OpenDSS Features
Model Partitioning Assistant

Abstract: This document describes the main aspects of modeling and usage of the Model Partitioning Assistance feature provided in the OpenDSS library.

CONTENTS

INTRODUCTION

Model partitioning is one of the most common issues users find in the modeling stage of the Typhoon HIL Toolchain. Questions about coupling placement and parameterization require experience on real-time modeling issues and knowledge about the electrical system under study. Those issues can be very challenging for Power System applications, considering the high number of elements in the model (transmission lines, generators, circuit breakers, buses, etc.). Besides the placement and parameterization issues, the default stability analysis on the Typhoon HIL Control Center (THCC) runs during the compilation process, which might require a lot of time depending on the complexity of the model.

To support the users in the coupling parametrization task issues, the OpenDSS Model Partitioning Assistant (MPA) was developed. Using the power flow results obtained from the OpenDSS engine, it is possible to evaluate the stability of the coupling before the THCC's compilation to real-time stage. Also, using the power flow report, the user can check the impacts of the snubbers' parameterization before running it in the real-time environment. This document will present the main aspects of the MPA strategy.

Background

The MPA feature currently supports only the Ideal Transformer Method (ITM) based components from the THCC core library:

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

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

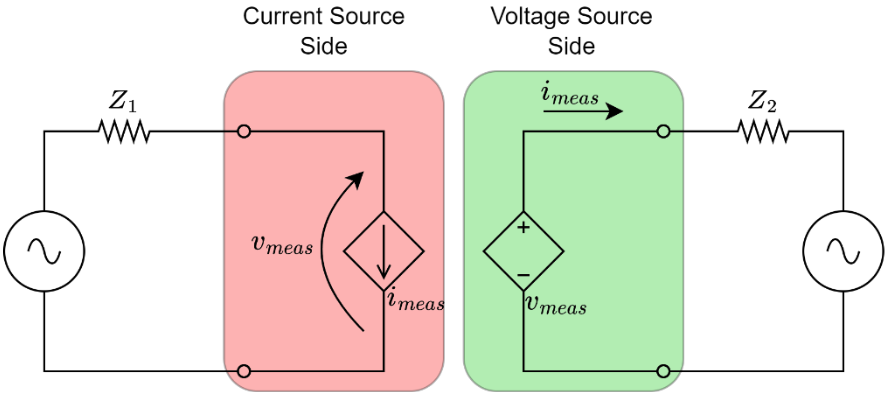


Figure 1 – Single-phase ITM implementation.

The pros and cons of this method are very well established in the literature (references are presented at the end of this document). In what concerns this application, it is enough to know that the stability of the method is given by the ratio between the (Thevenin) impedance "seen" by the Current Source Side (Z1) and the Voltage Source Side (Z2): ${}^{Z_1}/_{Z_2}$.

When the "Coupling Stability Analysis" is enabled in the THCC's "Model Settings", the compiler evaluates the coupling stability following the steps:

1. All the capacitors and inductors are replaced by equivalent resistors using Equations 1 and 2.
2. All non-dependent sources are disabled in the circuit (current sources and voltage sources are replaced by open-circuits and short-circuits, respectively).
3. The Thevenin resistances of the coupling sides are computed for each switch combination that is present in the circuit.
4. The report indicates the stability of the coupling according to Equation 3. If any pair of resistances falls in the "Unstable" region of equation 3, the coupling is considered unstable, else, it is considered borderline stable or stable

$$R_{cap} = \frac{T_s}{C} \tag{1}$$

$$R_{ind} = \frac{L}{T_s} \tag{2}$$

$$\begin{cases} \frac{R_1}{R_2} \leq 0.9 \rightarrow Stable \\ 0.9 < \frac{R_1}{R_2} < 1.1 \rightarrow Border \\ \frac{R_1}{R_2} \geq 1.1 \rightarrow Unstable \end{cases} \tag{3}$$

The stability criterium from Equation 3 is that the Thevenin impedance on the Current Source Side should be smaller than the impedance on the Voltage Source Side. The discretization method described on equations 1 and 2 suggests that capacitors have a lower equivalent resistance than the inductors. From this viewpoint, having the current source side of the coupling connected to a capacitor and the voltage source side connected to an inductor is preferred, following the ITM's stability criterium. In cases in which the circuit doesn't provide natural capacitors and inductors to satisfy this preference, it is possible to reinforce the stability through the addition of coupling snubbers. On the voltage source side, a parallel resistor/inductor snubber impedance is connected in series to the source and to the system's impedance Z2. On the current source side, a series resistor/capacitor snubber impedance is connected in shunt to the source and to the system's impedance Z1.

The MPA feature in the OpenDSS library uses the same approach to support the user in understanding better the stability issues of the model in the study. Figure 2 shows details of the feature's implementation. In the OpenDSS engine, the Coupling element is represented as a Line element with small impedance. During the model stability evaluation, the line is opened, and the Thevenin Impedance is computed for both sides of the line.

All the inductances and capacitances in the OpenDSS' components are compensated with the equivalent discretized resistance described in equations 1 and 2 before the stability evaluation is done. This process approximates the impedances calculated from OpenDSS to the impedances calculated by the THCC for real-time simulation.

Due to the disabling of the circuit sources, each side of the coupling interfaces in different ways with the rest of the system. The coupling internal sources and their respective connections depend on the coupling number of phases, in which the number of sources is "n - 1" for a coupling of "n" phases. For example, the disabling of the sources on the current source side removes the mutual connection between its phases, resulting in only the Thevenin self-impedance being used. On the voltage source side, the short-circuiting of the sources results in mutual coupling between phases, therefore, a Kron Reduction is used to get the proper phase resistance.

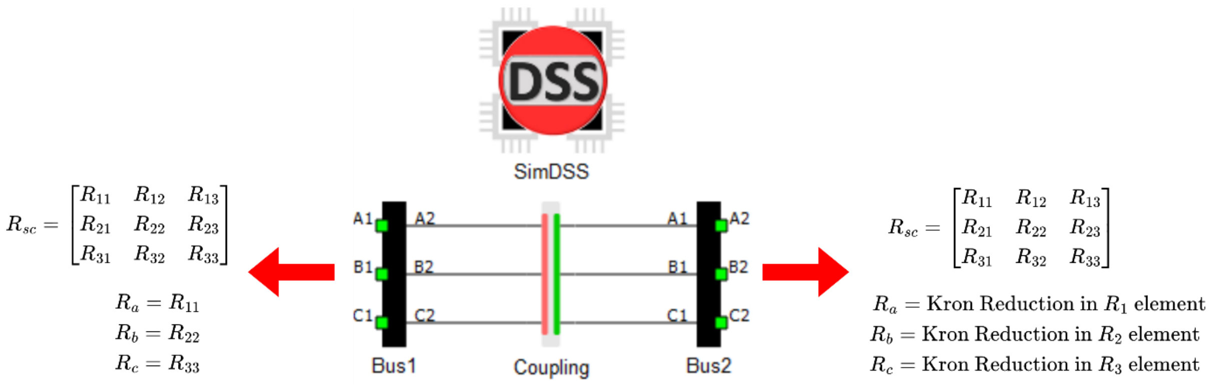


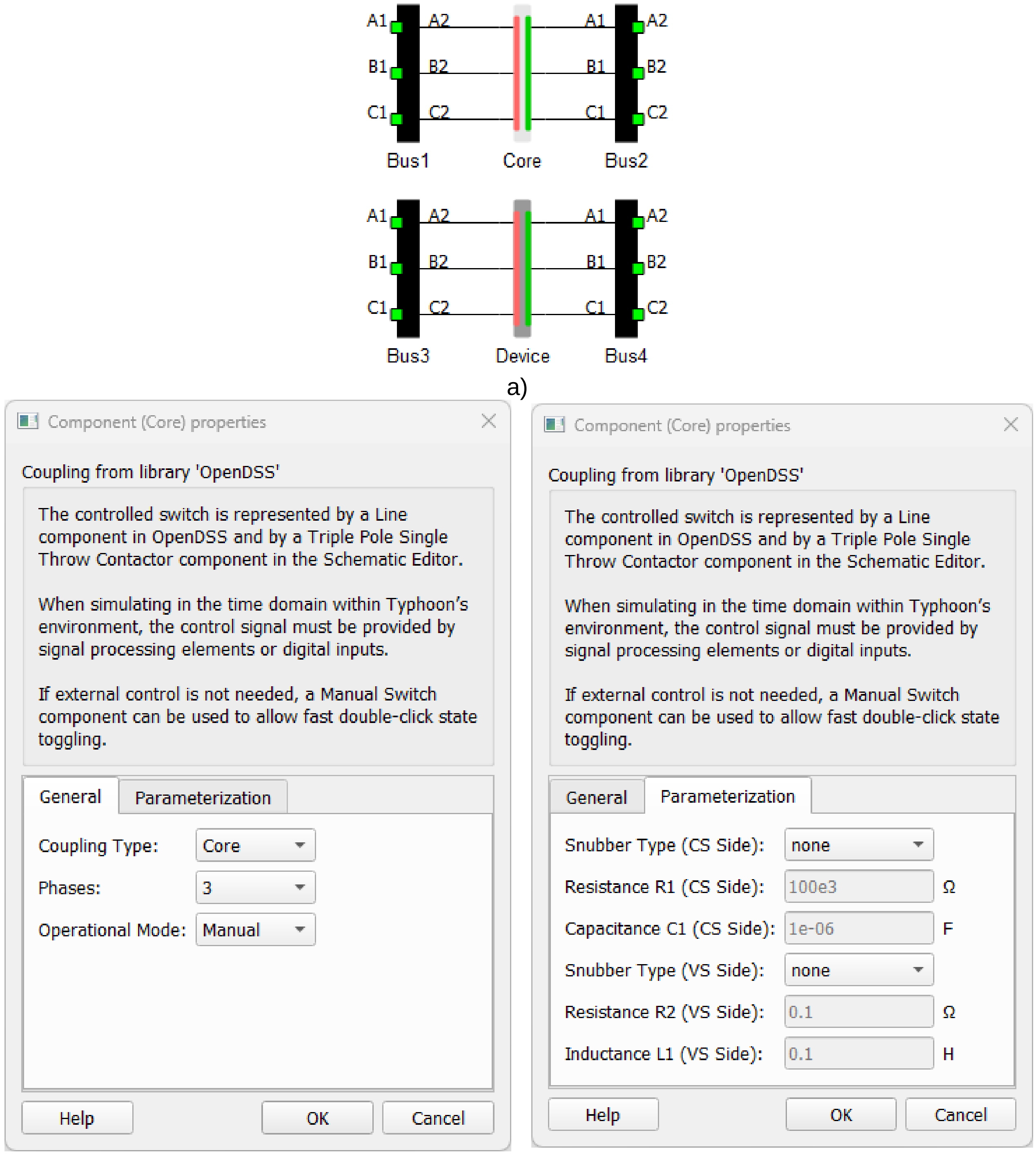
Figure 2 – Approach used for the coupling terminals impedance calculation.

Besides the Thevenin impedance calculation, the MPA feature provides enough information to support/evaluate the snubbers parameterization through the power flow results from the OpenDSS engine.

Component Description

The OpenDSS Coupling component is found in the main OpenDSS category on the Library Explorer of the THCC. As the component is represented by a Line element in OpenDSS, each of its terminals should be connected to a Bus element. Figure 3.a shows the device and core coupling components. Variations, including the number of phases, operational mode, and the Stability algorithm result, modify the component's icon.

The component's properties are divided into two tabs. In the "General" tab, the user can choose the type of coupling (either core or device), the number of phases, and its mode algorithm used in the Model Partitioning Analysis (manual or automatic), as shown in Figure 3.b. A second tab, "Parameterization," is used when "manual mode" is selected to configure the coupling snubbers. Those parameters are set automatically in the "automatic mode", shown in Figure 3.c.



b) c)

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

EXAMPLE

This subsection describes, through an example, how the user can manage the coupling parameterization based on the provided information from the OpenDSS Model Partitioning Assistant. A modified branch of the Banshee microgrid is used as the system example. As shown in Figure 4, the model is divided into six (6) cores through five (5) couplings. All couplings are initially configured to operate in the Manual mode, and no snubbers are used in this initial model representation. The blue squares represent the Controlled Switches, while the black squares represent the Manual Switches from the OpenDSS library. All loads are modeled as constant impedance.

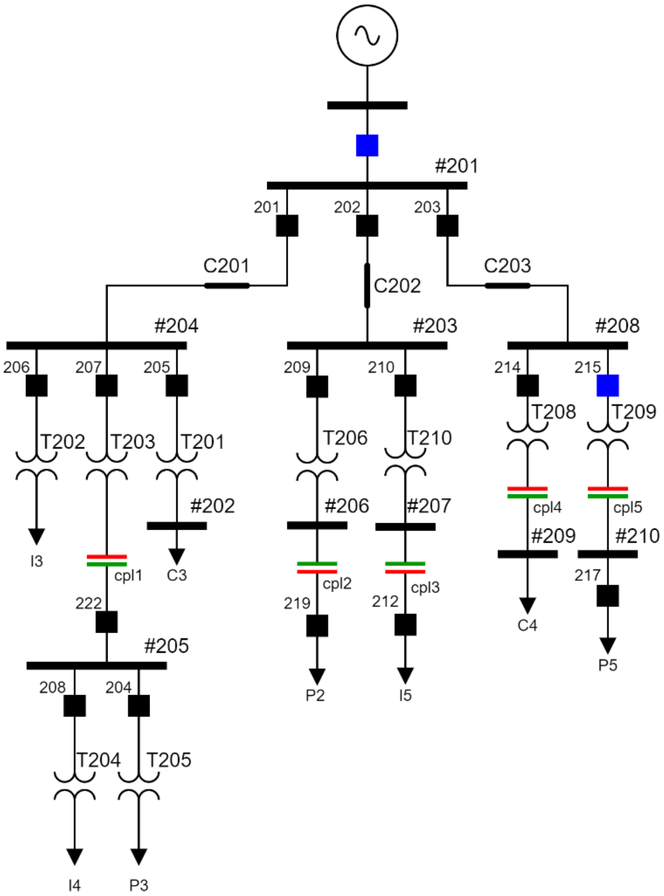


Figure 4 – Power system example.

The MPA can be started in the “Typhoon HIL” tab properties of the SimDSS component (Figure 5). Once executed, the MPA provides a summary report on the “Compilation Status Dock” of the Schematic Editor and a detailed (.txt) report in the DSS folder created inside the model’s Target Files folder (the full path is also shown in the summary report). The report shows the model's main aspects, such as timestep, number of couplings, and number of switches. In the next section, the report presents information about each Coupling element in the circuit, such as:

- Operational Mode - if it is Automatic or Manual.
- Topological conflicts of the coupling with the rest of the model, the snubbers values used for each side of the coupling and its impact on the power flow.
- Stability Data, informing if the coupling is stable or not (and for which switch permutation) and tips to bring it to stability.

Besides providing information, the MPA automatically modifies the coupling elements that were configured to the “Automatic” mode to achieve model stability.

The following subsections present details of the “Manual” and “Automatic” operation modes of the couplings.

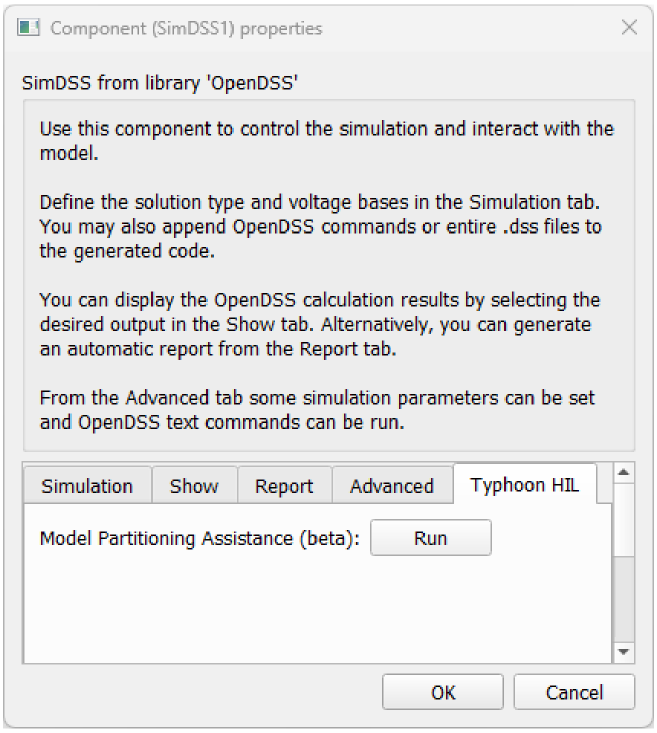


Figure 5 – Model Partitioning Assistance on the SimDSS component.

Manual Mode

Considering the initial parameterization of the example, the MPA summary report is shown in Figure 6. Couplings 1, 4, and 5 are stable, while Couplings 2 and 3 are unstable. The report shows on which switch conditions each coupling is unstable. In the example, Couplings 2 and 3 are unstable on all conditions of SW1 and SW2.

Another relevant piece of information is the snubber's parameterization. Couplings 1, 2, and 3 do not have snubbers parametrized in the original system configuration, but only Coupling 1 has topological conflicts (with the Transformer T203). As it is known that Coupling 1 is stable, it is possible to use a high resistance resistor on the current source side of the coupling to solve the topological conflict, while minimizing the impact of the snubber when compared to the original system. This would configure Coupling 1 similarly to Couplings 4 and 5. In these couplings, snubbers of 100 kΩ on the Current Source Side and 1 mΩ on the Voltage Source Side are used. The report also shows the impact of these snubbers on the circuit: about 700 mW on the shunt snubber, about 1 V of drop voltage, and 1 kW of loss on the series snubber. The user can use the power flow results on the detailed information to evaluate if the values are acceptable for its real-time simulation analysis.

The detailed report is shown in Figure 7. As the report is too long to put in this document, just a cut set within the Coupling 2 information is shown. In addition to the Topological Conflicts, Snubber

Parameterization, and Stability Check sections of the summary report, the detailed report shows the power flow and the Thevenin Impedance for each switch combination.

```
-----------------------------------Coupling1 Element-----------------------------------
Operational Mode: Manual
Topological Conflicts: Yes
- There are topological conflicts between Coupling1 and T203.
  Please, considers to use a snubber at the current source side of the Coupling1
Snubbers Parameterization:
- Current Source Side: none
- Voltage Source Side: none
Stability Check: Coupling1 is stable

-----------------------------------Coupling2 Element-----------------------------------
Operational Mode: Manual
Topological Conflicts: No
Snubbers Parameterization:
- Current Source Side: none
- Voltage Source Side: none
Stability Check: Coupling2 is unstable for SW1=Open|SW2=Open, SW1=Open|SW2=Close, SW1=Close|SW2=Open, SW1=Close|SW2=Close switches combinations.
Stability tips can be found on the detailed report

-----------------------------------Coupling3 Element-----------------------------------
Operational Mode: Manual
Topological Conflicts: No
Snubbers Parameterization:
- Current Source Side: none
- Voltage Source Side: none
Stability Check: Coupling3 is unstable for SW1=Open|SW2=Open, SW1=Open|SW2=Close, SW1=Close|SW2=Open, SW1=Close|SW2=Close switches combinations.
Stability tips can be found on the detailed report

-----------------------------------Coupling4 Element-----------------------------------
Operational Mode: Manual
Topological Conflicts: No
Snubbers Parameterization:
- Current Source Side: R1=100.00 kΩ (maximum snubber power: 726.15 mW)
- Voltage Source Side: R2=1.00 mΩ (maximum drop voltage 1.16 V, and maximum loss 1.35 kW)
Stability Check: Coupling4 is stable

-----------------------------------Coupling5 Element-----------------------------------
Operational Mode: Manual
Topological Conflicts: No
Snubbers Parameterization:
- Current Source Side: R1=100.00 kΩ (maximum snubber power: 733.95 mW)
- Voltage Source Side: R2=1.00 mΩ (maximum drop voltage 816.46 mV, and maximum loss 666.61 W)
Stability Check: Coupling5 is stable
---------------------------------------------------------------------------------------
```

Figure 6 – Model Partitioning Assistance summary report.

According to the Stability Data section of the Coupling 2 detailed report, a flip of the coupling, changing where the current sources point to, would solve the stability issue. The flip action will change the r1 and r2 impedances of the coupling, and with the new orientation, all switch conditions will achieve the stability criteria. We can already assume the need to use a snubber on the Current Source Side of the coupling now that this side points to the Transformer (similar to Coupling 1 as discussed above). If no snubbers are used, it will inform a topological conflict on the next MPA run.

In regard to the snubber's parametrization, once flipped the Coupling 2 becomes similar to Coupling 1. It is stable and has topological conflicts on the Current Source Side. A big value of resistance can be used without major impact on the power flow results (100 kΩ will be used).

The same steps are followed for Coupling 3, but not described here. After the modifications, we can rerun the MPA and check the new results for this arrangement. The summary report is shown in Figure 8.

```
--------------------------------------------------Coupling2 Element--------------------------------------------------
Operational Mode: Manual
Snubbers Parameterization:
- Current Source Side: none
- Voltage Source Side: none
Topological Conflicts: No
                    --- Switch Condition: SW1=Open|SW2=Open ---
Power Flow data at the Coupling:
 - S1= 0.0 + j0.0 kVA        S2= 0.0 + j0.0 kVA        S3= 0.0 + j0.0 kVA
 - I1= 0.0 A < 0.0°          I2= 0.0 A < 0.0°          I3= 0.0 A < 0.0°
 - V1= 0.0 kV < 0.0°         V2= 0.0 kV < 0.0°         V3= 0.0 kV < 0.0°
Stability Data (ITM):
- Phase1: r1=26.85 Ω,  r2=1.67 Ω **UNSTABLE**
- Phase2: r1=26.85 Ω,  r2=1.67 Ω **UNSTABLE**
- Phase3: r1=26.85 Ω,  r2=1.67 Ω **UNSTABLE**
- A flip on the Coupling2 might solve this issue.
                    --- Switch Condition: SW1=Open|SW2=Close ---
Power Flow data at the Coupling:
 - S1= 0.0 + j0.0 kVA        S2= 0.0 + j0.0 kVA        S3= 0.0 + j0.0 kVA
 - I1= 0.0 A < 0.0°          I2= 0.0 A < 0.0°          I3= 0.0 A < 0.0°
 - V1= 0.0 kV < 0.0°         V2= 0.0 kV < 0.0°         V3= 0.0 kV < 0.0°
Stability Data (ITM):
- Phase1: r1=26.85 Ω,  r2=1.63 Ω **UNSTABLE**
- Phase2: r1=26.85 Ω,  r2=1.63 Ω **UNSTABLE**
- Phase3: r1=26.85 Ω,  r2=1.63 Ω **UNSTABLE**
- A flip on the Coupling2 might solve this issue.
                    --- Switch Condition: SW1=Close|SW2=Open ---
Power Flow data at the Coupling:
 - S1= 282.005 + j137.279 kVA   S2= 282.005 + j137.279 kVA   S3= 282.005 + j137.279 kVA
 - I1= 1163.378 A < 122.11°     I2= 1163.378 A < 2.11°       I3= 1163.378 A < -117.89°
 - V1= 0.27 kV < -31.94°        V2= 0.27 kV < -151.94°       V3= 0.27 kV < 88.06°
Stability Data (ITM):
- Phase1: r1=26.85 Ω,  r2=1.38 Ω **UNSTABLE**
- Phase2: r1=26.85 Ω,  r2=1.38 Ω **UNSTABLE**
- Phase3: r1=26.85 Ω,  r2=1.38 Ω **UNSTABLE**
- A flip on the Coupling2 might solve this issue.
                --- Switch Condition (initial state): SW1=Close|SW2=Close ---
Power Flow data at the Coupling:
 - S1= 281.41 + j136.99 kVA    S2= 281.41 + j136.99 kVA    S3= 281.41 + j136.99 kVA
 - I1= 1162.151 A < 122.01°    I2= 1162.151 A < 2.01°      I3= 1162.151 A < -117.99°
 - V1= 0.269 kV < -32.03°      V2= 0.269 kV < -152.03°     V3= 0.269 kV < 87.97°
Stability Data (ITM):
- Phase1: r1=26.85 Ω,  r2=1.37 Ω **UNSTABLE**
- Phase2: r1=26.85 Ω,  r2=1.37 Ω **UNSTABLE**
- Phase3: r1=26.85 Ω,  r2=1.37 Ω **UNSTABLE**
- A flip on the Coupling2 might solve this issue.
```

Figure 7 – Model Partitioning Assistance detailed report (only Coupling 2 information).

```
-----------------------------------Coupling1 Element------------------------------------
Operational Mode: Manual
Topological Conflicts: No
Snubbers Parameterization:
- Current Source Side: R1=100.00 kΩ (maximum snubber power: 54.82 W)
- Voltage Source Side: none
Stability Check: Coupling1 is stable

-----------------------------------Coupling2 Element------------------------------------
Operational Mode: Manual
Topological Conflicts: No
Snubbers Parameterization:
- Current Source Side: R1=100.00 kΩ (maximum snubber power: 733.69 mW)
- Voltage Source Side: none
Stability Check: Coupling2 is stable

-----------------------------------Coupling3 Element------------------------------------
Operational Mode: Manual
Topological Conflicts: No
Snubbers Parameterization:
- Current Source Side: R1=100.00 kΩ (maximum snubber power: 731.33 mW)
- Voltage Source Side: none
Stability Check: Coupling3 is stable

-----------------------------------Coupling4 Element------------------------------------
Operational Mode: Manual
Topological Conflicts: No
Snubbers Parameterization:
- Current Source Side: R1=100.00 kΩ (maximum snubber power: 726.15 mW)
- Voltage Source Side: R2=1.00 mΩ (maximum drop voltage 1.16 V, and maximum loss 1.35 kW)
Stability Check: Coupling4 is stable

-----------------------------------Coupling5 Element------------------------------------
Operational Mode: Manual
Topological Conflicts: No
Snubbers Parameterization:
- Current Source Side: R1=100.00 kΩ (maximum snubber power: 733.95 mW)
- Voltage Source Side: R2=1.00 mΩ (maximum drop voltage 816.46 mV, and maximum loss 666.61 W)
Stability Check: Coupling5 is stable
---------------------------------------------------------------------------------------
```

Figure 8 – Model Partitioning Assistance summary report after the changes on the Coupling.

Automatic Mode

The Automatic Mode reports are similar to the Manual Mode. A summary report and a detailed report inform the user about the Coupling impacts on the model. The main difference is that the actions are performed automatically by the assistant. The MPA algorithm automatically changes all couplings configured as Automatic according to the results shown in the previous section: Flip action and Snubber Parameterization.

All five couplings are initially changed to Automatic Mode of operation on the component's properties mask. After the change, the component icon will be updated, informing the Auto mode (Figure 9). Running the MPA feature from the SimDSS component will start the algorithm. Figure 10.a shows the summary report for this new condition. Note that all couplings are now stable on the first MPA running. The detailed report describes the actions taken to achieve stability for each coupling. The changes are also presented on the component icon. Figure 10.b shows the flip actions on Couplings 2 and 3.

For this example, a flip action makes the couplings stable for all switches combination. If it is not possible, the MPA will do the flip actions based on the initial switches' conditions provided on the Switch component's mask. If the stability is not met, the snubbers are calculated according to the maximum power flow condition. Users should still use the Manual mode and optimally parameterize according to the application requirements.

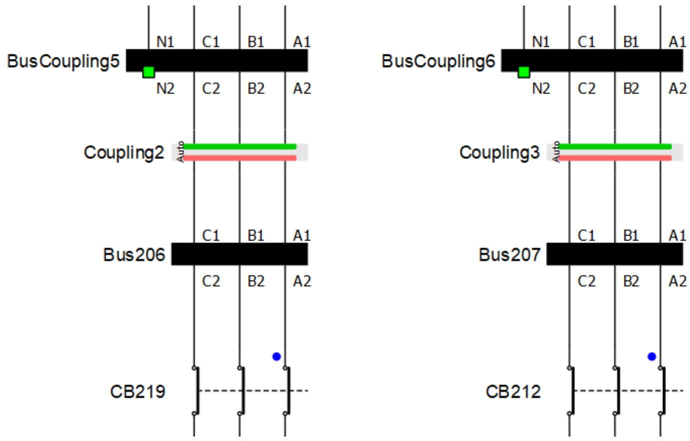


Figure 9 – Coupling Icons in Automatic Mode.

-------------------------------------Coupling1 Element-------------------------------------
Operational Mode: Automatic
Snubbers Parameterization:
- Current Source Side: R1=1.00 MΩ (maximum snubber power: 5.48 W)
- Voltage Source Side: R2=1.00 mΩ (maximum drop voltage 217.45 mV, and maximum loss 47.28 W)
Stability Check: Coupling1 is stable

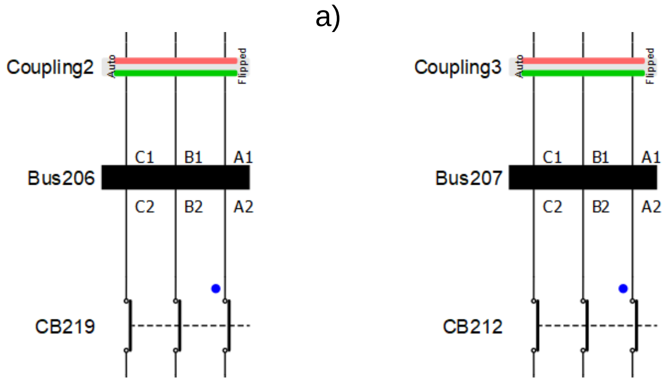
-------------------------------------Coupling2 Element-------------------------------------
Operational Mode: Automatic
Snubbers Parameterization:
- Current Source Side: R1=1.00 MΩ (maximum snubber power: 72.53 mW)
- Voltage Source Side: R2=1.00 mΩ (maximum drop voltage 1.16 V, and maximum loss 1.35 kW)
Stability Check: Coupling2 is stable

-------------------------------------Coupling3 Element-------------------------------------
Operational Mode: Automatic
Snubbers Parameterization:
- Current Source Side: R1=1.00 MΩ (maximum snubber power: 72.80 mW)
- Voltage Source Side: R2=1.00 mΩ (maximum drop voltage 467.33 mV, and maximum loss 218.40 W)
Stability Check: Coupling3 is stable

-------------------------------------Coupling4 Element-------------------------------------
Operational Mode: Automatic
Snubbers Parameterization:
- Current Source Side: R1=1.00 MΩ (maximum snubber power: 72.61 mW)
- Voltage Source Side: R2=1.00 mΩ (maximum drop voltage 1.16 V, and maximum loss 1.35 kW)
Stability Check: Coupling4 is stable

-------------------------------------Coupling5 Element-------------------------------------
Operational Mode: Automatic
Snubbers Parameterization:
- Current Source Side: R1=1.00 MΩ (maximum snubber power: 73.40 mW)
- Voltage Source Side: R2=1.00 mΩ (maximum drop voltage 816.46 mV, and maximum loss 666.61 W)
Stability Check: Coupling5 is stable

a)



b)

Figure 10 – MPA results from the Automatic mode. a) Summary report, b) Changed Icons indicating the actions taken by the MPA.

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