Harnessing Green Microgrids: Optimizing Renewable Energy and Hydrogen Production

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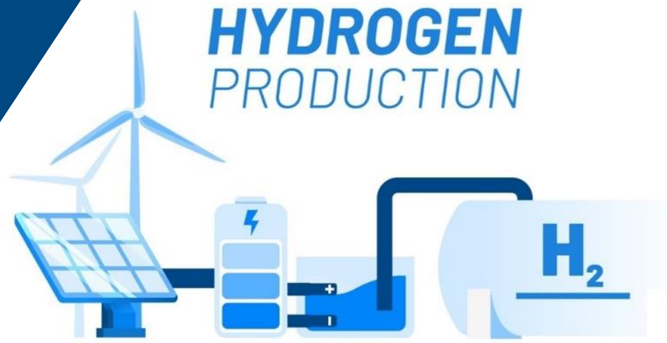
Senior Application Engineer,
Power Electronics

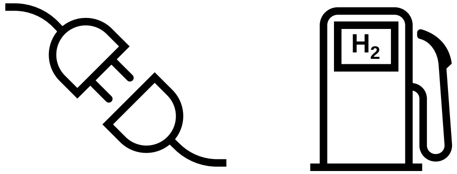


Overview

- Introduction to the Green Hydrogen Microgrid
- Technology Readiness and Model Fidelity
- Examples of Electrolyzers
- Testing the Electrolyzer
- Solar Maximum Power Point Tracking (MPPT) and Impedance Matching
- Evaluating System Operation
- Reduced Order Modeling (ROM) and Evaluating the ROM system
- Techno-Economic Studies and Quasi-Steady Simulation
- Summary

Hydrogen & Electrification| Common Challenges

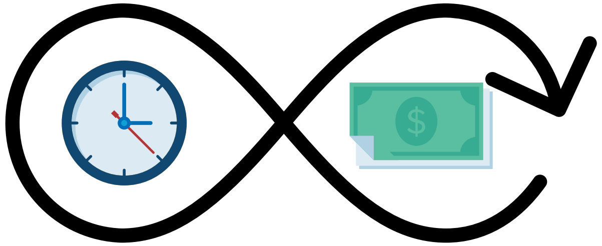
- Energy Intensive



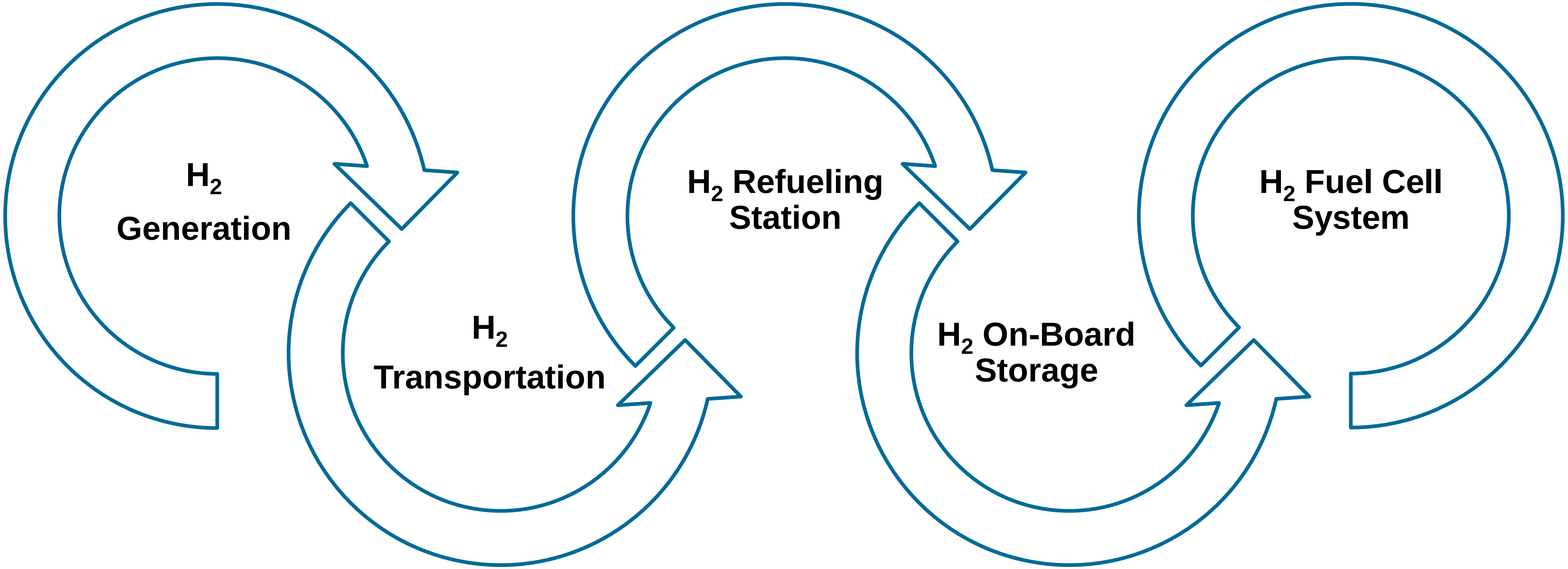
- Hardware Accessibility

- Safety

- Controls & Diagnostics



Hydrogen: Generation to Application



Green Hydrogen Production

Grey/Black Hydrogen

- Hydrogen produced using fossil fuels such as Natural Gas (reforming) and coal (gasification)
- No emissions capture

Brown Hydrogen

- Hydrogen produced using fossil fuels such as coal/lignite using gasification
- Carbon emissions captured and stored or reused

Blue Hydrogen

- Hydrogen produced using fossil fuels such as Natural Gas; non-renewable energy such as Nuclear Energy
- Carbon emissions captured and stored or reused; Meets low-carbon threshold

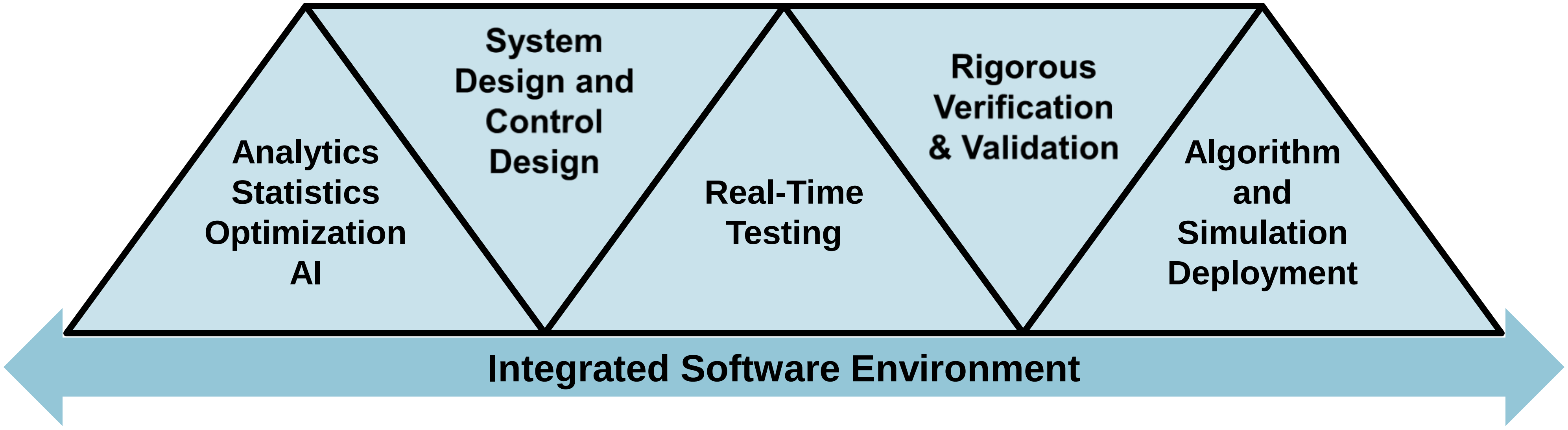
Green Hydrogen

- Hydrogen produced using electricity from renewable energy (such as solar, wind, hydroelectric) through electrolysis
- Meets low-carbon threshold

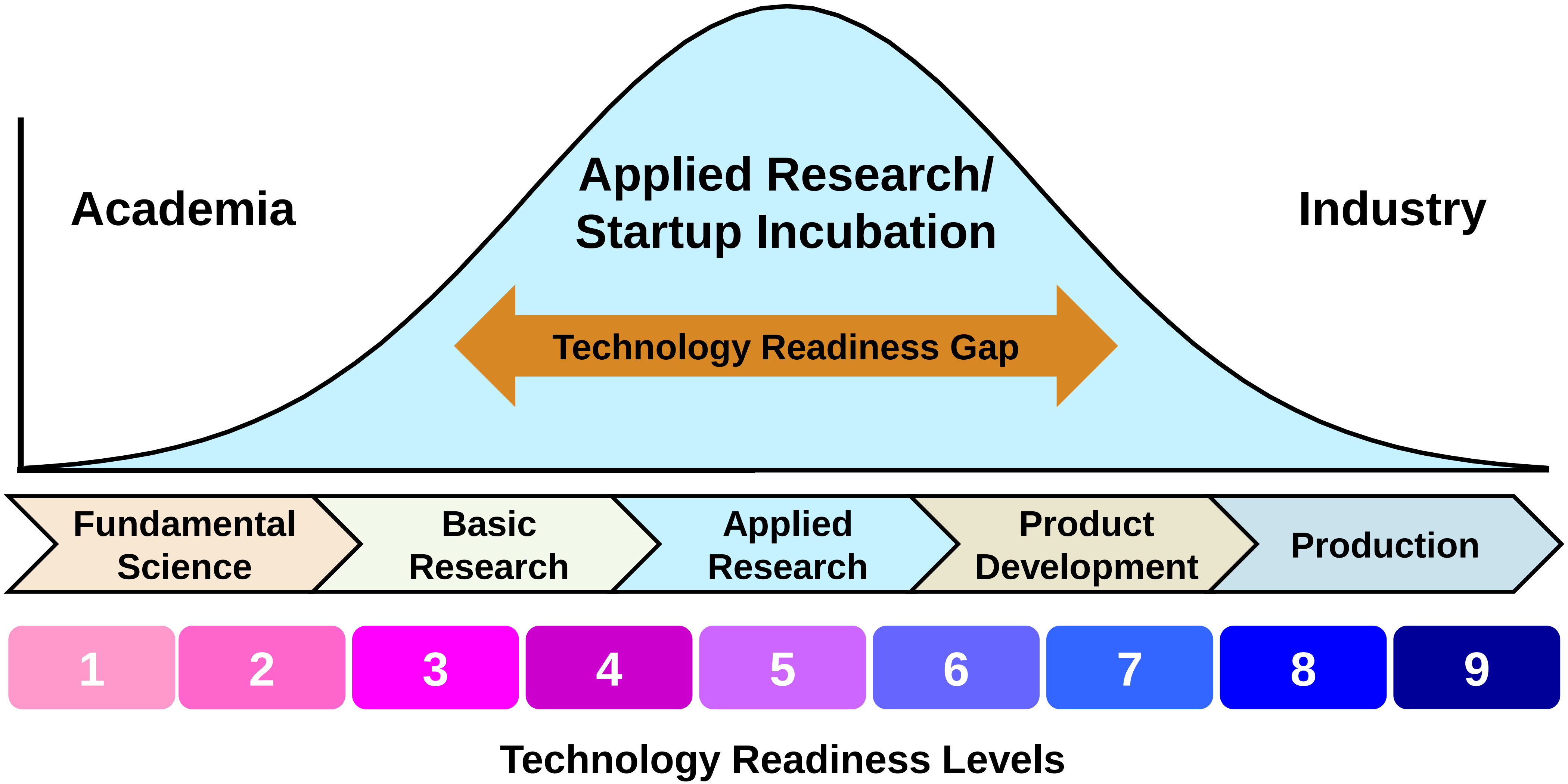
Focus of today's talk

Create a bridge from idea to implementation

- MathWorks software creates a bridge across a technology development cycle through five foundational elements.

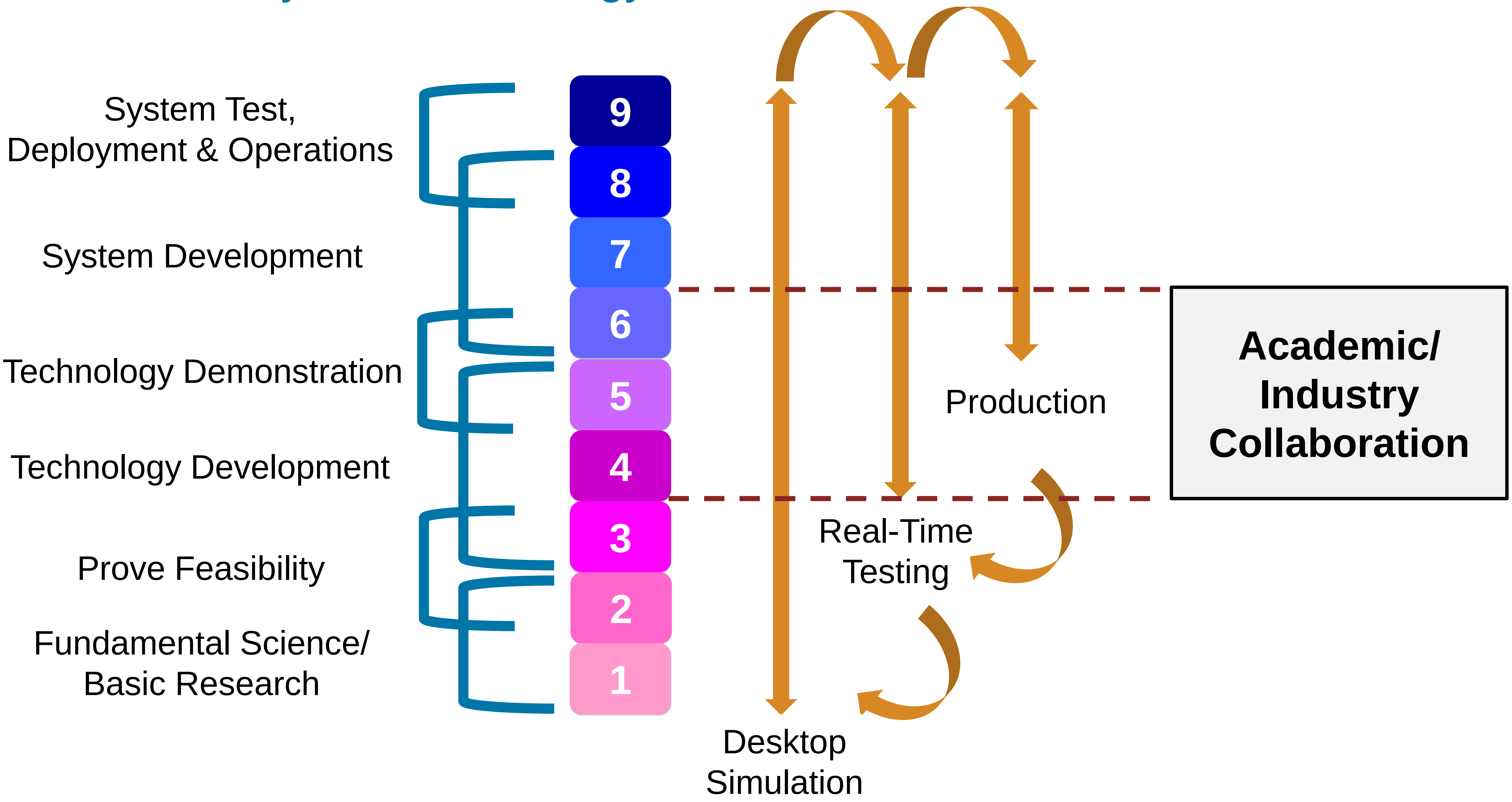


Moving Fundamental Science to Proven Technology

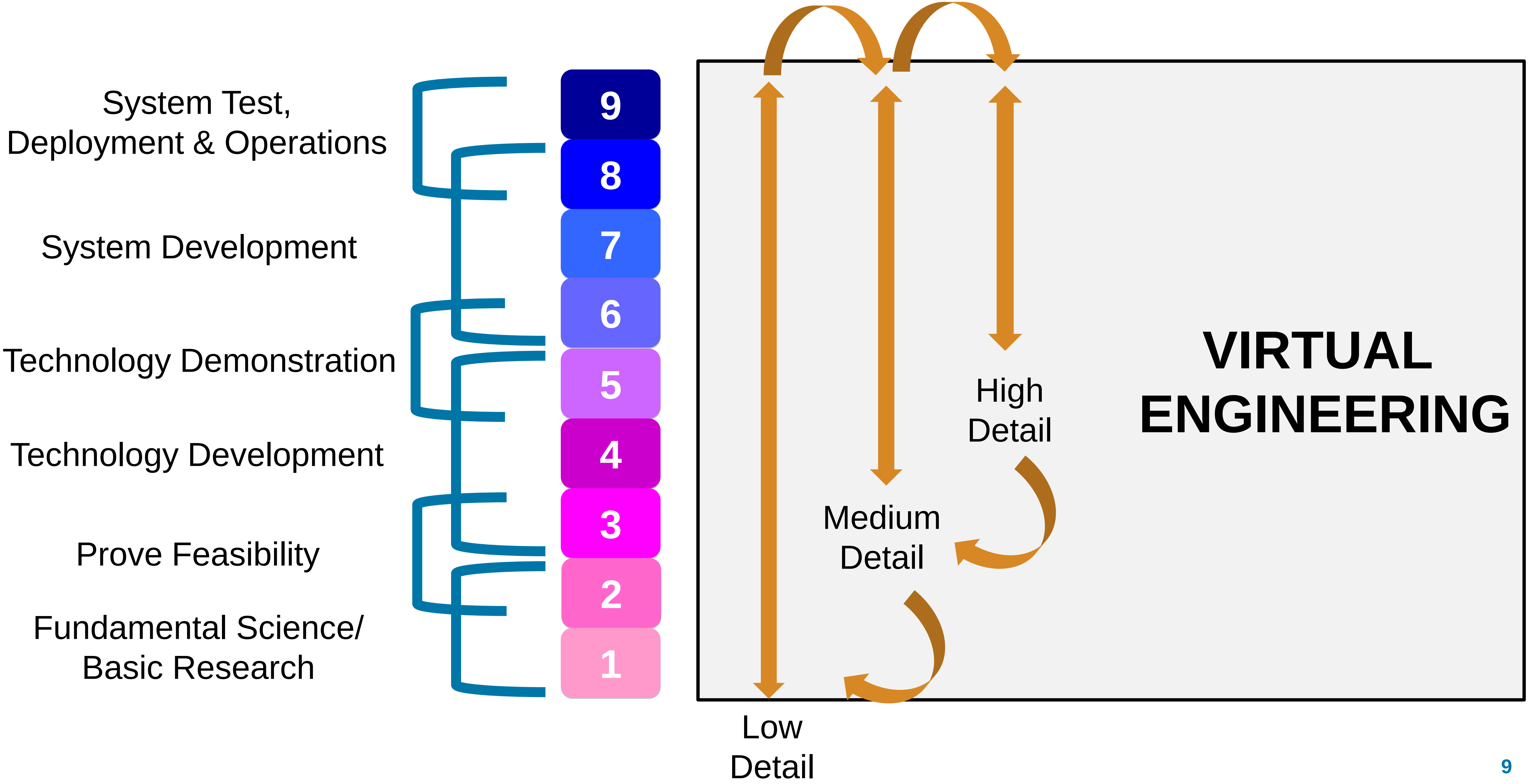


https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html

Model Fidelity and Technology Readiness



Model Fidelity and Technology Readiness



Types of Electrolyzers

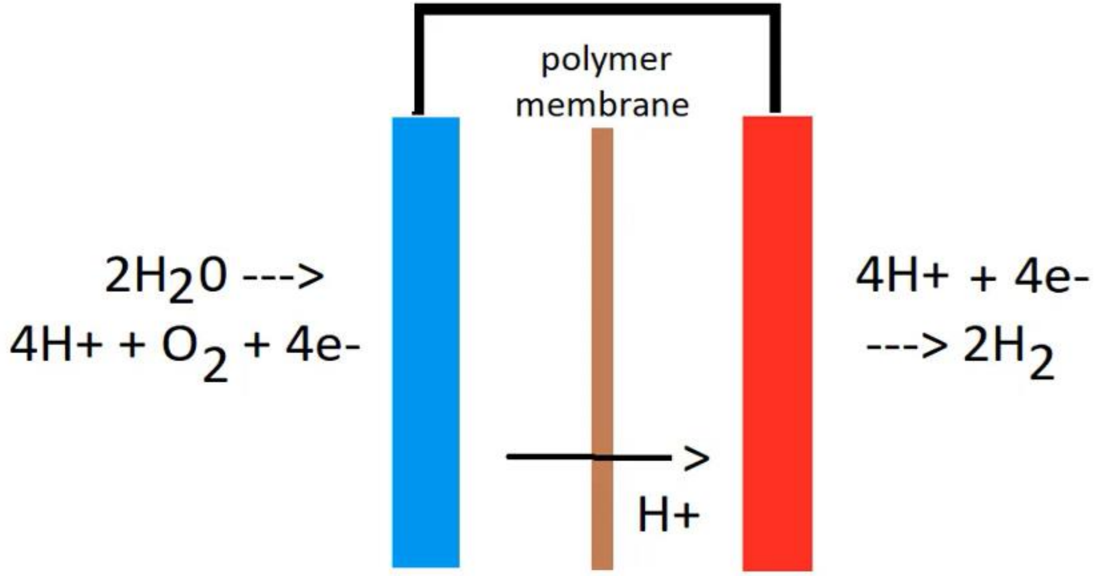
Type	Operating temperature (Deg C)	Operating pressure (Bar)	Membrane & Electrolyte
Acidic (PEM)	40-80	< 30	Polymer Electrolyte Membrane (PEM) Nafion H^+
Alkaline (AEL)	65-220	< 30	KOH Electrolyte OH^-
Solid Oxide (SOEC)	600-1000	< 10	ZrO_2, $La_{0.8}Sr_{0.2}Ga_{0.8}Mg_{0.2}O_3$ O^{2-}

Will be the discussed in today's talk.

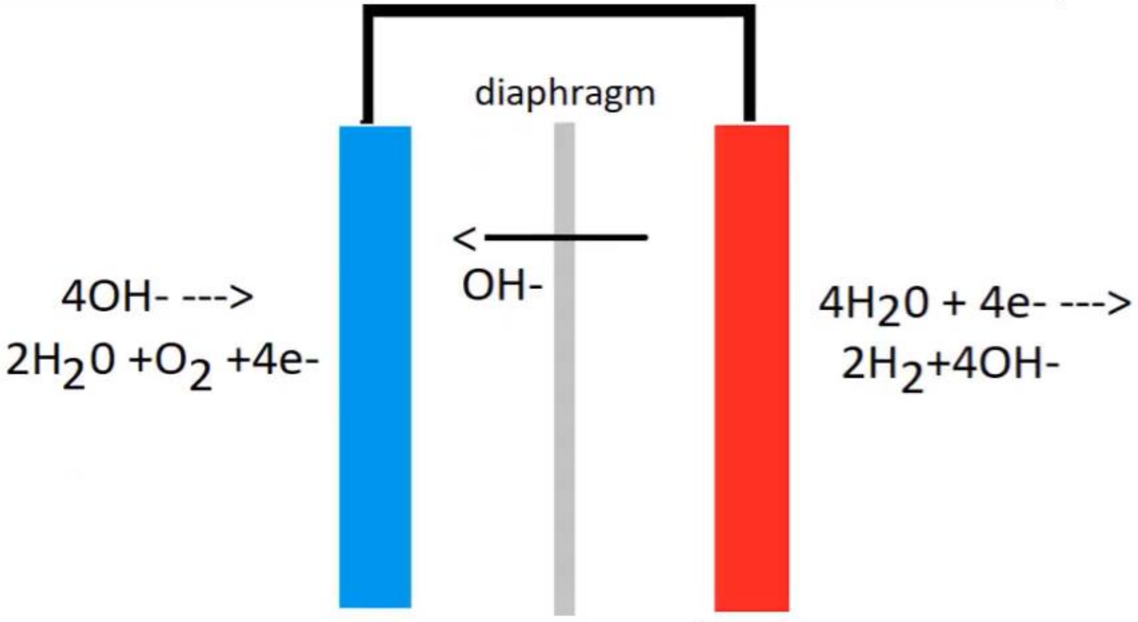
[*An Analytical Model for the Electrolyser Performance Derived from Materials Parameters*]

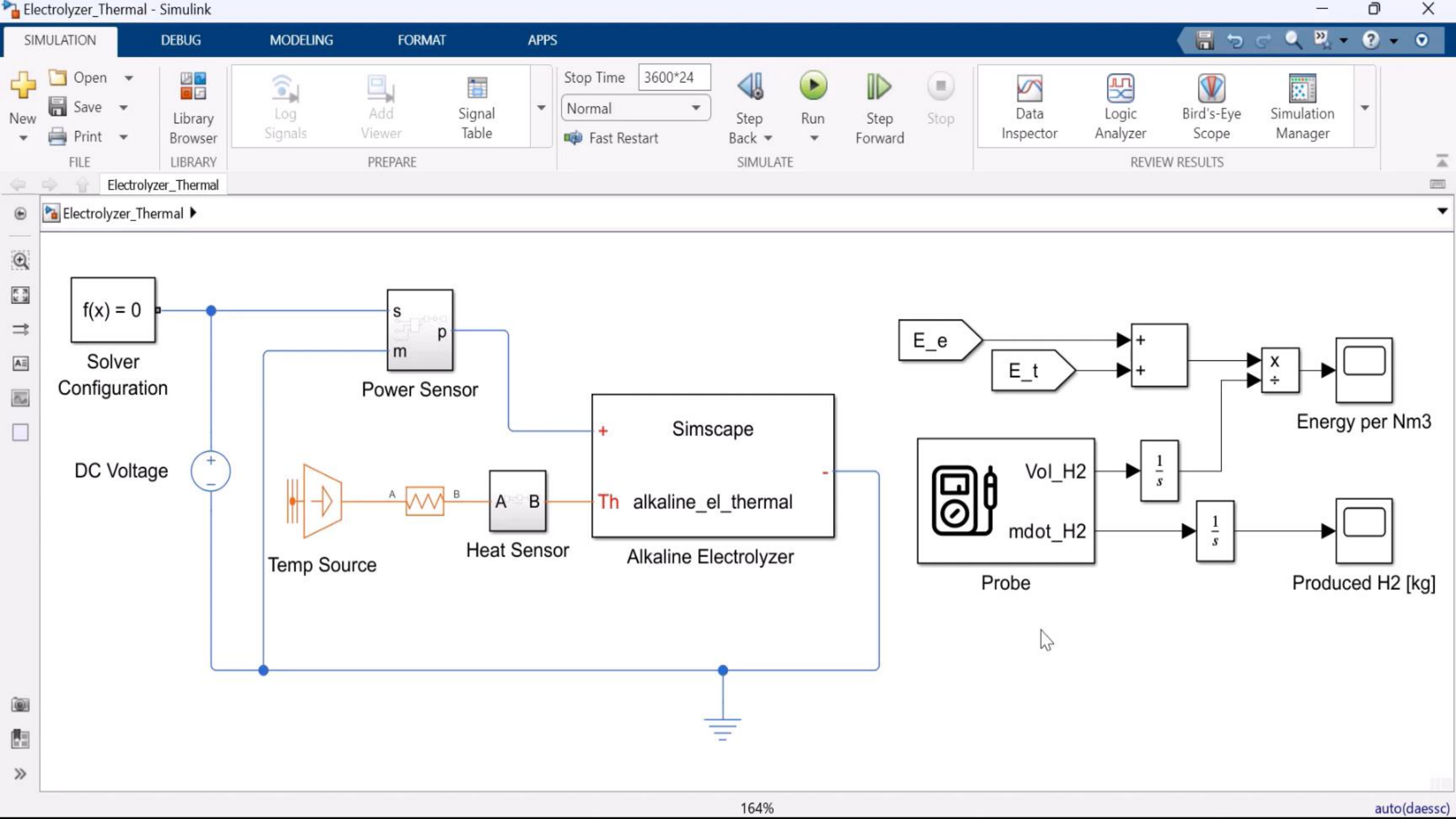
Types of Electrolyzers

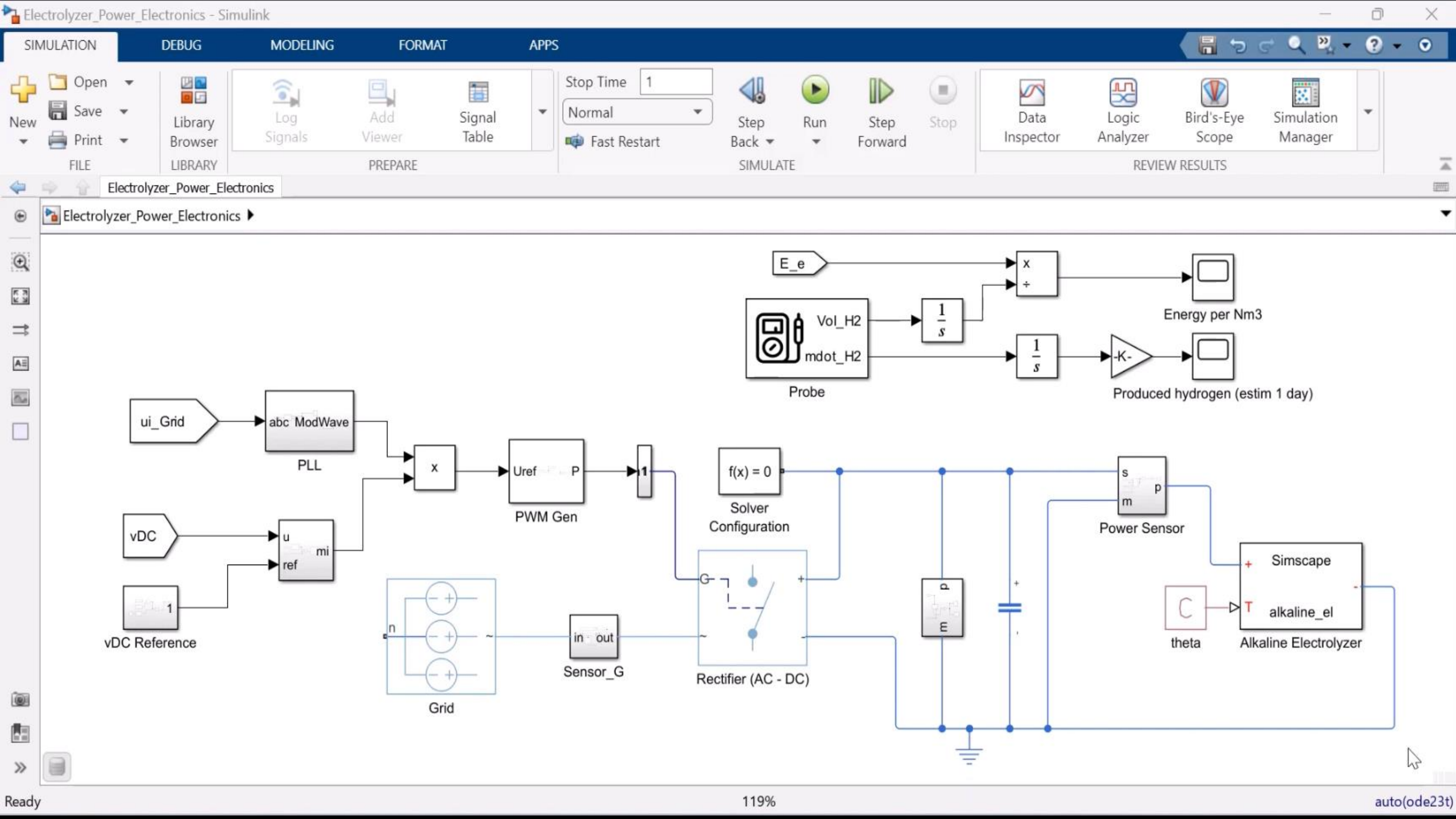
PEM (proton-exchange membrane)



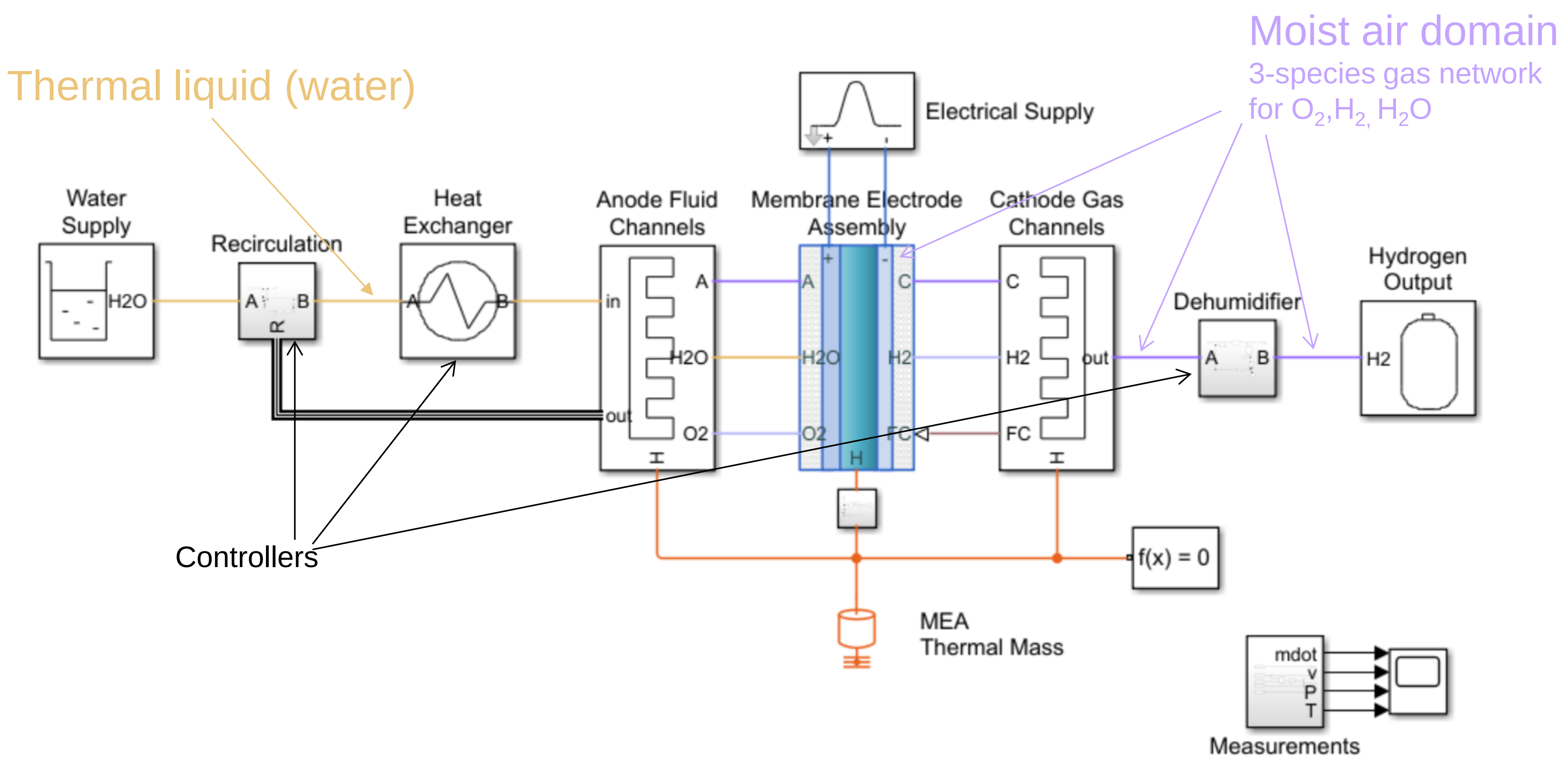
Alkaline




Electrolyzer_Thermal - Simulink
SIMULATION
DEBUG
MODELING
FORMAT
APPS
New
Open
Save
Print
FILE
Library Browser
LIBRARY
Log Signals
Add Viewer
Signal Table
PREPARE
Stop Time
3600*24
Normal
Fast Restart
Step Back
Run
Step Forward
Stop
SIMULATE
Data Inspector
Logic Analyzer
Bird's-Eye Scope
Simulation Manager
REVIEW RESULTS
Electrolyzer_Thermal
f(x) = 0
Solver Configuration
s
p
m
Power Sensor
DC Voltage
Temp Source
A
B
Heat Sensor
Simscape
Th
alkaline_el_thermal
Alkaline Electrolyzer
E_e
E_t
Energy per Nm3
Vol_H2
mdot_H2
Probe
Produced H2 [kg]
164%
auto(daessc)


Electrolyzer_Power_Electronics - Simulink
SIMULATION
DEBUG
MODELING
FORMAT
APPS
New
Open
Save
Print
FILE
Library Browser
LIBRARY
Log Signals
Add Viewer
Signal Table
PREPARE
Stop Time
1
Normal
Fast Restart
Step Back
Run
Step Forward
Stop
SIMULATE
Data Inspector
Logic Analyzer
Bird's-Eye Scope
Simulation Manager
REVIEW RESULTS
Electrolyzer_Power_Electronics
E_e
Vol_H2
mdot_H2
Probe
Energy per Nm3
-K-
Produced hydrogen (estim 1 day)
ui_Grid
abc ModWave
PLL
PWM Gen
Uref
f(x) = 0
Solver Configuration
Power Sensor
vDC
u
ref
mi
vDC Reference
Grid
in out
Sensor_G
Rectifier (AC - DC)
Simscape
alkaline_el
theta
Alkaline Electrolyzer
Ready
119%
auto(ode23t)

PEM Electrolyzers!



Since R2022a

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>> ssc_electrolyzer
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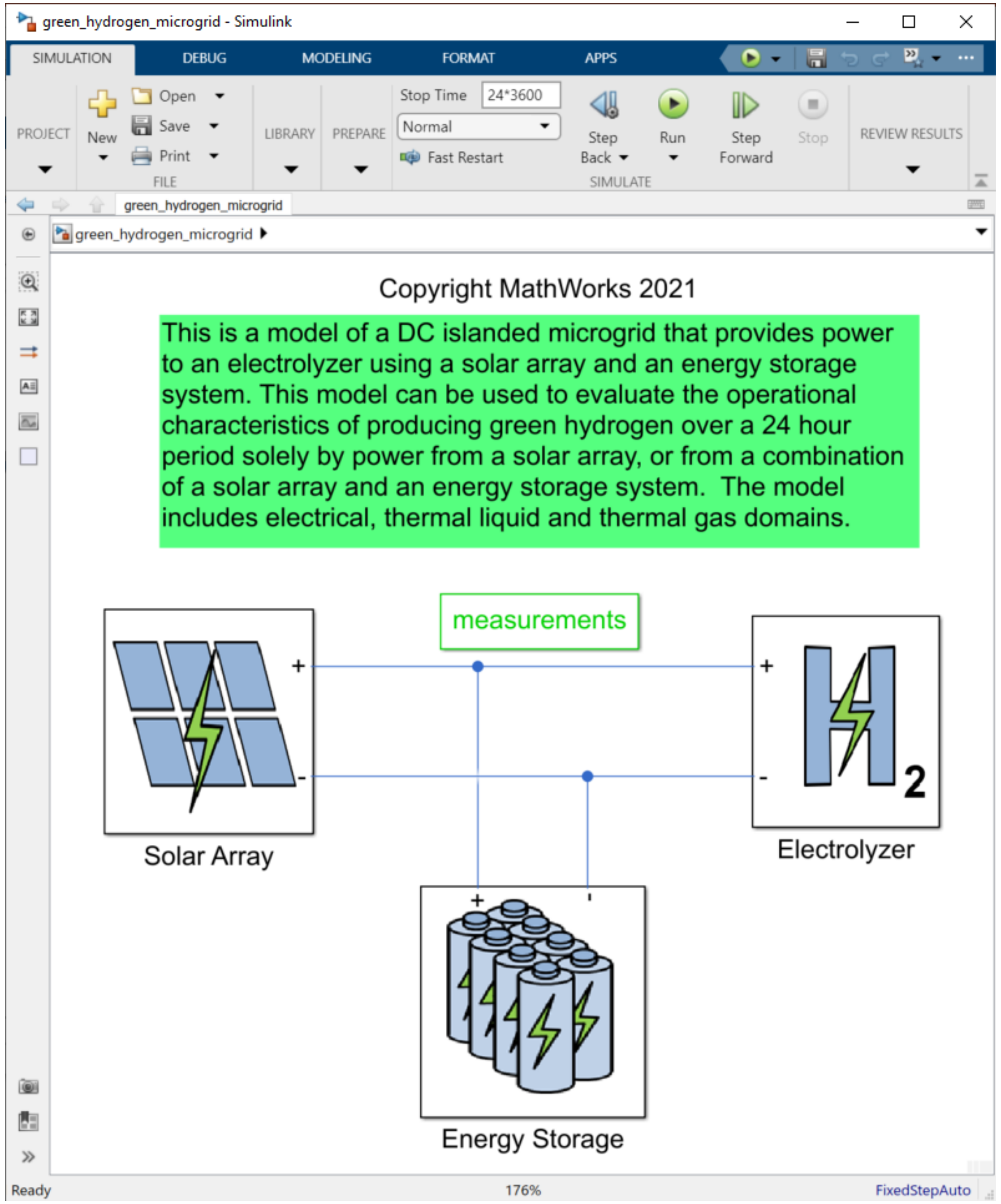
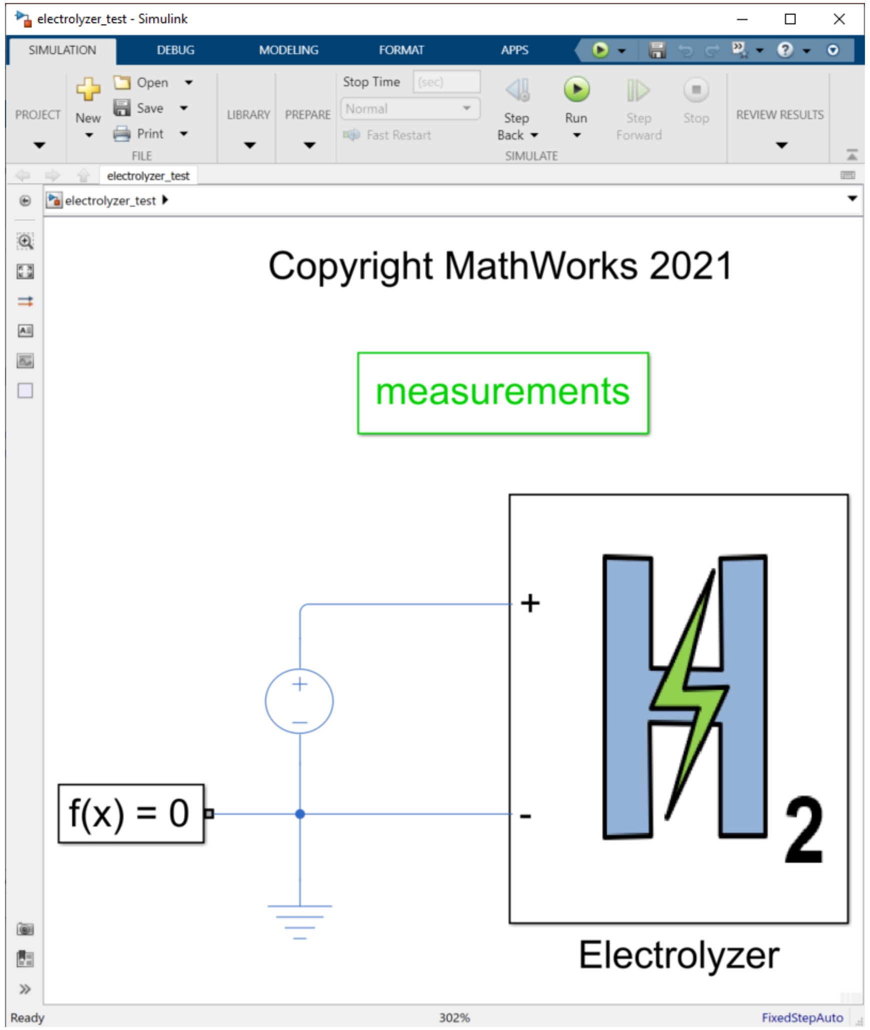
Introduction to the Green Hydrogen Microgrid

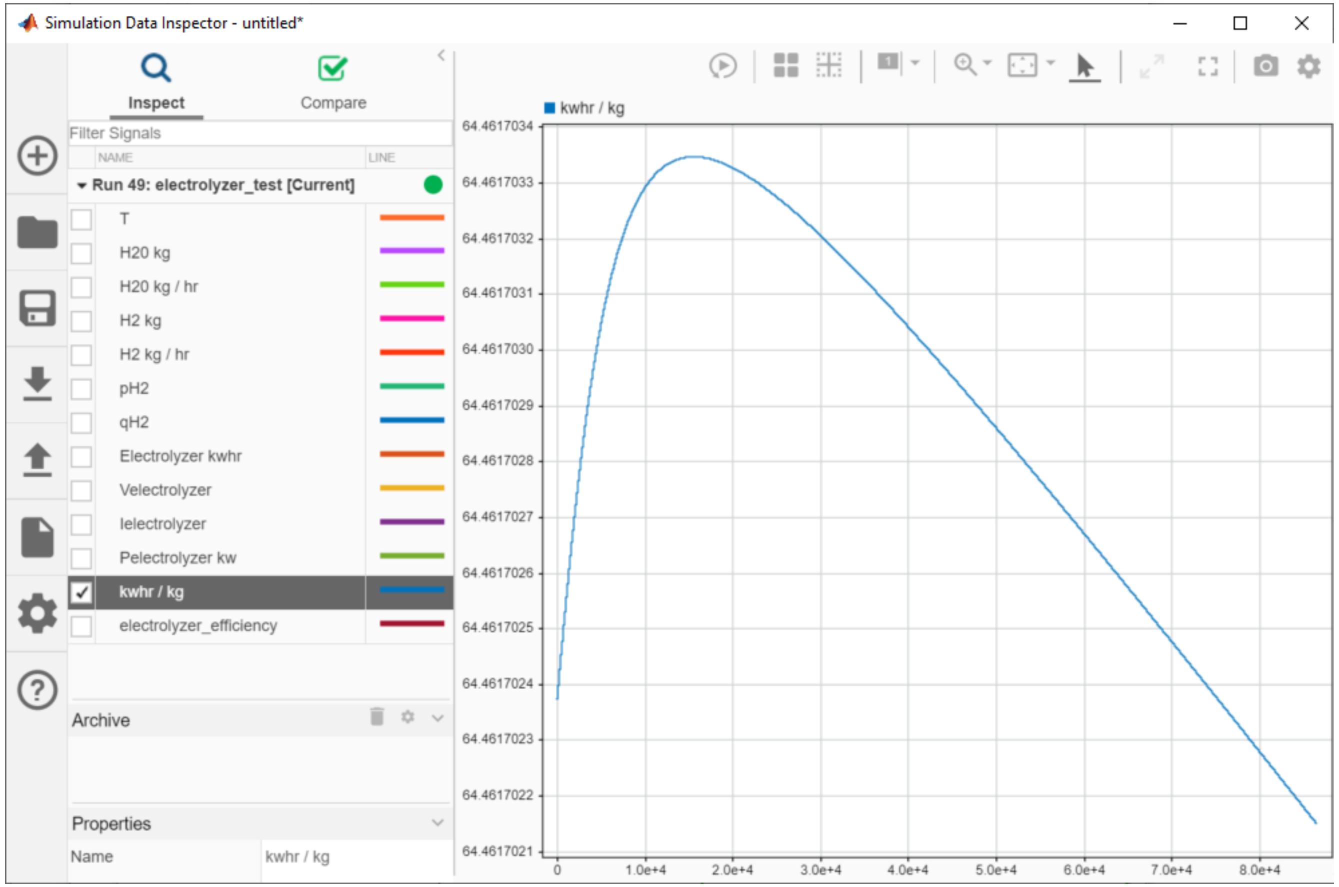


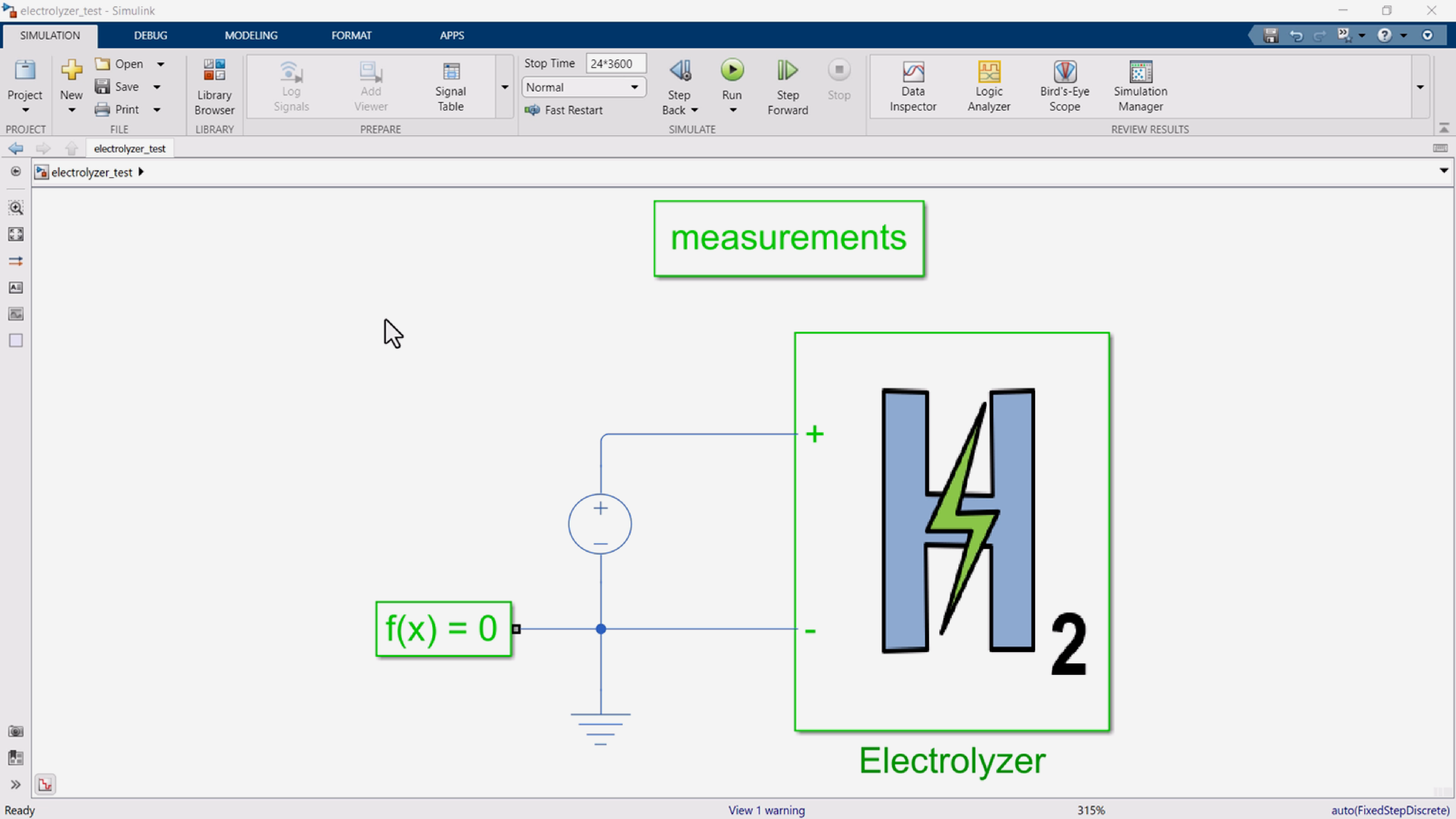
[Green Hydrogen (Wind & Solar) from (Alkaline) Electrolysis.](#)

Testing the Electrolyzer

- The electrolyzer is connected to an ideal DC voltage source at 240V.

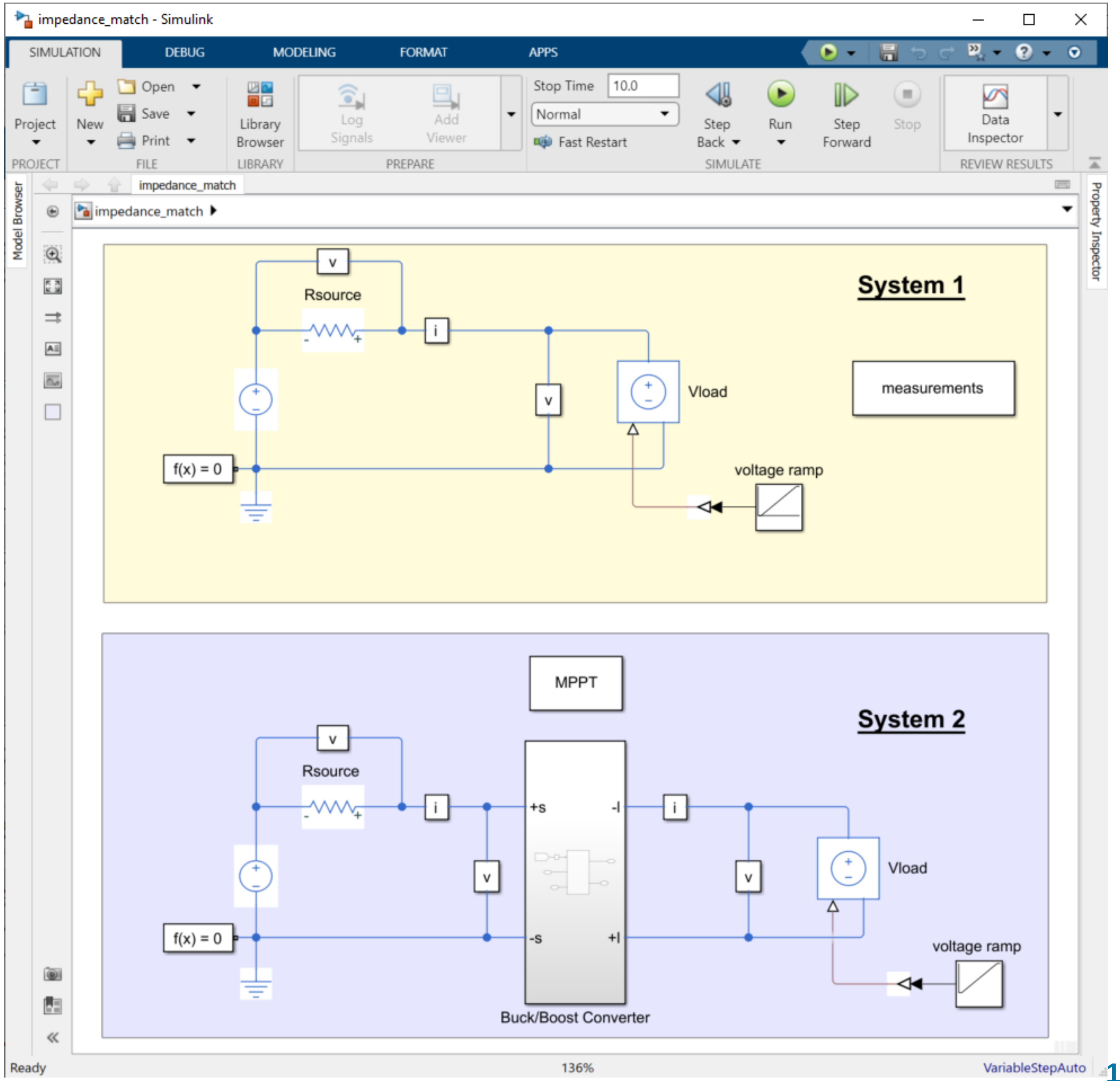





electrolyzer_test - Simulink
SIMULATION
DEBUG
MODELING
FORMAT
APPS
Project
New
Open
Save
Print
Library Browser
Log Signals
Add Viewer
Signal Table
Stop Time
24*3600
Normal
Fast Restart
Step Back
Run
Step Forward
Stop
Data Inspector
Logic Analyzer
Bird's-Eye Scope
Simulation Manager
PROJECT
FILE
LIBRARY
PREPARE
SIMULATE
REVIEW RESULTS
electrolyzer_test
electrolyzer_test
measurements
f(x) = 0
+
-
2
Electrolyzer
Ready
View 1 warning
315%
auto(FixedStepDiscrete)

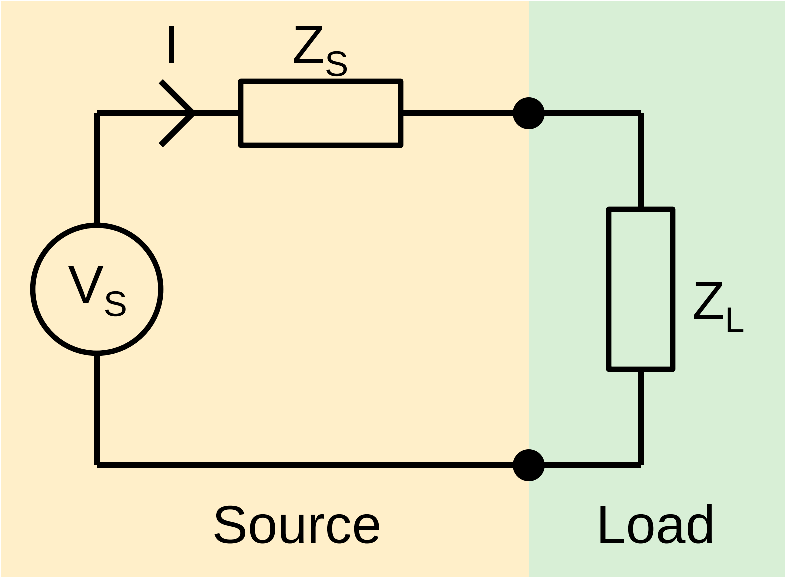
Solar MMPT and Impedance Matching

- MPPT operates on the principle of impedance matching.



Impedance Matching

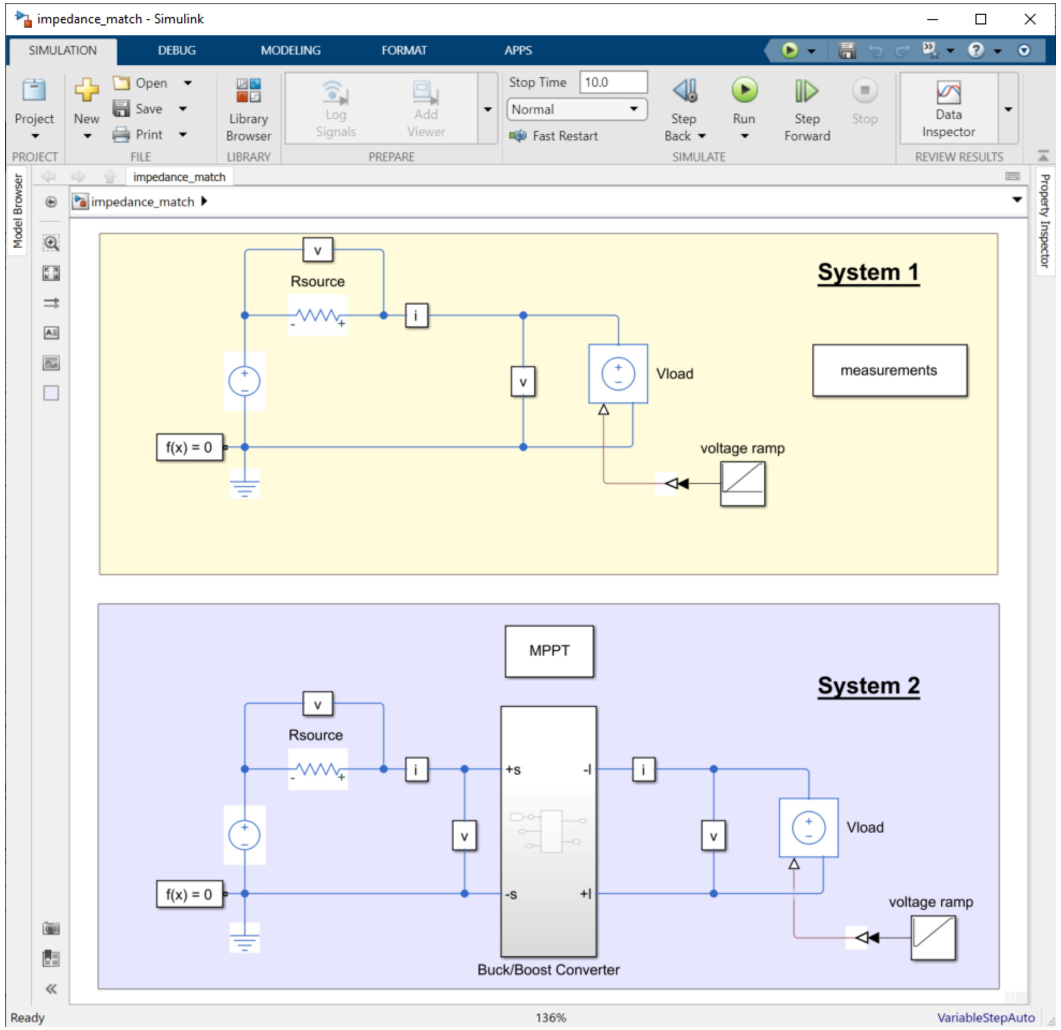
- Maximum power is delivered to a load when the load impedance matches the source impedance.

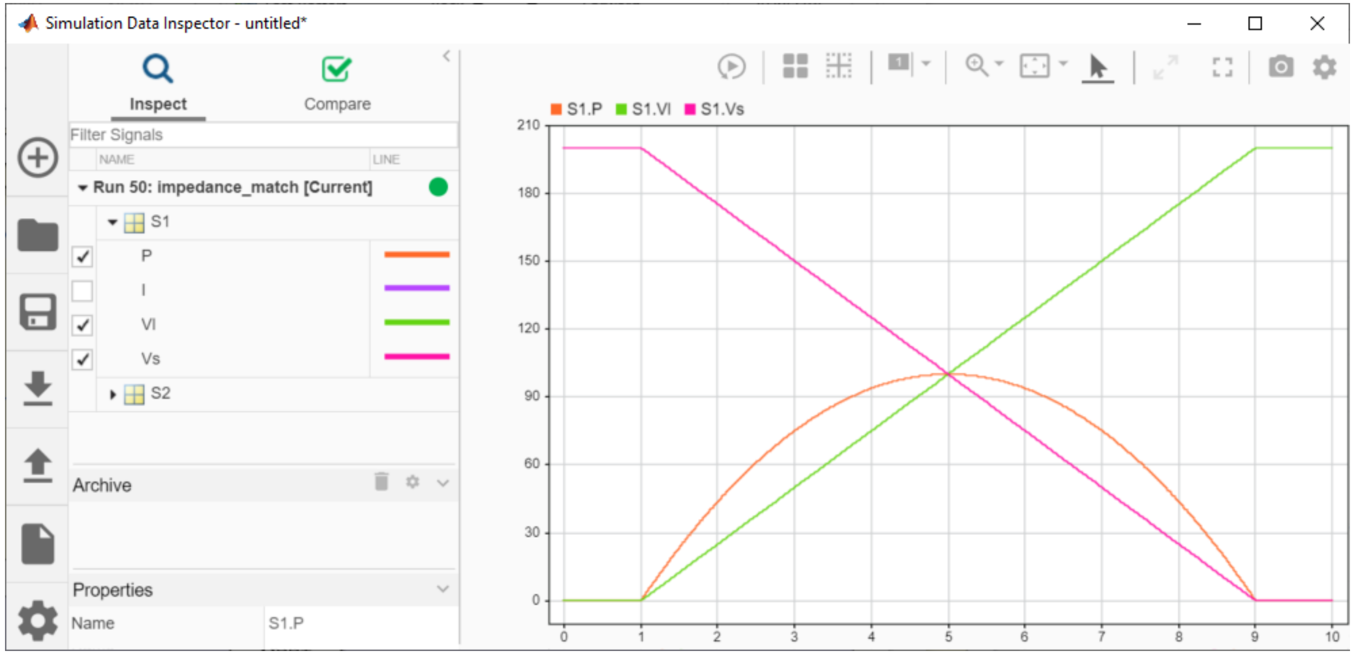


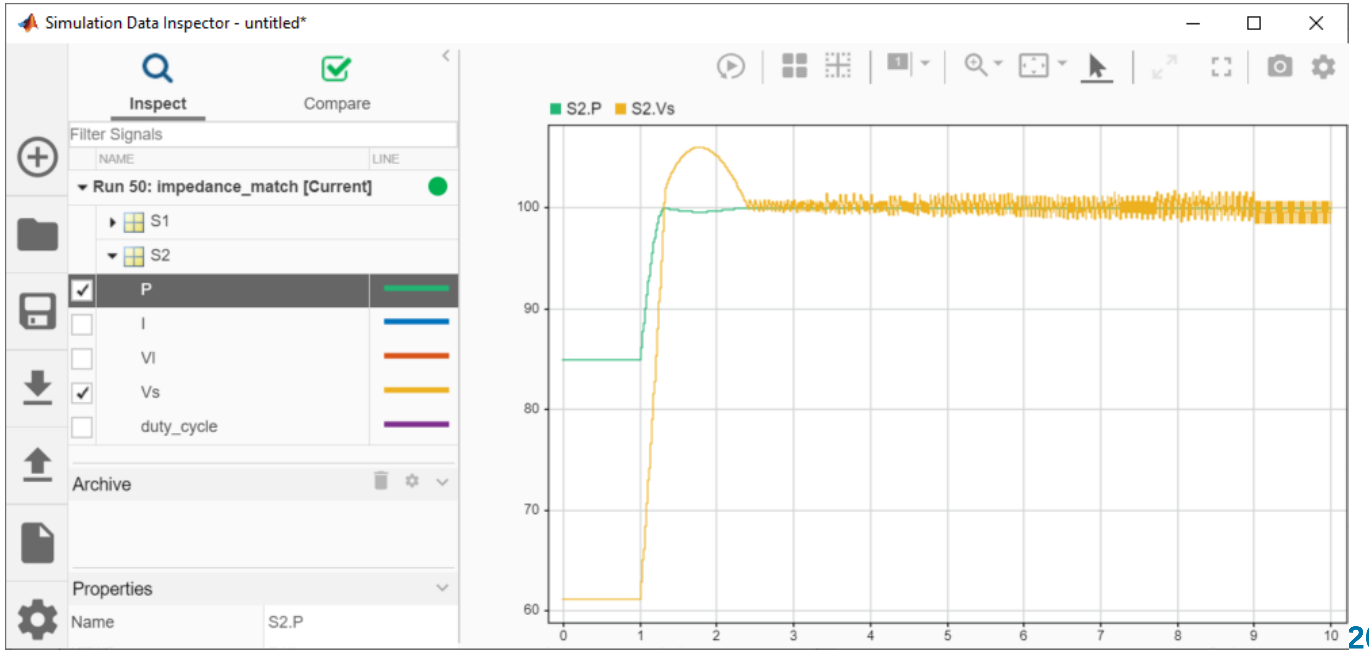
If $Z_L = Z_S$ then P_L = max P

If $Z_L \neq Z_S$ then $P_L <$ max P

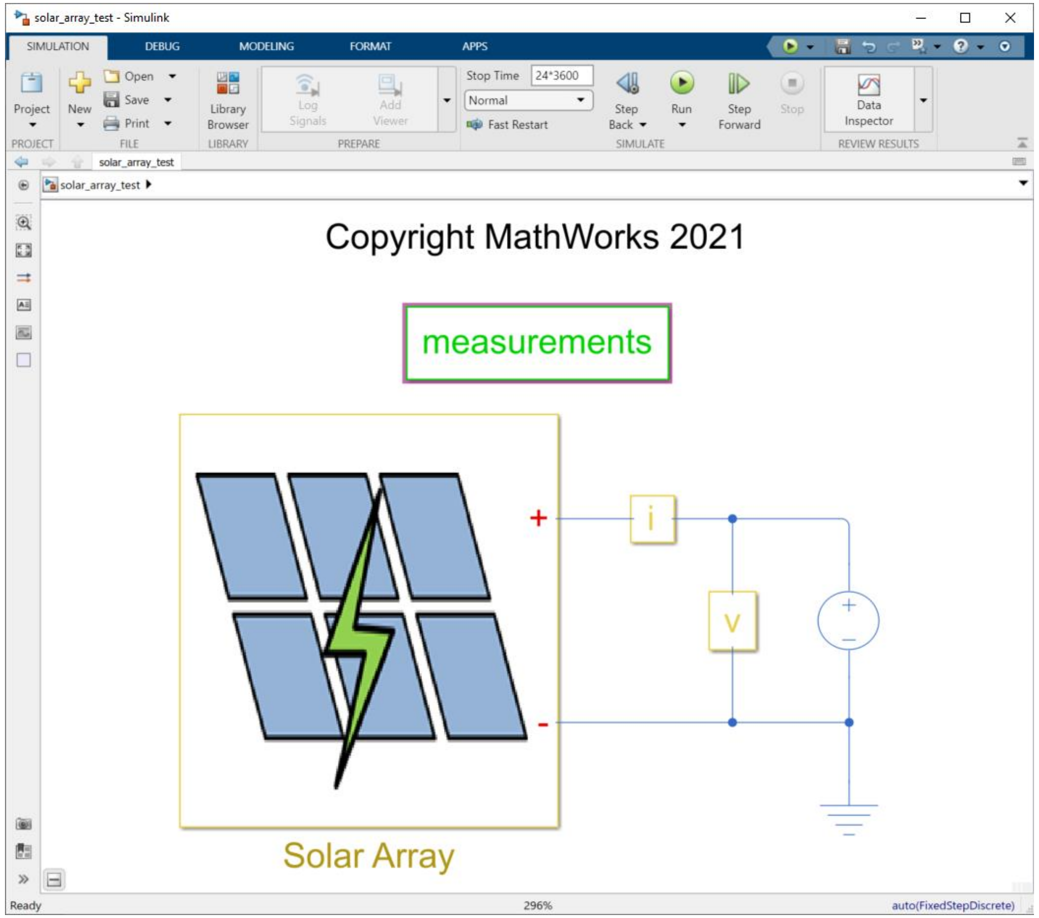
Impedance matching

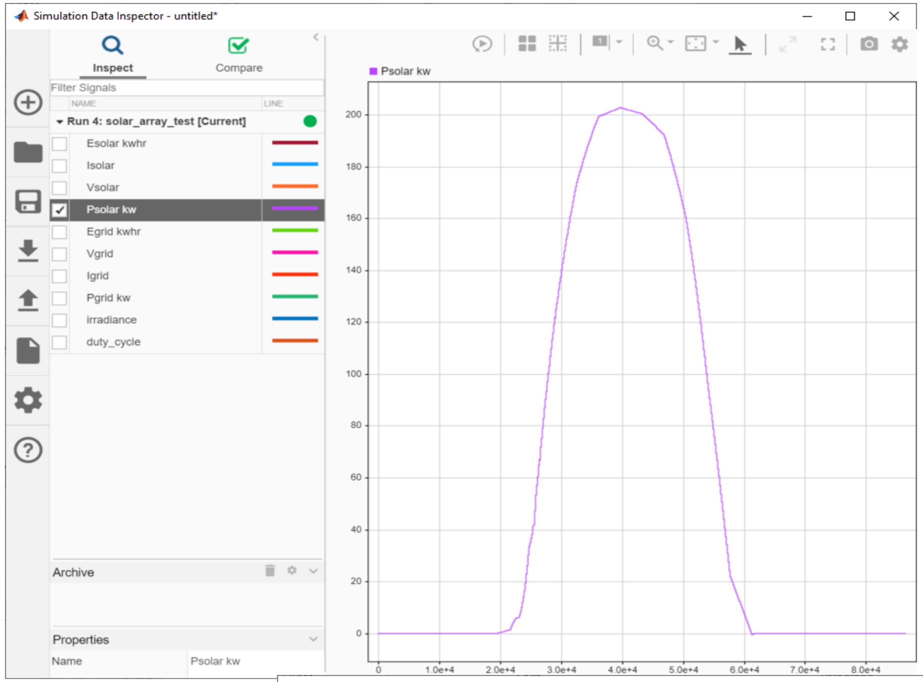


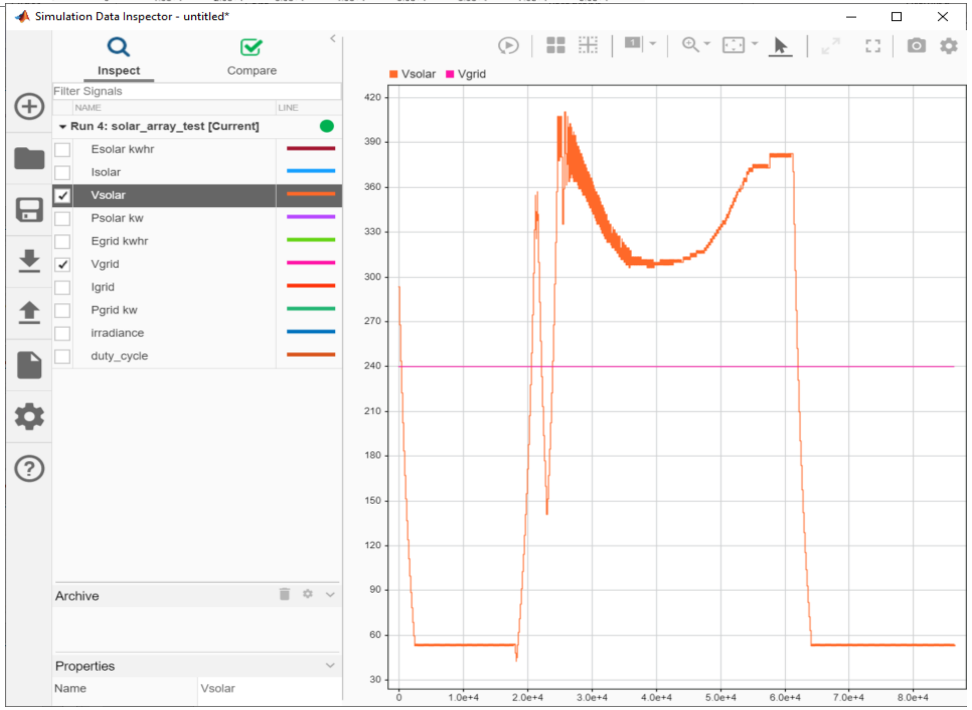


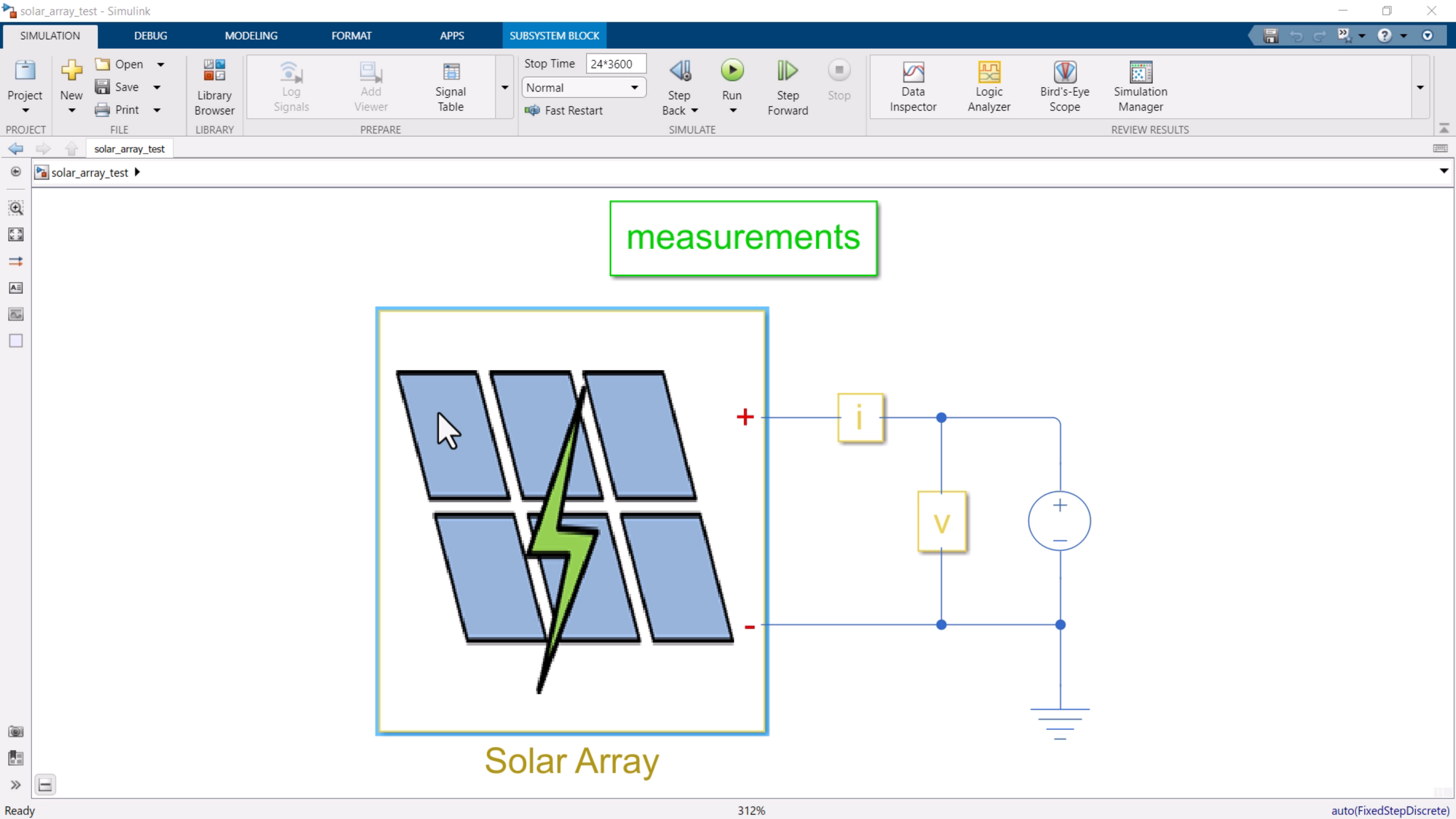


Testing the Solar Array

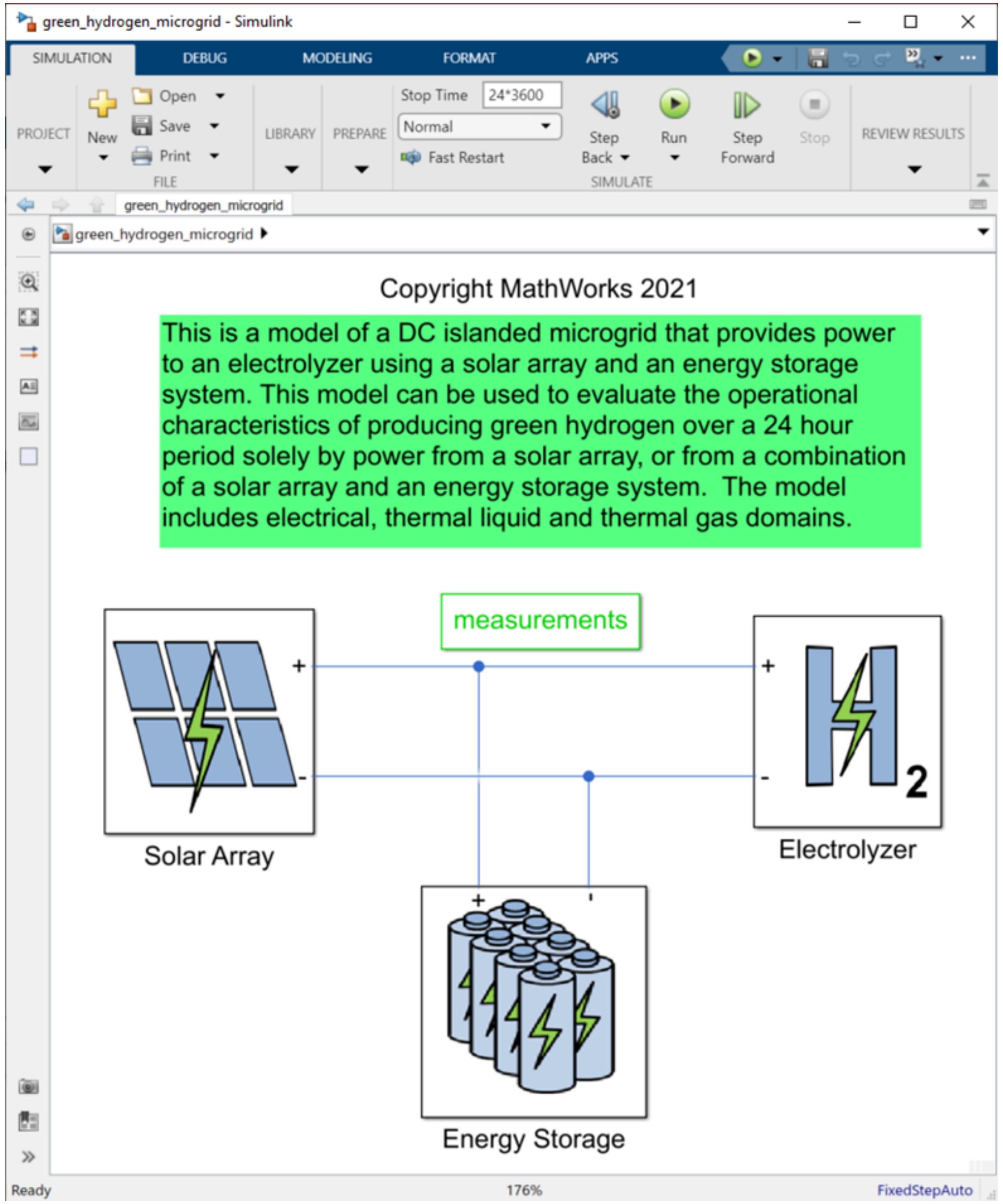


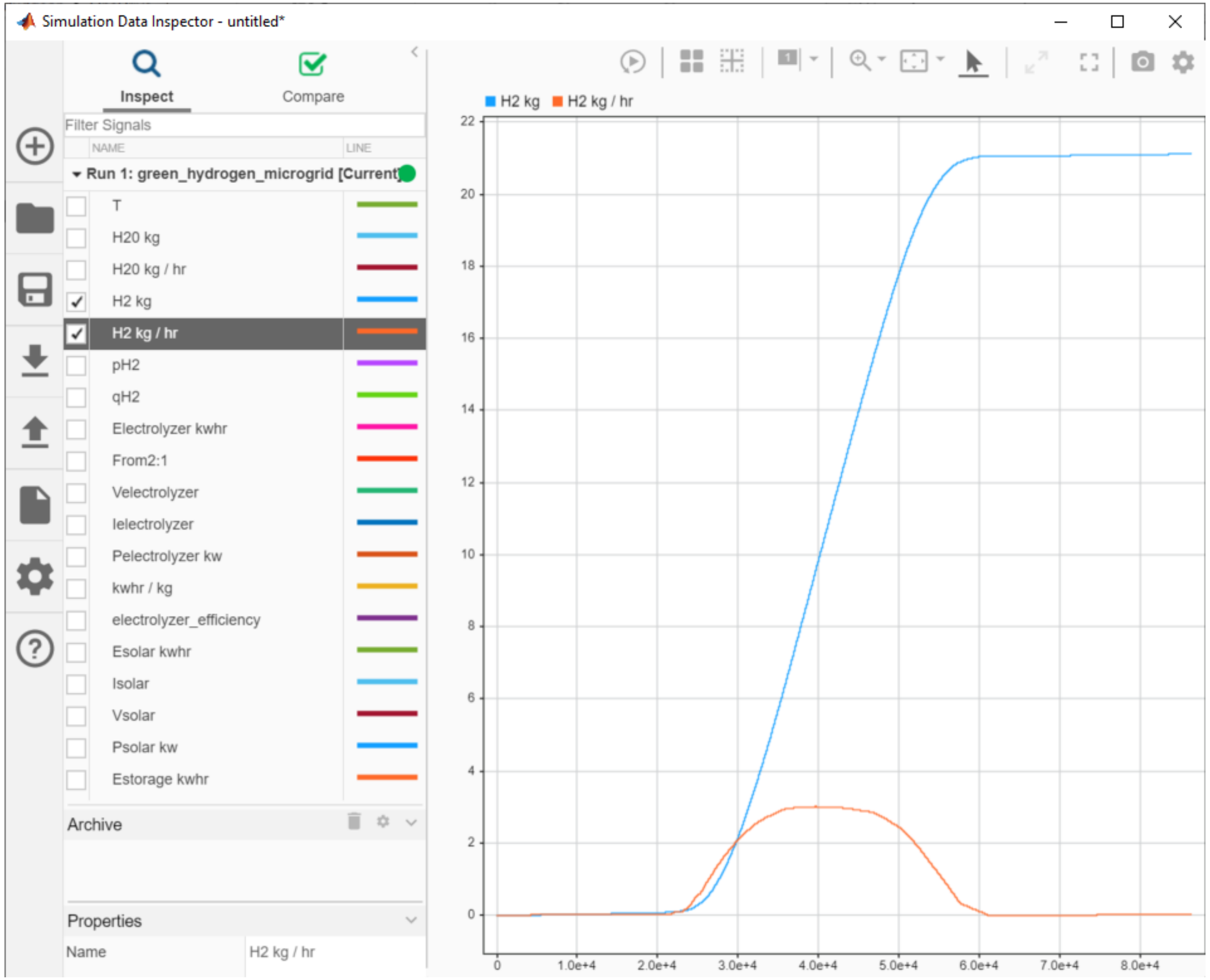


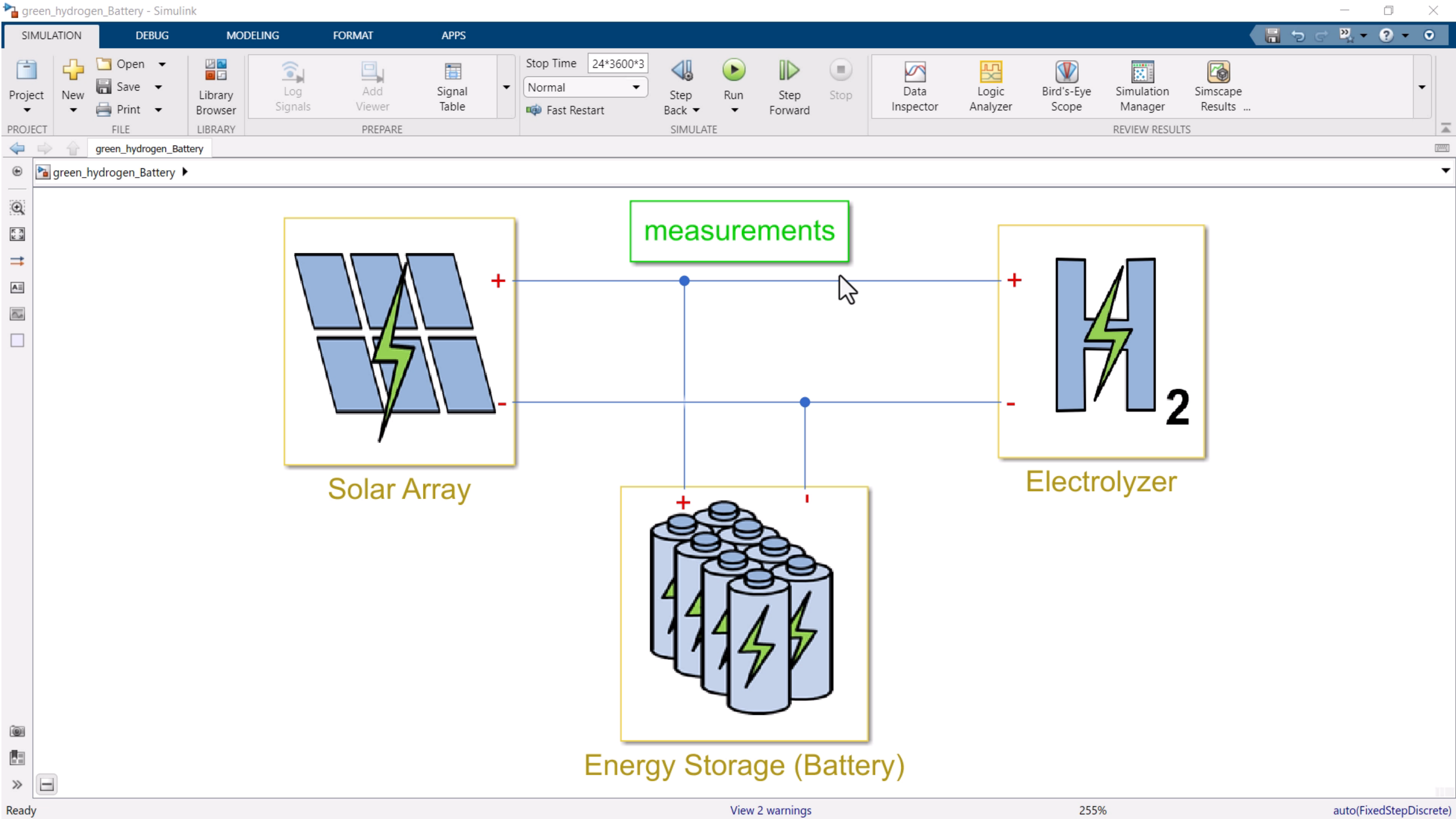



solar_array_test - Simulink
SIMULATION
DEBUG
MODELING
FORMAT
APPS
SUBSYSTEM BLOCK
Project
New
Open
Save
Print
Library Browser
Log Signals
Add Viewer
Signal Table
Stop Time
24*3600
Normal
Fast Restart
Step Back
Run
Step Forward
Stop
Data Inspector
Logic Analyzer
Bird's-Eye Scope
Simulation Manager
PROJECT
FILE
LIBRARY
PREPARE
SIMULATE
REVIEW RESULTS
solar_array_test
solar_array_test
measurements
+
-
i
V
Solar Array
Ready
312%
auto(FixedStepDiscrete)

Evaluating System Operation



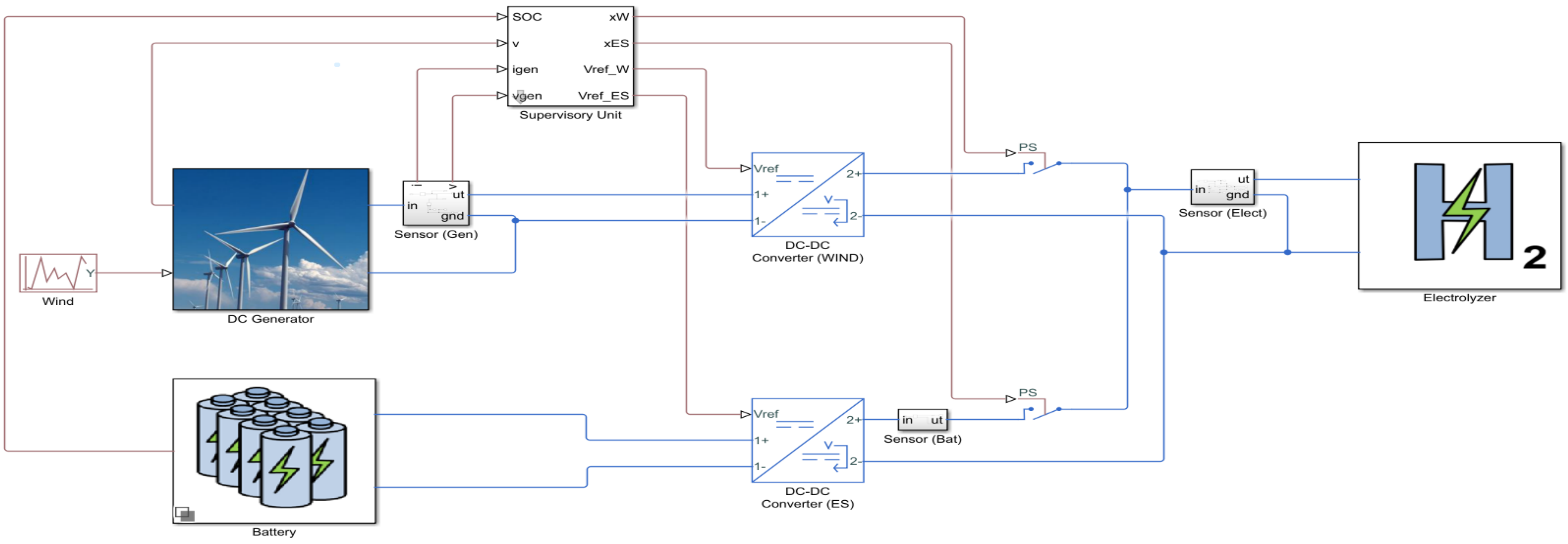


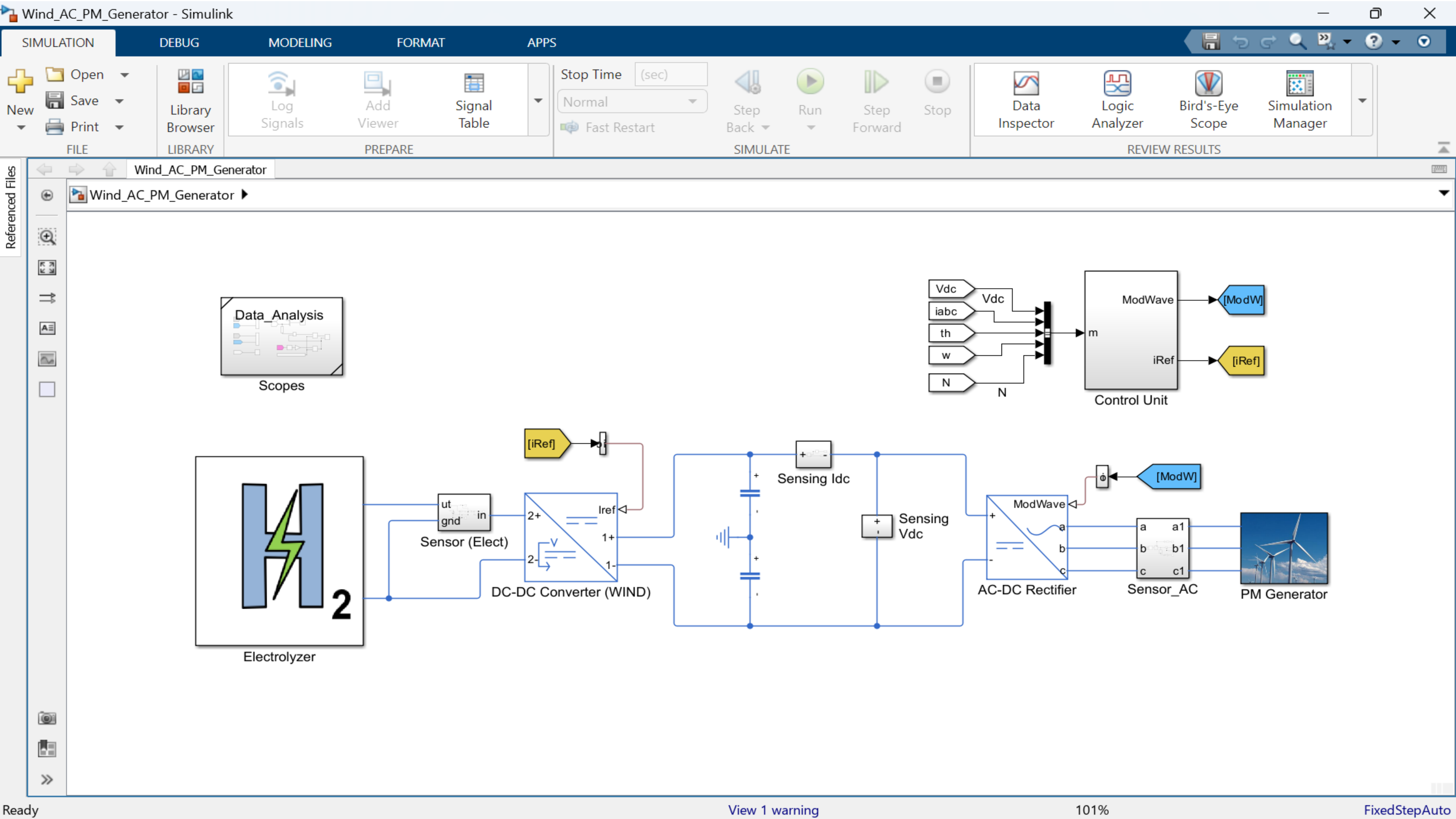

green_hydrogen_Battery - Simulink
SIMULATION
DEBUG
MODELING
FORMAT
APPS
Project
New
Open
Save
Print
Library Browser
Log Signals
Add Viewer
Signal Table
Stop Time
24*3600*3
Normal
Fast Restart
Step Back
Run
Step Forward
Stop
Data Inspector
Logic Analyzer
Bird's-Eye Scope
Simulation Manager
Simscape Results
PROJECT
FILE
LIBRARY
PREPARE
SIMULATE
REVIEW RESULTS
green_hydrogen_Battery
measurements
Solar Array
Electrolyzer
Energy Storage (Battery)
Ready
View 2 warnings
255%
auto(FixedStepDiscrete)

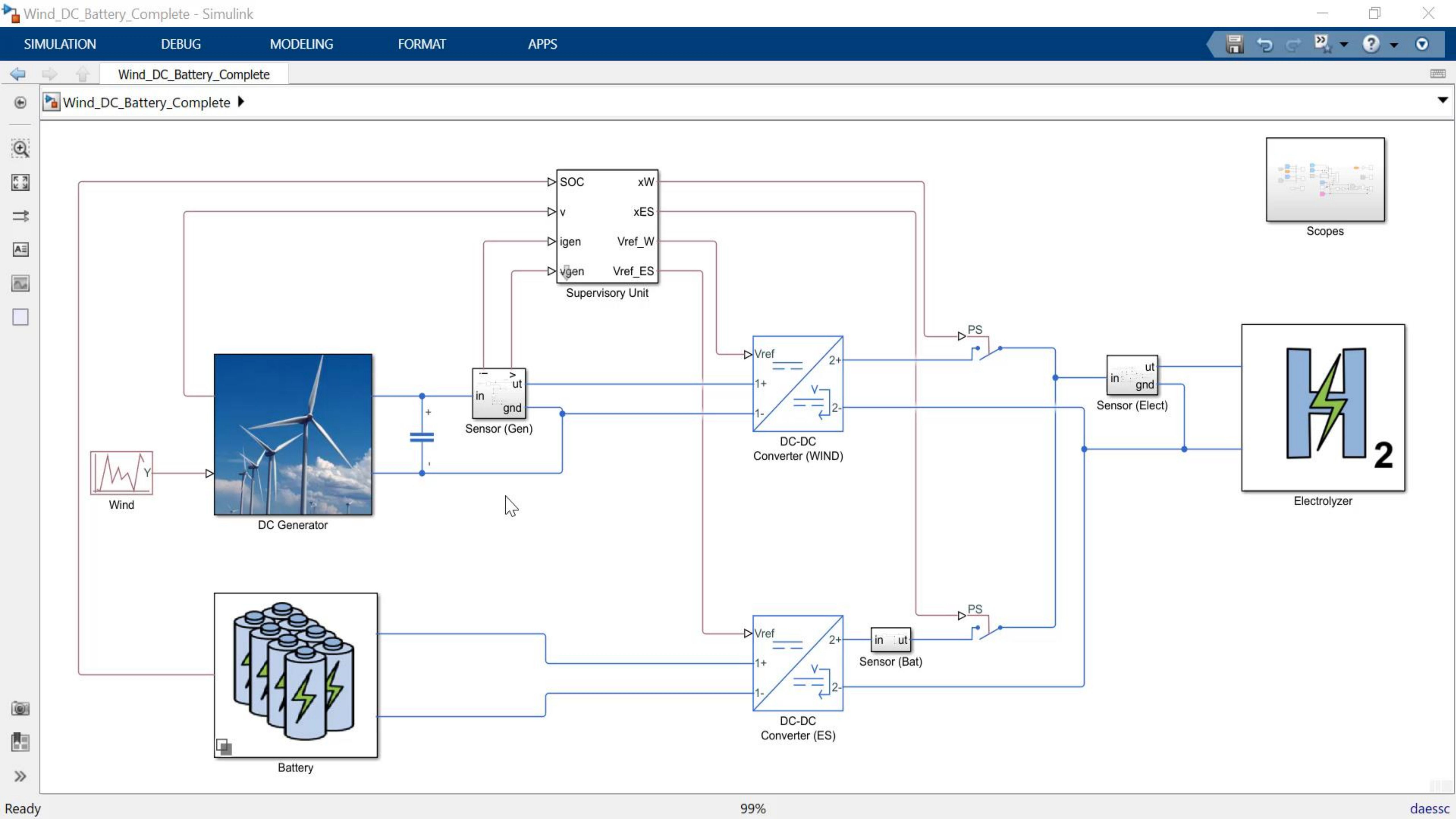
Enabling green hydrogen – System performance

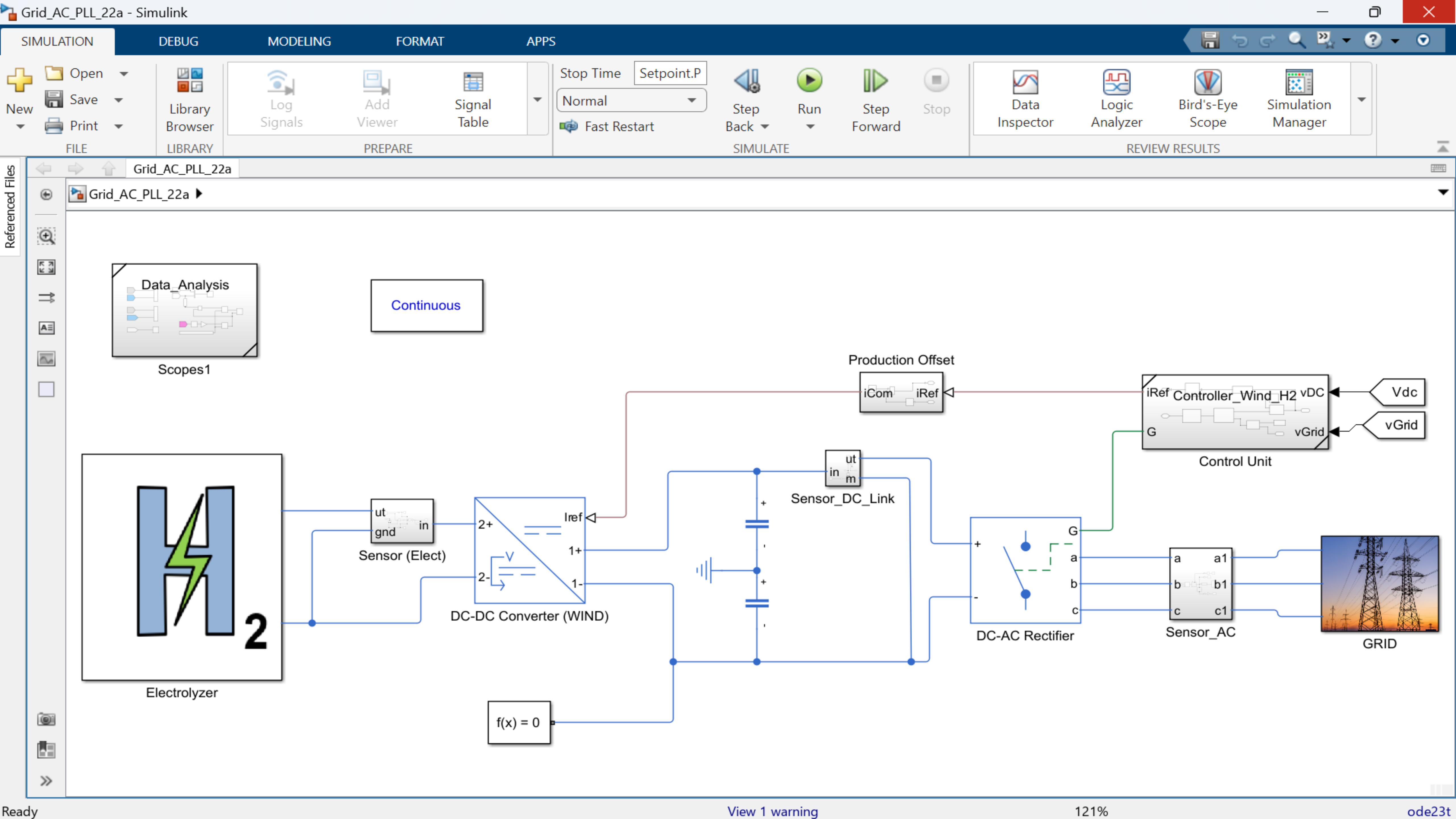
Medium fidelity

- expected H_2 production & water consumption
- suitable control strategy (conditions, use of physical assets)
- energy storage (dimensioning, expected duty regime)
- planning of operations (collect – replace - maintain)

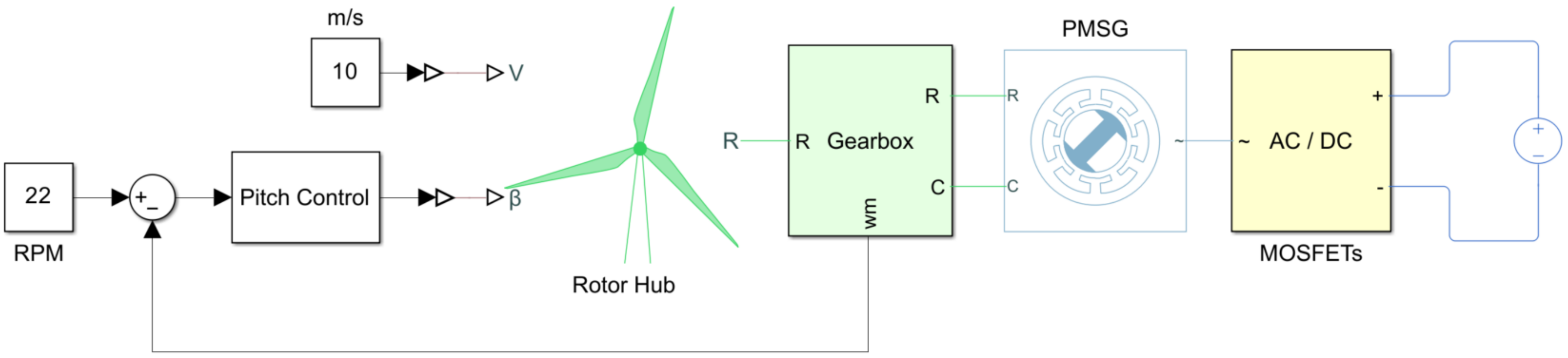



Wind_AC_PM_Generator - Simulink
SIMULATION
DEBUG
MODELING
FORMAT
APPS
New
Open
Save
Print
FILE
Library Browser
LIBRARY
Log Signals
Add Viewer
Signal Table
PREPARE
Stop Time
(sec)
Normal
Fast Restart
Step Back
Run
Step Forward
Stop
SIMULATE
Data Inspector
Logic Analyzer
Bird's-Eye Scope
Simulation Manager
REVIEW RESULTS
Referenced Files
Wind_AC_PM_Generator
Data_Analysis
Scopes
Vdc
iabc
th
w
N
ModWave
m
iRef
[ModW]
[iRef]
Control Unit
Sensing Idc
Iref
2+
1+
2-
1-
ut
gnd
in
Sensor (Elect)
DC-DC Converter (WIND)
Sensing Vdc
a
b
c
a1
b1
c1
AC-DC Rectifier
Sensor_AC
PM Generator
2
Electrolyzer
Ready
View 1 warning
101%
FixedStepAuto

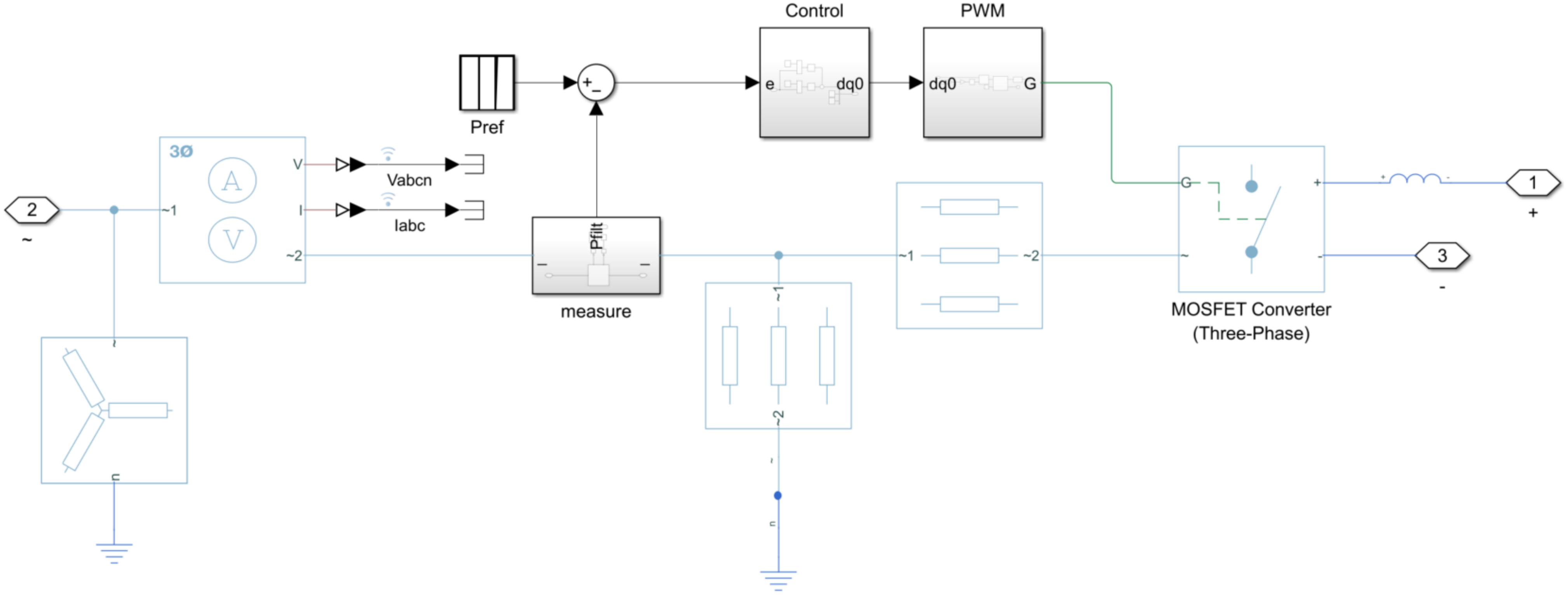

Wind_DC_Battery_Complete - Simulink
SIMULATION
DEBUG
MODELING
FORMAT
APPS
Wind_DC_Battery_Complete
Wind_DC_Battery_Complete
SOC
v
igen
vgen
xW
xES
Vref_W
Vref_ES
Supervisory Unit
Scopes
Wind
DC Generator
in
ut
gnd
Sensor (Gen)
Vref
1+
1-
2+
2-
DC-DC
Converter (WIND)
PS
PS
in
ut
gnd
Sensor (Elect)
Electrolyzer
Battery
Vref
1+
1-
2+
2-
DC-DC
Converter (ES)
in
ut
Sensor (Bat)
Ready
99%
daessc


Grid_AC_PLL_22a - Simulink
SIMULATION
DEBUG
MODELING
FORMAT
APPS
New
Open
Save
Print
FILE
Library Browser
LIBRARY
Log Signals
Add Viewer
Signal Table
PREPARE
Stop Time
Setpoint.P
Normal
Fast Restart
Step Back
Run
Step Forward
Stop
SIMULATE
Data Inspector
Logic Analyzer
Bird's-Eye Scope
Simulation Manager
REVIEW RESULTS
Referenced Files
Grid_AC_PLL_22a
Data_Analysis
Scopes1
Continuous
Production Offset
iCom
iRef
Controller_Wind_H2
vDC
G
vGrid
Control Unit
Vdc
vGrid
ut
in
m
Sensor_DC_Link
ut
gnd
in
Sensor (Elect)
Iref
2+
1+
2-
1-
DC-DC Converter (WIND)
Electrolyzer
+
-
DC-AC Rectifier
a
b
c
a1
b1
c1
Sensor_AC
GRID
f(x) = 0
Ready
View 1 warning
121%
ode23t

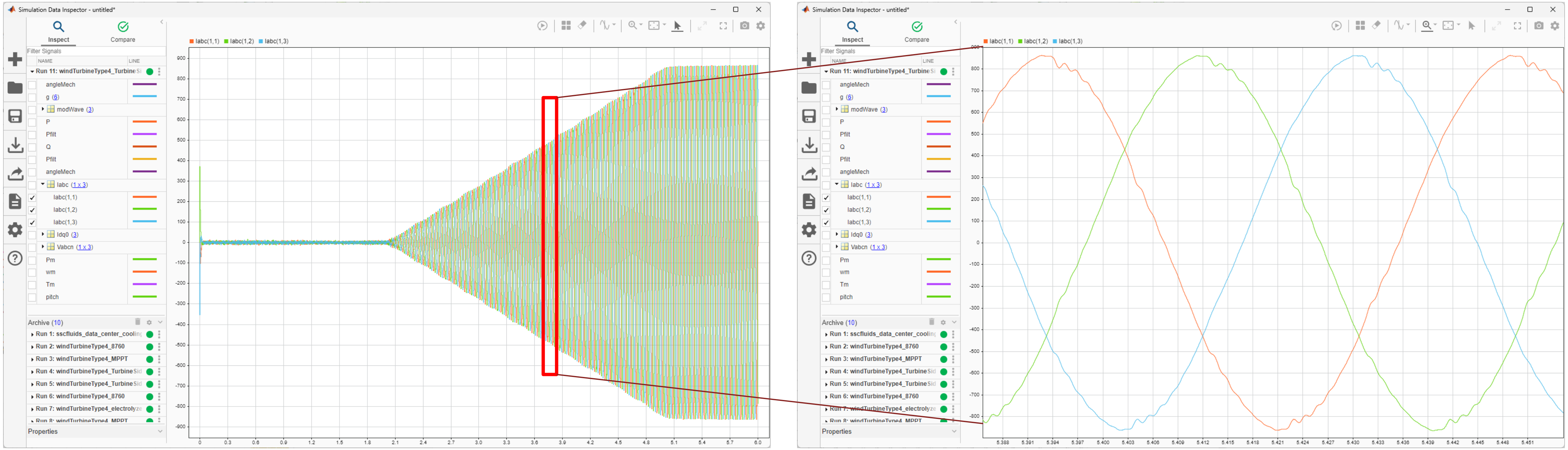
High Fidelity Models



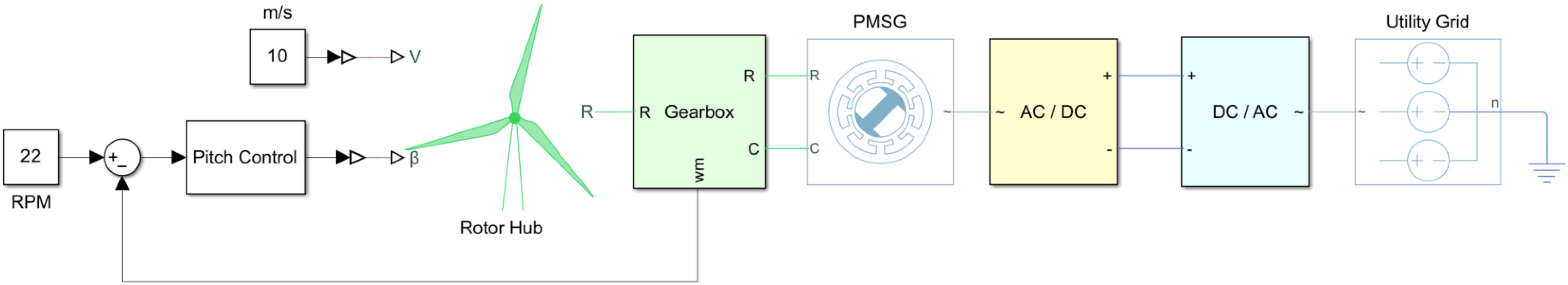
MOSFET converter



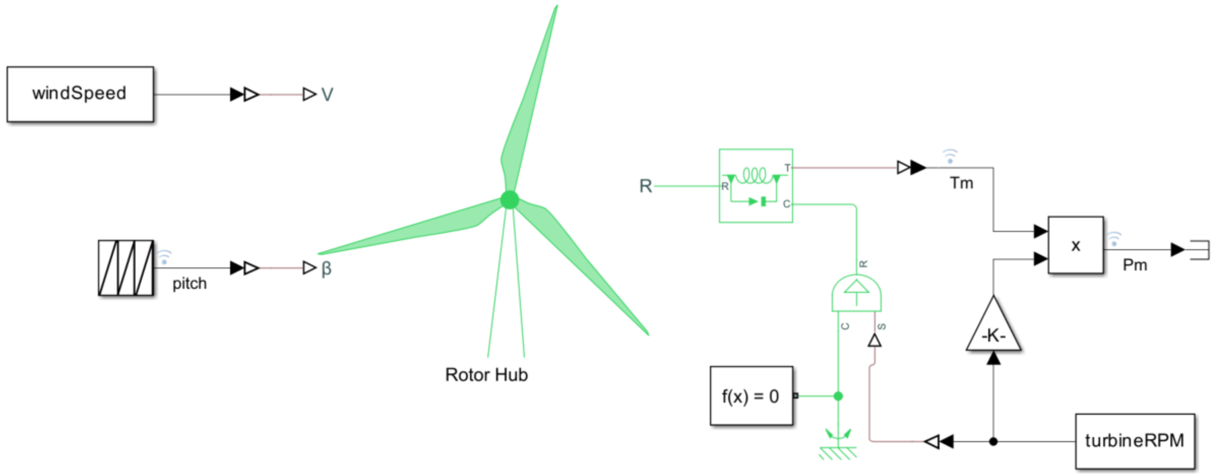
Power Electronics studies

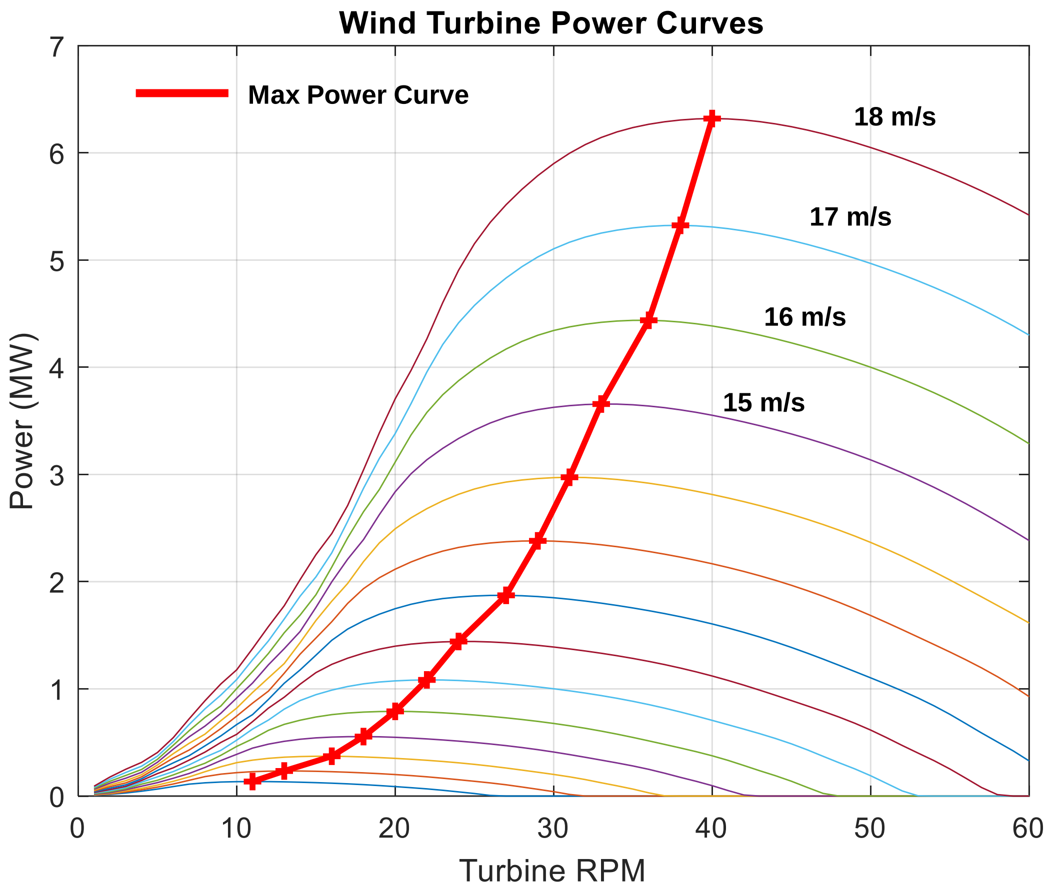


From Microseconds to Months

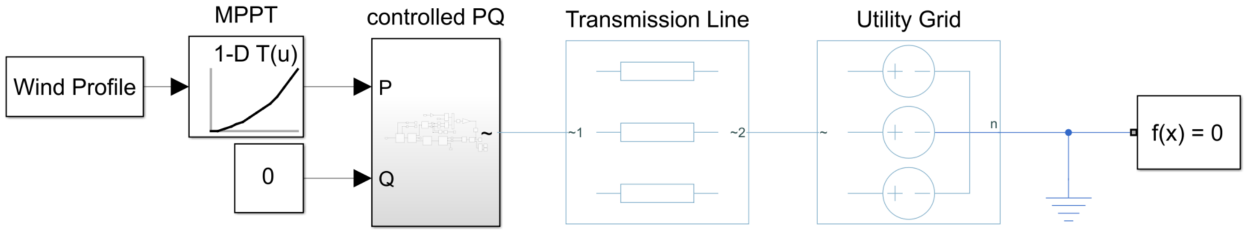


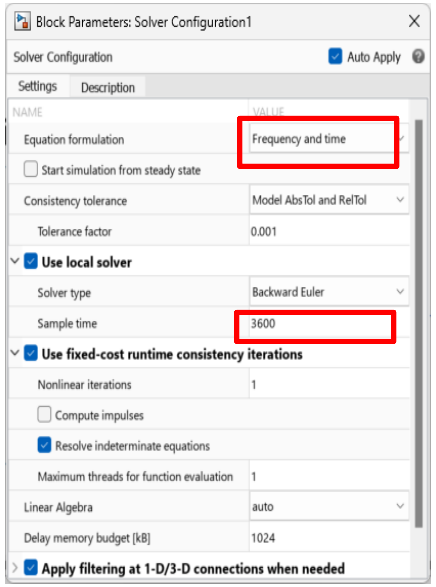
From Microseconds to Months with Reduced Order Modeling

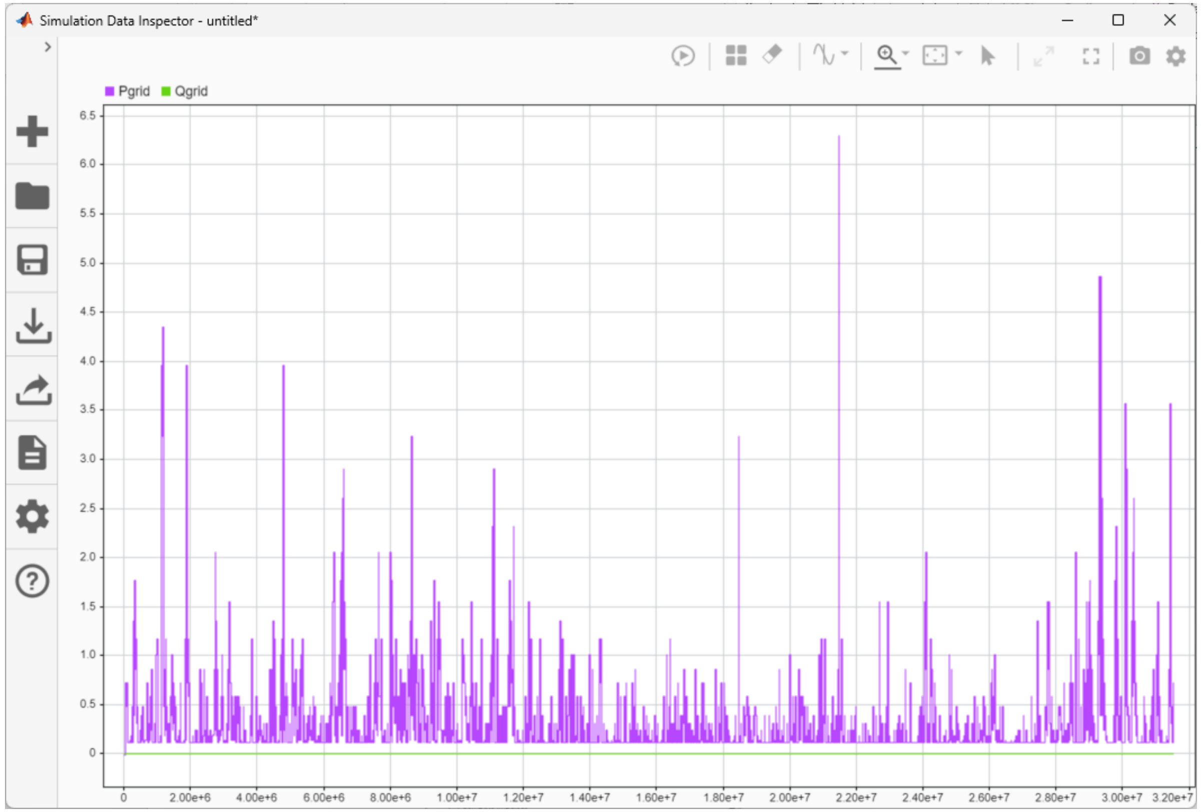




Quasi-steady Simulations







Enabling Green Hydrogen – TEA (solar microgrid)

Performance assessment

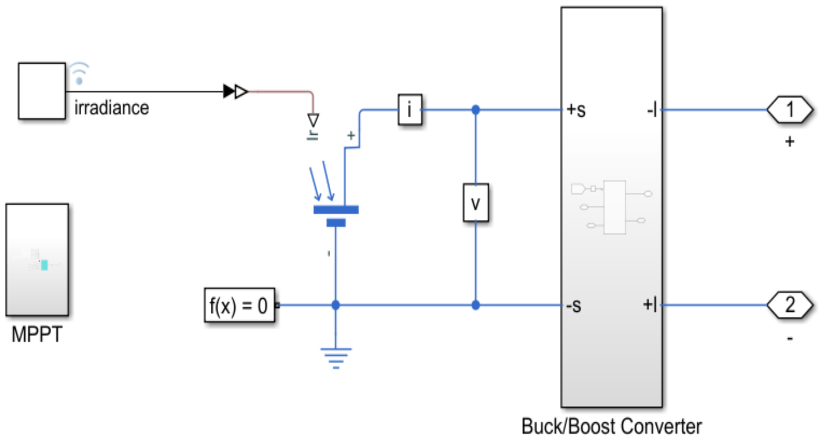
Techno-economic analyses

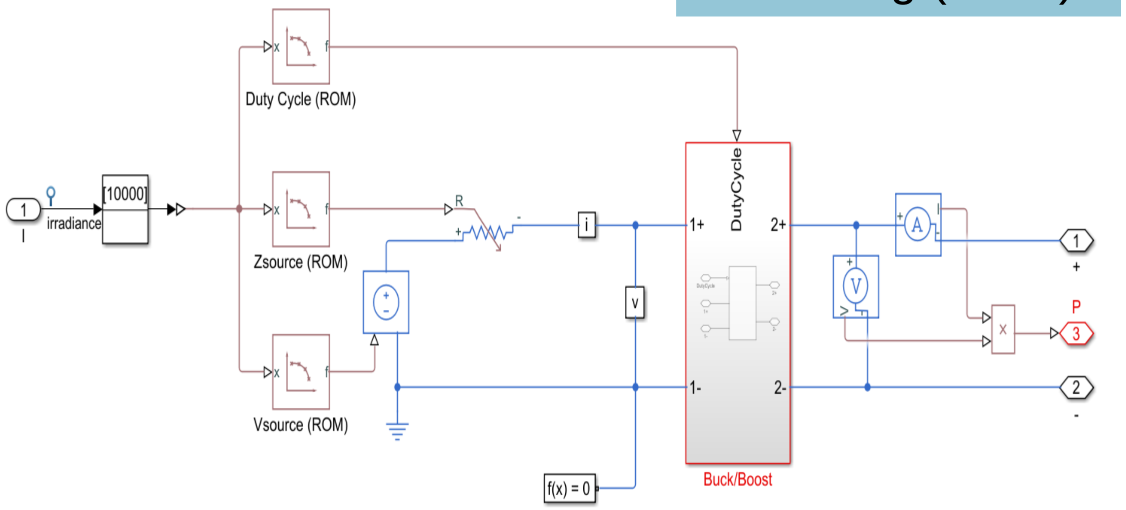
Medium fidelity

Low fidelity

Solar cell & MPPT algorithm

Reduced Order Modeling (ROM)

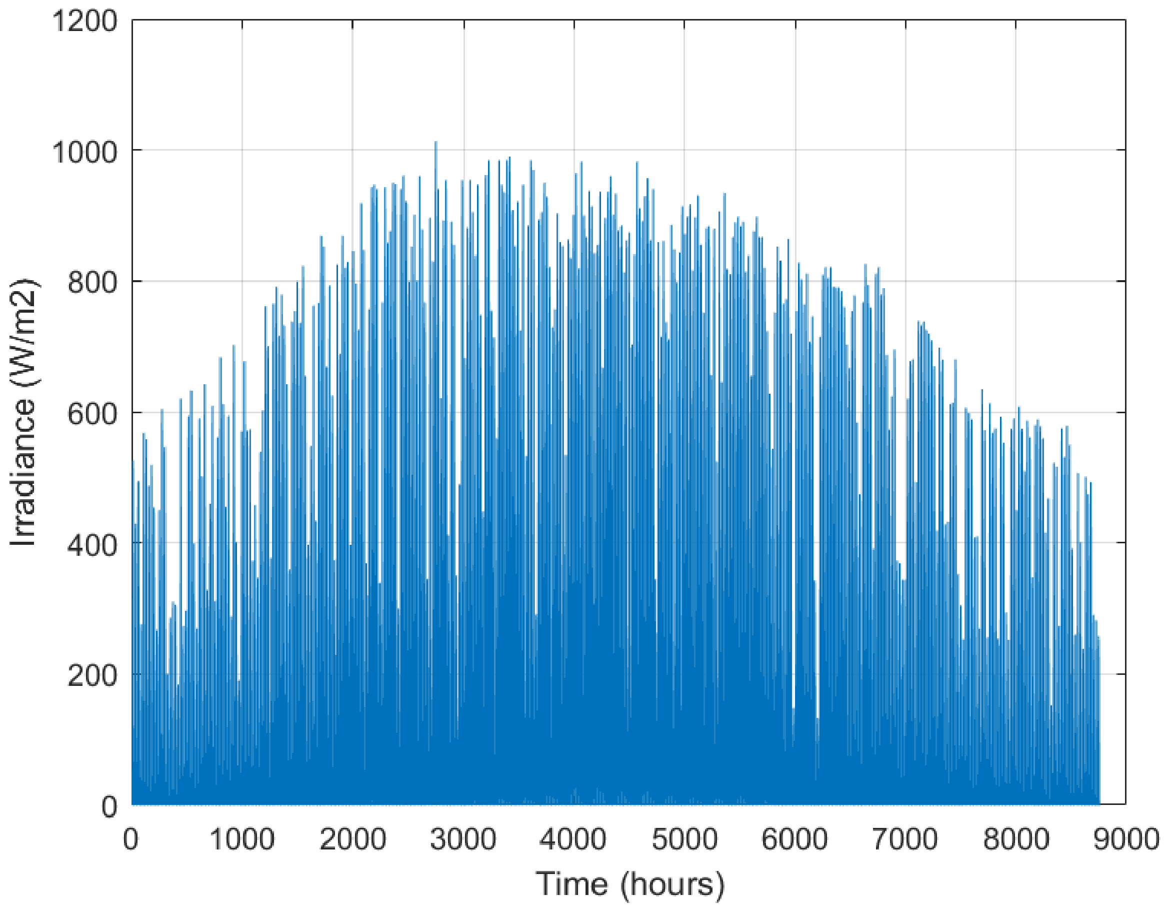




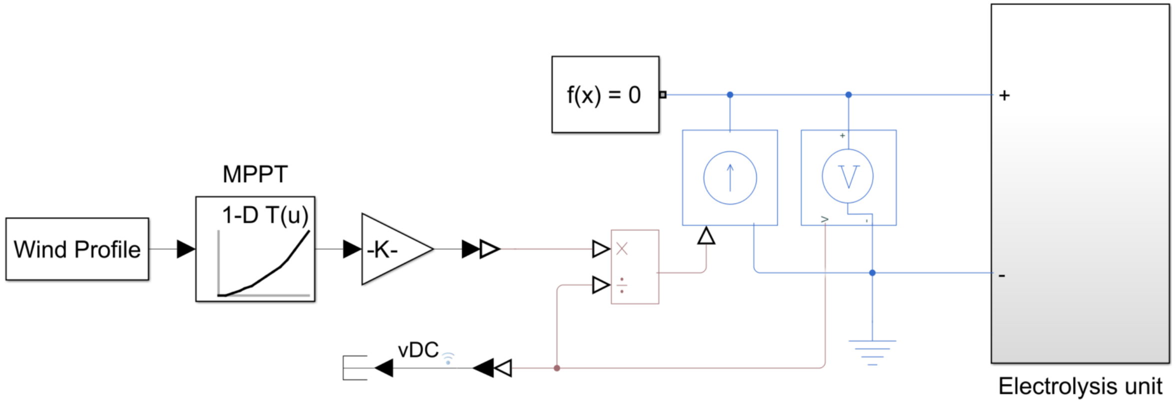
Irradiance Data

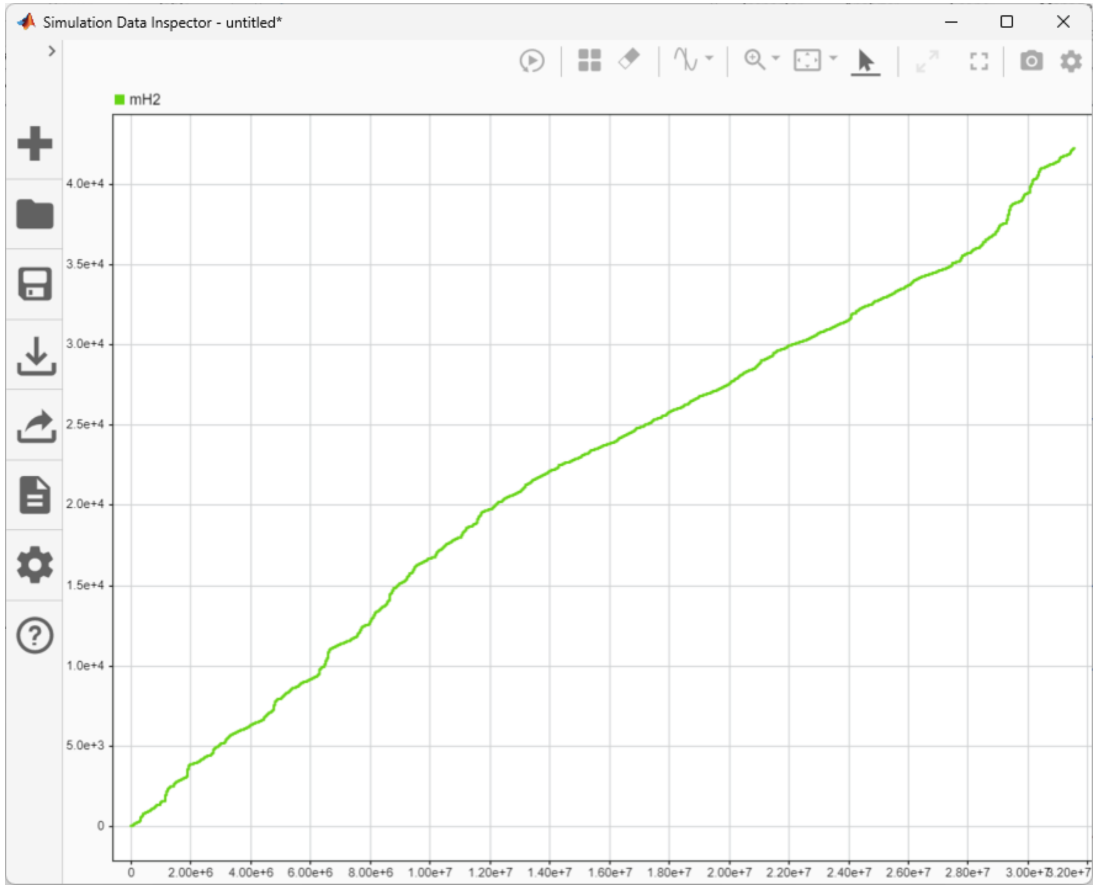
- The irradiance data is 8760 TMY3 data available from NREL. There are 242 locations in the data set.

```
>> load('StationData_UPDATE.mat')
>> StationData(1)

ans =

  struct with fields:

     NumberByName: 188
    NumberByState: 1
             Name: {'Birmingham Municipal AP'}
            State: {'AL'}
            USAFN: 722280
       Irradiance: [8760×1 double]
      Temperature: [8760×1 double]
        WindSpeed: [8760×1 double]
          GHIWm2: [8760×1 double]
          DNIWm2: [8760×1 double]
          DHIWm2: [8760×1 double]
```

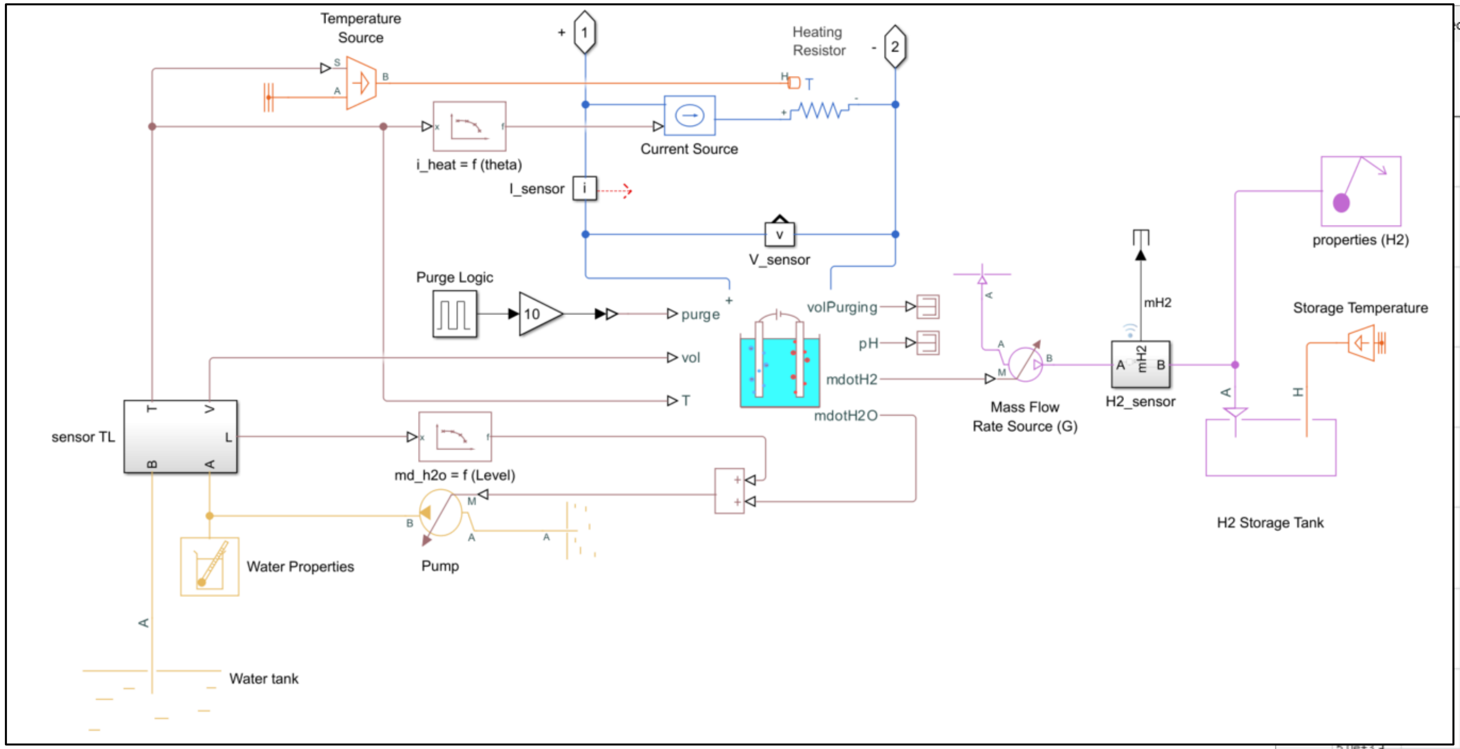


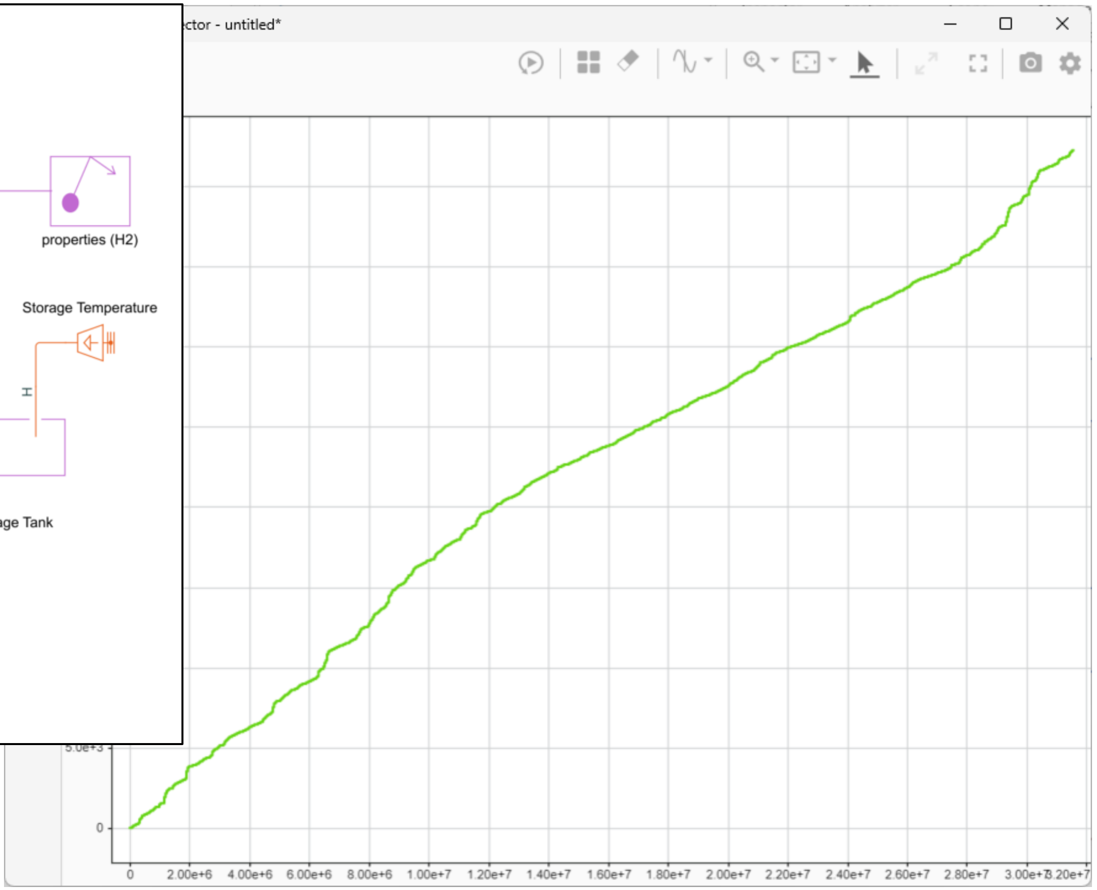
Reduced Order Modeling



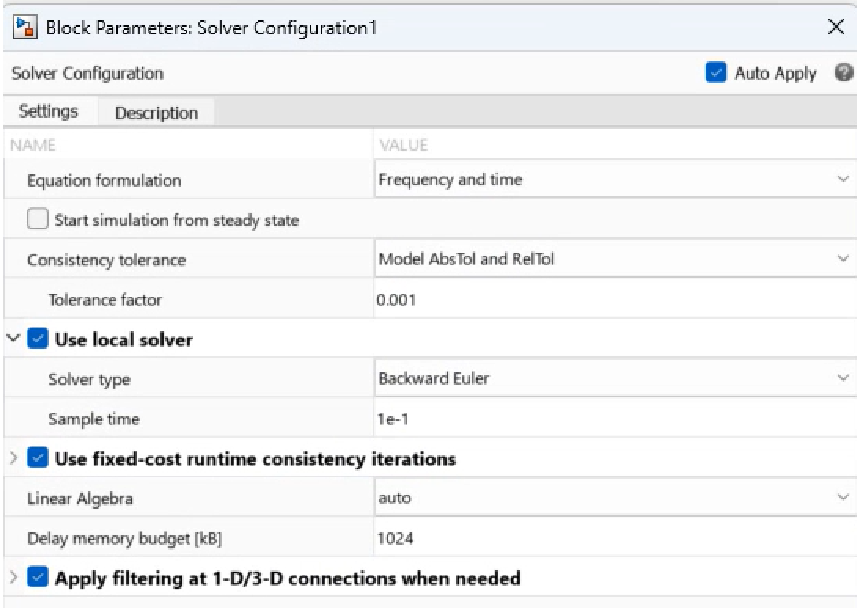


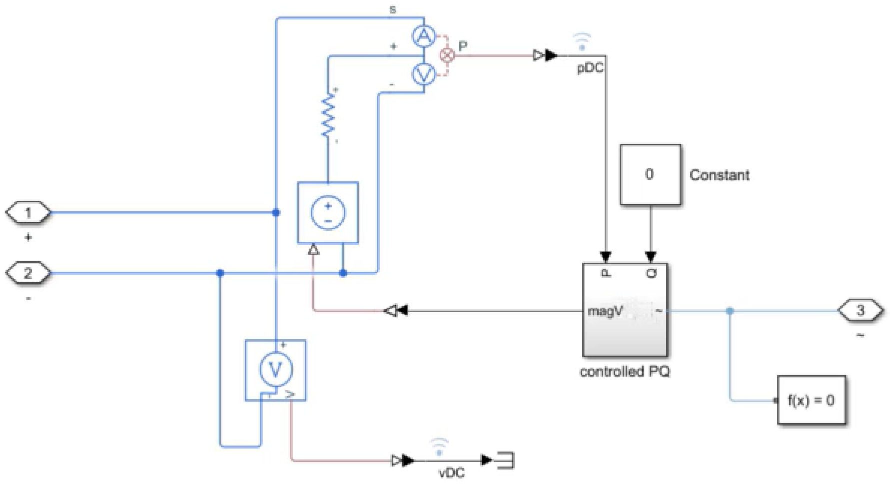
Electrolyzer

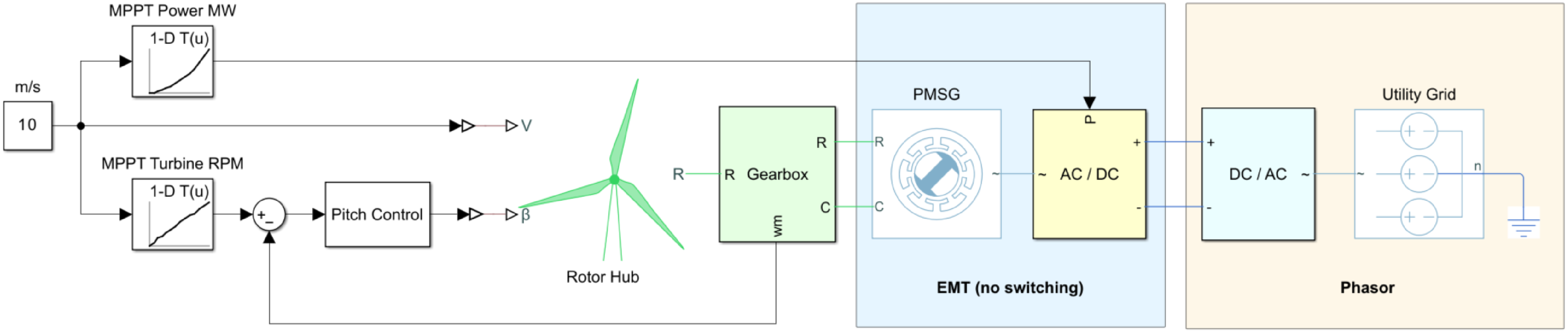




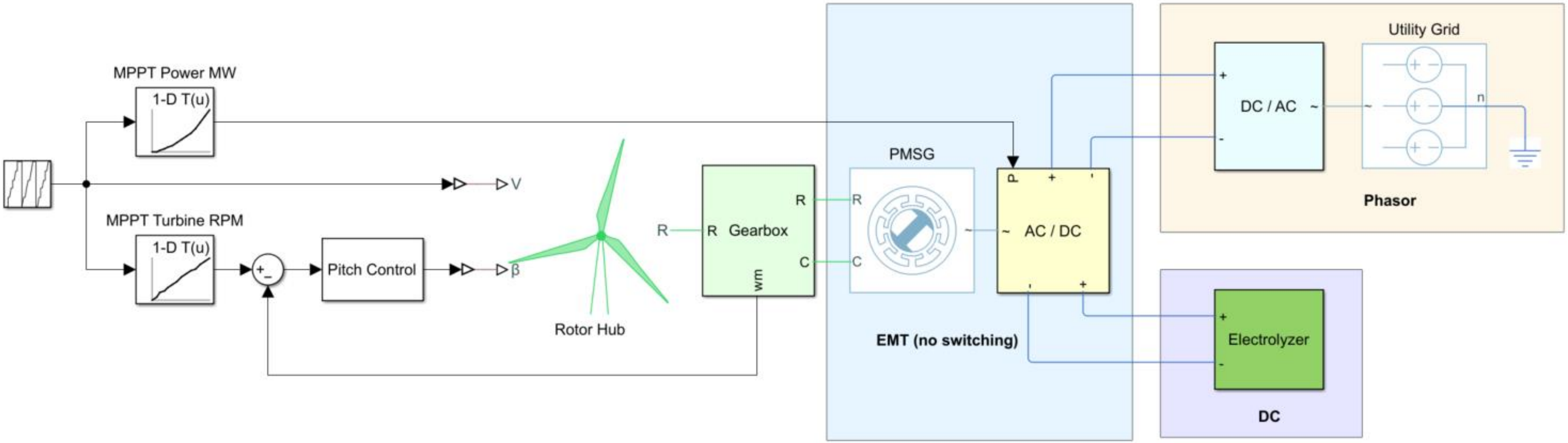
From Microseconds to Months



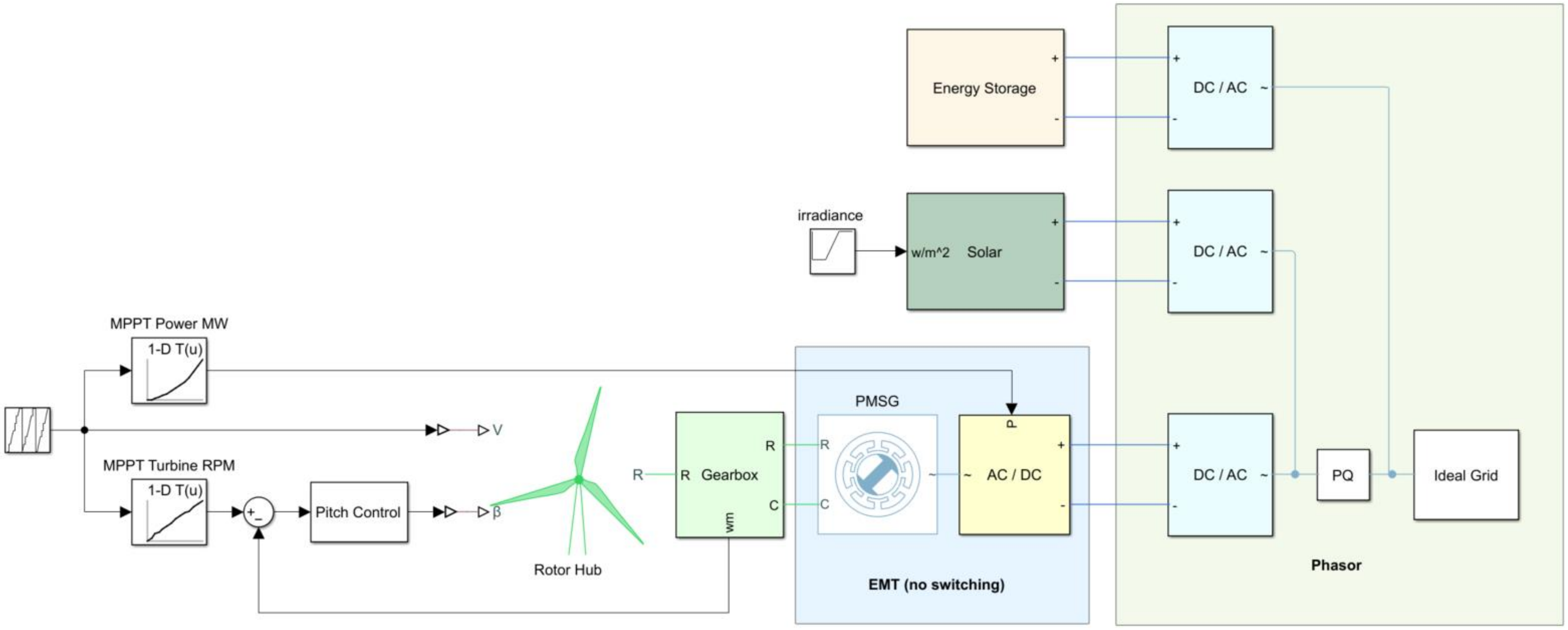




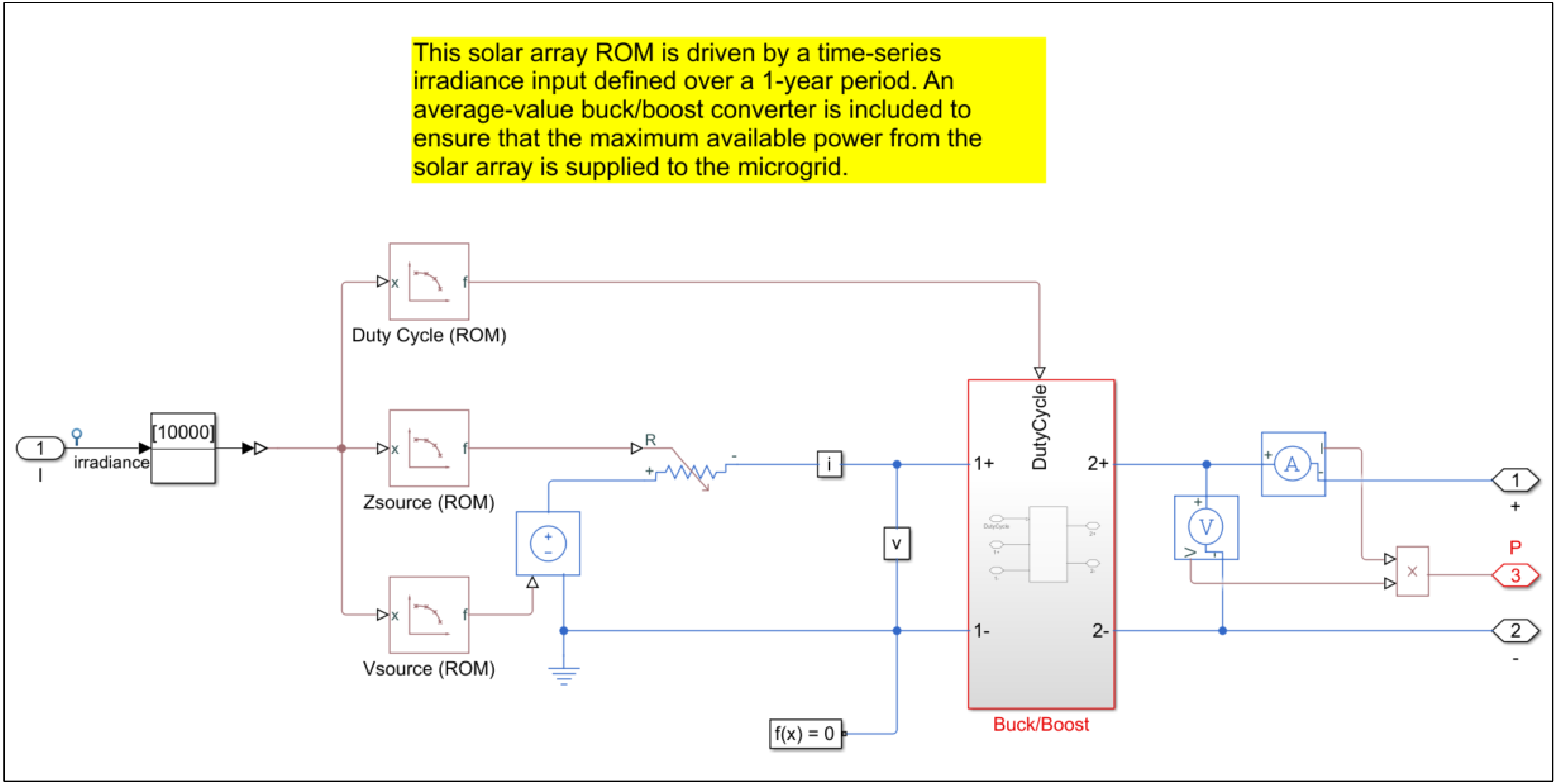
From Months to Microseconds



From Months to Microseconds

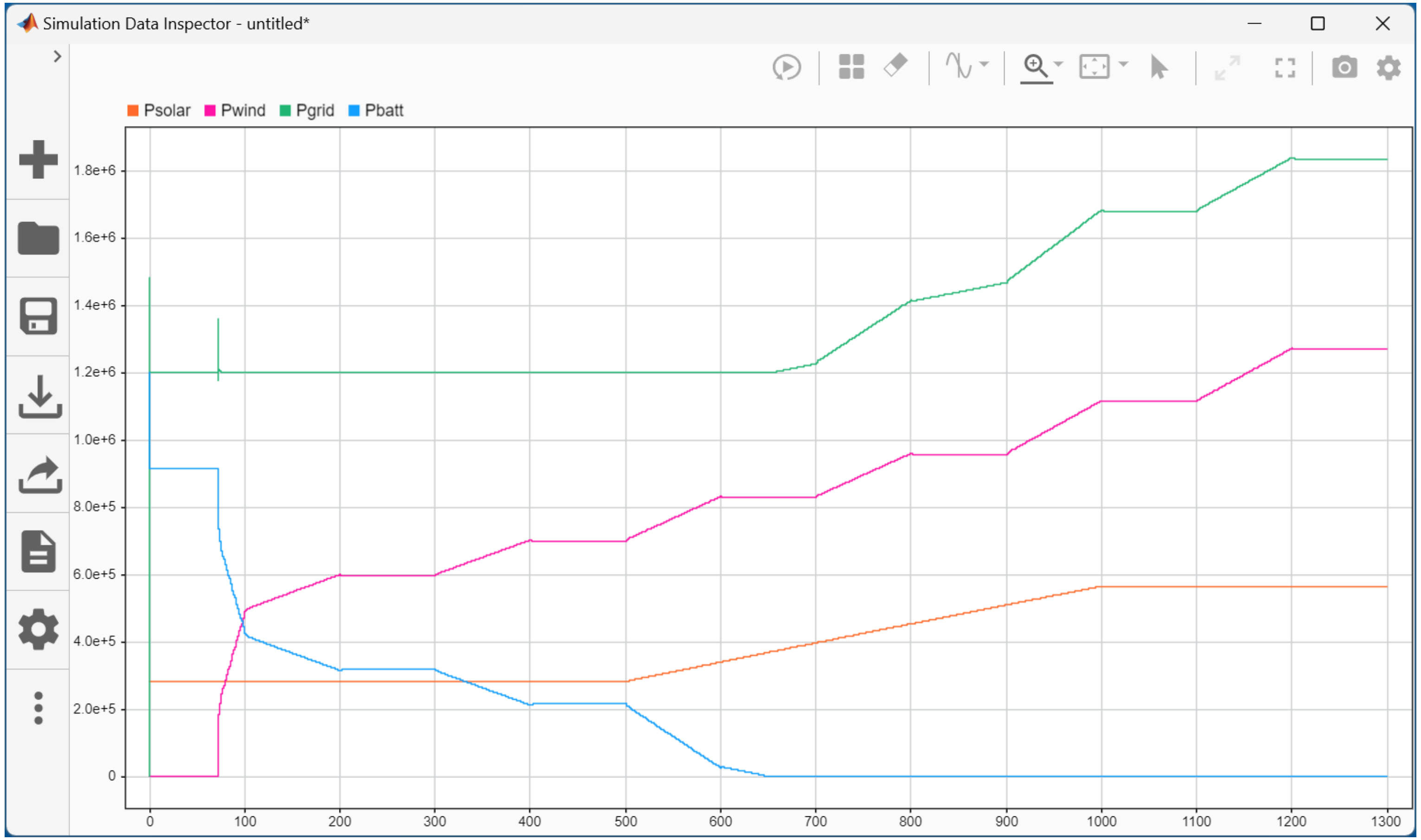


Reduced Order Modeling (Solar + MPPT)



From Months to Microseconds

- To efficiently evaluate the full system over time-scales of seconds to minutes, we can use ideal power conversion and a combination of EMT, DC and phasor simulation.

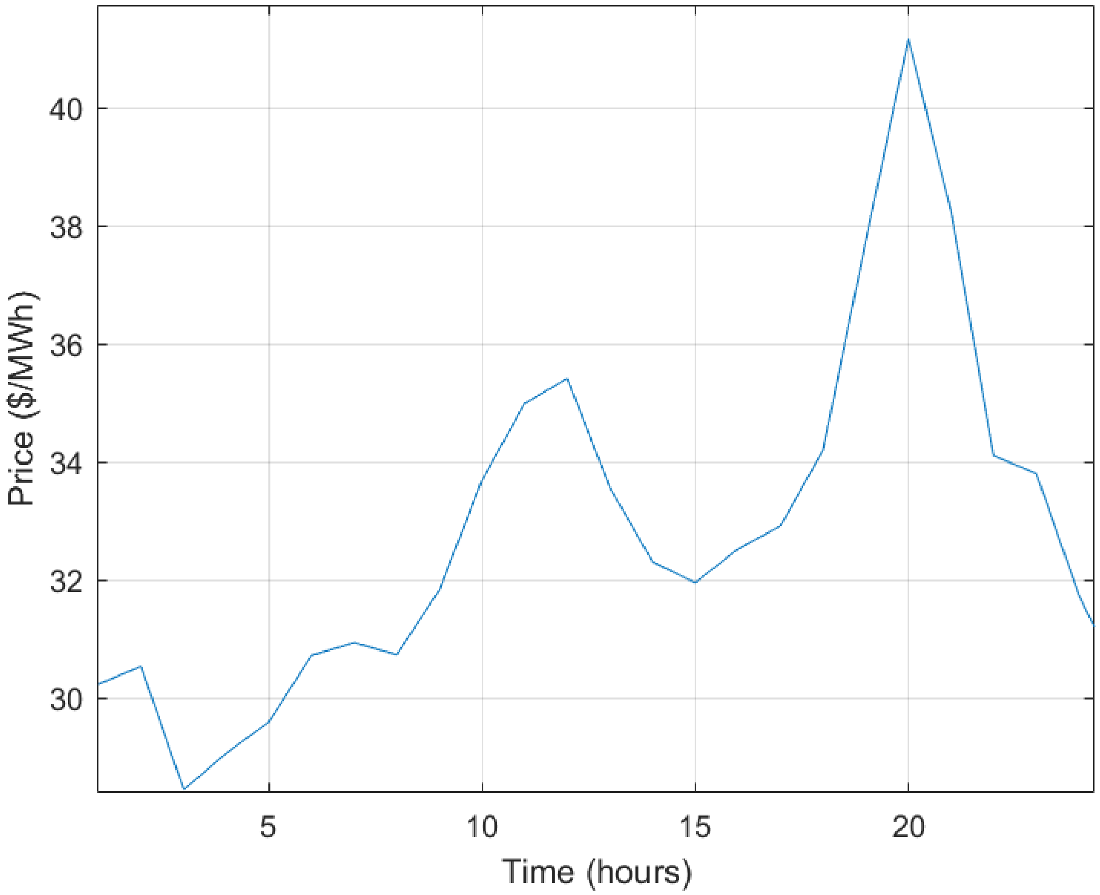


Enabling Green Hydrogen – Model fidelity

milliseconds (ms) *microseconds (us)*	*seconds* *minutes*	*months* *years*
Embedded development (component)	Key performance assessment (system)	Techno-economic Analysis (TEA)
High fidelity	**Medium fidelity**	**Low fidelity**
		Quasi-steady (8760) simulations

Optimize Green Hydrogen Production System with MATLAB

Electricity Price Data



Run scenarios using parsim

>> parsimScenarios

```
Elapsed time is 510.209014 seconds.
-----------------------------------------

Lowest grid cost is USD 6761.6456 at Phoenix Sky Harbor Intl AP
Highest solar resource is 497.1227MWh at Daggett Barstow-Daggett AP

Highest grid cost is USD 13217.5585 at Quillayute State Airport
lowest solar resource is 291.2997MWh at Quillayute State Airport


-----------------------------------------
```

With equation-based electrolyzer

242 years in 510 seconds
i.e.
1 year every 2.1 seconds

```
Elapsed time is 132.519040 seconds.
-----------------------------------------

Lowest grid cost is USD 6764.7007 at Phoenix Sky Harbor Intl AP
Highest solar resource is 497.1232MWh at Daggett Barstow-Daggett AP

Highest grid cost is USD 13224.2457 at Quillayute State Airport
lowest solar resource is 291.2999MWh at Quillayute State Airport


-----------------------------------------
```

With ROM electrolyzer

242 years in 132 seconds
i.e.
1 year every 0.54 seconds

Summary

- Early stage R&D typically does not require high-fidelity models, but modeling architectures should be organized to allow the fidelity to be readily enhanced as more detail is needed.
- A quasi-steady simulation provides a foundation for techno-economic assessments and allow long-duration system-level scenarios to be run efficiently.
- Reduced order models (ROMs) suitable for quasi-steady simulation can be readily generated from more detailed models.
- Both technical and economic input data is readily connected to a quasi-steady simulation.
- Multiple scenarios can be efficiently run using parsim.

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