User Guide: NIST Smart Grid Testbed Toolbox 1.0

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1. Introduction

1.1 Overview

This document contains a detailed description of various blocks and device models to simulate NIST smart grid testbed experiments. These models are mostly based on Simulink and Simscape Electrical toolboxes. Therefore, both of the toolboxes are required to use any of these models and custom blocks. Initially, most of these models were developed for Matlab R2018b, then updated and verified full compatibility to run in R2020b.

The objective of these detailed device modeling task is to ensure simulation capability of various hardware equipment within the testbed. The NIST smart grid testbed enables experiments to investigate the operation and dynamics of different grid architectures, including the effects of various grid topology, deployed resources/technologies, and control schema. The safety of NIST researchers and protection of testbed equipment are critically important to the success of testbed. Modeling and simulation capabilities of various devices shall enable testbed staff to analyze part of these concerns prior to actual experiment.

These models maybe used in two following scopes:

a. Run on standalone computer

b. Proxy for actual device within integrated control and data acquisition systems (ICDAS)

Either way, the primary objective to study potential concerns and dynamics could be achieved.

Details of the testbed is available for further reading on the Summary Report on NIST Smart Grid Testbeds and Collaborations Workshops [1].

1.2 Chapter Rundown

- Chapter 2 sets the ground for the rest of the document. It describes how to access the models and custom Simulink library and have them setup to run on a standalone computer.
- Chapters 3,4,5,6,7 describe the underlying details of each device models.
- Chapter 8 describes the steps for using these models as proxy for an actual device withing ICDAS.
- Chapter 9 is a brief summary of what has been done and what can be potentially added to the next versions of these models.
- Chapter 10 lists some notes, pointers, and best practices to deal with potential errors.

[1] Gopstein, Avi, et al. "Summary Report on NIST Smart Grid Testbeds and Collaborations Workshops." (2021). Link: https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1900-102.pdf

2. Installation Instructions

The contents covered in this chapter are applicable to prepare a standalone computer for running device models. These are also required steps and must be completed prior to the steps described in Chapter 8 for ICDAS-Simulink interfacing.

The steps to integrate custom blocks to Matlab/Simulink library browser are also described in this chapter, however, these are not required to be able to run standalone models. Custom blocks are greatly useful to create a standalone model on a user computer from the scratch similar to any other typical Simulink model.

2.1 Download

All modeling source files are publicly accessible via GitHub link below. This repo is created by Jose Ortiz and linked to the C:\Projects\TestbedModels directory on Infinity computer.

GitHub: `https://github.com/usnistgov/TestbedModels`

In addition, all source files are uploaded to NIST GitLab. This directory is not linked to any source folder and not accessible without NIST credentials. This repo was created by Amimul Ehsan; DJ Anand and Allen Goldstein have maintainer roles.

GitLab: `https://gitlab.nist.gov/gitlab/mdamimul.ehsan/nist-smart-grid-testbed-toolbox`

Step 1: Download GitHub repo. It will be downloaded as .zip file.

Step 2: Unzip the downloaded file and you have all models, source files and drivers on your standalone computer.

2.2 System Requirements

Matlab R2020b: Following toolboxes are necessary. It is likely, a standalone development computer shall have many other toolboxes as per overall modeling needs. Versions on the below links are listed from Infinity computer at the time of creating this document.

- MATLAB Version 9.9
- Simulink Version 10.2
- DSP System Toolbox Version 9.11
- Database Toolbox Version 10.0
- Signal Processing Toolbox Version 8.5
- Simscape Version 5.0
- Simscape Electrical Version 7.4

2.3 Installation Steps (Custom Simulink Library)

Step 1: Locate the folder "SmartGridSimulinkToolbox" and place it to the "Matlab Simulink Toolbox" directory.

Step 2: locate .slx file: "sgtb_tlbx_1_0_demo.slx", this is the source library file. This folder contains a few additional files including graphics.

Step 3: Open and run slblocks.m in Matlab.

Step 4: Open Simulink library browser and refresh.

Step 5: ”NIST Smart Grid Testbed Toolbox 1.0” should be available now.

2.4 Run Standalone Device Models

All standalone device models are stored under separate folders as per the folder names. Following are the steps to run any specific device model of interest.

Step 1: Prior to running any model, it is recommended to add the folder containing to Matlab path. You may find this option by right clicking on the folder from the Matlab workspace directory.

Step 2: Open a device model, example: NHR9200Model4960_2020b.slx (Matlab will now open this file in Simulink and it may take a minute or so).

Step 3: Access and provide block parameters by double clicking on the blocks. You may follow if there are any steps or instructions listed on the Simulink model workspace as text boxes. However, custom blocks are likely set with some default values for required parameters to allow quick runs for demonstration purposes.

Step 4: Hit run on the Simulink ”Simulation” tab.

Step 5: If any error message is reported, feel free to use #testbedmodeling or #icds-simulink Slack channel to report it (sometimes the model may need debugging based on Matlab version or solver settings). Some common error messages are listed in Chapter 10.

3. DC Power Module (NHR 9200)

3.1 Device Overview

NHR 9200 cabinet may contain up to three DC power modules of different specifications. They are: NHR Model 4904, 4912, and 4960. All of these, while constrained by device specifications, may work in source, sink or battery mode. In the interest of keeping this document focused on Simulink models, the detailed device specifications are not extensively covered. However, most of the relevant hardware specifications will be addressed in their respective simulation block descriptions as necessary. NHR Hardware Reference Manual is recommended to find device related detailed information [2].

The NHR 9200 (Model: 4960) is developed as the base model for this device group. This particular module is designed to:

- **Source** current to charge batteries up to 600 Volts, 40 Amps and 8000 Watts
- **Sink** current to discharge batteries up to 600 Volts, 40 Amps and 12000 Watts
- **Emulate a battery** up to 600 Volts, 40 Amps
  - up to 8000 Watts (**sourcing** current)
  - up to 12000 Watts (**sinking** current)

Below are the overall operational features that are addressed in this version of device model to demonstrate basic functionality of NHR 9200.

- This module has programmable current, voltage, resistance, and power limits
- Ability to have two or more regulation modes active at the same time, namely: constant current (CC), constant voltage (CV), constant resistance (CR), and constant power (CP).

Fig. 1 shows NHR 9200 hardware cabinet. The overall operation of this device is modeled in Simulink by breaking down into following five custom blocks. Multiple block implementation allows re-using most of these blocks in a modular fashion to implement other NHR 9200 Models- 4904 and 4912. Only input block is different among NHR 9200 Models.

1. **Input** by operator to select proper operating mode and relevant setting parameters.
2. **NHR 9200/ functional unit** takes input and safety settings to determine output.
3. **Safety settings** to set the associated safety parameters coupled with the intended mode of operation.
4. **Battery detection** strategy is needed to determine the presence of external battery unit.
5. **Display** output signals and plots such as safety settings etc.

The rest of this chapter describes these five custom blocks are in detail and run an example simulation.

Custom blocks that are developed to implement NHR 9200 Model 4960 are shown in Fig. 2. Moving forward at first masked parameters are discussed and then detailed implementation of each subsystems shall be addressed.

3.2 Input Panel

3.2.1 "Input Panel" block I/O ports and mask parameters

Fig. 3 shows the input panel block and the mask parameters. Below are the input and output pins associated with this block.

[2] NH Research 9200 Cabinet DC Power Module Hardware Reference Manual. Part No. 09-0314, Rev. M. (2015).

Figure 1: NHR 9200 cabinet DC power module

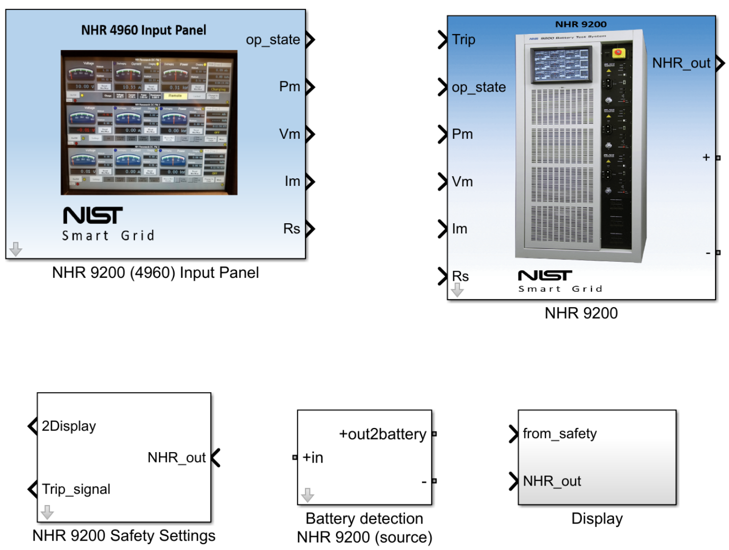

Figure 2: All custom blocks for NHR 9200 Model 4960

Inputs: N/A.
Outputs: Table 1

Table 1: “Input Panel” block output signals

Pin/signal name	To	Description
op_state	NHR 9200	Selected operating mode– 1: Standby; 2: Charge; 3: Discharge; 4: Battery
P_m	NHR 9200	Maximum power set value (CP)
V_m	NHR 9200	Maximum voltage set value (CV)
I_m	NHR 9200	Maximum current set value (CC)
R_s	NHR 9200	Series resistance (CR)

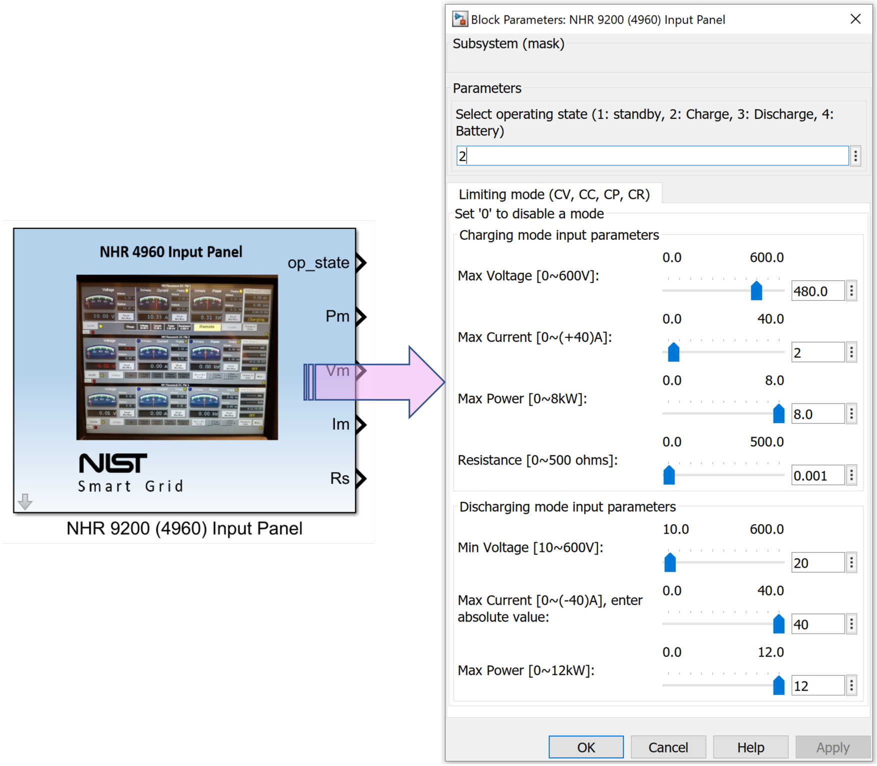

Figure 3: "Input Panel" block for NHR 9200 Model 4960

3.2.2 "Input Panel" subsystems under the mask

Fig. 4 shows the blocks under the "Input Panel" masked subsystem. Subsystem blocks under the primary masked layer maybe accessed by clicking on the downward arrow to the lower left corner of custom block (highlighted). It shall populate the workspace that contains two other subsystems. The "Charging mode Input Params" and "Discharging mode Input Params" subsystems are expanded by double clicking on them and shown below linked with blue arrows. These underlying subsystems checks the masked input parameters against device specification to ensure compliance with hardware limits.

A screenshot of mask parameter editor window is shown in Fig. 5. The variable names assigned to masked parameters which are then used within underlying subsystems are listed in Table 2. This table connects the masked parameters and variables used as shown in Figures 5 & 4. The table also lists the parameter limits as per device specifications in the "range/specification" column.

3.3 NHR 9200

3.3.1 "NHR 9200" block I/O ports and mask parameters

Fig. 6 shows the device block for NHR 9200 that implements Simscape Electrical implementation of controlled voltage source. Depending on settings and safety parameters, overall device operation could be either voltage source or current source. Below are the input and output pins associate with this custom block.

Inputs: Table 3
Outputs: Table 4

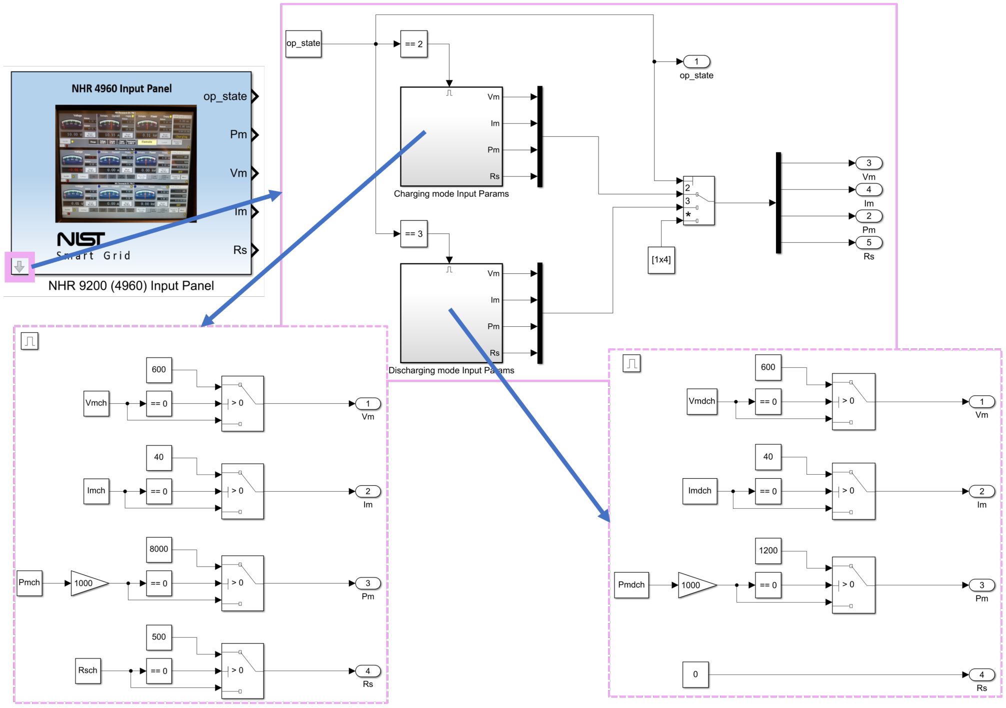

Figure 4: NHR 9200 Model 4960 ”Input Panel” under the mask

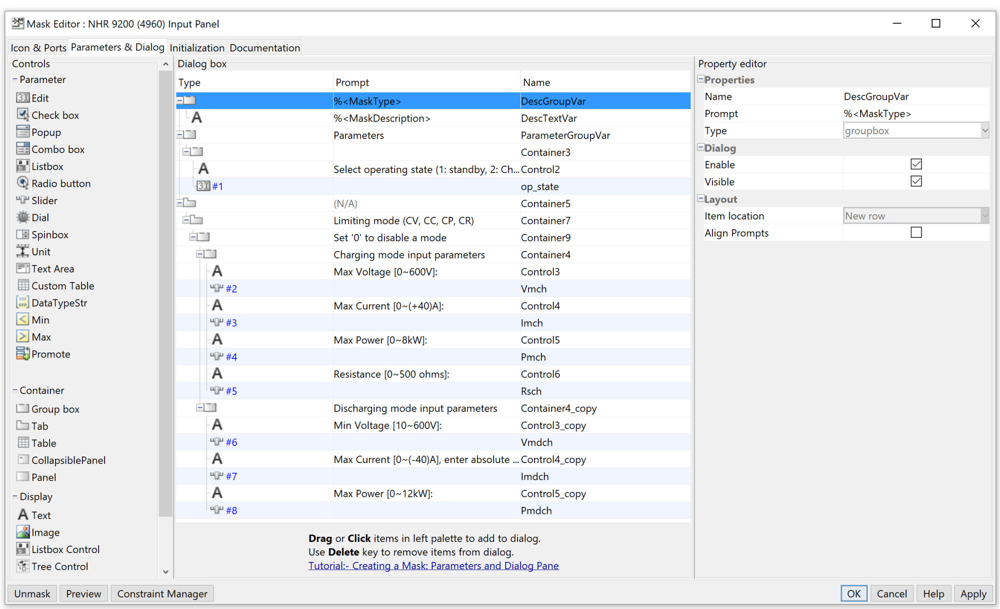

Figure 5: NHR 9200 Model 4960 ”Input Panel” mask parameters

3.3.2 ”NHR 9200” subsystems under the mask

Fig. 7 shows the blocks under the ”NHR 9200” masked subsystem. Primary masked subsystem consists of two other subsystems for ”source” and ”sink” mode implementations.

Table 2: “Input Panel” block parameters of NHR 9200

Parameter description	Range/specification	Mask variable
Select operating state	1: Standby; 2: Charge; 3: Discharge; 4: Battery	op_state
(For charge/source mode)		
Maximum Voltage (CV)	0 – 600 V	V_{mch}
Maximum Current (CC)	0 – 40 A	I_{mch}
Maximum Power (CP)	0 – 8 kW	P_{mch}
Series Resistance (CR)	0 – 500 ■	R_{sch}
(For discharge/sink mode)		
Minimum Voltage	10 – 600 V	V_{mdch}
Maximum Current (CC)	0 – (-40) A	I_{mdch}
Maximum Power (CP)	0 – 12 kW	P_{mdch}

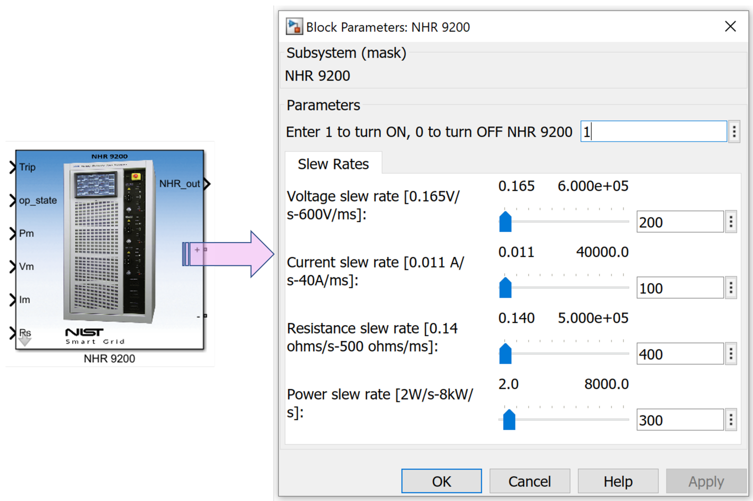

Figure 6: ”NHR 9200” custom block

Table 3: “NHR 9200” block input signals

Pin/signal name	From	Description
Trip	Safety settings	Trip signal
op_state	Input panel	Selected operating mode– 1: Standby; 2: Charge; 3: Discharge; 4: Battery
P_m	Input panel	Maximum power set value (CP)
V_m	Input panel	Maximum voltage set value (CV)
I_m	Input panel	Maximum current set value (CC)
R_s	NHR 9200	Series resistance (CR)

”Source” subsystem contains a controlled voltage source that receives the voltage set point signal from ”source control” subsystem.

”Sink” subsystem contains a variable load which value is set by an external control signal coming from ”sink control” subsystem.

In addition, the primary masked subsystem contains two other ”Connect” subsystems which connects or

Table 4: “NHR 9200” block output signals

Pin/signal name	To	Description
NHR_out	Safety settings; Display	Muxed signal contains power, voltage, current and operating state
+	+UUT	Unit under test (UUT) maybe a load or battery
-	-UUT	

disconnects Simscape Electrical physical blocks to/from the external circuit depending on which operating mode is selected from ”source” and ”sink”.

A screenshot of mask parameter editor window is shown in Fig. 8. These are the power ON/OFF control, and slew rates. The variable names assigned to masked parameters which are then used within underlying subsystems are listed in Table 5. This table connects the masked parameters and variables used as shown in Figures 8 & 7. The table also lists the slew parameter limits as per device manual in the ”range/specification” column.

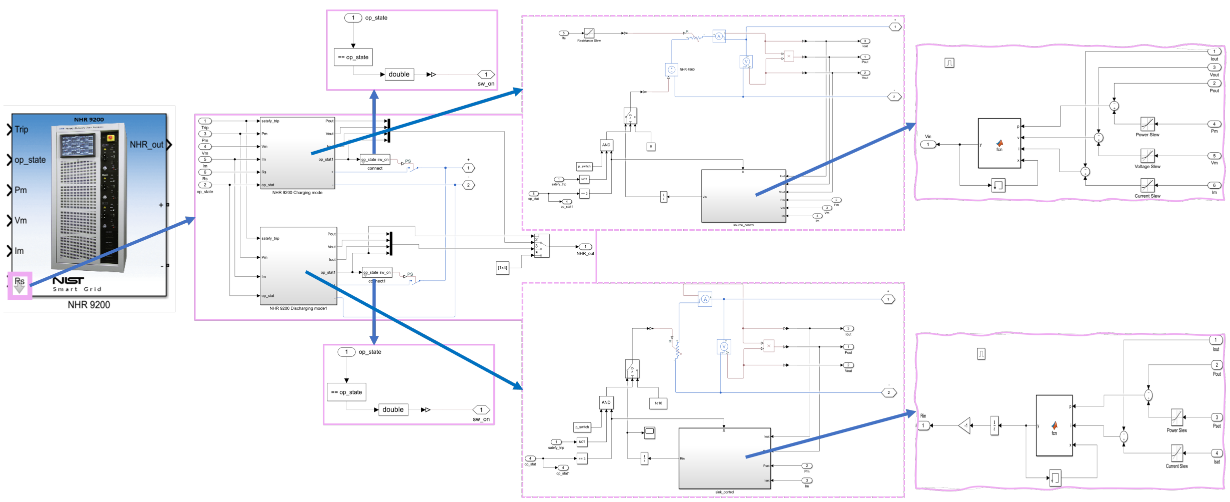

Figure 7: ”NHR 9200” under the mask

Table 5: “NHR 9200” block parameters

Parameter description	Range/specification	Mask variable
NHR Power ON/OFF	1: ON; 0: OFF	P_switch
	(Slew rates)	
Voltage slew rates	0.165 V/s – 600 V/ms	V_{slew}
Current slew rate	0.011 A/s – 40 A/ms	I_{slew}
Resistance slew rate	0.14 ■/s – 500 ω/ms	R_{slew}
Power slew rate	2 W/s – 8 kW/s	P_{slew}

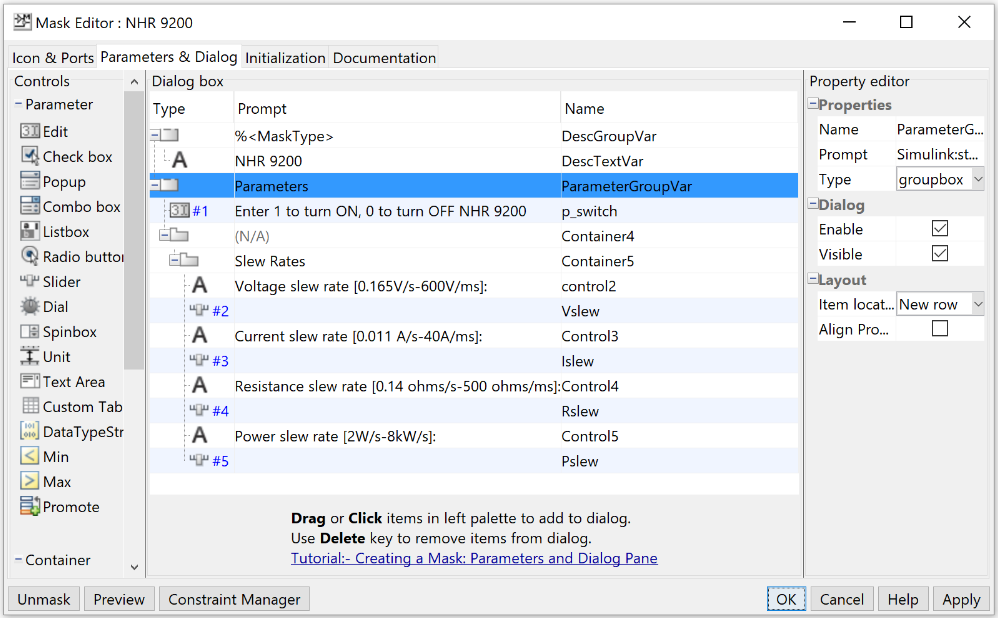

Figure 8: "NHR 9200" mask parameters

3.4 Safety settings

3.4.1 "Safety settings" block I/O ports and mask parameters

Fig. 9 displays custom block "Safety settings" that checks all safety parameters as per device manufacturer specification as well as user selections. This block continuously keeps output values in check and generates a trip signal whenever a set logical condition is violated. Below are the input and output pins associate with this custom block.

Inputs: Table 6
Outputs: Table 7

Table 6: "Safety settings" block input signals

Pin/signal name	From	Description
NHR_out	NHR 9200	Muxed signal contains power, voltage, current and operating state

Table 7: "Safety settings" block output signals

Pin/signal name	To	Description
2Display	Display	Muxed overall trip signal and individual trip signals that triggers the overall trip

3.4.2 "Safety settings" subsystems under the mask

Overall safety settings are modeled in three separate subsystem blocks- global, discharge and charge safety settings as shown in Fig. 10.

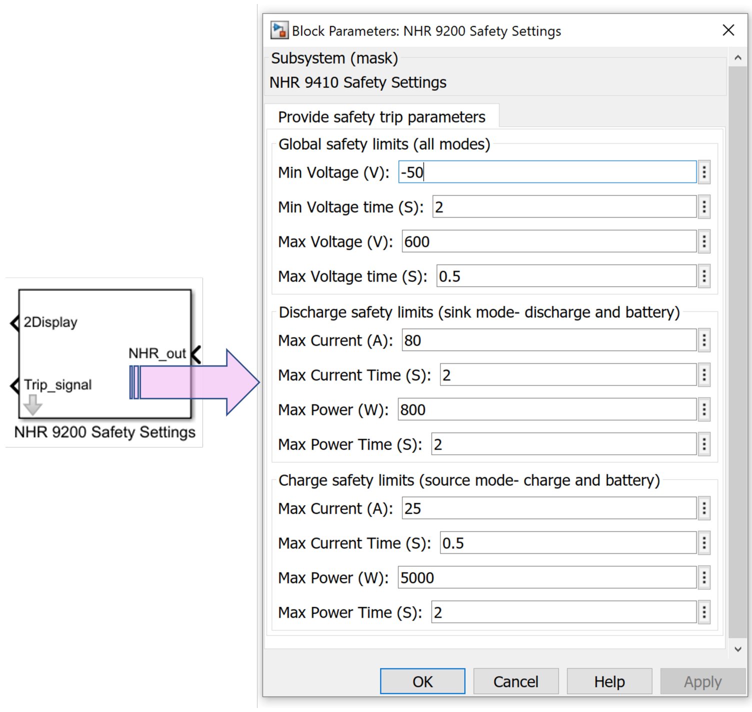

Figure 9: "Safety settings" custom block

"Global safety limits" subsystem is always active and keeps common parameters under check.

"Discharge safety limits" subsystems (Fig. 11 and "Charge safety limits"subsystems (Fig. 12 keeps the mode specific parameters under check.

A screenshot of mask parameter editor window is shown in Fig. 13. These are various safety settings the user is able to change within device manual specification and some are operating mode specific. The variable names assigned to masked parameters which are then used within underlying subsystems are listed in Table 8. This table connects the masked parameters and variables used as shown in Figures 13, 10, 11, & 12.

3.5 Battery detection

3.5.1 "Battery detection" block I/O ports and mask parameters

Fig. 14 shows the battery detection custom block and mask parameter. There is only mask parameter is required from the user that determines the battery detection voltage. If set to zero, this feature is disabled. Below are the input and output pins associate with this custom block.

Inputs: Table 9
Outputs: Table 10

3.5.2 "Battery detection" subsystems under the mask

There is a voltage sensor under the mask that measures the connected battery voltage and compares it with the battery detect voltage value provided by the user. Underlying detailed building blocks are shown in Fig. 15. Variable that denotes battery detect voltage is listed in Table 11 that establishes the connection between masked parameters Fig. 16 & 15.

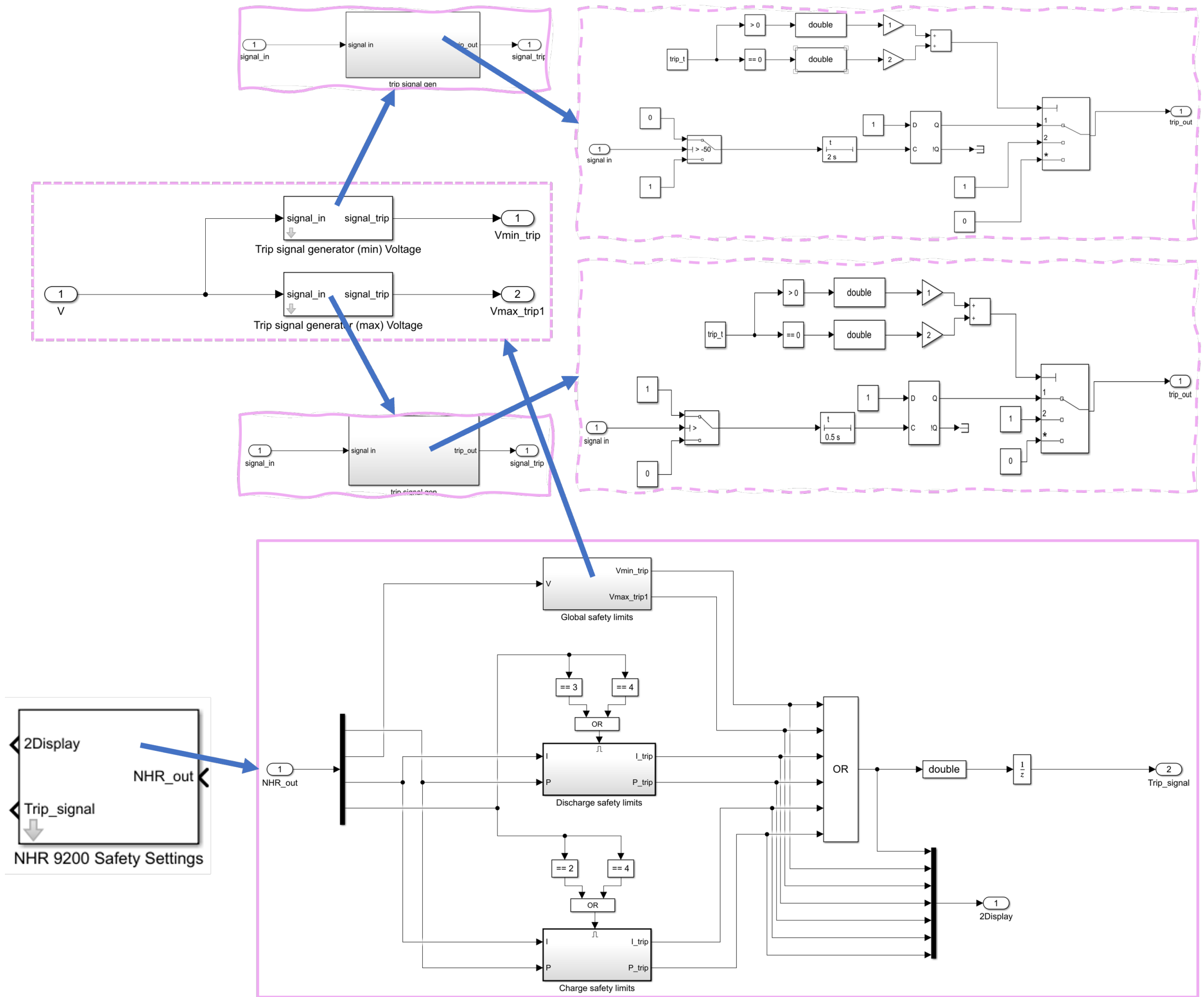

Figure 10: "Safety settings" under the mask "Global safety settings"

3.6 Display

3.6.1 "Display" block I/O ports

Display block as shown in Fig. 17 does not have any masked parameter nor any outputs. It just displays parameters of interest on Simulink scope. Below are the input associate with this custom block.

Inputs: Table 12
Output: N/A

3.6.2 "Display" subsystems under the mask

Fig. 17 shows the display subsystems underlying architecture. It displays NHR 9200 output signals- voltage, current, and power on one scope and trip signals from "Safety settings" to a separate scope. "Trip signals" scope is useful to identify exactly what triggered a trip action.

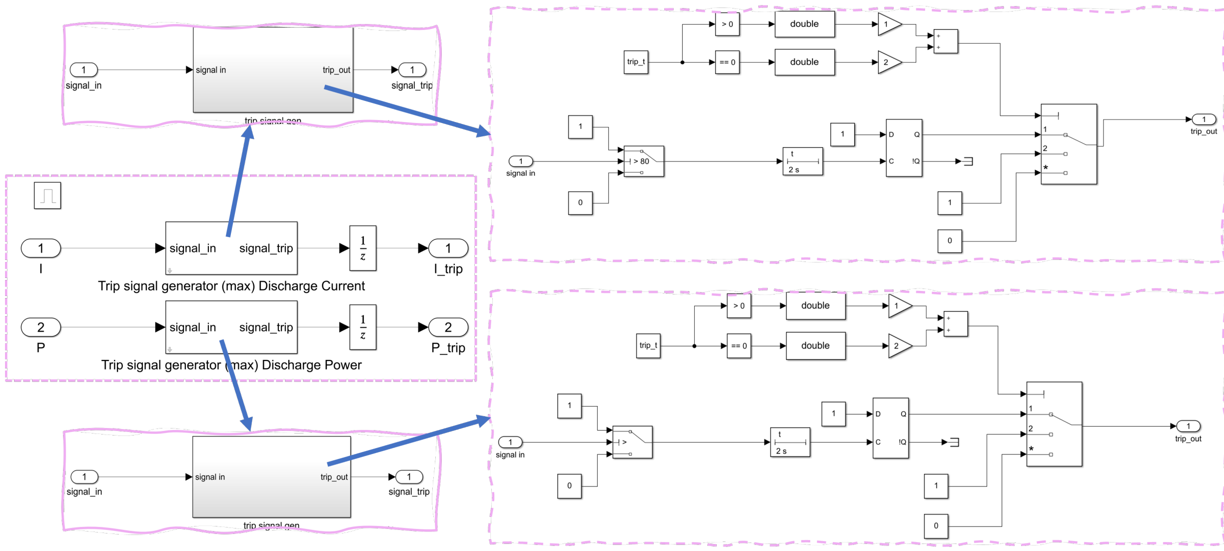

Figure 11: ”Safety settings” under the mask ”Discharge safety settings”

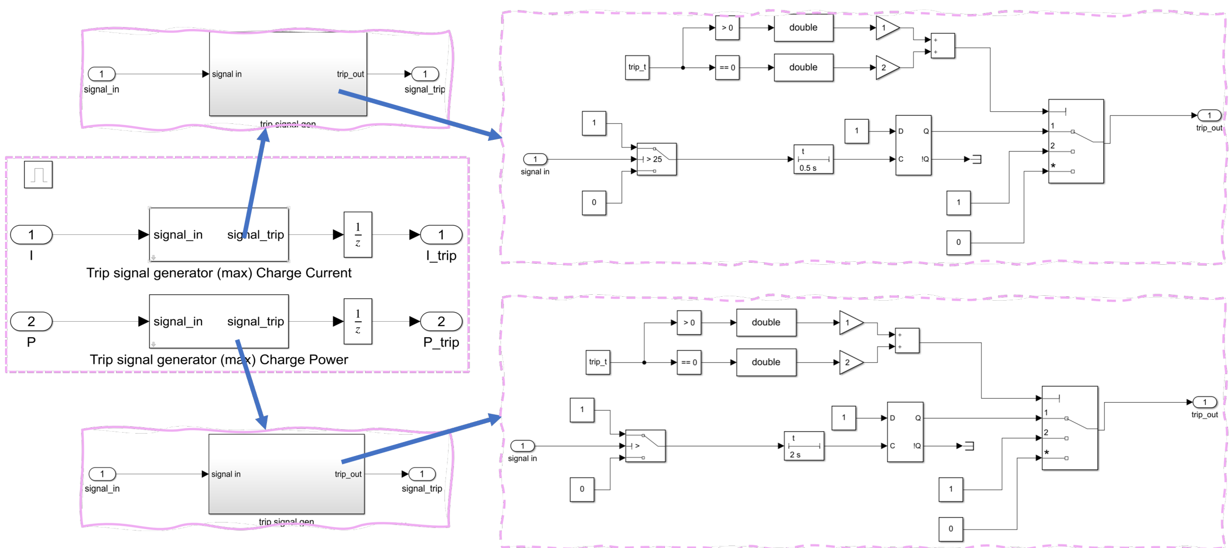

Figure 12: ”Safety settings” under the mask ”Charge safety settings”

3.7 Test Simulation

This section runs through the steps to simulate NHR 9200 complete model. Parameters and settings are kept similar to the previous block specific subsections. Fig. 18 shows the connections between various blocks. For a quick demonstration, steps described in ”Run Standalone Device Models” from Section 2 maybe followed. Alternatively, following are the steps to build this model from the scratch using custom Simulink library blocks.

Step 1: Find custom Simulink library from the library browser.

Step 2: Drag and drop ”Input panel” for NHR 9200 Model 4960, ”NHR 9200”, ”Safety settings”, ”Battery detection”, and ”Display” custom blocks.

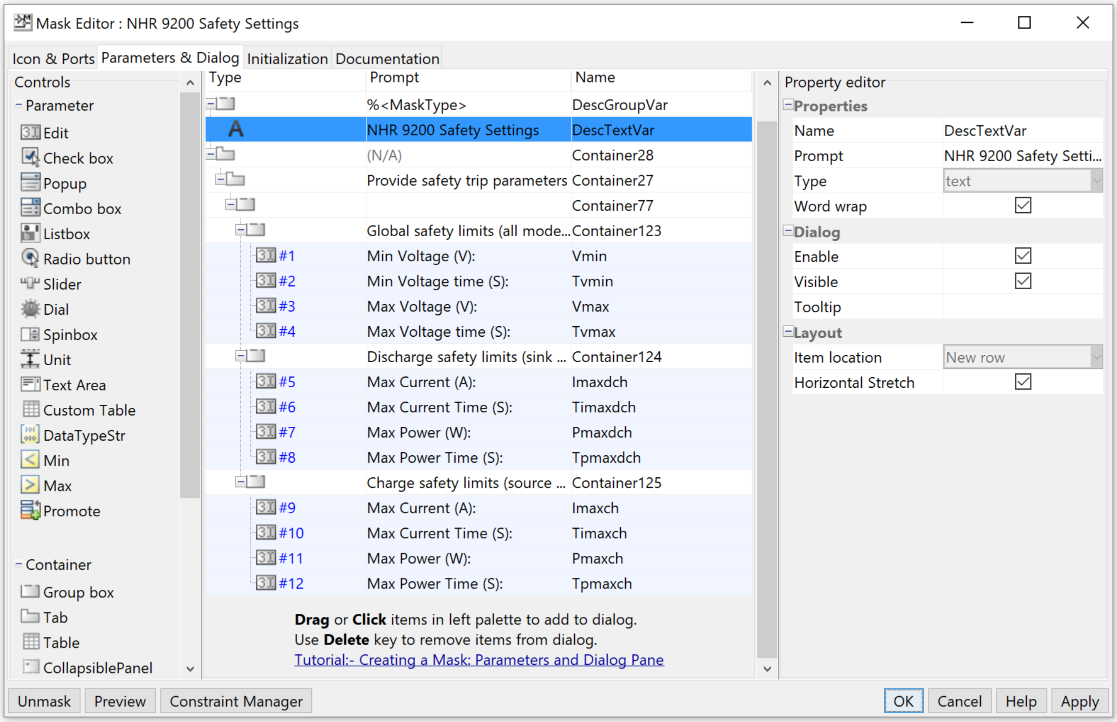

Figure 13: "Safety settings" mask parameters

Table 8: "Safety Settings" block parameters

Parameter description	Range/specification	Mask variable
(Global safety limits)		
Minimum voltage		V_{min}
Minimum voltage time		T_{vmin}
Maximum voltage		V_{max}
Maximum voltage time		T_{vmax}
(Discharge/sink mode)		
Maximum current		I_{maxdch}
Maximum current time		$T_{imaxdch}$
Maximum power		P_{maxdch}
Maximum power time		$T_{pmaxdch}$
(Charge/source mode)		
Maximum current		I_{maxch}
Maximum current time		T_{imaxch}
Maximum power		P_{maxch}
Maximum power time		T_{pmaxch}

Table 9: "Battery detection" block input signals

Pin/signal name	From	Description
+in	NHR 9200	Switch terminal connected to NHR

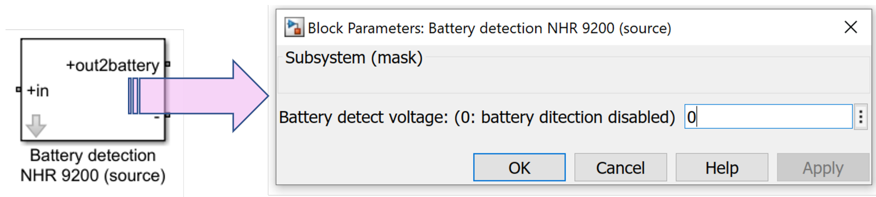

Figure 14: ”Battery detection” custom block

Table 10: “Battery detection” block output signals

Pin/signal name	To	Description
+out2battery	Battery positive terminal	Connects the battery to the circuit if battery detection condition is passed
-	Battery negative terminal	

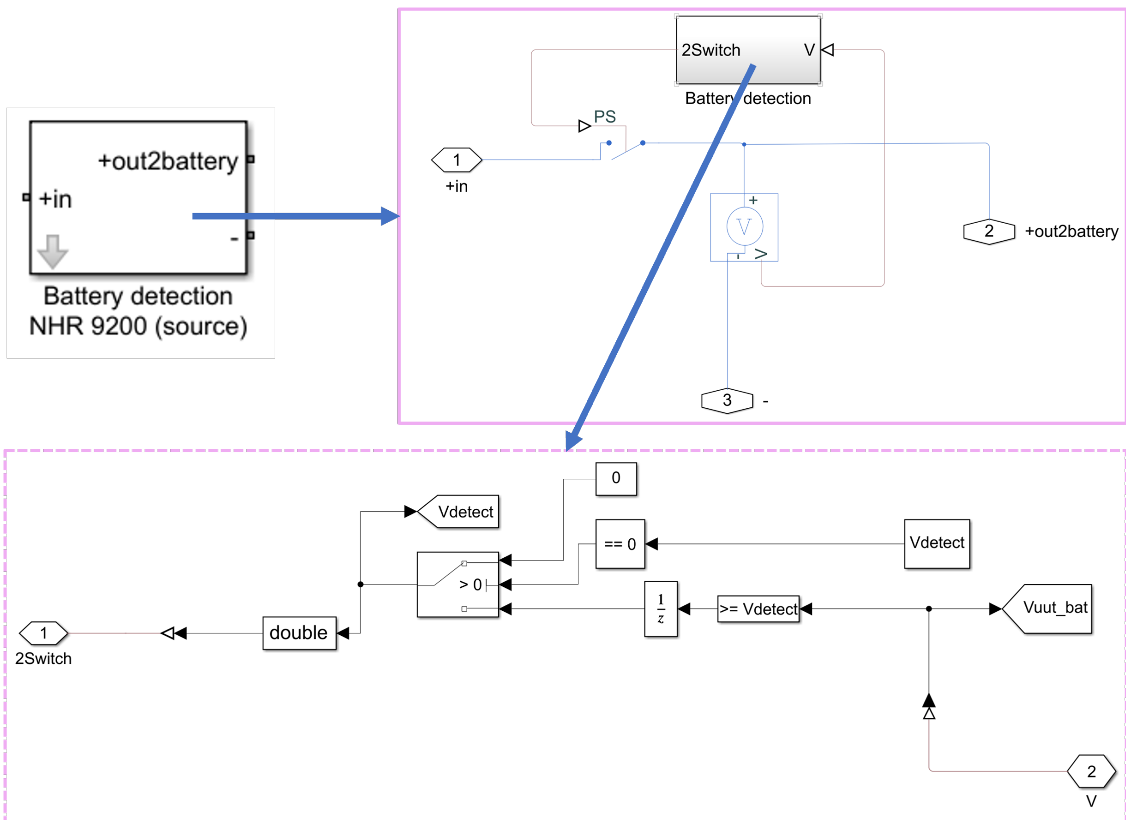

Figure 15: ”Battery detection” under the mask

Table 11: “Battery Detection” block parameters

Parameter description	Range/specification	Mask variable
Battery detect voltage	0: to disable; >0: set voltage	V_{detect}

Step 3: Connect the blocks as shown in Fig. 18.

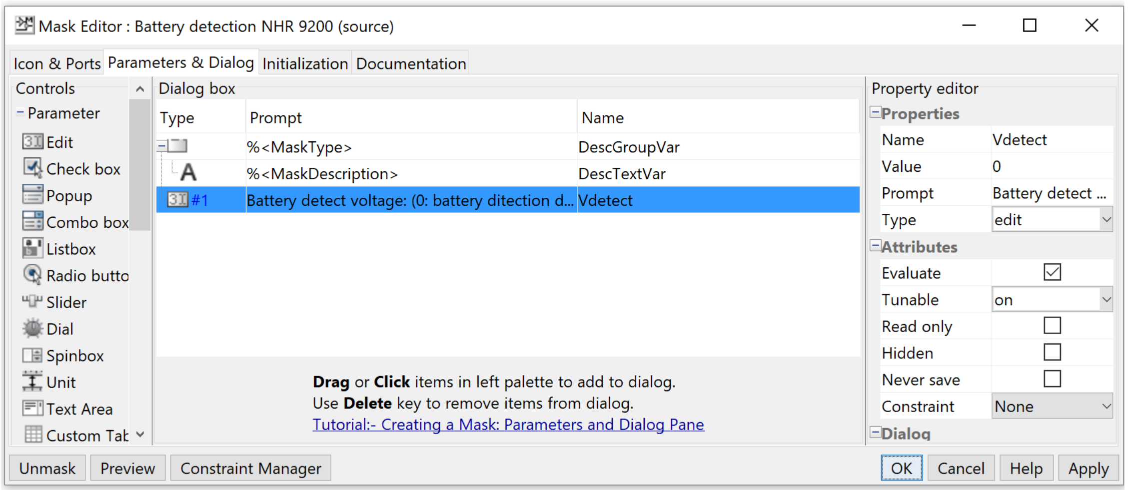

Figure 16: "Battery detection" mask parameters

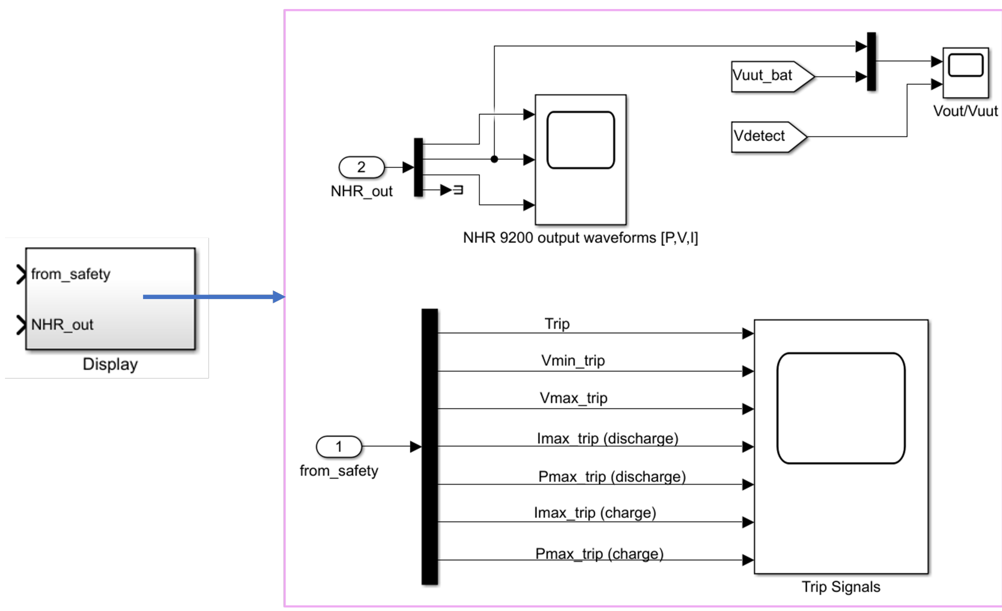

Figure 17: "Display" block

Table 12: "Display" block input signals

Pin/signal name	From	Description
from_safety	Safety settings	Muxed overall trip signal and individual trip signals that triggered overall trip
NHR_out	NHR 9200	Muxed signal contains power, voltage, current and operating state

Step 4: Masked parameters may be changed as per user need. Everything kept as default for this example.

Step 5: "Solver Configuration" must be connected for Simscape simulation.

Step 6: Comment or uncomment battery blocks depending on which operation mode is selected in **Step 4**.

Step 7: Load value can be anything of interest for the demonstration. However, it will depend on the experiment requirement.

Step 8: Run simulation.

Fig. 19 shows the simulation results.

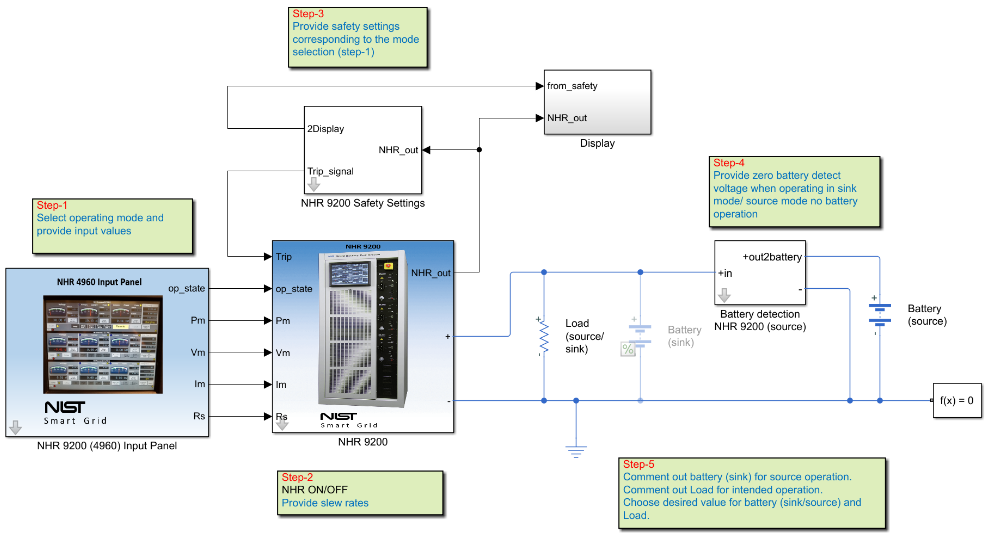

Figure 18: NHR 9200 full model

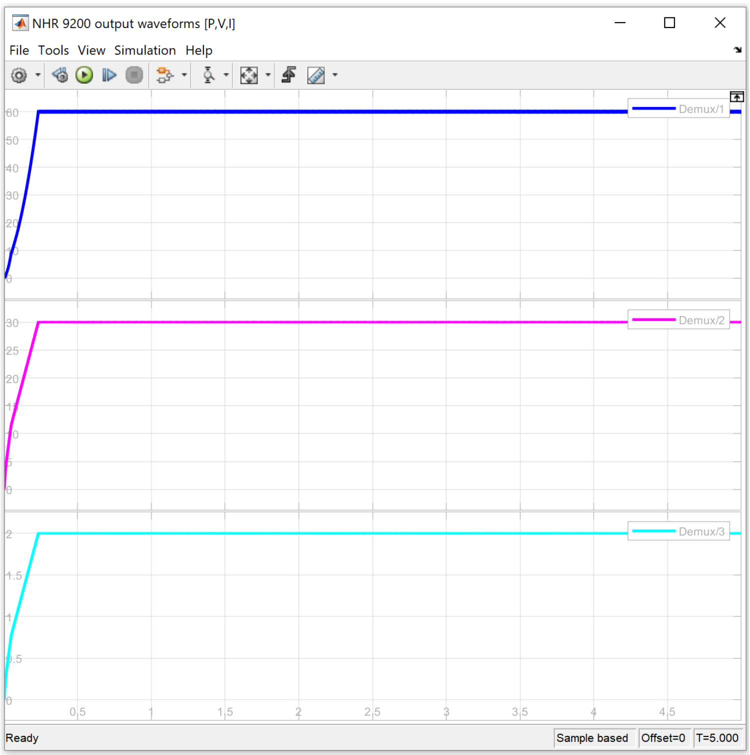

Figure 19: NHR 9200 simulation results

4. Regenerative Grid Emulator (NHR 9410)

4.1 Device Overview

NHR 9410 cabinet contains three output channels. These three channels maybe configured in 13 unique operating modes consisting of both DC and AC power output. There are three hardware models of this device family- 24k, 48k, and 96k. In the interest of keeping this document focused on Simulink models, the detailed device specifications are not extensively covered. However, most of the relevant hardware specifications will be addressed in their respective simulation block descriptions as necessary. NHR Hardware Reference Manual is recommended to find device related detailed information [3].

The NHR 9410-96k is developed as the base model for this device group.

Fig. 20 shows NHR 9410-96k output channel configurations and associated ratings. The overall operation of this device is modeled in Simulink by breaking down into following five custom blocks. Multiple block implementation allows re-using most of these blocks in a modular fashion to implement other NHR 9410 Models- 24k and 48k. Only input block is different among NHR 9410 Models.

1. **Input** by operator to select proper operating mode and relevant setting parameters.
2. **NHR 9410/ functional unit** takes input and safety settings to determine output.
3. **Safety settings** to set the associated safety parameters coupled with the intended mode of operation.
4. **Mode fixtures** are specific to output mode selection and needs to be changed as per channel outputs.
5. **Display** output signals and plots such as safety settings etc.

	Operating Mode	Chanel 1	Chanel 2	Chanel 3
Mode 0	One Three Phase AC	AC1: 96 kW/ 350 Vrms Line-Neutral/ 240 Arms-per-phase		
Mode 1	One AC	AC1: 96 kW/ 350 Vrms Line-Neutral/ 720 Arms-per-phase		
Mode 2	One DC	DC1: 96 kW/ 400 VDC/ 720 A		
Mode 3	Three AC	AC1: 32 kW/ 350 Vrms Line-Neutral/ 240 Arms-per-phase	AC2: 32 kW/ 350 Vrms Line-Neutral/ 240 Arms-per-phase	AC3: 32 kW/ 350 Vrms Line-Neutral/ 240 Arms-per-phase
Mode 4	Three DC	DC1: 32 kW/ 400 VDC/ 240 A	DC2: 32 kW/ 400 VDC/ 240 A	DC3: 32 kW/ 400 VDC/ 240 A
Mode 5	One 2-Phase AC and One AC	AC1 (2-Phase): 64 kW/ 250 Vrms Line-Neutral (500 Vrms Line-Line)/ 240 Arms-per-phase		AC3: 32 kW/ 350 Vrms Line-Neutral/ 240 Arms-per-phase
Mode 6	One 2-Phase AC and One DC	AC1 (2-Phase): 64 kW/ 250 Vrms Line-Neutral (500 Vrms Line-Line)/ 240 Arms-per-phase		DC3: 32 kW/ 400 VDC/ 240 A
Mode 7	Two AC	AC1: 64 kW/ 250 Vrms Line-Neutral/ 480 Arms-per-phase		AC3: 32 kW/ 350 Vrms Line-Neutral/ 240 Arms-per-phase
Mode 8	One AC and One DC	AC1: 64 kW/ 350 Vrms Line-Neutral/ 480 Arms-per-phase		DC3: 32 kW/ 400 VDC/ 240 A
Mode 9	Two AC and One DC	AC1: 32 kW/ 350 Vrms Line-Neutral/ 240 Arms-per-phase	AC2: 32 kW/ 350 Vrms Line-Neutral/ 240 Arms-per-phase	DC3: 32 kW/ 400 VDC/ 240 A
Mode 10	One AC and Two DC	AC1: 32 kW/ 350 Vrms Line-Neutral/ 240 Arms-per-phase	DC2: 32 kW/ 400 VDC/ 240 A	DC3: 32 kW/ 400 VDC/ 240 A
Mode 11	One DC and One AC	DC1: 64 kW/ 400 VDC/ 480 A		AC3: 32 kW/ 350 Vrms Line-Neutral/ 240 Arms-per-phase
Mode 12	Two DC	DC1: 64 kW/ 400 VDC/ 480 A		DC3: 32 kW/ 400 VDC/ 240 A

Figure 20: NHR 9410-96k cabinet operating modes

The rest of this chapter describes these five custom blocks are in detail and run an example simulation.

Custom blocks that are developed to implement NHR 9410-96k are shown in Fig. 21. Moving forward at first masked parameters are discussed and then detailed implementation of each subsystems shall be addressed.

[3] NH Research 9410 Regenerative Grid Emulator Hardware Reference Manual. (2015).

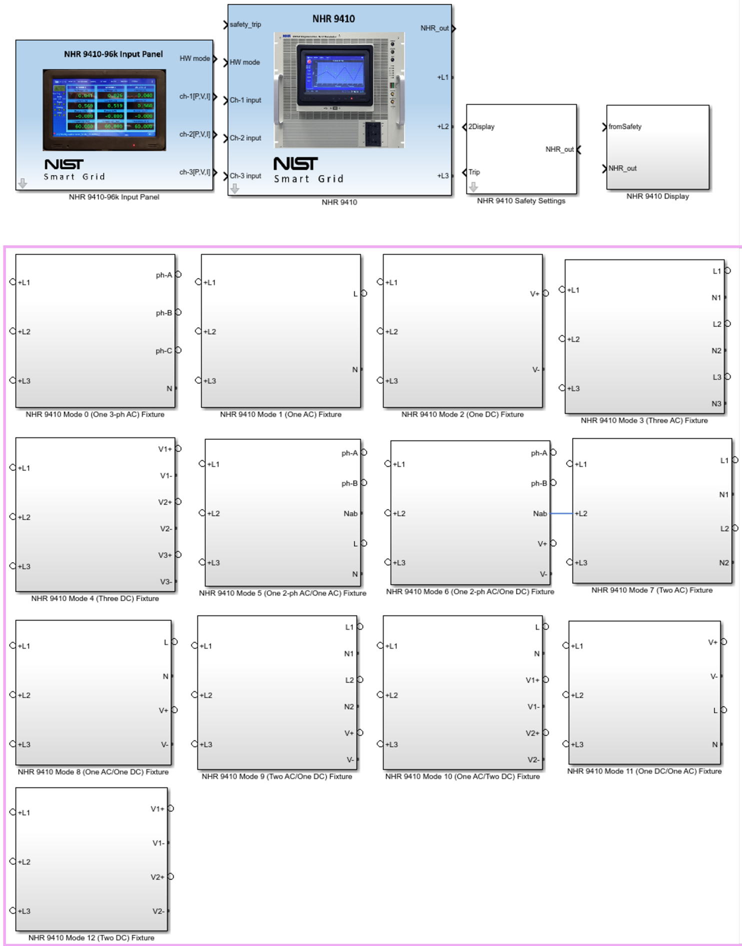

Figure 21: All custom blocks for NHR 9410-96k

4.2 Input Panel

4.2.1 "Input Panel" block I/O ports and mask parameters

Fig. 22 shows the input panel block and the mask parameters. First, a hardware operating mode needs to be selected on the top and then associated mode parameters are required to be provided by expanding the arrow below mode name on the list. Below are the input and output pins associated with this block.

Input signals: N/A.
Output signals: Table 13

4.2.2 "Input Panel" subsystems under the mask

Fig. 23

Fig. 24

Fig. 25

Below tables contains, mask parameters of the custom blocks. Table 14 lists the parameters under the

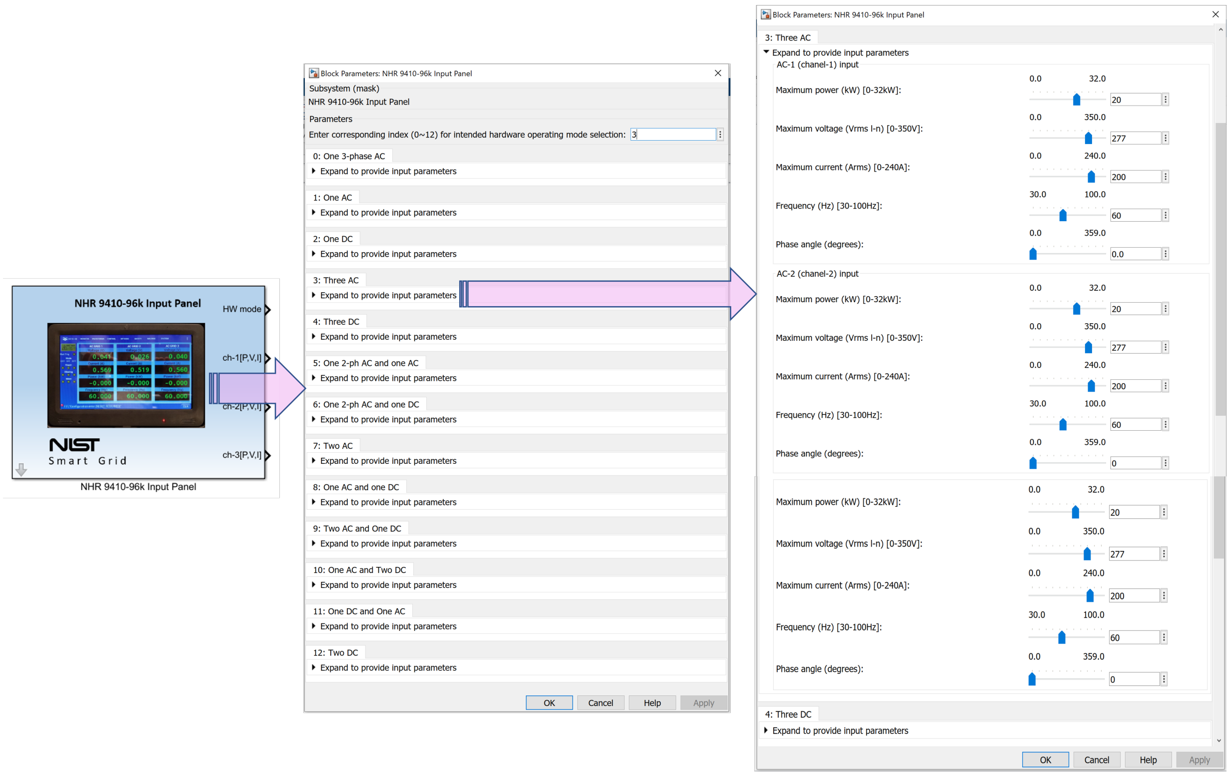

Figure 22: ”Input panel” block for NHR 9410-96k

Table 13: “Input Panel” block output signals

Pin/signal name	To	Description
HW mode	NHR 9410	Selected operating mode– 0 to 12
channel-1 [P,V,I]	NHR 9410	Maximum power (CP), voltage (CV), and current (CC) set value set value for channel-1
channel-2 [P,V,I]	NHR 9410	Maximum power (CP), voltage (CV), and current (CC) set value set value for channel-2
channel-3 [P,V,I]	NHR 9410	Maximum power (CP), voltage (CV), and current (CC) set value set value for channel-3

mask of “Input Panel” block.

Table 14: “Input Panel” block parameters of NHR 9200

Parameter description	Range/specification	Mask variable

Select operating state	0: one 3-phase AC; 1: one AC; 2: one DC; 3: three AC; 4: three DC; 5: one 2-phase AC, one AC; 6: one 2-phase AC, one DC; 7: two AC; 8: one AC, one DC; 9: two AC, one DC; 10: one AC, two DC; 11: one DC, one AC; 12: two DC	sel
(0: one 3-phase AC)		
Maximum power	0 – 96 kW	$md0P_m1$
Maximum voltage, RMS (L-N)	0 – 350 V	$md0V_{rms}1$
Maximum current/phase, RMS	0 – 240 A	$md0I_{rms}1$
Frequency	30 – 100 Hz	$md0f_1$
(1: one AC)		
Maximum power	0 – 96 kW	$md1P_m1$
Maximum voltage, RMS (L-N)	0 – 350 V	$md1V_{rms}$
Maximum current, RMS	0 – 720 A	$md1I_{rms}$
Frequency	30 – 100 Hz	md1f
Phase angle	0 – 359 degrees	md1ph
(2: one DC)		
Maximum power	0 – 96 kW	$md2P_m$
Maximum voltage	0 – 400 V	$md2V_m$
Maximum current	0 – 720 A	$md2I_m$
(3: three AC)		
AC1: channel-1 output		
Maximum power	0 – 32 kW	$md3P_m1$
Maximum voltage, RMS (L-N)	0 – 350 V	$md3V_{rms}1$
Maximum current, RMS	0 – 240 A	$md3I_{rms}1$
Frequency	30 – 100 Hz	md3f1
Phase angle	0 – 359 degrees	md3ph1
AC2: channel-2 output		
Maximum power	0 – 32 kW	$md3P_m2$
Maximum voltage, RMS (L-N)	0 – 350 V	$md3V_{rms}2$
Maximum current, RMS	0 – 240 A	$md3I_{rms}2$
Frequency	30 – 100 Hz	md3f2
Phase angle	0 – 359 degrees	md3ph2
AC3: channel-3 output		
Maximum power	0 – 32 kW	$md3P_m3$
Maximum voltage, RMS (L-N)	0 – 350 V	$md3V_{rms}3$
Maximum current, RMS	0 – 240 A	$md3I_{rms}3$
Frequency	30 – 100 Hz	md3f3
Phase angle	0 – 359 degrees	md3ph3
(4: three DC)		
DC1: channel-1 output		
Maximum power	0 – 32 kW	$md4P_m1$
Maximum voltage	0 – 400 V	$md4V_m1$
Maximum current	0 – 240 A	$md4I_m1$
DC2: channel-2 output		
Maximum power	0 – 32 kW	$md4P_m2$

Maximum voltage	0 – 400 V	md4V_m2
Maximum current	0 – 240 A	md4I_m2
DC3: channel-3 output		
Maximum power	0 – 32 kW	md4P_m3
Maximum voltage	0 – 400 V	md4V_m3
Maximum current	0 – 240 A	md4I_m3
(5: one 2-phase AC, one AC)		
AC1: channel-1,2		
Maximum power	0 – 64 kW	md5P_m1
Maximum voltage, RMS (L-N)	0 – 500 V	md5V_{rms}1
Maximum current/phase, RMS	0 – 240 A	md5I_{rms}1
Frequency	30 – 100 Hz	md5f1
AC3: channel-3 output		
Maximum power	0 – 32 kW	md5P_m2
Maximum voltage, RMS (L-N)	0 – 350 V	md5V_{rms}2
Maximum current, RMS	0 – 240 A	md5I_{rms}2
Frequency	30 – 100 Hz	md5f2
Phase angle	0 – 359 degrees	md5ph2
(6: one 2-phase AC, one DC)		
AC1: channel-1,2		
Maximum power	0 – 64 kW	md6P_m1
Maximum voltage, RMS (L-N)	0 – 500 V	md6V_{rms}1
Maximum current/phase, RMS	0 – 240 A	md6I_{rms}1
Frequency	30 – 100 Hz	md6f1
DC3: channel-3 output		
Maximum power	0 – 32 kW	md6P_m2
Maximum voltage	0 – 400 V	md6V_m2
Maximum current	0 – 240 A	md6I_m2
(7: Two AC)		
AC1: channel-1,2		
Maximum power	0 – 64 kW	md7P_m1
Maximum voltage, RMS (L-N)	0 – 350 V	md7V_{rms}1
Maximum current, RMS	0 – 480 A	md7I_{rms}1
Frequency	30 – 100 Hz	md7f1
Phase angle	0 – 359 degrees	md7ph1
AC3: channel-3		
Maximum power	0 – 32 kW	md7P_m2
Maximum voltage, RMS (L-N)	0 – 350 V	md7V_{rms}2
Maximum current, RMS	0 – 240 A	md7I_{rms}2
Frequency	30 – 100 Hz	md7f2
Phase angle	0 – 359 degrees	md7ph2
(8: one AC, one DC)		
AC1: channel-1 output		
Maximum power	0 – 64 kW	md8P_m1
Maximum voltage, RMS (L-N)	0 – 350 V	md8V_{rms}1
Maximum current, RMS	0 – 480 A	md8I_{rms}1
Frequency	30 – 100 Hz	md8f1
Phase angle	0 – 359 degrees	md8ph1
DC3: channel-3 output		

Maximum power	0 – 32 kW	md8P_m2
Maximum voltage	0 – 400 V	md8V_m2
Maximum current	0 – 240 A	md8I_m2
(9: two AC, one DC)		
AC1: channel-1 output		
Maximum power	0 – 32 kW	md9P_m1
Maximum voltage, RMS (L-N)	0 – 350 V	md9V_{rms}1
Maximum current, RMS	0 – 240 A	md9I_{rms}1
Frequency	30 – 100 Hz	md9f1
Phase angle	0 – 359 degrees	md9ph1
AC2: channel-2 output		
Maximum power	0 – 32 kW	md9P_m2
Maximum voltage, RMS (L-N)	0 – 350 V	md9V_{rms}2
Maximum current, RMS	0 – 240 A	md9I_{rms}2
Frequency	30 – 100 Hz	md9f2
Phase angle	0 – 359 degrees	md9ph2
DC3: channel-3 output		
Maximum power	0 – 32 kW	md9P_m3
Maximum voltage	0 – 400 V	md9V_m3
Maximum current	0 – 240 A	md9I_m3
(10: one AC, two DC)		
AC1: channel-1 output		
Maximum power	0 – 32 kW	md10P_m1
Maximum voltage, RMS (L-N)	0 – 350 V	md10V_{rms}1
Maximum current, RMS	0 – 240 A	md10I_{rms}1
Frequency	30 – 100 Hz	md10f1
Phase angle	0 – 359 degrees	md10ph1
DC2: channel-2 output		
Maximum power	0 – 32 kW	md10P_m2
Maximum voltage	0 – 400 V	md10V_m2
Maximum current	0 – 240 A	md10I_m2
DC3: channel-3 output		
Maximum power	0 – 32 kW	md10P_m3
Maximum voltage	0 – 400 V	md10V_m3
Maximum current	0 – 240 A	md10I_m3
(11: one DC, one AC)		
DC1: channel-1,2		
Maximum power	0 – 64 kW	md11P_m1
Maximum voltage	0 – 400 V	md11V_m1
Maximum current	0 – 480 A	md11I_m1
AC3: channel-3 output		
Maximum power	0 – 32 kW	md11P_m2
Maximum voltage, RMS (L-N)	0 – 350 V	md11V_{rms}2
Maximum current, RMS	0 – 240 A	md11I_{rms}2
Frequency	30 – 100 Hz	md11f2
Phase angle	0 – 359 degrees	md11ph2
(12: two DC)		
DC1: channel-1,2		
Maximum power	0 – 64 kW	md12P_m1

Maximum voltage	0 – 400 V	$md12V_m1$
Maximum current	0 – 480 A	$md12I_m1$
DC3: channel-3 output		
Maximum power	0 – 32 kW	$md12P_m2$
Maximum voltage	0 – 400 V	$md12V_m2$
Maximum current	0 – 240 A	$md12I_m2$

4.3 NHR 9410/Functional Unit

4.3.1 ”NHR 9410” block I/O ports and mask parameters

Table 15: “NHR 9410” block parameters

Parameter description	**Range/specification**	**Mask variable**
NHR Power ON/OFF	1: ON; 0: OFF	P_switch
(Slew rates)		
AC voltage slew rate	0 – 500000 V/s	V_{slewAC}
Frequency slew rate	0 – 500 /s	F_{slewAC}
DC voltage slew rate	0 – 20000 V/s	V_{slewDC}
DC current slew rate	0 – 100000 A/s	I_{slewDC}
DC power slew rate	0 – 1000000 W/s	P_{slewDC}

4.3.2 ”NHR 9410” subsystems under the mask

Input signals: Table 16
Output signals: Table 17

Table 16: “NHR 9410” block input signals

Pin/signal name	**From**	**Description**
safety_trip	Safety settings	Trip signal
HW mode	Input panel	Selected operating mode: 0 – 12
Channel-1 input	Input panel	Maximum power (CP), voltage (CV) and current (CC) set value for channel-1
Channel-2 input	Input panel	Maximum power (CP), voltage (CV) and current (CC) set value for channel-2
Channel-3 input	Input panel	Maximum power (CP), voltage (CV) and current (CC) set value for channel-3

4.4 Safety Settings

4.4.1 ”Safety settings” block I/O ports and mask parameters

Table 18: “Safety Settings” block parameters

Parameter description	**Range/specification**	**Mask variable**

(Channel-1 safety limits)		
Minimum voltage		$V_{im}1$
Minimum voltage time		$T_{vmin}1$
Enable/disable feature	-1: disable; 1: enable	$S_{vmin}1$
Maximum voltage		$V_{max}1$
Maximum voltage time		$T_{vmax}1$
Enable/disable feature	-1: disable; 1: enable	$S_{vmax}1$
Absolute peak voltage		$V_{peak}1$
Enable/disable feature	0: disable; 1: enable	$V_{peaken}1$
Maximum source current		$I_{maxsrc}1$
Maximum source current time		$T_{imaxsrc}1$
Enable/disable feature	-1: disable; 1: enable	$S_{imaxsrc}1$
Maximum sink current		$I_{imaxsnk}1$
Maximum sink current time		$T_{imaxsnk}1$
Enable/disable feature	-1: disable; 1: enable	$S_{imaxsnk}1$
Absolute peak current		$I_{peak}1$
Enable/disable feature	0: disable; 1: enable	$I_{peaken}1$
Maximum source power		$P_{maxsrc}1$
Maximum source power time		$T_{pmaxsrc}1$
Enable/disable feature	-1: disable; 1: enable	$S_{pmaxsrc}1$
Maximum sink power		$P_{maxsnk}1$
Maximum sink power time		$T_{pmaxsnk}1$
Enable/disable feature	-1: disable; 1: enable	$S_{pmaxsnk}1$
(Channel-2 safety limits)		
Minimum voltage		$V_{im}2$
Minimum voltage time		$T_{vmin}2$
Enable/disable feature	-1: disable; 1: enable	$S_{vmin}2$
Maximum voltage		$V_{max}2$
Maximum voltage time		$T_{vmax}2$
Enable/disable feature	-1: disable; 1: enable	$S_{vmax}2$
Absolute peak voltage		$V_{peak}2$
Enable/disable feature	0: disable; 1: enable	$V_{peaken}2$
Maximum source current		$I_{maxsrc}2$
Maximum source current time		$T_{imaxsrc}2$
Enable/disable feature	-1: disable; 1: enable	$S_{imaxsrc}2$
Maximum sink current		$I_{imaxsnk}2$
Maximum sink current time		$T_{imaxsnk}2$
Enable/disable feature	-1: disable; 1: enable	$S_{imaxsnk}2$
Absolute peak current		$I_{peak}2$
Enable/disable feature	0: disable; 1: enable	$I_{peaken}2$
Maximum source power		$P_{maxsrc}2$
Maximum source power time		$T_{pmaxsrc}2$
Enable/disable feature	-1: disable; 1: enable	$S_{pmaxsrc}2$
Maximum sink power		$P_{maxsnk}2$
Maximum sink power time		$T_{pmaxsnk}2$
Enable/disable feature	-1: disable; 1: enable	$S_{pmaxsnk}2$
(Channel-3 safety limits)		
Minimum voltage		$V_{im}3$
Minimum voltage time		$T_{vmin}3$

Enable/disable feature	-1: disable; 1: enable	$S_{vmin}3$
Maximum voltage		$V_{max}3$
Maximum voltage time		$T_{vmax}3$
Enable/disable feature	-1: disable; 1: enable	$S_{vmax}3$
Absolute peak voltage		$V_{peak}3$
Enable/disable feature	0: disable; 1: enable	$V_{peaken}3$
Maximum source current		$I_{maxsrc}3$
Maximum source current time		$T_{imaxsrc}3$
Enable/disable feature	-1: disable; 1: enable	$S_{imaxsrc}3$
Maximum sink current		$I_{imaxsnk}3$
Maximum sink current time		$T_{imaxsnk}3$
Enable/disable feature	-1: disable; 1: enable	$S_{imaxsnk}3$
Absolute peak current		$I_{peak}3$
Enable/disable feature	0: disable; 1: enable	$I_{peaken}3$
Maximum source power		$P_{maxsrc}3$
Maximum source power time		$T_{pmaxsrc}3$
Enable/disable feature	-1: disable; 1: enable	$S_{pmaxsrc}3$
Maximum sink power		$P_{maxsnk}3$
Maximum sink power time		$T_{pmaxsnk}3$
Enable/disable feature	-1: disable; 1: enable	$S_{pmaxsnk}3$

4.4.2 ”Safety settings” subsystems under the mask

Input signals: Table 19
Output signals: Table 20

4.5 Mode Fixtures

4.5.1 ”Mode fixtures” block I/O ports and mask parameters

“Fixture” block hosts the channel neutrals and well as interconnection/port number/label modification for different hardware operating modes. Each hardware operating mode corresponds to a different fixture.

4.5.2 ”Mode fixtures” subsystems under the mask

Input signals: Table 21
Output signals: N/A

4.6 Display

4.6.1 ”Display” block I/O ports and mask parameters

“Display” block hosts the scopes to visualize different signals/parameters: mainly output power, voltage and current; and trip signals.

4.6.2 ”Display” subsystems under the mask

Input signals: Table 22
Output signals: N/A

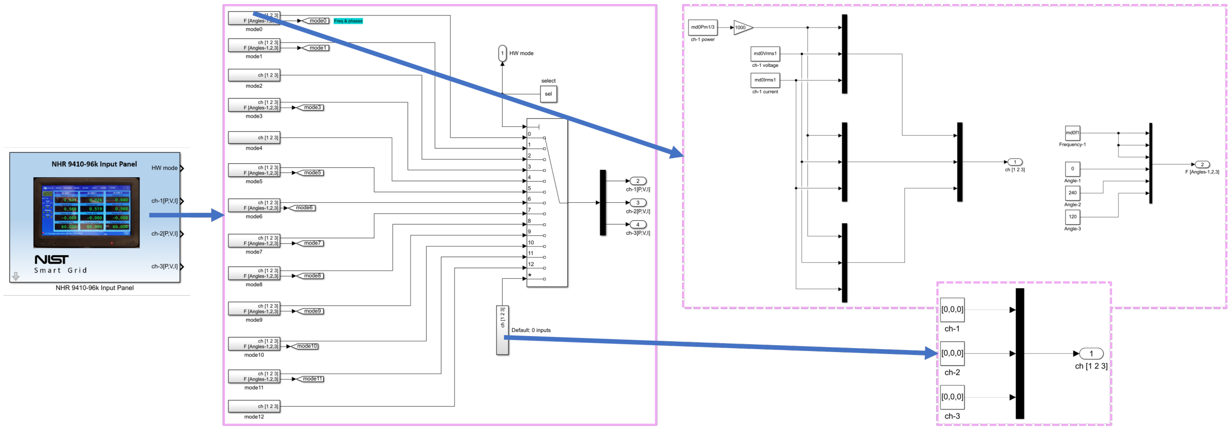

Figure 23: Mode 0 and default for NHR 9410-96k "Input panel" block

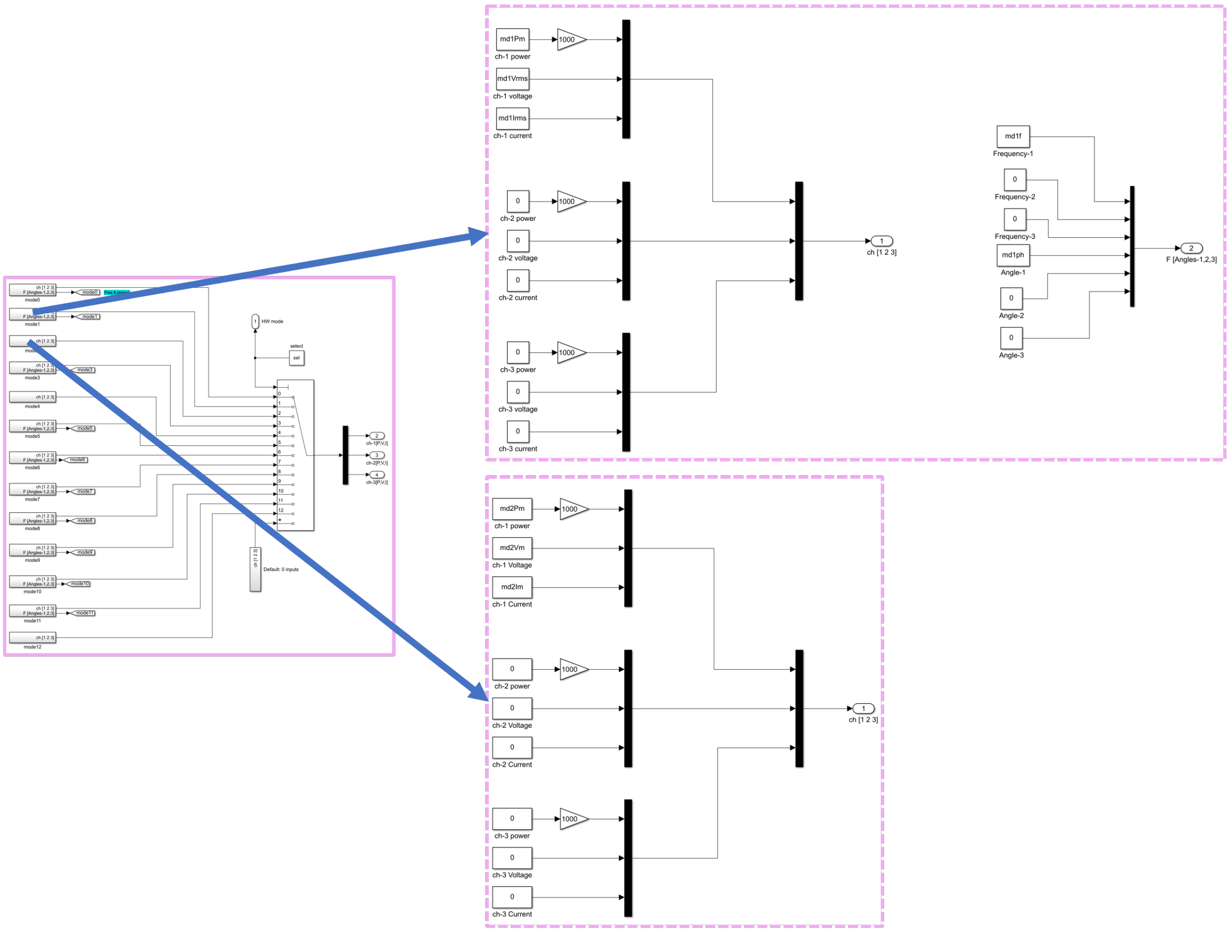

Figure 24: Mode 1,2 for NHR 9410-96k "Input panel" block

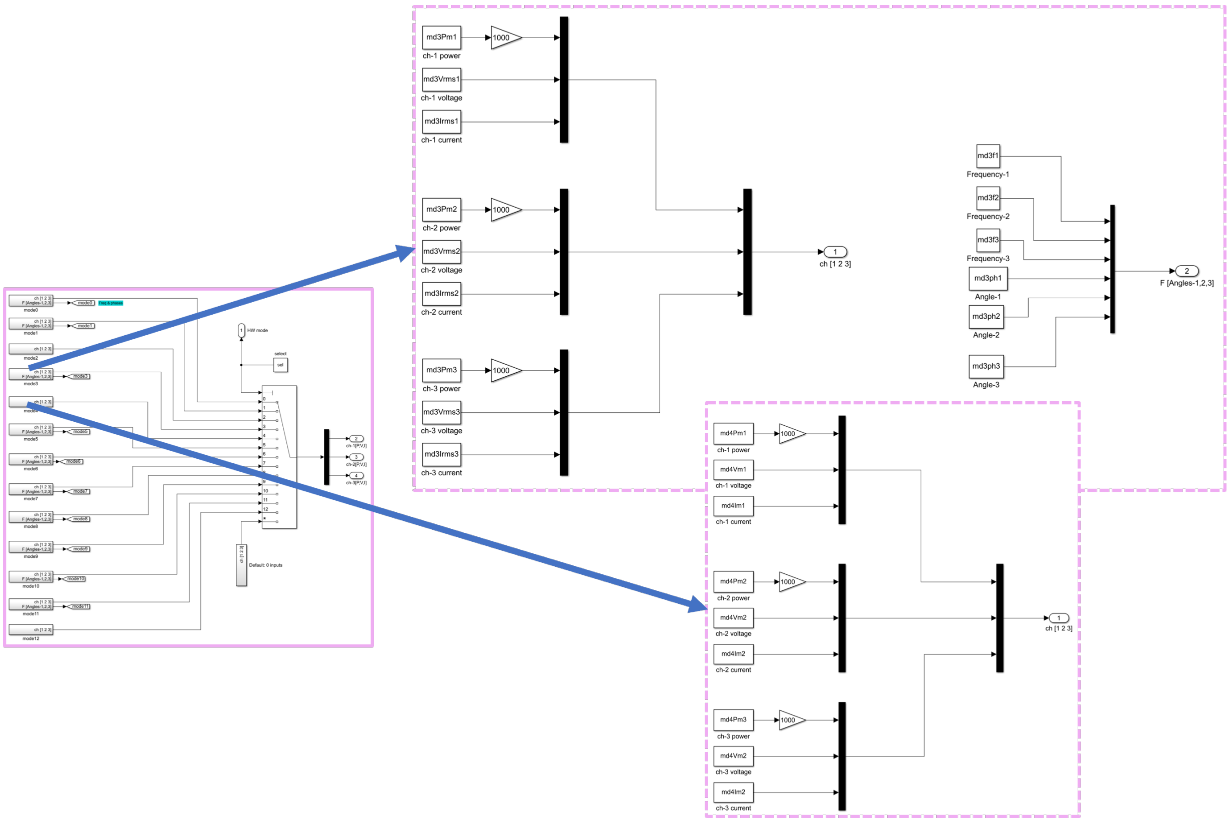

Figure 25: Mode 3,4 for NHR 9410-96k ”Input panel” block

Table 17: “NHR 9410” block output signals

Pin/signal name	To	Description
NHR_out	Safety settings; Display	Muxed signal contains power, voltage, current and operating mode
+L1	Mode fixture	Channel-1 output
+L2	Mode fixture	Channel-2 output
+L3	Mode fixture	Channel-3 output

Table 19: “Safety settings” block input signals

Pin/signal name	From	Description
NHR_out	NHR 9410	Muxed signal contains power, voltage, current and operating mode

Table 20: “Safety settings” block output signals

Pin/signal name	To	Description
2Display	Display	Muxed overall trip signal and individual trip signals that triggers the overall trip
Trip	NHR 9410	Overall trip signal (muxed ch-1,2,3)

Table 21: “Mode fixtures” block input signals

Pin/signal name	**From**	**Description**
fromSafety	Safety settings	Muxed overall trip signal and individual trip signals that triggered overall trip
NHR_out	NHR 9410	Muxed signal contains power, voltage, current and operating mode

Table 22: “Display” block input signals

Pin/signal name	**From**	**Description**
fromSafety	Safety settings	Muxed overall trip signal and individual trip signals that triggers overall trip
NHR_out	NHR 9410	Muxed signal contains power, voltage, current and operating mode

5. Pacific Power Supply

Following are the description/specification of Pacific Power Supply (model: 360AMXT) modeling effort.

Custom Simulink blocks: UPC-32; PacificPower360AMXT; Metering & Display.

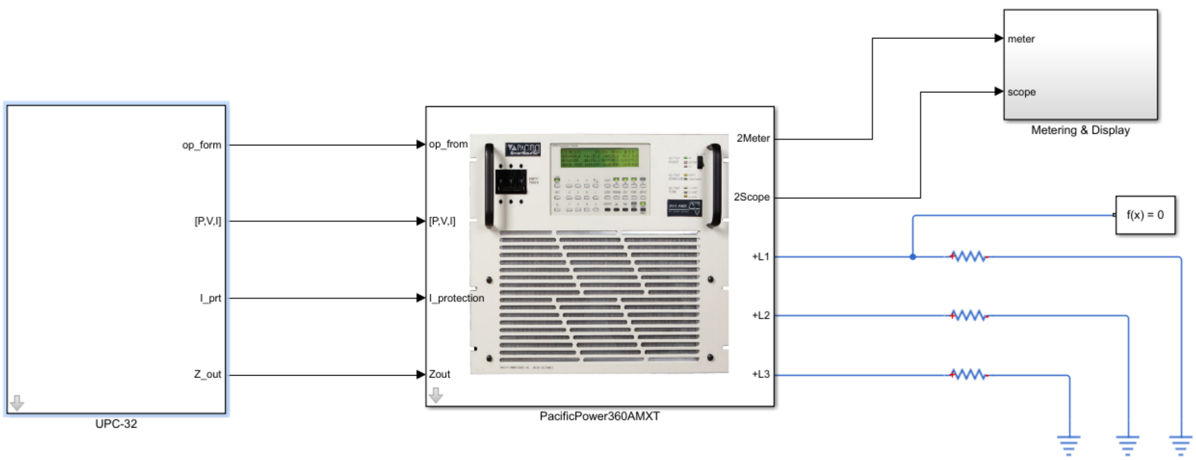

Figure 26: Pacific power supply Simulink model

5.1 Block Parameters (Masked)

Below tables contains, mask parameters of the custom blocks. Table 23 lists the parameters under the mask of “UPC-32” block.

“PacificPower360AMXT” block hosts the power supply itself.

“Metering & Display” block hosts the metering output displays and scopes to visualize different signals/parameters.

Table 23: “UPC-32” block parameters

Parameter description	**Range/specification**	**Mask variable**
Select frequency set point	20 – 5000 Hz	f
Select coupling	1: direct coupling; 2: transformer coupling	sel
Select operating Form	1: single phase (form-1); 2: two-phase (form-2); 3: three-phase (form-3)	form_sel
Output impedance		Z_{out}
Current protection	1: ON; 0: OFF	I_{prt}
Current/phase protection limit		I_{prtlim}
Current/phase protection time		T_{iprt}
(Direct coupling)		
Form-1: single-phase AC		
Voltage limit, RMS (L-N)	0 – 135 V	V_m11
Current/phase limit, RMS	0 – 48 A	I_m11
Form-2: two-phase AC		

Voltage limit, RMS (L-L)	0 – 270 V	V_m12
Current/phase limit, RMS	0 – 16 A	I_m12
Form-3: three-phase AC		
Phase-A voltage limit, RMS (L-N)	0 – 135 V	V_m13a
Phase-B voltage limit, RMS (L-N)	0 – 135 V	V_m13b
Phase-C voltage limit, RMS (L-N)	0 – 135 V	V_m13c
Phase-A angle	0 degrees	
Phase-B angle	120 degrees	Ph13b
Phase-C angle	240 degrees	Ph13c
Current/phase limit, RMS	0 – 16 A	I_m13
(Transformer coupling)		
Form-1: single-phase AC		
Voltage limit, RMS (L-N)	0 – 273 V	V_m21
Current/phase limit, RMS	0 – 24 A	I_m21
Form-2: two-phase AC		
Voltage limit, RMS (L-L)	0 – 546 V	V_m22
Current/phase limit, RMS	0 – 8 A	I_m22
Form-3: three-phase AC		
Phase-A voltage limit, RMS (L-N)	0 – 273 V	V_m23a
Phase-B voltage limit, RMS (L-N)	0 – 273 V	V_m23b
Phase-C voltage limit, RMS (L-N)	0 – 273 V	V_m23c
Phase-A angle	0 degrees	
Phase-B angle	120 degrees	Ph23b
Phase-C angle	240 degrees	Ph23c
Current/phase limit, RMS	0 – 8 A	I_m23

Table 24: “PacificPower360AMXT” block parameters

Parameter description	**Range/specification**	**Mask variable**
Power ON/OFF	1: ON; 0: OFF	P_switch
(Slew rates)		
AC voltage slew rate	0 – 500000 V/s	V_{slewAC}
Frequency slew rate	0 – 500 /s	F_{slewAC}
DC voltage slew rate	0 – 20000 V/s	V_{slewDC}
DC current slew rate	0 – 100000 A/s	I_{slewDC}
DC power slew rate	0 – 1000000 W/s	P_{slewDC}

5.2 Block Pins and Visuals

block pins and visuals in detail

UPC-32: Fig. 27
Input signals: N/A.
Output signals: Table 25

PacificPower360AMXT: Fig. 28
Input signals: Table 26
Output signals: Table 27

Metering & Display: Fig. 29

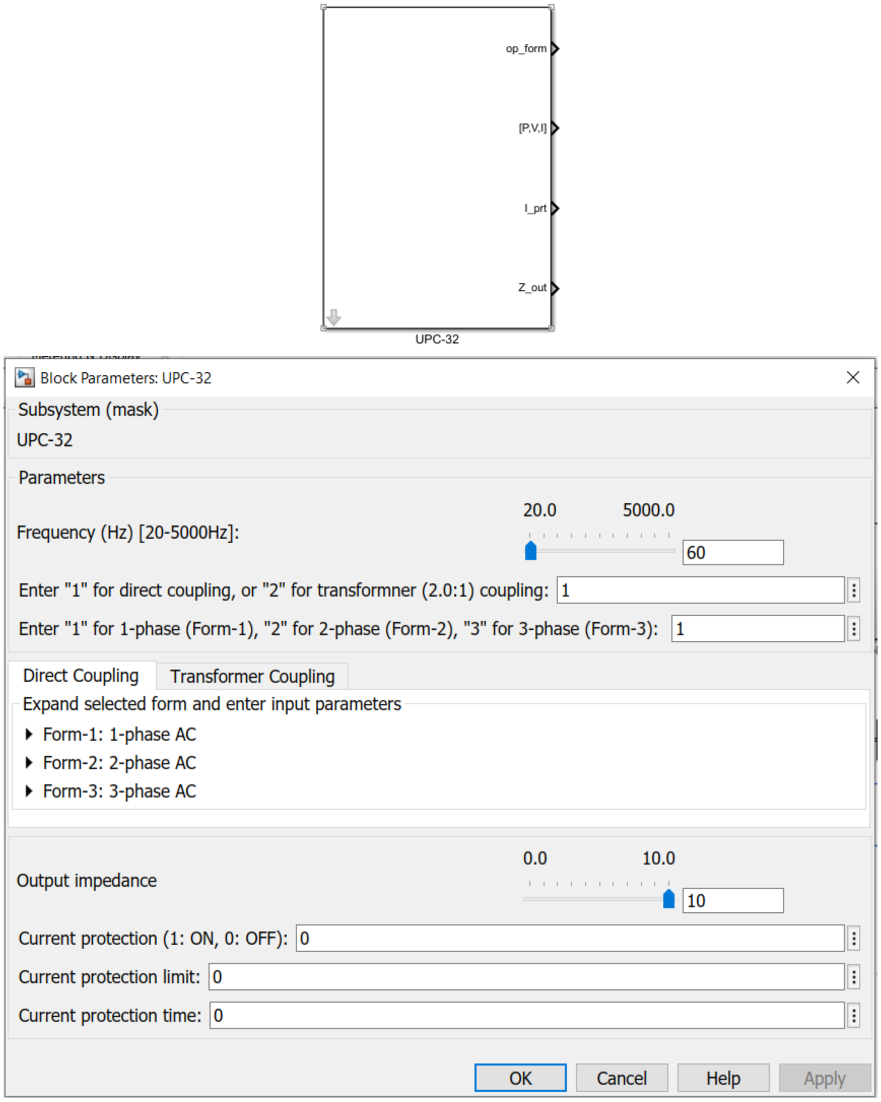

Figure 27: "UPC-32" block (top) and mask parameters (bottom)

Table 25: "UPC-32" block output signals

Pin/signal name	To	Description
op_from	PacificPower360AMXT	operating mode
[P,V,I]	PacificPower360AMXT	input set points for power, voltage and current
I_prt	PacificPower360AMXT	current protection
Z_out	PacificPower360AMXT	output impedance

Input signals: Table 28
Output signals: N/A

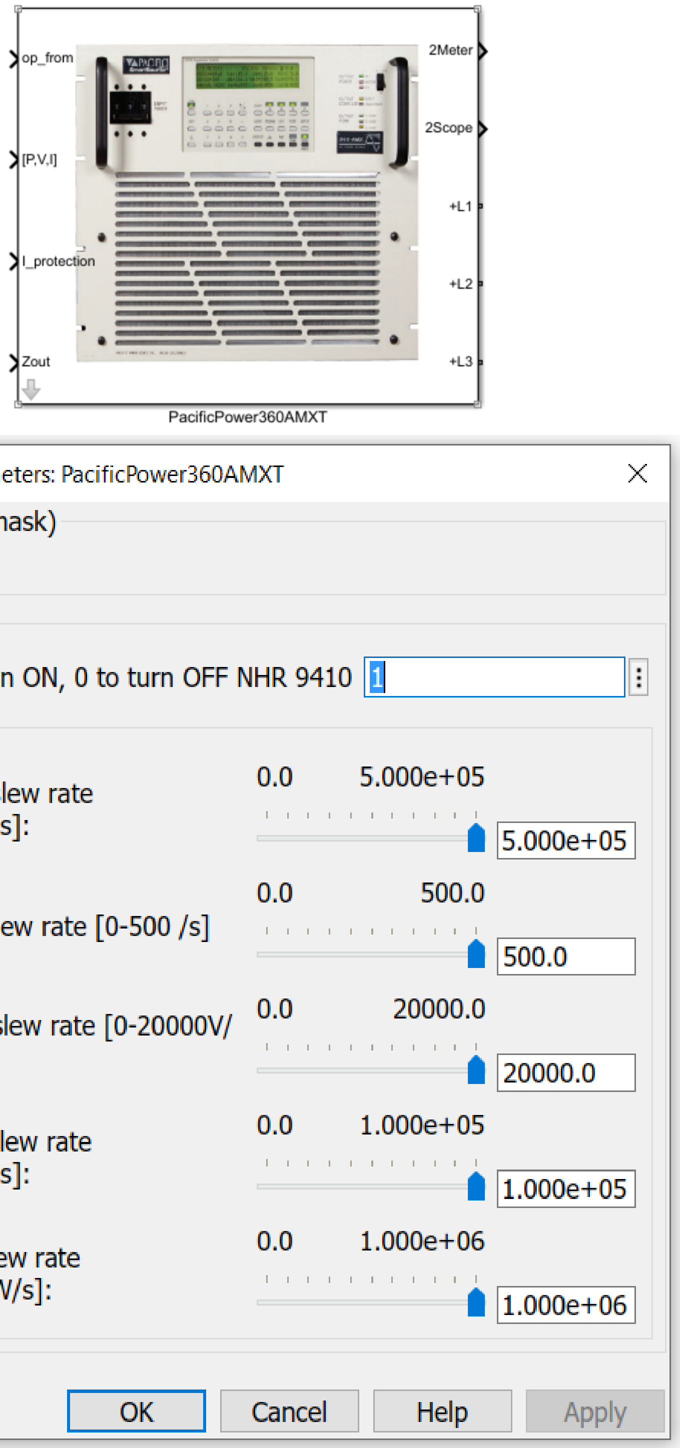

Figure 28: “PacificPower360AMXT” block (top) and mask parameters (bottom)

Table 26: “PacificPower360AMXT” block input signals

Pin/signal name	From	Description
op_from	UPC-32	operating mode
[P,V,I]	UPC-32	input set points for power, voltage and current
I_protection	UPC-32	current protection
Zout	UPC-32	output impedance

Table 27: “PacificPower360AMXT” block output signals

Pin/signal name	To	Description
2Meter	Metering & Display	Muxed signal contains phase to phase voltage measurements
2Scope	Metering & Display	Muxed signal contains power, voltage, current of individual phases
+L1	load	Channel-1 output
+L2	load	Channel-2 output
+L3	load	Channel-3 output

Table 28: “Metering & Display” block input signals

Pin/signal name	From	Description
meter	PacificPower360AMXT	Muxed signal contains phase to phase voltage measurements
scope	PacificPower360AMXT	Muxed signal contains power, voltage, current of individual phases

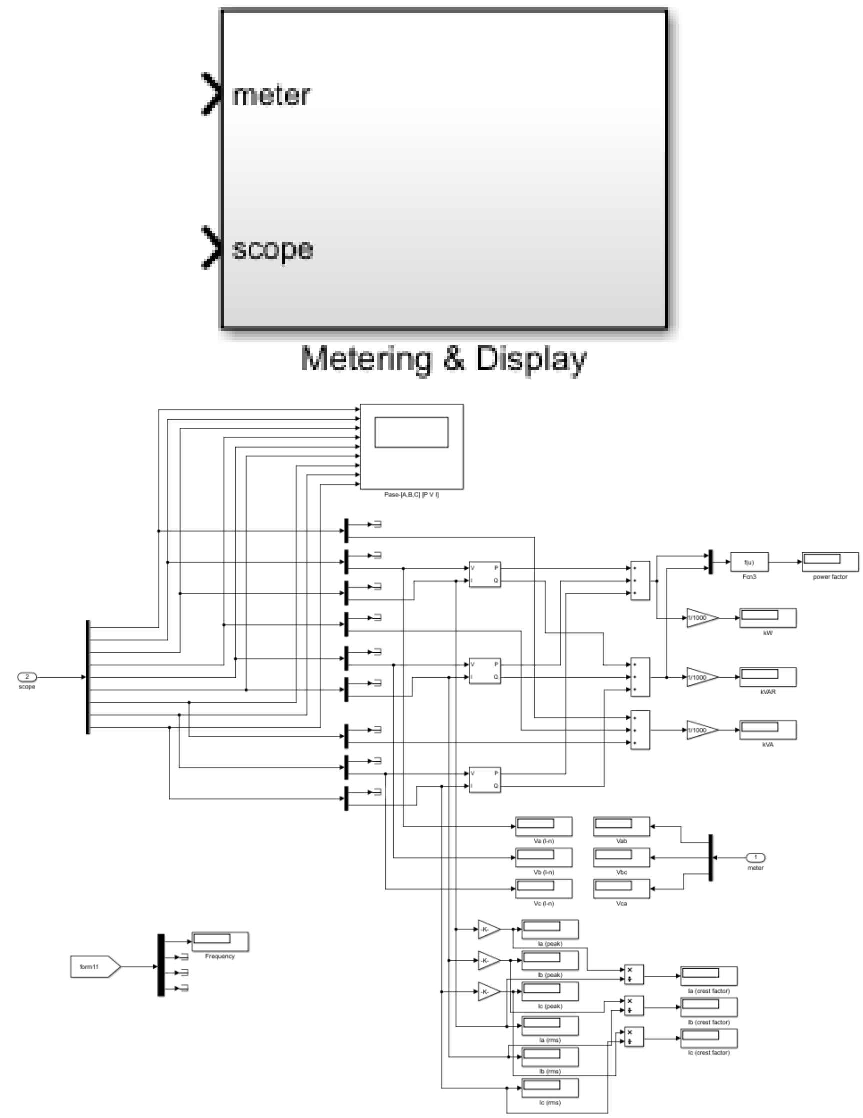

Figure 29: “Metering & Display” block (top) and mask parameters (bottom)

6. Chroma DC Power Supply

6.1 Device Overview

6.2 Block Parameters (Masked)

Table 29

Table 29: “Input Panel” block parameters of Chroma Supply

Parameter description	**Range/specification**	**Mask variable**
Output ON,OFF	1: ON; 0: OFF	set_out
Voltage output	within Vmin to Vmax	v_out
Current output	within Imin to Imax	i_out
CONFIG		
OUTPUT SETUP		
Maximum Voltage	0 – 40 V	V_{max}
Minimum Voltage	0 – 40 V (less than Vmax)	V_{min}
Maximum Current	0 – 120 A	I_{max}
Minimum Current	0 – 120 A (less than Imax)	I_{min}
Voltage slew rate	0.000001 – 0.005 V/S	V_{slew}
Current slew rate	0.000001 – 0.001 A/S	I_{slew}
PROTECTION		
Over voltage protection (OVP)	Max OVP $\leq 1.10\times$Vmax	V_{max_prot}
Over current protection (OCP)	Max OCP $\leq 1.05\times$Imax	I_{max_prot}
Over power protection (OPP)	$\leq$ 1260W	P_{max_prot}

6.3 Block Pins and Visuals

7. Chroma Load

8. ICDAS-Simulink Interfacing

8.1 Required softwares and drivers

8.2 Connect Modeling PC to Database using pgAdmin

8.3 Connect Matlab/DatabaseExplorer to Database

8.4 Run Model

9. Summary

10. Appendix A: Common Errors