



SHIFTING THE LIMITS



FRONIUS ECO 27.0/25.0 KW SIMULATION MODEL

EN

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Gender-specific wording refers equally to female and male form.

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1 FRONIUS ECO SIMULATION MODEL DESCRIPTION

The following documentation intends to describe a MATLAB-Simulink model of solar inverters of the Fronius inverter ECO family: 27.0/25.0 kW.

1.1 Simulation model overview

A masked MATLAB-Simulink block has been created for the Fronius inverter series ECO. The block is a masked-subsystem consisting of standard blocks of the Simulink library, including a Level-2 Matlab S-Function. An example of such implementation is shown in Figure 1.

It must be noted that the mentioned S-Function block expects a corresponding MEX file, in order to properly function. The S-Function block operation, together with input and output definitions are explained in detail in the following sections.

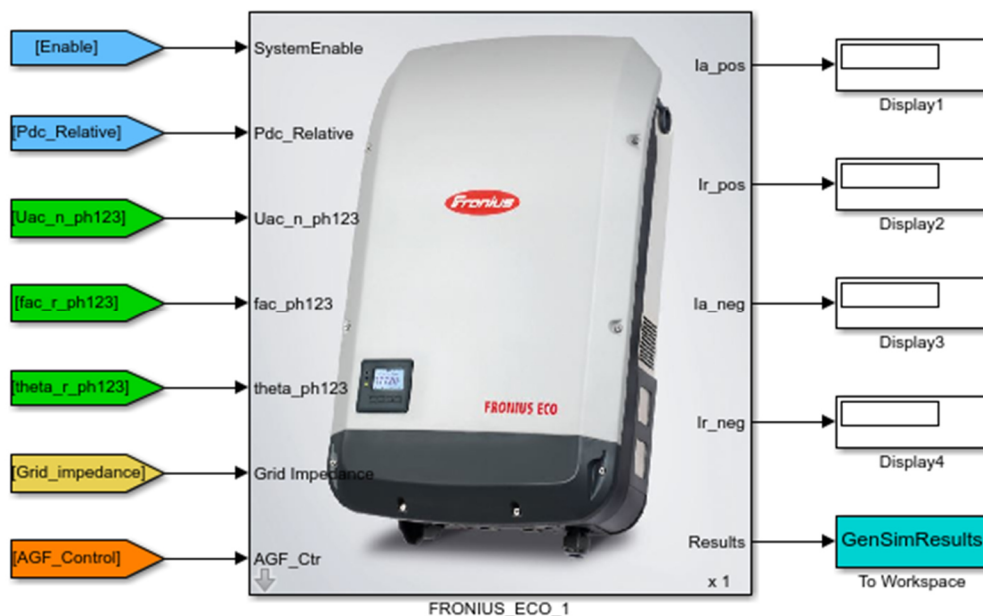


Figure 1. Simulation model overview

1.2 Fronius ECO family

The Fronius ECO family consists of two different inverters: *FRONIUS ECO 27.0-3-S* and *FRONIUS ECO 25.0-3-S*. Either inverter can be simulated from the above depicted model: simply double clicking on the block will open the parameter window, where one can choose which inverter to simulate.

Each implementation of this masked subsystem must be paired with a specific and unique MEX-file. This assignment is done automatically, for which is necessary that such group of MEX-files is located in the simulation's working directory (or any sub-folder of it).

This masked subsystem was delivered with a group of MEX-files: **FroniusInverter_SFunctionX.mexw64** (X from 1 to 249); this allows for up to 250 converters to be simulated in a single simulation model.

The MEX-files have been built using the actual C++ source code implemented in the real systems. Because the source code is the same for each ECO systems, their functionality is also the same. The difference lays in internally defined parameters/limitations: for example, the maximum current/power limitations.

1.3 Simulation requirements

1.3.1 Software environment

The following software requirements are necessary in order to properly simulate the delivered models:

- 64-bit Matlab Version 9.4 (R2018a) or higher
- Simulink Version 9.1 (R2018a) or higher

1.3.2 Simulation files

The following files are contained within a simulation package. The model file (*.**slx**) and the MEX file group (*.**mexw64**) are absolutely necessary for the simulation of the intended inverter. An optional figure (*.jpg) is also included and briefly described:

- *ECO_EZE.slx*: Simulink EZE model of inverter.
- *ECO_EZA.slx*: Simulink EZA model of inverter.
- *FroniusInverter_SFunctionX.mexw64*: Group of Matlab executable files (X from 1 to 249).
- *Fronius_ECO.jpg*: Simulink subsystem's mask figure, depicting a Fronius inverter of the ECO series.

It must be noted that all delivered files must be placed in the same folder/location. In addition, the simulation is to be run from Simulink and so, Matlab's current working directory must be the same as where these files are located. To check Matlab's current directory simply enter in Matlab's workspace the command

```
>> cd
```

2 SIMULINK MODEL STRUCTURE

2.1 Simulink model skeleton

The block diagram in Figure 2 describes the main components of the built Simulink model. Input signals are divided in five categories: **System Enable**, **Pdc Relative**, **AGF Control**, **Grid Voltage** and **Grid Impedance**. These signals are to be processed by the subsystem shown in red: **AGF** (Advanced Grid Features). The output of this subsystem is recorded and stored (**Results**) for further processing. The following sections provide a more detailed explanation of each component.



Figure 2. Simulink model skeleton

2.1.1 System Enable

Input *System Enable* is a boolean scalar which when true enables inverter's operation. A value of false will turn off the inverter.

2.1.2 Pdc Relative

Input *Pdc_Relative* is a fractional value relative to the available DC power, which allows to feed in the maximum possible active power during grid fault. Valid input range from 0 to +1.

2.1.3 Grid Voltage

This set of inputs consists of derived components of each grid phase. That is, voltage magnitude, frequency and phase-angle. The monitoring of these signals is critical for correct functionality of the AGF block. Such inputs, as named in the Simulink file are listed:

Signal name	Description	Unit
<i>Uac_n_ph123</i>	1-D vector with 3 elements (U1, U2, U3), which specifies normalized grid voltage magnitude for all three phases.	V
<i>fac_ph123</i>	1-D vector with 3 elements (f1, f2, f3), which specifies grid voltage frequency (in Hz) for all three phases.	Hz
<i>theta_ph123</i>	1-D vector with 3 elements (th1, th2, th3), which specifies the line voltage angle (in degrees) between phases. Nominal phase angles for each phase are defined to be (0,240,120), respectively.	degree

Table 1. Grid Voltage

2.1.4 Grid Impedance

This input (a 1-D vector with 2 elements) defines the grid impedance Z_G (depicted in Figure 3), which is the series combination $R + j\omega L$. These inputs, as named in the Simulink file *ECO_EZE.slx*, are listed in Table 2.

Signal name	Description	Unit
R_grid	Equivalent grid series resistance	Ohm
L_grid	Equivalent grid series inductance	Henry

Table 2. Grid Impedance

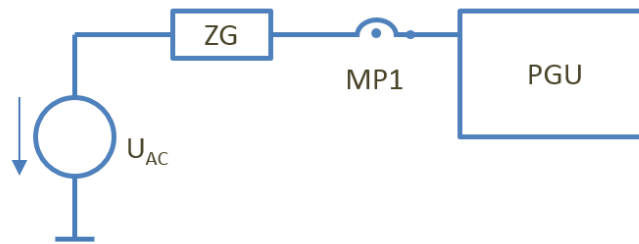


Figure 3. Power Generating Unit (PGU) connection to the grid

2.1.5 AGF Control

Inputs in this category include all inverter settings, which in the real system the user (or energy provider) is able to configure. Such inputs are listed:

- **ReactiveSelect**: Use this signal to choose the method in which the reactive power is set. The possible options are listed:
 - $\cos(\phi)$ (Reactive Select = **1**): set a fix desired cosine of angle (ϕ) between output current and grid voltage.
 - Relative reactive power (Reactive Select = **2**): set a fix desired reactive power (in percent) relative to the specified machine's nominal power.
 - Absolute reactive power (Reactive Select = **3**): set a fix desired reactive power (in var).
 - Voltage regulated reactive power (Reactive Select = **5**): the reactive power will follow a predefined characteristic curve, as a function of the grid voltage.
 - No reactive power (Reactive Select = **0**): no reactive power will be feed into the grid.
- **CosPhi**: desired $\cos(\phi)$ value. Valid input range from 0 to ± 1 , where positive values indicate a positive reactive power - the phase current will lag the phase voltage. Notice that this range might be further limited by internal system settings. This setting is only relevant when ReactiveSelect is set to 1.
- **Q_Relative**: desired reactive power (in percent) relative to the specified inverter's nominal power. Valid input range from 0 to ± 100 , where positive values indicate a positive reactive power - the phase current will lag the phase voltage. Notice that this range might be further limited by internal system settings. This setting is only relevant when ReactiveSelect is set to 2.
- **Q_Absolute**: desired total (from all three phases) reactive power (in var). Valid input range from 0 to $\pm 2^{32}$, where positive values indicate a positive reactive power - the phase current will lag the phase voltage. Notice that this range might be further limited by internal system settings. This setting is only relevant when ReactiveSelect is set to 3.

- **FRTSelect**: Fault Ride Through response mode. The possible options are listed:
 - Off (FRT Select = 0): Inverter is not to react to a grid voltage fault event.
 - On-Passive (FRT Select = 1): Output currents are preserved during a fault event.
 - On-Zero (FRT Select = 2): Output currents are set to 0 during a fault event.
 - On-Active (FRT Select = 5): Normal FRT mode, as specified in regulation norms.
 - ON-Zero/ON-Active (FRT Select = 10): Limited dynamic grid support.
- **FRT_kFactor**: FRT k factor. Valid input range from 0 to +10.
- **PSlewRate**: Slope at which active power changes will take place, after start-up. Value is in milli-percent per second.
- **QTimeConstant**: Time constant for a first-order low-pass filter, which defines how reactive power changes will take place. Value is in milliseconds.
- **P_Relative**: Fractional value relative to the machine's nominal power, which sets/limits the active power to be feed in grid. Valid input range from 0 to +1.

The following table shows how the above listed parameters are named in the actual inverter:

Simulink Block Name	Block Value	Label in Inverter
FRTSelect	-	LVRT On/Off
	0	OFF
	1	ON-Passive
	2	ON-Zero
	5	ON-Active (Normal FRT mode)
	10	ON-Zero/ON-Active (Limited dynamic grid support)
FRT_kFactor	-	FRT K factor
ReactiveSelect	-	Reactive Power Mode
	0	OFF
	1	C. CosPhi
	2	C. Qrel
	3	C. Qabs
	5	Q/U
CosPhi	-	Const. CosPhi
Q_Relative	-	Const. Q Rel.
Q_Absolute	-	Const. Q. Abs.
QTimeConstant	-	Const. CosPhi TimeC. Const. Q Rel. TimeC. Const. Q Abs. TimeC.
P_Relative	-	<i>Not available in inverter – Value is only accessible through Data Manager interface</i>
PSlewRate	-	<i>Not available in inverter – Value is only accessible through Data Manager interface</i>

Table 3. AGF control parameter

2.1.6 AGF

The AGF subsystem comprises a set of functions which determine the system behavior when operating under a range of conditions. The main simulation block consists of a *Level-2 S-Function* compiled from a collection of C-written files. Within these C-files, the real system's source code has been included and its functions are called in the same manner as in the real system. Hence, equivalence between calculated values from the simulation and the calculated values by the controller in an actual inverter is assured.

The block expects as inputs all previously described signals, together with the calculated total active output power. The main output of this block are the active and reactive positive and negative sequence components of the output currents (I_{a_pos} , I_{r_pos} , I_{a_neg} and I_{r_neg}), per phase. The currents are used to calculate the voltage at point MP1 (Figure 3), together with the system's real, reactive and apparent output power. The real power is then feedback (internally) to the AGF block, as required.

2.1.7 Results

All relevant calculated output signals are grouped into a single structure referred to as *Results*. It comprises the following signals (in the listed order):

Number in structure	Name	Unit
1	Phase 1 UAC RMS	V
2	Phase 2 UAC RMS	V
3	Phase 3 UAC RMS	V
4	Active RMS current (positive sequence component) per phase	A
5	Reactive RMS current (positive sequence component) per phase	A
6	Total active power (positive sequence component) (for all three phases)	W
7	Total reactive power (positive sequence component) (for all three phases)	var
8	Total apparent power (positive sequence component) (for all three phases)	VA
9	Phase 1 UAC frequency	Hz
10	Phase 2 UAC frequency	Hz
11	Phase 3 UAC frequency	Hz
12	Set active power	W
13	Grid voltage (positive sequence component)	V
14	Grid voltage (negative sequence component)	V
15	Active RMS current (negative sequence component) per phase	A
16	Reactive RMS current (negative sequence component) per phase	A
17	Total active power (negative sequence component) (for all three phases)	W
18	Total reactive power (negative sequence component) (for all three phases)	var
19	Total apparent power (negative sequence component) (for all three phases)	VA

Table 4. Results structure

At the end of the simulation and with the specified sample time (i.e. 1 ms), the above signals are stored and available for further examination/visualization.

2.2 Simulink model

A snapshot of the Simulink model is presented in Figure 4.

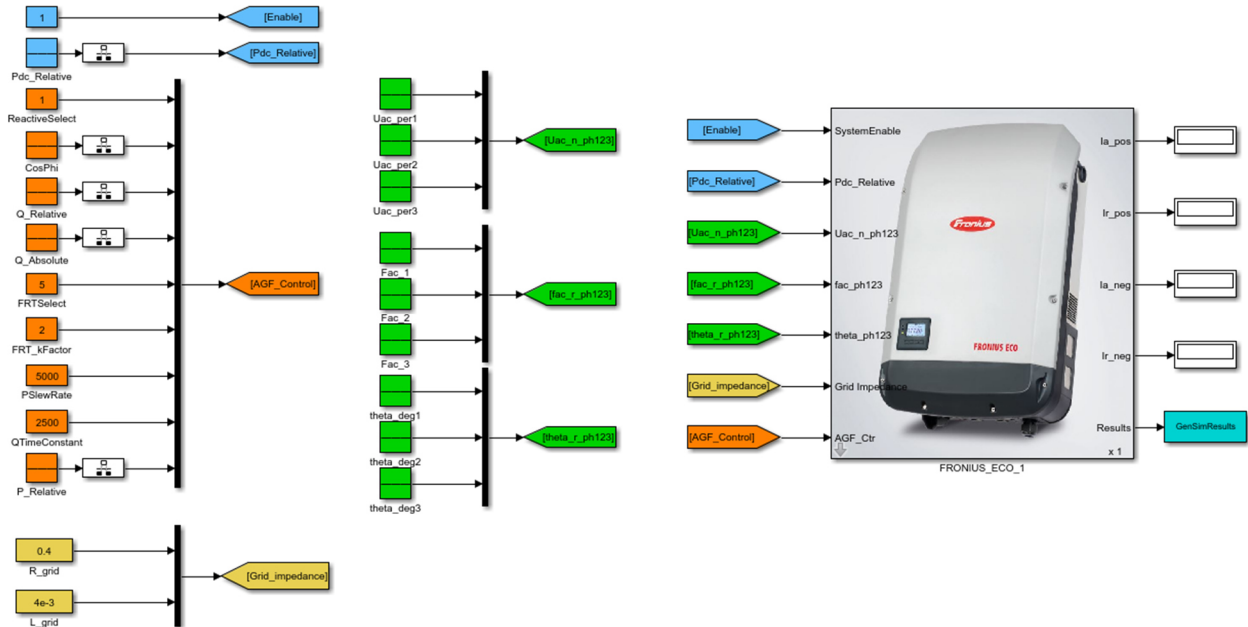


Figure 4. Simulink model snapshot

2.2.1 Additional Outputs

Besides the previously described structure *Results*, four particular signals are directly output by the inverter model. These signals can then be directly connected to a Display or Scope block for visualization, as shown in Figure 4. They are as listed and described in Table 5.

Signal name	Description	Unit
Ia_pos (A)	Active RMS current (positive sequence component) per phase	A
Ir_pos (A)	Reactive RMS current (positive sequence component) per phase	A
Ia_neg (A)	Active RMS current (negative sequence component) per phase	A
Ir_neg (A)	Reactive RMS current (negative sequence component) per phase	A

Table 5. Directly output signals of the inverter model

2.2.2 Inverter Settings

Double clicking on the inverter block will open the *Block Parameters* window, shown in Figure 5. The **Inverter Settings** parameter allows the user to choose from a drop down menu which inverter is to be simulated. The selection loads a pre-defined structure which contains specific configuration parameters of a given inverter (maximum power, current, nominal voltage, frequency, etc.).

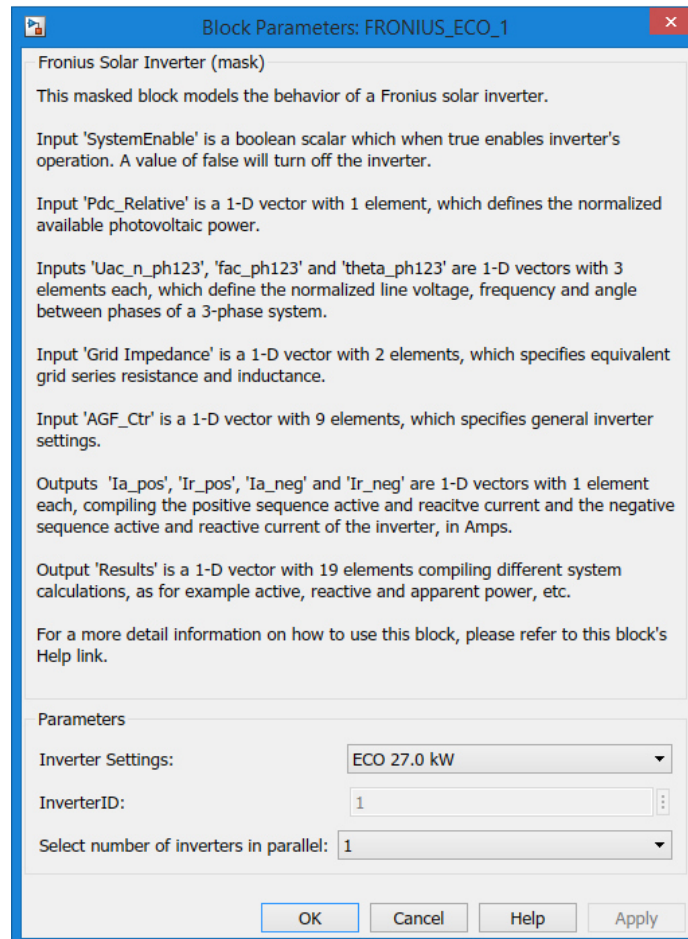


Figure 5. Fronius inverter Block Parameters window

2.2.3 Paralleling multiple inverters

The implemented inverter block model (as the one shown in Figure 4) allows the simulation of up to 20 inverters in parallel. One can choose the number of inverter's to be simulated in parallel by simply selecting it from a drop down menu in the block's mask. The selected number is then displayed on the bottom-right corner of the block as shown below:

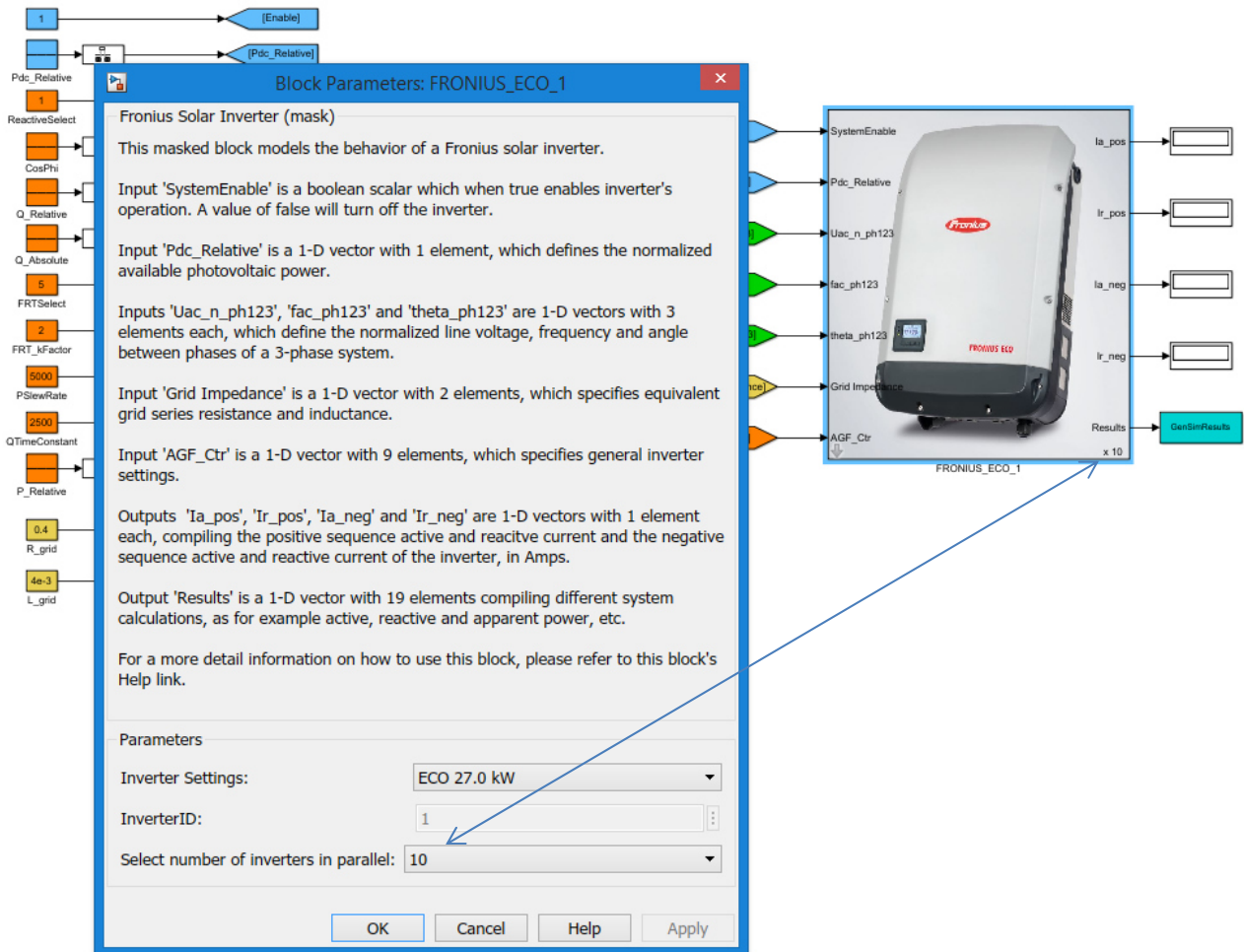


Figure 6. Paralleling of multiple inverters

3 SIMULATION AND RESULTS

3.1 Running the simulation model

Before running the simulation the user may configure all previously described input signals (**System Enable**, **Pdc_Relative**, **AGF Control**, **Grid Voltage** and **Grid Impedance**) as desired.

One must simply note that all input blocks are of either *Constant* or *Repeating Sequence* type. All *Constant* blocks in the model expect a 1-D element of *length* 1. On the other hand, all *Repeating Sequence* blocks expect two 1-D vectors of equal length, for the Time and Output value's parameter field. For more information on how to use these blocks, please refer to the Matlab help. Furthermore, the user may also change the simulation duration, in the Simulink simulation time field.

After defining all input signals, simulation time and number of inverters in parallel per block, one can simply press play in the Simulink Toolbar to start running the simulation.

3.2 Results

The inverter block outputs have been described in section **2.1.7** and **2.2.1**. In order to visualize the obtained results, the user may connect any output to any Simulink *Sink* block: *Scope*, *Display*, *ToWorkspace*, etc.

If the output **Results** is connected to a *ToWorkspace* block, as shown in Figure 1, one can access all the signals described in section **2.1.7** after the simulation is complete or stopped. For information on how to access stored data stored in a *ToWorkspace* block, please refer to the Matlab help.

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