

# 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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## OTHER SYSTEMS

### BANSHEE DISTRIBUTION NETWORK (MICROGRID)

The Banshee benchmark corresponds to a real-life small industrial facility, which reproduces typical microgrid challenges worldwide. Three utility feeders service the power plant at 13.8 kV levels (**Error! Reference source not found.**) that may interconnect through normally open tie switches. Twenty-two (22) distribution transformers reduce the 13.8 kV to service voltages of 4.16 kV, 480 V, and 208 V.

Eighteen (18) aggregated low voltage loads (480 V and 208 V) are classified as critical, priority, or interruptible (all loads are modeled as constant power mode). In that way, several circuit breakers perform a load-shedding logic on the microgrid controller according to the load classification. All circuit breakers on the power plant are modeled as static switches, although they should be changed to controlled switches according to the model applications.

Banshee also includes two large induction motors (200 HP) connected with the P1 and P6 loads. However, as motors are not present in the current Typhoon OpenDSS library, it still needs to be considered on the model in future versions. The same is applied to the PV generation connected to bus #202. In this context, BESS and synchronous generators of the power plant also are not used in this modeling version.

The power flow results compared in Table 1 – Table 3 show the match between the Typhoon model and the reference. 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.

It's worth mentioning two points about the results:

- Several TLM core coupling components divide the model resources due to the power plant size. That kind of core coupling has some advantages in terms of stability compared to the

ITM method, but it adds shunt capacitance to the model, which can be significant if the inductance of the TLM is small. To minimize that behavior, all TLM is placed inside the transformers. Even though those capacitors impact the system, as shown in Table 1 and Table 3, when significant errors are observed only on the SCADA tab. On the power flow impact, it is possible to see differences of around 30% in the reactive power flowing in some circuits. From the voltage viewpoint, it is also possible to check the capacitors' impact in over-voltages in some buses, in the worst cases, assuming values greater than 1.0 pu.

- CB102 flow has significant errors in both DSS and SCADA tabs. Comparing the data entry of the source code from the reference was noted a different input for the reactive power in a load of this branch. The model will use the load value from the reference paper instead.

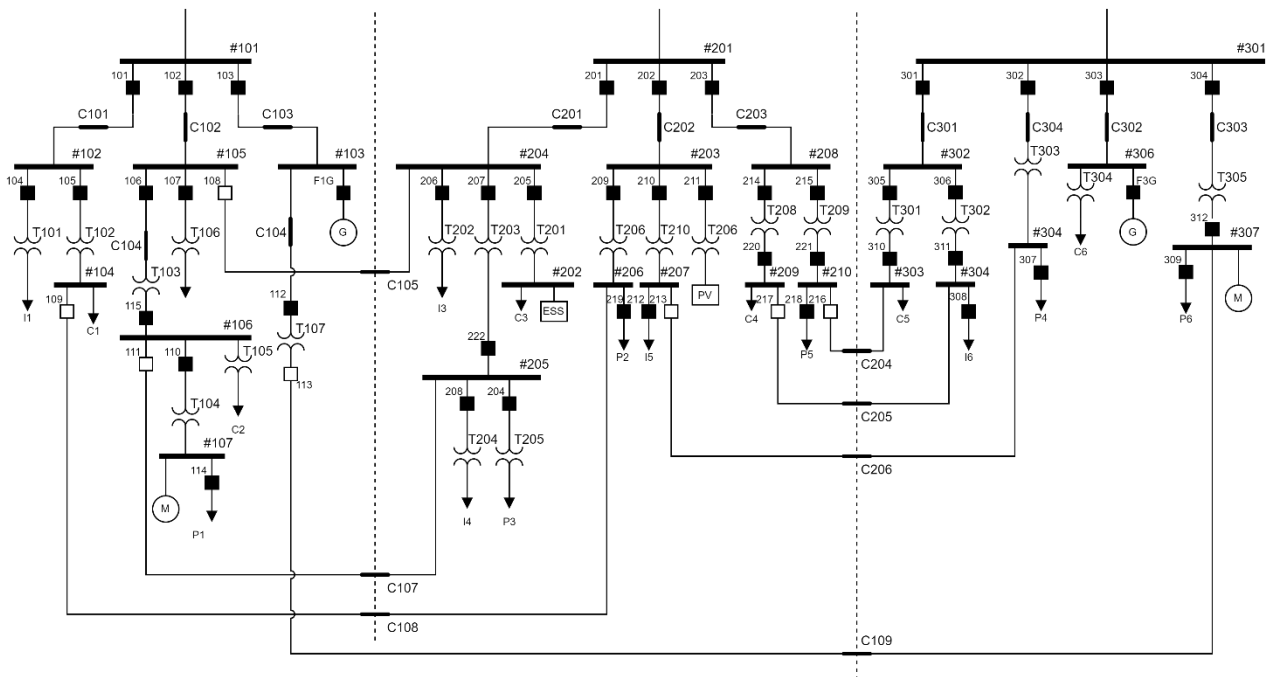


Figure 1 – Single Line diagram of the Banshee Microgrid.

## Results

Table 1. Power Flow at feeders PCC.

Circuit Breaker	REF.		DSS		SCADA	
	MW	Mvar	MW	Mvar	MW	Mvar
<b>CB101</b>	1.37	0.70	1.36	0.71	1.37	0.68
<b>CB102</b>	2.53	1.09	2.48	1.39	2.51	1.35
<b>CB103</b>	0.00	0.00	0.00	0.00	0.00	-0.02
<b>CB201</b>	2.67	1.40	2.64	1.41	2.65	1.41
<b>CB202</b>	1.28	0.65	1.27	0.65	1.27	0.86
<b>CB203</b>	1.55	0.76	1.54	0.79	1.54	0.92
<b>CB301</b>	1.46	0.74	1.46	0.75	1.46	0.70
<b>CB302</b>	0.55	0.29	0.55	0.28	0.55	0.27
<b>CB303</b>	0.74	0.39	0.73	0.39	0.74	0.39
<b>CB304</b>	0.91	0.46	0.91	0.47	0.91	0.46

Table 2. Power Flow errors at feeders PCC.

Circuit Breaker	DSS		SCADA	
	MW	Mvar	MW	Mvar
<b>CB101</b>	0.39%	-0.81%	0.00%	2.86%
<b>CB102</b>	1.98%	-27.32%	0.79%	-23.85%
<b>CB103</b>	--	--		
<b>CB201</b>	1.01%	-0.36%	0.75%	-0.71%
<b>CB202</b>	0.58%	0.00%	0.78%	-32.31%
<b>CB203</b>	0.44%	-3.87%	0.65%	-21.05%
<b>CB301</b>	0.15%	-1.00%	0.00%	5.41%
<b>CB302</b>	0.55%	1.76%	0.00%	6.90%
<b>CB303</b>	1.39%	0.56%	0.00%	0.00%
<b>CB304</b>	-0.38%	-2.17%	0.00%	0.00%

Table 3. Load Voltages Magnitudes and errors.

Load ID	REF Voltage	DSS		SCADA	
		Voltage	Error	Voltage	Error
<b>C1</b>	0.978	0.967	1.08%	0.976	0.20%
<b>C2</b>	0.950	0.941	0.94%	0.942	0.84%
<b>C3</b>	0.982	0.971	1.10%	1.000	-1.83%
<b>C4</b>	0.976	0.971	0.52%	0.997	-2.15%
<b>C5</b>	0.977	0.967	1.03%	0.974	0.31%
<b>C6</b>	0.964	0.961	0.33%	0.961	0.31%
<b>P1</b>	0.960	0.944	1.63%	0.952	0.83%
<b>P2</b>	0.982	0.970	1.20%	1.035	-5.40%
<b>P3</b>	0.949	0.948	0.08%	0.953	-0.42%
<b>P4</b>	0.973	0.965	0.78%	0.970	0.31%
<b>P5</b>	0.984	0.990	-0.65%	1.048	-6.50%
<b>P6</b>	0.982	0.966	1.61%	0.979	0.31%
<b>I1</b>	0.974	0.972	0.20%	0.973	0.10%
<b>I2</b>	0.976	0.973	0.34%	0.974	0.20%
<b>I3</b>	0.969	0.966	0.34%	0.993	-2.48%
<b>I4</b>	0.962	0.950	1.28%	0.956	0.62%
<b>I5</b>	0.982	0.972	0.98%	1.031	-4.99%
<b>I6</b>	0.986	0.973	1.28%	0.982	0.41%

## Modeling Data

Table 4. Cable Type Impedances.

Cable Type	R1 ( $\Omega/\text{km}$ )	X1 ( $\Omega/\text{km}$ )	R0 ( $\Omega/\text{km}$ )	X0 ( $\Omega/\text{km}$ )
<b>15kV Shielded 4/0 AWG 3C CU</b>	0.1668	0.1286	1.3302	0.9830
<b>15kV Shielded 500KCMIL SR 3C CU</b>	0.0749	0.1167	1.1405	0.7559

Table 5. Line Segment Data.

Line	From (#Bus)	To (#Bus)	Cable Type	Length ft (km)	Line	From (#Bus)	To (#Bus)	Cable Type	Length ft (km)
C101	#101	#102	500 kcmil	1800 (0.549)	C201	#201	#204	4/0 AWG	5500 (1.676)
C102	#101	#105	500 kcmil	5500 (1.676)	C202	#201	#203	500 kcmil	2000 (0.610)
C103	#101	#103	4/0 AWG	1000 (0.305)	C203	#201	#208	500 kcmil	3000 (0.914)
C104	#101	#T107	500 kcmil	3000 (0.914)	C204	#210	#303	500 kcmil	1500 (0.457)
C105	#105	#204	500 kcmil	3000 (0.914)	C205	#209	#304	500 kcmil	1500 (0.457)
C106	#105	#106	500 kcmil	1500 (0.457)	C206	#207	#305	500 kcmil	1500 (0.457)
C107	#106	#205	500 kcmil	2000 (0.610)	C301	#301	#302	500 kcmil	2500 (0.762)
C108	#104	#206	500 kcmil	1000 (0.305)	C302	#301	#306	4/0 AWG	2000 (0.610)
C109	#T107	#307	500 kcmil	2000 (0.610)	C303	#301	#307	500 kcmil	2000 (0.610)
					C304	#301	#305	4/0 AWG	1500 (0.457)

Table 6. Load Data.

Classification	ID	Connection	Demand kVA	Classification	ID	Connection	Demand kVA
Critical	C1	#104	1200	Critical	C4	#209	1000
	C2	#106 (T105)	1500		C5	#303	1000
	C3	#202	1000		C6	#306 (T304)	800
Priority	P1	#107	1000	Priority	P4	#305	600
	P2	#206	1000		P5	#210	700
	P3	#205 (T205)	1000		P6	#307	1000
Interruptible	I1	#102 (T101)	300	Interruptible	I4	#205 (T204)	600
	I2	#105 (T106)	250		I5	#207	400
	I3	#204 (T202)	300		I6	#304	600

Table 7. Transformers Data.

ID	Nameplate					Computed	
	Rating [kVA]	Vpri [kV]	Vsec [kV]	Z [%]	X/R	X [%]	R [%]
T101	500	13.8	0.48	5.00	4.9	4.90	1.00
T102	2500	13.8	0.48	5.75	6.6	5.69	0.86
T103	3750	13.8	4.16	4.75	11.4	4.73	0.42
T104	2000	4.16	0.48	5.75	4.7	5.62	1.20
T105	2000	4.16	0.48	5.75	4.7	5.62	1.20
T106	500	13.8	0.208	5.00	4.9	4.90	1.00
T107	2500	13.8	0.48	5.75	6.6	5.69	0.86
T201	2500	13.8	0.48	5.56	5.5	5.47	0.99
T202	500	13.8	0.208	5.00	4.9	4.90	1.00
T203	3750	13.8	4.16	4.75	11.4	4.73	0.42

ID	Nameplate					Computed	
	Rating [kVA]	Vpri [kV]	Vsec [kV]	Z [%]	X/R	X [%]	R [%]
<b>T204</b>	1000	4.16	0.48	5.75	4.2	5.59	1.33
<b>T205</b>	1500	4.16	0.48	5.75	5.0	5.64	1.12
<b>T206</b>	2500	13.8	0.48	5.75	6.6	5.69	0.86
<b>T207</b>	5000	13.8	0.48	5.00	5.4	4.92	0.90
<b>T208</b>	2000	13.8	0.48	5.75	4.7	5.62	1.20
<b>T209</b>	2000	13.8	0.48	5.75	4.7	5.62	1.20
<b>T210</b>	1000	13.8	0.48	5.75	4.2	5.59	1.33
<b>T301</b>	2000	13.8	0.48	5.75	4.7	5.62	1.20
<b>T302</b>	2000	13.8	0.48	5.75	4.7	5.62	1.20
<b>T303</b>	1000	13.8	0.48	5.75	4.2	5.59	1.33
<b>T304</b>	1000	13.8	0.48	5.75	4.2	5.59	1.33
<b>T305</b>	2500	13.8	0.48	5.75	6.6	5.69	0.86

## References

- [1] – Banshee distribution network benchmark and prototyping platform for hardware-in-the-loop integration of microgrid and device controllers. The Journal of Engineering, 2019: 5365-5373. <https://doi.org/10.1049/joe.2018.5174>
- [2] – Electric Power Hardware-in-the-loop Controls Collaborative. Available at <https://github.com/PowerSystemsHIL/EPHCC/releases/download/BansheeBenchmark/Supporting.Data.for.Banshee.Benchmark.Paper.zip>