Description of a model aggregation method for Voltage Source Converters with output AC impedance

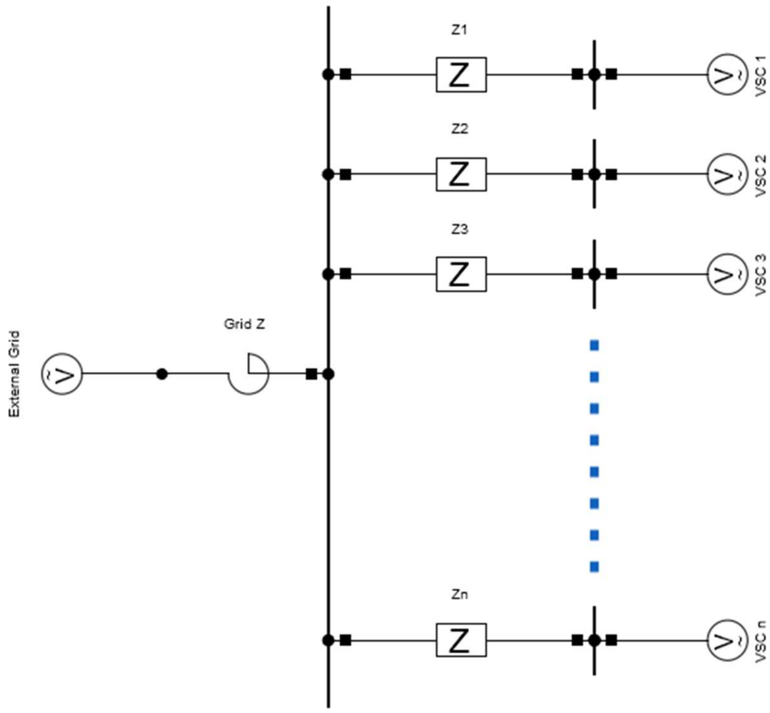
Author: DIgSILENT GmbH

Date: 2025.05.27

1 METHOD DESCRIPTION

The principle of operation is based on taking advantage of the fact that parallel electrical circuits organised in a radial topology and are driven by the same back EMF can be simplified into a single equivalent electrical circuit.

Assume the following electrical circuit topology:



In the above topology, a radial feeder containing n branches is shown. It is assumed that:

$$Z_1 = Z_2 = \cdots = Z_n$$

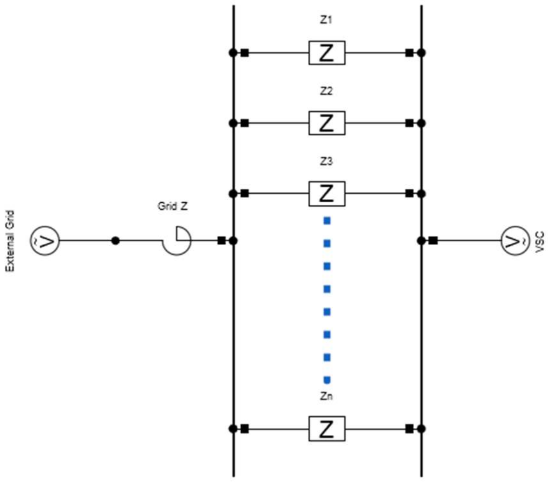
Where Z_i represents the output impedance of the voltage source converter VSC_i.

Furthermore, the following is also assumed:

$$V_{VSC} \quad = V_{VSC2} = \cdots = V_{VSCn}$$

Where V_{VSCi} represents the complex voltage of the voltage source converter VSC_i, driving the output current of each converter.

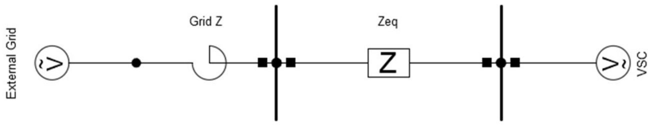
Based on the fore mentioned conditions, the radial feeder representation can be equivalent to the following circuit



Based on the above circuit, an equivalent impedance can be calculated Z_{eq} :

$$Z_{eq} = Z_1 \| Z_2 \| \dots \| Z_n = \frac{Z_1}{n}$$

The resulting circuit looks as follows:



For the purpose of model aggregation of an EMT model of a power park containing n units, the number of aggregated units shall be $n-1$. The remaining unit (up to n) shall remain unchanged, representing the "detailed unit". The following equivalent circuit can therefore be derived as well:

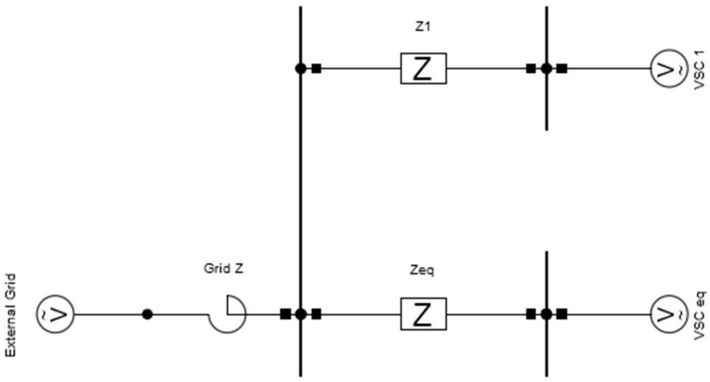


Figure 1: Basic equivalent circuit applied for model aggregation of a power park containing "n" units arranged in a radial topology.

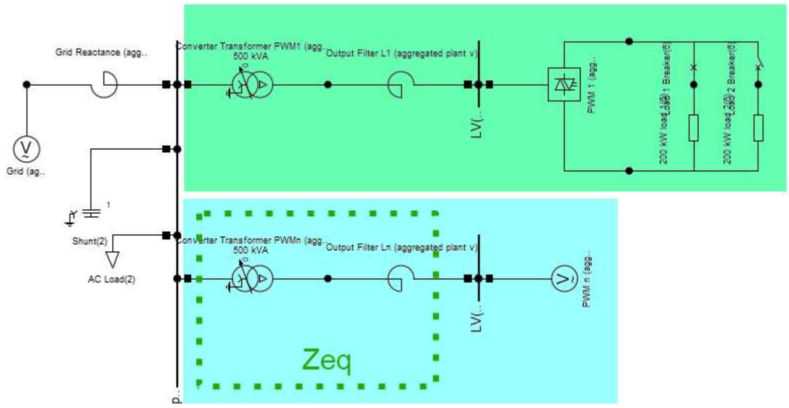
In the above circuit, the following conditions apply:

$$V_{VSC1} = V_{VSCeq}$$

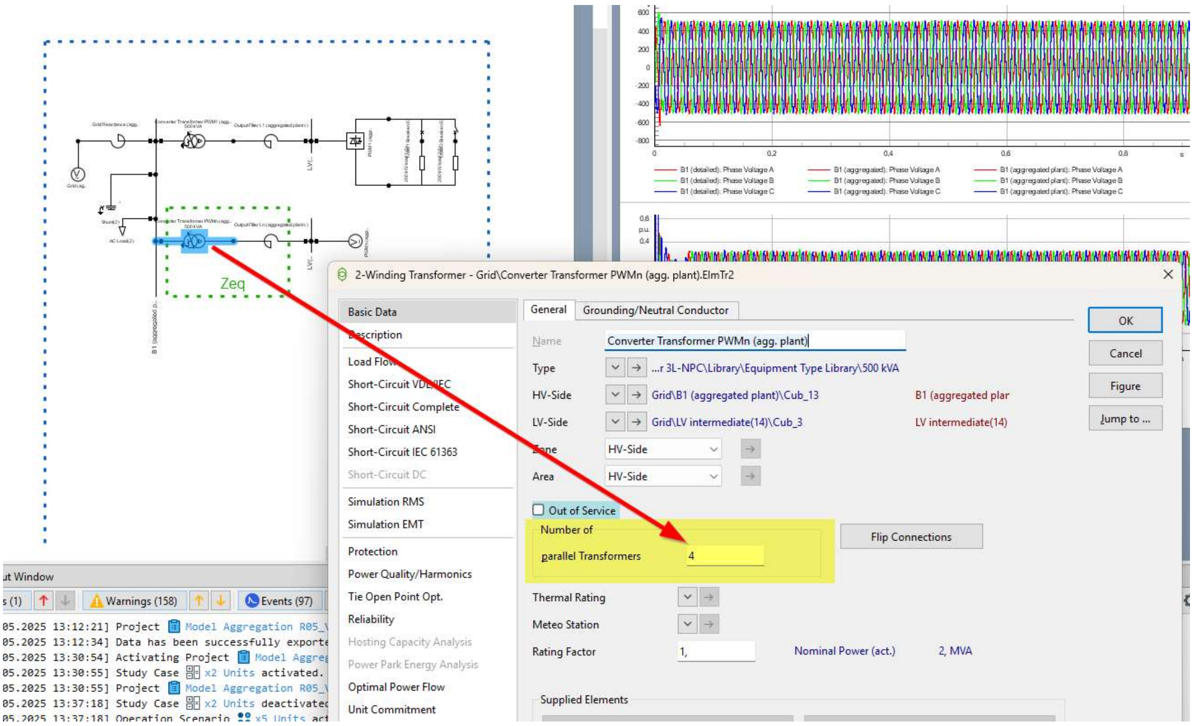
$$Z_{eq} = Z_2 \| Z_3 \| \dots \| Z_n = \frac{Z_1}{n-1}$$

The equivalent circuit shown in *Figure* 1 forms the basis for the EMT model aggregation method demonstrated in this example.

In practical applications, the components “Z1” and “VSC 1” may correspond to the elements belonging to the actual EMT simulation model of a VSC system unit. For example, a possible EMT model aggregation is shown in figure below. The components of a detailed EMT model of one unit are highlighted with light green, whereas the model aggregation components are highlighted with light blue. The EMT model of one unit can have a completely different structure than the representation of the model aggregation.

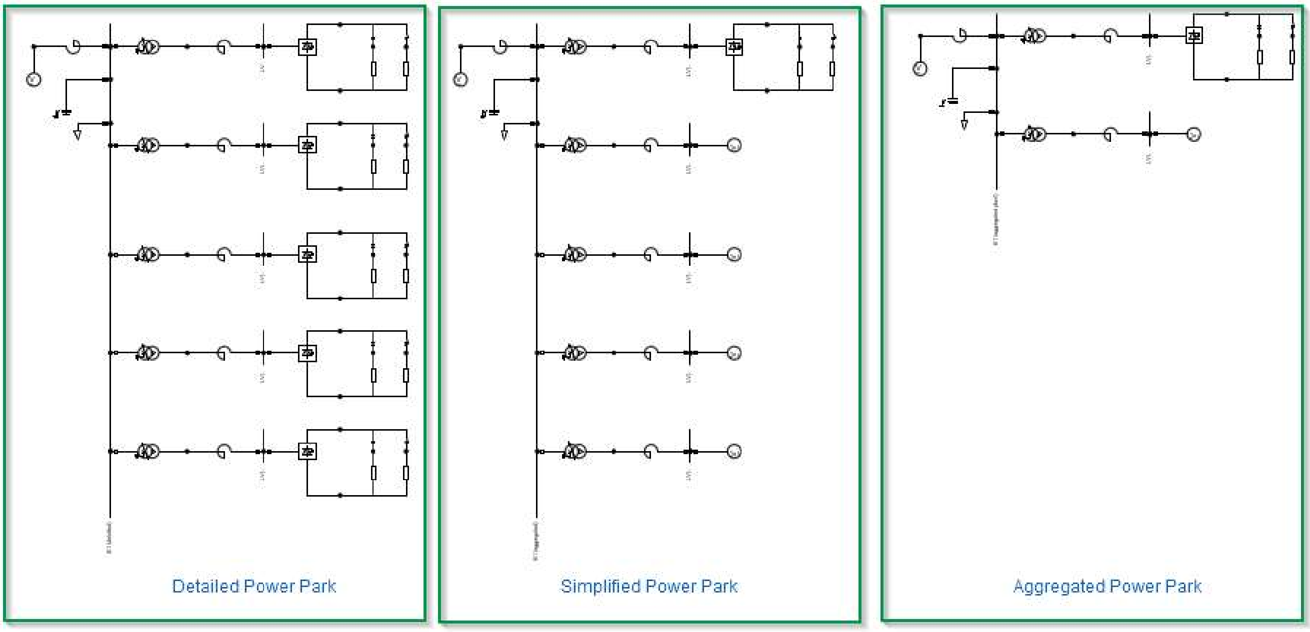


Nevertheless, it is important that the equivalent impedance is adequately modelled. The simplest method to do that is to duplicate the output filter of the VSC, along with the transformer and optionally any output cable stepouts and make use of the number of parallel units parameters of these built-in components. Note, some elements do not have a parameter for parallelisation e.g. ElmSind. In such cases, manual computation of the equivalent impedance is required.



2 DESCRIPTION AND USAGE INSTRUCTION FOR THE POWERFACTORY EXAMPLE

The project file “Model Aggregation RXX_VXX.pfd” contains one power network with the single line diagram as in figure below:



The example focuses on grid following control based units, but by applying corresponding changes, it should operate similarly for any other control types too e.g. grid-forming.

In the SLD, there are three independent circuits modelled:

- A detailed power park system containing a maximum of 5 units (system A)
- A simplified power park system containing a maximum of 5 units (system B)
- An aggregated power park system containing a maximum of 5 units (system C)

The system A contains detailed representations of all VSC units, including their dynamic control models.

System B, contains a detailed representation of the first VSC unit, including the dynamic control models. For all other units, a detailed representation of the AC output impedance is represented, while the converter itself (and the DC side) is idealised by replacing it with a controlled voltage source. As such, four voltage sources are modelled, one for each unit. Each voltage source is controlled by a voltage reference identical with that of the voltage measured on the AC output terminal of the first VSC unit.

System C, contains a detailed representation of the first VSC unit, including the dynamic control models. For all other units, an equivalent representation of the AC output impedance is used. The equivalent AC output impedance is driven by one aggregated ideal voltage source. The voltage source is controlled by a voltage reference identical with that of the voltage measured on the AC output terminal of the first VSC unit.

In practical terms, the approach is as follows:

- One converter system is represented in detail.

- A converter output bus "BUS_CONVERTER" is noted. A park output bus "BUS_PARK" is noted.

- Between the BUS_CONVERTER and the BUS_PARK it is expected that the converter's output filter, an optional LV/MV step up transformer and a cable/transmission line system are existing.

- An aggregation unit is added in parallel to the detailed converter system and connected to the "BUS_PARK". The aggregation unit is composed of a controlled voltage source (corresponding to the voltage created by the converter system at the BUS_CONVERTER) and an aggregated output filter (n times) and an optional n parallel units transformer placed between the voltage source and the BUS_PARK.

- The voltage applied at the controlled voltage source is identical with the one at the BUS_CONVERTER. In fact, it is measured from BUS_CONVERTER and reproduced identically on the voltage source.

- Depending on the aggregation procedure of the filter/transformer between the voltage source and the BUS_PARK, an aggregated plant of n units can be obtained.

- In load flow, a QDSL model is included such as to reproduce the positive sequence voltage measured at BUS_CONVERTER to the bus to which the voltage source connects to. Currently, the QDSL model only supports positive sequence voltage replication.

Refer to attached project, which contains the following models:

- on the left side of the diagram, a detailed 5 units park is represented (no aggregation)

- in the middle of the single line diagram, a simplified 5 units park is represented (1 detailed unit + 4 individual units using a controlled voltage source)

- on the right side of the SLD, an aggregated 5 units park is represented (1 detailed unit + 1 aggregated system representing 4 units)

There are three study cases:

- x2 Units – a case where only two of the five units are in service, the other three are out of service.
- x3 Units – a case where only three of the five units are in service, the other two are out of service.
- x5 Units – a case where all five units are in service.

To reproduce the results, click on the button “Press this button to run all cases”. This will trigger the execution of the Task Automation command, which will execute all study cases.

Observe in the shown plots that all three systems (A, B and C) generate identical results, which demonstrates the correct operation of the aggregation procedure.