Building a PyPSA Model

Modelling the Integration of Hydropower into Modern Energy Systems for Africa

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Open Energy Transition

from the creators of PyPSA meets Earth

International Centre for Hydropower

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Introduction

In this document, we provide a step-by-step guide to building a PyPSA model in eight exercises. These notes must be used in conjunction with the Google Colab Notebooks provided, course notes, and class activities. Collectively, these resources provide the skills and context for developing PyPSA models.

The approach uses a mini-grid as a foundation to demonstrate basic functionality and introduce users to the components of PyPSA and data source management. In the final exercise, participants will be introduced to applying this modelling approach to a national grid.

The minigrid analysed is shown in the image below. It is based on the Upper Blinkwater Project.

- A description of the project can be found here.
- The data for the project can be found here.

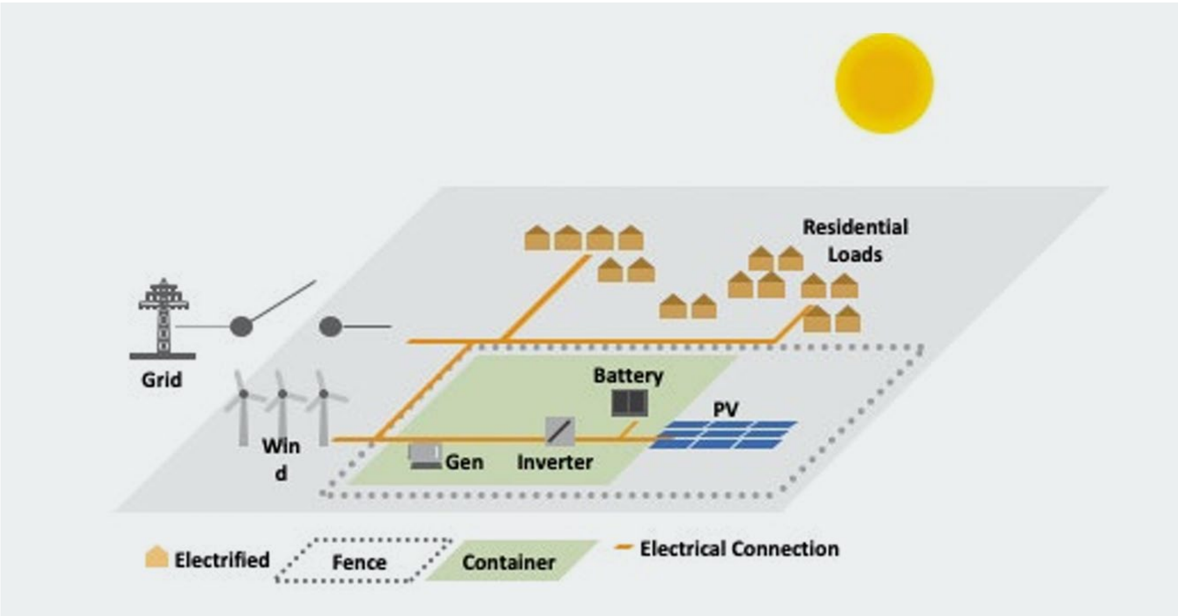

Figure 1: Example mini-grid[1]

This course's objective is to introduce users to the PyPSA toolbox, which provides many of the tools and code needed to simplify the model development process. Participants interested in furthering their skills should consider taking formal courses on using Python and courses on energy systems and geographic information systems.

[1] Ravanbach, B., Hanke, B. and Kühnel, M., 2020. The Upper Blinkwater Minigrid South Africa, Eastern Cape Project Summary & Lessons Learned. Link

Exercise 1: Building a three-node network

Expected time to complete: 60 minutes

[Link to Google Colab Notebook]

[Link to Excel workbook]

Objectives:

- Familiarise participants with the input spreadsheet and Google Colab environment.
- Build a three-node network and run the optimiser.
- Interpret the results.

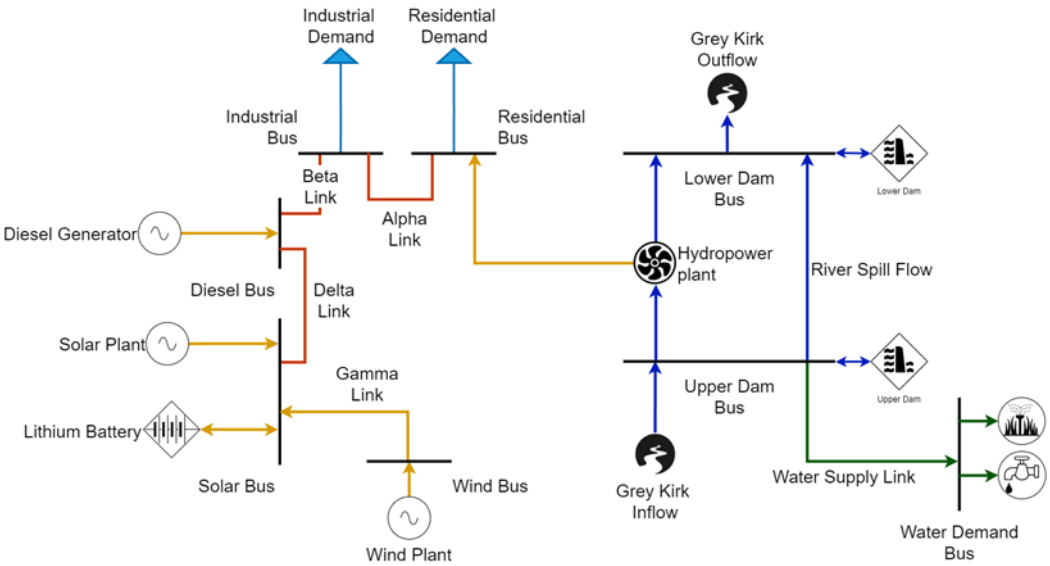

Figure 2 Network diagram for Exercise 1

Step 1: View the tabs in the worksheet.

- Note that some data contains component characteristics and time series data.
- Some data is hidden. Right-click on any tab and click "Unhide", then select any sheet to view it. To hide the sheet, right-click on the tab and click "Hide".
- The notebook also provides information on the input and outputs for all the components.
- Notice that the time-series data is prepopulated for 2024.

Step 2: Add three busses

name	Residential Bus	Industrial Bus	Diesel Bus
carrier	AC	AC	AC

Step 3: Link the busses

Link name	bus0	bus1
Link Alpha	Industrial Bus	Residential Bus
Link Beta	Diesel Bus	Industrial Bus

Step 4: Configure the links with the same values

Variable	Value	Units
p_nom	80	kW
efficiency	1	
capital_cost	0	currency/MW
marginal_cost	0	currency/MWh
p_nom_extendable	FALSE	
ramp_limit_up	1	timesteps
ramp_limit_down	1	timesteps
p_min_pu	0	
p_max_pu	1	
committable	TRUE	
min_up_time	0	timesteps
min_down_time	0	timesteps

Step 5: Add in loads

Load Name	bus	p_set	Units
Residential Load	Residential Bus	50	kW
Industrial Load	Industrial Bus	50	kW

Step 6: Add in the Diesel Generator and Slack Generators

Generator names	Diesel Generator	CUE Diesel CUE Residential CUE Industrial	Units
carrier	AC	AC	
efficiency	1	1	
marginal_cost	10	1000	
p_nom	80	1	kW
p_nom_extendable	FALSE	TRUE	
p_nom_min	0	0	kW
ramp_limit_up	1	1	timesteps
ramp_limit_down	1	1	timesteps
p_min_pu	0	0	

We use CUE, or Cost of Unserved Energy, to represent slack generators. This can be used to identify areas with insufficient generation capacity to meet demand. Without these generators, the model will give an infeasible output that cannot be traced.

Step 7: Run the model and observe the results.

- Open the Google Colab notebook.
- Copy the file to the “ICH_Training” folder in your Google Drive.
- Import the model
- Inspect the network.
- Run the optimise cell
- View the outputs

Step 8: Observe the output charts

- **Tooltip Display:** When you hover over a point on the line chart, a tooltip appears, displaying information about the data point, such as the x and y values.
- **Zooming:** You can zoom into a specific area of the chart by clicking and dragging to create a box around the region you want to zoom into. Double-clicking the chart resets the zoom.
- **Panning:** After zooming in, you can pan around the chart by clicking and dragging the chart itself. This allows you to explore different parts of the zoomed-in data.
- **Legend Click:** Clicking on an item in the legend hides or shows the corresponding line in the chart. This helps in focusing on specific data series.
- **Legend Double Click:** Double-clicking an item in the legend isolates that line, hiding all other lines. Double-clicking again resets the view to show all lines.
- **Image Format Options:** Users can choose to download the chart as a PNG or JPEG image. This choice is often available through a small menu or by clicking the icon multiple times to cycle through available formats.

Download the completed model for Exercise 1

Exercise 2: Add in time-series constraints

Expected time to complete: 60 minutes

Link to Google Colab Notebook

Link to Excel workbook

Objectives:

- Adding time-series constraints.
- Using the store and storage unit data.
- Using the optimiser to size components in the system.

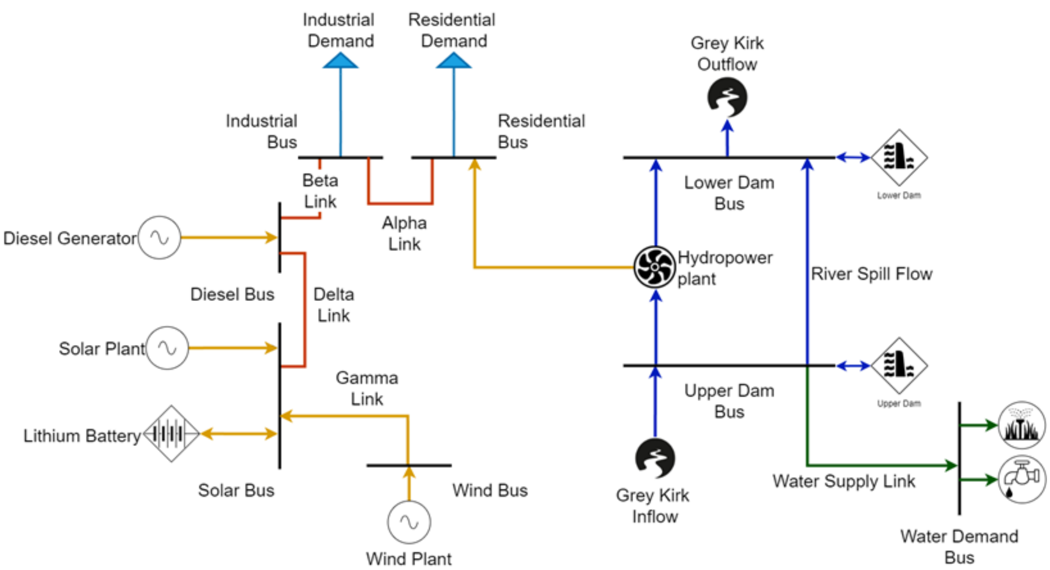

Figure 3 Network diagram for Exercise 2

Step 1: Add in a load profile

- Open the "loads-p_set" tab
- Copy and paste the load profile given in the input data spreadsheet.
- Run the model and observe the input load profile and the resulting generator profile.

Step 2: Add in a solar generator

- Create a bus called Solar Bus.
- Then go to generators and create a generator called Solar Plant.
- The input data is given below.

Name	Solar Plant	Units
bus	Solar Bus	
carrier	AC	
efficiency	1	
marginal_cost	0	currency
p_nom	20	kW
p_nom_extendable	FALSE	
p_nom_min	0	kW
ramp_limit_up	1	timesteps
ramp_limit_down	1	timesteps
p_min_pu	0	

Step 3: Link the Solar Bus to the network using the same link connection from the previous exercise.

Step 4: Add in the solar load profile constraint

- Go to www.renewables.ninja
- Find this location:
  - Search: UBW Minigrid on Google Maps.
  - Right-click on the location and click on the coordinates; this will copy the coordinates to your clipboard.
  - Alternatively, use this location: 32.57579448548223, 26.55707786488919.
- Paste this location in the renewables ninja “Search by location” bar.
- Click on the “Solar photovoltaic power (PV) tab, use the settings below, and click “Run”.

Option	Selected item
Dataset	Merra-2 (global)
Select year of data	2019
Capacity	1
System loss fraction	0.1
Tracking	None
Tilt	35
Azumith	180
Include raw data	yes

- Observe the daily mean profile and note the daily variation and the annual changes in peak production.
- Click on “Save hourly production as CSV”. A file will be downloaded.
- Open the file. If the file does not automatically place your data in columns, change your regional settings [Link]
- In the PyPSA model, open the tab “generators-p_max_pu”
- Copy and paste the data in the electricity column from the file downloaded from Renewables Ninja.

Step 5: Add a battery with a storage_unit

- The nominal power for this battery is 27kW with a storage capacity of 130 kWh. Calculate the maximum hours the battery can operate at p_nom.

$$max_{hours} = \frac{e_{nom}[kwh]}{p_{nom}[kw]}$$

- Open the storage_unit tab.

Name	Lithium Battery	Units
bus	Solar Bus	
capital_cost	0	
marginal_cost	0	
p_nom	27	kW
carrier	AC	
max_hours	calculated	hours

Step 6: Add in a wind generator.

- Create a bus called Wind Bus.
- Create the generator with the following component inputs.

Name	Nordex N27 150	Bonus B23 150	Units
bus	Wind Bus	Wind Bus	
carrier	AC	AC	
efficiency	1	1	
marginal_cost	0	0	
p_nom	150	150	kW
p_nom_extendable	FALSE	FALSE	
p_nom_min	0	0	
ramp_limit_up	1	1	
ramp_limit_down	1	1	
p_min_pu	0	0	

- Go to renewables.ninja and find the Upper Blinkwater Location.
- Find the Nordex N27 150 and Bonus B23 150 wind turbines.

Option	Selected item
Dataset	Merra-2 (global)
Select year of data	2019
Capacity	1
Hub height	80m
Turbine model	Nordex N27 150 Bonus B23 150

- Compare the results.

Exercise 3: Add in a hydropower plant

Expected time to complete: 60 minutes

Link to Google Colab Notebook

Link to Excel workbook

Objectives:

- Add in a river flow.
- Utilise a link with one input and two outputs.
- Connect a dam.
- Run the model with a hydropower plant.

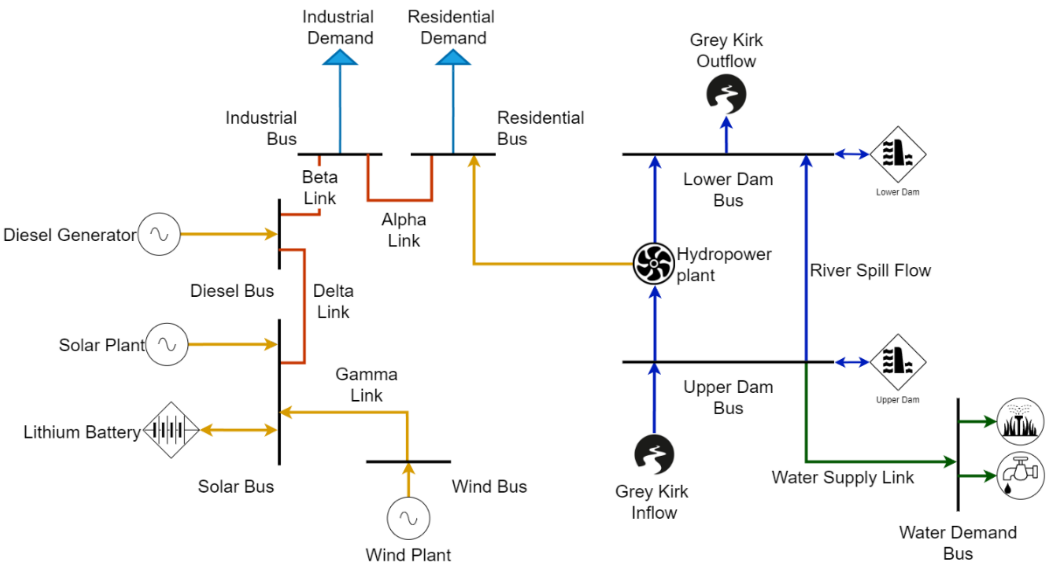

Figure 4 Network diagram for Exercise 5

Step 1: Open the busses tab and add the following busses.

name	Grey Kirk In Bus	Grey Kirk Out Bus
carrier	water	water

Step 2: Open the link tab and add the following spill flow lines.

Variable	Value	Units
p_nom	20000	m3/h

efficiency	1
capital_cost	0
marginal_cost	0
p_nom_extendable	FALSE
ramp_limit_up	1
ramp_limit_down	1
p_min_pu	0
p_max_pu	1
committable	TRUE
min_up_time	0
min_down_time	0

Step 3: Open the generator tab and add in the river inflow and outflow terms

Name	Grey Kirk Inflow	Grey Kirk Outflow	Units
bus	Upper Dam Bus	Lower Dam Bus	
p_set	50		m^3/h
carrier	AC		
efficiency	1		
marginal_cost	0		
p_nom	50		m^3/h
p_nom_extendable	FALSE		
p_nom_min	0		
ramp_limit_up	1		
ramp_limit_down	1		
p_min_pu	0		

Step 4: Run the model.

- Note the postprocessing steps that have been added.

Step 5: Add in the hydro generator

- Open the link tab.
- Create the following link.

Variable	Value	Units
p_nom	80	m^3/h
efficiency	1	
capital_cost	0	
marginal_cost	0	
p_nom_extendable	FALSE	
ramp_limit_up	1	

ramp_limit_down	1
p_min_pu	0
p_max_pu	1
committable	TRUE
min_up_time	0
min_down_time	0

- Run the model.

Step 6: Add in a dam

- Open the tab storage units and create the following storage unit.

Name	Upper Dam	
bus	Solar Bus	
capital_cost	0	currency/ m^3
marginal_cost	0	currency/ m^3
e_nom	10	m^3
e_nom_extendable	FALSE	
carrier	AC	
e_initial	5	m^3
e_initial_per_period	FALSE	
e_cyclic	FALSE	
e_cyclic_per_period	FALSE	

- Run the model.

Step 7: Add a water demand loads.

Load Name	bus	p_set	Units
Residential Load	Water Supply Bus	50	m^3/h
Industrial Load	Water Supply Bus	50	m^3/h

- Add water demand load profile.
- Run the model and analyse the results.

Step 8: Add in river flow data.

- Go to the tab “River Inflow Data (Backup)”.
- Copy the data from this tab to the tab “generators-p_set”.
- Run the model and analyse the results.

Download the completed model for Exercise 3