Chapter 17
Direct-Current Devices

This chapter describes dc devices used for modelling hybrid electro-magnetic and electro-mechanical power system models. The devices included in this chapter are: dc nodes (Section 17.1), common interface equations for dc devices (Section 17.2), ideal generators (Section 17.3) and basic components such as RLC circuits (Section 17.4), dc machines (Section 17.5), and unconventional dc generators, namely solid oxide fuel cell, solar photovoltaic cell and energy battery (Section 17.6).

17.1 Direct-Current Nodes

Like ac buses, dc nodes has only a topological function. Dc nodes also serve for defining the base dc voltages $V_{dc,n}$ that are used for computing system pu values of dc devices. Table 17.1 defines all dc node parameters.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$v_0$</td>
<td>Initial voltage guess</td>
<td>pu</td>
</tr>
<tr>
<td>$V_{dc,n}$</td>
<td>Dc voltage rating</td>
<td>kV</td>
</tr>
</tbody>
</table>

17.2 Common Interface Equations for Direct-Current Devices

Each dc node introduces a new variable (i.e., the node voltage $v_{dc,h}$) and an equation (i.e., the current balance at that node). The approach used in this section and in the following Chapter 18 for modelling dc devices is the current injection model. As discussed in Chapter 9, the balance equations for the dc system are:
\[
0 = \sum_{i \in \Omega_h} i_{dc,h,i}(x_i, \hat{y}_i, v), \quad h \in \mathcal{N}
\]

where \( i_{dc,h,i} \) is the current injected at node \( h \) by device \( i \) and \( \mathcal{N} \) is the set of nodes of the dc network.

Since all devices described in this section (except for the ground element described in following Section 17.3) connect two nodes, the dc equation interfaces can be standardized in a common class. The general two-node dc device is depicted in Figure 17.1. Using the generator convention, the dc network interface equations are:

\[
0 = v_{dc,h} - v_{dc,k} - v_{dc}(x_i, \hat{y}_i)
\]

\[
i_{dc,h} = i_{dc}(x_i, \hat{y}_i)
\]

\[
i_{dc,k} = -i_{dc}(x_i, \hat{y}_i)
\]

With this simple interface, completing a device model only requires defining \( v_{dc}(x_i, \hat{y}_i) \) and \( i_{dc}(x_i, \hat{y}_i) \) along with one differential equation per each element of the internal state variables \( x_i \) and one algebraic equation per each element of the internal algebraic variables \( \hat{y}_i \).

This approach does not distinguish between series and shunt devices and allows a high grade of flexibility because the same device (i.e., same programming code) can be used both in series and shunt configurations. This is not the case of ac devices described so far. A pure inductive shunt admittance and a pure reactive transmission line are the same electrical element (i.e., a reactance), but require two different classes for being defined. The key point is that in the ac network the ground bus is implicitly used by all shunt devices. Hence, the proposed dc device modelling approach requires to explicitly define the ground dc node. The different approach used for ac and dc networks has a rationale. For ac networks, defining the ground bus does not provide a significant advantage from the implementation viewpoint since shunt and series devices are conceptually different devices with quite different functioning. On the other hand, in dc networks, most devices can be connected in series or in parallel (e.g., photovoltaic cell grids).