Flexibility Modeling

Modeling framework

- **Input**
  - Generation (Capacity, Variable cost, Fixed cost, Ramping constraints, Type, Slot wise availability for RE)
  - Substation level load (Aggregation of flexible, RE, adjustable, battery loads etc)
  - Feeder level load (Aggregation of flexible, RE, adjustable, battery loads etc)
  - Tariff category wise (Flexible loads, RE loads, adjustable loads, battery loads etc)
  - Scenarios (End use pattern for different pricing scenarios)
- **Model**
  - Objective function, Problem formulation etc
- **Output**
  - Dynamic pricing signal, Tariff structure, Base case load curve, Load curves for scenarios, Benefit to utility, Benefits to consumer etc.

Overall objectives

- **Renewable energy utilization maximization**
  - RE prioritization
  - Carbon tax on conventional power
- **Consumer bill minimisation**
  - Shifting and adjusting loads to achieve minimum energy cost
- **Utility power purchase cost minimisation**
  - Utilisation of low cost RE, embedded RE to reduce overall power cost
  - Optimal resource utilisation

Data

- Generation
  - MODCON.xlsx, RE power PPA.xlsx, RE.xlsx
- Demand side
  - Consumer indexing, End use assumptions, Solar rooftop, Tariff plan, Various scenarios
- Assumptions
  - Fraction of solar adoption, fraction of DF participation, number of consumers, solar capacity, losses etc

Generation

Plant	Capacity	Variable cost	Fixed cost	Type	Ramping_up	Ramping down	Startup cost
1	87	4.8538	0	Thermal	52.2	-52.2	10
2	144	0	0	Nuclear	86.4	-86.4	11
3	391	0	0	Hydro	234.6	-234.6	12
4	50	4.3015	0	Thermal	30	-30	13
5	128	1.18	1.48	Thermal	76.8	-76.8	14
6	620	2.26	0.95	Thermal	372	-372	15
7	420	3.07	0.84	Thermal	252	-252	16
8	180	1.92	2.51	Gas	108	-108	17
9	140	2.43	1.1	Thermal	84	-84	18
10	166	1.38	1.69	Thermal	99.6	-99.6	19

Solar	Wind
3.7017921	4.47885

Solar	Wind
0	1186
0	901
0	793
0	587
0	649
0	630
39.815	737
816.58	650
1745	444
2353	429
2697.8	398
2976.3	494
2999.1	595
2810.6	614
2368.7	653
1584.4	596
636.67	878
98.419	827
0	1158
0	803
0	744
0	985
0	1149
0	1022

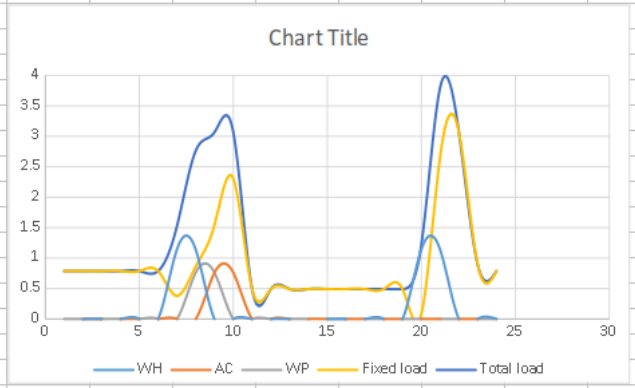
Demand

Feeder Name	11 KV SHREEYASH FEEDER			22 KV MCCH FEEDER		
Row Labels	Sum of SALE MWh	Sum of NO OF CONS	% SHARE	Sum of SALE MWh	Sum of NO OF CONS	% SHARE
HT RAILWAY/METRO/MONO 11 KV	12.32	1	2%	0.00	0	0%
LT-COMMERCIAL	136.21	692	25%	552.63	1861	42%
LT-DOMESTIC	338.73	2708	62%	501.43	3426	38%
LT-INDUSTRIAL	28.67	10	5%	45.65	20	3%
LT-PD CONSUMERS	0.05	643	0%	0.00	0	0%
LT-PUBLIC SER.-OTHER	27.77	13	5%	72.54	36	5%
ST.LIGHT	0.00	1	0%	18.94	13	1%
HT Commercial 22 KV	0.00	0	0%	86.84	3	7%
HT Public Services Govt. Educational Inst	0.00	0	0%	7.55	1	1%
HT Public Services Others 22 KV	0.00	0	0%	40.60	1	3%
Total Commercial + Domestic	474.94	3400.00	87%	1140.89	5290.00	86%

FEEDER NAME	FEEDER TYPE	FEEDER KV	CATEGORY	2212
11 KV SHREEYASH FEEDER	58	11	1.Res	20
11 KV SHREEYASH FEEDER	58	11	2.Com	3
11 KV SHREEYASH FEEDER	58	11	7.Public S	2
22KV MCCH SOCIETY	58	22	1.Res	11
22KV MCCH SOCIETY	58	22	2.Com	1
22KV MCCH SOCIETY	58	22	7.Public S	3

Demand – end use assumptions

	A	B	C	D	E	F	G	H	I	J	K	L
1	Average l	3.8										
2	% of max	30%	20%	20%								
3	slot	WH	AC	WP			slot	WH	AC	WP	Fixed load	Total load
4	1	0		0			1	0	0	0	0.78675	0.78675
5	2	0		0			2	0	0	0	0.78675	0.78675
6	3	0		0			3	0	0	0	0.78675	0.78675
7	4	0		0			4	0	0	0	0.78675	0.78675
8	5	0		0			5	0	0	0	0.78675	0.78675
9	6	0		0			6	0	0	0	0.78675	0.78675
10	7	1		0			7	1.14	0	0	0.38039	1.52039
11	8	1		1			8	1.14	0	0.76	0.86149	2.76149
12	9	0	1	1			9	0	0.76	0.76	1.54636	3.06636
13	10	0	1	0			10	0	0.76	0	2.30636	3.06636
14	11	0		0			11	0	0	0	0.49172	0.49172
15	12	0		0			12	0	0	0	0.49172	0.49172
16	13	0		0			13	0	0	0	0.49172	0.49172
17	14	0		0			14	0	0	0	0.49172	0.49172
18	15	0		0			15	0	0	0	0.49172	0.49172
19	16	0		0			16	0	0	0	0.49172	0.49172
20	17	0		0			17	0	0	0	0.49172	0.49172
21	18	0		0			18	0	0	0	0.49172	0.49172
22	19	0		0			19	0	0	0	0.49172	0.49172
23	20	1		0			20	1.14	0	0	0.07749	1.21749
24	21	1		0			21	1.14	0	0	2.66	3.8
25	22	0		0			22	0	0	0	3.06636	3.06636
26	23	0		0			23	0	0	0	0.89296	0.89296
27	24	0		0			24	0	0	0	0.78675	0.78675
28												
29												
30												



hospital | hotel | mall | office | IT | **residential** | Consumer load profile | Reference load profile

Demand - scenarios

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
	Scnr_1	Scnr_2	Scnr_3	Scnr_4	Scnr_5	Scnr_6	Scnr_7	Scnr_8	Scnr_9	Scnr_10	Scnr_11	Scnr_12	Scnr_13	Scnr_14	Scnr_15	Scnr_16	Scnr_17	Scnr_18	Scnr_19	Scnr_20
0	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675
1	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675
2	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675
3	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675
4	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675
5	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	1.92675	1.92675	1.92675	1.92675	1.92675	1.92675	1.92675	1.92675	1.92675	1.92675
6	1.52039	1.52039	1.52039	1.52039	1.52039	1.52039	1.52039	1.52039	1.52039	1.52039	1.52039	1.52039	1.52039	1.52039	1.52039	1.52039	1.52039	1.52039	1.52039	1.52039
7	2.76149	2.76149	2.00149	2.00149	2.00149	2.00149	2.00149	2.00149	2.00149	2.00149	1.62149	1.62149	0.86149	0.86149	0.86149	0.86149	0.86149	0.86149	0.86149	0.86149
8	3.06636	2.99036	2.30636	2.23036	2.30636	2.23036	2.30636	2.23036	2.30636	2.23036	3.06636	2.99036	2.30636	2.23036	2.30636	2.23036	2.30636	2.23036	2.30636	2.23036
9	3.06636	2.99036	3.06636	2.99036	3.82636	3.75036	3.06636	2.99036	3.06636	2.99036	3.06636	2.99036	3.06636	2.99036	3.82636	3.75036	3.06636	2.99036	3.06636	2.99036
10	0.49172	0.49172	0.49172	0.49172	1.25172	1.25172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	1.25172	1.25172	0.49172	0.49172	0.49172	0.49172
11	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	1.25172	1.25172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	1.25172	1.25172
12	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	1.25172	1.25172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	1.25172	1.25172
13	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172
14	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172
15	0.49172	0.49172	1.25172	1.25172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	1.25172	1.25172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172
16	0.49172	0.49172	1.25172	1.25172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	1.25172	1.25172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172
17	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172
18	0.49172	0.49172	0.49172	0.49172	0.49172	0.49172	1.25172	1.25172	0.49172	0.49172	1.63172	1.63172	1.63172	1.63172	1.63172	1.63172	2.39172	2.39172	1.63172	1.63172
19	1.21749	1.21749	1.21749	1.21749	1.21749	1.21749	1.97749	1.97749	1.21749	1.21749	1.21749	1.21749	1.21749	1.21749	1.21749	1.21749	1.97749	1.97749	1.21749	1.21749
20	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	2.66	2.66	2.66	2.66	2.66	2.66	2.66	2.66	2.66	2.66
21	3.06636	3.06636	3.06636	3.06636	3.06636	3.06636	3.06636	3.06636	3.06636	3.06636	3.06636	3.06636	3.06636	3.06636	3.06636	3.06636	3.06636	3.06636	3.06636	3.06636
22	0.89296	0.89296	0.89296	0.89296	0.89296	0.89296	0.89296	0.89296	0.89296	0.89296	0.89296	0.89296	0.89296	0.89296	0.89296	0.89296	0.89296	0.89296	0.89296	0.89296
23	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675	0.78675

Setup

Base loads	*(= end use assumptions)*
Residential	eua_total
Hospital	eua_total
Hotel	eua_total
Mall	eua_total
Office	eua_total
IT	eua_total
...	
etc	eua_total

Setup

N = 50

Base scenarios						
Residential	Scnr_1	Scnr_2	Scnr_3	Scnr_4	...	Scnr_N
Hospital	Scnr_1	Scnr_2	Scnr_3	Scnr_4	...	Scnr_N
Hotel	Scnr_1	Scnr_2	Scnr_3	Scnr_4	...	Scnr_N
Mall	Scnr_1	Scnr_2	Scnr_3	Scnr_4	...	Scnr_N
Office	Scnr_1	Scnr_2	Scnr_3	Scnr_4	...	Scnr_N
IT	Scnr_1	Scnr_2	Scnr_3	Scnr_4	...	Scnr_N
...						
etc	Scnr_1	Scnr_2	Scnr_3	Scnr_4	...	Scnr_N

Create solar base loads

Base loads solar	*(= base loads – (solar capacity * solarper1w))*
Residential	base_solar
Hospital	base_solar
Hotel	base_solar
Mall	base_solar
Office	base_solar
IT	base_solar
...	
etc	base_solar

Create solar scenarios

N = 50

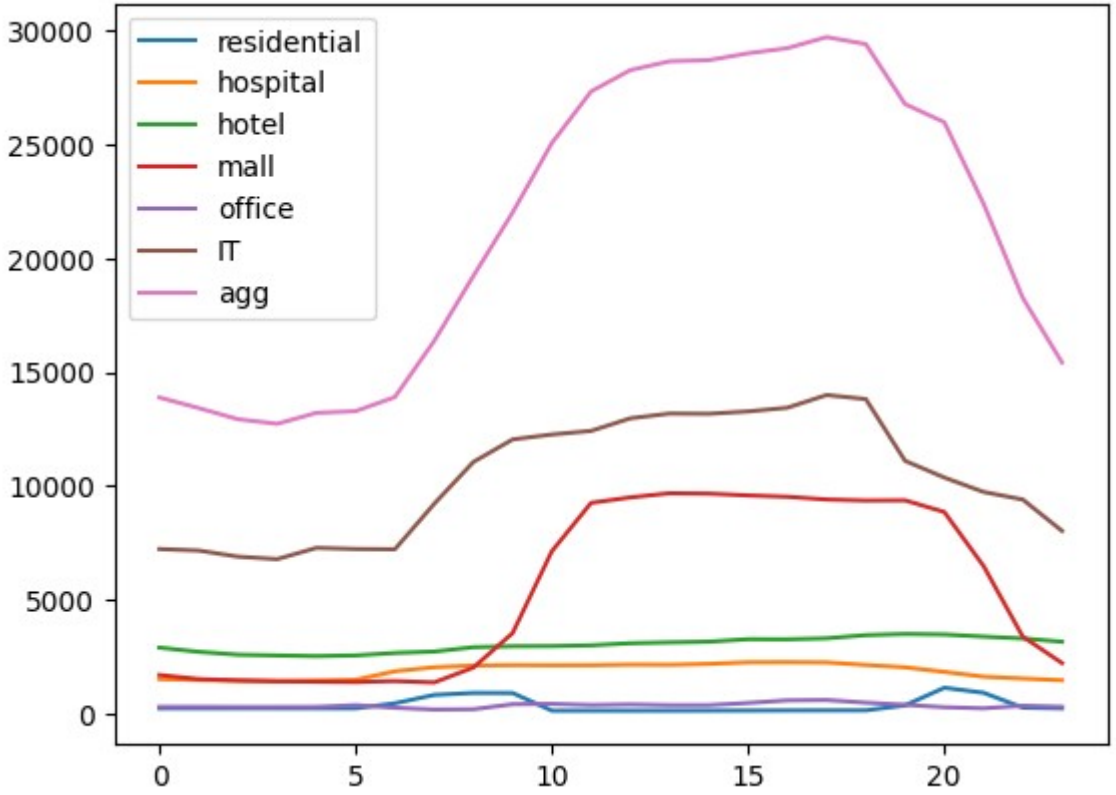
Base scenarios solar	*(= base scenarios – base loads solar)*					
Residential	Scnr_1	Scnr_2	Scnr_3	Scnr_4	...	Scnr_N
Hospital	Scnr_1	Scnr_2	Scnr_3	Scnr_4	...	Scnr_N
Hotel	Scnr_1	Scnr_2	Scnr_3	Scnr_4	...	Scnr_N
Mall	Scnr_1	Scnr_2	Scnr_3	Scnr_4	...	Scnr_N
Office	Scnr_1	Scnr_2	Scnr_3	Scnr_4	...	Scnr_N
IT	Scnr_1	Scnr_2	Scnr_3	Scnr_4	...	Scnr_N
...						
etc	Scnr_1	Scnr_2	Scnr_3	Scnr_4	...	Scnr_N

aggregate_base_load()

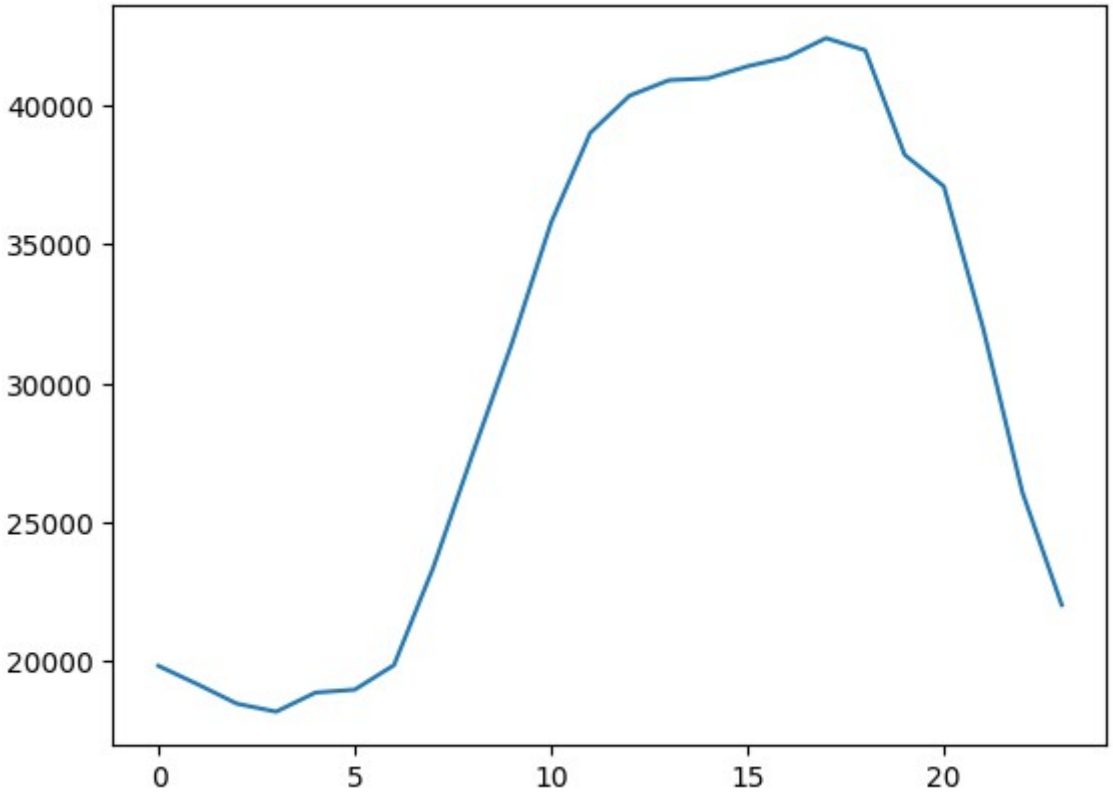
- Returns total_base_load and total_bill
- Total = solar + non_solar

	residential	hospital	hotel	mall	office	IT	agg
0	236.024845	1518.600638	2900.517573	1699.032434	299.482252	7228.166533	13881.824276
1	236.024845	1479.319658	2717.049831	1520.168983	300.100459	7163.405842	13416.069618
2	236.024845	1450.853971	2590.454983	1460.888525	293.222915	6895.734646	12927.179885
3	236.024845	1431.182222	2557.911050	1421.708913	293.338828	6785.233770	12725.399627
4	236.024845	1459.210296	2528.316081	1406.718452	297.202617	7279.465752	13206.938042

Total base load

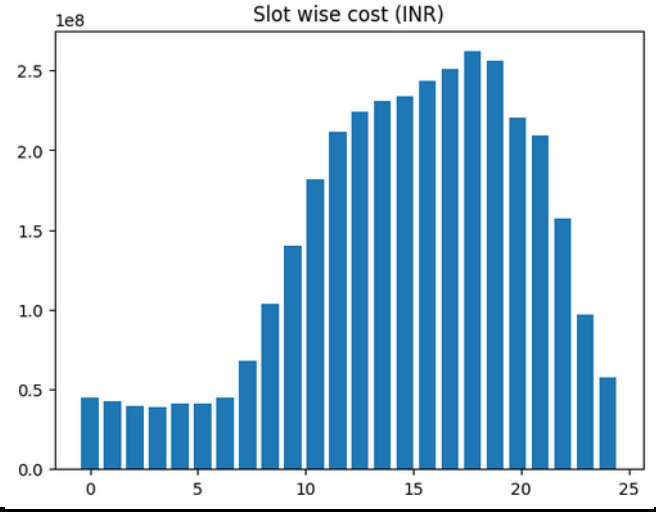


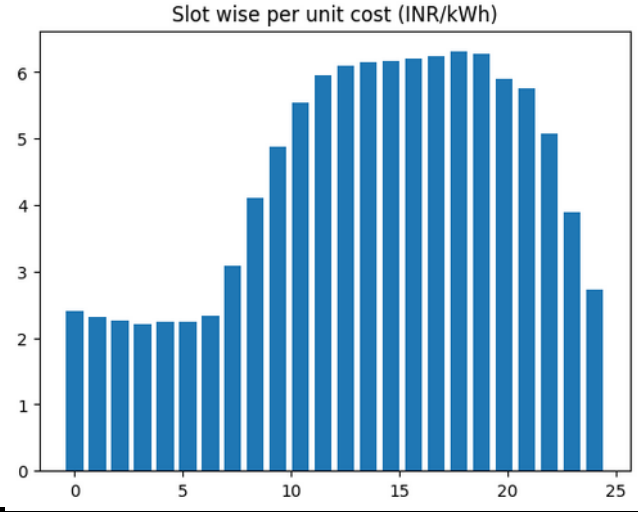
Projected load (/= *1 - losses*)



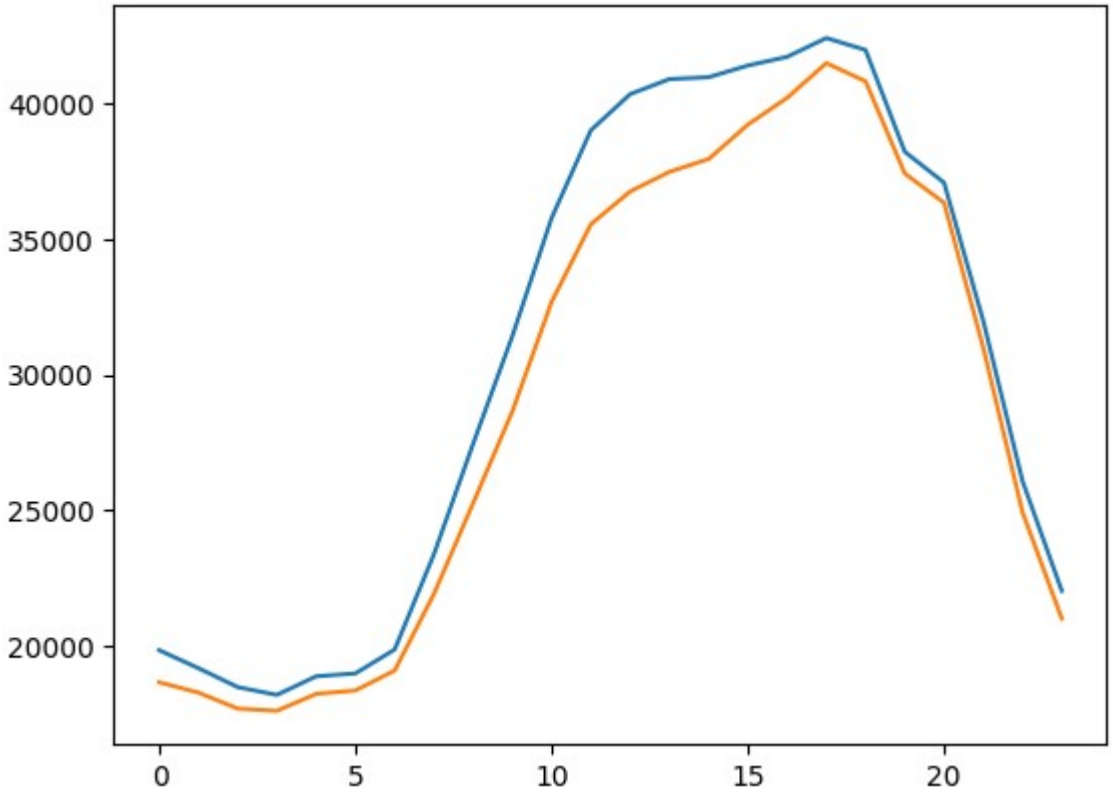
Generation cost optimization

- *compute_gen_curve (projected_demand, n)*
- Returns solt wise cost, slot wise per unit cost





Projected load vs scheduled gen



compute_optimal_load_curve()

- Input: pricing signal (tariff plan initially)
- Returns: optimal_load_curve, optimal_bill

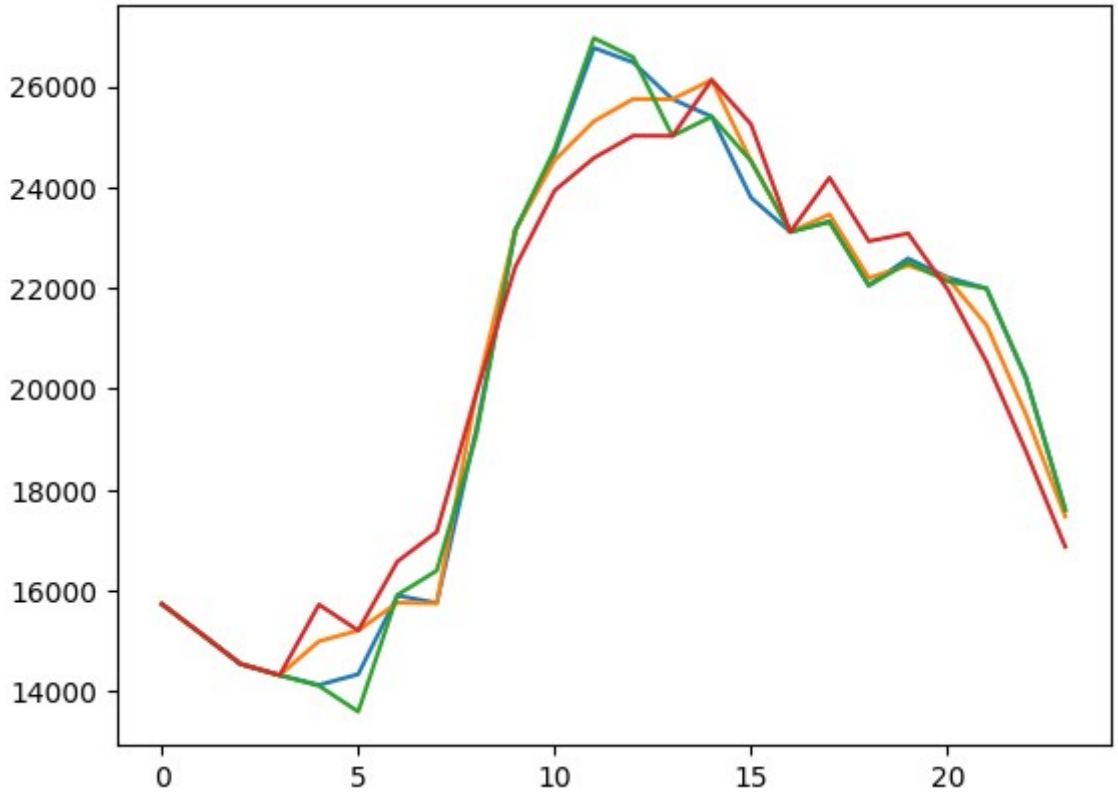
Demand flexibility algorithm

- Compute num_customers : solar (s), nonsolar (ns)
- compute participating num_customers : solar (ps), nonsolar (pns)

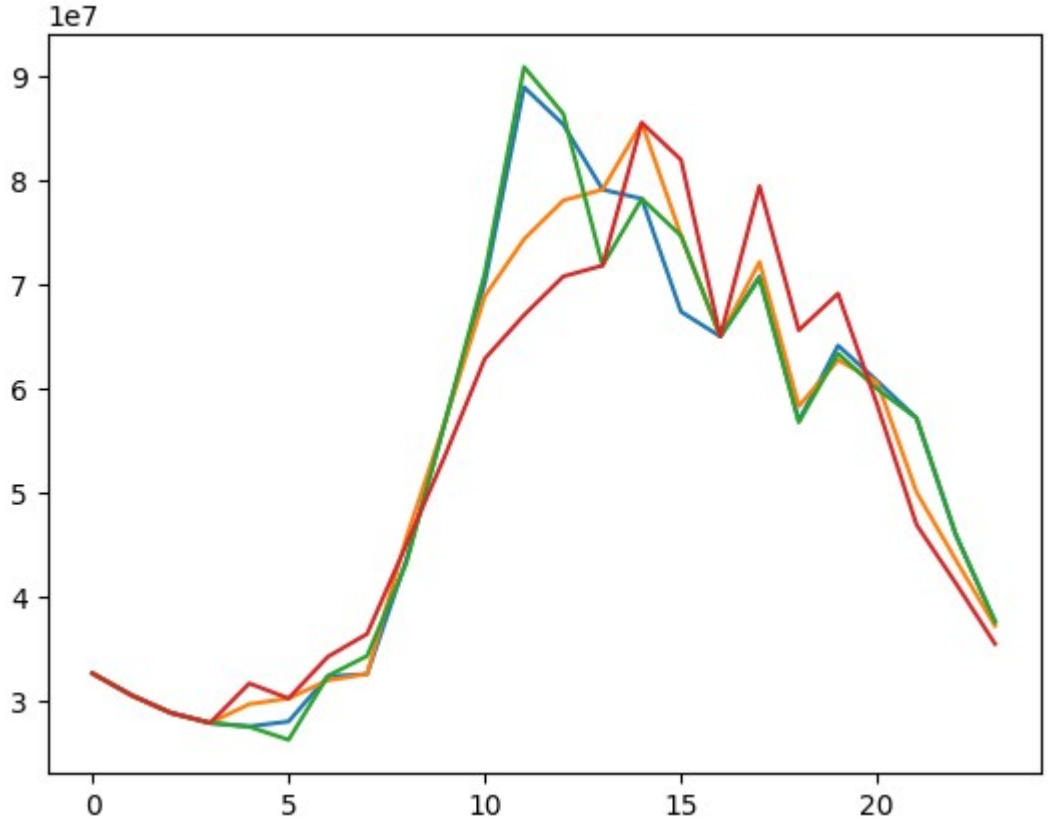
- customer_segment = [residential, hospital, hotel, mall, office, IT]

  for every segment in customer_segment:
  - scn = base load profile for that segment (single user)
  - solar_scn = base load profile with solar for that scenario (single user)
  - a = scn * (ns-pns) + solar_scn * (s-ps)
  - bill_a = a*tariff_plan
  - find optimal scenarios, optimal_scn and optimal_solar_scn
  - + use s, ns and tariff signal plus
  - + use ps, pns and pricing signal
  - b = optimal_scn * (pns) + optimal_solar_scn * (ps)
  - bill_b = b*pricing_signal
  - agg_load = a + b
  - agg_bill = agg_a + agg_b
  - compute projected_demand from agg_load by factoring losses
  - compute generation cost per slot
  - run pricing signal update rule

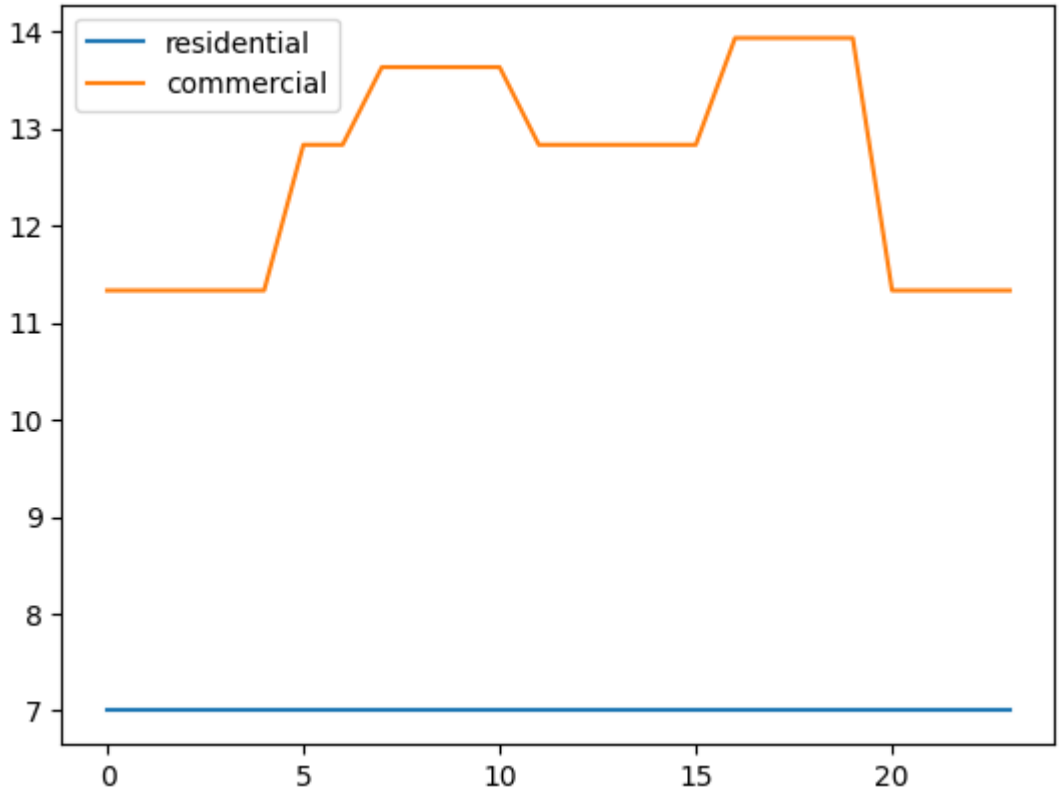
Load through iterations



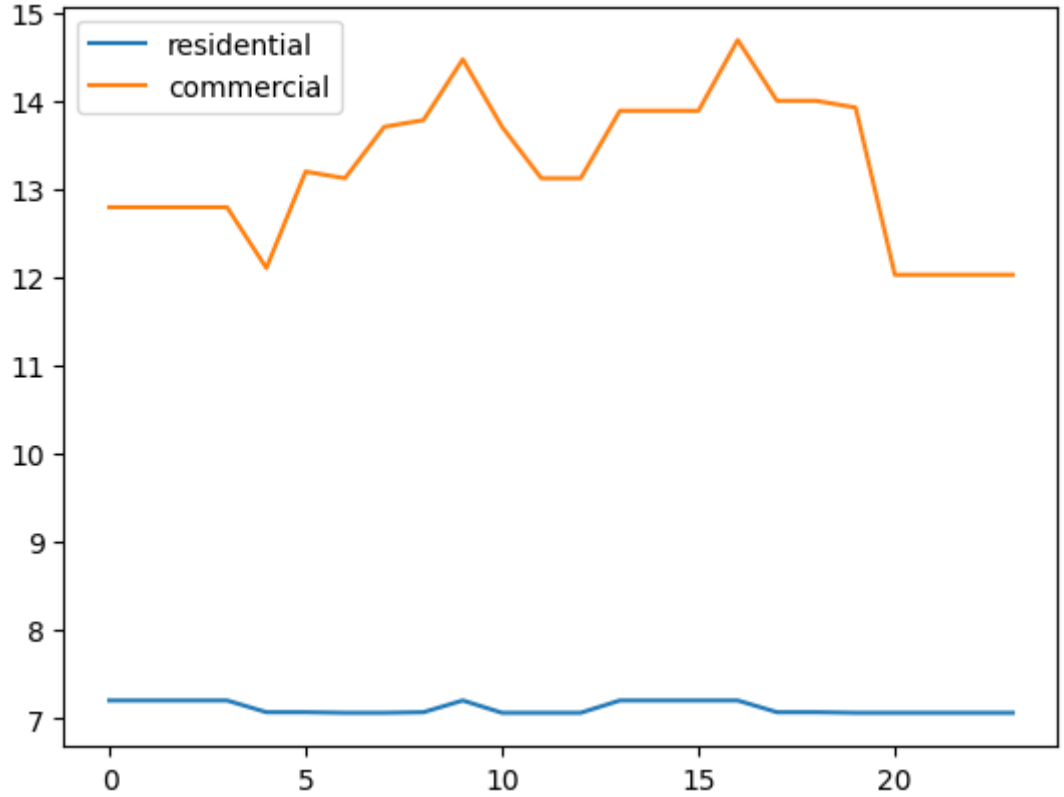
Generation cost through iterations



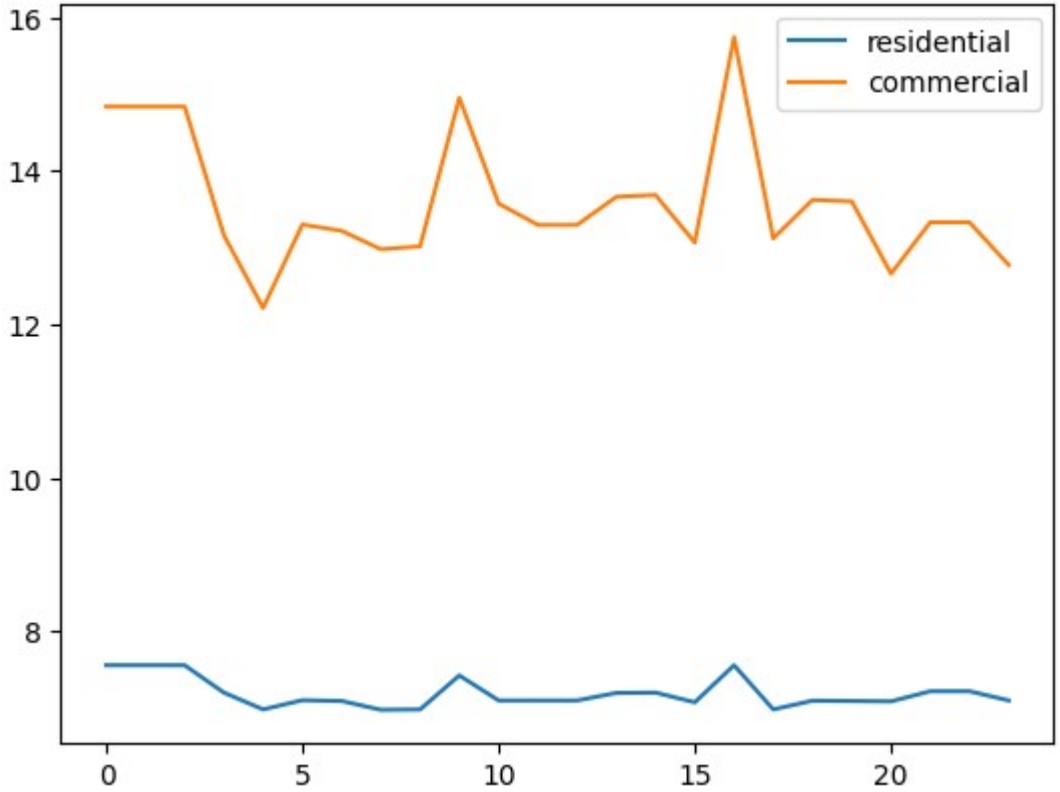
Initial pricing signal



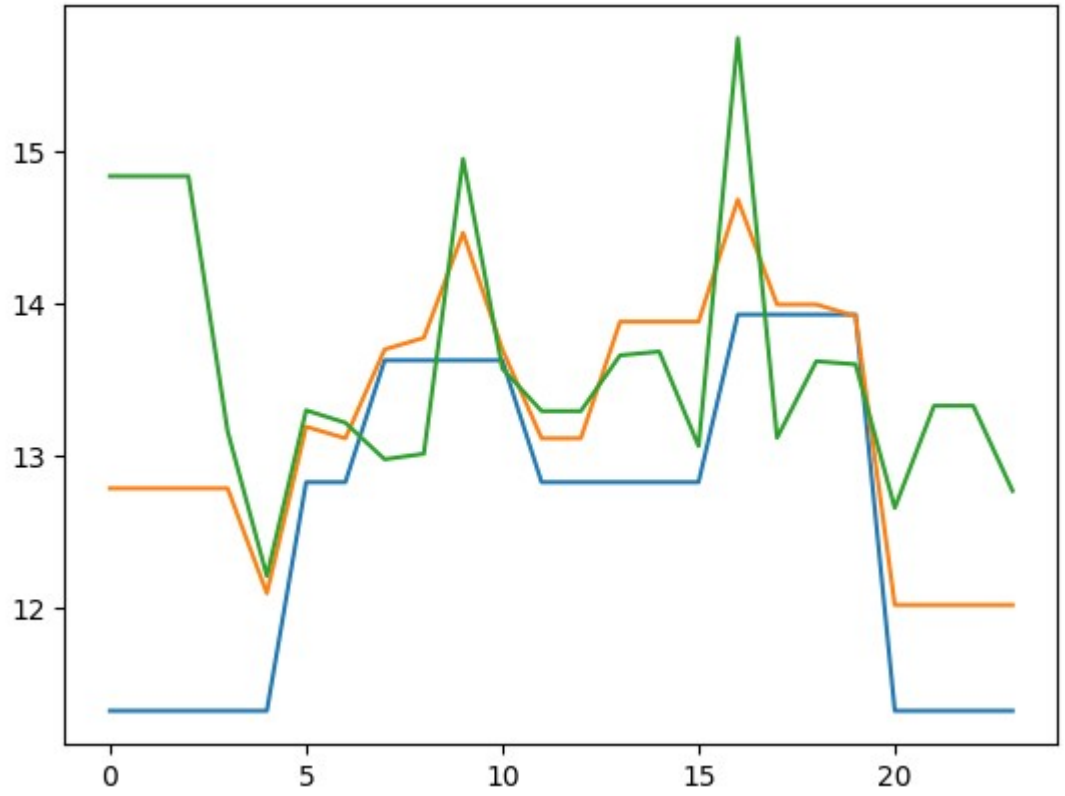
Pricing signal later



Pricing signal at the end



Pricing signal for commercial



Profit = bill – generation cost