About

Provide general information regarding the described model.

Model name	Grid-following inverter
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Short description	A grid-following three-phase grid-connected inverter. The inverter regulates the real and reactive power injection to their reference values through the appropriate current control mechanism, while it also achieves a smooth grid synchronization.
Present use / development status	The controller was developed for the purposes of the ERIGRID 2.0 H2020 project, based on existing literature.

Classification

Describe the context of the model regarding application (modelling domain, intended use) and technical details (modelling approach, model dynamics, model of computation, functional representation).

Domain	☐ electrical storage ☐ thermal storage ☐ energy conversion device ☒ other, please specify: DERs
Intended application (including scale and resolution)	The intended application is the electrical benchmark network that is being developed in ERIGRID 2.0 project. This model will aim to represent grid-connected inverters that follow a grid-following control philosophy, while its resolution lies in the range of ms.
Modelling of spatial aspects *Explain the approach of how this model describes the spatial distribution of the system.*	☐ lumped (single device) ☐ discretized (single device) ☒ averaged (multiple devices) ☐ other, please specify: This inverter can represent multiple grid-connected inverters as long as they are supposed to follow a grid-following control philosophy.
Model dynamics *Explain how the model captures the dynamic behaviour of the system.*	☒ quasi-static ☒ dynamic ☐ other, please specify: The inverter current is controlled during both steady-state and transient conditions.

Model of computation *Explain how the model captures the system's evolution with respect to time and/or external stimuli.*	☒ time-continuous ☒ discrete-event ☐ state machine ☐ other, please specify: The controller of the inverter continuously reads the voltage at the point of common coupling and adjusts the inverter current injection to meet the reference real and reactive power.
Functional representation *Are the model functions explicit, i.e., of type y = f(x), or implicit, i.e., of type g(x,y) = 0?*	☒ explicit ☐ implicit ☐ other, please specify: The controller functions are typical Proportional-Integral (PI) control functions. For the inverter, average modelling is assumed.

Mathematical Model

This section provides information about the actual mathematical model by specifying variables, parameters and equations. Variables and parameters should be specified with type (Real, Integer, Boolean, String) and (physical) unit. In case the equations are too complex to be reproduced here, also a reference to a book or any other publication can be given.

Input variables (name, type, unit, description)	V, PCC voltage, [V] P_set, Reference real power, [W] Q_set, Reference reactive power, [Var]
Output variables (name, type, unit, description)	Inverter output voltage
Parameters (name, type, unit, description)	PI controllers' gains, K_p & K_i Current limit of the inverter, I_max, [A]
Internal variables (name, type, unit, description)	PI controllers' states
Internal constants (name, type, unit, description)	N/A
Model equations *Formulate or provide references to the model's governing equations (describing the system state) and the constitutive equations (describing material properties)*	Governing equations Current controller: $v_d = v_{pccd} + \left(k_{pi} + \frac{k_{ii}}{s}\right)\left(i_d^{ref} - i_d\right) - \omega L i_q$ $v_q = v_{pccq} + \left(k_{pi} + \frac{k_{ii}}{s}\right)\left(i_q^{ref} - i_q\right) + \omega L i_d$ The inverter is considered as an ideal voltage source (average modelling)

	Constitutive equations
	N/A
Initial conditions	Controller: Input to PI controller is set to zero and the PCC voltage is forwarded to the PWM generator until the point of connection of the inverter to the grid.
Boundary conditions	Controller: m_abc (duty ratio) in the range [-1,1]
Optional: graphical representation (schematic diagram, state transition diagram, etc.)	N/A

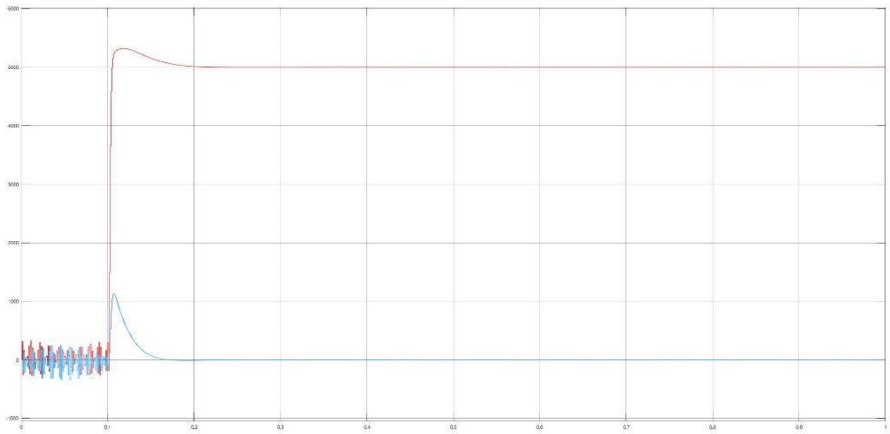
Testing

Please provide a (simple) test design for the purpose of component model validation. This test should enable three different kinds of comparisons:

- ***model validation**: compare the behaviour of an implementation of the exact same model based on time-series data*
- ***model harmonization**: compare the behaviour of an implementation of a (supposedly) similar model with the same or comparable intrinsic time resolution based on the comparison of key performance indicators*
- ***model upscaling**: compare the behaviour of an implementation of a (supposedly) similar model with a lower intrinsic time resolution based on the comparison of aggregated key performance indicators*

Model Validation *Provide the description of a test setup (i.e., simulation) that enables others to validate their implementation of the same model. The results should be provided as time series.*	
Narrative *Provide a simple description of the test specification.*	The controller ensures the safe synchronization of the inverter with the power grid. After the connection to the grid, the controller regulates the power injection of the inverter to its reference values, while during grid faults, the controller limits the inverter current to its maximum value.
Test system configuration *Describe the test setup, including:* *How long does the simulation run?* *Are there any other models required for this setup? If yes, provide a link to their description.*	The inverter represents grid-connected grid-following inverters of the electrical benchmark power system developed through ERIGRID 2.0 project. The simulation may run for some ms up to many hours.

Is a controller required for this setup (see also below)?	
Inputs and parameters *Specify the (exogeneous) inputs of the model used in this test. Also specify the model parameters used in this test. If necessary, attach this information as dataset.*	Same as in mathematical model.
Control function (optional) *Specify any additional control functions used for this test.*	N/A
Initial system state *Describe the initial state of the system.*	Same as "Initial conditions" in the mathematical model.
Temporal resolution *Provide information regarding the temporal resolution of the test simulation, such as integrator step size, time resolution for event handling, etc.*	Sampling time in the MATLAB/Simulink environment is accordingly selected as Ts=1e-3 to capture transient phenomena.
Evolution of system state *Describe (textual and/or graphical) the expected qualitative behaviour of the component model in this simulation.*	The inverter power injection is zero before the grid connection. When the inverter is connected to the grid, the controller regulates the power injection to the reference real and reactive power values. In the case of a grid voltage drop, the current is driven to its maximum value due to unavailability of injection of the reference power. Saturation units in the reference currents maintain the current inside its thermal limits.
Expected results *Provide a quantitative description of the expected simulation output based on time series. This information must be comprehensive enough*	The simulation results of the electrical benchmark network show that the controller manages to synchronize the inverter safely to the grid and also regulate the real and reactive power to their reference values. Moreover, it is shown that when a grid fault occurs, the inverter current is limited at its maximum value to avoid damages to the inverter device.

for someone else to validate his/her own implementation of this model. If necessary, attach this information as dataset.	<u>Indicative result:</u> Grid-following inverter synchornization to the grid with P_set=5000 and Q_set=0 (Red-real power [W], blue-reactive power [VAr]):  Relevant simulation results are provided in the main body of the deliverable.

Additional Information

Provide any other additional information here.

Reference implementation	N/A
Similar / related models	See ERIGRID 2.0 Github
Related publications	N/A
Intellectual property concerns (if applicable)	N/A