1. Document History

Date	Versions	Description	Author
23-07-2021	0.1	First draft version	Antonios Marinopoulos (JRC)
13-10-2021	0.2	Basic version of the model for simulations over short time intervals	Antonio De Paola (JRC)

1.1 System configuration identification

ID	Name
JRA1-EO-ST	JRA1 Electrical-Only system configuration – basic version

1.2 Short description of context

Context description
The system configuration described in this document has been developed as part of a reference setup for electrical only system simulations, performed in a Simulink/MATLAB environment. The goal of this reference setup is to become a benchmark for dynamic simulations over short time scales (up to tenths of seconds) of electrical distribution systems including loads, generators, DER (PV, wind, energy storage) and microgrids. The level of detail, as well as the component models, have been specifically selected to perform simulations that account for a wide range of events such as faults, connection/disconnection of assets and microgrid islanding.
Key figures
• Distribution grid: MV grid equivalent (as a 20kV voltage source), MV/LV transformer (including OLTC), 6 LV lines and 6 circuit breakers operating at 420V. • 2 RL static loads (both drawing 10 kW of active power a 1kVAr of reactive power). • 1 synchronous generator (nominal power of 60 kVA). • 1 grid-following inverter (maximum active power of 50kW) • 1 asynchronous motor (nominal power of 160 kVA) • 1 interconnected microgrid, which includes: - 1 grid-forming inverter - 1 static resistive load (drawing 2 kW of active power)
Key words
• LV distribution network • Inverter connected DER • OLTC MV/LV transformer • Interconnected microgrid (can also operate autonomously in islanding mode)

1.3 Climate

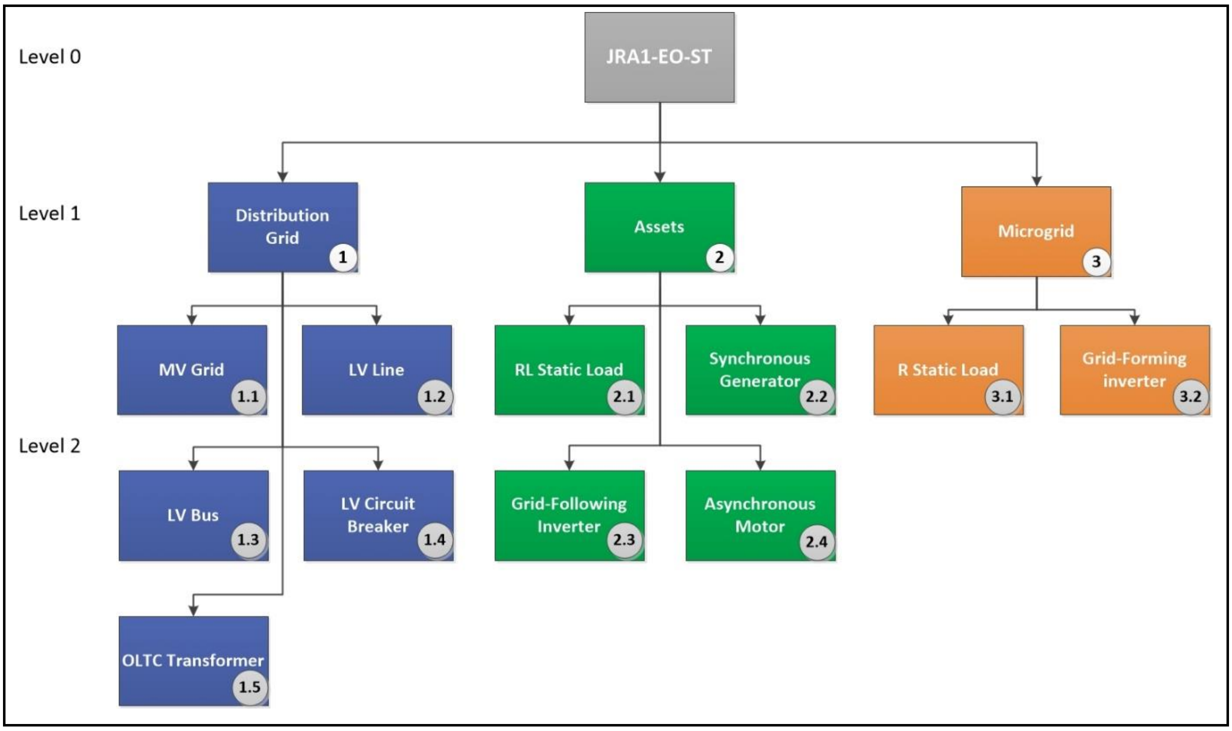
Climate conditions
N/A

Files attached		
File ID	Description	Units

1.4 Geographical features

Geographical features
N/A

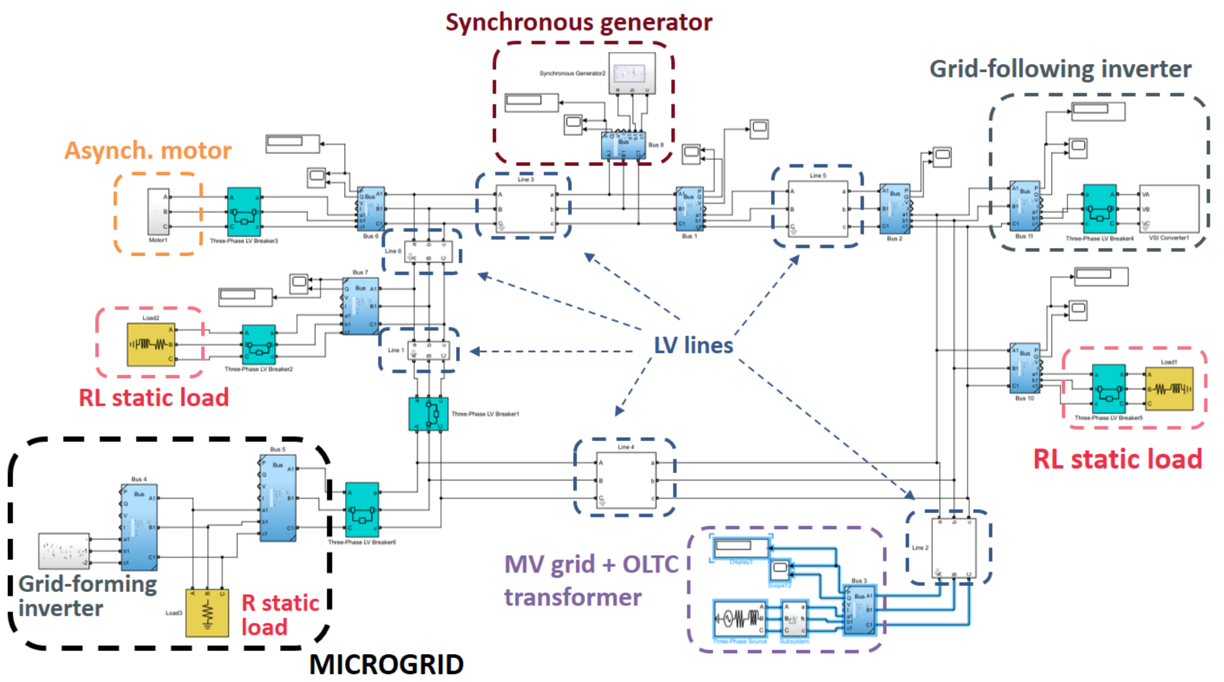
2. System breakdown (SBD)



3. Graphical representations of SC

3.1 Network diagrams

Overview



4. Element connections

Name	ID	Type of exchange	Types of class connected	Comment
Control signal port	ControlPort	Interface for control signal		
Electric power port	ElectricPort	Interface for electric power flow		

5. Elements description

Replicate the following table for every element in the SBD

About	
ID in SBD	1
Level in SBD	1
Class name	LVDistributionGrid
Parent class	-
Contained in	JRA1-EO-ST

Description	Overall model of the considered distribution network, containing the different electrical components present at the LV level and the interconnection with the upstream MV grid.
Number of elements in SC	1
Attributes	
Functionality	An electrical distribution network containing interconnected components, with the purpose of delivering electrical energy from the MV grid and from LV interconnected sources to the LV loads.
Physical characteristics	U_LV_n (float) – Nominal low voltage [V] U_MV_n (float) – Nominal medium voltage [V] f_n (float) - Nominal frequency [Hz]
Surroundings	-
Quality	-
Support	-
Operation type	Continuous type
Economical features	-
Legal constraints	-
Instances characterization	
Interfaces	-
ID in simulation	LVDG
Files attached	

About	
ID in SBD	1.1
Level in SBD	2
Class name	MVGrid
Parent class	-
Contained in	LVDG
Description	This element is used to represent the MV level of the electrical power system. It is modelled through a 3-phase voltage source in series with an RL branch, using the parameters of an equivalent MV electrical grid (CIGRE MV Benchmark model).
Number of elements in SC	1
Attributes	

Functionality	This element sets fixed values for voltage, frequency, and phase angle at the busbar to which it is connected.
Physical characteristics	U_rms (float) – Nominal medium voltage [Volt] Ph_ang (float) – Phase angle of phase A [degrees] f_n (float) - Nominal frequency [Hz]
Surroundings	-
Quality	-
Support	-
Operation type	-
Economical features	-
Legal constraints	-
Instances characterization	
Interfaces	port (ElectricPort) - bus where the lowstream LV grid is connected (three phase)
ID in simulation	MVGrid
Files attached	-

About	
ID in SBD	1.2
Level in SBD	2
Class name	LVLine
Parent class	-
Contained in	LVDG
Description	This element is used to model cables or overhead lines of a LV electric power system and is represented as a 3-phase series RL branch.
Number of elements in SC	6
Attributes	
Functionality	LV lines are used to connect two nodes/buses of a LV electric power system.
Physical characteristics	R (float) - Resistance [Ω] L (float) – Inductance [H]
Surroundings	-
Quality	-
Support	-
Operation type	-

Economical features	-
Legal constraints	-
Instances characterization	
Interfaces	port_a (ElectricPort) - connection with the bus on the sending end of the line (3-phase) port_b (ElectricPort) - connection with the bus on the receiving end of the line(3-phase)
ID in simulation	Line 1 – Line 6
Files attached	-

About	
ID in SBD	1.3
Level in SBD	2
Class name	LVBus
Parent class	-
Contained in	LVDG
Description	Graph node of the network diagram at which voltage and other electrical quantities are measured. It can correspond to physical busbars in substations.
Number of elements in SC	10
Attributes	
Functionality	The bus elements connect the different network components operating at the same voltage level. It also provides measurement of voltage, current, active and reactive power.
Physical characteristics	V_rms (float) – Root-mean-square voltage [Volt] Ph_ang (float) – Phase voltage angle of phase A [degrees] I_rms (float) – Root-mean-square current [Ampere] P_act (float) – Active power [W], with positive sign if flowing in the direction of the associated Simulink diagram Q_react (float) – Reactive power [VAr], with positive sign if flowing in the direction of the associated Simulink diagram
Surroundings	-
Quality	-
Support	-
Operation type	-
Economical features	-

Legal constraints	-
Instances characterization	
Interfaces	port (ElectricPort) - bus to which other electrical power system components can be connected.
ID in simulation	Bus 1 – Bus 10
Files attached	

About	
ID in SBD	1.4
Level in SBD	2
Class name	LVCircuitBreaker
Parent class	-
Contained in	LVDG
Description	Three-phase component of the electrical power system that can open/close in order to disconnect/connect the network components connected to its two terminals.
Number of elements in SC	6
Attributes	
Functionality	A three-phase circuit breaker (CB) can be normally open (NO) or normally closed (NC). It can then close (for a NO) or open (for a NC) at either a predefined time or following an external triggering signal. The CB can open/close any or all of its three phases.
Physical characteristics	t_s (float) – switching time [t] R_on (float) – breaker resistance [Ω] R_s (float) – snubber resistance [Ω] C_s (float) – snubber capacitance [F]
Surroundings	-
Quality	-
Support	-
Operation type	-
Economical features	-
Legal constraints	-
Instances characterization	
Interfaces	port_a (ElectricPort) - port_b (ElectricPort) -

	Representation of the two distinct terminals of the circuit breaker, to which the relevant sections of the LV network are connected
ID in simulation	Three Phase LV Breaker 1-6
Files attached	

About	
ID in SBD	1.5
Level in SBD	2
Class name	OLTC_trafo
Parent class	-
Contained in	LVDG
Description	A three-phase two-winding transformer model that transfers electrical energy between the MV and LV sections of the network. The component includes also an On-Load Tap Changer (OLTC) and the respective controls.
Number of elements in SC	1
Attributes	
Functionality	The transformer (Yg/Delta1) connects the voltage level of the node at the primary side (the feeding MV grid) to the voltage level of the node at the secondary side (LV distribution grid). The three-phase primary multi-tap winding is modeled with three Variable-Ratio Transformer blocks. The OLTC is controlled by the secondary voltage using a feedback control loop and adapts the voltage ratio between the primary and secondary side, so that the secondary voltage is kept between an upper and a lower boundary. The transformer voltage ratio V_2/V_1 is given by: V_2/V_1= 1/ (1+TapPosition*Δ_U) Tap position 0 corresponds to nominal voltage ratio. When the 'Voltage regulator' is 'on', the signal applied at the 'Vm' input is monitored and the voltage regulator asks for a tap change if: abs(Vm-V_ref)>db/2, during a time t > del.
Physical characteristics	<u>Transformer</u> P_nom (float) – nominal apparent power [VA] F_nom (float) – nominal frequency [Hz] V_1 (float) – winding 1 (Yg) rated ph-ph rms [V] R_1 (float) – winding 1 (Yg) resistance [pu] X_1 (float) – winding 1 (Yg) reactance [pu]

	V_2 (float) – winding 2 (D1) rated ph-ph rms [V] R_2 (float) – winding 2 (D1) resistance [pu] X_2 (float) – winding 2 (D1) reactance [pu] R_m (float) – magnetization branch resistance [pu] L_m (float) – magnetization branch inductance [pu] <u>OLTC</u> Δ_U (float) – voltage step per tap [pu] min_tap (float) – minimum tap position max_tap (float) – maximum tap position init_tap (float) – initial tap position t_tap (float) – tap selection time [s] <u>Voltage Regulator (if selected)</u> V_ref – reference voltage [pu] db (float) – voltage dead band [pu] del (float) – time delay [s] v_tap (float) – voltage per tap [%] shift (float) – transformer phase shift angle [°]
Surroundings	-
Quality	-
Support	-
Operation type	-
Economical features	-
Legal constraints	-
Instances characterization	
Interfaces	port_1 (ElectricPort) - connection of the primary side (MV) of the transformer port_2 (ElectricPort) - connection of the secondary side (LV) of the transformer
ID in simulation	Three-Phase Tap Changer Transformer
Files attached	

About	
ID in SBD	2
Level in SBD	1
Class name	Assets
Parent class	-
Contained in	JRA1-EO
Description	This is a collection of elements representing electrical components that can be connected to the LV electrical distribution grid.

Number of elements in SC	1
Attributes	
Functionality	The different electrical components can produce, consume, or convert electrical energy.
Physical characteristics	-
Surroundings	-
Quality	-
Support	-
Operation type	-
Economical features	-
Legal constraints	-
Instances characterization	
Interfaces	-
ID in simulation	Assets
Files attached	-

About	
ID in SBD	2.1
Level in SBD	2
Class name	RLStaticLoad
Parent class	-
Contained in	Assets
Description	Component of the electrical power system that consumes electric power.
Number of elements in SC	1
Attributes	
Functionality	The component represents a load with constant resistance and inductance (series RL).
Physical characteristics	Conf (text) – type of 3-ph configuration [Yg, Yn, Y, D] V_n (float) – nominal ph-ph rms voltage [V] f_n (float) – nominal frequency [Hz] P (float) – active power [W] Q_L (float) – inductive reactive power [VAr] Q_c (float) – capacitive reactive power [VAr] L_type (text) – load type for load flow simulation [constant Z, PQ, I]
Surroundings	-

Quality	-
Support	-
Operation type	-
Economical features	-
Legal constraints	-
Instances characterization	
Interfaces	port (ElectricPort) — connection to the LV network
ID in simulation	RLStatic
Files attached	

About	
ID in SBD	2.2
Level in SBD	2
Class name	SynchronousGenerator
Parent class	-
Contained in	Assets
Description	Component of the electrical power system that generates electric power.
Number of elements in SC	1
Attributes	
Functionality	The synchronous generator is modelled with a 3-phase synchronous machine model in the dq rotor reference frame. The stator windings are connected in wye to an internal neutral point.
Physical characteristics	P_n (float) – nominal power [VA] V_n (float) – line to line rms voltage [V] f_n (float) – frequency [Hz] Xd, Xd', Xd'', Xq, Xq'', Xl (float) – reactances [pu] Td', Td'', Tq'' (float) – d and q time constants (open or close circuits) [s] Rs (float) – stator resistance [pu] H (float) – inertia coefficient [s] F (float) – friction factor [pu] p (float) – number of pole pairs Initial conditions dw (float) – speed deviation Δω [%] th (float) – electrical angle of rotor Θe [deg] i_a, i_b, i_c – line current magnitude [pu] ph_a, ph_b, ph_c – line phase angles [deg] V_f (float) – field voltage [pu]

	No-load saturation curve parameters Magnetic saturation of the stator and rotor iron is modeled by a piecewise linear relationship specifying points on the no-load saturation curve. The first row of this matrix contains the values of field currents. The second row contains values of corresponding terminal voltages. i_fd (float) – field current [pu] v_t (float) – terminal voltage [pu]
Surroundings	-
Quality	-
Support	-
Operation type	-
Economical features	-
Legal constraints	-
Instances characterization	
Interfaces	port_1 (ElectricPort) - connection to the LV grid (three phase terminal of the generator) port_2 (ControlPort) –control signal of the field voltage V_f from the excitation system block. port_3 (ControlPort) - control signal of the mechanical power P_m . port_4 (ControlPort) – provides relevant measurement signals.
ID in simulation	SynGen
Files attached	

About	
ID in SBD	2.3
Level in SBD	2
Class name	GridFollowingInverter
Parent class	-
Contained in	Assets
Description	Component that converts direct current into alternating current. In the present benchmark network, it is implicitly assumed that the DC energy source of the inverter corresponds to a renewable generator.
Number of elements in SC	
Attributes	

Functionality	The grid following inverter is modelled as a VSI Converter (Voltage Source Inverter), which outputs an AC voltage from a DC voltage source. The AC voltage signal follows the frequency of the grid.
Physical characteristics	P_max (float) – maximum active power [W] Q_max (float) – maximum reactive power [VAr] V_dc (float) – DC bus voltage [V[f_s (float) – switching frequency [Hz] L_f (float) – filter inductance [H] L_out (float) – output inductance [H] C_f (float) – filter capacitance [F]
Surroundings	-
Quality	-
Support	-
Operation type	-
Economical features	-
Legal constraints	-
Instances characterization	
Interfaces	port_1 (ElectricPort) - connection to the LV grid (three phase terminal of the converter) port_2 (ControlPort) – control signal of the active power reference. port_3 (ControlPort) - control signal of the reactive power reference. port_4 (ControlPort) – connection to the PI controller triggering signal is connected. port_5 (ControlPort) – voltage and current signal for the grid and the DC bus. port_6 (ControlPort) – saturation control signal.
ID in simulation	InvGrFollow
Files attached	

About	
ID in SBD	2.4
Level in SBD	2
Class name	AsynchronousMotor
Parent class	-
Contained in	Assets
Description	Component of the electrical power system that consumes electrical power, transforming electrical energy to mechanical.

Number of elements in SC	1
Attributes	
Functionality	The asynchronous motor is modelled with a three-phase asynchronous machine (squirrel cage) in a selectable dq reference frame (rotor). Stator and rotor windings are connected in wye to an internal neutral point. The shaft mechanical torque is an input to the model.
Physical characteristics	P_n (float) – nominal power [VA] V_n (float) – line to line rms voltage [V] f_n (float) – frequency [Hz] Rs (float) – stator resistance [Ω] Lls (float) – stator inductance [H] Rr' (float) – rotor resistance [Ω] Llr' (float) – rotor inductance [H] Lm (float) – mutual inductance [H] J (float) – inertia coefficient [kg.m^2] F (float) – friction factor [N.m.s] p (float) – number of pole pairs <u>Initial conditions</u> s (float) – slip [%] th (float) – electrical angle Θe [deg] i_a, i_b, i_c – stator current magnitude [A] ph_a, ph_b, ph_c – stator phase angles [deg] V_f (float) – field voltage [pu] <u>No-load saturation curve parameters</u> Magnetic saturation of the stator and rotor iron is modeled by a piecewise linear relationship specifying points of the no-load saturation curve. The first row of this matrix contains the values of stator currents. The second row contains values of corresponding terminal voltages. i (float) – stator rms current [A] v (float) – line to line terminal rms voltage [V]
Surroundings	-
Quality	-
Support	-
Operation type	-
Economical features	-
Legal constraints	-
Instances characterization	
Interfaces	port_1 (ElectricPort) - connection of the motor to the grid (three phase terminal of the motor) port_2 (ControlPort) – control signal of the mechanical torque Tm.
ID in simulation	SynMot

Files attached	

About	
ID in SBD	3
Level in SBD	1
Class name	Microgrid
Parent class	-
Contained in	JRA1-EO
Description	Group of energy sources and loads that has the capability to either operate synchronously with the interconnected grid or autonomously in islanded mode. In this model, the microgrid is composed by a grid-forming inverter and by a resistive load.
Number of elements in SC	1
Attributes	
Functionality	The electrical microgrid, containing a grid-forming inverter and a resistive load, is connected to the main LV distribution grid through a common point of coupling. The microgrid can operate in interconnected and autonomous (grid islanding) mode. In the latter case, the local load is fed by the renewable energy source that is assumed to be powering the grid forming inverter.
Physical characteristics	U_n (float) – nominal voltage [V] f_n (float) - nominal frequency [Hz]
Surroundings	-
Quality	-
Support	-
Operation type	Continuous type
Economical features	-
Legal constraints	-
Instances characterization	
Interfaces	-
ID in simulation	MG
Files attached	

About

ID in SBD	3.1
Level in SBD	2
Class name	RStaticLoad
Parent class	-
Contained in	MG
Description	Component of the electrical power system that consumes electric power.
Number of elements in SC	1
Attributes	
Functionality	The component represents a resistive load with constant impedance (R type).
Physical characteristics	Conf (text) – type of 3-ph configuration [Yg, Yn, Y, D] V_n (float) – nominal ph-ph rms voltage [V] f_n (float) – nominal frequency [Hz] P (float) – active power [W] Q_L (float) – inductive reactive power [VAr] Q_c (float) – capacitive reactive power [VAr] L_type (text) – load type for load flow simulation [constant Z, PQ, I]
Surroundings	-
Quality	-
Support	-
Operation type	-
Economical features	-
Legal constraints	-
Instances characterization	
Interfaces	port (ElectricPort) -– connection of the component to the microgrid
ID in simulation	RStatic
Files attached	

About	
ID in SBD	3.2
Level in SBD	2
Class name	GridFormingInverter
Parent class	-

Contained in	MG
Description	Component that converts direct current into alternating current. In the present benchmark network, it is implicitly assumed that the DC energy source of the inverter corresponds to a renewable generator.
Number of elements in SC	
Attributes	
Functionality	The grid forming inverter is modelled using a Universal 3-arm Bridge with ideal switches, fed by a constant DC source, in series with an RL and a shunt capacitor. The bridge is driven by a PWM signal created by an appropriate voltage controller. The inverter is able to independently set up and maintain the network frequency at its nominal value (50Hz), without the need for a reference grid voltage.
Physical characteristics	Universal Bridge Rs (float) – snubber resistance [Ω] Cs (float) – snubber capacitance [F] Ron (float) – internal resistance [Ω] Ideal DC Voltage source V (float) – voltage amplitude [V] Three-phase series RL branch R (float) – resistance [Ω] L (float) – inductance [H] Three-phase series C branch C (float) – capacitance [F]
Surroundings	-
Quality	-
Support	-
Operation type	-
Economical features	-
Legal constraints	-
Instances characterization	
Interfaces	port_1 (ElectricPort) - Connection of the converter to the grid (three phase terminal of the converter)
ID in simulation	InvGrForm
Files attached	