



POLITÉCNICA

UNIVERSIDAD
POLITÉCNICA
DE MADRID

Plant-based vs. unit-based hydropower production function

**Juan I. Pérez-Díaz¹, Jesús González
Martínez²**

¹ Universidad Politécnica de Madrid (UPM)

² Spanish Ministry of Defense

ji.perez@upm.es

1. OBJECTIVE

The objective of the paper is performing a comparison between the use of a **plant-based** and a **unit-based production function** for the **day-ahead energy** and automatic frequency restoration **reserve** (aFRR) **scheduling** of a hydropower plant with 2 hydro units and **common waterways**



2. METHODOLOGY

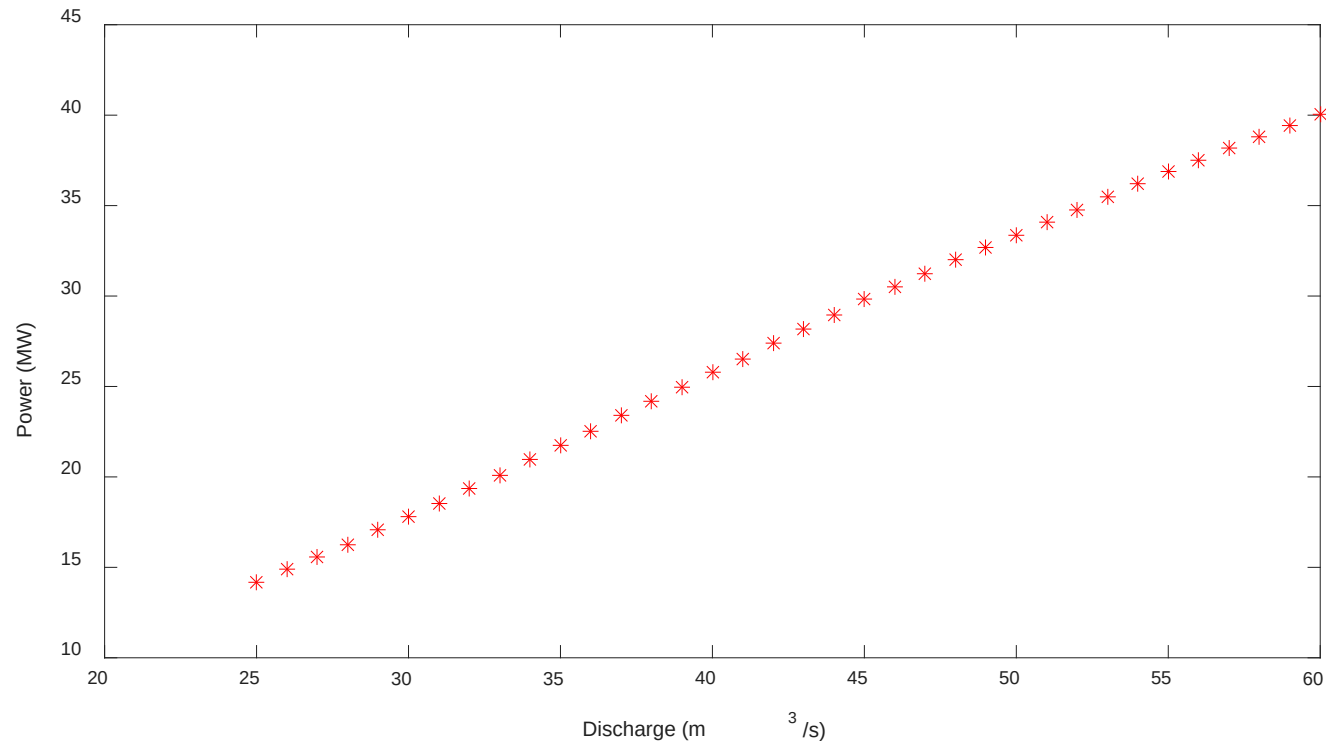
Common features and constraints of the **optimization models**:

- 24-h time horizon
- 1-h time resolution
- Total water release set by the River Basin Authority
- Unit start-up costs
- Maximum and minimum power
- Maximum and minimum discharge
- Maximum up and down reserve
- Constant gross head → 1 p-q curve (plant- or unit-based)
- Energy and reserve prices are assumed known (input)
- Deterministic mixed integer program

2. METHODOLOGY

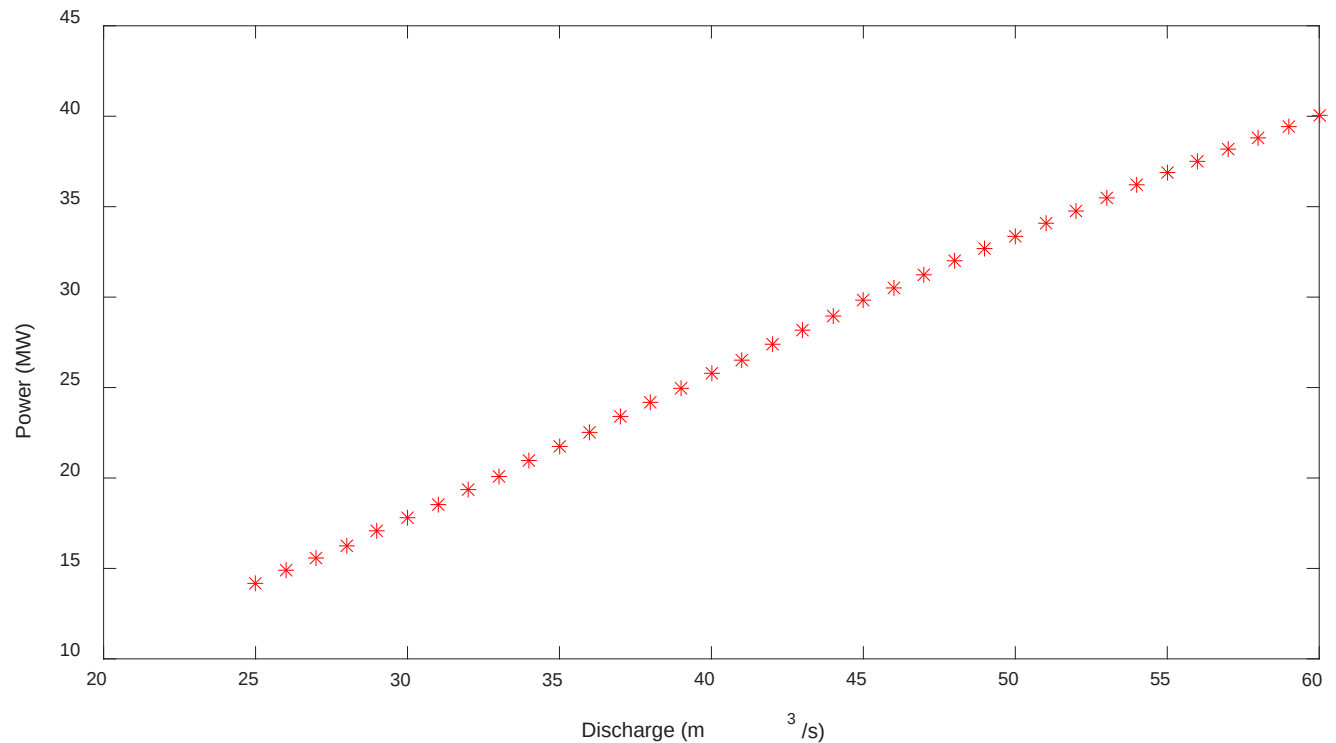
The **unit-based production function (PF)** is obtained by direct calculation from the following data:

- Reservoir curve
- Turbine hill chart
- Head loss coefficient (1, 5, 10 and 15 % of the max. gross head)



2. METHODOLOGY

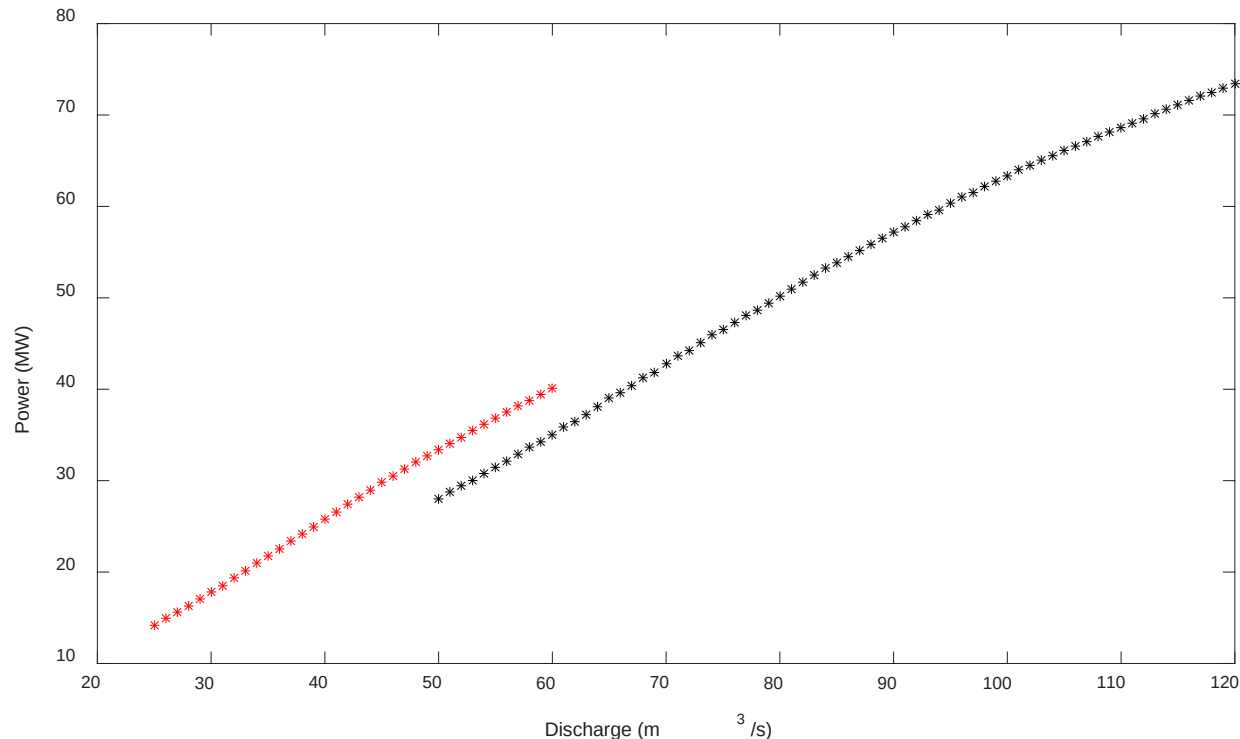
Each unit PF is **blind** to the amount of water discharged through the other unit and the corresponding loss



2. METHODOLOGY

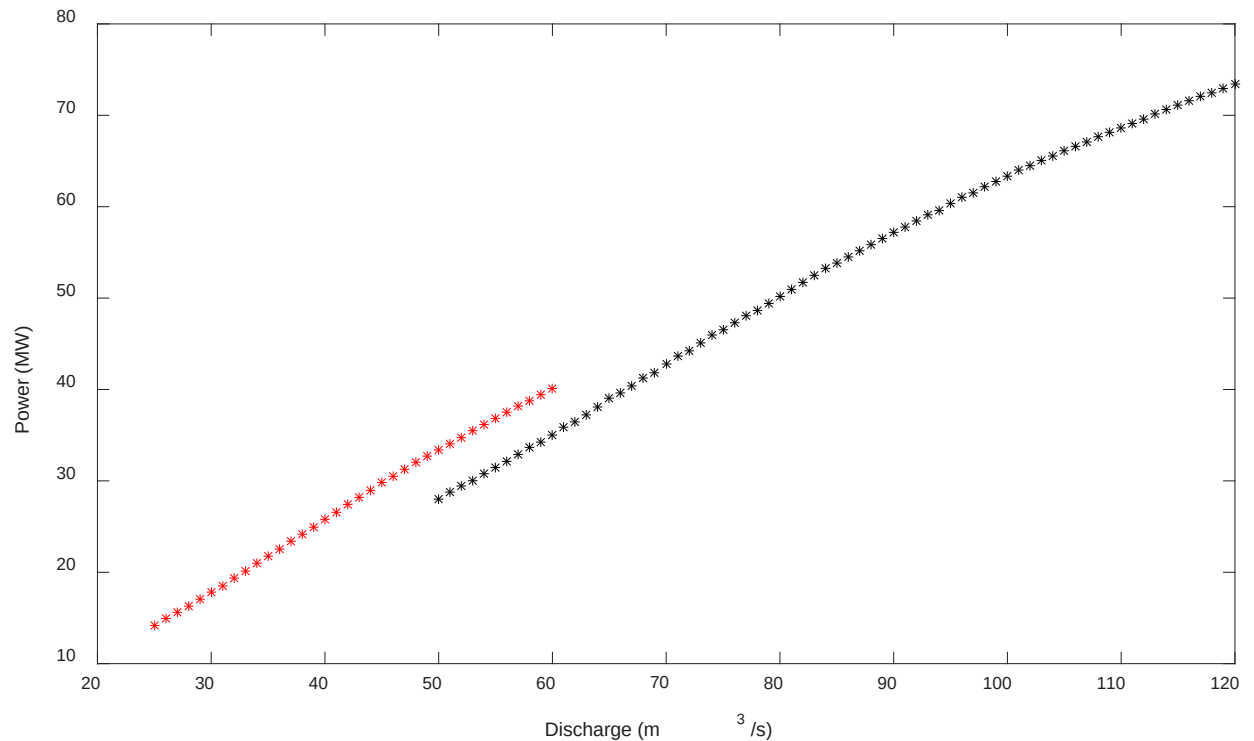
The **plant-based PF** is obtained by an iterative approach from the following data:

- Reservoir curve
- Turbine hill chart
- Head loss coefficient (1, 5, 10 and 15 % of the max. gross head)



2. METHODOLOGY

The plant-based PF is **aware** of the total water release and head loss



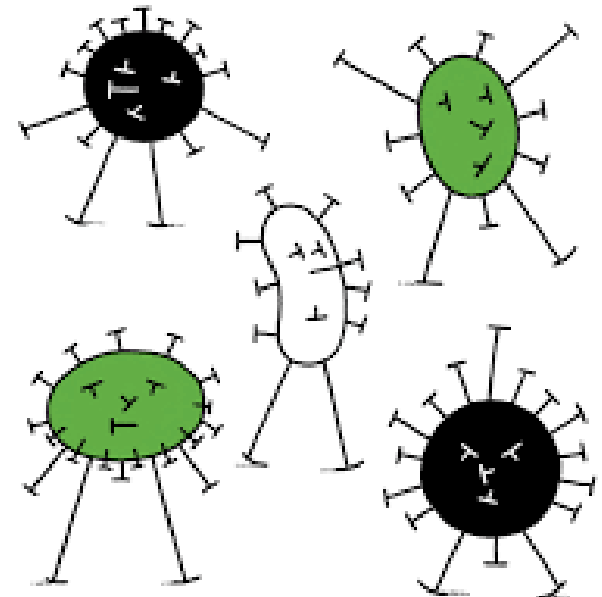
2. METHODOLOGY

8 historic scenarios of:

- Hourly energy price
- Hourly reserve prices (Spanish aFRR market)
- Gross head

Model variants:

- Only energy market
- Energy and reserve markets
- Plant-based PF with 2+1+2 flow segments
- Unit-based PF with 2 flow segments each
- Same as above neglecting head losses
- Unit-based PF with 5 flow segments each
- Unit-based PF with 14 flow segments each



2. METHODOLOGY

Postprocess:

- Hourly power and reserve are calculated as a function of the hourly discharge decisions considering the actual head loss and using the turbine hill chart



3. RESULTS

ONLY ENERGY

Head loss (% maximum gross head)	Plant-based PF 2+1+2 flow segments (€)	Unit-based PF 2 flow segments (%)	Unit-based PF w/o losses 2 flow segments (%)		Plant-based PF 2+1+2 flow segments (€)	Unit-based PF 2 flow segments (%)	Unit-based PF w/o losses 2 flow segments (%)
	Scenario 01				Scenario 02		
1	40825	0,00	0,00		38632	-0,06	-0,06
5	40299	-2,15	-2,15		37354	-1,20	-1,20
10	39742	-5,25	-5,25		36835	-5,59	-5,59
15	39256	-7,07	-8,73		36317	-10,30	-10,30
	Scenario 03				Scenario 04		
1	30130	0,00	0,00		33165	0,00	0,00
5	29023	0,00	0,00		32315	-1,14	-1,14
10	27665	-0,53	-0,53		31782	-4,68	-4,68
15	26653	-2,76	-2,76		31429	-9,20	-9,20
	Scenario 05				Scenario 06		
1	34024	-0,14	-0,14		30266	0,00	0,00
5	33734	-2,03	-2,52		29408	-0,83	-0,83
10	33324	-6,18	-6,18		28267	-2,60	-2,61
15	32950	-10,01	-10,01		27533	-5,93	-5,94
	Scenario 07				Scenario 08		
1	29915	0,00	0,00		28303	0,00	0,00
5	28845	-1,02	-1,02		27140	0,00	0,00
10	28081	-4,40	-4,40		25930	-0,94	-0,94
15	27721	-6,56	-9,88		25077	-3,89	-3,89

3. RESULTS

ONLY ENERGY

Head loss (% maximum gross head)	Plant-based PF 2+1+2 flow segments (€)	Unit-based PF 2 flow segments (%)	Unit-based PF 5 flow segments (%)	Unit-based PF 14 flow segments (%)		Plant-based PF 2+1+2 flow segments (€)	Unit-based PF 2 flow segments (%)	Unit-based PF 5 flow segments (%)	Unit-based PF 14 flow segments (%)
	Scenario 01					Scenario 02			
1	40825	0,00	0,00	0,00		38632	-0,06	-0,06	0,00
5	40299	-2,15	-2,15	-2,15		37354	-1,20	-1,20	-1,20
10	39742	-5,25	-5,25	-3,99		36835	-5,59	-4,45	-3,27
15	39256	-7,07	-8,73	-8,55		36317	-10,30	-8,53	-6,31
1	30130	0,00	0,00	0,00		33165	0,00	0,00	0,00
5	29023	0,00	0,00	0,00		32315	-1,14	-1,14	-1,14
10	27665	-0,53	-0,53	-0,53		31782	-4,68	-4,68	-4,68
15	26653	-2,76	-2,76	-2,76		31429	-9,20	-9,20	-9,20

3. RESULTS

ENERGY + RESERVE

Head loss (% maximum gross head)	Plant-based PF 2+1+2 flow segments (€)	Unit-based PF 2 flow segments (%)	Unit-based PF w/o losses 2 flow segments (%)		Plant-based PF 2+1+2 flow segments (€)	Unit-based PF 2 flow segments (%)	Unit-based PF w/o losses 2 flow segments (%)
	Scenario 01				Scenario 02		
1	41497	-0,03	-0,29		42642	-0,12	-0,12
5	41097	-1,11	-1,75		42098	-1,12	-1,20
10	40713	-2,98	-4,15		41403	-2,56	-2,61
15	40377	-4,93	-4,92		41046	-4,94	-5,04
	Scenario 03				Scenario 04		
1	35587	0,39	0,39		35228	-0,01	-0,01
5	35318	-1,78	-1,79		34650	-0,15	-0,15
10	34892	-4,83	-4,86		34228	-1,78	-1,79
15	34558	-8,41	-8,45		33996	-4,10	-4,11
	Scenario 05				Scenario 06		
1	34913	0,07	0,07		31107	0,16	0,16
5	34326	0,70	0,70		30506	-0,04	-0,04
10	34060	-0,10	-0,10		29845	-1,12	-1,12
15	33790	-2,22	-1,11		29295	-2,79	-2,78
	Scenario 07				Scenario 08		
1	32120	-0,01	-0,01		30423	-0,05	-0,05
5	31310	-0,10	-0,23		29537	-0,35	-0,37
10	30400	-1,00	-0,98		28706	-1,89	-1,91
15	29874	-3,35	-3,35		28119	-4,70	-4,73

3. RESULTS

ENERGY + RESERVE

Head loss (% maximum gross head)	Aggregate PF 2+1+2 flow segments (€)	Unit-based PF 2 flow segments (%)	Unit-based PF w/o losses 2 flow segments (%)	Unit-based PF 14 flow segments (%)
Scenario 01				
1	41497	-0,03	-0,29	0,68
5	41097	-1,11	-1,75	0,01
10	40713	-2,98	-4,15	-1,45
15	40377	-4,93	-4,92	-4,51
Scenario 03				
1	35587	0,39	0,39	0,56
5	35318	-1,78	-1,79	-1,38
10	34892	-4,83	-4,86	-4,11
15	34558	-8,41	-8,45	-7,77

3. RESULTS

ENERGY + RESERVE

Head loss (% maximum gross head)	Aggregate PF 2+1+2 flow segments (€)	Unit-based PF 2 flow segments (%)	Unit-based PF w/o losses 2 flow segments (%)	Unit-based PF 14 flow segments (%)
Scenario 02				
1	42642	-0,12	-0,12	0,42
5	42098	-1,12	-1,20	-0,38
10	41403	-2,56	-2,61	-1,97
15	41046	-4,94	-5,04	-4,21
Scenario 04				
1	35228	-0,01	-0,01	0,15
5	34650	-0,15	-0,15	-0,03
10	34228	-1,78	-1,79	-1,70
15	33996	-4,10	-4,11	-4,06

4. CONCLUSION



The model using a plant-based PF provides better results than the one using a unit-based PF (and all its variants) in mostly all cases analysed

The difference between the two approaches reduces when the plant sells both energy and reserve

5. FUTURE WORK



- Use a larger set of energy and reserve price scenarios
- Upgrade the plant-based PF with a higher number of flow segments (e.g. 14)
- Consider uncertainty in the energy and reserve prices
- Take into account the real-time use of the scheduled reserves
- Replace the release target with the water value at the end of the day

Thanks for your attention!



Juan I. Pérez-Díaz
Universidad Politécnica de Madrid (UPM)

ji.perez@upm.es