GRID EMT

SIMULATION INITIATIVE

Uniform User Interface and Internal Structure for EMT Plant Models

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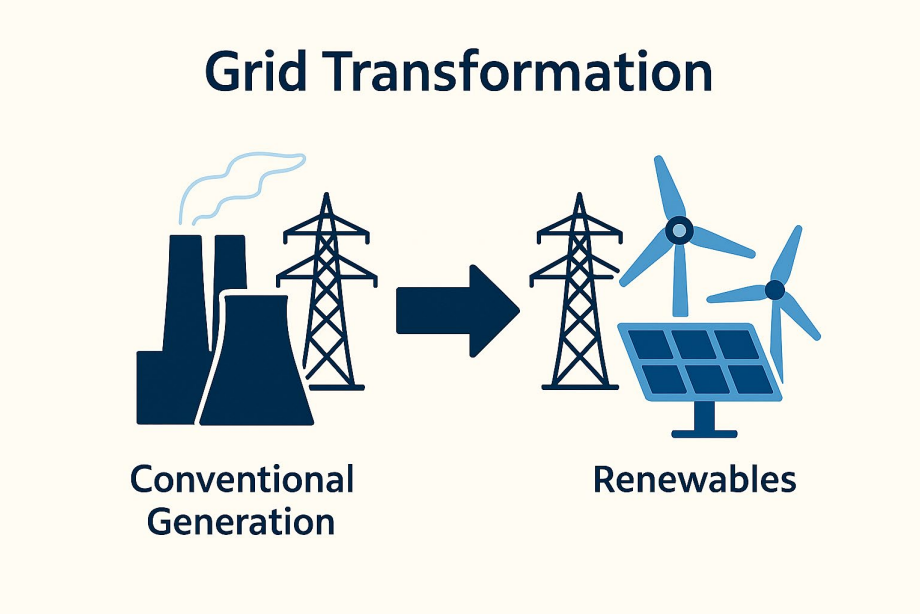
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White Paper Development History

- **April 2026 | Industry Review**:
  - Received technical feedback and comments from five industry organizations.
- **May 13 – June 12, 2026 | RSTC Review**:
  - Revised white paper was submitted to RSTC for formal review.
  - Received 20 RSTC comments
- **June – August 2026 | Comment Resolution**
  - Reviewed and addressed all RSTC comments
  - Revised white paper to be resubmitted to RSTC
- **Mid-September 2026**: Final RSTC consensus and review process.

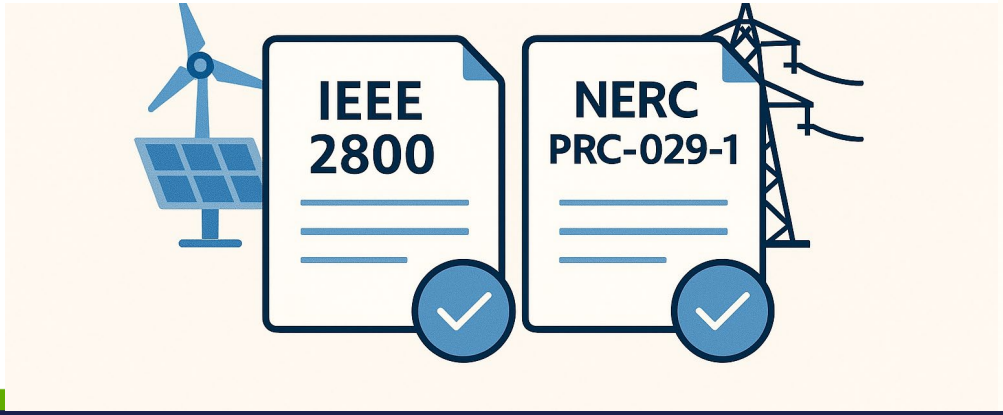
Motivation

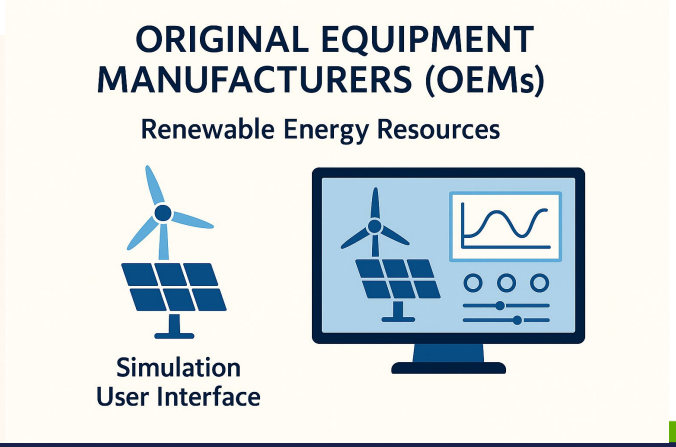
- IBR Interconnection requests are increasing rapidly, creating new validation and verification challenges.
- EMT models are now needed in addition to traditional Phasor Domain (PD) models.



Motivation

- **Standards:** IEEE 2800-2022 and NERC PRC-029-1 establish performance and testing requirements for inverter-based resources (IBRs).
- **Industry gap:** There is **no common practice or harmonized approach** for structuring and presenting EMT-based IBR plant models.
- **Implication:** Model User Interface (UI), internal structure, including electrical and control components, can vary significantly across projects and vendors (OEMs).





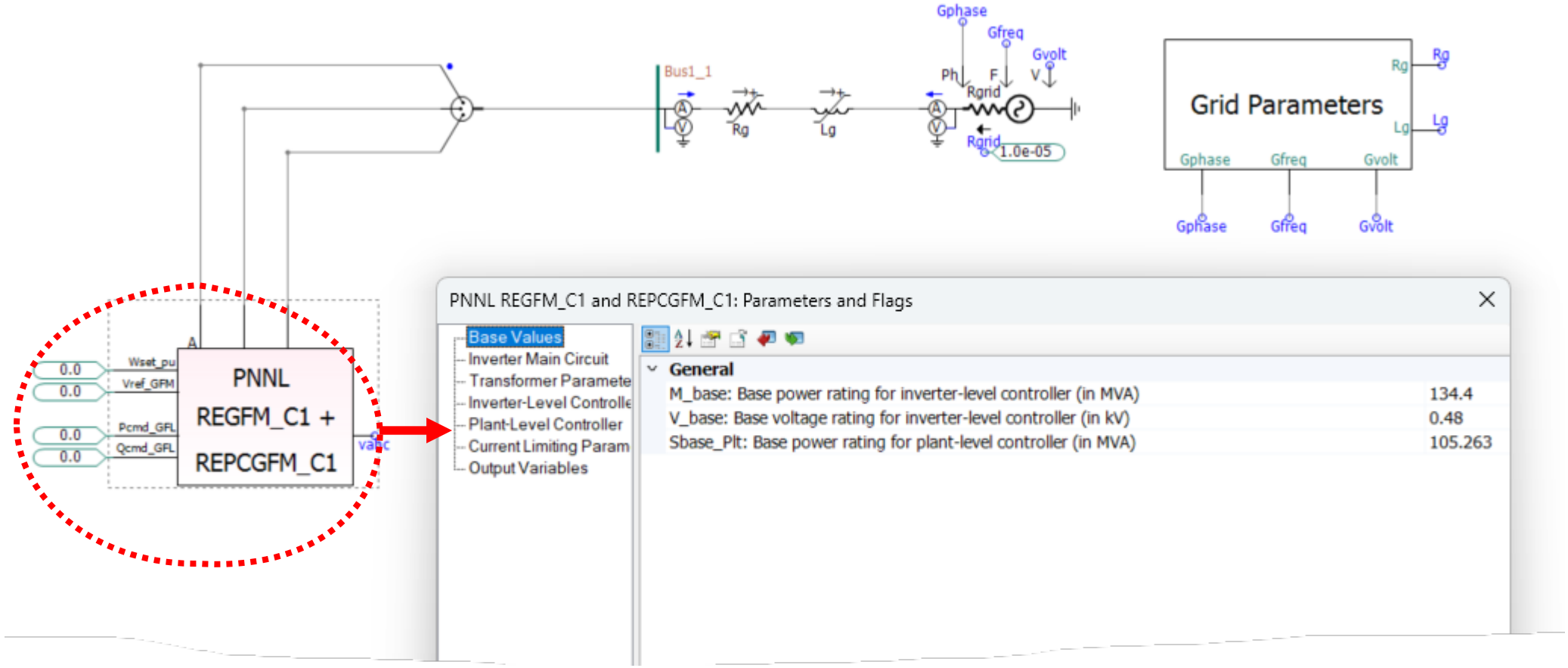
Approach

This white paper proposes a unified framework for EMT-based IBR plant models:

- **A uniform user interface (test harness)**
- **A uniform internal structure**

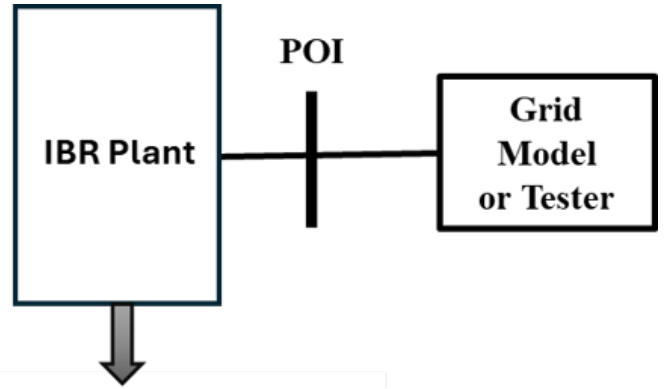


Example of User Interface (Test Harness)



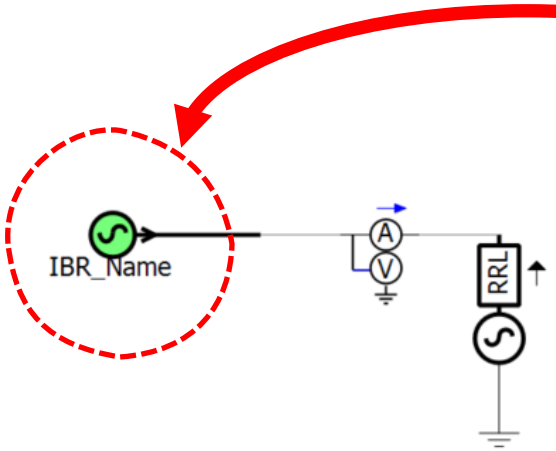
Conceptual Uniform User Interface (Uniform Test Harness)

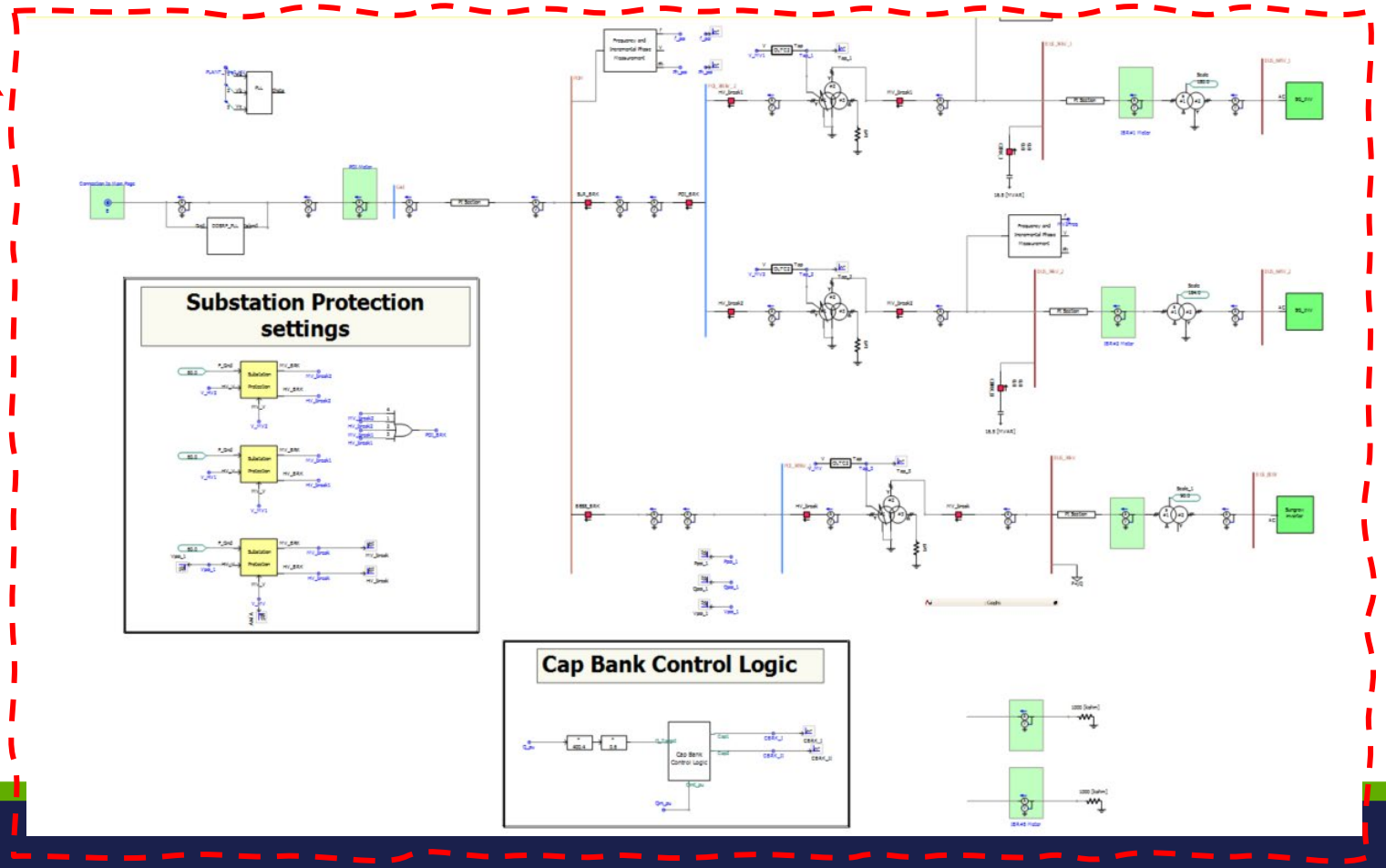
- Provides a standardized set of inputs, outputs, operating modes, and initialization parameters for EMT-based IBR plant models.
- Ensures essential data, voltages, currents, active/reactive power, control references, and protection settings, is consistently defined.
- Makes key model information readily accessible for system studies and testing by engineering teams.



Inputs	Described in Table 1.1
Outputs	Described in Table 1.2
Operation modes	Described in Table 1.3
Initialization	Described in Table 1.4

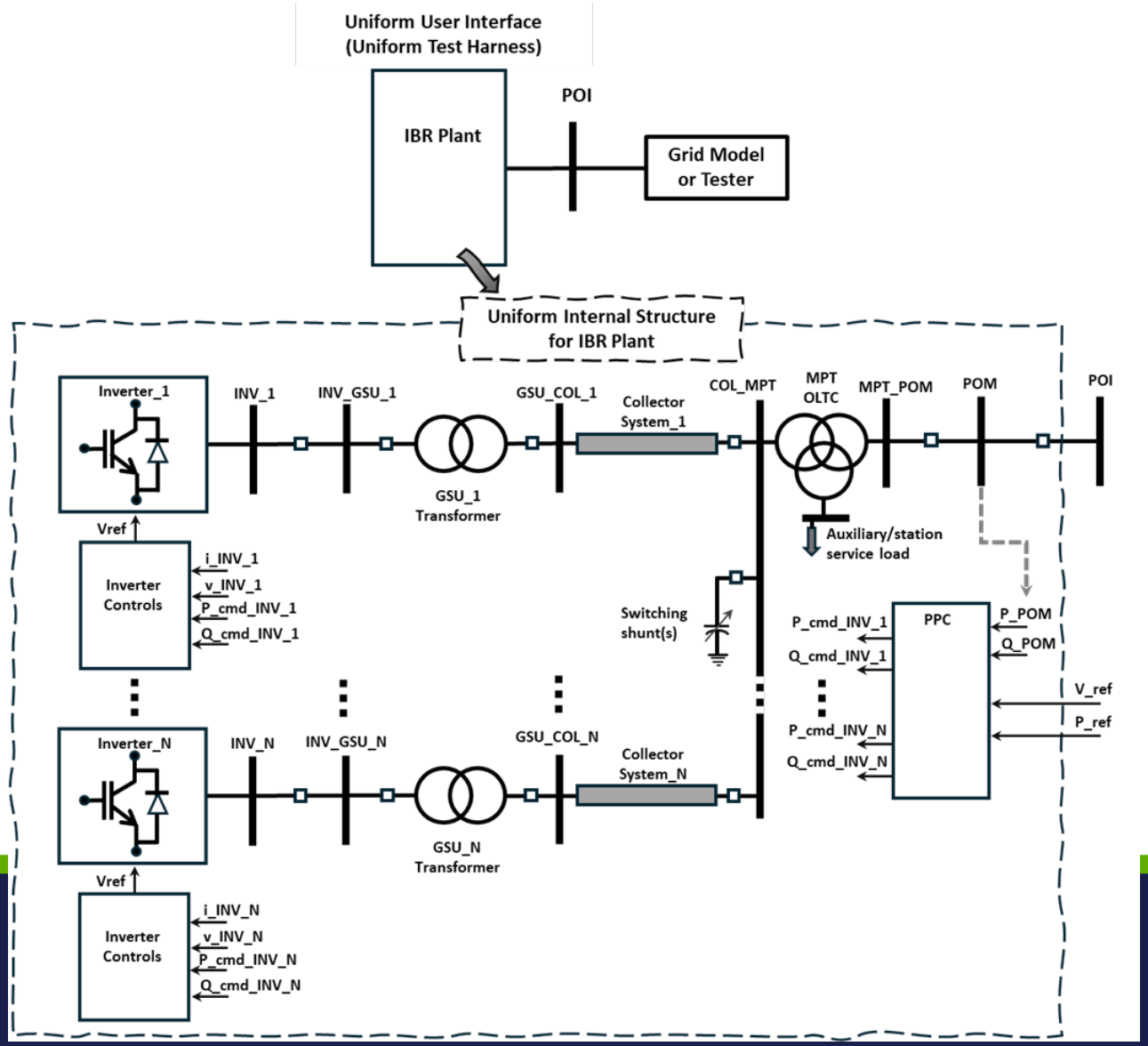
Example of Internal Structure



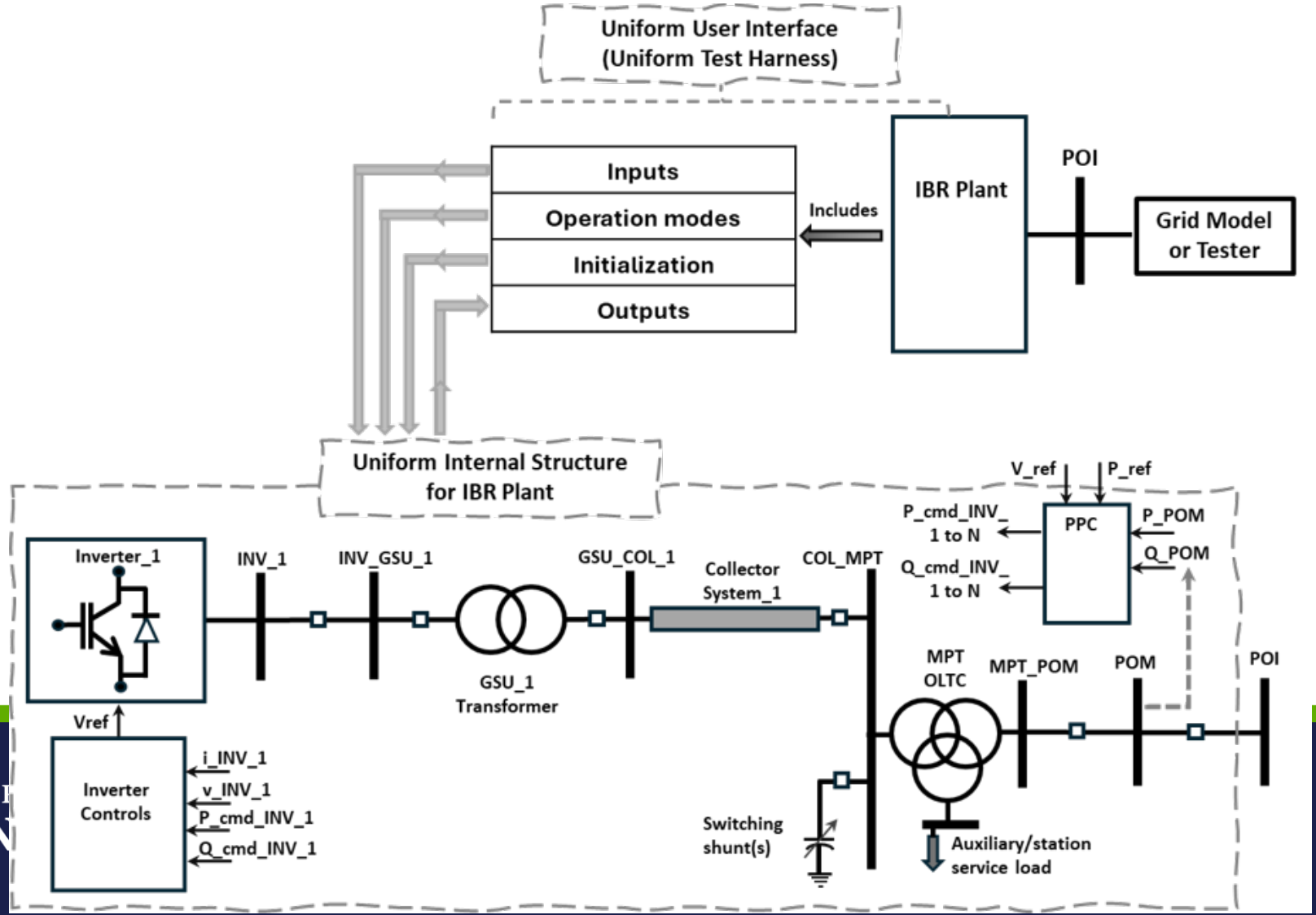


Conceptual Uniform Internal Structure

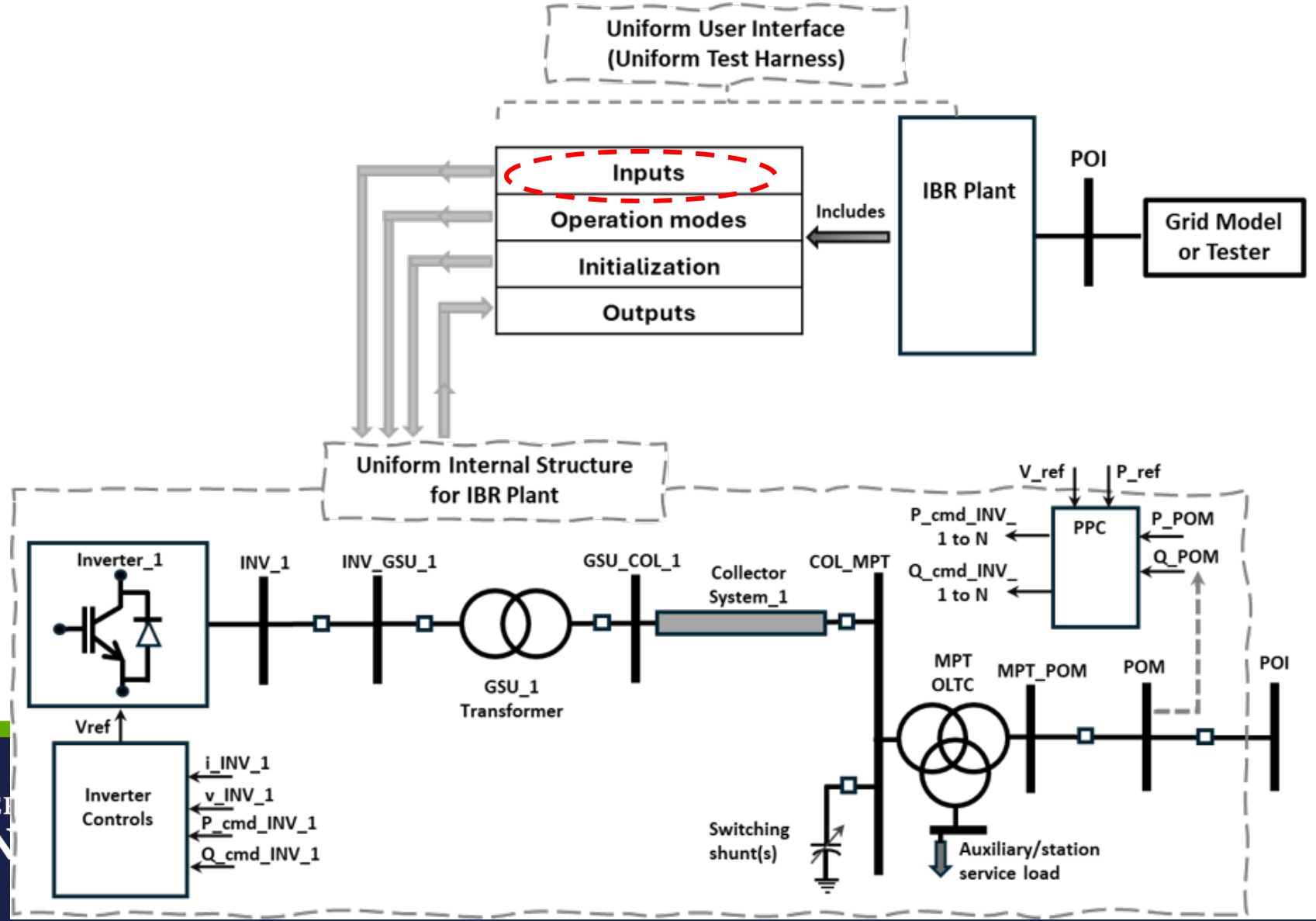
- Provides a consistent framework for organizing all internal components of EMT-based IBR plant models.
- Covers electrical network elements, plant-level controls, inverter-level controls, and protection systems.
- Ensures model elements are arranged in a predictable, standardized way to support efficient analysis and testing.



Overall Conceptual Diagram for Uniform User Interface and Uniform Internal Structure



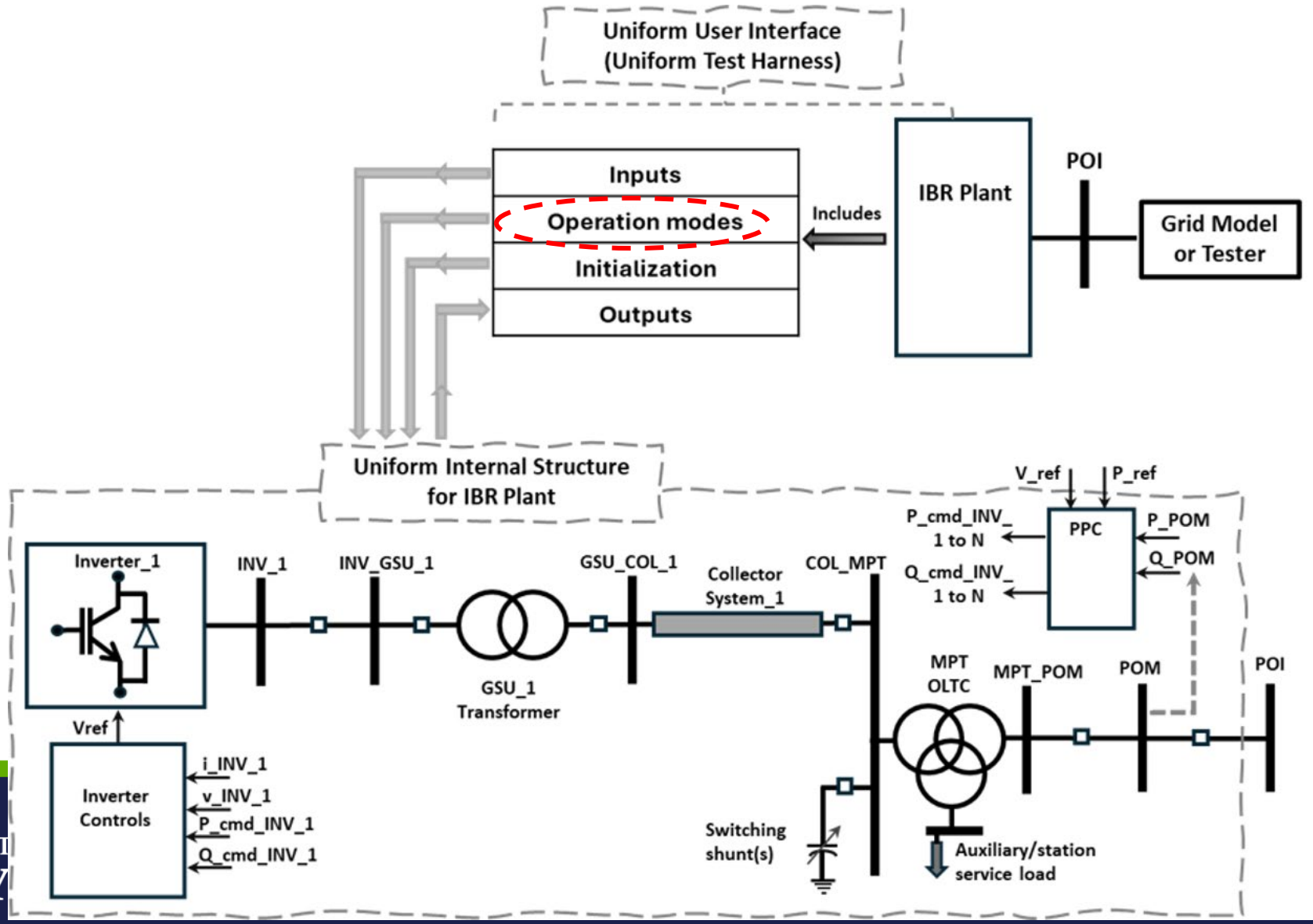
Uniform User Interface (Test Harness) – Inputs



Uniform User Interface (Test Harness) – Inputs

Inputs		
Parameter Name	**Description**	**Unit**
Pref_plant	Active power reference(s) for the PPC. If multiple dispatches are required for separate project sections, each should have a reference included.	MW or p.u.
Fref_plant	Frequency reference for the PPC	Hz
Qref_plant	Reactive power reference for the PPC	MVAr or p.u.
Vref_plant	Voltage reference for the PPC if it works on voltage control mode	kV or p.u.
PFref_plant	Power factor reference for the PPC if it works on PF control mode	MW or p.u.
MVA_Base	Base power of the plant	MVA
Voltage_Base	Base voltage at point of measurement (POM)	kV

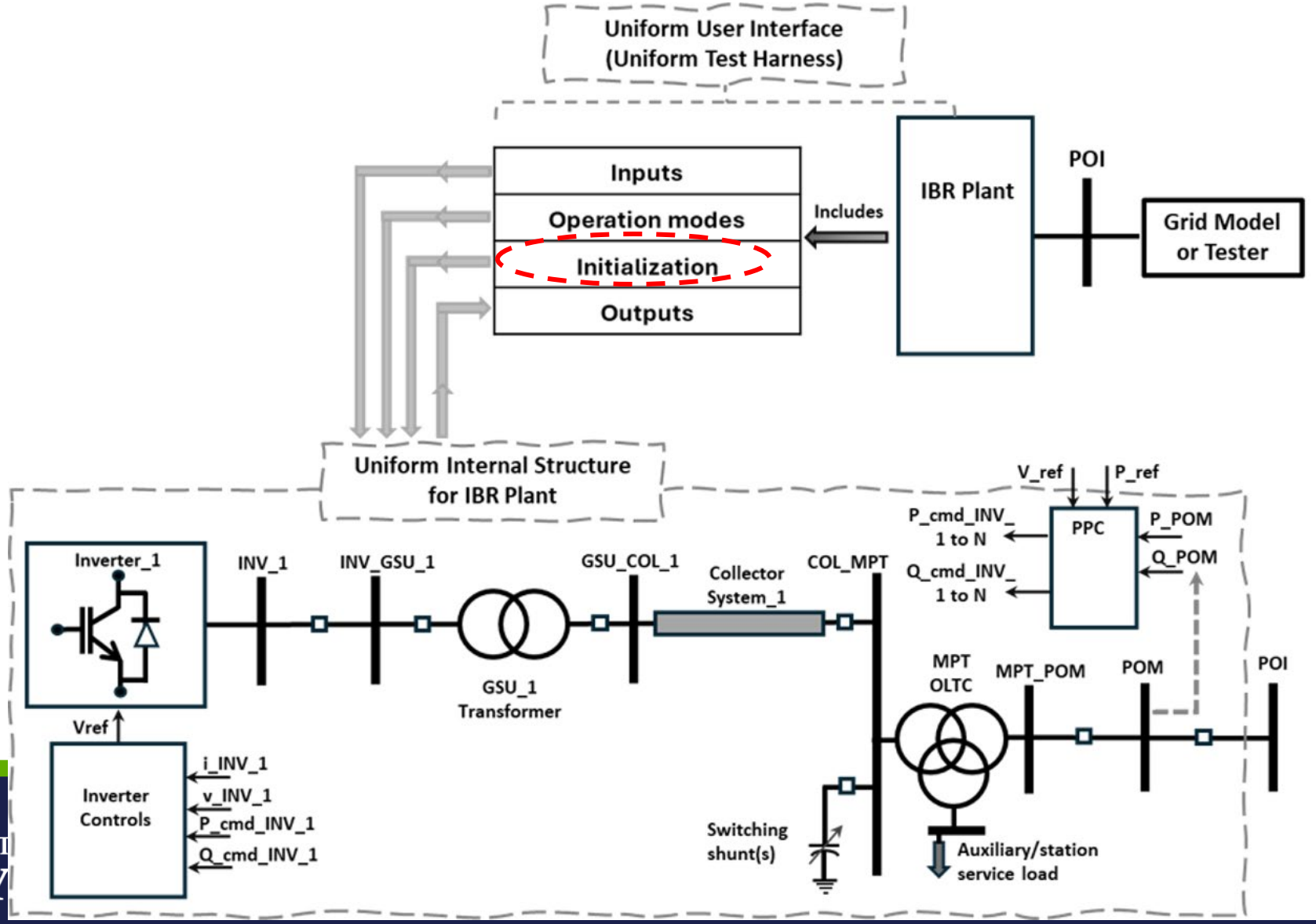
Uniform User Interface (Test Harness) – Operation Modes



Uniform User Interface (Test Harness) – Operation Modes

Operation Modes	
Operation Modes	**Description**
1	PV/Wind Only–PV/Wind injecting, BESS Idle
2	BESS Only–Injecting, PV/Wind Idle
3	BESS Only–Charging, PV/Wind Idle
4	Hybrid Mode 1–PV/Wind Injecting, BESS Charging
5	Hybrid Mode 2–PV/Wind Injecting, BESS Injecting

Uniform User Interface (Test Harness) – Initialization

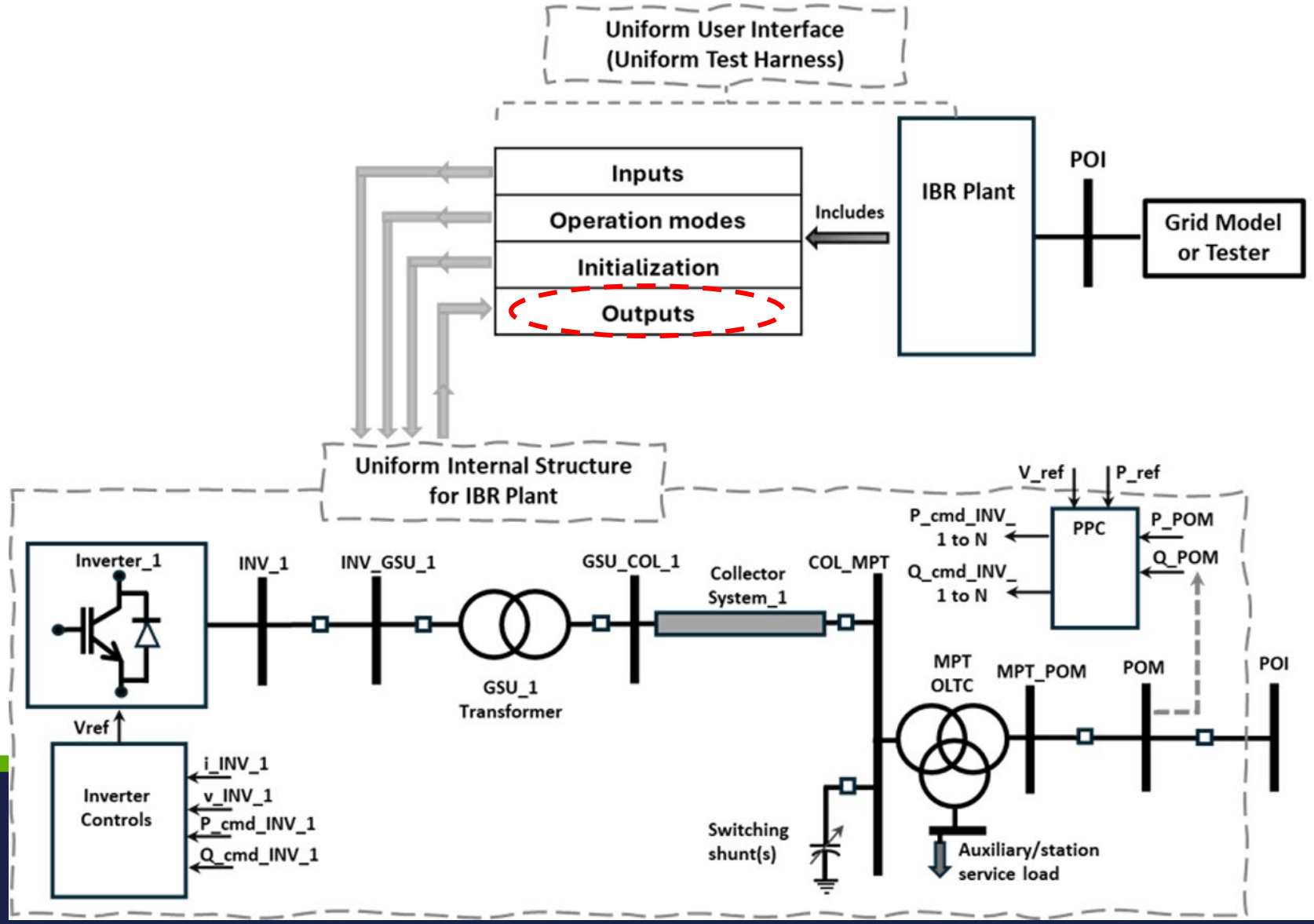


Uniform User Interface (Test Harness) – Initialization

Initialization for the Uniform Test Harness		
Initialized Parameters	**Description**	**Unit**
P_init	Initialize the active power for the PPC. Separate active power setpoints may be necessary for hybrid facilities to ensure that each component of the facility initializes to its target active power setpoint.	MW, p.u.
Q_init	Initialize the reactive power for the PPC and inverter.	MAVr, p.u.
V_init	Initialize the RMS voltage for PPC.	kV, p.u.
Tap_MPT_init	Initialize the status of MPT OLTP, if included in the facility's design.	-
Shunt_init	Initialize the status of shunt (e.g., cap banks or reactor.) internal to the plant, if included in the facility's design.	-
Angle_init	Initialize voltage angle for PPC.	Degree
Dblock	Deblocking signal for the IBR plant.	-

Uniform User Interface (Test Harness) - Outputs

- Voltages
- Currents
- Active Power
- Reactive Power
- Signals
- PPC Command Signals



Uniform User Interface (Test Harness) - Outputs

Outputs		
Parameter Name	**Description**	**Unit**
Voltages		
V_POM	Voltage at POM	kV or p.u.
V_POI	Voltage at POI	kV or p.u.
V_HV_MPT	Voltage at bus on the transmission grid side of the transformer	kV or p.u.
V_LV_MPT	Voltage at bus on the collector grid side of the transformer	kV or p.u.
V_HV_GSU_i	Voltage at high side of i-th GSU	kV or p.u.
V_LV_GSU_i	Voltage at low side of i-th GSU	kV or p.u.
V_INV_Terminal_i	Voltage at the terminal of i-th inverter	kV or p.u.
V_DC_P_i	dc-side positive voltage of i-th inverter	kV or p.u.
V_DC_N_i	dc-side negative voltage of i-th inverter	kV or p.u.
V_DC_UN_i	dc-side unbalanced voltage of i-th inverter	kV or p.u.

Uniform User Interface (Test Harness) - Outputs

Outputs		
Parameter Name	**Description**	**Unit**
Currents		
I_HV_MPT	Current at bus on the transmission grid side of the transformer	kA or p.u.
I_LV_MPT	Current at bus on the collector side of the transformer	kA or p.u.
I_INV_Terminal_i	Current at the terminal of i-th inverter	kA or p.u.
I_HV_GSU_i	Current at high side of i-th GSU	kA or p.u.
I_LV_GSU_i	Current at low side of i-th GSU	kA or p.u.
I_INV_Terminal_i	Current at the terminal of i-th inverter	kA or p.u.
I_SHNT_Terminal_i	Current at i-th shunt device	kA or p.u.

Uniform User Interface (Test Harness) - Outputs

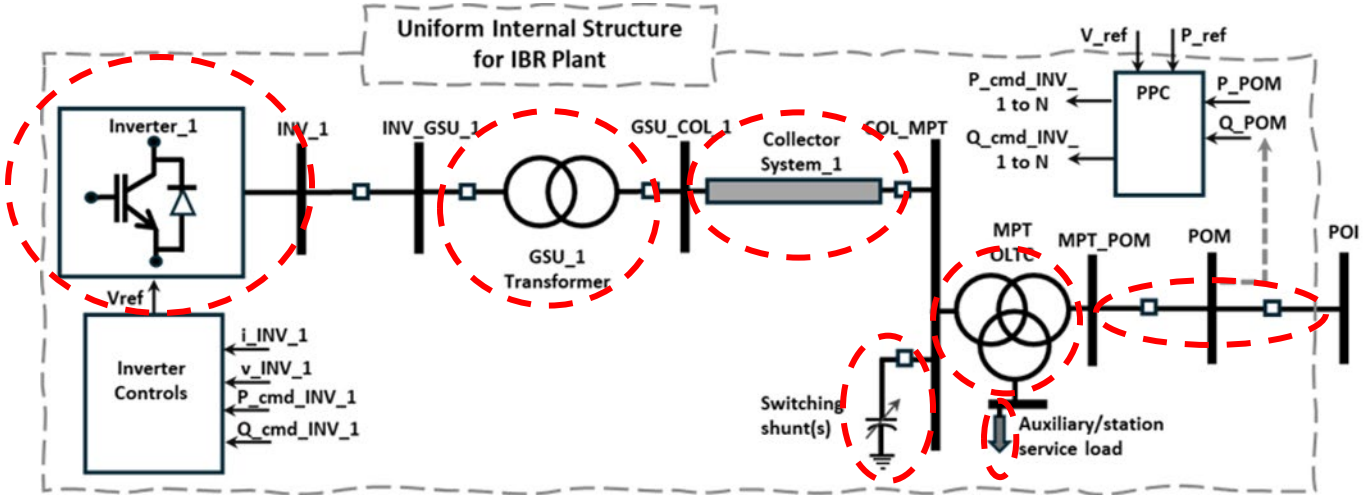
Outputs		
Parameter Name	**Description**	**Unit**
Active Power		
P_POI and/or POM	Active power at POI and/or POM	MW or p.u.
P_HV_MPT	Active power at HV side of MPT	MW or p.u.
P_LV_MPT	Active power at LV side of MPT	MW or p.u.
P_HV_GSU_i	Active power at HV side of i-th GSU	MW or p.u.
P_LV_GSU_i	Active power at LV side of i-th GSU	MW or p.u.
P_INV_Terminal_i	Active power at i-th inverter terminal	MW or p.u.
P_SHNT_Terminal_i	Active power at i-th shunt device	MW or p.u.
Reactive Power		
Q_POI and/or POM	Reactive power at POM and/or POM	MVAr or p.u.
Q_HV_MPT	Reactive power at HV side of MPT	MVAr or p.u.
Q_LV_MPT	Reactive power at LV side of MPT	MVAr or p.u.
Q_HV_GSU_i	Reactive power at HV side of i-th GSU	MVAr or p.u.
Q_LV_GSU_i	Reactive power at LV side of i-th GSU	MVAr or p.u.
Q_INV_Terminal_i	Reactive power at i-th inverter terminal	MVAr or p.u.
Q_SHNT_Terminal_i	Reactive power at i-th shunt device	MVAr or p.u.

Uniform User Interface (Test Harness) - Outputs

Outputs		
Parameter Name	**Description**	**Unit**
Signals		
HVRT_FLAG	HVRT flag	-
LVRT_FLAG	LVRT flag	-
UV_INV_i and OV_INV_i	UV/OV protection flag at i-th inverter	-
UF_INV_i and OF_INV_i	UF/OF protection flag at i-th inverter	-
UV_Feeder_i and OV_Feeder_i	UV/OV protection flag at i-th collector system	-
UV_MPT and OV_MPT	UV/OV protection flag at MPT	-
SHNT_Prt	Shunt device or Cap bank protection	-
Cessation_Flag	Momentary cessation flag	-
OC_INV_i	Overcurrent protection at the terminal of the i-th inverter	-
Tap_MPT	Tap position at OLTC of MPT	-
SW_shunt_i	Switching shunt at i-th shunt device	-
BRK_FLAG_i	Breaker status for low-side breakers	-
PPC Command Signals		
Pcmd_i	Active power command for the i-th inverter	MW or p.u.
Qcmd_i	Reactive power command for the i-th inverter	MW or p.u.
SHNT_SW	Shunt switching commands	-

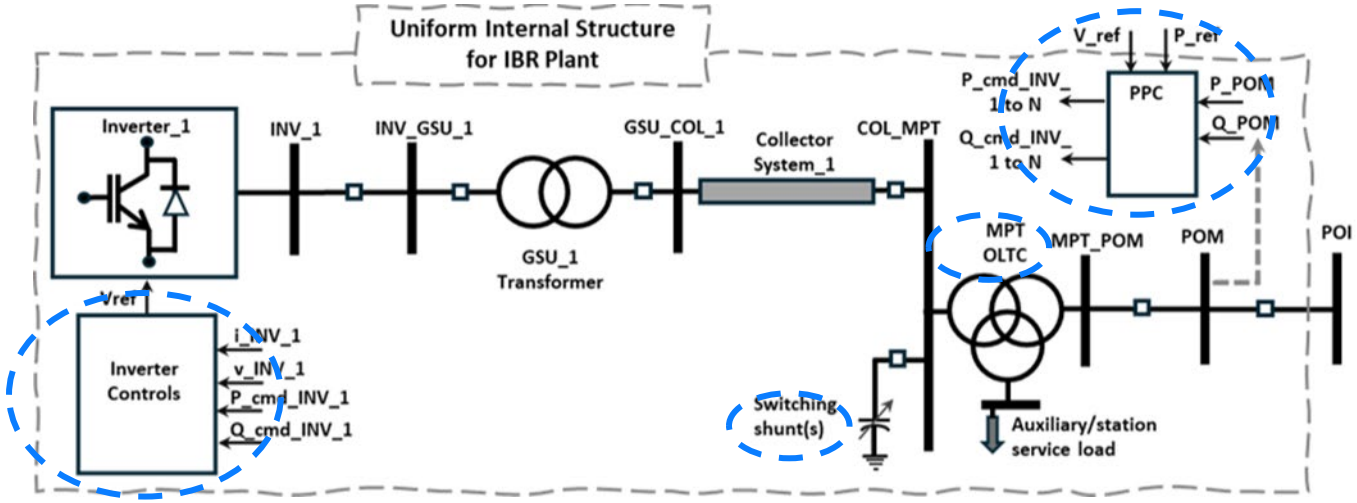
Uniform Internal Structure - Circuit Components

- Transmission lines from main power transformer (MPT) to the POI,
- MPT(s),
- Switching shunt(s),
- Auxiliary and station service load,
- Collector system,
- Generator step-up (GSU) transformer(s),
- Inverters and its AC side filters and DC side impedance.



Uniform Internal Structure - Protection and Control Components

- Power plant controller (PPC),
- Onload tap changer (OLTC) settings of MPT
- Switching shunt(s) logics,
- Inverter control and protections,
- Substation and feeder's protections.



Uniform Internal Structure – Main Power Transformer

Main Power Transformer		
Parameters	**Description**	**Unit**
S_MPT	Power rating/Capacity of MPT	MVA
V_lv	Rated LV-side voltage	kV
V_hv	Rated HV-side voltage	kV
Z_MPT	Leakage impedance of MPT	% or p.u.
Saturation Curve	Saturation characteristics if required for the studies and provided by the OEM	-

Auxiliary and Station Service Load		
Parameters	**Description**	**Unit**
P_Aux	Nominal auxiliary load power rating	MW
Q_Aux	Reactive power demand of auxiliary system	MVAr
V_Aux	Operating voltage for auxiliary system	kV

Uniform Internal Structure – Switching Shunt(s) Parameters

Switching Shunt(s) Parameters		
Parameters	**Description**	**Unit**
Q_Nom	Nominal reactive power rating of the shunt device	Mvar
V_Reg	Voltage regulation setpoint for automatic control	p.u. or kV
Control_Mode	Defines control type	Text: Fixed / Discrete / Continuous / SVC
Step_Size	Size of each reactive power step	Mvar per step
Num_Steps	Total number of steps available	Integer
V_High	Upper voltage limit for switching logic	p.u. or kV
V_Low	Lower voltage limit for switching logic	p.u. or kV
T_Delay_On	Time delay before switching ON	s
T_Delay_Off	Time delay before switching OFF	s
Deadband	Voltage deadband to prevent frequent switching	p.u.
Xc0	Initial reactance value for capacitor/reactor bank	p.u.
I_Max	Maximum continuous current rating	p.u. on system base

Uniform Internal Structure – Inverter

Inverter-Level Control and Protection Characteristics		
Parameter Name	**Description**	**Unit/Note**
Inputs		
Pcmd_Inv	Reference for inverter's active power	MW or p.u.
Qcmd_Inv	Reference for inverter's reactive power	MVAr or p.u.
Vcmd_Inv	Reference for voltage (if voltage control mode)	p.u. or kV
Settings		
PQpriority	PQpriority: = P priority (1) = Q priority (0)	p.u.
Vth_lv	Threshold for LVRT	p.u.
Vth_hv	Threshold for HVRT	p.u.
Db_vrt	deadband for VRT restore	p.u.
Kf_hv	K factor for LVRT	p.u.
Vth_lvex	Threshold for LVRT exit	p.u.
lv	Undervoltage protection threshold	p.u.
t_lv	Undervoltage protection trip time	s
hf	Overfrequency protection threshold	Hz
t_hf	Overfrequency protection trip time	s

Uniform Internal Structure – Inverter

Inverter-Level Control and Protection Characteristics		
Parameter Name	**Description**	**Unit/Note**
Outputs		
HVRT_FLAG	Output signal indicating that the inverter is in HVRT mode	Binary signal
LVRT_FLAG	Output signal indicating that the inverter is in LVRT mode	Binary signal
TRIP _FLAG	Output signal indicating that the inverter is disconnected	Binary signal
MC_FLAG	Output signal indicating that the inverter is in momentary cessation	Binary signal
UV_INV	Undervoltage (UV) protection flag of an inverter	Binary signal
OV_INV	Overvoltage (OV) protection flag of an inverter	Binary signal
UF_INV	Under-frequency (UF) protection flag of an inverter	Binary signal
OF_INV	Over-frequency (OF) protection flag of an inverter	Binary signal
P_M_Inv	Measured Real power at Inverter	MW or p.u.
Q_M_Inv	Measured Reactive power measured at Inverter	Mvar or p.u.
V_M_Inv and v_M_Inv	Measured RMS/instantaneous voltage at Inverter terminal	p.u. or kV
V_DC_P	DC-side positive voltage	kV or p.u.
V_DC_N	DC-side negative voltage	kV or p.u.
V_DC_UN	DC-side unbalanced voltage (V_DC_P - V_DC_N)	kV or p.u.
I_M_Inv and i_M_Inv	Measured RMS/instantaneous currents at Inverter terminal	kA or p.u.
Id_cmd_i	Direct current (Id) command signal for the i-th inverter	p.u.
Iq_cmd_i	Perpendicular current (Iq) command signal for the i-th inverter	p.u.
PLL_freq_i	Measured frequency at the Phase Lock Loop for the i-th inverter	Hz

Uniform Internal Structure – Power Plant Controller

Power Plant Controller Parameters		
Parameter Name	**Description**	**Unit**
Inputs		
Pref_plant	Active power reference for the PPC	MW or p.u.
Qref_plant	Reactive power reference for the PPC	Mvar or p.u.
Vref_plant	Voltage reference for the PPC (if voltage control mode)	p.u. or kV
V_base	Base voltage at POM	kV
V_POM	RMS voltage magnitude at POM	p.u. or kV
P_POM	Real power measured at POM	MW or pu
Q_POM	Reactive power measured at POM	Mvar or p.u.
F_POM	System frequency at POM	Hz
P_avail	Available active power from resource	MW or p.u.
FLG_LVRT	LVRT active flag from inverters	Boolean
FLG_HVRT	HVRT active flag from inverters	Boolean
Outputs		
P_cmd_INV	Active power command to inverter n	MW or p.u.
Q_cmd_INV	Reactive power command to inverter n (GFL mode)	Mvar or p.u.
V_cmd_INV	Voltage command to inverter n (GFM mode)	p.u.

Uniform Internal Structure – Power Pant Controller

Power Plant Controller Parameters		
Parameter Name	**Description**	**Unit**
Settings		
Pctrl_mode	Active power control method	Constant P or P–f droop
Kp_P	Proportional gain for P controller	p.u. or p.u./s
Ki_P	Integral gain for P controller	P.u. or p.u./s
Droop	Frequency droop setting	% or p.u.
F_db	Frequency deadband (upper and lower)	Hz
Tp_filt	Active power measurement filter time constant	s
dPmax, dPmin	Active power ramp rate limits	MW/s or p.u./s
Pmax, Pmin	Active power output limits	MW or p.u.
Pctrl_antiwindup	Anti-windup logic for P controller	If supported by equipment
Qctrl_mode	Reactive power control method	V-control / Q-control / PF / Volt_Var-control
Kp_Q	Proportional gain for Q controller	p.u./p.u.
Ki_Q	Integral gain for Q controller	p.u./p.u./s
Kp_V	Proportional gain for V controller	p.u./p.u.
Ki_V	Integral gain for V controller	p.u./p.u./s
Kqv	Q-V droop slope	p.u./p.u.
V_db	Voltage deadband for Q-V droop	p.u.

Conclusions

- **Current IBR plant models for EMT simulation vary in:**
  - **Signal/parameter naming, observability, and accessibility**
  - **Electrical, protection, and control component organization**
  - **Model structure and configuration**
- **Result: More time and effort for IBR plant model V&V, testing, integration, and reuse**
- **This paper addresses these challenges by proposing:**
  - **Uniform Test Harness: Standardized I/O, operation modes, and initialization**
  - **Uniform Internal Structure: Consistent arrangement of electrical, control, and protection components**
- **Expected benefits:**
  - **Greater transparency and traceability → Less Human Errors**
  - **Reduced model V&V effort → Less time consuming and enable automation process**
  - **Enhance automation and model reuse → Faster EMT studies**

Acknowledgements

Table B.1: Contributors	
Name	Company
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Henry Gras	EMTP
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Francisco De La Rosa	Independent Contributor



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Scope of Work

- This document is a guideline, not a mandatory standard.
- It does not prescribe validation procedures or acceptance criteria.
- It provides a common reference framework applicable to diverse OEMs.
- Implementation should be guided by engineering judgment.

Uniform UI enables the following benefits:

- More efficient and consistent Model Validation and review
- Automated and repeatable EMT testing
- Simplified integration of models into system-level studies
- Reduced reliance on OEM-specific knowledge during model evaluation

Uniform Internal Structure enables the following benefits:

- Transparency and traceability of model behavior
- Efficiency of Model Validation, troubleshooting, and model updates
- Consistency across models from different OEMs
- Portability of models across organizations and study environments