Electricity Storage and It's Economic Potential in Deregulated Markets

- An analysis from a trading perspective

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Outline

- Electricity market, energy storage and trading

- Potential profit of arbitraging the electricity market

- Demonstration of the trading strategies

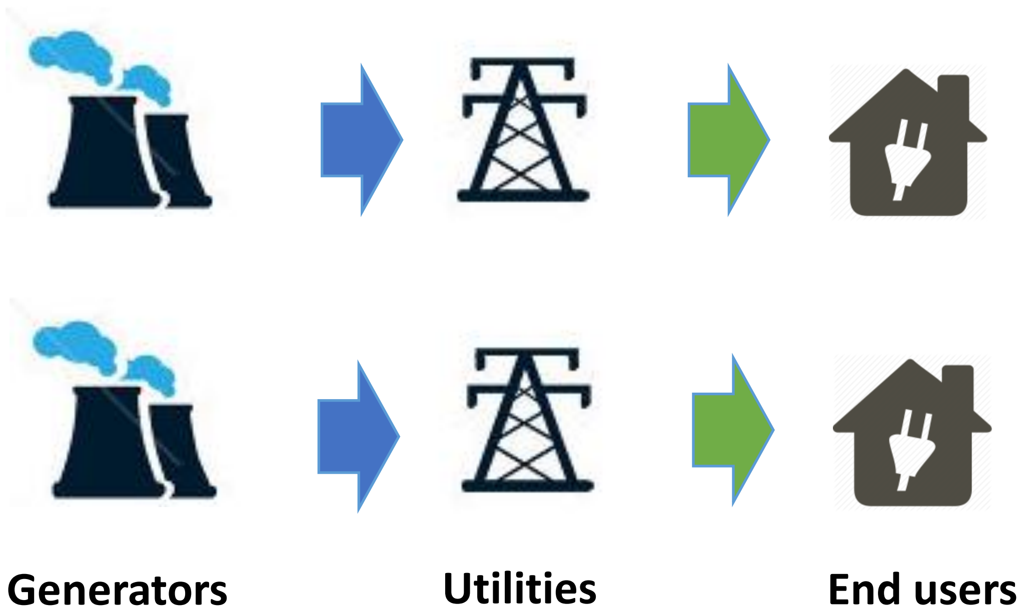
Part 1: An overview

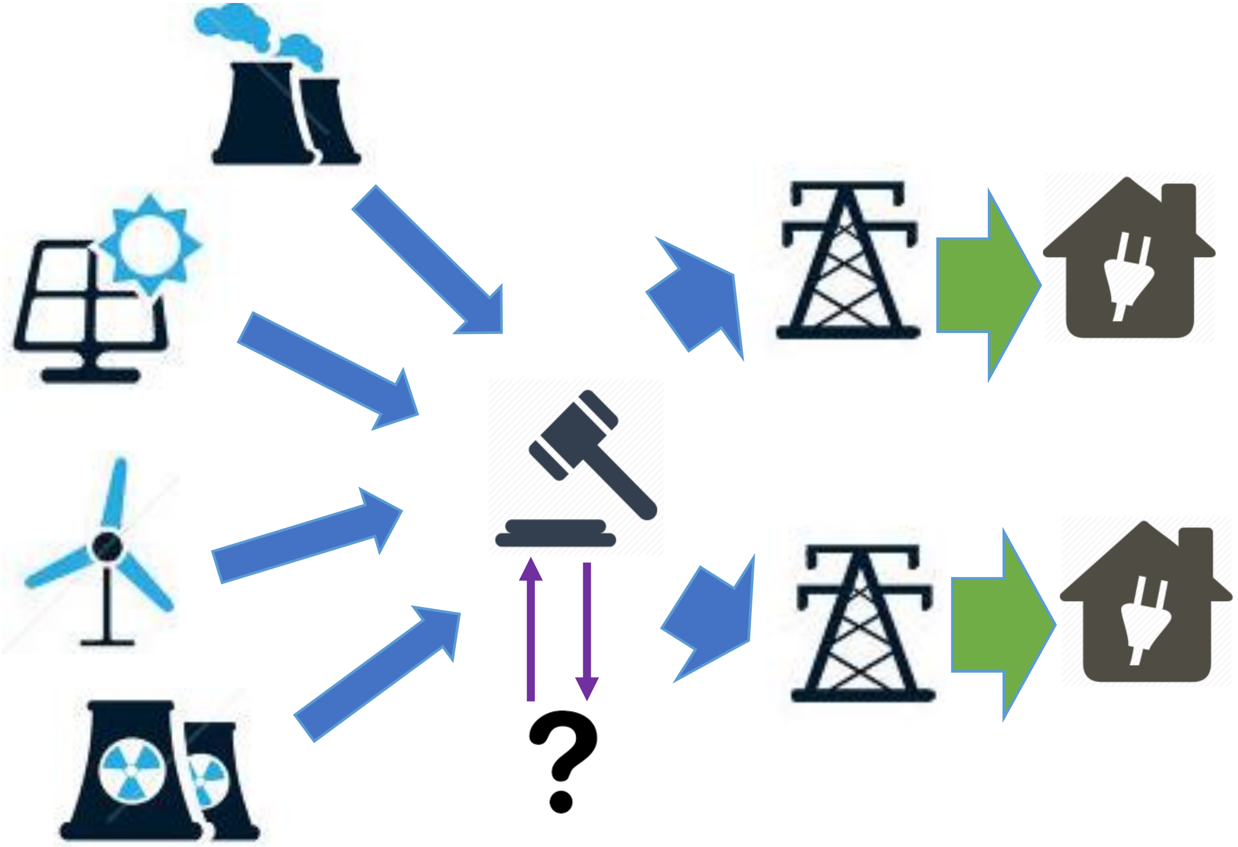
- **Electricity market, energy storage and trading**
  - **Deregulated electricity market**
  - **Trading opportunities for private investors**
  - **Flow battery as a new energy storage**

- Potential profit of arbitraging the electricity market

- Demonstration of trading strategies.

Regulated and Deregulated Electricity Market

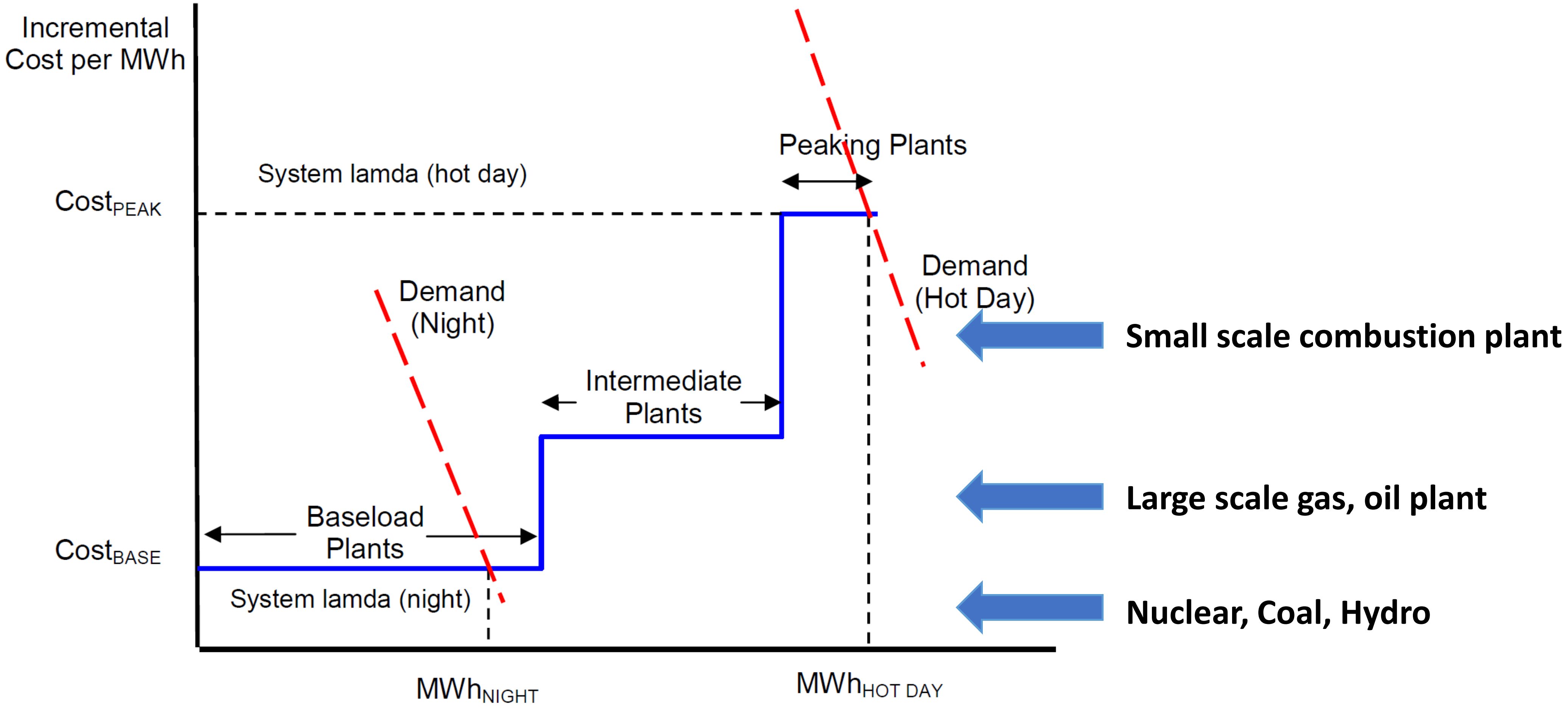




- Traditional regulated market
- Fixed wholesale and retail price

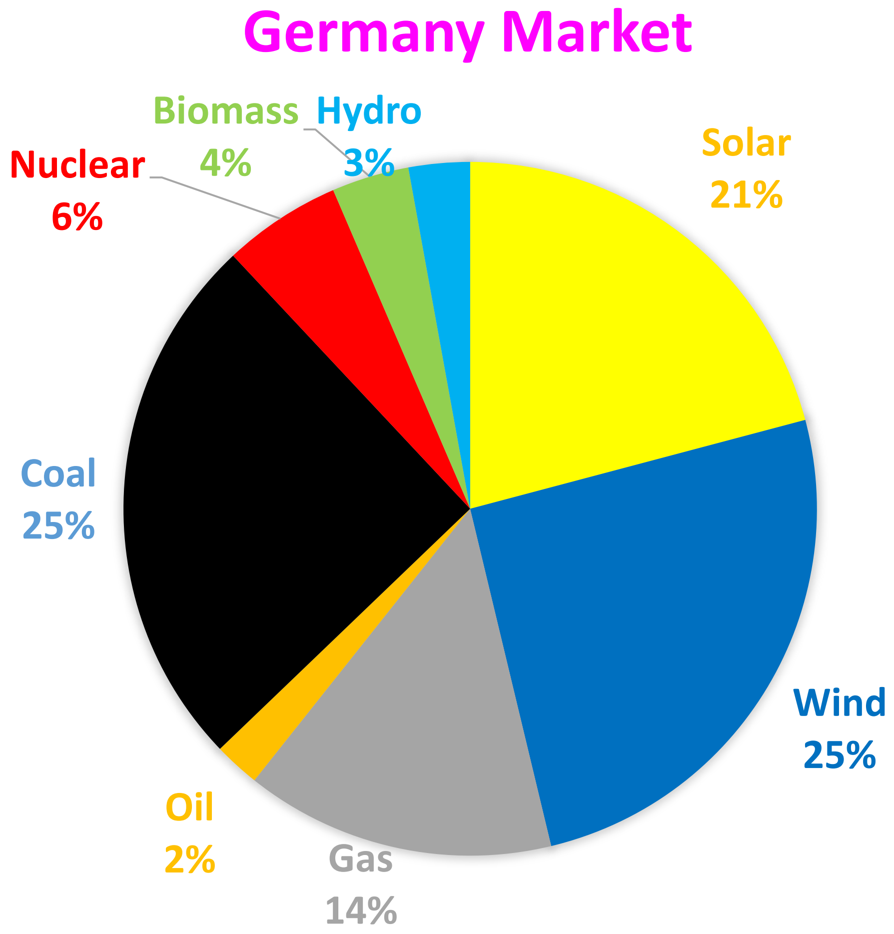
- Deregulated market
- Bidding to set whole sale price

Electricity bidding mechanism

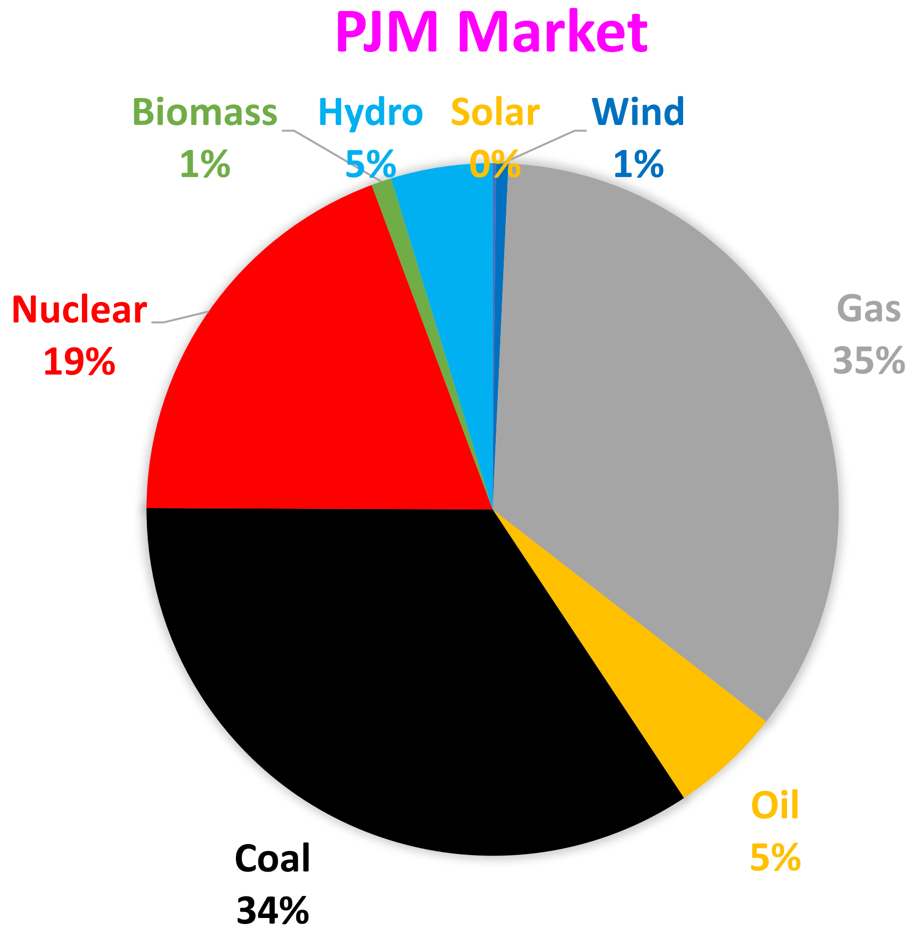


- Marginal price paid for all electricity
- Lower bidding price encouraged, but volatility gets higher

Compare Germany and PJM electricity source



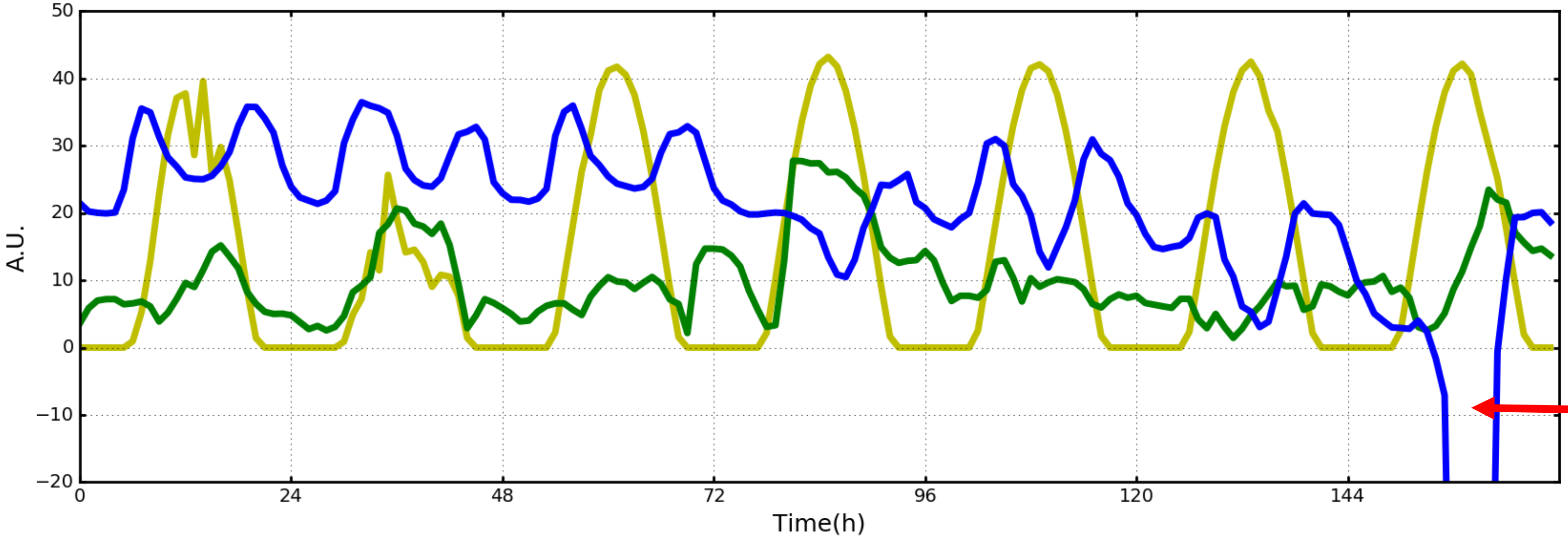
46% unstable source (solar & wind)



Almost no unstable source

Summer electricity price curve

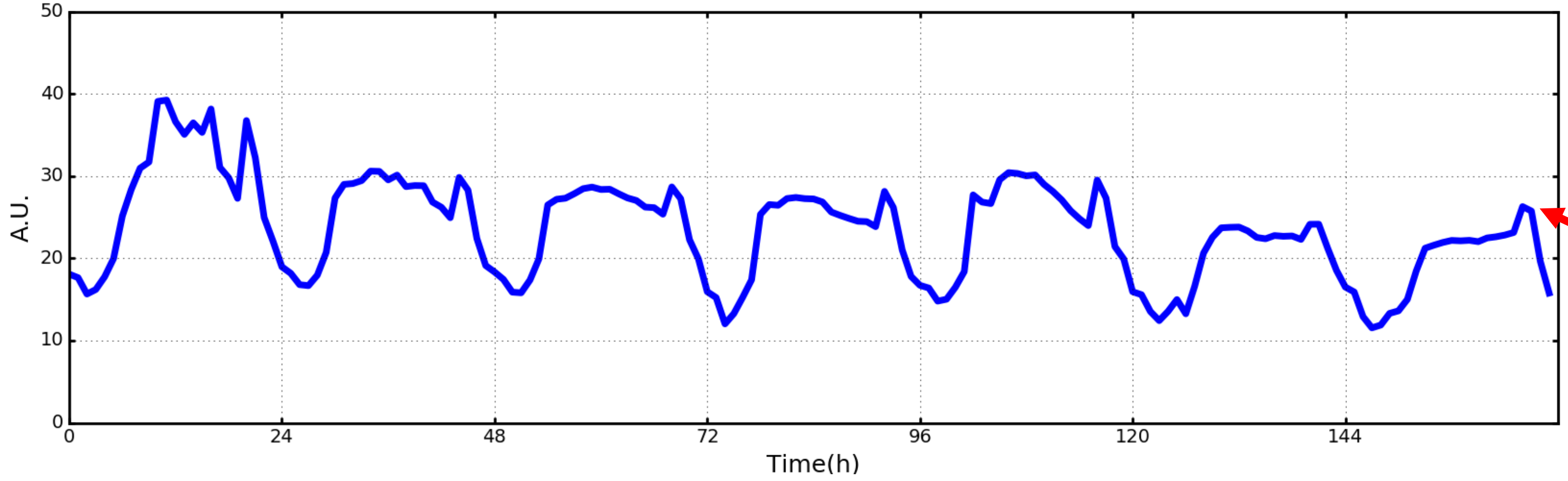
Germany



Price valley at noon due to solar input

Negative price occasionally

PJM

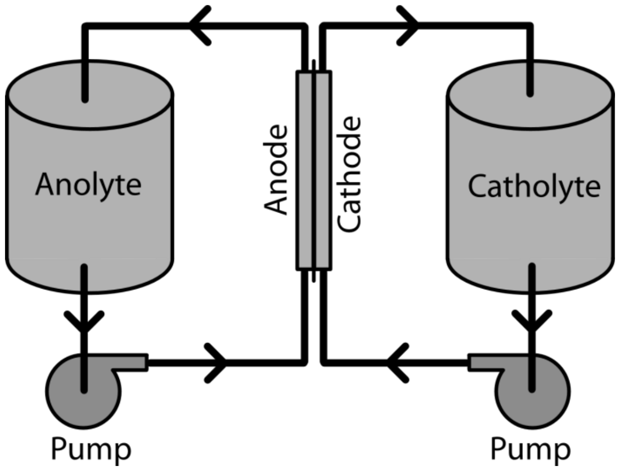


No valley at noon.

Spikes at 7pm due to household usage

Can we store the electricity to arbitrage and reduce the volatility?

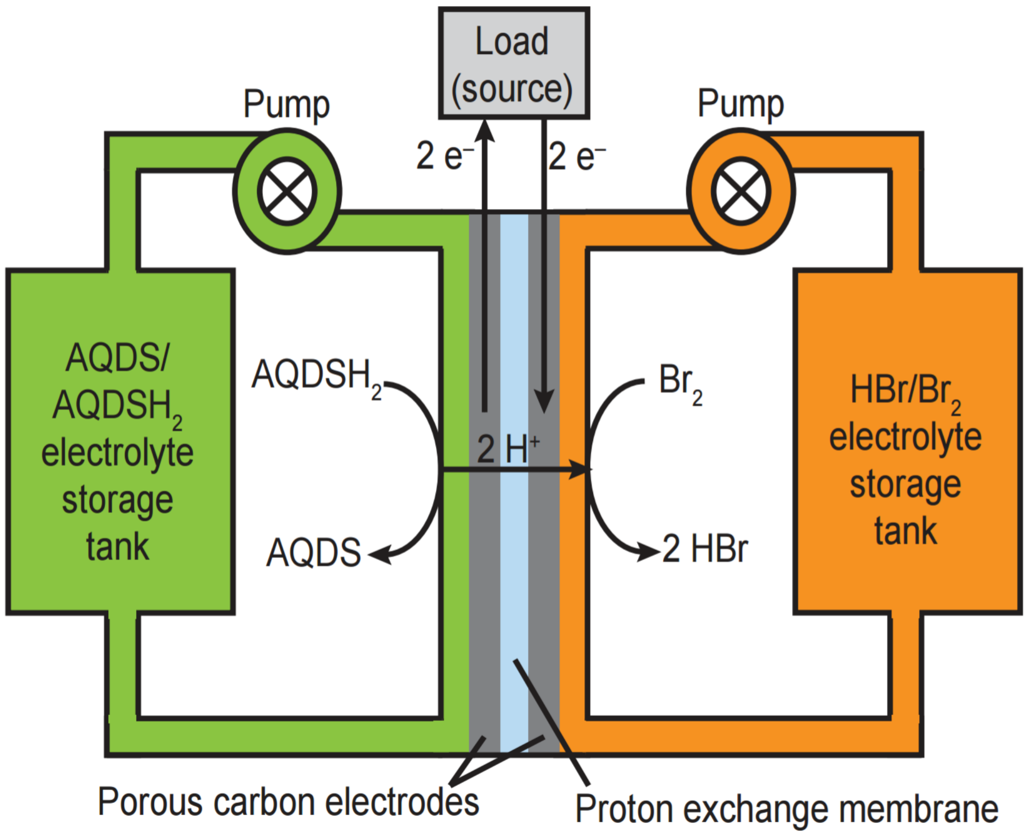
Energy storage technologies



	Pump Hydro	Li ion battery	Flywheel	Flow battery
Pros	Large capacity, low cost	Easy setup	Fast charging	Low cost
Cons	Restricted location	Expensive	Expensive	Occupy large volume
Cost $/kWh	30-50	350	~1,200	~80 (traditional)

Flow battery may be a good choice of arbitraging electricity market

Organic flow battery



By replacing Vanadium with organic compound
Cost reduced to $27/kWh

Summary

- Electricity price is volatile in a deregulated market
  - Price fluctuates with daily with periodic pattern
- Unstable generators (solar and wind) may significantly change the price pattern of a day.
- Flow battery may be a good choice for arbitraging the electricity price.

Part 2: Profit limit

- Electricity market, energy storage and trading

- Potential profit of arbitraging the electricity market
  - Optimized profit with linear optimization model
  - Storage parameter design: efficiency and capacity
  - Economic comparison between Li battery and flow battery

- Demonstration of trading strategies.

Optimized profit: buy low and sell high

- Assumptions:
  - Full knowledge of future price curve
  - Instant turn on and off
  - Uniform charge and discharge

- Approach:
  - Linear optimization algorithm: iterate until highest profit is achieved
  - Setting boundary conditions: starting with empty storage, charging and discharging speed limited by the power.

Boundary conditions

$$\text{total profit} = \sum_{t=1}^{T} P_t(D_t - C_t); \qquad (1)$$

$$S_t = S_{t-1} + D_t + \omega * C_t \qquad (2)$$

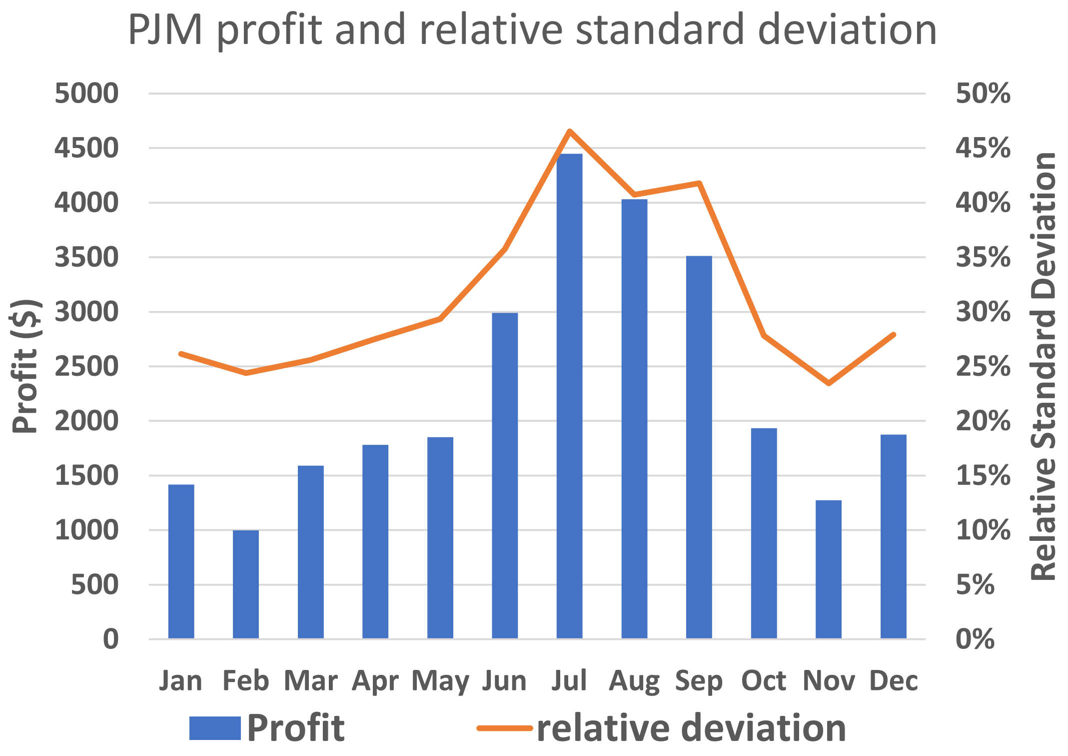
$$S_t \in [0, h * k] \qquad (3)$$

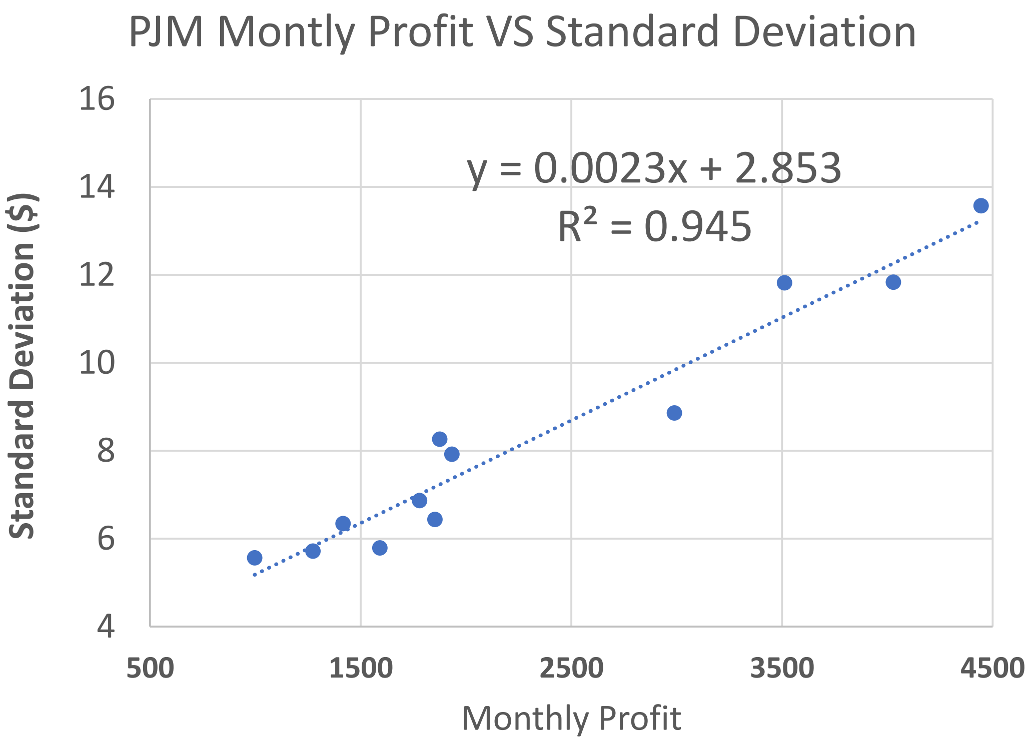
$$D_t\ , C_t\ \in [0, k] \qquad (4)$$

Maximize total profit with Linear Optimization function in Scipy

Example: a 1MW storage profitability in PJM

7MWh storage capacity, 1 MW power, 80% round trip efficiency





- 2016 Total profit: $27,700
- Profit increases with standard deviation linearly

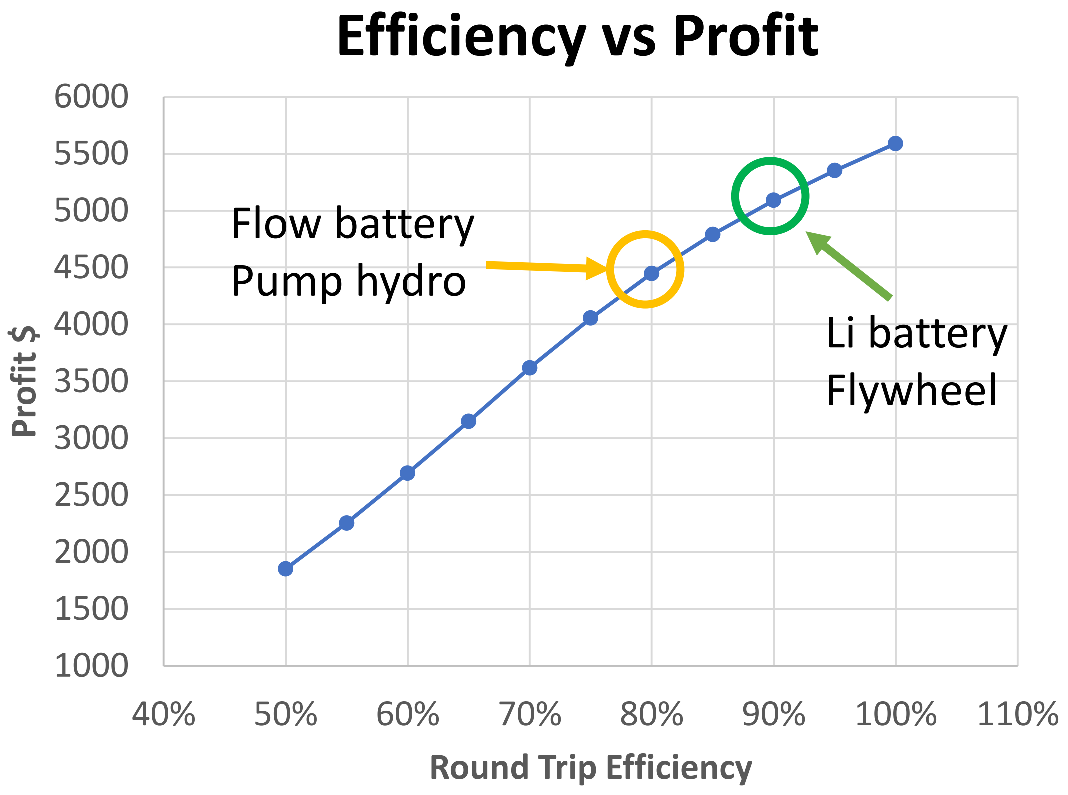
Design of a storage device

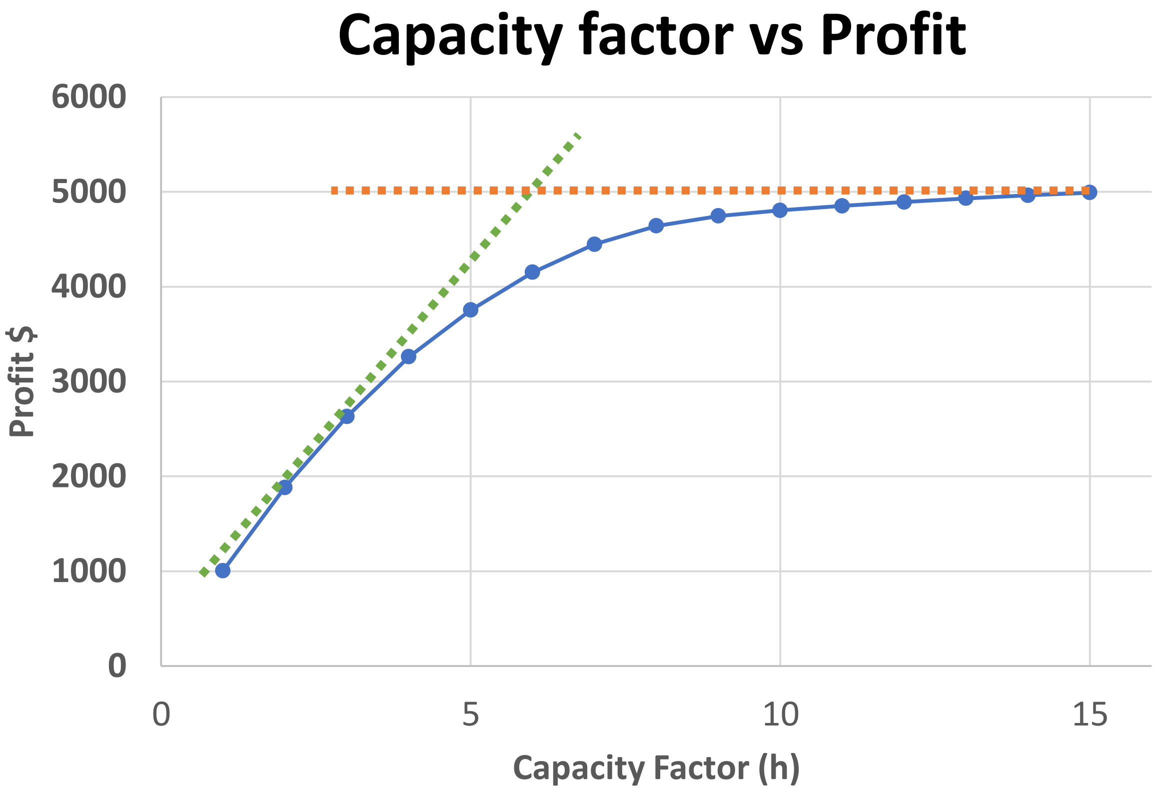
- Two major components of a storage device:
  - Power component (inverter, converter, transformer). Cost ∝ power (MW)
  - Capacity component (battery, chemical tank, reservoir, etc). Cost ∝ capacity (MWh)

- Use one parameter to depict both power and capacity: **capacity factor**
  - Capacity factor(h)= Capacity(discharge) / Power
  - Depict how many hours does it take to deplete a storage device

Assume 1MW power, use capacity factor and efficiency as variables

Capacity Factor and Efficiency





Assuming 1MW power

- **Profit increase with efficiency linearly but render much higher cost**
- **Marginal benefit of increasing capacity factor decreases beyond 5h**

Estimating payback periods of flow battery(FB) and Li battery(LB)

- Capacity cost: $27,000/MWh (**FB**), $350,000/MWh (**LB**)
- Power components cost roughly $200,000/MW for both system.
- Annual profit: ~$25,000(FB), ~28,500(LB)

	Capacity cost (5MWh)	Power cost (1MW)	Total cost	Annual profit $	Payback period
Flow battery	135,000	200,000	335,000	25,000	15.4y
Li battery	1,750,000	200,000	1,950,000	28,500	68y

Both coal fire plant and pump hydro have payback period around 20y

Flow battery seems to be economically feasible to arbitrage electricity market

Summary

- A medium size 1MW(5h) storage device can achieve an annual profit of $25,000 in PJM 2016.
- Marginal profit of capacity factor decreases beyond 5h.
- Although 90% storage render higher profit, the higher cost does not work with this business model.
- Payback period indicates flow battery is commercially feasible

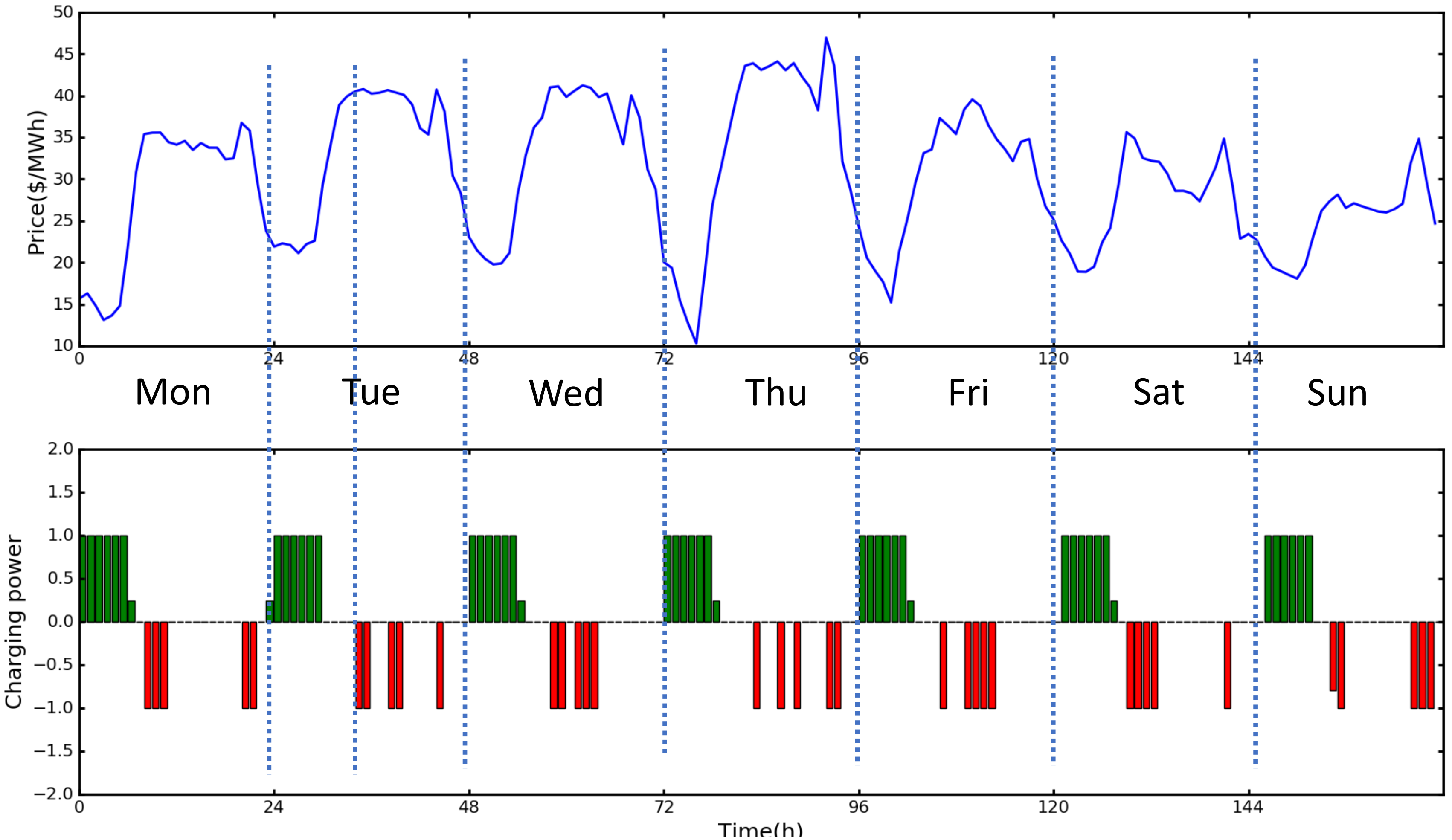
Part 3: on going

- Electricity market, energy storage and trading
- Potential profit of arbitraging the electricity market
- Demonstration of trading strategies.
  - Dumb approach
  - Machine learning approach

Optimized trading strategy: from linear optimization

Price in a week

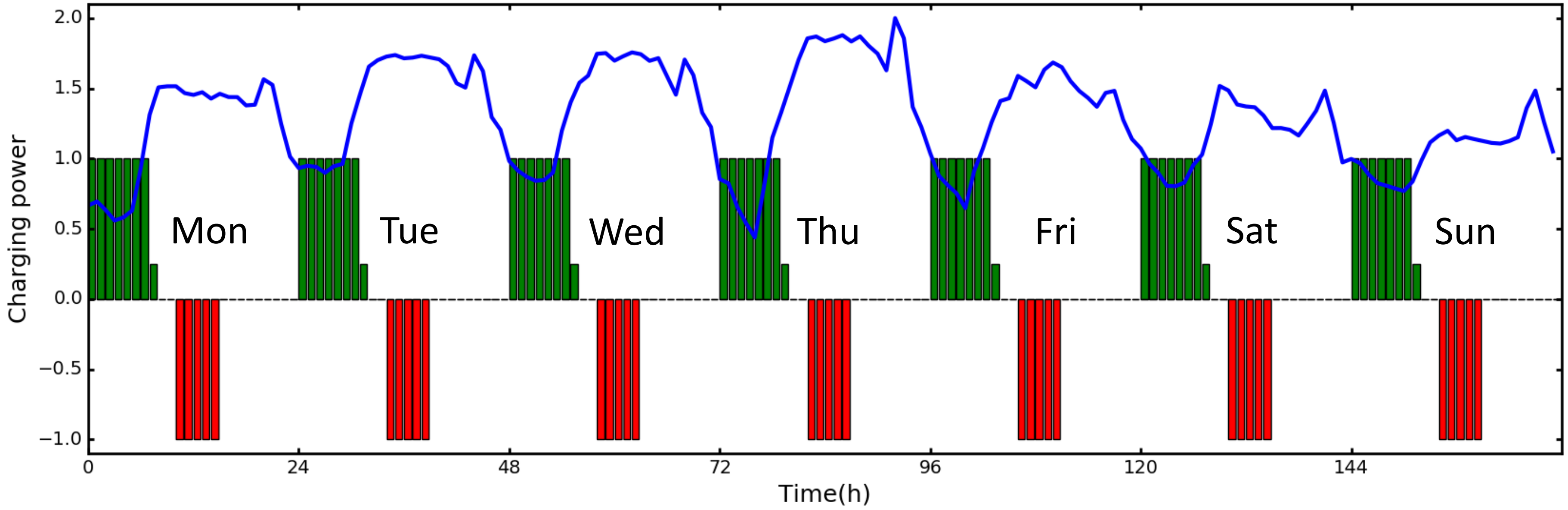
Trading activities in a week



Charging : ~0:00 to 6:00; Discharging: 10:00-14:00 and 19:00-20:00

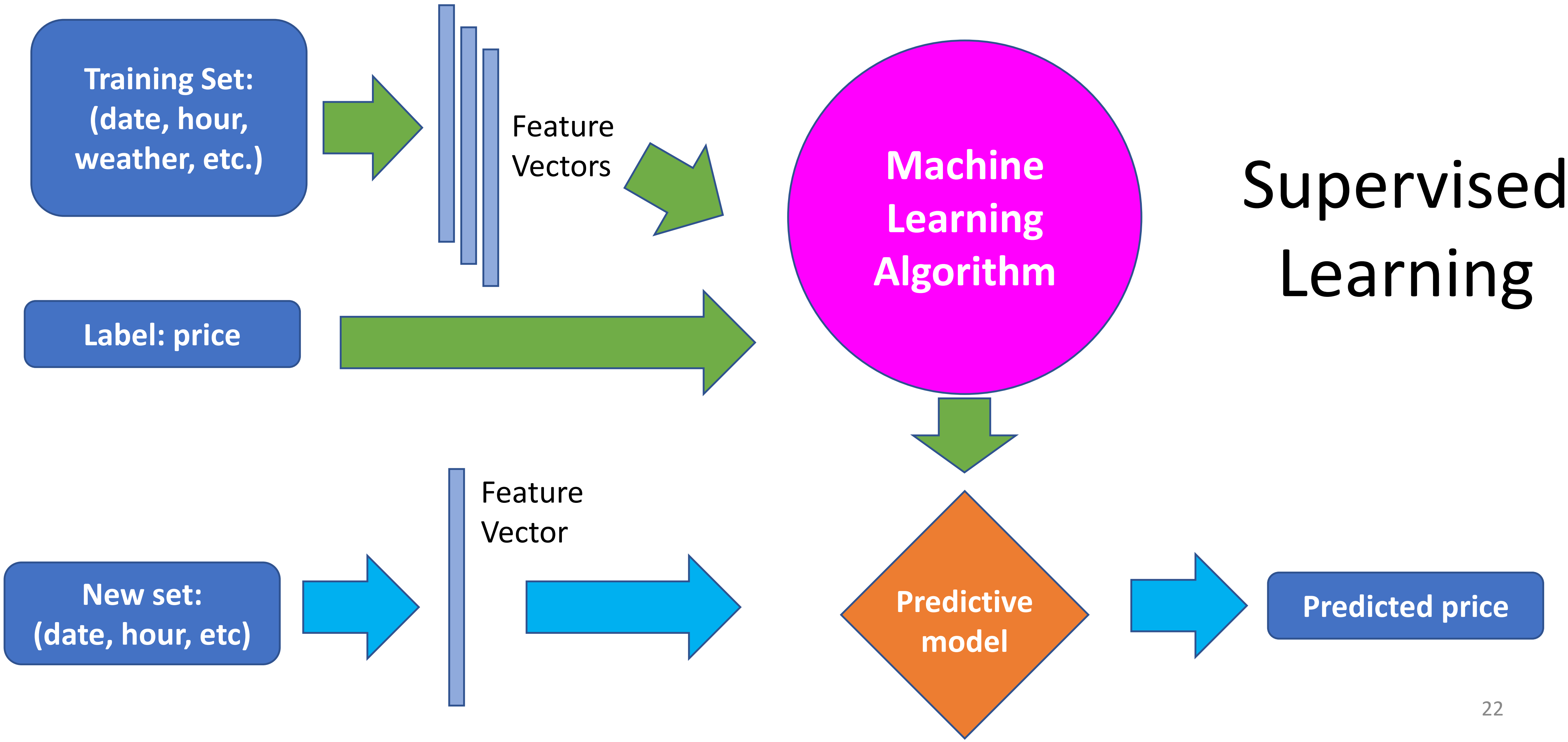
Dumb approach: fixed trading every day

- Charge during night 0:00 to 6:15 (assume 80% efficiency)
- Discharge at noon and evening: 10:00-14:00 and 19:00 to 20:00



Recovers 52% profit compare with optimized strategy

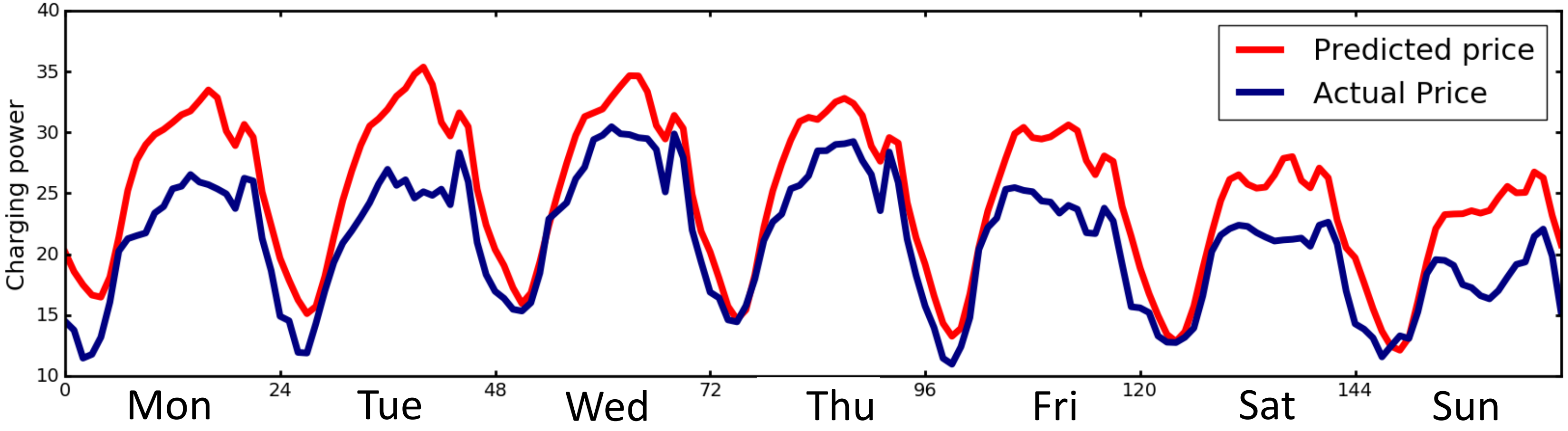
Machine learning approach



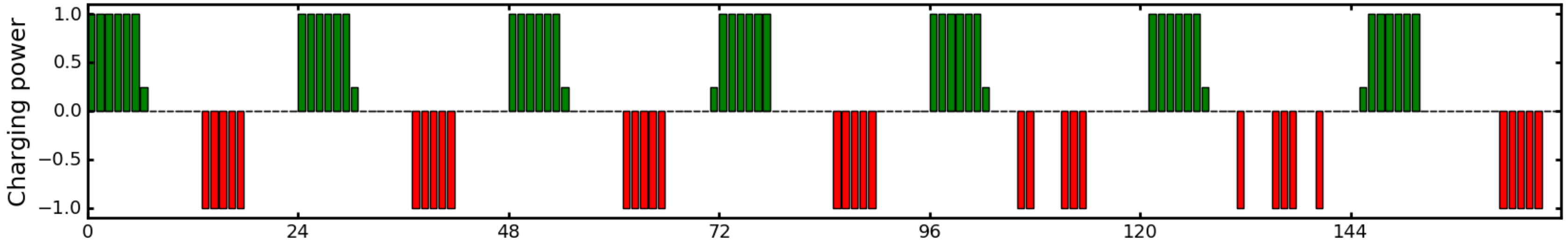
Supervised
Learning

Trading strategy based on machine learning

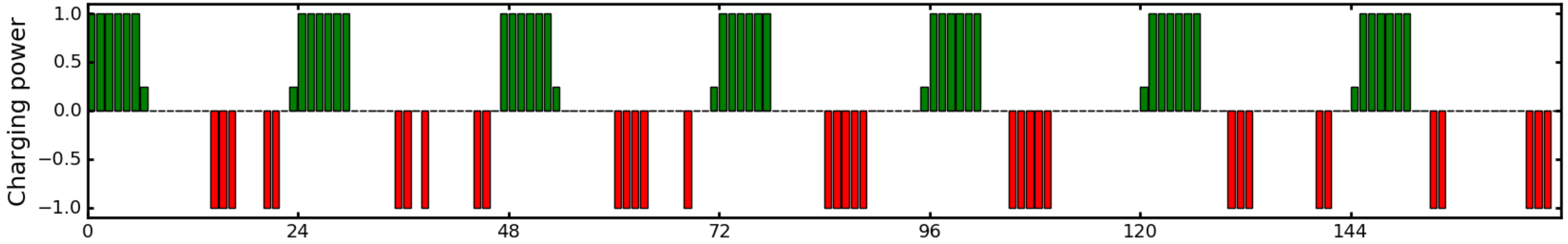
Predicted and actual price



Trading behavior based on predicted price



Trading behavior based on actual price



Recovers 90% profit

Summary

- Simple dumb trading approach cannot effectively recover the profit.

- Machine learning can effectively predict the future electricity price.

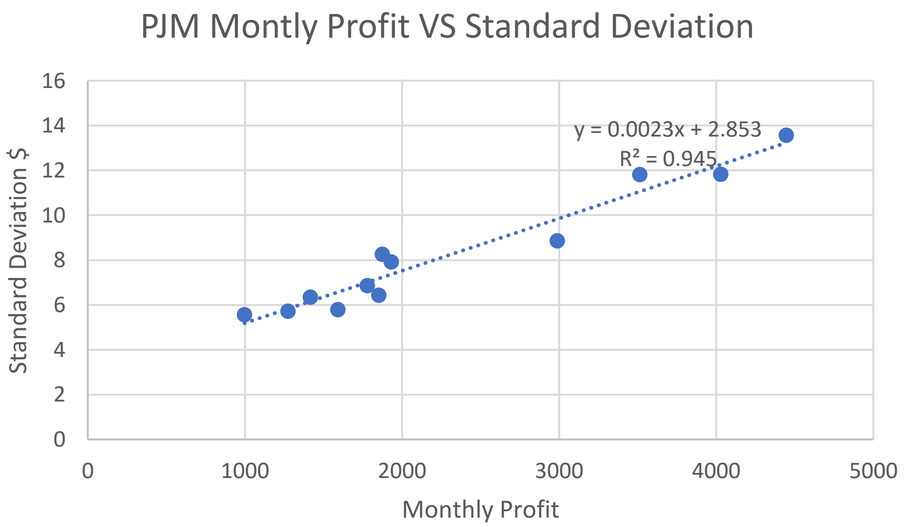
- 90% of theoretical profit can be recovered based on the predicted price.

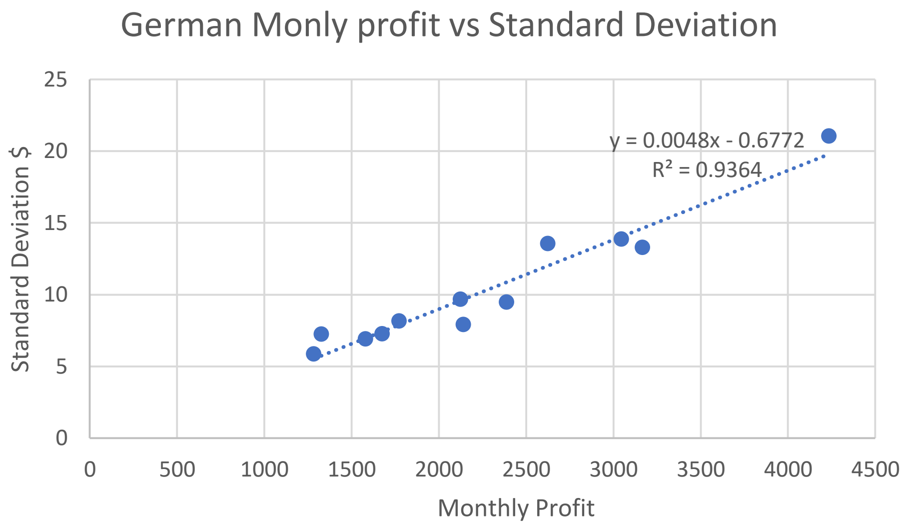
Conclusions

- Electricity price in deregulated market is volatile due to demand and supply fluctuation thus provides an opportunity for arbitrage.
- The profit of a electricity storage device can be evaluated with historical data and optimization algorithm.
- Flow battery is economically the best choice.
- A SVR machine learning trading strategy can effectively recover the theoretical profit.

Thank you very much

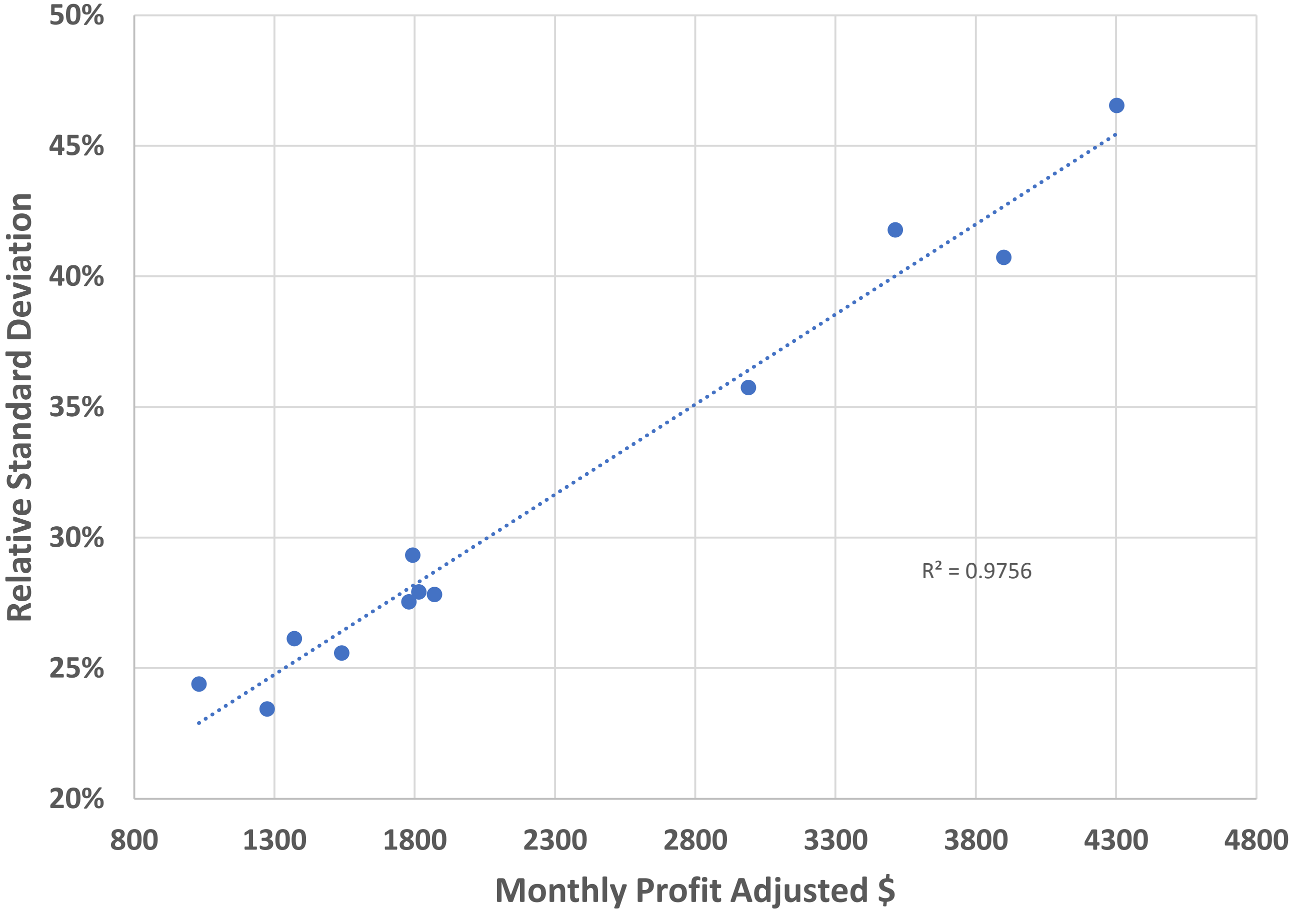
Monthly profit vs standard deviation



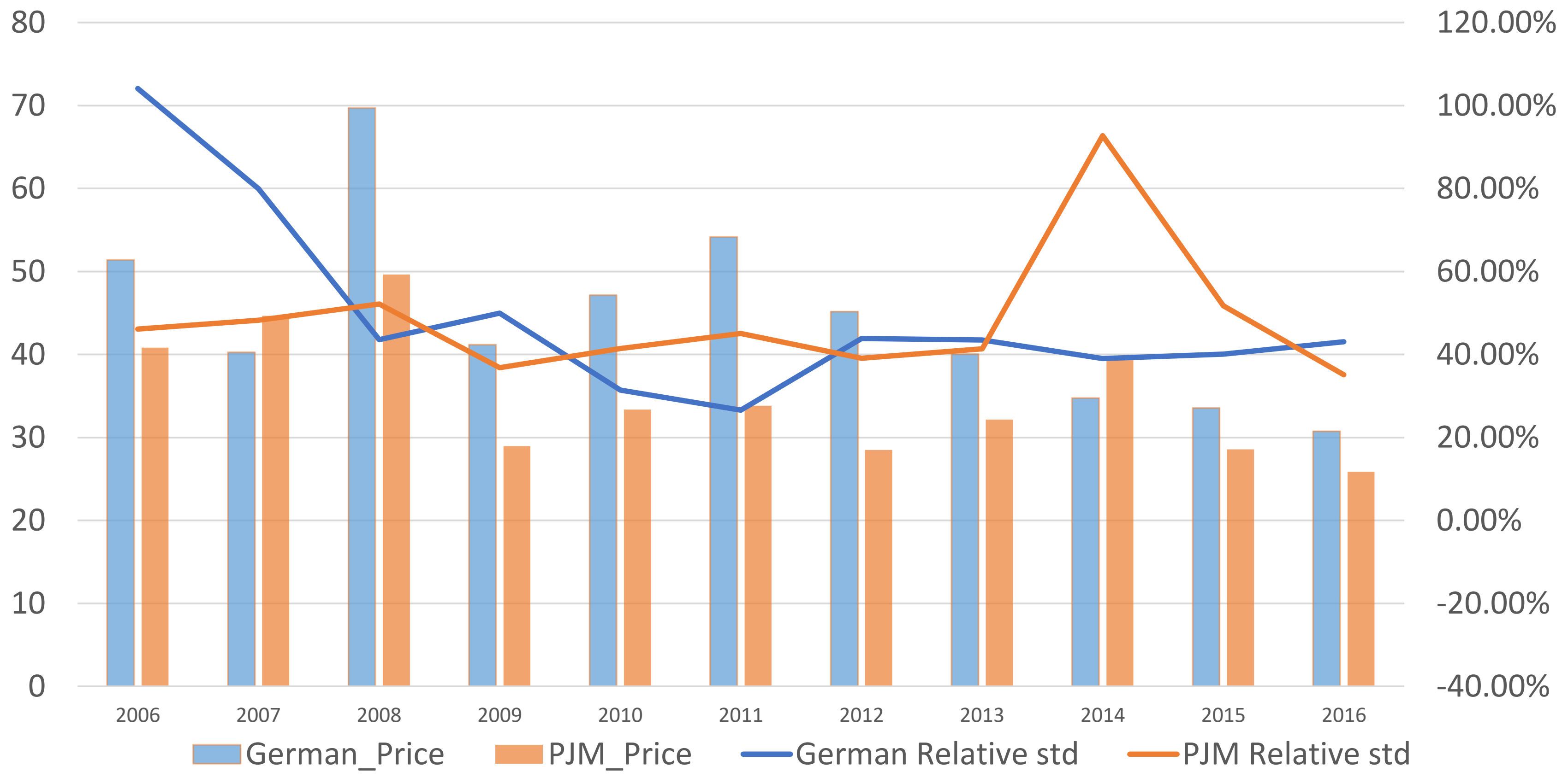


References

- http://www.omnesenergy.com/product/


50%
45%
40%
35%
30%
25%
20%
Relative Standard Deviation
R^2 = 0.9756
800
1300
1800
2300
2800
3300
3800
4300
4800
Monthly Profit Adjusted $

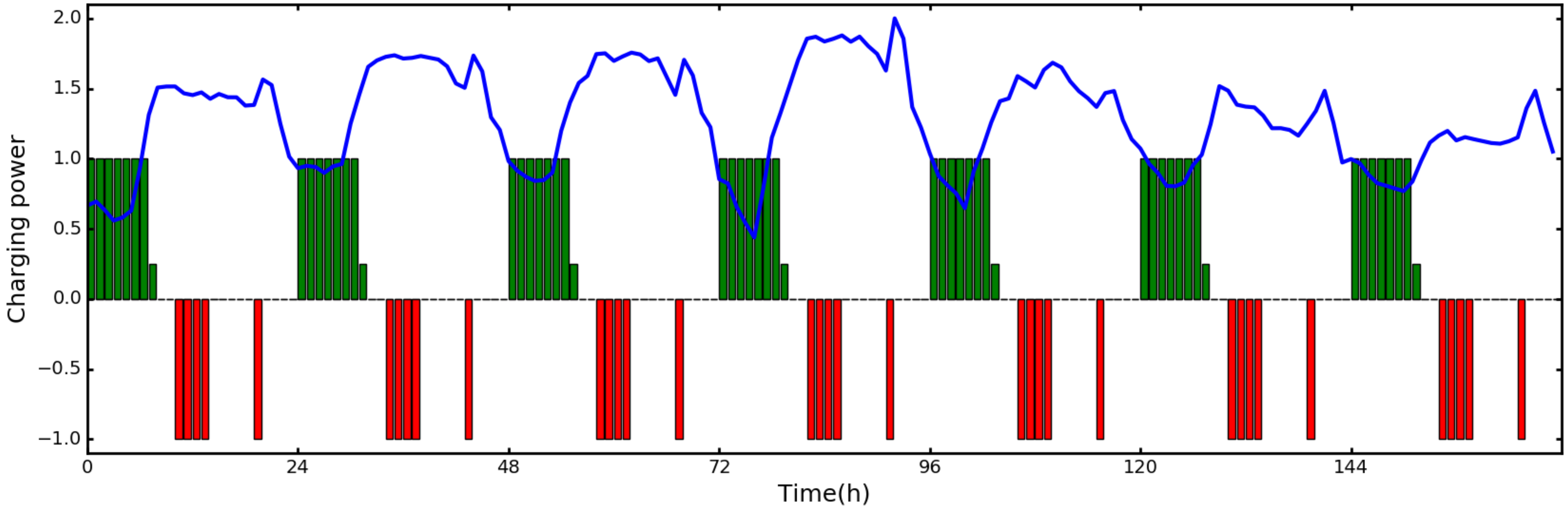
Standard deviation difference over the years

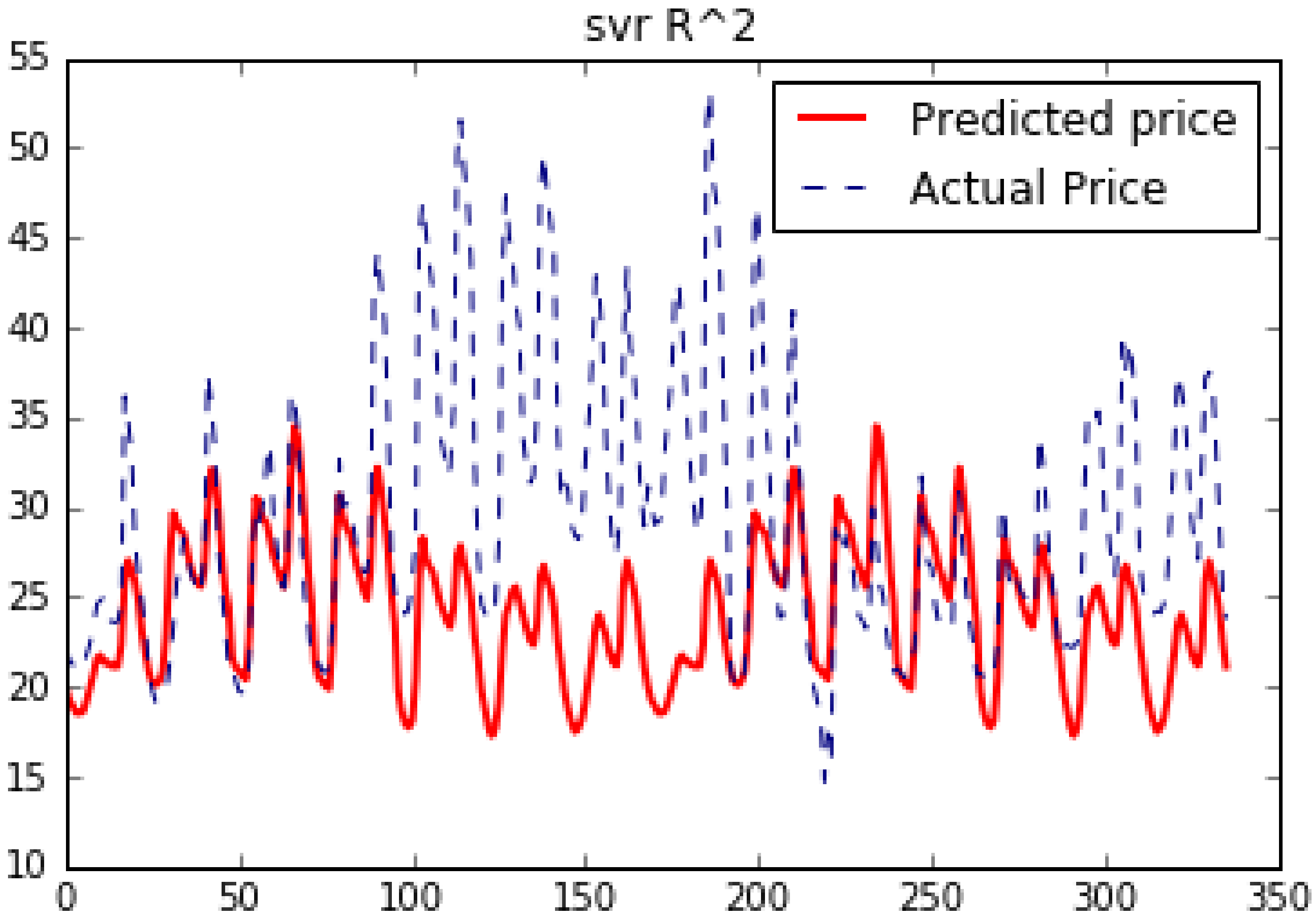


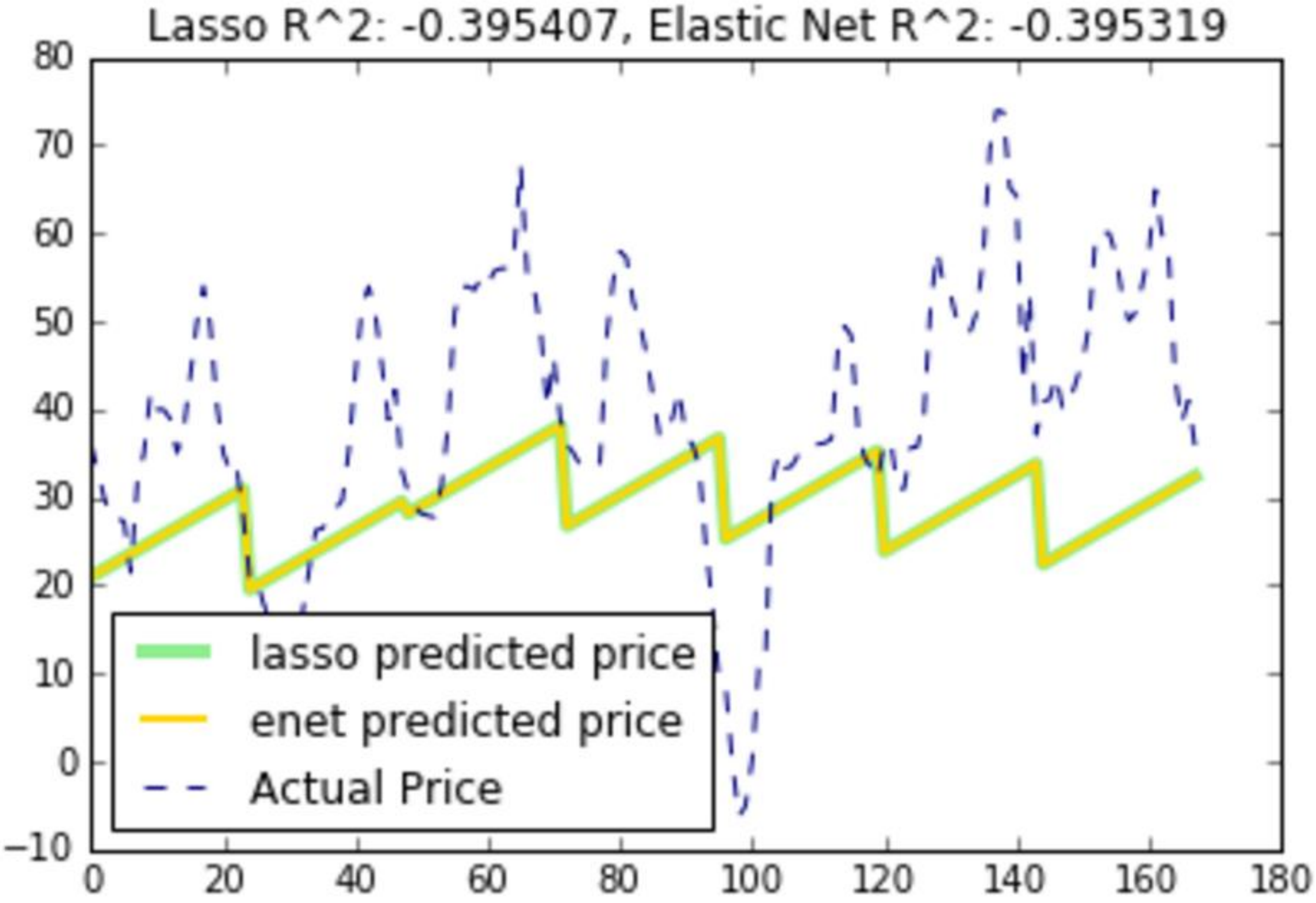
Both markets has about 40% average fluctuation in electricity price

Winter electricity curve

Dumb strategy 2




svr R^2
Predicted price
Actual Price
55
50
45
40
35
30
25
20
15
10
0
50
100
150
200
250
300
350


Lasso R^2: -0.395407, Elastic Net R^2: -0.395319
80
70
60
50
40
30
20
10
0
−10
0
20
40
60
80
100
120
140
160
180
lasso predicted price
enet predicted price
Actual Price