

Load-Flow options

ON



Load-Flow options.....	1
1 Description	1
1.1 First step: Load-Flow solution	2
1.2 Convergence control	3
1.3 What to do when convergence fails	4
1.4 Multiple frequencies.....	4
1.5 Data loading options.....	4
1.6 Load now.....	7
1.7 Load-Flow solution data file.....	7
1.8 Device Load-Flow data file	7
2 Netlist format.....	8
3 Example.....	8

Jean Mahseredjian, 10/15/2014 3:15:00 PM

1 Description

This device is used to setup Load-Flow solution options.

The EMTP Load-Flow solution is fully integrated to transparently coexist with standard EMTP solution modules. The user can create a new design or take an existing design and add load-flow constraints. Load-flow constraints (LF-devices) are created using the “Load-Flow Bus” device found in the sources.clf library. Each source type LF-device representing a constraint on a bus is modeled as an ideal positive sequence source behind a Thevenin impedance matrix. One more LF-device named “PQ load” is found in the “RLC branches.clf” library.

The currently available load-flow constraints are Slack bus, PQ-control, PQ-load and PV-control.

The source type LF-devices inserted using the “Load-Flow Bus”, exist only in the Load-Flow solution. The “PQ load” is currently the only device that is enabled in all solution options.

EMTP allows running a Load-Flow solution and then automatically loading all required data into the receiving devices for subsequent Steady-state and/or Time-domain simulations. These are the possible simulation steps (data saving/loading and initialization steps are automatic):

1. Find Load-Flow solution using LF-devices and passive network devices.
2. Save Load-Flow solution data for all LF-devices: creation of “Load-Flow solution data file”
3. Save extra computed initialization data for some non-LF-devices: creation of “Device Load-Flow data file”
4. Create Load-Flow web for presenting results.

5. User restarts EMTP after unchecking the Load-Flow solution in “Design>Advanced>Simulation Options” and selecting Steady-state solution.
6. Start Steady-state solution.
7. Load previously created “Load-Flow solution data file” and “Device Load-Flow data file”.
8. Initialize active devices and machines from the Load-Flow solution.
9. Find Steady-state solution.
10. Initialize all state variables.
11. Move into Time-domain solution.

Most of the above steps are automatic.

1.1 First step: Load-Flow solution

In EMTP the Load-Flow solution is another type of steady-state solution. The main difference is that the Load-Flow solution allows entering power constraints directly without providing lumped circuit models for some generation and load devices. The lumped circuit models can be used in the standard Steady-state solution option and initialized from the Load-Flow solution. The only difference between Load-Flow and Steady-state solution circuits is in the participation of LF-devices and standard source devices. LF-devices go into the Load-Flow solution and standard (non-LF-devices) source devices become active only in the subsequent Steady-state and/or Time-domain solutions. It is also possible to follow with a “Frequency scan” simulation which is initialized the same way as the Steady-state simulation.

Control systems are disabled in Load-Flow solutions.

The ultimate goal of finding a steady-state operating point is to correctly initialize the time-domain simulation. This is specially true when synchronous machines are used. Due to Steady-state circuit correspondence with time-domain circuit, the Steady-state solution is used for initializing the Time-domain solution. Initializing the state variables for starting the Time-domain simulation will minimize startup transients and thrust to achieve steady-state operating conditions within the first simulation cycle.

The Load-Flow solution can be selected in the Load-Flow options device (see Figure 1-1) or in “Design>Advanced>Simulation Options” shown in Figure 1-2. Only one Load-Flow options device can exist in a given design. It must appear at the top level circuit.

Extra Load-Flow solution parameters are only available through the data panel of Figure 1-1.

In the current EMTP version, the Load-Flow solution is performed at one frequency. This frequency can be specified in Figure 1-2 as the “Default Power Frequency”. This frequency is used for building the passive network equations. Future EMTP versions will allow finding a harmonic load-flow solution.

The “Save Load-Flow solution” is normally turned on to request the creation of “Load-Flow solution data file” and “Device Load-Flow data file”.

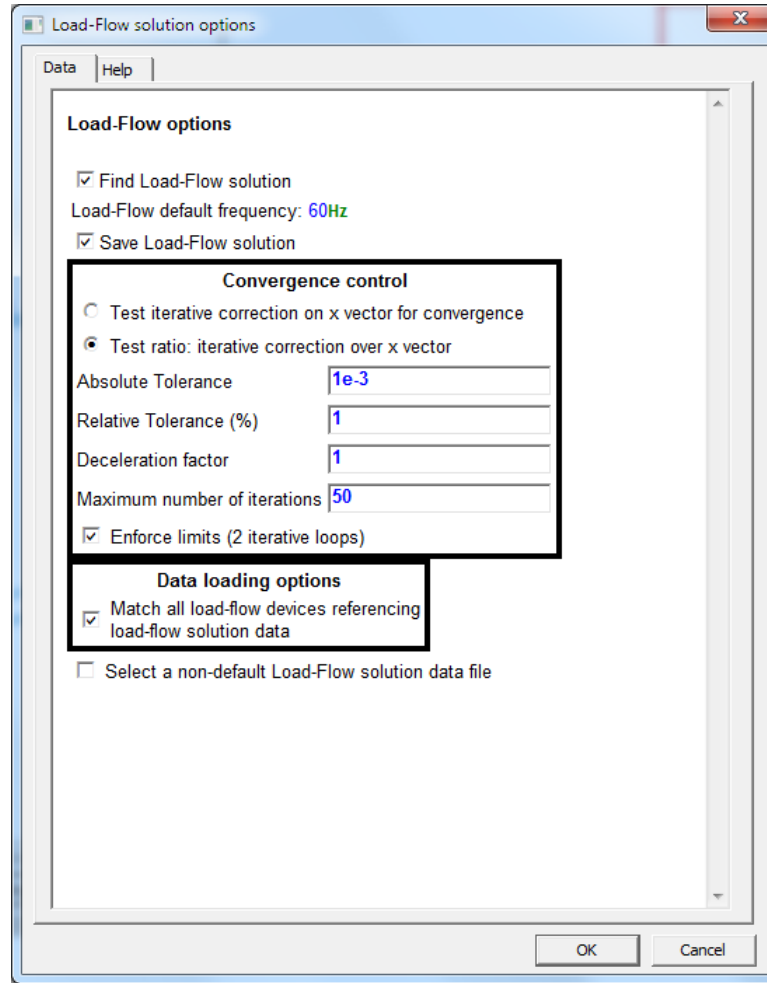


Figure 1-1 Load-Flow options for the Load-Flow solution

1.2 Convergence control

The Load-Flow solver uses an iterative Newton method for solving its system of equations:

$$\mathbf{f}(\mathbf{x}^{(k)}) + \mathbf{J}^{(k)}\Delta\mathbf{x}^{(k)} = \mathbf{0} \quad (1)$$

The solution vector \mathbf{x} will make $\mathbf{f}(\mathbf{x}) = \mathbf{0}$. In equation (1) k is the iteration counter, \mathbf{J} is the Jacobian and $\Delta\mathbf{x}$ is the correction (update) on \mathbf{x} during iterations. The vector of unknowns for the following iteration is found from:

$$\mathbf{x}^{(k+1)} = \mathbf{x}^{(k)} + \Delta\mathbf{x}^{(k)} \quad (2)$$

Two options are available in Figure 1-1 for testing convergence. In the first test “Test iterative correction on x vector”, convergence is achieved when the maximum value of $|\Delta\mathbf{x}|$ or the maximum value of $|\mathbf{f}(\mathbf{x}^{(k+1)})|$ is equal to zero within the specified tolerance.

In the second test “Test ratio: iterative correction over x vector”, the convergence criteria is given by:

$$\max \left(\frac{|\Delta\mathbf{x}^{(k)}|}{|\mathbf{x}^{(k+1)}|} \right) \leq \varepsilon$$

In this case a percentage tolerance ε is used. This test may be used in some non-converging cases where the first test fails, but the network variables are very close to the final solution.

The deceleration factor is used in some problematic cases and may help to achieve convergence. It is multiplied by $\Delta\mathbf{x}^{(k)}$ in equation (2). Typical values are 0.8 and 0.9. The default value of 1 should be used if there are no convergence problems.

When an LF-device has specified limits, such as the PV bus (PV-control) reactive power limits, then the Load-Flow solver uses two iterative loops. In the first loop limits are not enforced. When the first loop converges and at least one limit has been exceeded, EMTP starts a second iterative loop where limits are now enforced. This loop can be optionally turned off in Figure 1-1.

1.3 What to do when convergence fails

A convergence failure is not necessarily a critical problem. It can be assessed by checking the power balance data displayed at the end of the Load-Flow web. The Load-Flow web is available through a button at the completion of the Load-Flow solution and can be also opened using the “Show Load-Flow web” device located in the “options.clf” library.

The power balance is the power mismatch given in watts and Vars. Generation minus loads and minus transmission losses should normally be close to zero. In some cases convergence may fail for the given tolerance, but the power balance may be sufficiently small to provide almost steady-state phasors.

The power balance numbers must be placed in context. When the network is dealing with mega-watts and mega-VARs then power balance values below 10 or even 100 are acceptable.

Ideally the power balance should be zero, but due to numerical conditions and convergence criteria, perfect zero is almost impossible to achieve.

Power balance can be further reduced by decreasing the tolerances discussed in the previous section. Requesting very small tolerances may reduce the power balance, but may also cause a non-convergence message.

When convergence fails and the power balance is unacceptable, then the following measures can be taken to help convergence:

- Increase convergence tolerance.
- Change convergence testing method (see previous section).
- Use a “Deceleration factor” smaller than one (0.8 or 0.9).
- Increase the “Maximum number of iterations”.
- Cancel “Enforce limits” to check if it is the source of problems.

If none of the above is helpful then one of the following conditions might exist in the solved network:

- Floating (disconnected) LF-devices.
- Physically impossible load-flow constraints: wrong data in LF-devices.
- Contradictory PV-control settings on a given bus.
- Wrong PV-control data in relation to surrounding transformer ratios.
- Floating network conditions caused by poor grounding or floating delta windings.
- Special configurations of 3-winding transformers that cause numerical conditioning problems.

1.4 Multiple frequencies

EMTP is capable of solving the load-flow of a network with several slack buses. If the networks includes sources (Load-Flow constraints) with different frequencies, EMTP will find the solution without testing for discrepancies in frequencies. It is the user’s responsibility to ensure that networks with different fundamental frequencies are disconnected (independent) or interconnected through HVDC transmission.

1.5 Data loading options

A Load-Flow solution can be restarted from a previous Load-Flow solution by selecting “Start from Load-Flow solution” in Figure 1-2. In this case LF-devices must search the previously saved “Load-Flow solution data file” and retrieve voltage (phasor) solutions when applicable. Devices are matched by name. If a new device is added to the design, then its data will not be available and EMTP will stop with an error message if “Match all

load-flow devices referencing ...” is turned on in Figure 1-1. It will otherwise find only available devices and start the Load-Flow solution.

The default file name setting for previously saved Load-Flow solution is based on the design file name and found in the project folder of the simulation case. It is also possible to use the checkbox option of Figure 1-1 (Select a non-default Load-Flow solution data file) to specify a different location and file name. This option is useful when the user wants to avoid resolving the Load-Flow when using a design copy found in a different folder.

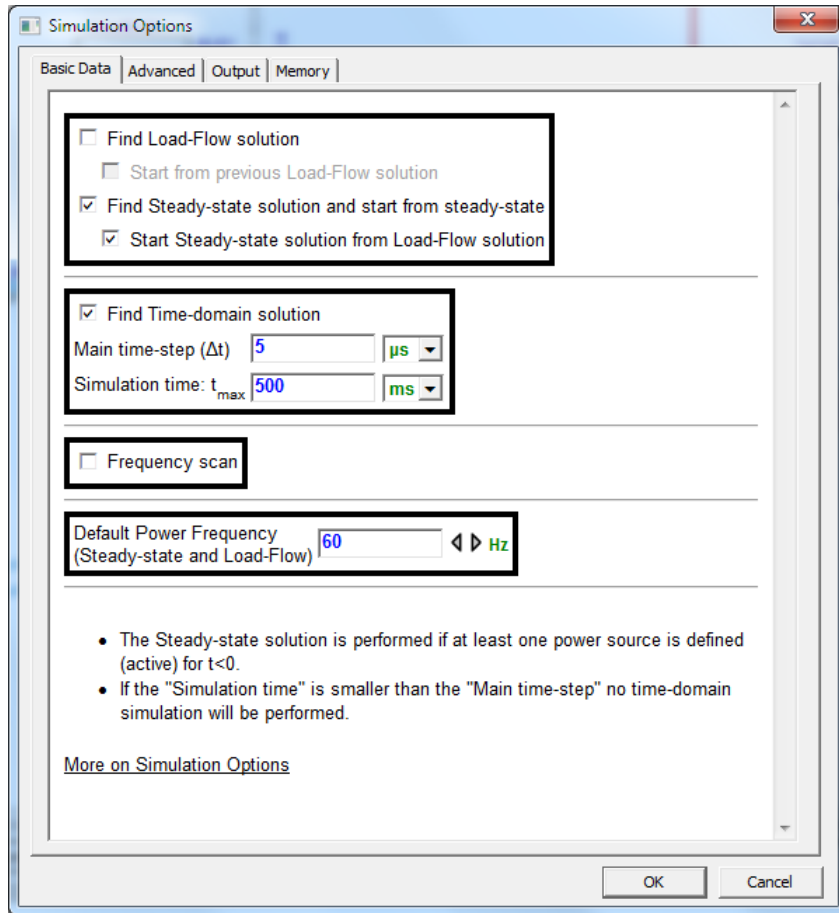


Figure 1-2 Selecting the Load-Flow solution option from Design>Advanced>Simulation Options

Other “Data loading options” are available when moving from Load-Flow to another simulation method, Steady-state, for example. These options are shown in Figure 1-3.

Each LF-device can be paired with a source type or machine device for carrying the Load-Flow solution into the Steady-state solution.

In Figure 1-4 V_BUS6 is paired with SM_BUS6. V_BUS6 points (“Load-Flow solution device” field) to SM_BUS6. V_BUS6 searches the “Load-Flow solution data file” to match the name SM_BUS6 and retrieves its voltage phasors behind the Thevenin impedance. A dropdown menu “Load-Flow solution device” in V_BUS6 data forms is listing a blank string followed only by the LF-devices attached to its terminals.

V_BUS6 is also called the *parent* or *caller* of SM_BUS6. V_BUS6 is a *non-LF-device*.

The following matching options are available in Figure 1-4:

- ❑ Single match for load-flow device: This option is used to avoid errors when more than one standard network device is pointing to a given LF-device attached to a bus.

- ❑ Match Load-Flow device by caller device name if no other selection: A caller (parent) device will be matched to a load-flow device using its name if there is no other selection on the parent device data forms. This option is not applicable for some devices, such as the "asynchronous machine". In the example of Figure 1-4 the name V_BUS6 can be changed to SM_BUS6 and its "Load-Flow solution device" dropdown must point to a blank string. Although this option is less straightforward and therefore not recommended, it can become useful when the parent device needs to refer to an LF-device not attached to its bus.
- ❑ Match all devices referencing Load-Flow solution data: All non-LF-devices pointing to LF-devices must be able to find their match in the "Load-Flow solution data file". If this option is not checked, then no error messages are sent when there is no match and the caller device uses the phasor data manually entered in its data forms.

The above data loading options are useful when after finding a Load-Flow solution the following network topology is modified by adding or deleting LF and non-LF devices.

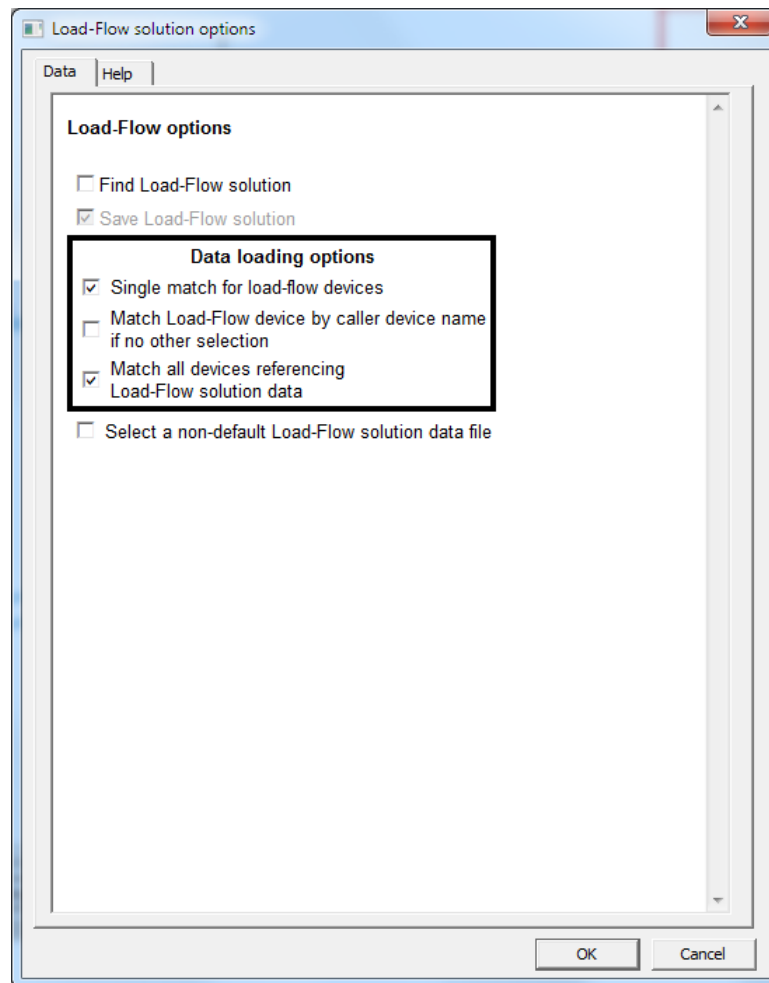


Figure 1-3 Load-Flow options for automatic data loading into Steady-state or Time-domain solutions

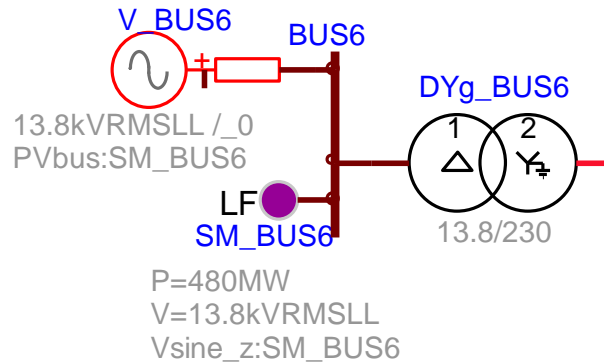


Figure 1-4 Example of adjacent (paired) LF-device and non-LF-device

It is noticed that the parent devices are not required if the purpose is only to perform a Load-Flow solution without following it by standard EMTP simulations such as Steady-state and Time-domain.

1.6 Load now

Starting from a Load-Flow solution is automatically available when a “Load-Flow solution data file” exists, but the user may also choose to discard all LF-devices and start to maintain a design correctly initialized from a previous Load-Flow solution. This is achieved by simply using the “Load now” button in all parent devices and unchecking “Start from Load-Flow solution” in “Design>Advanced>Simulation Options”.

A global function available in the Design menu “Load Load-Flow solution data” can be used to load data for all devices shown in the current circuit level.

1.7 Load-Flow solution data file

This file is created at the end of the Load-Flow solution and located in the design project directory. For a given design named *mydesign.ecf* the produced file is *mydesign_lf.dat*. This is an ASCII file. Needed by EMTP when the “Start from Load-Flow solution” option is selected. Also used to load data into data forms in EMTPWorks when the “Load now” button is pushed.

An example of data content is given by:

```
_Slack Slack BUS10
3 +0.600000000000000E+02
+0.408377645192924E+06 +0.129568203625190E+02 +0.352285887355360E+03 -0.83110777409764E+02 +0.408248290463917E+06 +0.129600000000066E+02
+0.408377645192924E+06 -0.107043179637481E+03 +0.352285887359329E+03 +0.156889222259447E+03 +0.408248290463789E+06 -0.107039999999997E+03
+0.408377645192924E+06 +0.132956820362519E+03 +0.352285887331842E+03 +0.368892222572078E+02 +0.408248290463883E+06 +0.132959999999990E+03
```

The first line identifies the LF-device by giving its Part name, followed by its instance name and then the 3-phase node name to which the device is connected.

It is noticed that identification includes the device name and Part name. If a Slack-bus is changed into a PV-bus (PV-control) it cannot be matched if the case is rerun using existing Load-Flow solution data file.

The second line provides the number of phases and the frequency of the device.

The following 3 lines provide the phasors E, I and V. E is the positive sequence voltage source behind the Thevenin impedance, I is the current flowing from the source and V is the voltage at device terminals. Each phasor is listed by its amplitude (node-to-ground for voltages) and angle in degrees.

1.8 Device Load-Flow data file

This file is created at the end of the Load-Flow solution by devices that need to perform specific initialization data computations using Load-Flow solution phasors. For a given design *mydesign.ecf* the produced file is *mydesign_dev_lf.dat*. This is an ASCII file. Needed by EMTP when the “Start from Load-Flow solution” option is selected. Also used to load data into some device data forms in EMTPWorks when the “Load now” button is pushed.

An example of data content is given by:

```
_ASM ASM1 BUS3
3 +0.6000000000000000E+02
+0.531290099744659E+04 -0.204842484464201E+02 +0.348522567716318E+03 +0.770576723924561E+02
+0.531290099744822E+04 -0.140484248446428E+03 +0.348522567716425E+03 -0.429423276075514E+02
+0.531290099744807E+04 +0.995157515535730E+02 +0.348522567716415E+03 -0.162942327607551E+03
+0.5500000000000000E-02
```

The first line identifies the device by giving its Part name, followed by its instance name and then the node name to which the device is connected. In this case the asynchronous machine ASM1 is performing and saving computations at the end of the Load-Flow solution. The second line gives the number of phases followed by frequency.

The following 3 lines provide the phasors V and I. V is the terminal voltage and I is the current flowing into the machine terminal bus. Each phasor is listed by its amplitude (node-to-ground for voltages) and angle in degrees.

2 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.

The ModelData attribute is used for saving data for this device. Only non-default data is saved.

3 Example

This example file is available in the list of examples given through the Example menu (Load-Flow example). The design name is [network230LFM.ecf](#).

A complete circuit diagram is shown in Figure 3-1. The network is composed of 6 source type LF-devices: 5 PV-control buses and 1 Slack bus. These devices are found in the machine subnetworks and in 500 kV subnetwork. The Slack source (500 kV) actually represents power exchange with another network. There are also 5 PQ loads: 2 are 3-phase and 3 are 1-phase. The 1-phase loads connected to BUS13 are used to create an unbalanced load condition. The network is also unbalanced due to the presence of untransposed transmission lines.

Since after running the Load-Flow it is needed to study transients, the existing source type LF-devices are paired with 5 synchronous machines. The Slack bus is paired with a Thevenin equivalent source.

On BUS8, for example, the load-flow device SM_BUS8 is retrieving impedance data from the synchronous machine SM8. This is marked by "SM:SM8". It is paired with the synchronous machine SM8 which is pointing to SM_BUS8 (marked by "PVbus:SM_BUS8") for retrieving its load-flow solution phasors for the subsequent Steady-state solution.

It is optionally possible to select the "Load-Flow solution device" name "BUS:" in the machine dropdown menu. This option means that when retrieving data from the "Load-Flow solution data file", the machine will match the LF-device attached to its bus (3-phase power signal).

The Load-Flow solution is run first by selecting it in the "Design>Advanced>Simulation Options" or through the Load-Flow options device. It is also needed to check "Save Load-Flow solution" in Load-Flow options. After running the Load-Flow, and verifying power balance in the Load-Flow web, the user can unclick the Load-Flow solution in "Design>Advanced>Simulation Options" and select Steady-state solution followed by Time-domain.

As shown in Figure 3-2 and Figure 3-3, all synchronous machines are able to initialize from the Load-Flow solution and enter steady-state operating mode. Starting without a load-flow solution would have resulted in dramatically longer simulation time before reaching the same steady-state solution.

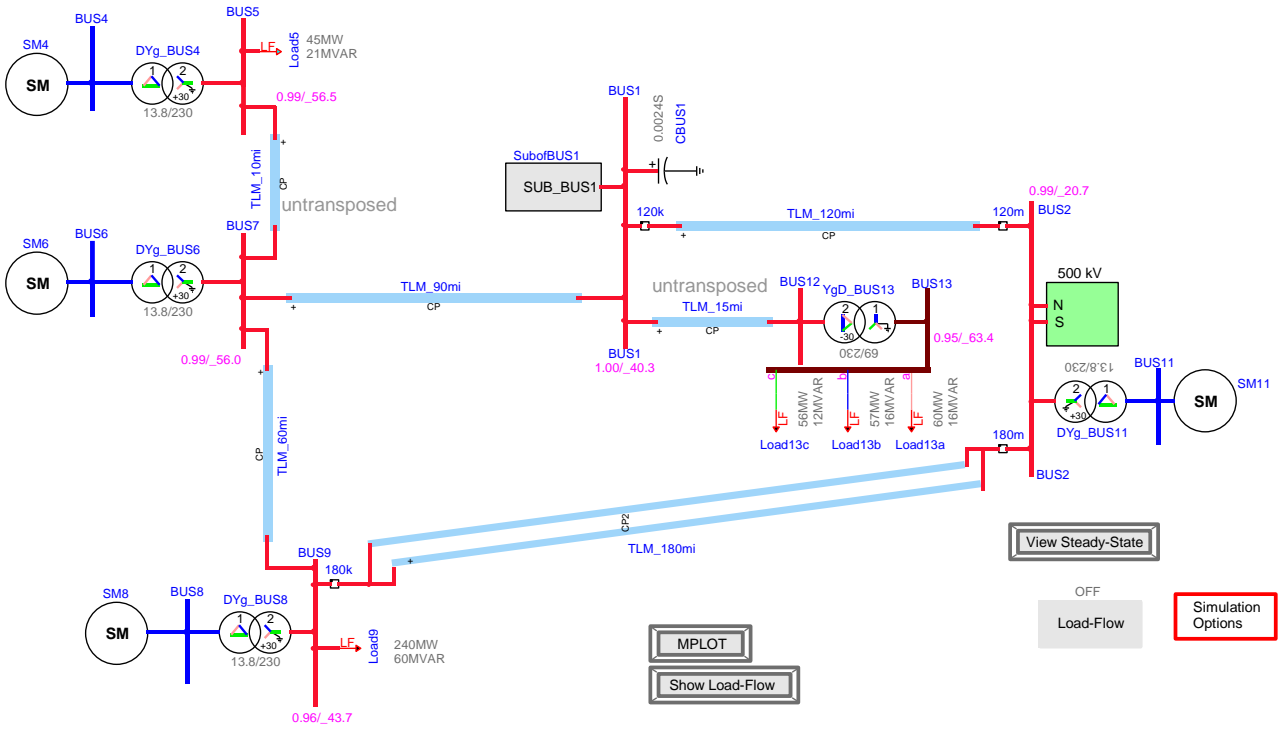


Figure 3-1 Load-Flow test case

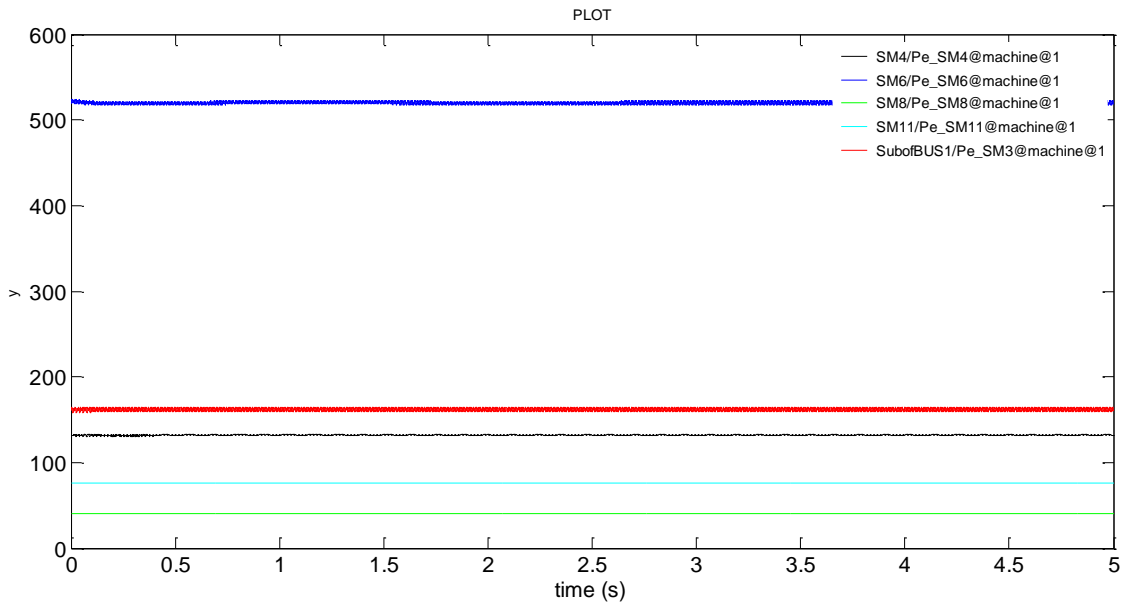


Figure 3-2 Electrical power generated by synchronous machines (MW)

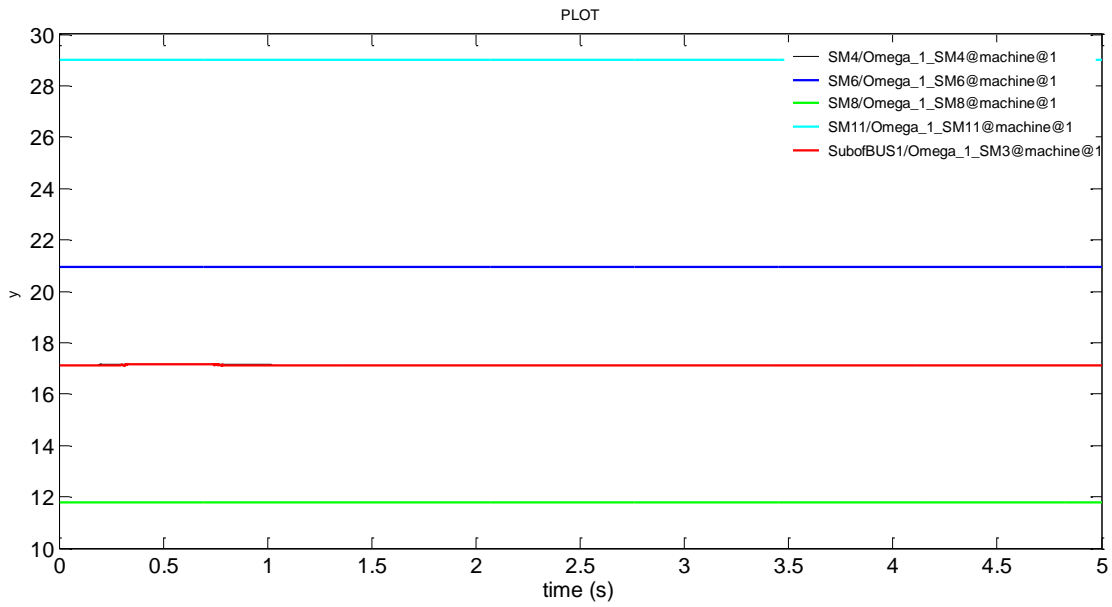


Figure 3-3 Machine angular velocities (rad/s)