Chapter 51

Motor Starting

51.1 Introduction

The chapter presents *PowerFactory* tools for performing motor starting simulations using the Motor Starting command (*ComMot*). A Motor Starting analysis typically includes an assessment of the following:

- Voltage sag.

- Ability of motor to be started against the load torque.

- Time required to reach nominal speed.

- Supply grid loading.

- Starting methodology (Direct Online, Star-Delta, Variable Rotor Resistance, Reactor, Auto Transformer).

The Motor Starting command makes use of the *PowerFactory* stability module by providing a pre-configured shortcut for easy-to-use motor starting analysis. Pre-selected and pre-configured plots are automatically created and scaled with full flexibility for user-configuration. In *PowerFactory*, there are two "Simulation Types" that may be used to perform a motor starting simulation:

1. *Dynamic Simulation*, which will execute a time-domain motor starting simulation.

2. *Static Simulation*, which will execute a load flow calculation when the motors are disconnected from the system. Then, it will execute a short-circuit calculation, using the complete method, simultaneously with the occurrence of the motors being connected to the network. Finally, a load flow calculation will be executed after the motors have been connected to the system.

51.2 How to define a motor

To define the starting method of a motor, a Type must first be selected. This sub-section describes how to define a motor and (optionally) define a motor driven machine (mdm).

51.2.1 How to define a motor Type and starting methodology

A comprehensive library of low-voltage, medium-voltage, and high-voltage motor Types are available in the *PowerFactory* Global Library. Typical motors supported are: single- and double-cage asynchronous machines and squirrel motors.

To define a motor Type and starting methodology for a dynamic simulation:

1. On the asynchronous machine Basic Data page, press *select* (⌄) and then choose an existing or define a new asynchronous machine Type. Press **OK** twice.

2. From the Data Manager or single line graphic, double-click the asynchronous machine to open the element dialog.

3. Depending on whether a dynamic or static motor starting simulation is to be executed:
   - For a dynamic starting simulation, navigate to the RMS-Simulation page, Advanced tab.
   - For a static starting simulation, navigate to the Complete Short-Circuit page.

4. Check *Use Motor Starting Method*.

5. Use radio buttons to select a starting method (see below).

Directly Online
For the direct online starting method, select *Directly Online*.

Star-Delta
For star-delta starting:

1. Select *Star-Delta*.

2. For a dynamic motor starting simulation, on the RMS-Simulation page, Advanced tab:
   - Select *Triggered by. . .* either *Time* or *Speed*.
   - Enter a simulation time for the motor to switch from the star winding to the delta winding *Switch to 'D' after*, or a speed for the motor to switch from the star winding to the delta winding *Switch to 'D' at Speed* >=.

Variable Rotor Resistance
For variable rotor resistance starting:

1. Select *Variable Rotor Resistance*.

2. For a static motor starting simulation, on the Complete Short-Circuit page:
   - Enter the *Additional Rotor Resistance*.

3. For a dynamic motor starting simulation, on the RMS-Simulation page, Advanced tab:
   - Select *Triggered by. . .* either *Time* or *Speed*.
   - In the *Variable Rotor Resistance* table, enter additional rotor resistance, and the time (or speed) at which the rotor resistance should be added.
   - For additional entries, right-click and Append or Insert rows as required. Note that a minimum of two-points must be entered.

Reactor
For reactor starting:

1. Select *Reactor*.

2. For a static motor starting simulation, on the Complete Short-Circuit page:
   - Enter the *Rated Apparent Power* and *Reactance*.

3. For a dynamic motor starting simulation, on the RMS-Simulation page, Advanced tab:
   - Select *Triggered by. . .* either *Time* or *Speed*.
   - Enter the *Rated Apparent Power*, *Reactance*.
   - Enter the time at which the reactor should be removed *Bypass after*, or speed at which the reactor should be removed *Bypass at Speed* >=.

Auto Transformer
For auto transformer starting:

1. Select *Auto Transformer*.

2. For a static motor starting simulation, on the Complete Short-Circuit page:
   • Enter the *Rated Apparent Power*, *Reactance*, and *Tap*.

3. For a dynamic motor starting simulation, on the RMS-Simulation page, Advanced tab:
   • Select *Triggered by...* either *Time* or *Speed*.
   • Enter the *Rated Apparent Power*, *Reactance*, and *Tap*.
   • Enter the time at which the star contactor should be released *Release Star Contactor after* and the time at which the auto-transformer should be bypassed *Bypass after*, or the speed at which the star contactor should be released *Release Star Contactor at Speed* $>=$ and the speed at which the auto-transformer should be bypassed *Bypass at Speed* $>=$.

51.2.2 How to define a motor driven machine

Selection of a motor driven machine model provides enhanced flexibility to define the torque-speed characteristic of the motor. A motor driven machine can be user-defined, or selected from a range of Compressors, Fans, and Pumps available in the *PowerFactory* Global Library. Refer to the asynchronous machine Technical Reference Asynchronous Machine and motor driven machine Technical Reference for further details Motor Driven Machine.

To define a motor driven machine, in a Data Manager or on the Single Line Graphic, right-click on the asynchronous machine and:

- For a new motor driven machine:
  1. Select *Define...* → *New Motor Driven (mdm) machine*.
  2. Select a motor driven machine element (Type 1, Type 3, or Type 5).
  3. Enter the torque-speed characteristic.

- For a motor driven machine from the library:
  1. Select *Define...* → *Motor Driven (mdm) machine from library*.
  2. Select an existing motor driven machine from the project library, or global library *Database* → *Library* → *Motor Driven Machine*.

Note: Motor driven machines may also be defined for Synchronous motors by selecting the "Composite Type Sym frame" (or creating a user-defined frame). Refer to the mdm Technical Reference for further details: Motor Driven Machine.

51.3 How to run a Motor Starting simulation

To run a motor starting simulation:

1. Select the motor or group of motors for the motor starting simulation.

2. Right-click a selected motor and select *Calculate* → *Motor Starting*.

3. Enter the command options (see following subsections for a description of the command options).

51.3.1 Basic Options Page

51.3.1.1 Motor(s)

The motors selected for the Motor Starting command.

51.3.1.2 Simulation Type

Select either:

- *Dynamic Simulation* to initiate a dynamic motor starting simulation.

- *Static Simulation* to initiate a static motor starting simulation.

Note: Load Flow, Initial Conditions, Run Simulation, Simulation Events, Short-Circuit and Results Definitions objects in the active study case will be overwritten by the Motor Starting command.

51.3.1.3 Simulation Method

Either:

- If *User defined simulation settings* is not checked:
    1. Select to run either a *Balanced* or *Unbalanced* Motor Starting simulation.
    2. Enter the *Simulation Time* in seconds.

- If *User defined simulation settings* is checked:
    1. Define the variables to be monitored.
    2. Modify Load Flow Calculation command (*ComLdf*) settings as required.
    3. Modify Initial Conditions command (*ComInc*) settings as required. Note that motor starting events are automatically created, and that previously defined events are not deleted. Similarly, user-defined variable sets are merged with the Motor Starting command default variables.
    4. Modify Simulation command (*ComSim*) settings as required.

51.3.1.4 Monitoring

Click *Select* (⌄) and select the *Additional Terminals* to be monitored for the Motor Starting simulation.

51.3.1.5 Check Thermal Limits of Cables and Transformers

Optionally select to *Check Thermal Limits of Cables and Transformers*. When this option is selected, the feeding cables and transformers of every motor will automatically be gathered, and its thermal limit will be checked.

The calculation of the thermal limits is performed depending on the type of simulation selected.

- **Dynamic Simulation**

    Given the rated thermal overcurrent limit of the cable at 1 second (I_{thr1s}), the thermal overcurrent limit of the line at the starting time of the motor (I_{thrTs}) is calculated according to equation 51.1:

$$I_{thrTs} = \sqrt{\frac{I_{thr1s}^2}{T_{start}}} \tag{51.1}$$

    Where:
    T_{start} = is the time calculated during the Motor Starting simulation.

The calculated thermal energy (I_{2t}) during the motor starting is defined as:

$$I_{2t} = \int_0^{T_{start}} I^2 \, dt \approx \sum_0^{T_{start}} I^2 \Delta t \tag{51.2}$$

Where:
Δt = is the integration step size of the simulation.

The calculated thermal current ($I_{thrcalc}$) is then calculated as follows:

$$I_{thrcalc} = \sqrt{\frac{I_{2t}}{T_{start}}} \tag{51.3}$$

Finally, the thermal loading is calculated as the relation between rated thermal current and calculated thermal current at starting time:

$$ThermalLoading = \frac{I_{thrcalc}}{I_{thrTs}} \tag{51.4}$$

• **Static Simulation**

Given the rated thermal overcurrent limit of the cable at 1 second (I_{thr1s}), the thermal overcurrent limit of the line at the starting time of the motor (I_{thrTs}) is calculated according to equation 51.5 :

$$I_{thrTs} = \sqrt{\frac{I_{thr1s}^2}{T_{start}}} \tag{51.5}$$

The starting time is the variable $tstart$ specified in the "Protection" page of the Asynchronous and the Synchronous Machine dialogs.

The calculated thermal current is the positive-sequence current calculated at the motor starting

$$I_{thrcalc} = I_{start} \tag{51.6}$$

Finally, the thermal loading is calculated as the relation between rated thermal current and calculated thermal current at starting time:

$$ThermalLoading = \frac{I_{thrcalc}}{I_{thrTs}} \tag{51.7}$$

51.3.2 Output Page

51.3.2.1 Dynamic Simulation

Report
Check *Report* to report results to the output window. By default, report results include voltage before starting, minimum voltage during starting, voltage after starting, starting current and power factor, successful start, and starting time. The user can optionally modify report *Settings*.

Starting Tolerance for Simplified Models
Define the *Max. Speed Tolerance*, the maximum deviation from nominal speed at which the motor is considered to be successfully started. This applies only to simplified (i.e. synchronous) motors.

51.3.2.2 Static Simulation

Report
Optionally modify report *Settings* and *Results*. Figure 51.3.1 shows an example of a Static Simulation Report with the option "Check Thermal Limits of Cables and Transformers" selected.

```
----------------------------------------------------------------------------------------------------------
|              |                                            |  DIgSILENT  | Project:                        |
|              |                                            |  PowerFactory |-----------------------------|
|              |                                            |  15.0.1     | Date:                           |
|---------------------------------------------------------------------------------------------------------|
| Motor Starting                                                                                          |
|---------------------------------------------------------------------------------------------------------|
| Study Case:        Study Case                              | Annex:                          / 1        |
|---------------------------------------------------------------------------------------------------------|
| Simulation Type:   Static Simulation                                                                    |
|---------------------------------------------------------------------------------------------------------|
| Motors                                                                                                  |
|---------------------------------------------------------------------------------------------------------|
| Detailed Models                                                                                         |
|---------------------------------------------------------------------------------------------------------|
| Motor Name        | Terminal Name  | Terminal | Motor Voltage         | Starting       | Starting | Successful | Approx.   |
|                   |                | Voltage  | Minimum on| After     | Current        | P.F.     | Start?     | Starting  |
|                   |                | Before   | Starting  | Starting  |                |          |            | Time      |
|                   |                | Starting |           |           |                |          |            |           |
|                   |                | (p.u.)   | (p.u.)    | (p.u.)    | (kA) | (p.u.)  |          |            | (s)       |
|---------------------------------------------------------------------------------------------------------|
| ASM1line          | BB             | 1.000    | 0.447     | 0.984     | 1.523 | 15.826 | 0.706    | Yes        | 7.221     |
|---------------------------------------------------------------------------------------------------------|
| Thermal Limits Violations                                                                               |
|---------------------------------------------------------------------------------------------------------|
| Cables                                                                                                  |
|---------------------------------------------------------------------------------------------------------|
| Cable Name                             | Starting |         Rated              |         Calculated          |       |
|                                        | Time     | Thermal    | Thermal       | Thermal    | Thermal       |       |
|                                        |          | Current    | Current       | Current    | Loading       |       |
|                                        |          | @ 1 s      | @ Start. Time |            |               |       |
|                                        | (s)      | (kA)       | (kA)          | (kA)       | (%)           |       |
|---------------------------------------------------------------------------------------------------------|
| LineBBx1                               | 7.221    | 2.000      | 0.744         | 1.523      | 204.601       |       |
----------------------------------------------------------------------------------------------------------
```

Figure 51.3.1: Report Example

Starting Tolerance for Simplified Models
Define the *Max. Voltage Drop* at which the motor is considered to be successfully started. This applies only to simplified models.

Simplified models are:

- All synchronous motors.

- Asynchronous motors with type Asynchronous Machine Type (*TypAsmo*), and without the Type option *Consider Transient Parameter (i_trans)* checked.

- Asynchronous motors with any Type other than Asynchronous Machine Type (*TypAsmo*).

Detailed models are: Asynchronous motors with type Asynchronous Machine Type (*TypAsmo*), and which have the option *Consider Transient Parameter* checked on the VDE/IEC Short-Circuit page or Complete Short-Circuit page of the Type dialog. This provides a more precise result for the motor starting time.

Display results for
Select to display results on the Single Line Graphic:

- After motor starting.

- During motor starting.

- Before motor starting.

51.3.3 Motor Starting simulation results

51.3.3.1 Dynamic simulation results

Following a motor starting simulation, *PowerFactory* will automatically create a plot (VI) for each motor showing the active power (m:Psum:bus1), reactive power (m:Qsum:bus1), current (m:I1:bus1), speed (s:speed), mechanical and electrical torques (c:xmt and c:xmem) and voltage of the motor terminal (m:u1). A second plot is created showing the voltage of monitored Terminals. Flexible data results variables available following a dynamic Motor Starting simulation are found on the motor data Motor Starting Calculation page.

The Motor Starting calculation variables are as follows:

- Terminal Pre-start Voltage, Magnitude (c:uprestart).

- Motor Start Voltage, Magnitude (c:ustart).

- Motor Post-start Voltage, Magnitude (c:upoststart).

- Starting current, Magnitude in kA (c:Istart).

- Starting current, Magnitude in p.u. (c:istart).

- Starting Power Factor (c:cosphistart).

- Successfully Started (c:started).

- Approx. Starting Time (c:Tstart).

The criterion of a successful start is as follows:

- Synchronous motors: Successful start if $Actual speed >= Synchronous speed - Tolerance$, where $Actual speed$ is the value of variable "s:speed", and $Tolerance$ is the value specified in the input field *Max. Speed Tolerance (tolspeed)*.

- Asynchronous motors: Successful start if $Actual speed >= Nominal speed - Slip$, where $ActualSpeed$ is the value of variable "s:speed", and $Slip$ is the value of variable "t:aslkp" of the asynchronous motor.

51.3.3.2 Static simulation results

Following a motor starting simulation, new calculation variables are available for asynchronous (*ElmAsm*) and synchronous (*ElmSym*) motors. For the Static Simulation, these variables are found on the Motor Starting Calculation page. Results variables are described in the preceding sub-section.

The criterion of a successful start is as follows:

- Simplified models: Successful start if *Voltage During Starting* >= *Voltage Before Starting* *(1 - *Voltage Tolerance*), where *Voltage Before Starting* is the voltage value at the terminal before the motor is connected to the system, *Voltage During Starting* is the transient positive-sequence voltage value at the terminal during the motor start, and *Voltage Tolerance* is the value specified in the input field **Max. Voltage Drop** (tolvolt).

- Detailed models: The electrical and mechanical torque are calculated for the minimum voltage value during the motor start up. A detailed model is considered to be successfully started up if the mechanical torque is always smaller than the electrical torque from zero speed up the peak of the electrical torque.

51.3.4 Motor Starting Example

Consider the following dynamic motor starting example for a single 6.6kV asynchronous motor shown in Figure 51.3.2.
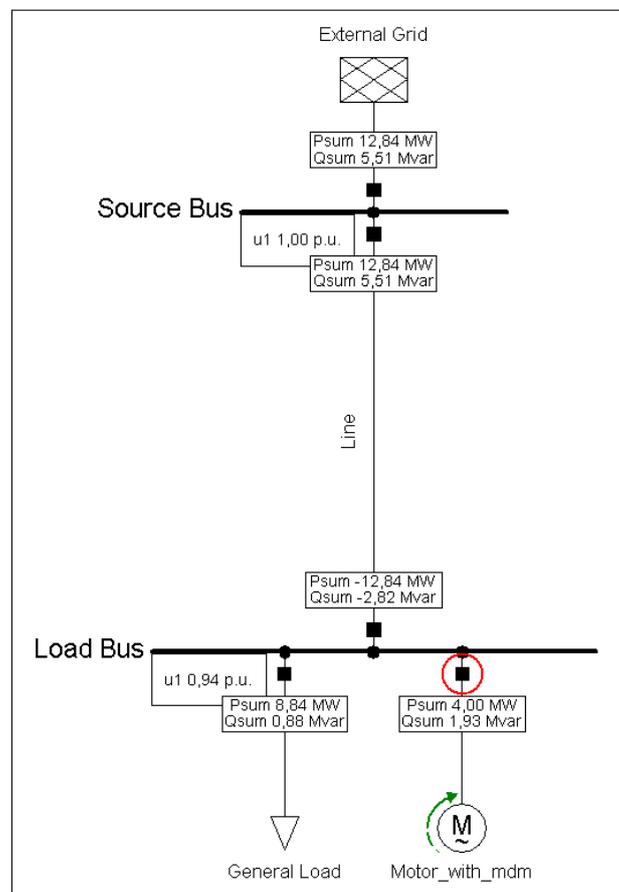

Figure 51.3.2: Motor Starting example Single Line Graphic

The *Variable Rotor Resistance* starting method has been selected, with three values of time-dependent resistance, as shown in Figure 51.3.3.
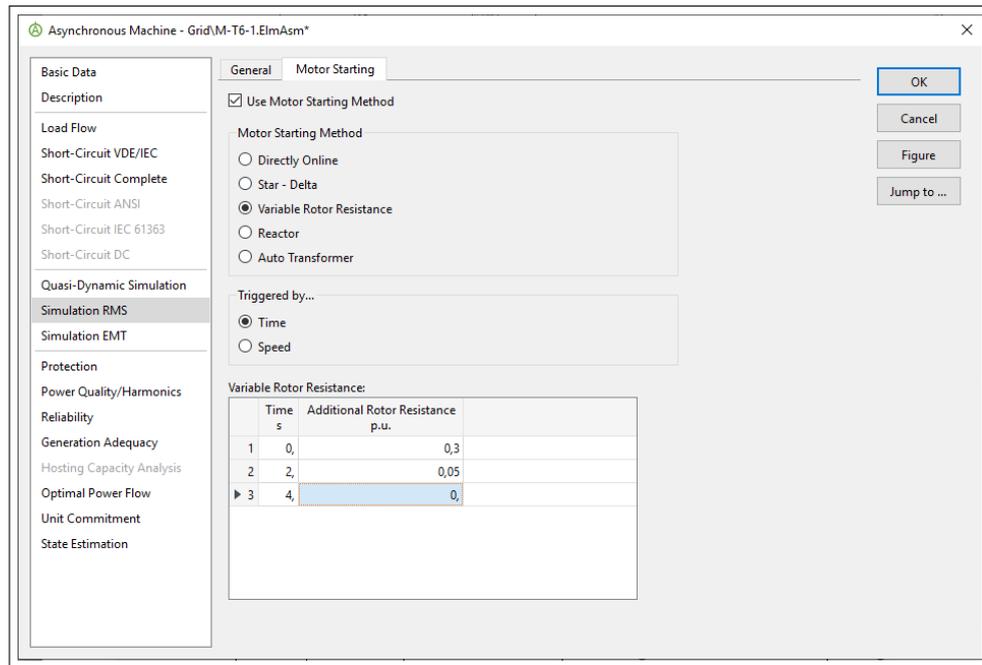
Figure 51.3.3: Motor starting methodology options

A dynamic, balanced Motor Starting simulation is executed and run to 10 seconds, with "Source Bus" selected as an *Additional Terminal* to be monitored, as shown in Figure 51.3.4.

Figure 51.3.4: Motor starting Basic Options

Following execution of the command, *PowerFactory* automatically produces plots showing motor quantities of interest (as described in Section 51.3.3.1) and monitored voltage results as shown in Fig-
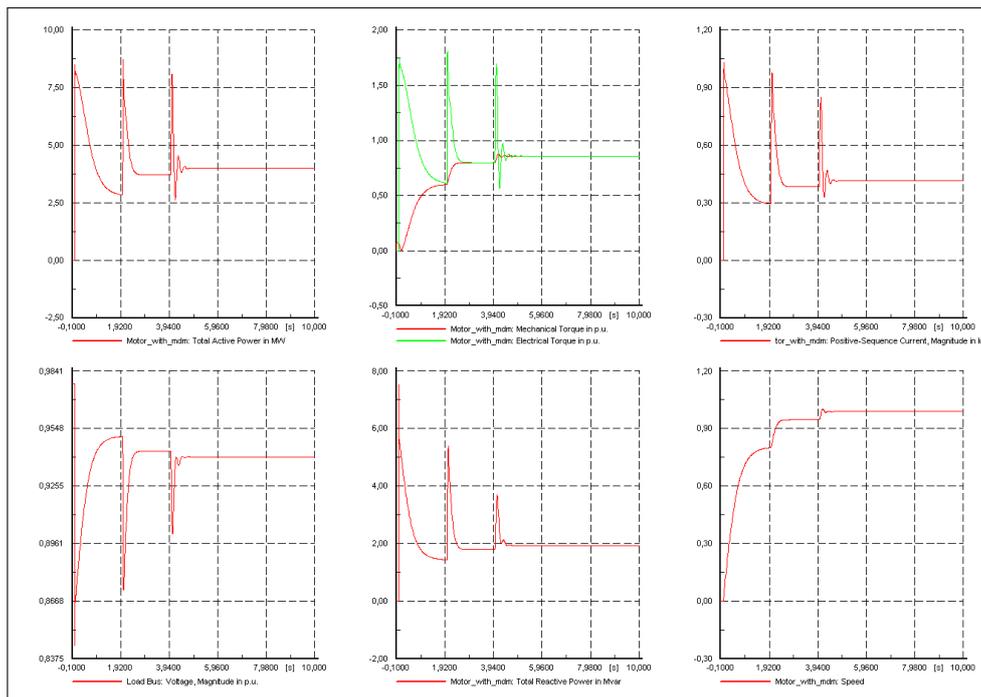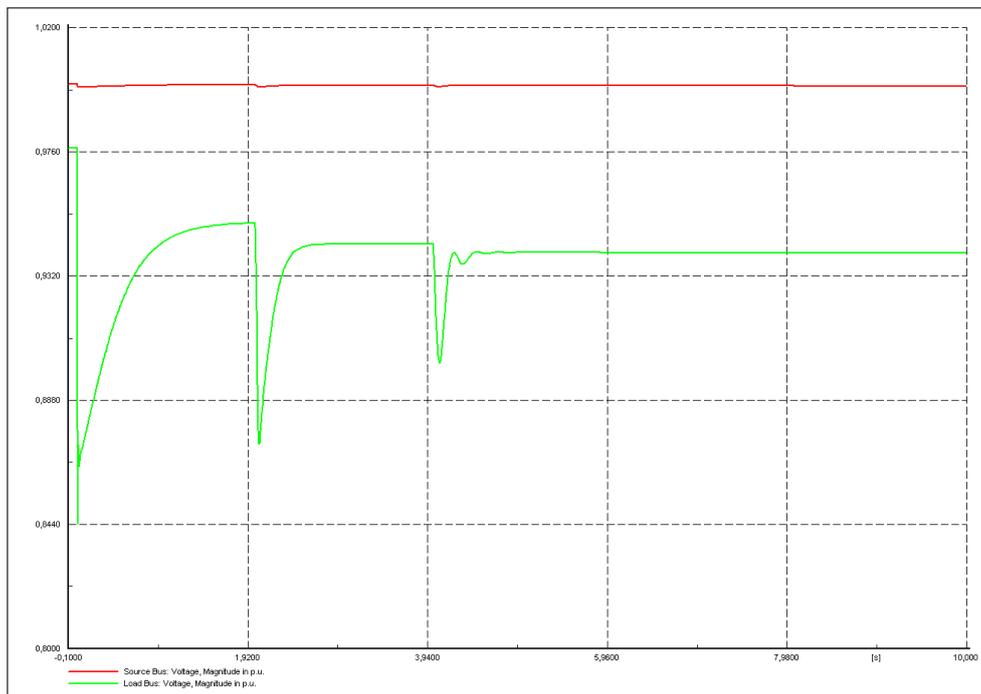
Figure 51.3.5: Motor starting example motor results

Figure 51.3.6: Motor starting example voltage results