Exercises

Optimal sizing methodology of HPP

Inputs

- Electricity prices for SM and BM
- Site location for weather data
- Technologies cost

Sizing Optimization

Output (Design Variables)			Output
Wind	**Solar**	**Battery**	**Finance model**
Rotor diameter, hub height	AC power	Power rating	NPV/CAPEX
Area of land	Surface tilt angle	Energy storage Capacity	IRR
Rated power	Surface azimuth angle		LCOE
Number of wind turbines			AEP
Wind power density			Number of batteries

Optimal sizing methodology of HPP

Financial model of HPP

C_H: Total CAPEX

O_H: Total OPEX

$$C_H = \; C_W + C_S + C_B + C_E$$
$$O_H = \; O_W + O_S + O_b + O_E$$

Financial parameter calculation

Yearly income (R_y is revenue) → $I_y \; = (R_y - O_H)(1 - r_{tax})$

Annual Cashflow → $F_y \; = \begin{cases} -C_H \text{ for } y = 0 \\ I_y \text{ for } y > 0 \end{cases}$

Net present Value → $NPV \; = \sum_y F_y/(1 + \text{WACC}_{\text{tx}})^y$

Internal rate of return → $0 \; = \sum_y F_y/(1 + IRR)^y$

$C_L \; = \sum_y (O_H/(1 + \text{WACC}_{\text{tx}})^y) + C_H$

Annual energy production → $AEP_L \; = \sum_y (AEP_y/(1 + \text{WACC}_{\text{tx}})^y)$

Levelized cost of electricity → $LCoE \; = C_L/AEP_L$

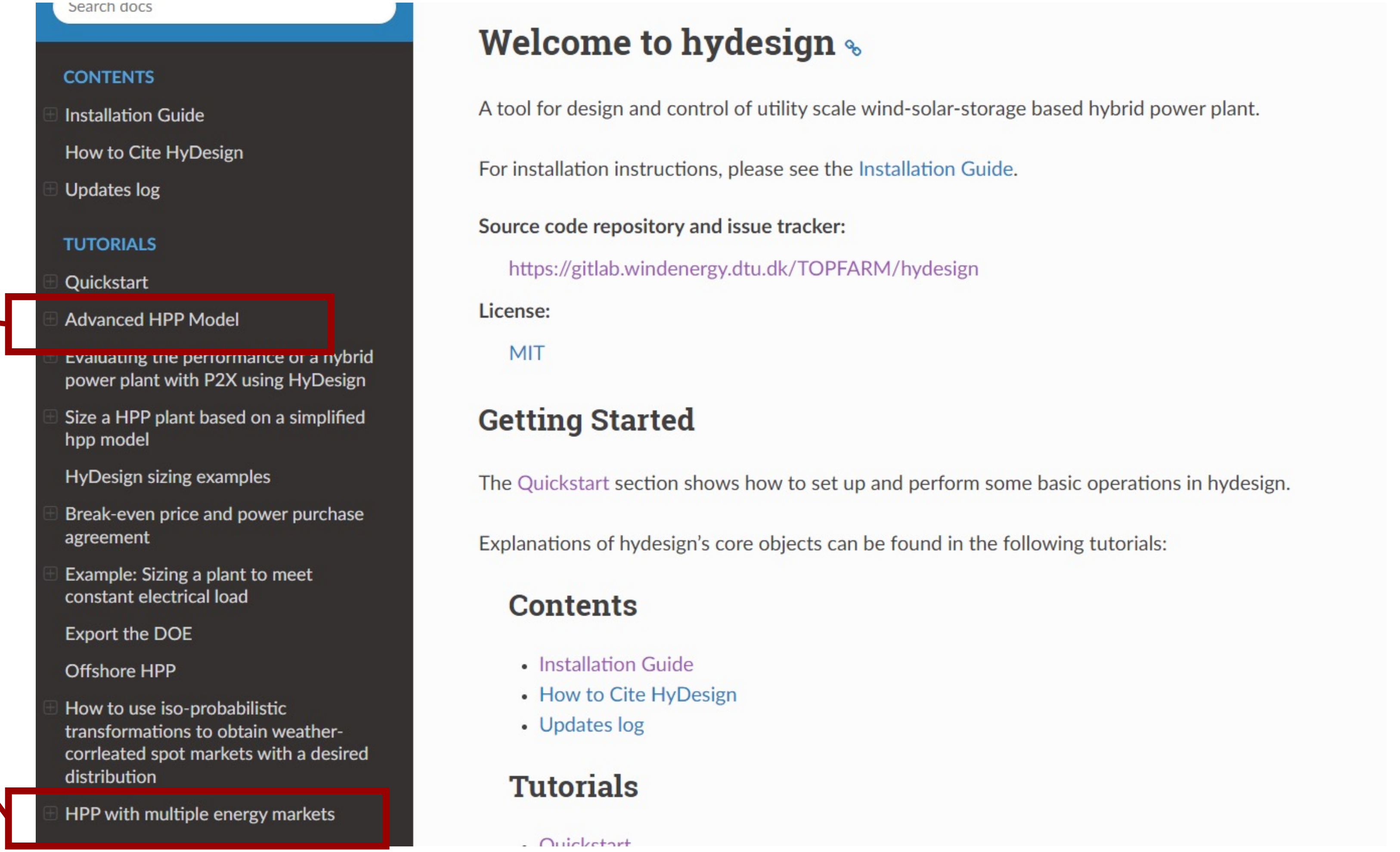
Let’s see how HyDesign looks, and how it works……..

- Gitlab repository: https://gitlab.windenergy.dtu.dk/TOPFARM/hydesign
- At the bottom -> link to documentation -> https://topfarm.pages.windenergy.dtu.dk/hydesign

Exercises:

Exercise 1: Advanced HPP Model -> HPP design evaluation

Exercise 2: HPP with multiple energy markets -> HPP design evaluation with SM and BM



Exercises:

Open the notebook in Google Colab

Advanced HPP Model   View page source

Open in Colab | Edit on Gitlab

Advanced HPP Model

Evaluating the performance of a hybrid power plant using HyDesign

- Run each cell
- Check for the list of example sites (select the test site).
- Change the site name accordingly.

	case	name	longitude	latitude	altitude	
0	India	Indian_site_good_wind	77.500226	8.334294	679.803454	
1	India	Indian_site_good_solar	68.542204	23.542099	29.883557	
2	India	Indian_site_bad_solar_bad_wind	77.916878	17.292316	627.424643	Indi
3	Europe	France_good_solar	4.229736	44.422011	204.000000	
4	Europe	France_good_wind	-0.864258	48.744116	302.000000	
5	Europe	France_bad_solar_n_wind	2.167969	47.428087	140.000000	
6	Europe	Germany_bad_solar_n_wind	10.766602	49.310798	442.000000	Eu
7	Europe	Germany_good_wind	7.873535	53.287111	5.000000	
8	Europe	Denmark_good_solar	11.813965	55.397760	42.000000	
9	Europe	Denmark_good_wind	8.594398	56.227322	85.000000	

```
[11] name = 'Denmark_good_wind'
ex_site = examples_sites.loc[examples_sites.name == name]

longitude = ex_site['longitude'].values[0]
latitude = ex_site['latitude'].values[0]
altitude = ex_site['altitude'].values[0]
```

Exercises:

- In this cell, the evaluation of a HPP design is done
- Select the size of HPP:
  - wind plant size in MW: Nwt * P_rated;
  - solar_MW;
  - battery size
    - b_P: battery power in MW
    - b_E_h: battery energy hours)

Evaluating the HPP model

[13]

```
start = time.time()

clearance = 10
sp = 350
p_rated = 5
Nwt = 62
wind_MW_per_km2 = 7
solar_MW = 50
surface_tilt = 50
surface_azimuth = 180
solar_DCAC = 1.5
b_P = 20
b_E_h  = 3
cost_of_batt_degr = 5
```

Exercises:

The output of the HPP model evaluation:

Objective function: maximize NPV/CAPEX

NPV: Net present Value

IRR: Internal rate of return

LCOE: Levelized cost of electricity

CAPEX: Total capital expenditure

OPEX: Total operational expenditure

AEP: Annual energy production

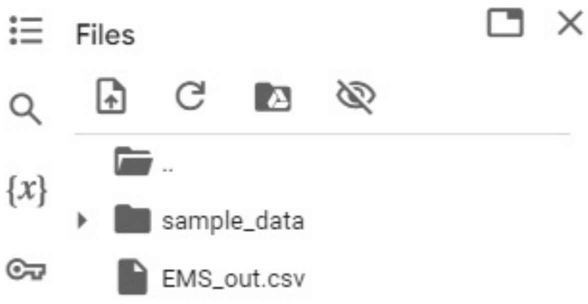
GUF: Grid utilization factor

Grid [MW]: grid capacity

```
NPV_over_CAPEX: 0.726
NPV [MEuro]: 230.293
IRR: 0.120
LCOE [Euro/MWh]: 22.151
CAPEX [MEuro]: 317.377
OPEX [MEuro]: 5.960
Wind CAPEX [MEuro]: 236.934
Wind OPEX [MEuro]: 5.622
PV CAPEX [MEuro]: 16.583
PV OPEX [MEuro]: 0.338
Batt CAPEX [MEuro]: 3.470
Batt OPEX [MEuro]: 0.000
Shared CAPEX [MEuro]: 60.390
Shared Opex [MEuro]: 0.000
penalty lifetime [MEuro]: 0.000
AEP [GWh]: 1321.424
GUF: 0.503
grid [MW]: 300.000
wind [MW]: 310.000
solar [MW]: 50.000
Battery Energy [MWh]: 60.000
Battery Power [MW]: 20.000
Total curtailment [GWh]: 417.558
Awpp [km2]: 44.286
Rotor diam [m]: 134.867
Hub height [m]: 77.434
Number_of_batteries: 1.000

exec. time [min]: 0.3864752968152364
```

Exercises: Download output files and plots

- The output files can be downloaded from here for further analysis. (Note: Remember to download and rename the file before starting the new simulation, the results won't get saved automatically)




```
df = pd.DataFrame(results_1year)
df.to_csv('EMS_out.csv')
```

```
design_df = design_df.transpose()
design_df.to_csv('output.csv')
```

- The output files can be renamed here.
- Re-run the evaluation function and check for the results.

Exercises: Notes

- Select site (9): Denmark_good_wind
- First, run the exercise with only HPP participating in spot market and save results.
- Next, run the exercise with HPP participating in spot and balancing (Intra-day) markets both (It works only for Wind + Battery plants, make solar_MW =0).

- By default: there are some specific design given (Wind + Battery HPP): Wind-350 MW, Grid connection-300 MW, Battery: 100 MW/ 300 MWh
- Check for improvement in NPV, NPV/CAPEX, LCOE for HPP participating in SM and BM both.
- Change the size of battery and plot the sensitivity of NPV/CAPEX with the battery size.
- Comment on the impact of grid connection capacity (100/ 300 MW) on econometrics (with SM + BM).

Exercises: Changing input file data

Download the input file ‘hpp_pars.yml’ -> contains technology (Wind, solar, battery, grid connection) costs value and other parameters

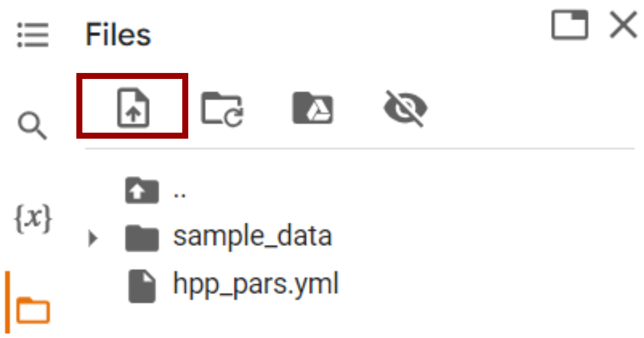
https://gitlab.windenergy.dtu.dk/TOPFARM/hydesign/-/blob/main/hydesign/examples/Europe/hpp_pars.yml

hpp_pars.yml 5.12 KiB Open in Web IDE Replace Delete


```yaml
# ---------------------------------------------------------------------------------------
# HPP Global
# ---------------------------------------------------------------------------------------
G_MW: 300 # Grid capacity
year: '2012' # Single representative year
N_life: 25

# ---------------------------------------------------------------------------------------
# Wind
# ---------------------------------------------------------------------------------------
wind_turbine_cost: 640_000  # [Euro/MW] for reference turbine
wind_civil_works_cost: 260_000  # [Euro/MW]
wind_fixed_onm_cost: 12_600  # Wind fixed O&M cost per year [Euro/MW /year]
wind_variable_onm_cost: 1.35 #[EUR/MWh_e] Danish Energy Agency

wpp_efficiency: 1.0
d_ref: 145
hh_ref: 100
p_rated_ref: 5.0 #[MW]

# ---------------------------------------------------------------------------------------
# PV
# ---------------------------------------------------------------------------------------
solar_PV_cost: 110_000   # [Euro/MW DC]
solar_hardware_installation_cost: 100_000  # [Euro/MW DC]
solar_inverter_cost: 20_000 #[Euro/MW]
solar_fixed_onm_cost: 4_500  # Solar O&M cost per year [Euro/MW] DC
pv_deg_per_year: 0.5e-2
land_use_per_solar_MW: 0.01226 # Danish energy agency
```

Exercises: Changing input file data

- Modify the input data in 'hpp_pars.yml' as desired. Upload the modified the input file 'hpp_pars.yml' in the current directory. (Note: The file name can be renamed as well)




```python
name = 'France_good_wind'
ex_site = examples_sites.loc[examples_sites.name == name]

longitude = ex_site['longitude'].values[0]
latitude = ex_site['latitude'].values[0]
altitude = ex_site['altitude'].values[0]

input_ts_fn = examples_filepath+ex_site['input_ts_fn'].values[0]
sim_pars_fn = 'hpp_pars.yml'
```

- Rename the input file name in the notebook to point toward the modified set of inputs.
- Re-run the evaluation function and check for the results.

Tasks:

1. Change the size of wind plant/ battery/ grid capacity for example site 9 (check for just 2-3 different configurations) and compare change in values of
   a) NPV
   b) NPV/CAPEX
   c) LCOE
   d) AEP
   e) GUF
   f) Total curtailment
2. Perform any one set of HPP configurations (wind + battery) as in Exercise 1 with BM. Make comparison and analyze the results.
3. For HPP with BM, find optimal size of battery doing sensitivity analysis with an objective to maximize NPV/CAPEX

Sample template for results for one configuration			
S. No.	**Parameter**	**HPP with SM**	**HPP with SM and BM**
1	NPV		
2	NPV/CAPEX		
3	LCOE		
4	AEP		
5	GUF		
6	Total cutailment		

Learning Objectives:

- Impact of the size of a HPP on the econometrics such as NPV/CAPEX, LCOE.
- Improvement in curtailment and econometrics of HPP when participating in multiple energy markets.
- Impact of cost of various technologies in HPP on the econometrics.