Load-Flow Bus

Slack: 13.8kVRMSLL/_0
LF ● —
LF1

P=480MW
Q=480MVAR
LF ● —
LF2

P=480MW
V=13.8kVRMSLL
LF ● —
LF3

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1   Available versions

This device models a 3-phase load-flow bus constraint. The available constraint (bus) types are Slack-bus, PQ-control and PV-control.

These devices are also called Load-Flow (LF) devices. Each LF-device representing a constraint on a bus is modeled as an ideal positive sequence source behind a Thevenin impedance matrix.

1.1   Common impedance data

The three bus types have a common data section for the internal Thevenin impedance matrix.

❑ Source impedance R: The resistive (real) part of the Thevenin impedance. It can be entered using sequence data or actual matrix.

❑ Source impedance L: The inductive (imaginary) part of the Thevenin impedance. It can be entered using sequence data or actual matrix.

The actual impedance matrix is given by:

$$\mathbf{Z} = \mathbf{R} + j\omega\mathbf{L}$$

The power variant Fortescue transformation matrix is used in EMTP to calculate the full matrices from sequence components.

The LF-devices can also retrieve impedance data from referenced non-load-flow devices. A non-load-flow source device is usually a device that is initialized using the load-flow solution from the adjacent LF-device. A non-load-flow source device does not participate in the Load-Flow solution, but can provide its impedance data for simplifying the network creation task. In the example of Figure 1-1, the V_BUS6 "V with Impedance" device is a source that does not participate in the Load-Flow solution. The SM_BUS6 LF-device is set to retrieve its impedance data from V_BUS6. The part name of V_BUS6 is "Vsine_z".
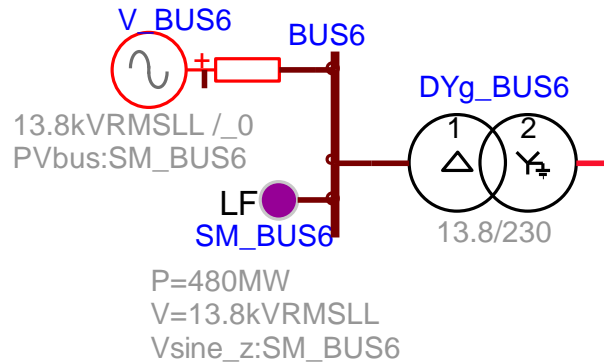
Figure 1-1 Example of adjacent (paired) LF-device and non-LF-device

In the case above the impedance data link is readily available in EMTPWorks. Changing the impedance data of V_BUS6 will automatically change the impedance data of SM_BUS6.

It is also feasible to extract data from a synchronous machine, as shown in Figure 1-2. In this case the machine impedance at 60Hz is internally calculated by EMTP and sent to LF-device SM_BUS8.
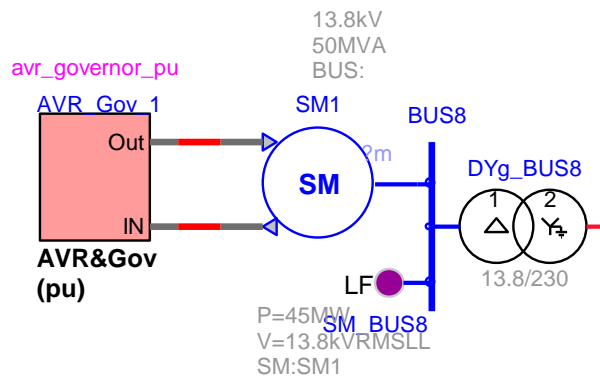

Figure 1-2 Example of adjacent LF-device and synchronous machine

LF-devices can refer to non-LF-devices for impedance data and non-LF-devices (sources) can refer to LF-devices for retrieving the load-flow solution data after load-flow convergence. These features are also documented in the Load-Flow option Help section.

1.2 Slack bus data

This bus represents a 3-phase slack source.
The data forms of this type of constraint are given in Figure 1-1. The parameters are:
- ❑ Frequency: this is the frequency at which this device data is calculated. This includes sources and conversion of inductance data when specified in ohms.
- ❑ Controlled voltage: Specified positive sequence voltage amplitude at the LF-device terminals (the bus where the device is connected). Units are provided for convenience and used for internally converting to peak line-to-ground volts.
- ❑ Controlled phase: Specified positive sequence voltage (node-to-ground) phase at the LF-device terminals.
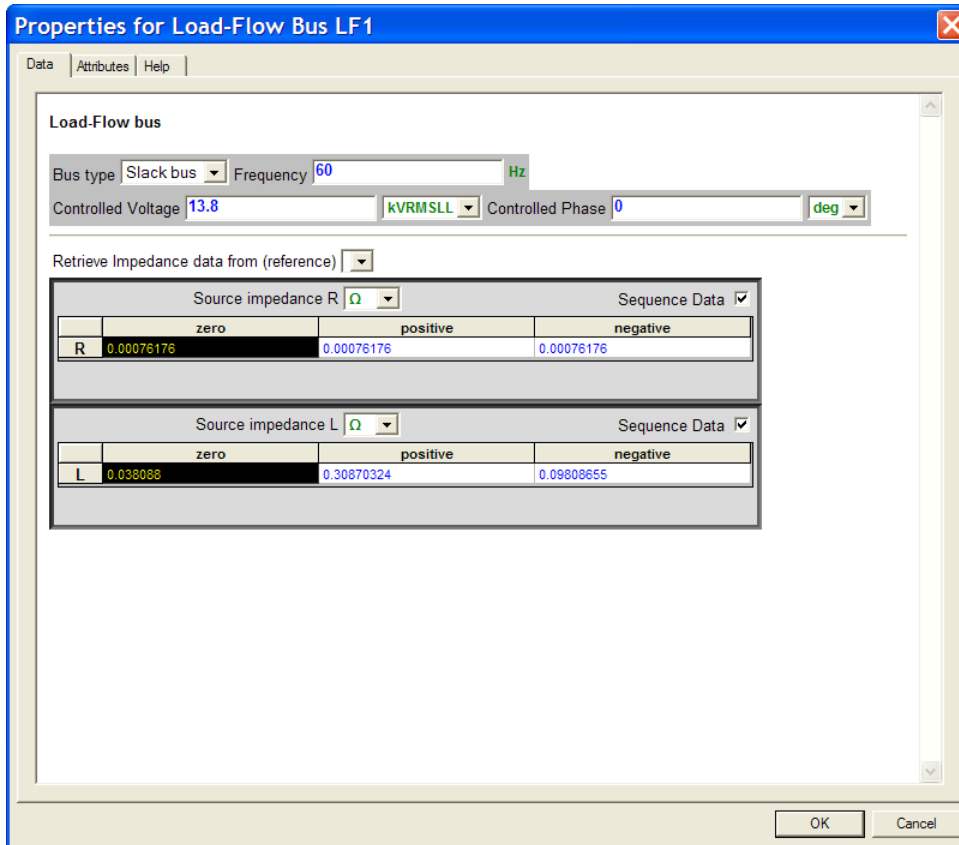
Figure 1-3 Data for Slack-bus

1.3 PQ-control data

This device is used to establish PQ (active and reactive power) constraints.

The data forms of this type of bus are shown in Figure 1-4. The parameters are:

- ❑ Frequency: this is the frequency at which this device data is calculated. This includes sources and conversion of inductance data when specified in ohms.
- ❑ Voltage: Predicted line-to-ground positive sequence voltage amplitude at the LF-device terminals (the bus where the device is connected). Units are provided for convenience and used for internally converting to peak line-to-ground volts. This voltage is used for initialization.
- ❑ Phase: Predicted positive sequence voltage (node-to-ground) phase at the LF-device terminals.
- ❑ P: Controlled active power.
- ❑ Q: Controlled reactive power.

This device can restart from a previous Load-Flow solution. This option is available if a previously saved Load-Flow solution exists and the "Start from Load-Flow solution" option is selected in EMTP>Simulation Options. Restarting a Load-Flow solution from a previously saved Load-Flow solution can help to decrease the number of iterations. Only when "Retrieve Load-Flow solution data" is on, EMTP automatically looks into the previously found solution and starts from the calculated voltage phasor (Voltage and Phase).

The "Load now" is available for showing the previously calculated voltage phasor (Voltage and Phase fields).
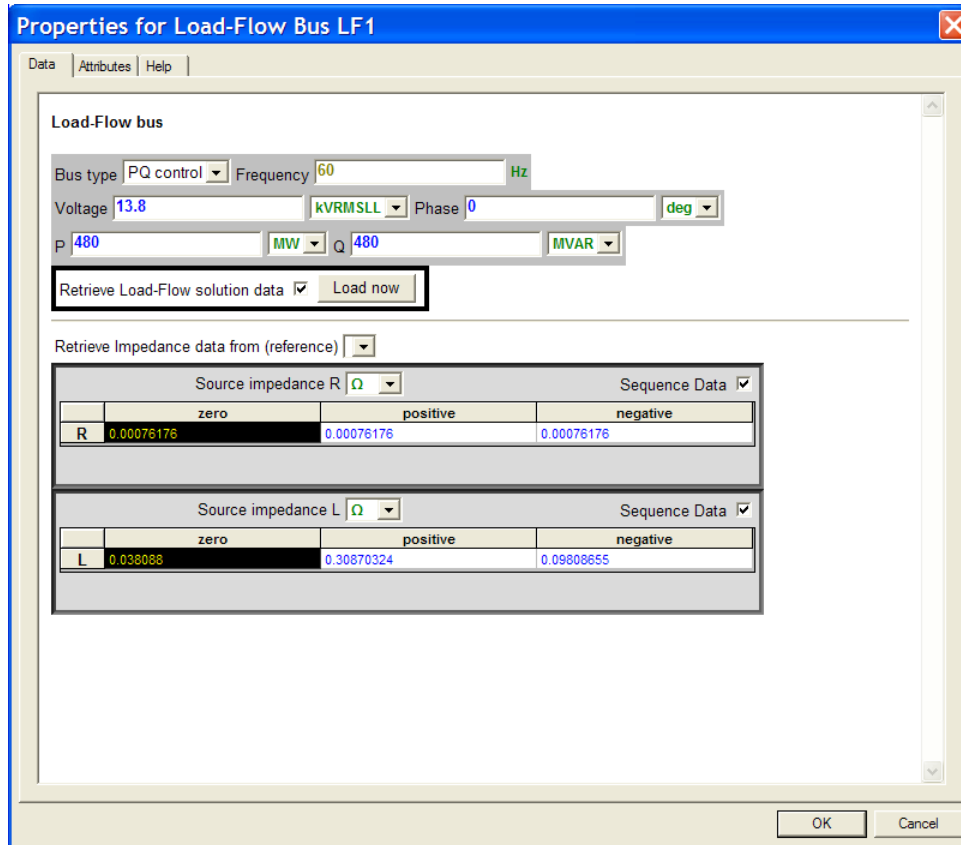
Figure 1-4 Data for PQ-control bus

1.4 PV-control data

This device allows specifying PV (power and voltage) control.
The data input for this selection is shown in Figure 1-5. The parameters are:

- ❑ Frequency: this is the frequency at which this device data is calculated. This includes sources and conversion of inductance data when specified in ohms.
- ❑ Controlled voltage: Specified voltage amplitude at the LF-device terminals (the bus where the device is connected). Units are provided for convenience and used for internally converting to peak line-to-ground volts.
- ❑ Phase: Predicted positive sequence voltage (node-to-ground) phase at the LF-device terminals.
- ❑ Control type: The default setting is "Phase-a-to-ground Voltage", "Phase-to-ground Voltage, remote control" and "Phase-to-phase Voltage, remote control".
- ❑ P: Controlled active power.
- ❑ Q_{min}: Lower reactive power generation limit.
- ❑ Q_{max}: Upper reactive power generation limit.

When the Control type is "Phase-to-ground Voltage, remote control" or "Phase-to-phase Voltage, remote control", then it is needed to enter a guess voltage for the voltage (Voltage and Phase) at the bus terminals and the "Controlled Remote Voltage" on remote nodes. Units are again available for convenience and used for converting to line-to-ground peak volts. This is also true in the phase-to-phase control case, where the found "line-to-ground" voltage is applied between the controlled nodes.
The "Remote k-node" is enabled to allow entering the remote node name. The "Remote m-node" is enabled for the phase-to-phase case only. Only signal names from the current circuit level are accepted.
It must be recalled that 3-phase signals are internally split into 3 separate signals by concatenating the phase characters. If, for example, it is needed to control the (3-phase) BUSX phase-b voltage, then the entered "Remote k-node" name must be BUSXb.

If an entered name is not found in the current circuit, then EMTP creates a dummy new node. This condition will result into warning about floating network nodes and will not allow the Load-Flow solution to converge.
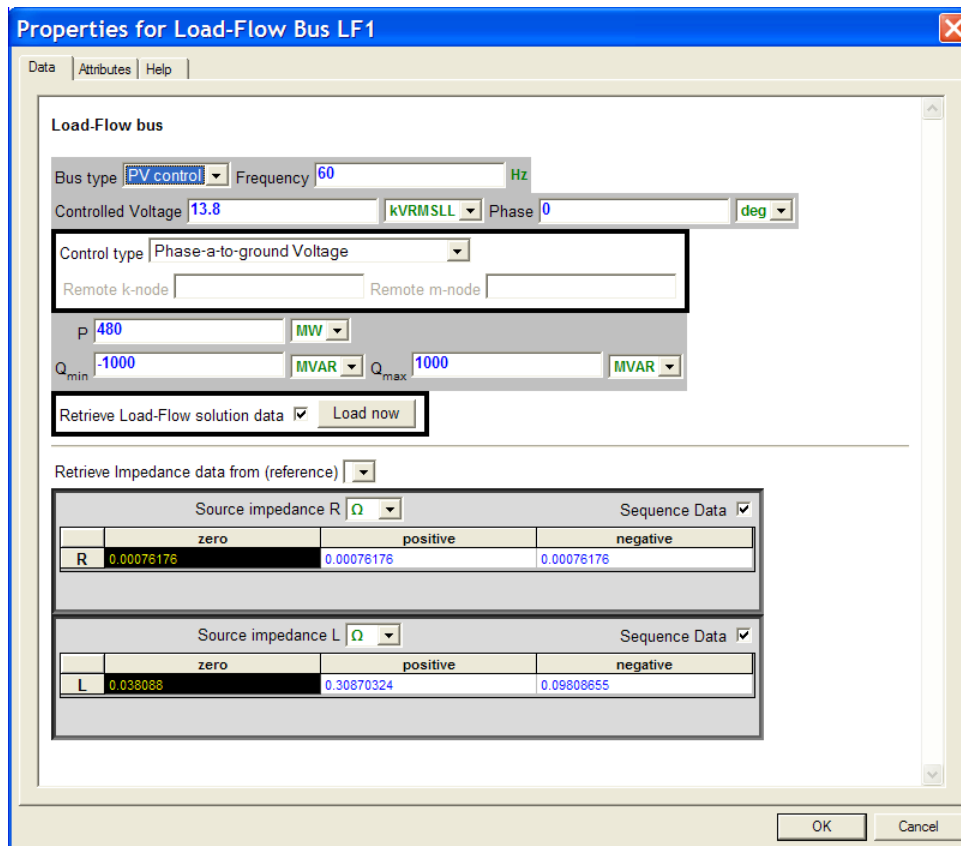
Figure 1-5 Data for PV-control bus

The reactive power limits in this device are dealt with using 2 iterative loops. The first iterative Load-Flow solution loop does not enforce limits and just tries to converge. The second iterative loop starts only if the first one is successful and enforces the limits.

2   Rules and limitations

If an LF-device is disconnected (floating) then the Load-Flow solution will not converge since it becomes impossible to enforce the specified constraints.
Physically unacceptable constraints can also cause Load-Flow solution divergence.
In most cases it is acceptable specifying the voltage guess phasor amplitude as the nominal bus voltage. The predicted phase can be set to zero if no other data is available. In some cases, incorrect predictions may cause divergence or an increased number of iterations.

3   Netlist format

This device allows method-based scripting. The object data and methods are described in the script file referenced by the device Script.Open.Dev attribute.

A Netlist example for a Slack bus is given by:

```
_Slack;LF1a;3;1;s23a,
60,13.8kVRMSLL,0,1,1,1Ohm,1,,
_Slack;LF1b;3;1;s23b,
_Slack;LF1c;3;1;s23c,
0.00076176 0.00076176 0.00076176
0.038088 0.30870324 0.09808655
```

Field	Description
Slack	Part name
LF1a	Phase a name
3	Total number of pins.
1	Number of pins on this data line
s23a	Phase-a node name
60	frequency
13.8kVRMSLL	Voltage amplitude
0	Voltage phase
1	Resistance units
1	Sequence data when 1
1Ohm	Inductance units
1	Sequence data when 1
Reference	Referenced device for impedance data
Phase b name and node line	
Phase c name and node line	
Resistance matrix data	Only one line when sequence data, 3 lines when matrix
Inductance matrix data	Only one line when sequence data, 3 lines when matrix

Comma separated data fields are saved in ParamsA device attribute. ModelData attribute is used for storing matrix data lines.

A Netlist example for a PQ-control bus is given by:

```
_PQbus;LF1a;3;1;s23a,
60,13.8kVRMSLL,0,1,480MW,480MVAR,1,1,1Ohm,1,,
_PQbus;LF1b;3;1;s23b,
_PQbus;LF1c;3;1;s23c,
0.00076176 0.00076176 0.00076176
0.038088 0.30870324 0.09808655
```

Field	Description
PQbus	Part name
LF1a	Phase a name
3	Total number of pins.
1	Number of pins on this data line
s23a	Phase-a node name
60	frequency
13.8kVRMSLL	Voltage amplitude
0	Voltage phase

1	Retrieve Load-Flow solution data when 1
480MW	Active Power specification
480MVAR	Reactive Power specification
1	Resistance units
1	Sequence data when 1
1Ohm	Inductance units
1	Sequence data when 1
Reference	Referenced device for impedance data
Phase b name and node line	
Phase c name and node line	
Resistance matrix data	Only one line when sequence data, 3 lines when matrix
Inductance matrix data	Only one line when sequence data, 3 lines when matrix

A Netlist example for PV-control bus is given by:

```
_PVbus;LF1a;3;1;s23a,
60,13.8kVRMSLL,0,1,3,13.8kVRMSLL,knode,mnode,480MW,-1000MVAR,1000MVAR,1,1,1Ohm,1,,
_PVbus;LF1b;3;1;s23b,
_PVbus;LF1c;3;1;s23c,
0.00076176 0.00076176 0.00076176
0.038088 0.30870324 0.09808655
```

Field	Description
PVbus	Part name
LF1a	Phase a name
3	Total number of pins.
1	Number of pins on this data line
s23a	Phase-a node name
60	frequency
13.8kVRMSLL	Voltage amplitude
0	Voltage phase
1	Retrieve Load-Flow solution data when 1
3	Control type: 1, 2 or 3
13.8kVRMSLL	Remote voltage, only when Control type 2 or 3
knode	Controlled k-node name
mnode	Controlled m-node name
480MW	Controlled power
-1000MVAR	Reactive power lower limit
1000MVAR	Reactive power upper limit
1	Resistance units
1	Sequence data when 1
1Ohm	Inductance units
1	Sequence data when 1
Reference	Referenced device for impedance data
Phase b name and node line	
Phase c name and node line	
Resistance matrix data	Only one line when sequence data, 3 lines when matrix
Inductance matrix data	Only one line when sequence data, 3 lines when matrix

4   Load-flow model

This device provides its Thevenin source equivalent and constraint equations to the Load-Flow solution matrix. It exists only in the Load-Flow solution and becomes automatically disabled for all other solution options.