FLEXIBLE DC GRIDS

MODELING AND SIMULATION OF POWER ELECTRONIC DEVICES AND GRIDS

Andreas Olenmark & Jens Sloth

The need for electrical energy is increasing continuously and in order for these needs to be met the electrical grid has to be able to handle the energy which is to be transferred. In addition to this, renewable energy sources are increasingly introduced in the electrical grid which contributes to the grid dependence on external conditions. This applies to electrical grids of all sizes whether it is a large national grid or a smaller household grid. Common for these grid setups are that several units are coupled together and need to be controlled in some manner in order to keep the grid operational in the desired voltage level and meet the grid specifications. The units are power electronic devices e.g. converters which can operate either in alternating current (AC) or in direct current (DC) which also offers the option of controllability.

POWER ELECTRONIC CONVERTERS

Power electronic converters are used for many different applications such as AC/DC transformation, DC/DC conversion, controlling electrical drives, etc. It provides precise controllability and keeps high energy efficiency and is therefore an important component in the electrical grid.

ACTIVE FRONT END (AFE)

Usually, power electronic devices are supplied with DC voltage, conventionally obtained by rectifying the grid voltage using a diode or a thyristor rectifier bridge. The problem with these rectifiers is that they introduce harmonic content in the current drawn from the grid and also lower the power factor due to its nonlinear properties. This result in a decrease in the power transferred across the line.

An AFE is a three phase converter connected to the utility grid (see figure 1). Between the converter and the grid an inductance is placed to provide the voltage boosting feature and also filter the currents. On the DC side the capacitors are needed to provide energy storage and to smooth the DC voltage. The AFE can be seen as a 4 quadrant DC/DC Boost Converter meaning that it can boost up the DC voltage side to a suitable level and power can flow in both directions. The DC voltage can then be switched using the transistors creating an in average sinusoidal voltage. By controlling the switching of the transistors the currents passing through the inductors are controlled. In that way the DC voltage can be controlled at the same time as the currents can be tuned to eliminate harmonics and purely active power consumed from the grid.

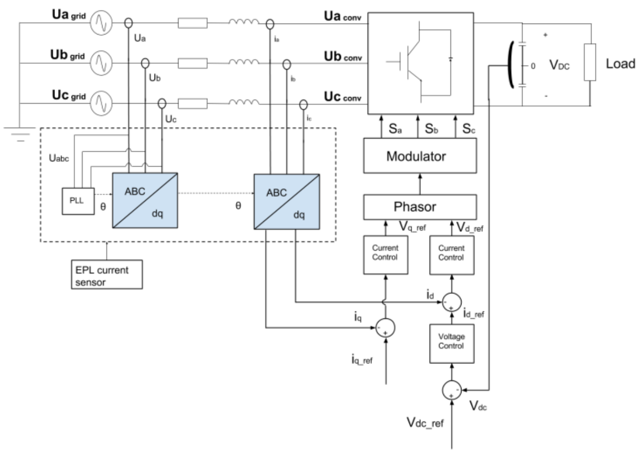

Figure 1 The AFE connected to the utility grid with DC voltage control.

The three phase currents are controlled by applying Park transformation of the currents into *dq* coordinates. The d part of the transformed current corresponds to the active power and DC voltage. The q part is related to the reactive power. Thus by controlling the *d*-current and *q*-current separately the DC voltage and the reactive power consumption is controlled separately.

POWER CONTROLLED AC/DC CONVERTER

If instead the power supplied to a load or power generated by a wind turbine needs to be controlled a similar structure as for the AFE is used. The active and reactive power is controlled using the d- and q-currents respectively. The control structure is seen in figure 2.

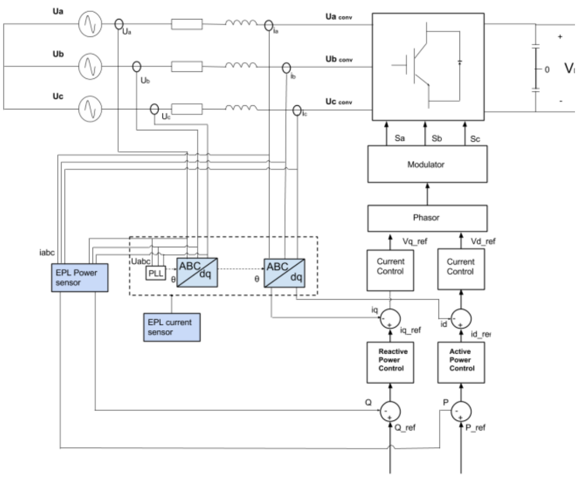

Figure 2 An illustration of the implemented power controller. The outer loop is controlling the power and the inner loop is controlling the current.

DROOP CONTROLLED AC/DC CONVERTER

A combination of the power and voltage control is called droop control. The droop control is used to ensure voltage stability of the internal DC grid, if for some reason the primary voltage control is disconnected or malfunctioning. The errors of the power and voltage are added together and the quantity which deviates most from its reference is subject of control. This control strategy is shown in figure 3.

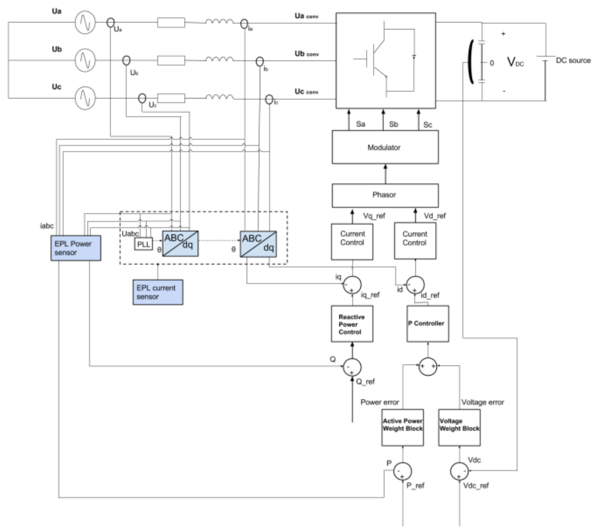

Figure 3 The droop control structure.

CONNECTING THE CONVERTERS INTO DC GRIDS

The converters are constructed in a simulation environment, in this case Dymola. Dymola is based on the Modelica language, which is a free equation-based object-oriented language. The Modelica language was especially developed for modeling dynamical systems.

The DC grid could consist of several converters connected in parallel (Multi Terminal Direct Current, MTDC) or it could be only two converters connected together. Regardless of the amount of devices, they are always connected in a back-to-back formation. There has to be at least one converter that is responsible for keeping a constant DC voltage level on the DC grid. The one controlling the DC voltage is called the master terminal and all other terminals controlling power to the different units are slave terminals. It is the master terminal that maintains the power flow balance in the DC grid.

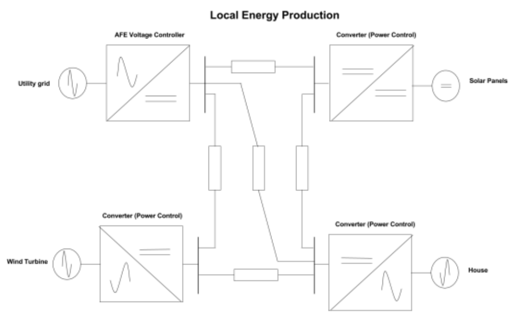

Figure 4 The MTDC grid for a household with local power generation

The grid seen in figure 4 resembles a general household with local energy production. When implementing the household in the simulation two wind turbines are connected to the DC grid and one smart house model is connected to the grid. The wind turbines have an installed capacity of 4 kW each. The AC distribution grid is connected to the DC grid through an AC/DC converter set to DC voltage control, which keeps the DC voltage of the DC grid to 1.5 kV. The AC distribution grid is represented by an AC source operating in 50Hz and 400 V line-line. Additionally a solar power plant is connected to the DC grid through a power controlled DC/DC converter. The solar power plant is represented by a DC source with voltage 100 V. The power generated by the solar plant varies sinusoidally between 0-2 kW with frequency 0.04 Hz. The Dymola implementation of the grid setup can be viewed in figure 5.

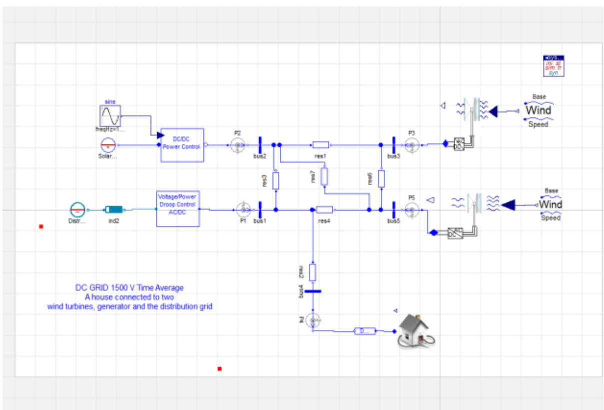

Figure 5 The grid setup for the DC grid with Smart Grid Library and Wind Power Library models connected

Requirements for the simulation are:

The voltage of the internal DC grid voltage should be kept constant when changing the load characteristics and with varying power supply. The power supplied should be consumed by the load when load is active. The residual power should be fed to the AC distribution grid. The AC distribution grid supplies power when the local generation is insufficient.

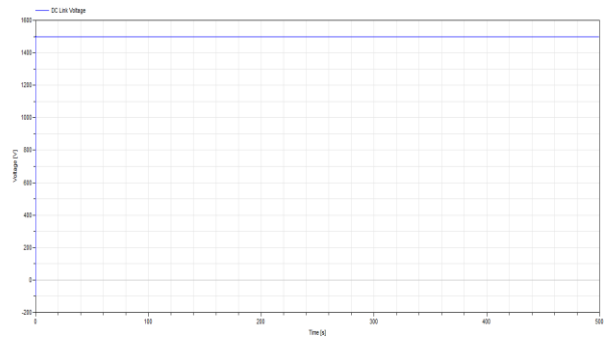

Figure 6 The voltage of the DC grid.

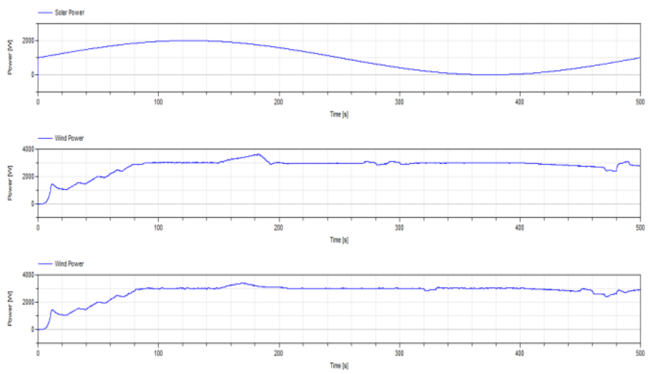

Figure 7 The power supplied by the generators, in the wind power plants and for the solar power plant

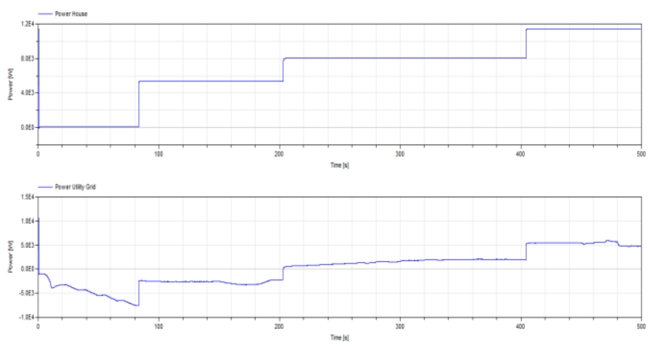

Figure 8 The power consumed by the load and the power supplied to/consumed from the AC distribution grid

Comments on the requirements:

The voltage of the DC grid is kept at 1.5 kV throughout the simulation as can be seen in figure 6. The amount of power consumed by the load is generated by the wind and solar power plants when power can be generated by these units as shown through figures 7 and 8. The excess power is fed to the AC distribution grid as can be seen in figure 8, when the power flow is negative in the upper graph. Through this figure it is also seen that the AC distribution grid supplies the remaining power consumed by the load, in this case when the power flow is positive in the upper graph in figure 8.

CONCLUSIONS

The simulation resembles a household with local energy production as mentioned before, but the inputs to the grid can be changed easily in order to resemble a completely different application. It could just as well represent a charging station of electric vehicles, where several vehicles are connected to the DC grid. Power can be drawn from the grid to charge the cars but also retrieved from the cars when needed. The internal grid of a wind power plant where many wind turbines are interconnected could also be represented in this manner. The wind turbines rotate with different speed depending on the wind. By connecting them to converters into a DC grid the wind turbines are able to rotate with different speed without affecting each other. This means that the maximum power that could be generated by the wind turbines is always supplied to the DC grid.

By modeling these converters and connecting them in DC grids, different applications can be simulated and studied.