OpenDSS Features

Model Partitioning Assistance

**Abstract:** This document describes the main aspects of the modeling and the usage of the Core Coupling Assistance feature provided on the OpenDSS library.

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## Introduction

Comentar os problemas de model partitioning

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### Background

The OpenDSS Model Partitioning feature currently supports only the Ideal Transformer Method (ITM) based components from the core library of the THCC:

* Single/Three/Four Phase Core Coupling; and
* Single/Three/Four Phase Device Coupling.

As the proper name suggests, the ITM split the model into two subcircuits over an ideal transformer with an unitary voltage ratio. Figure 1 shows the representation of a single-phase component (either core or device coupling) using the same colors representation than the THCC: red color to the Current Source Side, and green color to the Voltage Source Side.

The pros and cons of this method are very well established on the literature, and some references are shared at the final sections of the document. For the concerns of this document, it is enough to know that the stability of the method is given by the relationship between the impedance Z1 (current source side) and Z2 (voltage source side) .

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Figure 1 – Single-phase ITM implementation.

In general terms, the THCC evaluates the resistance of both sides of the coupling element considering the time step simulation of the circuit. All the capacitors and inductor are replaced by scaled resistors using equations 1 and 2, and all the non-dependent sources are turned off before the stability analysis of the software. The resistance of the phases is computed for each switch combination (if present on the circuit) and, as the output, the report indicate the stability of the coupling according to the Equation 3. If any pair of resistances match to the Unstable region of the equation 3, the coupling is considered Unstable, and so on following Border->Stable conditions.

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| --- | --- | --- |
|  |  | (1) |
|  |  | (2) |

|  |  |  |
| --- | --- | --- |
|  |  | (3) |

It is worth opening a parenthesis here to link to the best practices advised on the Typhoon documentation about the placement and parameterization of the couplings on the circuit. By the discretization (equations 1 and 2) method, capacitors has a very low equivalent resistance compared to the inductors. By this viewpoint, makes sense to have the current source side of couplings connected to a capacitor and the voltage source side connected to an inductor, following the Stable criterium of the ITM. Still, it is possible to reinforce this scenario through the coupling snubbers: The R1-C1 snubber has a parallel path to the Z1 impedance, decreasing the final impedance of this side. On the other side, R2||L1 is connected in a series path with the rest of the circuit.

The Model Partitioning feature from the OpenDSS library uses this context to support to the user to get a stable model. Initially, the impedance seen by the coupling sides can be computed very faster than the THCC software (is computed before the compilation process), and if needed, can use the power flow results to evaluate the snubber impact used on the coupling.

Figure 2 shows the approach used on this implementation. For the OpenDSS engine, the Coupling element is represented through a line with a small impedance. During the OpenDSS Stability process, the line is opened and it computes the Thevenin Impedance for the both sides of the line. Due to the internal connections of the sources, each side of the coupling has a different connection of the equivalent system. On the current source side, all current sources of the internal coupling arrangement[[1]](#footnote-2) are turned off, and only the self-impedance of the Thevenin Matrix is used. On the voltage source side, there is a mutual coupling between the phases occurred by the short circuit of the voltage sources, and then, a Kron Reduction is used to get the proper phase resistance.

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Figure 2 – Approach used for the coupling terminals impedance calculation.

It is worth mentioning that a compensation stage for all OpenDSS components is done before the impedance evaluation, which all the inductances and capacitances are converted to the equivalent resistance as used by the THCC stability analysis.

### Component Description

The OpenDSS Coupling component is found over the main OpenDSS category on the Library Explorer of the THCC. As the component is represented by a Line element on the OpenDSS, each terminal should be connected to a Bus element. Figure 3.a show the Coupling icons in the Core and Device couplings methods. Variations including the number of phases, operational mode, and the result from the Stability algorithm also can modify the component icon.

The component properties is divided into two tabs. On the “General” tab, the user can choose the type of the coupling (either core or device), number of phases, and its mode algorithm used during the Model Partitioning Analysis stage (manual or automatic). For the manual mode, a second tab “Parameterization” is used to configure the coupling snubbers. Those parameters are set automatically for the automatic mode. The Model Partitioning Assistance is started on the “Typhoon HIL” tab properties of the SimDSS component. An example describing this process is presented on the next section.

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|  | |
| a) | |
| A screenshot of a computer program  Description automatically generated | A screenshot of a computer  Description automatically generated |
| b) | c) |

Figure 3 – Coupling component: a) Core and Device icons, b) General tab properties, and c) Parameterization tab properties.

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Figure 4 – Model Partitioning Assistance on the SimDSS component.

## Example

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Colocar os dados iniciais dos couplings

### Manual Mode

This subsection describes how the user can use the information from the Manual Mode of the OpenDSS couplings. The user can check the general information of the coupling on the summary report. Figure X show the summary report for the initial configuration of the system example.

The main information get by the report is about the coupling stability. The Coupling 1, 4, and 5 are stable, while the Coupling 2, and 3 are unstable. The report show for which switch conditions the coupling are unstable. In the case of the example, for all conditions of SW1 and SW2 the couplings are unstable. As the example system has switches combination, the report advises to consult the detailed report to check the action tips to stabilize the coupling. The detailed report it will be discussed on the sequence of the analysis.

Another relevant information is about the snubbers parameterization. On the original system configuration, the Coupling 1, 2, and 3 has not snubbers parameterized, but only the Coupling 1 has topological conflicts (with the Transformer T203 in this case). As it is know that Coupling 1 is stable, its possible just to use a big resistor on the current source side of the coupling, in order to minimize the impact of the snubber on the circuit and solve the topological conflict at the same time.

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### Automatic Mode

## References

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.

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| Graphical user interface, application  Description automatically generated |

Figure 2 – 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

1. Four-phase coupling uses three single-phase couplings connected in a star arrangement. Three-Phase uses two. [↑](#footnote-ref-2)