1.4000	0.0300	1.0000
10	5.0	0.06	-1	1	-0.0485	0.2500	0.0400	1.0000

[2] The stator resistance (Ra) is given as 0 pu in [2]. However, the synchronous machine model in RSCAD has a minimum value for this entry. Therefore, the 'Ra' is set to the minimum allowed value, which is 0.000125 pu on generator MVA.

Table 7 Exciter data-2 (IEEE Type T1)

GEN	EX1	S(EX1)	EX2	S(EX2)
2	3.0364	0.6600	4.0486	0.8800
3	2.3423	0.1300	3.1230	0.3400
4	2.8681	0.0800	3.8241	0.3140
5	3.9267	0.0700	5.2356	0.9100
6	3.5868	0.0640	4.7824	0.2510
7	2.8017	0.5300	3.7356	0.7400
8	3.1915	0.0720	4.2553	0.2820
9	4.2568	0.6200	5.6757	0.8500
10	3.5461	0.0800	4.7281	0.2600

Table 8 Governor Data (TGOV1)

GEN	R (pu)	T1 (s)	Vmax (pu)	Vmin (pu)	T2 (s)	T3 (s)	Dt (pu)
2	0.05	0.05	1.00	-1.00	2.1	7.0	0.0
3	0.05	0.05	1.00	-1.00	2.1	7.0	0.0
4	0.05	0.05	1.00	-1.00	2.1	7.0	0.0
5	0.05	0.05	1.00	-1.00	2.1	7.0	0.0
6	0.05	0.05	1.00	-1.00	2.1	7.0	0.0
7	0.05	0.05	1.00	-1.00	2.1	7.0	0.0
8	0.05	0.05	1.00	-1.00	2.1	7.0	0.0
9	0.05	0.05	1.00	-1.00	2.1	7.0	0.0
10	0.05	0.05	1.00	-1.00	2.1	7.0	0.0

4. LOADFLOW RESULTS

The loadflow results obtained using the embedded loadflow program in RSCAD is compared against the PSS/E loadflow results in Table 9 and Table 10. The comparison of dynamic simulation results for transient disturbances are presented in [4].

Table 9 Load Flow Results of Load Buses

BUS	|V| (pu)		∠V (deg)	
	RTDS	PSS/E	RTDS	PSS/E
1	1.0474	1.0474	-8.4362	-8.4368
2	1.0488	1.0487	-5.7601	-5.7519
3	1.0302	1.0302	-8.6012	-8.5967
4	1.0039	1.0039	-9.6067	-9.6048
5	1.0053	1.0053	-8.6120	-8.6100
6	1.0077	1.0077	-7.9499	-7.9479
7	0.9970	0.9970	-10.1230	-10.1219
8	0.9961	0.9960	-10.6143	-10.6135
9	1.0283	1.0282	-10.3180	-10.3201
10	1.0172	1.0172	-5.4285	-5.4253
11	1.0127	1.0127	-6.2853	-6.2825
12	0.9976	1.0002	-6.2451	-6.2418
13	1.0143	1.0143	-6.0992	-6.0959
14	1.0118	1.0117	-7.6568	-7.6546
15	1.0154	1.0154	-7.7372	-7.7342
16	1.0318	1.0318	-6.1906	-6.1856
17	1.0336	1.0336	-7.3036	-7.2994
18	1.0310	1.0309	-8.2262	-8.2220

19	1.0498	1.0499	-1.0312	-1.0209
20	0.9913	0.9912	-2.023	-2.0128
21	1.0318	1.0318	-3.7870	-3.7786
22	1.0498	1.0498	0.6572	0.6702
23	1.0448	1.0448	0.4577	0.4720
24	1.0374	1.0373	-6.0703	-6.0660
25	1.0576	1.0576	-4.3708	-4.3614
26	1.0522	1.0521	-5.5314	-5.5248
27	1.0379	1.0377	-7.4980	-7.4935
28	1.0503	1.0501	-2.0591	-2.0130
29	1.0500	1.0499	0.6917	0.7462

Table 10 Load Flow Results of Generator Buses

BUS	|V| (pu)		∠V (deg)[3]		PG (MW)		QG (MVAr)	
	RTDS	PSS/E	RTDS	PSS/E	RTDS	PSS/E	RTDS	PSS/E
30	1.0475	1.0475	-33.3404	-3.3322	250.0	250.0	146.0	146.2
31	0.9820	0.9820	-30.0000	0.0000	520.0	520.7	198.1	198.2
32	0.9831	1.0983	-27.4318	2.5705	650.0	650.0	205.1	205.1
33	0.9972	0.9972	-25.8119	4.1966	632.0	632.0	110.2	109.9
34	1.0123	1.0123	-26.8948	3.1769	508.0	508.0	165.3	165.8
35	1.0493	1.0493	-24.3799	5.6320	650.0	650.0	212.3	212.4
36	1.0635	1.0635	-21.6882	8.3248	560.0	560.0	101.1	101.2
37	1.0278	1.0278	-27.5865	2.4230	540.0	540.0	0.3	0.4

[3] The 30 degree difference in voltage angle is due to the Y-Δ step-up transformers at the generator buses in RSCAD.

38	1.0265	1.0265	-22.2444	7.8096	830.0	830.0	22.2	22.8
39	1.0300	1.0300	-10.0478	-10.0511	1000.0	1000.0	87.7	88.3

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