Controls and buses

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Controls are becoming much more prevalent as years go by. Compared to decades ago when synchronous generators dominated power networks and there was zero to little controllability, nowadays devices based on power electronics are increasing in popularity. Thus, there is a need to list all the possible controls that derive from each element. This document contains an exhaustive list of all devices and their controllable magnitudes, which are then mapped to the corresponding types of buses. It is taken into account that a power grid, as we understand it, can be composed of multiple interconnected AC and DC grids.

1 Glossary

- General:
  - δ: voltage angle.
  - V: voltage magnitude.
  - τ: transformer tap angle.
  - m: transformer tap magnitude.
  - P: active power.
  - Q: reactive power.
  - I: current magnitude.
  - f: from side of a branch, representing the AC side.
  - t: to side of a branch, representing the DC side.
- 1 magnitude:
  - P: bus with controlled P.
  - Q: bus with controlled Q.
  - V: bus with controlled V.
  - D: bus with controlled δ.
  - I: bus with controlled I.
- 2 magnitudes:
  - VD: bus with controlled V and δ.
  - PQ: bus with controlled P and Q.
  - PV: bus with controlled P and V.

  - PD: bus with controlled P and δ.
  - QV: bus with controlled Q and V.
  - QD: bus with controlled Q and δ.
  - PI: bus with controlled P and I.
  - QI: bus with controlled Q and I.
  - VI: bus with controlled V and I.
  - DI: bus with controlled δ and I.
- 3 magnitudes:
  - PVD: bus with controlled P, V and δ.
  - QVD: bus with controlled Q, V and δ.
  - VDI: bus with controlled V, δ and I.
  - PQD: bus with controlled P, Q and δ.
  - PID: bus with controlled P, I and δ.
  - QID: bus with controlled Q, I and δ.
  - PQV: bus with controlled P, Q and V.
  - PIV: bus with controlled P, I and V.
  - QIV: bus with controlled Q, I and V.
  - PQI: bus with controlled P, Q and I.
- 4 magnitudes:
  - PQVD: bus with controlled P, Q, V and δ.
  - PVDI: bus with controlled P, V, D and I.
  - QVDI: bus with controlled Q, V, D and I.
  - PQDI: bus with controlled P, Q, δ and I.
  - PQVI: bus with controlled P, Q, V and I.

2 Devices controls

This section unveils the controls associated with the most common devices found in power systems.

2.1 Load

Loads are best represented with their equivalent ZIP model as shown in Figure 1.

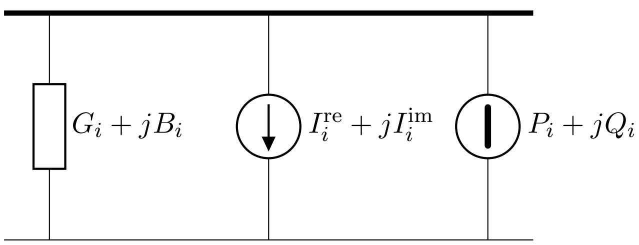

Figure 1: Representation of a load with its ZIP model.

2.2 Generator

Under GridCal, generators are classified into two categories: controlled generators and static generators. The first category corresponds to the ones that regulate the voltage and the active power, whereas the second class contains generators setting a given active and reactive power.

Figure 2 shows the scheme for a controlled generator.

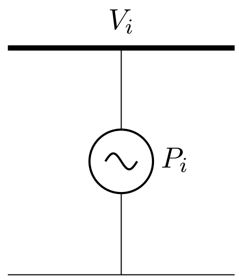

Figure 2: Representation of a controlled generator.

Figure 3 shows the scheme for a static generator.

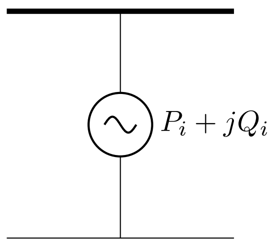

Figure 3: Representation of a static generator.

Note that generators have a capability curve that limits their range of operation. Hence, it is common practice to switch a controlled generator to a static one in case the reactive power limits are met.

2.3 Shunt converter

A shunt converter is understood as a device that links a resource (renewables, batteries, etc.) into the AC grid. Its model is captured in Figure 4.

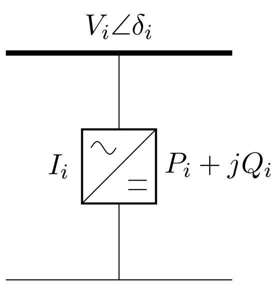

Figure 4: Representation of a shunt converter.

Seen from the AC side, a converter can control two magnitudes at a time, including the active and reactive powers, the voltage in magnitude and angle, and also operate at a set current magnitude. The operating mode determines the controlled variables.

2.4 Series converter

We define a series converter as a device of branch type, that is, a link between two buses where none of them is the ground. This kind of converter is found in HVDC links, for example. Figure 5 displays its model.

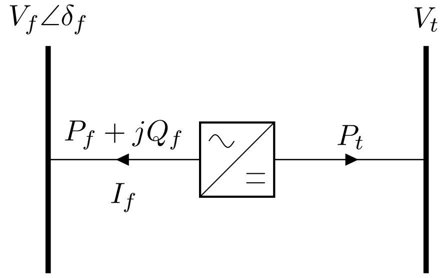

Figure 5: Representation of a series converter.

2.5 Transformer

A transformer is seen as a device where its tap is adjustable, both in terms of magnitude and phase. In a simplified way its model is shown in Figure 6.

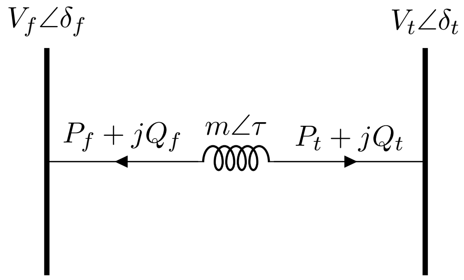

Figure 6: Representation of a transformer.

3 Fundamental rules

There are some basic rules to ensure controls are coherent:

- Each grid has to have only 1 slack bus [1]. This applies to both AC and DC grids. In AC grids the magnitude V and angle δ have to be specified, whereas in DC grids only the magnitude V.
- It is not possible to have two devices controlling the same nodal voltage. In case it happens, there has to be a dominant device that governs it and the non-dominant device must switch its state.
- Buses can have from 0 to 4 controlled magnitudes. In the most extreme case, a device connected to a given bus may be controlling two magnitudes of a nearby bus (hence one bus has zero controlled magnitudes and the other four). Controlling 5 magnitudes is deemed impossible.

4 Combinations

4.1 Load

Table 1: Load specified magnitudes and resulting bus types.

Controlled	**Bus type**	**Description**
P, Q	PQ	Regular load forcing a PQ bus at its node

[1] The only exception being distributed slacks, which are simply slack buses with coordination rules.

4.2 Generator

It is worth mentioning that a generator can be controlled in two different ways: by setting the voltage and active power, or by specifying the active and reactive power. Generators operate in this last mode if reactive powers are met or if it is a static generator. The controlled magnitudes can be specified in remote buses, not necessarily the one where the generator is connected to.

Table 2: Generator specified magnitudes and resulting bus types.

Controlled	Bus type	Description
P, V	PV	Typical PV bus
P, Q	PQ	PQ bus for static generators or if reactive limits are met

4.3 Shunt converter

The absolute value of the current I is set to the device, that is, it cannot be associated to a remote bus. The rest of the magnitudes can be linked to a bus where the converter is not directly connected.

Table 3: Shunt converter specified magnitudes and resulting bus types.

Controlled	Bus type	Description
P, Q	PQ	Unsaturated PQ converter
P, V	PV	Unsaturated PV converter
Q, I	QI	Partially saturated PQ converter
P, I	PI	Fully saturated PQ converter
V, I	VI	Partially saturated PV converter
V, D	VD	Unsaturated grid-forming converter
D, I	DI	Saturated grid-forming converter

4.4 Series converter

The absolute value of the current I is set to the device, that is, it cannot be associated to a remote bus. The rest of the magnitudes can be linked to a bus where the converter is not directly connected.

Table 4: Series converter specified magnitudes and resulting bus types.

Controlled	Description
P_f, P_t	Active power controlled on the AC and DC side
Q_f, P_t	Reactive power controlled on the AC and DC side
V_f, P_t	Voltage magnitude on the AC and active power on the DC side
δ_f, P_t	Voltage angle controlled on the AC and active power on the DC side
P_f, V_t	Active power controlled on the AC and voltage on the DC side
Q_f, V_t	Reactive power controlled on the AC and voltage on the DC side
V_f, V_t	Voltage magnitude controlled on the AC and DC side
δ_f, V_t	Voltage angle controlled on the AC and voltage DC side
I_f, P_t	Maximum current on the AC and active power on the DC side
I_f, V_t	Maximum current on the AC and voltage on the DC side

4.5 Transformer

The values of m and τ are set to the device, that is, they cannot be associated to a remote bus. The rest of the magnitudes can be linked to a bus where the transformer is not directly connected. In this sense, the transformer parameters are adjusted to control the voltage and power flow in the AC and DC sides.

Table 5: Transformer specified magnitudes and resulting bus types.

Controlled	Description
P_f, P_t	Active power controlled on the from and to sides
Q_f, P_t	Reactive power controlled on the from and to sides
V_f, P_t	Voltage magnitude on the from and active power on the to side
δ_f, P_t	Voltage angle controlled on the from and active power on the to side
P_f, Q_t	Active power controlled on the from and reactive power on the to side
Q_f, Q_t	Reactive power controlled on the from and to sides
V_f, Q_t	Voltage magnitude on the from and reactive power on the to side
δ_f, Q_t	Voltage angle controlled on the from and reactive power on the to side
P_f, V_t	Active power controlled on the from and voltage on the to side
Q_f, V_t	Reactive power controlled on the from and voltage on the to side
V_f, V_t	Voltage magnitude controlled on the from and to sides
δ_f, V_t	Voltage angle controlled on the from and voltage on the to side
P_f, δ_t	Active power controlled on the from and voltage angle on the to side
Q_f, δ_t	Reactive power controlled on the from and voltage angle on the to side
V_f, δ_t	Voltage magnitude on the from and voltage angle on the to side
δ_f, δ_t	Voltage angle controlled on the from and to sides
P_f	Active power controlled on the from side
Q_f	Reactive power controlled on the from side
V_f	Voltage magnitude controlled on the from side
δ_f	Voltage angle controlled on the from side
P_t	Active power controlled on the to side
Q_t	Reactive power controlled on the to side
V_t	Voltage magnitude controlled on the to side
δ_t	Voltage angle controlled on the to side

(Think about controlling nodal vs branch magnitudes, as here we are controlling branch magnitudes)

5 Switching rules

6 Bibliography