Modeling Battery Sizing Optimization Algorithms for Various Use Cases

Semanur Sancar

Electrical & Electronics Engineering
Ozyegin University
Istanbul, Turkey
semanur.sancar@ozu.edu.tr

Motivation

Developing battery sizing algorithms with a common methodology for consumer, producer and prosumer.

Increasing the accuracy of battery sizing algorithms with generation and consumption estimation algorithms.

Methodology - 1

Consumer	Producer	Prosumer
Minimizing bill	Maximizing revenue with LPA	Minimizing bill without selling to grid
Minimizing bill & TR loss	Maximizing revenue wih PPA	Minimizing bill with selling to grid
	Maximizing revenue with EMP	

Methodology - 2

ML Models

- ANN
- DNN
- LSTM

Optimization Models

- MILP
- MIQP

Methodology - 3

Common formulas

$$DoD \,.\, \mathcal{E} \leq e_t \quad , \quad \forall t \tag{1}$$

$$e_t \leq \mathcal{E} \quad , \quad \forall t \tag{2}$$

$$e_t = DoD \,.\, \mathcal{E} \quad , \quad t = \{1, T\} \tag{3}$$

$$e_t = e_{t-1} + (c_t \,.\, \eta^{charge} - d_t) \,.\, \Delta T \quad , \quad t = [2, T] \tag{4}$$

$$0 \leq c_t \quad , \quad \forall t \tag{5}$$

$$0 \leq d_t \quad , \quad \forall t \tag{6}$$

$$c_t \,.\, \eta^{charge} \,.\, \Delta T \leq \mathcal{E} - e_t \quad , \quad \forall t \tag{7}$$

$$d_t \,.\, \Delta T \leq e_t \quad , \quad \forall t \tag{8}$$

$$d_t \leq \mathrm{M}\, u_t \quad , \quad \forall t \tag{9}$$

$$c_t \leq \mathrm{M}\,(1 - u_t) \quad , \quad \forall t \tag{10}$$

Consumer tou

$$\min\left\{\sum_t g_t^{buy} \,.\, \mathcal{TOU}_t \,.\, \Delta T\right\} \tag{11}$$

subject to (1) – (10)

$$g_t^{buy} + d_t \,.\, \eta^{discharge} = \mathcal{D}_t + c_t \quad , \quad \forall t \tag{12}$$

$$0 \leq g_t^{buy} \quad , \quad \forall t \tag{13}$$

$$g_t^{buy} \leq \mathcal{G} \quad , \quad \forall t \tag{14}$$

Consumer tou + tr loss

$$\min\left\{\sum_t \left(g_t^{buy} \,.\, \mathcal{TOU}_t \,.\, \Delta T + P_k \,.\, \left(\frac{g_t^{buy}}{\mathcal{G}}\right)^2\right)\right\} \tag{15}$$

subject to (1) – (10)

$$g_t^{buy} + d_t \,.\, \eta^{discharge} = \mathcal{D}_t + c_t \quad , \quad \forall t \tag{16}$$

$$0 \leq g_t^{buy} \quad , \quad \forall t \tag{17}$$

$$g_t^{buy} \leq \mathcal{G} \quad , \quad \forall t \tag{18}$$

Producer EMP

$$\min\left\{-\left(\sum_t g_t^{sell} \,.\, DAM_t \,.\, \Delta T\right)\right\} \tag{19}$$

subject to (1) – (10)

$$s_t + d_t \,.\, \eta^{discharge} = g_t^{sell} + c_t \quad , \quad \forall t \tag{20}$$

$$0 \leq g_t^{sell} \quad , \quad \forall t \tag{21}$$

$$g_t^{sell} \leq \mathcal{G} \quad , \quad \forall t \tag{22}$$

Producer LPA

$$\min\left\{-\left(\sum_t g_t^{sell} \,.\, \mathcal{C} \,.\, \Delta T\right)\right\} \tag{23}$$

subject to (1) – (10)

$$s_t + d_t \,.\, \eta^{discharge} = g_t^{sell} + c_t \quad , \quad \forall t \tag{24}$$

$$0 \leq g_t^{sell} \quad , \quad \forall t \tag{25}$$

$$g_t^{sell} \leq \mathrm{LPA} \quad , \quad \forall t \tag{26}$$

Prosumer wo Selling

$$\min\left\{\left(\sum_t g_t \,.\, \mathcal{TOU}_t \,.\, \Delta T\right)\right\} \tag{30}$$

subject to (1) – (10)

$$s_t + g_t^{buy} + d_t \,.\, \eta^{discharge} = \mathcal{D}_t + c_t \quad , \quad \forall t \tag{31}$$

$$0 \leq g_t^{buy} \quad , \quad \forall t \tag{32}$$

$$g_t^{buy} \leq \mathcal{G} \quad , \quad \forall t \tag{33}$$

Prosumer w Selling

$$\min\left\{\left(\sum_t g_t \,.\, \mathcal{TOU}_t \,.\, \Delta T - \sum_t g_t^{sell} \,.\, \mathcal{TOU}_t \,.\, \Delta T\right)\right\} \tag{30}$$

subject to (1) – (10)

$$s_t + g_t^{buy} + d_t \,.\, \eta^{discharge} = \mathcal{D}_t + g_t^{sell} + c_t \quad , \quad \forall t \tag{31}$$

$$0 \leq g_t^{buy} \quad , \quad \forall t \tag{32}$$

$$g_t^{buy} \leq \mathcal{G} \quad , \quad \forall t \tag{33}$$

$$0 \leq g_t^{sell} \quad , \quad \forall t \tag{34}$$

$$g_t^{sell} \leq \mathcal{G} \quad , \quad \forall t \tag{35}$$

Producer PPA

$$\min\left\{-\left(\sum_t g_t^{sell} \,.\, \mathcal{C} \,.\, \Delta T\right) + \left(\sum_t (PPA_t - g_t^{sell}) \,.\, \mathcal{C}^{penalty} \,.\, \Delta T\right)\right\} \tag{27}$$

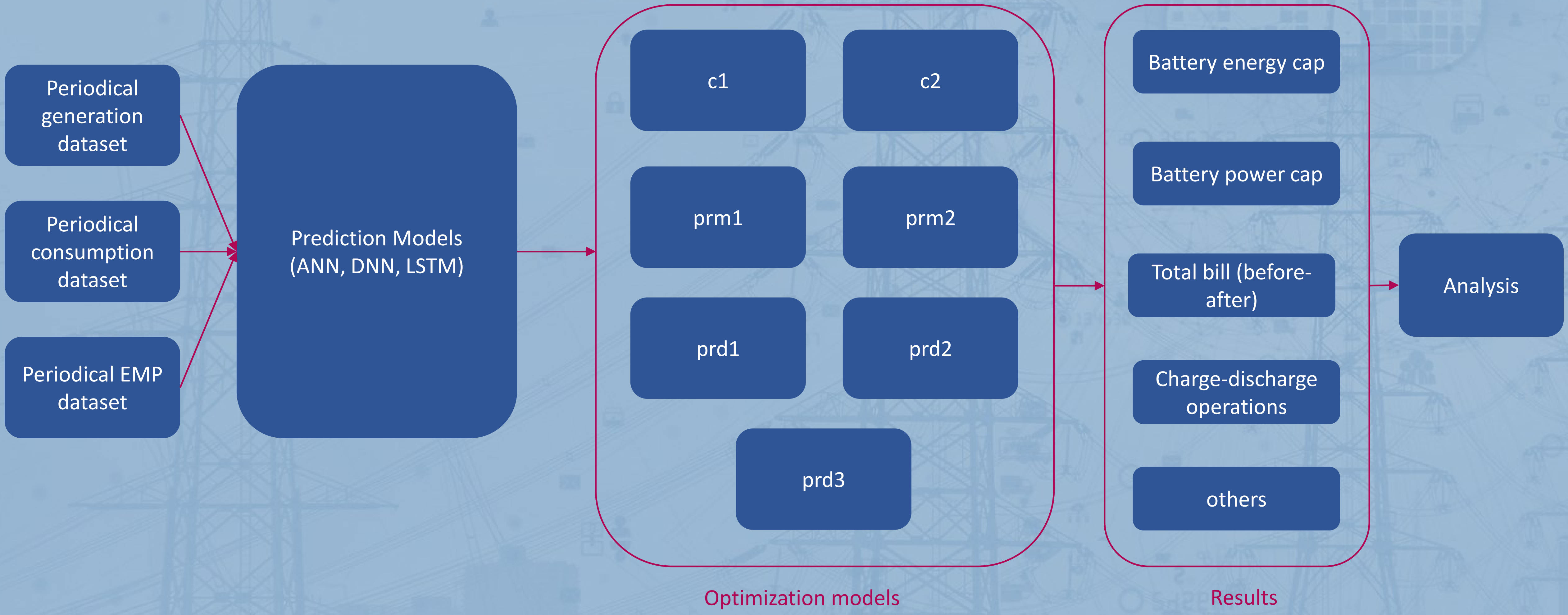
subject to (1) – (10)

$$s_t + d_t \,.\, \eta^{discharge} = g_t^{sell} + c_t \quad , \quad \forall t \tag{28}$$

$$0 \leq g_t^{sell} \quad , \quad \forall t \tag{29}$$

$$g_t^{sell} \leq PPA_t \quad , \quad \forall t \tag{30}$$

Methodology - 4



Result - 1 - Consumer TOU

Profile No.	Battery Energy Capacity (kWh)	Battery Power Capacity (kW)	Saving (TL-%)	Max Demand (kW)	Power Contract (kW)	Battery Energy Capacity / Total Energy Demand (%)	Mean Power Demand / Battery Power Capacity (%)
1	506	61	39	49.14	65	9	27
2	407	70	38	38.21	75	4	20
3	266	45	38	20.67	50	4	23
4	3,034	359	42	199.23	400	6	20
5	43,035	760	28	614.29	1000	2	53

- Consumers need a battery with an energy capacity of **5%** of their monthly total energy consumption for bill management.
- The battery power capacity of **30%** of the average power demand is sufficient.
- Bill earnings were found to be **37%** per month in TL.

Result - 2 – Consumer TOU + TR LOSS

Profile No.	Use-Case	Battery Energy Capacity (kWh)	Battery Power Capacity (kW)	Total Transformer Loss (Before) (TL)	Total Transformer Loss (After) (TL)
4	1	3,034	359	1,500.00	1,602.56
4	2	4,196	281	1,500.00	1,553.18
5	1	43,035	760	1,255.63	1,436.81
5	2	9,774	760	1,255.63	1,356.99

- The increase in transformer losses has been reduced by **50%**.
- In Consumer's 1st model, the battery can be charged unlimitedly to meet all peak consumption. However, **both peaks in power consumption and zero consumption cause the transformer to move away from its efficient working area**. In this case, the charging capacity of the battery is limited.

Result - 3 – Producer

				LPA		PPA		EMP	
Profile No.	Installed Power (kW)	Max Gen. (kW)	Total Energy Generation (kWh)	Battery Energy Capacity (kWh)	Battery Power Capacity (kW)	Battery Energy Capacity (kWh)	Battery Power Capacity (kW)	Battery Energy Capacity (kWh)	Battery Power Capacity (kW)
6	10	5	717	22	4	9	3	250	50
7	150	104	12,007	569	113	434	59	800	160
8	500	343	39,360	1,713	342	1,388	192	3,150	630
9	1,000	707	80,973	3,714	742	3,404	407	6,250	1,250
10	5,000	4,763	717,232	22,857	4,571	228,413	3,263	31,250	6,250

- **The highest sizing recommendations were observed in the EMP scenario.** In the EMP model, the estimated 1-month dynamic electricity market price is used. Since the goal was to maximize revenue, **the optimization algorithm considered all 1-month periods holistically and made large volume sales in the most expensive few periods**. It stored plenty of energy for big electricity sales.
- An extreme battery energy capacity increase was observed for profile 10 in the PPA model. There is a minimum electricity sales agreement in the PPA model. **Profile 10 has the largest minimum sales agreement due to its installed power. In order not to pay more penalty, the optimization algorithm suggested the energy storage capacity higher than the others**.

Result - 4 – Prosumer

			wo selling			w selling		
Profile No.	Installed Power (kW)	Power Contract (kW)	Battery Energy Capacity (kWh)	Battery Power Capacity (kW)	Saving (TL-%)	Battery Energy Capacity (kWh)	Battery Power Capacity (kW)	Saving (TL-%)
11	10	400	2,996	359	42.02037	2,996	359	42.02037
12	10	30	200	26	35.15218	200	26	35.1361
13	150	400	2,834	359	43.1613	2,836	359	42.30986
14	500	400	4775	357	71.08453	4,775	357	20.61097

- There were **no major changes in recommended battery sizes** between scenarios.
- The reason **why there is no change in bill saving is the equal determination of the purchase and sale price**.
- The generation of profile 14, which has more generation capacity than its consumption, would be wasted if there was no sale to the grid. So in the scenario **where there is no electricity sales to the grid, the battery has a big impact on bill saving**.

Key Findings - 1

The recommended battery energy capacity for consumers is **5%** of the total consumption.

The recommended battery energy capacity for producers is **4%** for LPA, **17%** for PPA, and **12%** for EMP of total generation.

Battery energy capacity for prosumer is affected by both generation and consumption.

Key Findings - 2

For prosumers, the inclusion of the battery in the system ensures 100% self-consumption as long as the mains electricity purchase price is not high.

Battery power capacities are generally affected by the agreement power limits with the grid. At this point, both the producer and the consumer must make an agreement with the grid by correctly estimating their electricity purchase-sale potential.

Self-sufficiency with battery may be negative for prosumers. The reason for this is the battery charge-discharge efficiency.

It is possible to establish self-sufficient systems with an optimal generation level. Here the sizing problem of the energy source is important.

Future Works

Microgrids

Wind tests

Self-sufficient parking & charge stations

Thank You !

Any Question?