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 significative 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.

|  |
| --- |
| Graphical user interface, application  Description automatically generated |

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** |
| **CB101** | 1.37 | 0.70 | 1.36 | 0.71 | 1.37 | 0.68 |
| **CB102** | 2.53 | 1.09 | 2.48 | 1.39 | 2.52 | 1.40 |
| **CB103** | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | -0.02 |
| **CB201** | 2.67 | 1.40 | 2.64 | 1.40 | 2.66 | 1.40 |
| **CB202** | 1.28 | 0.65 | 1.27 | 0.65 | 1.28 | 0.86 |
| **CB203** | 1.55 | 0.76 | 1.54 | 0.79 | 1.55 | 0.92 |
| **CB301** | 1.46 | 0.74 | 1.46 | 0.75 | 1.47 | 0.70 |
| **CB302** | 0.55 | 0.29 | 0.55 | 0.28 | 0.55 | 0.27 |
| **CB303** | 0.74 | 0.39 | 0.73 | 0.39 | 0.74 | 0.39 |
| **CB304** | 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** |
| **CB101** | 0.73% | -1.43% | 0.00% | 2.86% |
| **CB102** | 1.98% | -27.52% | 0.40% | -28.44% |
| **CB103** | -- | -- |  |  |
| **CB201** | 1.12% | 0.00% | 0.37% | 0.00% |
| **CB202** | 0.78% | 0.00% | 0.00% | -32.31% |
| **CB203** | 0.65% | -3.95% | 0.00% | -21.05% |
| **CB301** | 0.00% | -1.35% | -0.68% | 5.41% |
| **CB302** | 0.00% | 3.45% | 0.00% | 6.90% |
| **CB303** | 1.35% | 0.00% | 0.00% | 0.00% |
| **CB304** | 0.00% | -2.17% | 0.00% | 0.00% |

Table 3. Load Voltages Magnitudes and errors.

| **Load ID** | **REF**  **Voltage** | **DSS** | | **SCADA** | |
| --- | --- | --- | --- | --- | --- |
| **Voltage** | **Error** | **Voltage** | **Error** |
| **C1** | 0.978 | 0.967 | 1.08% | 0.976 | 0.20% |
| **C2** | 0.950 | 0.941 | 0.94% | 0.942 | 0.84% |
| **C3** | 0.982 | 0.971 | 1.10% | 0.997 | -1.53% |
| **C4** | 0.976 | 0.971 | 0.52% | 0.993 | -1.74% |
| **C5** | 0.977 | 0.967 | 1.03% | 0.974 | 0.31% |
| **C6** | 0.964 | 0.961 | 0.33% | 0.961 | 0.31% |
| **P1** | 0.960 | 0.944 | 1.63% | 0.952 | 0.83% |
| **P2** | 0.982 | 0.970 | 1.20% | 1.036 | -5.50% |
| **P3** | 0.949 | 0.948 | 0.08% | 0.954 | -0.53% |
| **P4** | 0.973 | 0.965 | 0.78% | 0.970 | 0.31% |
| **P5** | 0.984 | 0.990 | -0.65% | 1.048 | -6.50% |
| **P6** | 0.982 | 0.966 | 1.61% | 0.979 | 0.31% |
| **I1** | 0.974 | 0.972 | 0.20% | 0.973 | 0.10% |
| **I2** | 0.976 | 0.973 | 0.34% | 0.974 | 0.20% |
| **I3** | 0.969 | 0.966 | 0.34% | 0.995 | -2.68% |
| **I4** | 0.962 | 0.950 | 1.28% | 0.956 | 0.62% |
| **I5** | 0.982 | 0.972 | 0.98% | 1.032 | -5.09% |
| **I6** | 0.986 | 0.973 | 1.28% | 0.982 | 0.41% |

### Modeling Data

Table 4. Cable Type Impedances.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Cable Type** | **R1 (Ω/km)** | **X1 (Ω/km)** | **R0 (Ω/km)** | **X0 (Ω/km)** |
| **15kV Shielded 4/0 AWG 3C CU** | 0.1668 | 0.1286 | 1.3302 | 0.9830 |
| **15kV Shielded 500KCMIL SR 3C CU** | 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 |
| **T204** | 1000 | 4.16 | 0.48 | 5.75 | 4.2 | 5.59 | 1.33 |
| **T205** | 1500 | 4.16 | 0.48 | 5.75 | 5.0 | 5.64 | 1.12 |
| **T206** | 2500 | 13.8 | 0.48 | 5.75 | 6.6 | 5.69 | 0.86 |
| **T207** | 5000 | 13.8 | 0.48 | 5.00 | 5.4 | 4.92 | 0.90 |
| **T208** | 2000 | 13.8 | 0.48 | 5.75 | 4.7 | 5.62 | 1.20 |
| **T209** | 2000 | 13.8 | 0.48 | 5.75 | 4.7 | 5.62 | 1.20 |
| **T210** | 1000 | 13.8 | 0.48 | 5.75 | 4.2 | 5.59 | 1.33 |
| **T301** | 2000 | 13.8 | 0.48 | 5.75 | 4.7 | 5.62 | 1.20 |
| **T302** | 2000 | 13.8 | 0.48 | 5.75 | 4.7 | 5.62 | 1.20 |
| **T303** | 1000 | 13.8 | 0.48 | 5.75 | 4.2 | 5.59 | 1.33 |
| **T304** | 1000 | 13.8 | 0.48 | 5.75 | 4.2 | 5.59 | 1.33 |
| **T305** | 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