PowerFactory model for multi-terminal HVDC network with DC voltage droop control

Version 1.0

OffshoreDC workshop on modelling with PowerFactory

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Version history

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The present version 1.0 includes the following two .pfd files:

- `3MTDC-Version1-0_20111223.pfd`, suitable for PowerFactory version 14.1 and more recent.
- `3MTDC-Version1-0_20111223_PF14-0.pfd`, suitable for PowerFactory version 14.0 and more recent.

Contents

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Introduction

The present brief report gives an overview of the modelling work that has been carried out by the authors at Risø DTU on 15-16 December 2011. The workshop was promoted by the Nordic OffshoreDC project as a part of its targets related to efficient knowledge sharing and interaction between its diverse partners. Other seminars of the same kind are to take place in the future concerning other topics/softwares.

The focus of the meeting was the implementation of a DIgSILENT PowerFactory model for a simple multi-terminal VSC-based HVDC network, provided with DC voltage droop control. The participants, after a brief introduction to the simulation platform and a description of the control principles, have developed a model that is able to represent the measurement and control equipment of a VSC-HVDC converter. The control features the following actions:

- DC voltage droop control
- AC frequency control
- AC voltage droop control
- Reactive power control
- DC overvoltage limitation

The main objective of the work is, as stated above, the facilitation of knowledge transfer between project partners as well as towards the external academic and industrial world, by combining the experience of PowerFactory and HVDC experts in order to boost the learning potential.

Besides an illustrative presentation of the model, a list of references is also reported at the end of the document, in order to support the work presented with theoretical bases. Some sources on voltage droop control [1, 2, 3, 4, 5] are listed, together with others regarding frequency support and primary and secondary control from MTDC [6, 7]. More references regarding another possible control strategy, i.e. the voltage margin control, are also suggested [8, 9, 10, 11, 12].

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Brief model description

2.1 Grid layout - MTHVDC

The grid layout that has been chosen for testing the applied control strategy is a multi-terminal high voltage direct current (MTHVDC) network that consists of three terminals and is based on voltage source converter (VSC) technology. Nowadays, most of the HVDC installations are based on line commutated converters (LCC), that offer a series of advantages, among which low costs and losses. On the other hand, VSCs have recently drawn more and more attention, due to high flexibility and controllability and recent developments that improve efficiency and power quality. When considering offshore installations and multi-terminal grids, the advantages offered by VSCs become so large that they are as today thought of as the only viable solution.

However, no VSC-based MTHVDC grids exist to date, and this is one of the reasons for carrying out a research project such as OffshoreDC. In this work, the focus is on modelling and control of MTHVDC grids in PowerFactory, a software that is widely used in particular for large power system studies and is suitable for running a rather vast range of analyses. The basic multi-terminal configuration requires three buses fed by three different power electronic converters and has been chosen in this work. The grid can then be easily expanded by simply applying the developed model.

The targeted mixed AC/DC grid can be seen in Appendix A. It consists of two external AC grids feeding three AC busbars, from which three VSCs are derived in order to supply the three DC busbars that are then connected in a radial fashion to form a multi-terminal network. In this way the model and the DC voltage droop control strategy can be tested efficiently and simply. Once the model has been tested, the system can be expanded at will in order to assess the performance on different layouts.

The DC voltage level is 500 kV, while the AC RMS voltage is 400 kV[1], standard models have been used for DC lines and reasonable assumptions were made regarding the DC cables.

2.2 PWM converter

The standard PowerFactory model for the PWM two-level converter has been used in the model. The level of detail corresponds to that needed for RMS simulations and thus excludes the actual switching pattern, simply deriving the AC voltage value from DC voltage and modulation indexes. A more detailed

[1] The DC voltage level has been increased in order for it to be always higher than the peak AC voltage, even in quite extreme situations of AC overvoltage and/or heavy loading of the DC grid. This is done in order to prevent the converters from working in overmodulation. However, this issue can easily be tackled, in reality, by inserting a suitably designed transformer.

version is however available for EMT simulations and more information on the model can be found in PowerFactory's technical reference.

2.3 Converter control

The converter control strategy highly depends on the grid layout and going from point-to-point (P2P) to multi-terminal requires major changes to the control philosophy. Usually, in a P2P VSC configuration, a converter is performing power control - usually the rectifier - while the other controls the DC voltage, resembling what happens for big LCC connections or converters in a wind turbine. However, VSCs offer more controllability on the AC side, by for instance featuring, if required, AC voltage and/or reactive power control.

On the other hand, when expanding the DC network to more than two terminals, such simple control strategy may not be sufficient for the safe and effective operation of the system. As such, a new strategy for controlling power flow and DC voltages must be applied. The suggestions in the literature are variegated and, offering different pros and cons, are suitable for different grid layouts and control needs.

OffshoreDC project has drawn its attention to the DC voltage droop technique, which somehow resembles what is done in AC networks with frequency control and is under heavy focus in the research community, trying to establish operational principles and characterise its dynamic and static behaviour.

An as general as possible control structure suitable to host a DC voltage droop control block and other supplementary features has been devised after a brief discussion. The structure is illustrated in Figure 2.1. It can be seen that a power (PQ) control block is included in the diagram, which is fed in a cascaded fashion by more blocks performing different control actions. A DC voltage droop control and an AC frequency droop control ar acting in parallel in order to set the active power reference, that is then transformed into direct current set-point by the power controller. The reactive power reference, instead, is modulated by an AC voltage droop control, then being transformed into q-axis current set-point by the power controller. The fast current control action is provided by the integrated PowerFactory PI controller, while a possible slower and higher-level secondary control could set the reference values for voltages, powers and frequency - further discussion on such block is proposed below.

It should be noticed that the diagram refers to a composite frame, that can flexibly be used in PowerFactory, meaning that the blocks can be filled with different models depending on the user's wishes. A more detailed description of the models that have been used in this first version follows below.

2.3.1 Power control

The power control block simply realises a summation of the references coming from the blocks upstream, then adapting the signal to the current AC voltage level, in order to obtain direct and quadrature axis current references, that are respectively controlling active and reactive power. The sketch of the power controller is depicted in Figure 2.2.

The power reference signal P_{ref} is in this case solely deriving from initialisation, in order to shift the DC voltage droop curve to the right level and have nil initial contribution from the voltage droop block. For the purpose of correctly initialising the model, the measured power P_{meas} is needed as an input, but simply fed into a sink block.

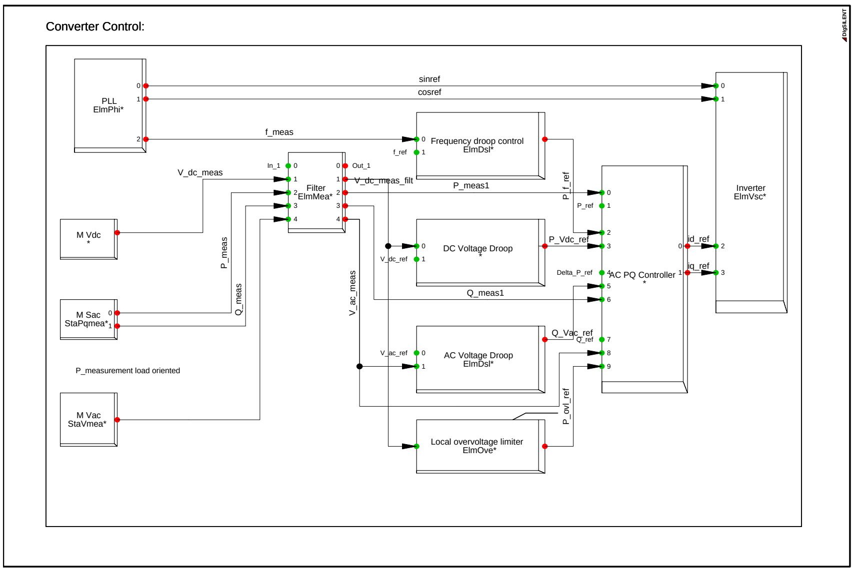

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Figure 2.1: Converter control structure.

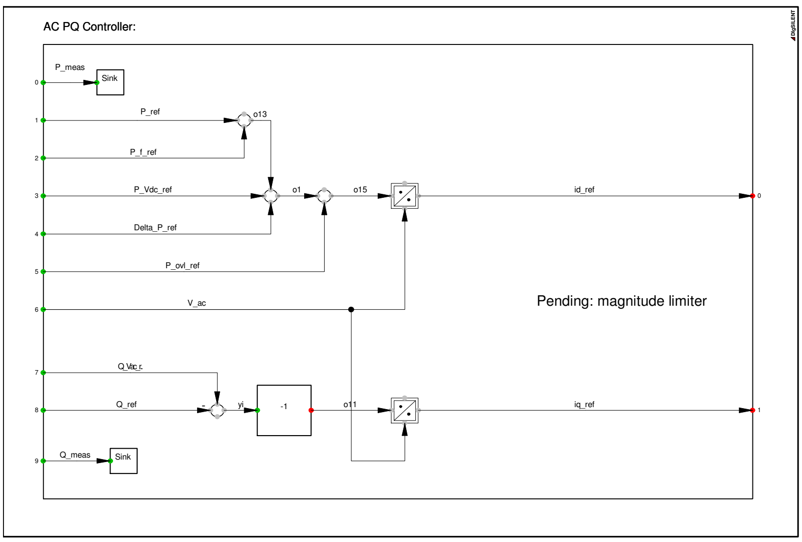

Figure 2.2: Power controller block diagram.

2.3.2 DC voltage droop

The DC voltage droop controller, as described in the literature, performs a proportional control action depending on the error between a reference DC voltage and its actual value. A constant gain R_{Vdc} is setting the stiffness of the power-voltage characteristic of the controller, in analogy with what happens in primary frequency control in classical AC systems. The DC voltage droop's block diagram is reported in Figure 2.3.

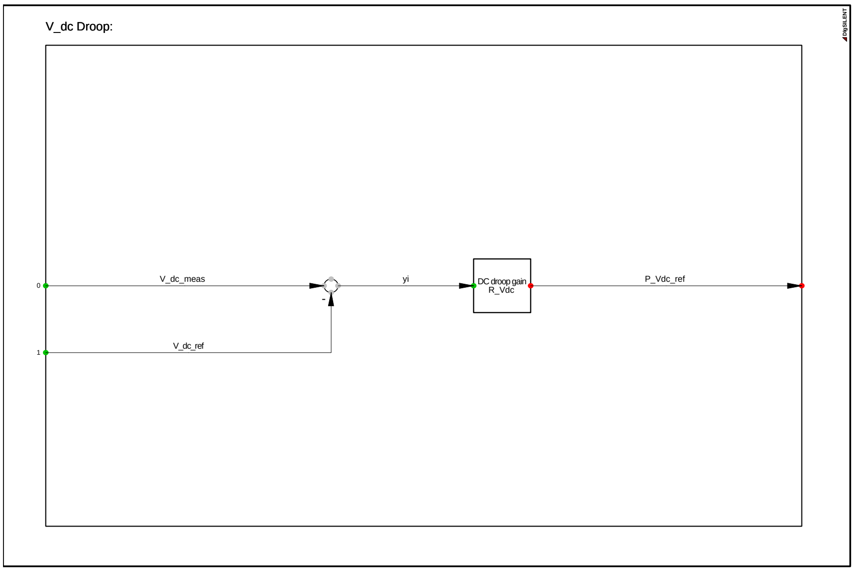

Figure 2.3: DC voltage droop control block diagram.

2.3.3 AC frequency droop

The AC frequency droop control block implements the primary frequency response that the conventional power plants are usually provided with. A proportional control action is applied to the frequency error, in order to inject more or less power depending on the frequency deviation and reduce the steady-state frequency error in case of large load/production contingency. The block diagram is therefore the classical one and is reported in Figure 2.4.

2.3.4 AC voltage droop control

As a support to the reactive power control, an AC voltage droop control has been added to the model, in order for the converter to consistently respond to AC voltage magnitude variations and adapt its reactive power injection/consumption accordingly. The block diagram is presented in Figure 2.5 and strongly resembles the other droop blocks described above.

2.3.5 Secondary controllers

Secondary control could be incorporated in the model in the future. Such slower and higher-level control loop would likely act on the following signals:

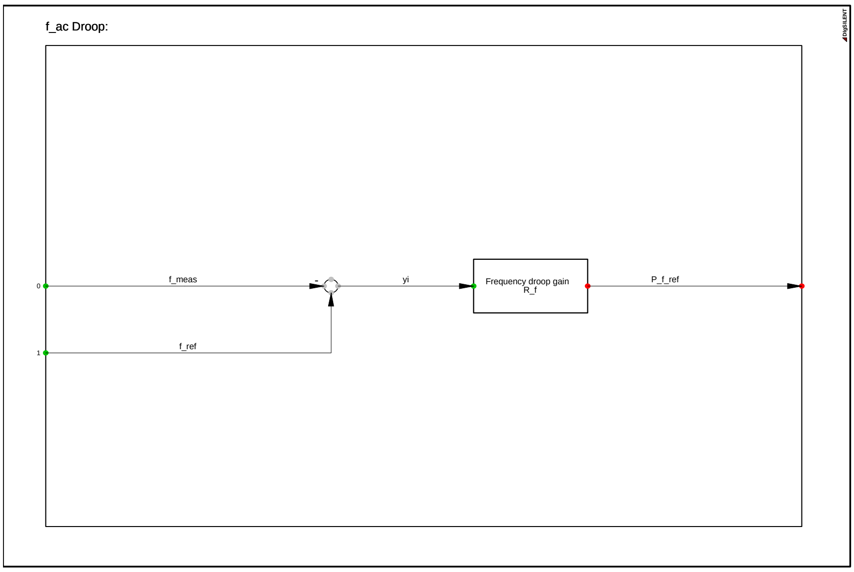

Figure 2.4: AC frequency droop control block diagram.

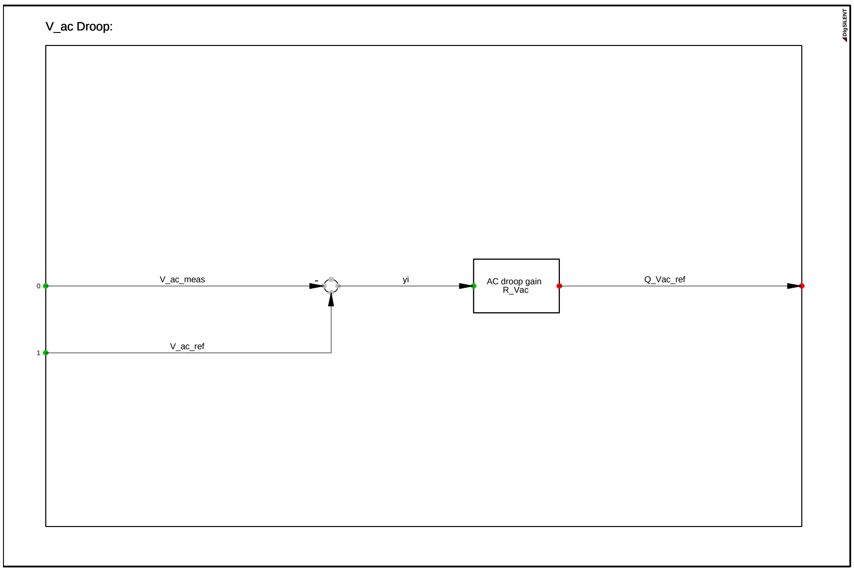

Figure 2.5: AC voltage droop control block diagram.

- Active power reference.
- Reactive power reference.
- AC voltage reference.
- Frequency reference.
- DC voltage reference.

The control objectives such secondary block should be based upon are still partially unknown, as no MTHVDC grid exist and the services to be provided to the AC grids will be depending on local grid code and operational conditions. A generic discussion took place during the workshop and the following possible targets have been listed:

- Correct realisation of scheduled power flow.
- Limitation of DC voltage within a certain range.
- Reactive power support based on TSOs plans.

In the first version of the model, for the sake of example, only a DC overvoltage controller has been built, in order to avoid drifts of the DC voltage above a certain limit, that are not automatically prevented by the voltage droop loop. The simple scheme that was utilised for this purpose is shown in Figure 2.6.

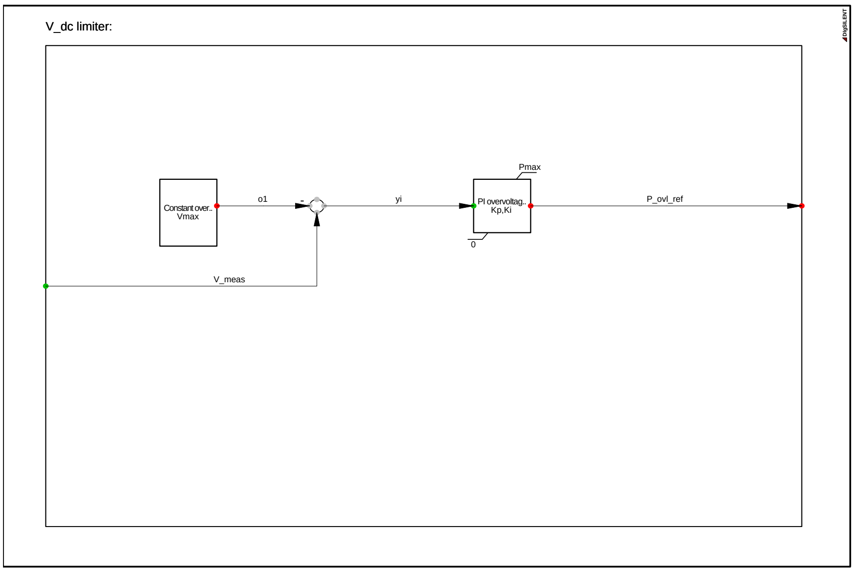

Figure 2.6: DC overvoltage control block diagram.

Obviously, the secondary controller could take many different forms and the room for discussion in this field is even larger than for the primary loops. Therefore, continuation of the discussion within and out of the working group is encouraged.

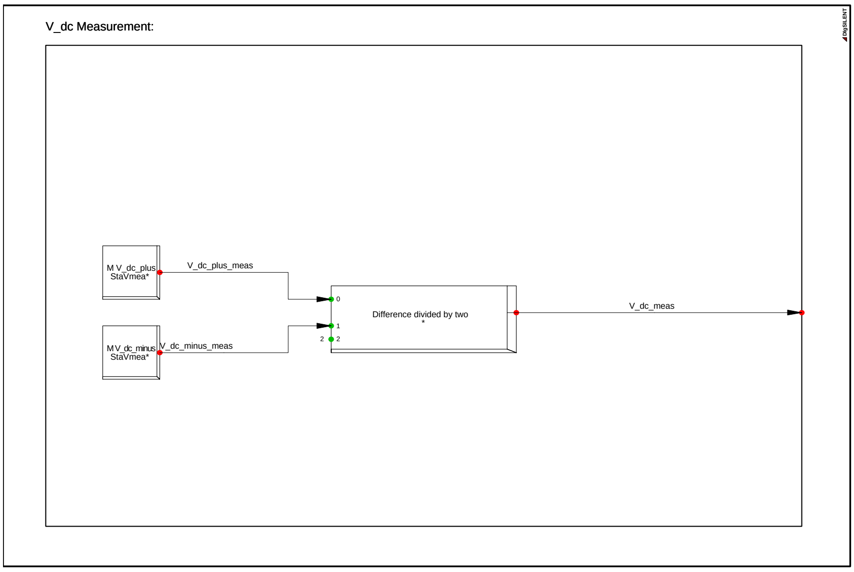

Figure 2.7: Modification of DC voltage measurement.

2.3.6 The measurement blocks

A set of measurements are needed for converter control purposes. These are lying on the left part of Figure 2.1 and are consisting of the following measurement devices:

- Phase locked loop: to measure the phase angle and frequency.
- AC voltage measurement: to sense the AC voltage at the converter's point of connection.
- PQ measurement: to measure the active and reactive power flowing from/to the converter. The measurement utilises the load orientation.
- DC voltage measurement: to provide the value of the current DC voltage.
- AC current measurement: to measure the AC current flowing in the converter's AC phases. This measurement block cannot be seen in Figure 2.1, as it is built-in in the current control.

Nearly all the measurements are implemented by using standard models provided by PowerFactory and choosing the right settings and point of connection. One can refere to PowerFactory's technical reference in order to obtain an overview of their features.

The only block that has undergone some refinement is the DC voltage measurement, that must be taken on both terminals and modified as shown in Figure 2.7 in order to provide the right pu value. It has to be noticed that such a scheme applies a division by 2 and can only be applied in symmetrical DC links.

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Pending work

A number of significant aspects were deemed not to be of fundamental importance for the sake of the workshop and were left pending for future work. These are not limited to:

- A vector limitation - with or without priority - should be introduced on the current references. This can be done in different ways and would also affect the initialisation of the model.
- The parameters of the PI controllers - in overvoltage control and current control - should be improved in order to optimise the performance. A first improvement of the overvoltage loop has been made.
- A fault ride through controller may be included. This is also a feature that can be implemented in many ways - with/without negative sequence control, compliance with one/more grid codes, etc. - and requires an amount of time that was not available in the two-days workshop.
- A template or DPL script may be built in order to easily insert the model into others.
- The secondary loop can be enriched with new features, following the guidelines stated above, but also considering other options.
- An offshore control may be developed, in order to be able to connect e.g. a wind farm to one of the terminals, since the assumption the developed model is based upon is to be connected to a relatively strong AC grid, while in offshore nodes the converter may actually be required to set voltage magnitude and angle.

4

Current simulation setup

The current simulation setup aims at showing the performance of all the controllers that have been built during the workshop. Table 4.1 summarises the events that were simulated, their time span and their target.

Table 4.1: Simulated events and objectives

Event	**Time span**	**Scope**
Reactive power consumption step on one AC grid	1-2 sec.	Test of the AC voltage droop controller
Active power consumption step on one AC grid	3-5 sec.	Test of AC frequency droop controller
Active power set-point change in one converter	7-8 sec.	Test of DC votlage droop controller
Converter trip	9 sec. - End	Test of DC overvoltage limiter

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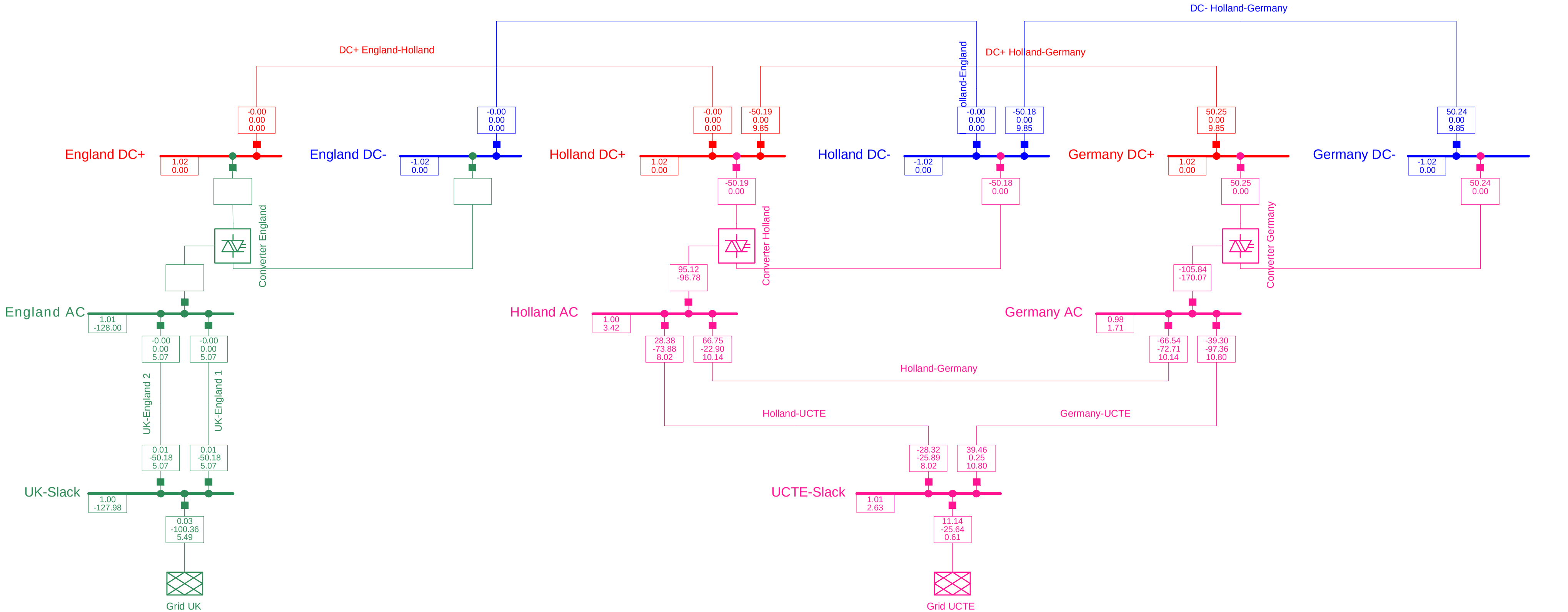
Grid layout



RMS-Simulation,balanced 14:999 s	
Nodes	Branches
Voltage, Magnitude [p.u.]	Active Power [MW]
Voltage, Angle [deg]	Reactive Power [Mvar]
	Loading [%]

		Project:
		Graphic: Network
		Date: 12/22/2011
PowerFactory 14.0.525		Annex: