Benchmark Systems

Modeling Description

Abstract: This document describes the modeling of the Benchmark Examples using the OpenDSS Library from the Typhoon HIL toolchain. The main goal of these systems is to support a starting point for the usage of the library applying its key features. The library modeling technique/features are applied according to the electrical system characteristics in the study.

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IEEE SYSTEMS

IEEE 13 BUS FEEDER (DISTRIBUTION SYSTEMS)

The IEEE 13 Bus feeder is commonly employed in studies involving distribution systems. Despite being a small system, the feeder has interesting characteristics [1]:

- Short and relatively loaded for a 4.16 kV feeder:
  - Unbalanced spot and distributed loads (~3466 MW and 2102 MVAR);
- Variety Overhead and Underground lines topologies:
  - Ten branches (~2.5 km of lines)
- Voltage Regulation equipment:
  - One series voltage regulator (three single-phase transformers);
  - Shunt Capacitor banks (one single-phase and one three-phase bank).

The feeder topology is shown in Figure 1. The system mainly operates at 4.16 kV. The reference provides one substation transformer data operating at 115 kV, but it is not considered in the modeling. Three single-phase voltage regulators are used between the #650 and #632 buses. At the default configuration, the transformers are parameterized using a line voltage drop compensation, but the current stage of the library does not support this feature. A modification on the voltage reference of the regulator is implemented to match the secondary level of the voltage regulator.

The inherent unbalance of the feeder is preserved through the load connections and line representation. All the loads from the feeder are modeled using a constant impedance approach. The lines are modeled using a matrix representation from linecodes feature from the library. All modeling data is provided in the following subsections.

The power flow results compared in Table 2 and Table 1 show a close match between the model and the reference, even with the abovementioned modifications. Table 2 compares the voltages at the load nodes. The DSS column refers to the results obtained from the SymDSS component from the Schematic Editor, and the SCADA column is the steady state voltages from the runtime simulation.

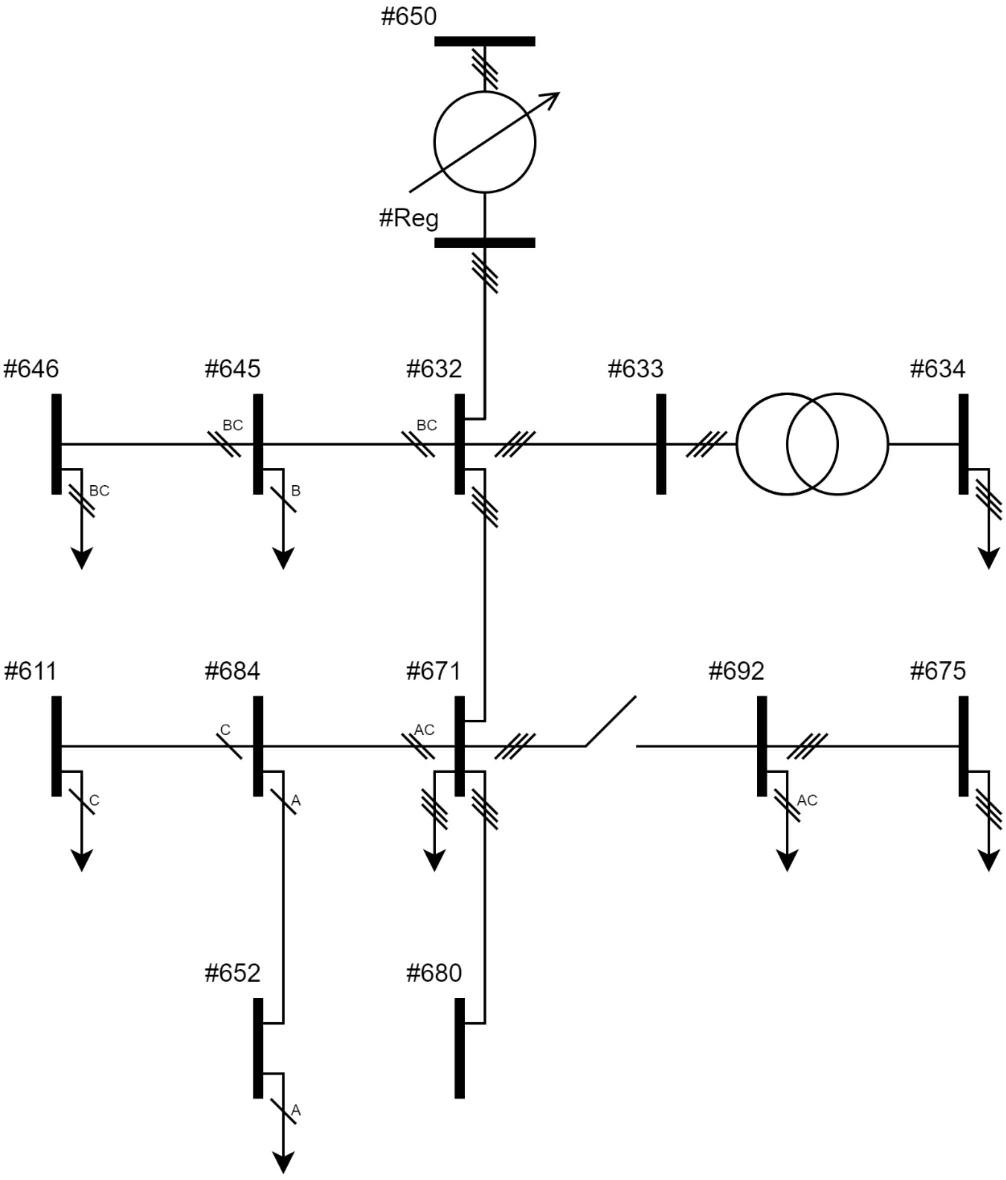

Figure 1 – Single Line diagram of the IEEE 13 Bus Feeder.

Results

Table 1. Power Flow – System Input.

#	IEEE Phase A	DSS Phase A	SCADA Phase A	IEEE Phase B	DSS Phase B	SCADA Phase B	IEEE Phase C	DSS Phase C	SCADA Phase C
kW	1251.398	1177.700	1135.211	977.332	1037.700	1016.234	1348.461	1301.500	1377.268
kvar	681.570	650.500	648.132	373.418	407.200	400.899	669.784	705.300	764.008
kVA	1424.968	1345.400	1307.203	1046.241	1114.700	1092.452	1505.642	1480.300	1574.984
PF	0.8782	0.8753	0.868	0.9341	0.9309	0.9302	0.8956	0.8792	0.8745

Table 2. Power Flow – Load Voltages Magnitudes.

Bus/Node	Phase	IEEE	DSS	SCADA	Bus/Node	Phase	IEEE	DSS	SCADA
#650	Va	1.0000	0.9999	1.0021	**#671**	Va	0.9900	0.9454	0.9295
	Vb	1.0000	1.0002	0.9999		Vb	1.0529	1.0536	1.0356
	Vc	1.0000	0.9998	0.9979		Vc	0.9778	0.9901	1.0197
#632	Va	1.0210	0.9928	0.9929	**#652**	Va	0.9825	0.9382	0.9182
	Vb	1.0420	1.0451	1.0140		Vb	--	--	--
	Vc	1.0174	1.0176	1.0444		Vc	--	--	--
#634	Va	0.9940	0.9668	0.9332	**#611**	Va	--	--	--
	Vb	1.0218	1.0239	0.9962		Vb	--	--	--
	Vc	0.9960	0.9963	1.0558		Vc	0.9738	0.9862	1.0156
#645	Va	--	--	--	**#692**	Va	0.9900	0.9453	1.0190
	Vb	1.0329	1.0355	1.0298		Vb	1.0529	1.0536	--*
	Vc	1.0155	1.0157	--*		Vc	0.9777	0.9900	0.9288
#646	Va	--	--	--	**#675**	Va	0.9835	0.9394	0.9215
	Vb	1.0311	1.0337	1.0240		Vb	1.0553	1.0557	1.0385
	Vc	1.0134	1.0136	1.0333		Vc	0.9758	0.9881	1.0182

Table 3. Power Flow – Load Voltages Errors.

Bus/Node	Phase	DSS	SCADA	Bus/Node	Phase	DSS	SCADA
#650	Va	0.01%	-0.21%	**#671**	Va	4.51%	6.11%
	Vb	-0.02%	0.01%		Vb	-0.07%	1.64%
	Vc	0.02%	0.21%		Vc	-1.26%	-4.29%
#632	Va	2.76%	2.75%	**#652**	Va	4.50%	6.54%
	Vb	-0.30%	2.69%		Vb	--	--
	Vc	-0.02%	-2.65%		Vc	--	--
#634	Va	2.74%	6.12%	**#611**	Va	--	--
	Vb	-0.21%	2.51%		Vb	--	--
	Vc	-0.03%	-6.00%		Vc	-1.27%	-4.29%

Bus/Node	Phase	DSS	SCADA	Bus/Node	Phase	DSS	SCADA
#645	Va	--	--	**#692**	Va	4.52%	-2.93%
	Vb	-0.25%	0.30%		Vb	-0.07%	--*
	Vc	-0.02%	--*		Vc	-1.26%	5.00%
#646	Va	--	--	**#675**	Va	4.49%	6.30%
	Vb	-0.25%	0.69%		Vb	-0.04%	1.59%
	Vc	-0.02%	-1.96%		Vc	-1.26%	-4.35%

Modeling Data

Table 4. Line Segment Data.

Line	From (#node)	To (#node)	Config ID	km	Phases
Line_650632	#650	#632	601	0.610	ABC
Line_632645	#632	#645	603	0.152	BC
Line_632633	#632	#633	602	0.152	ABC
XFM-1	#633	#634	500 kVA – 4.16/0.48 kV (Ynyn); Z=1.1+2%		
Line_645646	#645	#646	603	0.091	BC
Line_632671	#632	#671	601	0.610	ABC
Line_671684	#671	#684	604	0.091	AC
Line_671680	#671	#680	601	0.305	ABC
Switch	#671	#692	Static Switch (ABC)		
Line_684652	#684	#652	607	0.244	A
Line_684611	#684	#611	605	0.091	C
Line_692675	#692	#675	606	0.152	ABC

Table 5. Load Data.

Node	S_A [kVA]	FP_A	S_B [kVA]	FP_B	S_C [kVA]	FP_C	Notes
#634	194.16	0.82	150.00	0.80	150.00	0.80	Spot Load (Y ABC)
#645	--	--	211.01	0.81	--	--	Spot Load (B)
#646	--	--	265.19	0.87	--	--	Spot Load (BC)
#652	154.21	0.83	--	--	--	--	Spot Load (A)
#671	443.42	0.87	443.42	0.87	443.42	0.87	Spot Load (D ABC)
#675	520.89	0.93	90.69	0.75	359.23	0.81	Spot Load (Y ABC)
#692	--	--	--	--	227.38	0.75	Spot Load (AC)
#611	--	--	--	--	187.88	0.90	Spot Load (C)
#632	19.72/2	0.86	76.16/2	0.87	135.33/2	0.86	Distr. Load (Y ABC)
#671	19.72/2	0.86	76.16/2	0.87	135.33/2	0.86	Distr. Load (Y ABC)
#675	200	--	200	--	200	--	Capacitor (Y ABC)
#611	--	--	--	--	100	--	Capacitor (C)

Table 6. Impedances for Configuration 601 (Linecode CONFIG_601).

Resistance Matrix (Ω/km)			Reactance Matrix (Ω/km)			Capacitance Matrix (nF/km)		
0.2153			0.6325			10.3836		
0.0969	0.2097		0.3117	0.6511		-3.2896	9.8230	
0.0982	0.0954	0.2121	0.0982	0.2392	0.6430	-2.0760	-1.2225	9.2938

Table 7. Impedances for Configuration 602 (Linecode CONFIG_602).

Resistance Matrix (Ω/km)			Reactance Matrix (Ω/km)			Capacitance Matrix (nF/km)		
0.4676			0.7341			9.3933		
0.0982	0.4645		0.2632	0.7446		-1.7829	8.5371	
0.0969	0.0954	0.4621	0.3117	0.2392	0.7526	-2.7864	-1.0859	8.9411

Table 8. Impedances for Configuration 603 (Linecode CONFIG_603).

Resistance Matrix (Ω/km)			Reactance Matrix (Ω/km)			Capacitance Matrix (nF/km)		
--			--			--		
--	0.8261		--	0.8371		--	7.7627	
--	0.1284	0.8226	--	0.2853	0.8431	--	-1.4833	7.6904

Table 9. Impedances for Configuration 604 (Linecode CONFIG_604).

Resistance Matrix (Ω/km)			Reactance Matrix (Ω/km)			Capacitance Matrix (nF/km)		
0.8226			0.8431			7.6904		
--	--		--	--		--	--	
0.1284	--	0.8261	0.2853	--	0.8371	-1.4833	--	7.7627

Table 10. Impedances for Configuration 605 (Linecode CONFIG_605).

Resistance Matrix (Ω/km)			Reactance Matrix (Ω/km)			Capacitance Matrix (nF/km)		
--			--			--		
--	--		--	--		--	--	
--	--	0.8259	--	--	0.8373	--	--	7.4489

Table 11. Impedances for Configuration 606 (Linecode CONFIG_606).

Resistance Matrix (Ω/km)			Reactance Matrix (Ω/km)			Capacitance Matrix (nF/km)		
0.4960			0.2773			159.6977		
0.1983	0.4903		0.0204	0.2511		--	159.6977	
0.1770	0.1983	0.4960	-0.0089	0.0204	0.2773	--	--	159.6977

Table 12. Impedances for Configuration 607 (Linecode CONFIG_607).

Resistance Matrix (Ω/km)			Reactance Matrix (Ω/km)			Capacitance Matrix (nF/km)		
0.8342			0.3184			148.3273		
--	--		--	--		--	--	
--	--	--	--	--	--	--	--	--

Table 13. Voltage Regulator Settings.

Regulator ID:	1		
Line Segment:	650 - 632		
Location:	50		
Phases:	A - B -C		
Connection:	3-Ph,LG		
Monitoring Phase:	A-B-C		
Bandwidth:	2.0 volts		
PT Ratio:	20		
Primary CT Rating:*	700		
Compensator Settings:*	Ph-A	Ph-B	Ph-C
R - Setting:*	3	3	3
X - Setting:*	9	9	9
Volltage Level:	122	122	122

References

[1] – IEEE 13 Bus Feeder (https://cmte.ieee.org/pes-testfeeders/resources/)

CIGRE SYSTEMS

CIGRE EUROPEAN MEDIUM VOLTAGE (DISTRIBUTION SYSTEMS)

The CIGRE Medium Voltage distribution network is derived from a physical network in southern Germany [2], which supplies a small town and the surrounding rural area. In the European version, the modeling does not include unbalances on lines and loads.

Figure 2 shows the topology of the feeder. The system operates at 20 kV 50 Hz via separate transformers (T1 and T2) from the 110 kV transmission network. The topology can be modified between radial/radial/meshed configurations through S1, S2, and S3 switches.

The data modeling is presented in the following subsections. All lines are symmetrical, and the loads are represented as constant impedance. A fixed tap at the transformers T1 and T2 is set manually on the transformer parameterization (without voltage regulator).

The power flow results in the Results subsection show a good match between the OpenDSS and SCADA models compared to the reference.

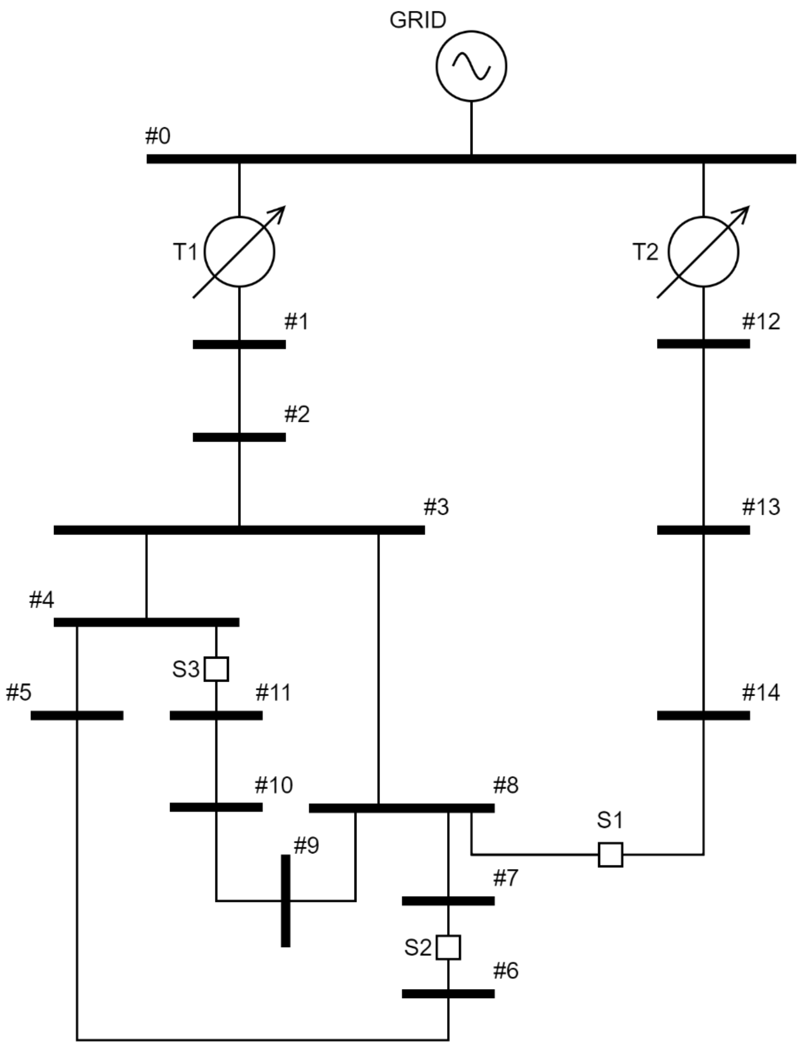

Figure 2 – Single Line diagram of the CIGRE European MV Feeder.

Results

Table 14. Power Flow – Load Voltages Magnitudes.

Bus	CIGRE	DSS	SCADA	Bus	CIGRE	DSS	SCADA
#0	1.0000	1.0004	1.0003	**#8**	0.9665	0.9625	0.9665
#1	1.0260	1.0213	1.0251	**#9**	0.9655	0.9616	0.9656
#2	1.0045	1.0003	--	**#10**	0.9645	0.9605	0.9645
#3	0.9715	0.9674	0.9714	**#11**	0.9645	0.9603	0.9643
#4	0.9700	0.9657	0.9697	**#12**	1.0020	1.0004	1.0035
#5	0.9690	0.9646	0.9686	**#13**	0.9970	0.9956	0.9986
#6	0.9675	0.9632	0.9673	**#14**	0.9940	0.9929	0.9958
#7	0.9665	0.9622	0.9662				

Table 15. Power Flow – Load Voltages Errors.

Bus	DSS	SCADA	Bus	DSS	SCADA
#0	-0.04%	-0.03%	**#8**	0.42%	0.00%
#1	0.46%	0.09%	**#9**	0.41%	-0.01%
#2	0.42%	--	**#10**	0.42%	0.00%
#3	0.43%	0.01%	**#11**	0.44%	0.02%
#4	0.44%	0.03%	**#12**	0.16%	-0.15%
#5	0.46%	0.04%	**#13**	0.14%	-0.16%
#6	0.44%	0.02%	**#14**	0.11%	-0.18%
#7	0.44%	0.03%			

Table 16. Power Flow – System Input.

Meas.	CIGRE	DSS		SCADA	
		Value	Error	Value	Error
P (MW)	45.9076	45.5472	0.79%	46.8195	-1.99%
Q (Mvar)	16.5096	16.8198	-1.88%	15.2924	7.37%
S (MVA)	48.7860	48.5536	0.48%	49.2536	-0.96%
PF	0.9410	0.9381	0.31%	0.9506	-1.02%

Modeling Data

Table 17. Line Segment Data.

Line	From (#Bus)	To (#Bus)	R1 (Ω/km)	X1 (Ω/km)	C1 (nF/km)	R0 (Ω/km)	x0 (Ω/km)	C0 (nF/km)	km
Line_1	#1	#2	0.5	0.72	151.18	0.82	1.6	151.18	2.82
Line_2	#2	#3	0.5	0.72	47.493	0.82	1.6	47.493	4.42
Line_3	#3	#4	0.5	0.72	47.493	0.82	1.6	47.493	0.61
Line_4	#4	#5	0.5	0.72	47.493	0.82	1.6	47.493	0.56
Line_5	#5	#6	0.5	0.72	47.493	0.82	1.6	47.493	1.54
Line_6	#6	#7	0.5	0.72	47.493	0.82	1.6	47.493	0.24
Line_7	#7	#8	0.5	0.72	47.493	0.82	1.6	47.493	1.67
Line_8	#8	#9	0.5	0.72	47.493	0.82	1.6	47.493	0.32
Line_9	#9	#10	0.5	0.72	47.493	0.82	1.6	47.493	0.77
Line_10	#10	#11	0.5	0.72	47.493	0.82	1.6	47.493	0.33
Line_11	#11	#4	0.5	0.72	47.493	0.82	1.6	47.493	0.49
Line_12	#3	#8	0.5	0.72	47.493	0.82	1.6	47.493	1.30
Line_13	#12	#13	0.510	0.37	10.097	0.66	1.61	4.0743	4.89
Line_14	#13	#14	0.510	0.37	10.097	0.66	1.61	4.0743	2.99
Line_15	#14	#8	0.510	0.37	10.097	0.66	1.61	4.0743	2.00

Table 18. Transformers T1 and T2 data.

Rated Primary Voltage:	110 kV
Rated Secondary Voltage:	20 kV
Connection:	Dyn
Rated Power:	25 MVA
R:	1 %
X:	12 %

Table 19. Load Data.

Bus	**Residential**		**Industrial**	
	S [kVA]	**PF**	**S [kVA]**	**PF**
#1	15300	0.98	5100	0.95
#2	---	---	---	---
#3	285	0.97	265	0.85
#4	445	0.97	---	---
#5	750	0.97	---	---
#6	565	0.97	---	---
#7	---	---	90	0.85
#8	605	0.97	---	---
#9	---	---	675	0.85
#10	490	0.97	80	0.85
#11	340	0.97	---	---
#12	15300	0.98	5280	0.95
#13	---	---	40	0.85
#14	215	0.97	390	0.85

References

[2] - TF C6.04.02 : TB 575 -- Benchmark Systems for Network Integration of Renewable and Distributed Energy Resources.