Homework 4 Submission – CBE 9413 Intro to Sustainable Energy Systems

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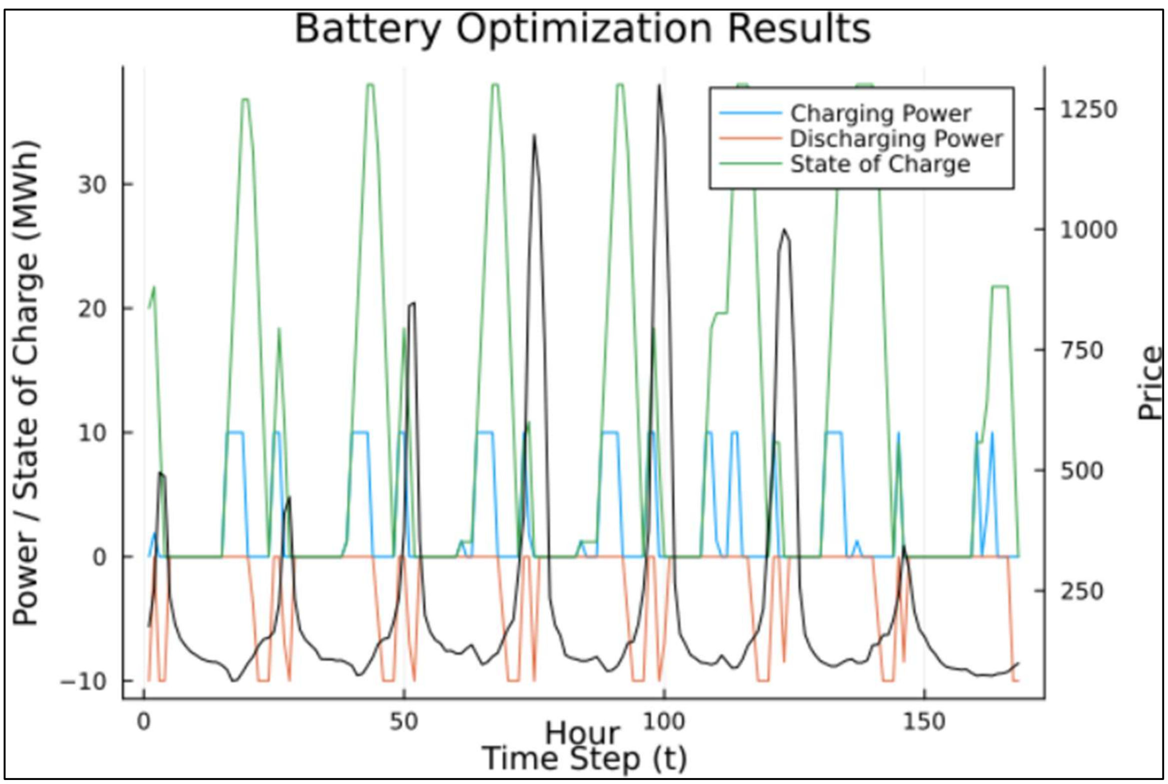
Date of Submission: 10/22/2025

Disclaimer: Copilot and GPT4 were used to develop pseudo-code. I have discussed HW problems with Harsh Gandhi and Anu Deshmukh.

Problem 1 (Please refer to the Julia code for the mathematical formulation of the problem)

Part (a) solution – No Foresight

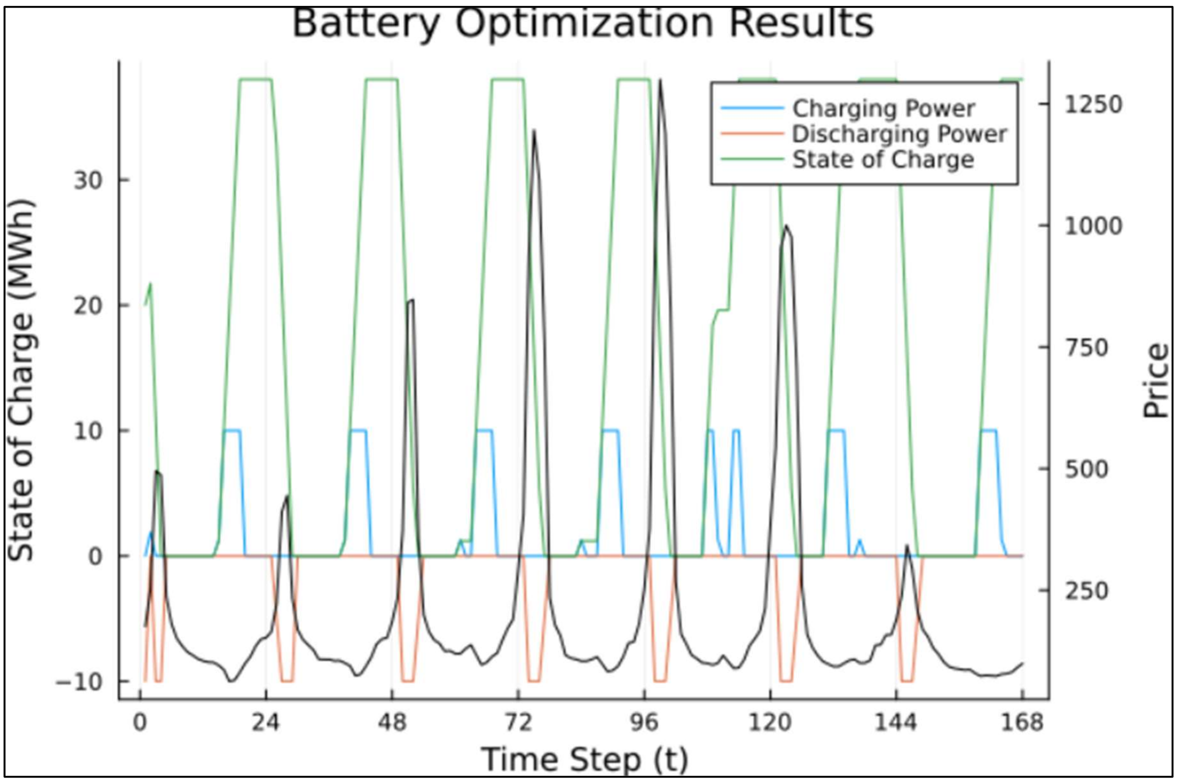
1. Total profit made with no foresight optimization is **~$ 56,000.**
2. The following graph shows profit maximizing operation of battery in this case.
3. Battery responds to price signals for the current day only.
   3.1. It discharges during end of day peak prices and disregards opportunity cost of discharge at a later day (day 4 and 5) with higher prices.
   3.2. It also charges at relatively higher prices towards end of day and disregards opportunity cost of charging at a later day with lower prices.



Part (b) solution – Rolling Horizon with 4 day lookahead

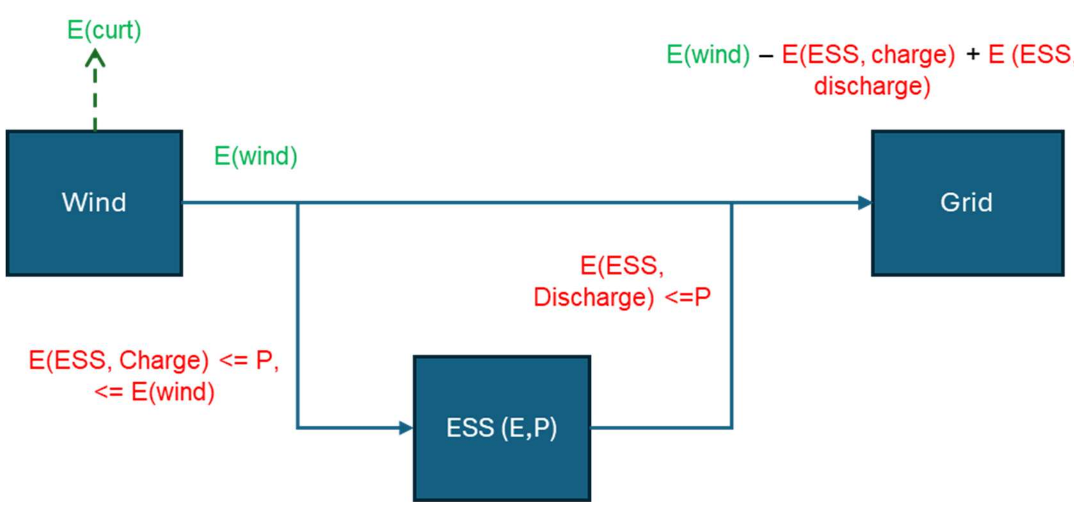
1. Total profit made with rolling horizon optimization is **~$ 136,000** (2.4x of earlier case).
2. The following graph shows profit maximizing operation of battery in this case.
3. Battery responds to price signals considering higher opportunity cost of discharging at

    3.1. It discharges during end of day peak prices and considers opportunity cost of discharge at a later day (day 4 and 5) with higher prices.
    3.2. It charges during low prices in later days rather than charging at end of day prices which tend to be higher.
4. Therefore, higher operating profits can be made with Battery when considering rolling horizon.
5. The economics would improve as the time horizon increases but may also be hampered by higher uncertainties in price forecast for longer time horizon.



Problem 2

The energy balance of system we are trying to optimize looks as follows:



We will ignore curtailment and assume that grid can sufficiently take all of wind power generated by wind turbine at any time t.

Part (a) Solution

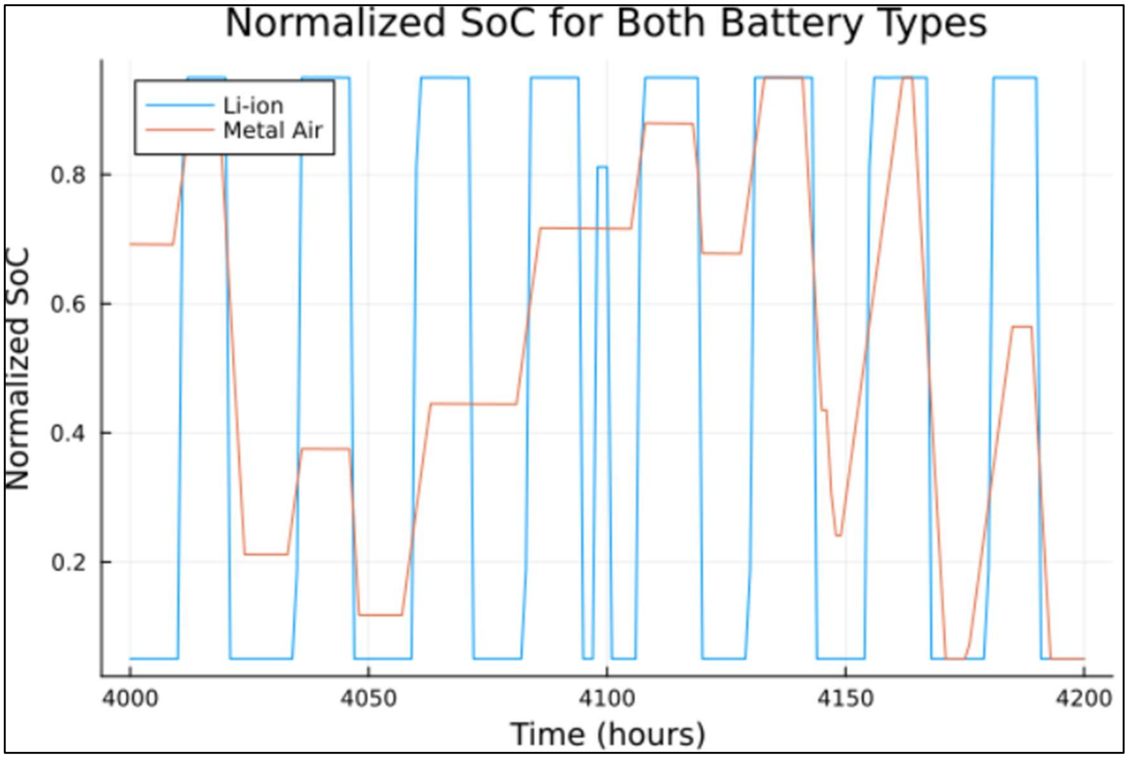
SN	Particulars	UoM	Li-ion Battery	Metal Air Battery
1	Baseline profit from wind power	Mn $	18.25	
2	Optimized profit with ESS	Mn $	18.04 (-1.2%)	17.73 (-2.8%)
3	Optimized profit with ESS excl. capex (% over baseline)	Mn $	18.72 (+2.6%)	19.17 (+5%)
4	Storage Capacity	MWh	12	132
5	Power Capacity	MW	10	10
6	Storage duration	hours	~1.2	~13

Findings and key takeaways:

1. Optimized profit in both cases suggests that ESS integrated system is worse off than the baseline.
2. The power capacity chosen corresponds to minimum bound given to the problem.
3. If we exclude the annualized capex of ESS, the profits are marginally better than the baseline.
4. This suggests that capex of ESS (both power and energy capacity far outweighs any profits accrued from shifting dispatch time through batteries.
5. Metal Air Battery (42%) has nearly half the roundtrip efficiency as compared to Li-ion battery (84%).
   5.1. For same storage duration and power capacity, system would choose Li-ion battery over Metal Air Battery.
6. For the same power capacity, Metal Air Battery has a higher storage duration than Li-ion battery in this optimization which makes it a better choice for storing larger quantities of energy.

Part (b) Solution

1. Li-ion battery completes **210 cycles**, whereas Metal Air battery completes **88 cycles**.
2. Here is a zoomed in version of Normalized SoC for both battery technologies.
3. Metal Air battery is capable of higher storage duration, which makes it cycle less while delivering same dispatch performance as Li-ion battery.
4. This can partly offset the lower roundtrip efficiency of Metal Air battery over Li-ion battery.



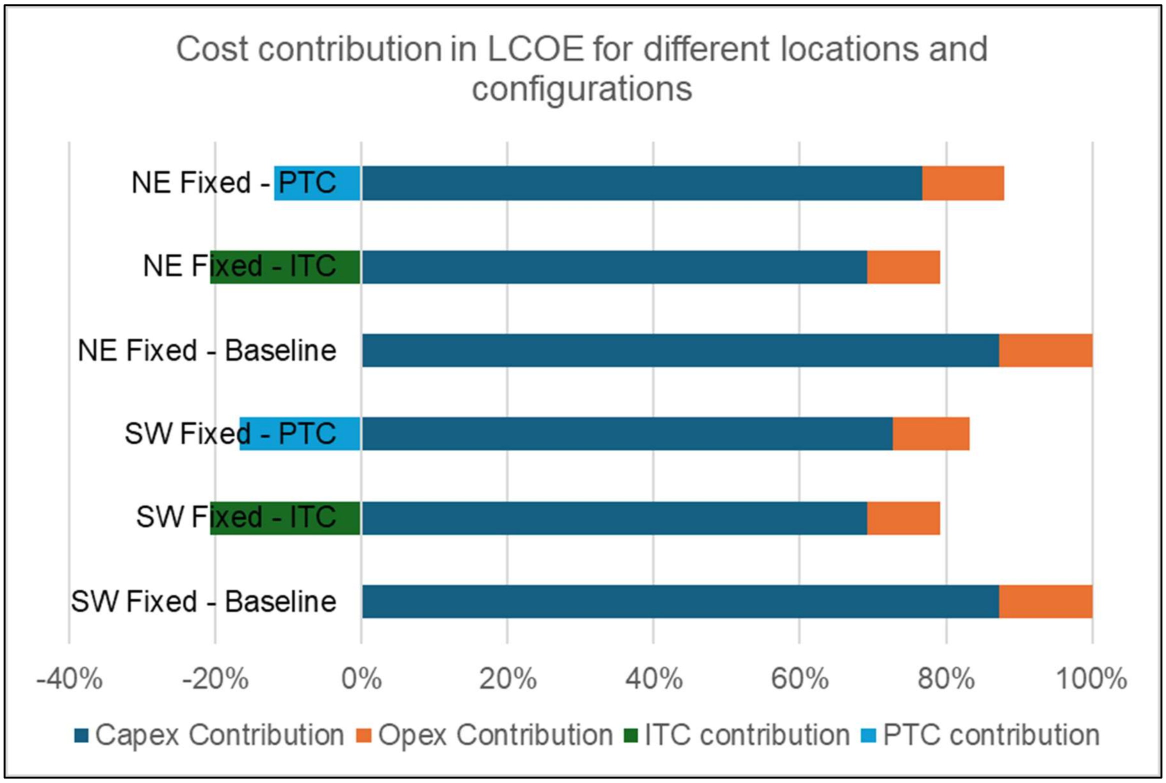
Problem 3

Part (a) – Impact of ITC or PTC

SN	Location	LCOE ($/MWh)		
		No PTC or ITC	With ITC = 30% of capex	With PTC = 25 $/MWh
1	Fixed-Tilt SW	56.2	41.5	45.0
2	Single axis tracking SW	58.5	43.2	47.2
3	Fixed-Tilt NE	82.7	61.0	71.4
4	Single axis tracking NE	84.8	62.6	73.6

Part (b) – Findings and key takeaways:

1. Capex contributes more than 80% of LCOE for Solar PV), rest is operating cost.
2. Although single axis tracking systems have higher CF (16% higher than fixed tilt), their per unit capex is even higher (20% higher than fixed tilt).
   2.1. Therefore, LCOE turns out to be slightly higher for single axis tracking systems and tracking does not bring cost advantage, albeit higher power production.
3. ITC assumes 30% reduction in capex, implying ~24% reduction in LCOE.
4. On the other hand, PTC of 25 $/MWh for 10 years reduces LCOE by ~10% - 20%.
   4.1. The reduction is higher for SW region with higher solar CF.
5. Therefore, ITC of 30% will give lower LCOE in each location.



Part (c) – Sensitivity to PTC

SN	Location	LCOE ($/MWh)		
		With PTC = 25 $/MWh	With PTC = 40 $/MWh	With ITC = 30% of capex
1	Fixed-Tilt SW	45.0	38.2	41.5
2	Single axis tracking SW	47.2	40.5	43.2
3	Fixed-Tilt NE	71.4	64.6	61.0
4	Single axis tracking NE	73.6	66.8	62.6

1. When PTC is increased to 40 $/MWh, cost reduction is ~30% in case of SW region. This has higher impact than 30% ITC, which reduces LCOE by only 24%.
2. At 40 $/MWh for 10 years, PTC is better than 30% ITC for SW region.