Packetized Energy Management

Connor

Outline

- Problem
- Solution
- Modeling
- Results

Problem

Grid Failure Modes

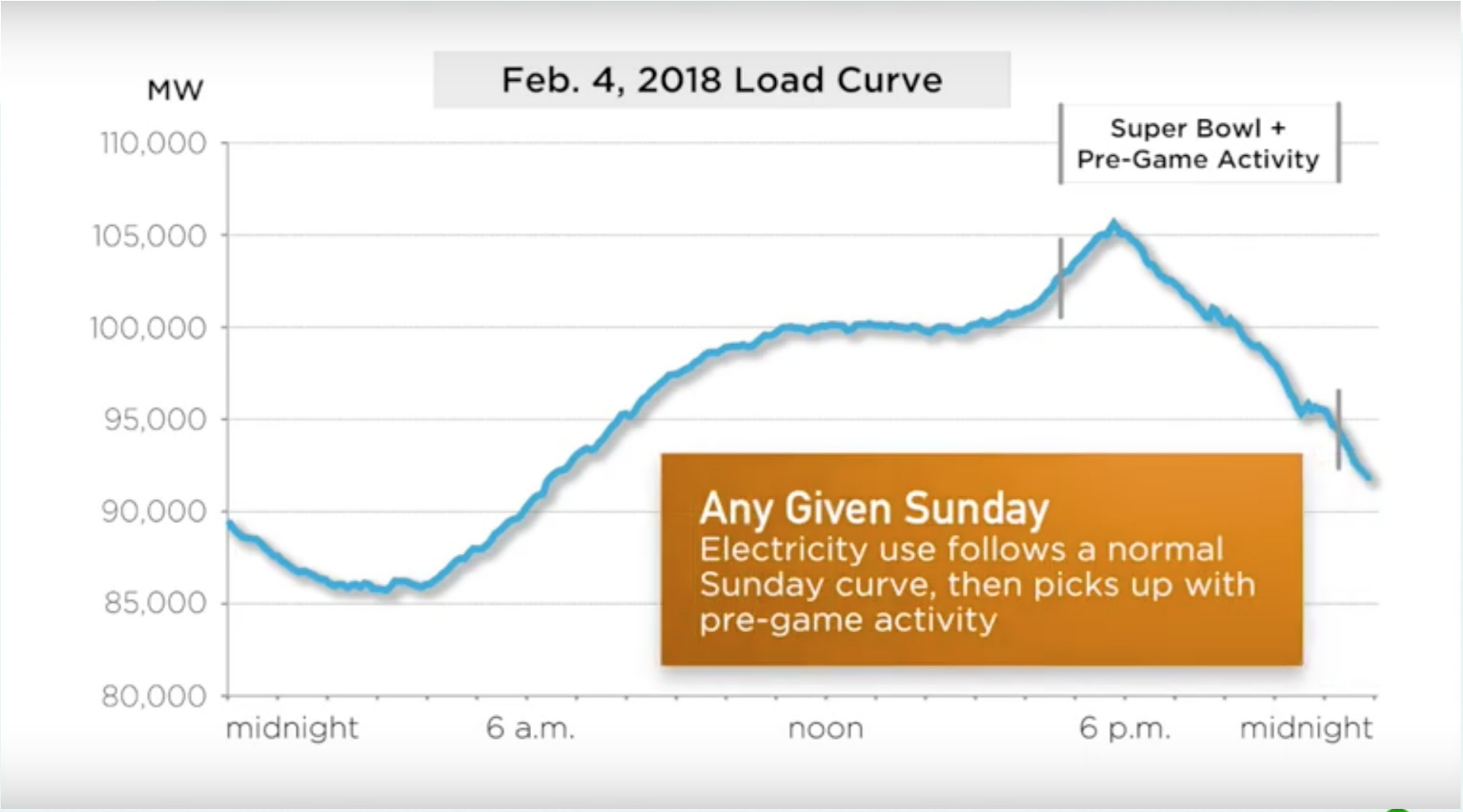
- Extreme oversupply (surge, spike)
- Oversupply
- Undersupply (brownout)
- Extreme Undersupply (blackout)

Each causes different problems/damage

The Brownout Problem

- Unexpectedly, transient, demand spikes
  - Sports game
  - Bad weather
- Expected but rapidly changing demand
  - Morning & evening routines
  - Large events

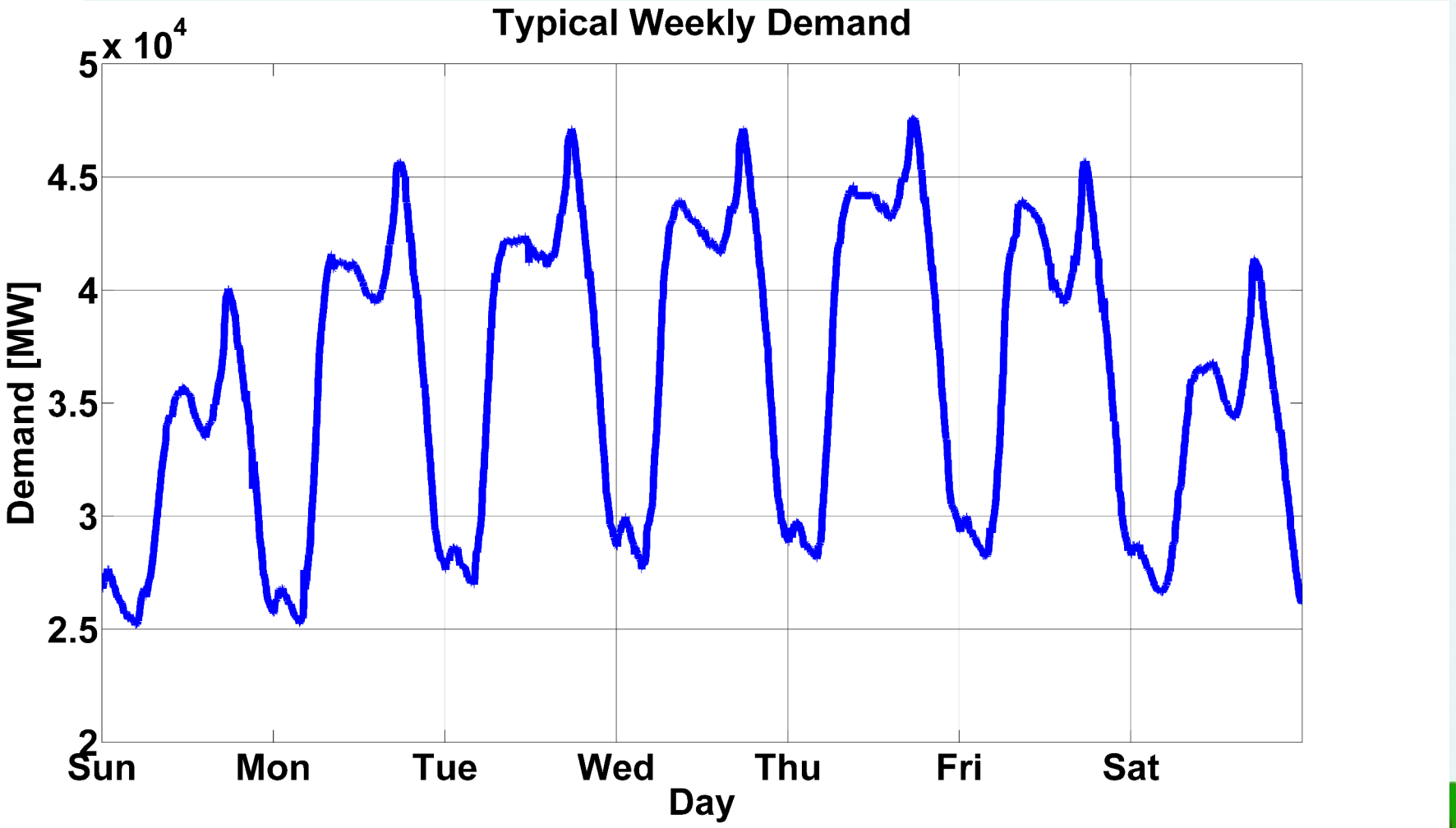
Unexpected Demand



"PJM serves all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia."

https://www.youtube.com/watch?v=nx1Viry2xdM

Rapidly Changing Demand



2011 Grid Data for all of Great Britain provided by the University of Glasgow.

A Solution

Packetized Energy Management

- Grid load is split into two categories:
  - Baseline load
  - Flexible load
- Flexible load energy is “packetized”
- Appliances request a packet
- Distributors allow packet consumption stochastically and according to supply

What is “flexible load”?

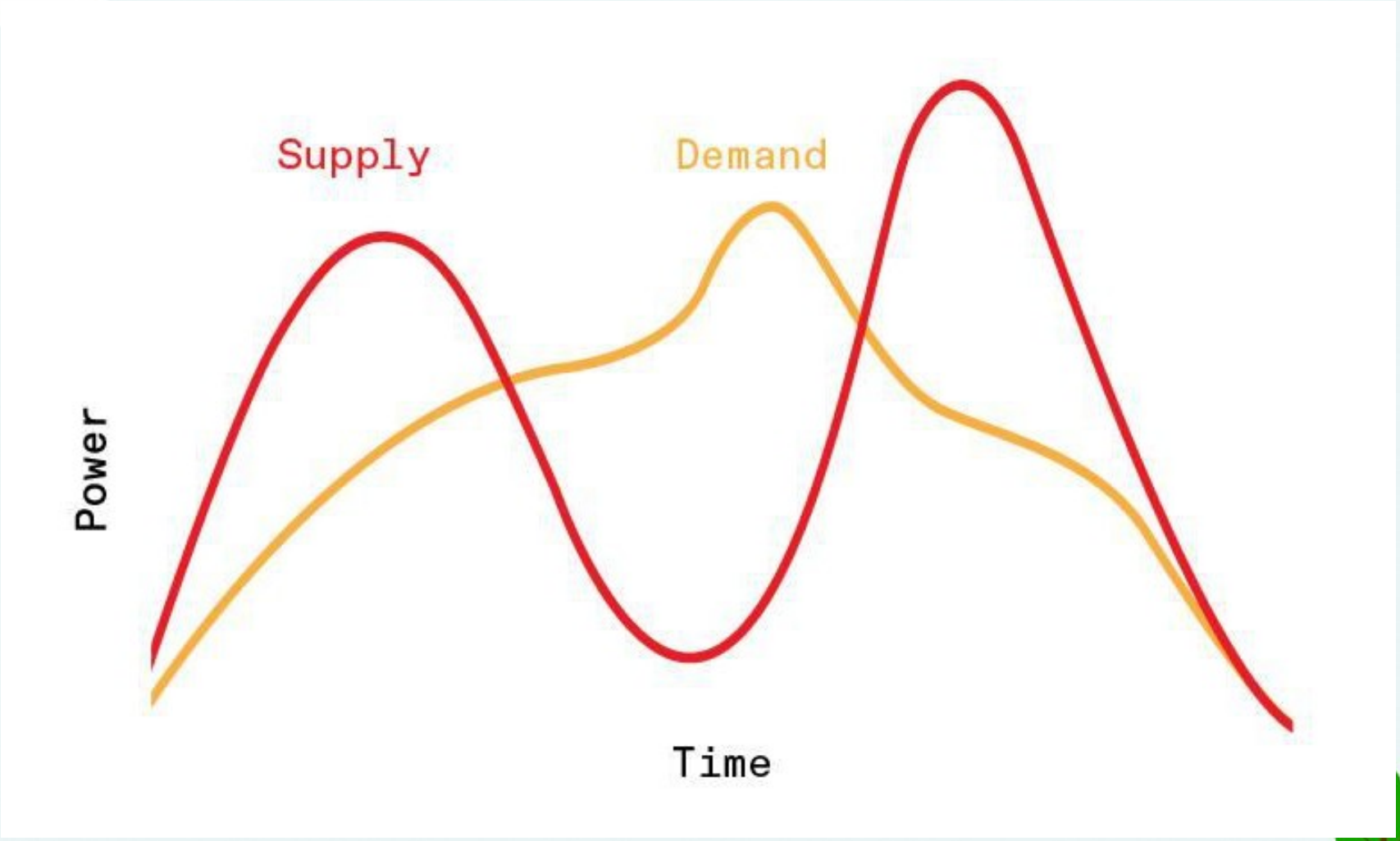
Things with “natural” energy reservoirs:

- Heaters
- Air Coolers
- Boilers
- Car chargers
- Refrigerators

NOT things for instant or continuous use:

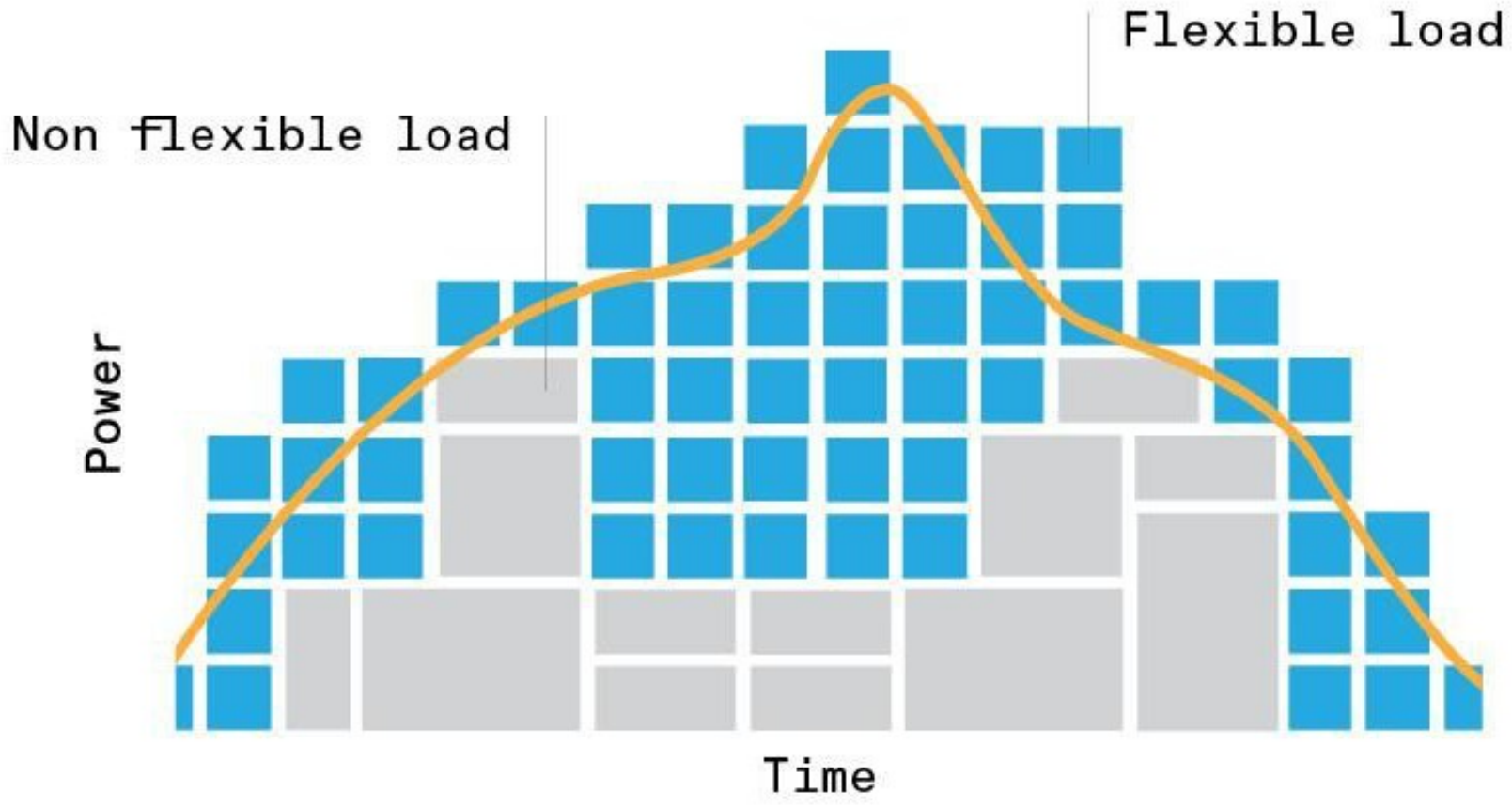
- Lights
- Plug in appliances
- Hair Dryer
- Cooking appliances

Before Packetization



https://spectrum.ieee.org/packetized-power-grid

Packetized Load



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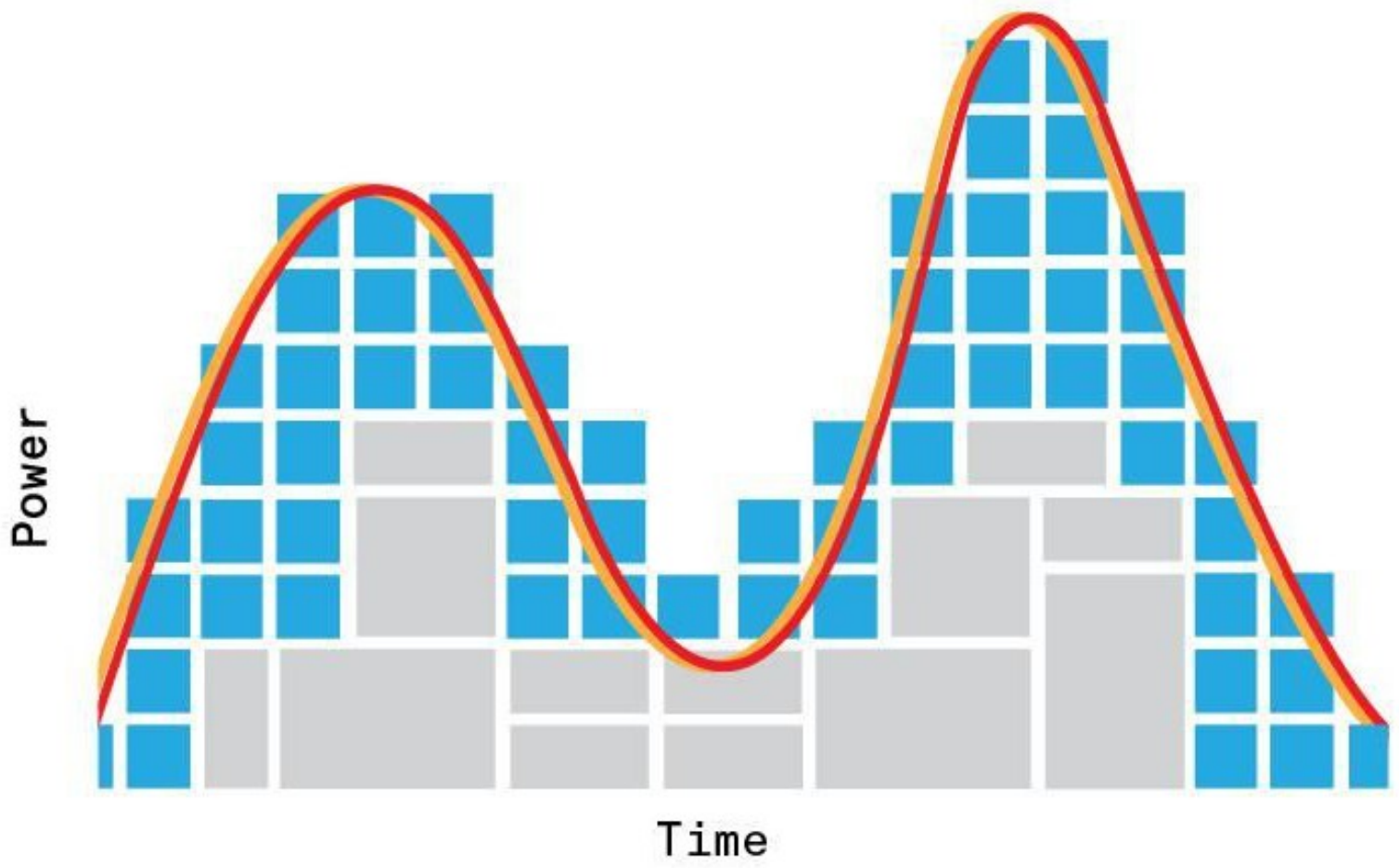
Managed Load



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Summary

- One central manager stochastically allows/denys requests according to available supply
- Many appliances requesting energy packets
- Communication over internet or dedicated infrastructure

Modeling

Simulation Parameters

Entities:

- Sinusoid-like energy supply
- Manager
- Electric water heaters

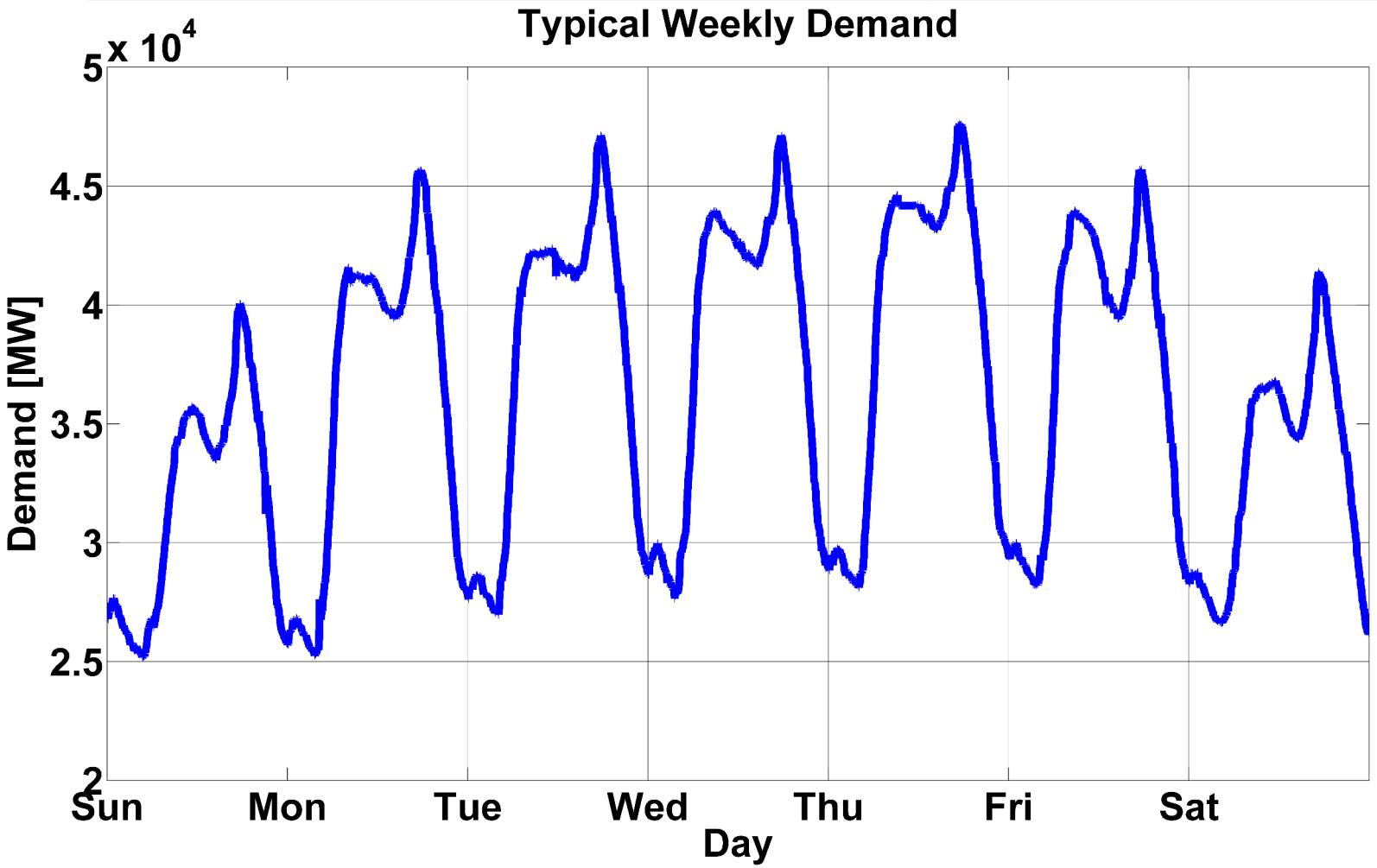
Complications:

- Thermal decay
- charge decay
- Stochastic use
- Management disregard threshhold

Additional Parameters

- 1 packet $\propto$ N Watts
- 1 epoch $\propto$ N seconds

Rapidly Changing Demand



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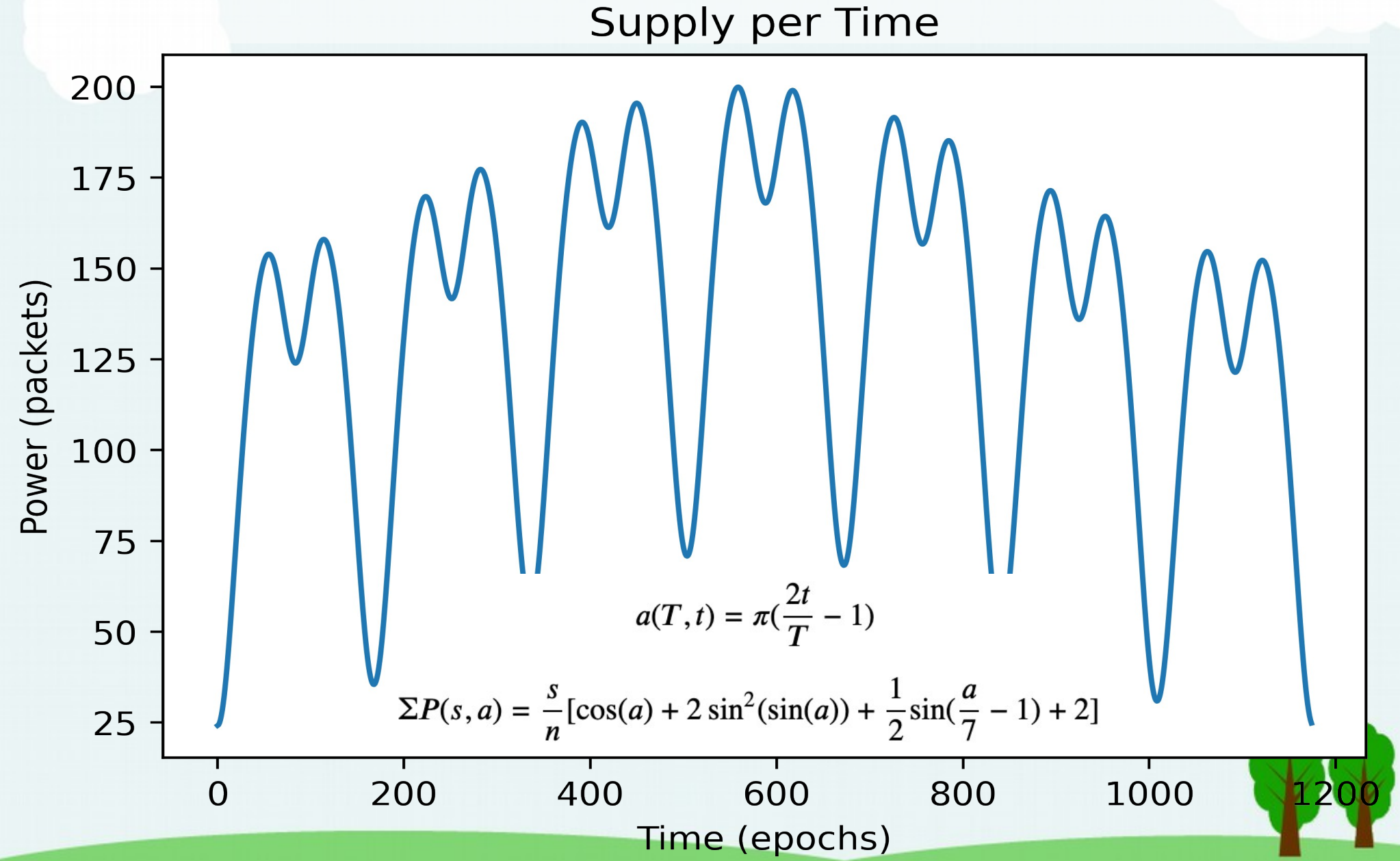
Total Grid Power Supply



n = 4.16333941 (normalization; experimentally determined)

Electric Water Heater State

$$T(t) = T_{amb} + (T - T_{amb})e^{-kt}$$

$$T_{new} = T_{old} + 3z - \frac{T_{old} - T_{ambient}}{T_{target}} - T_{old}w$$

$$T_{new} = old + input - environmental\ loss - useage\ loss$$

Code Sample

Running the Simulation

```
def progress(i,total): print(f'{int(i/total*100)}%', end='\r')
```

```
i = 0
load = []
mean_state = []
while i < (total_epochs*epoch_length) :
    i += epoch_length
    progress(i,total_epochs*epoch_length)

    # update for EWHs
    pop_df = update_ewh(pop_df)

    # determine total useage & requests quantity
    num_requests = len(pop_df.loc[pop_df['requesting'] == True])
    num_using = len(pop_df.loc[pop_df['using'] == True])

    # determine quantity of suppliable requests
    supply = update_supply(i)
    num_granted = int(max((supply - num_using),1))

    # isolate appropriate quantity of "requesting" but not "using" DERs
    sample_df = pop_df.query('requesting == True').query('using == False')
    if num_granted < len(sample_df['using']) : sample_df = sample_df.sample(n=num_granted)
    indexes = list(sample_df.index)

    # grant useage and remove requests
    pop_df.loc[pop_df['index'].isin(indexes), ['requesting']] = False
    pop_df.loc[pop_df['index'].isin(indexes), ['using']] = True

    # get metrics
    num_using = len(pop_df.loc[pop_df['using'] == True])
    load.append(num_using)
    mean_state.append(pop_df['state'].mean())

print(pop_df)
```

Data Table

- Initial states

index	type	state	using	requesting
0	ewh	53	False	False
1	ewh	45	False	False
2	ewh	54	False	False
3	ewh	59	False	False
4	ewh	51	False	False
5	ewh	57	False	False
6	ewh	51	False	False
7	ewh	57	False	False
8	ewh	56	False	False
9	ewh	53	False	False
10	ewh	45	False	False
11	ewh	46	False	False
12	ewh	50	False	False
13	ewh	59	False	False
14	ewh	49	False	False

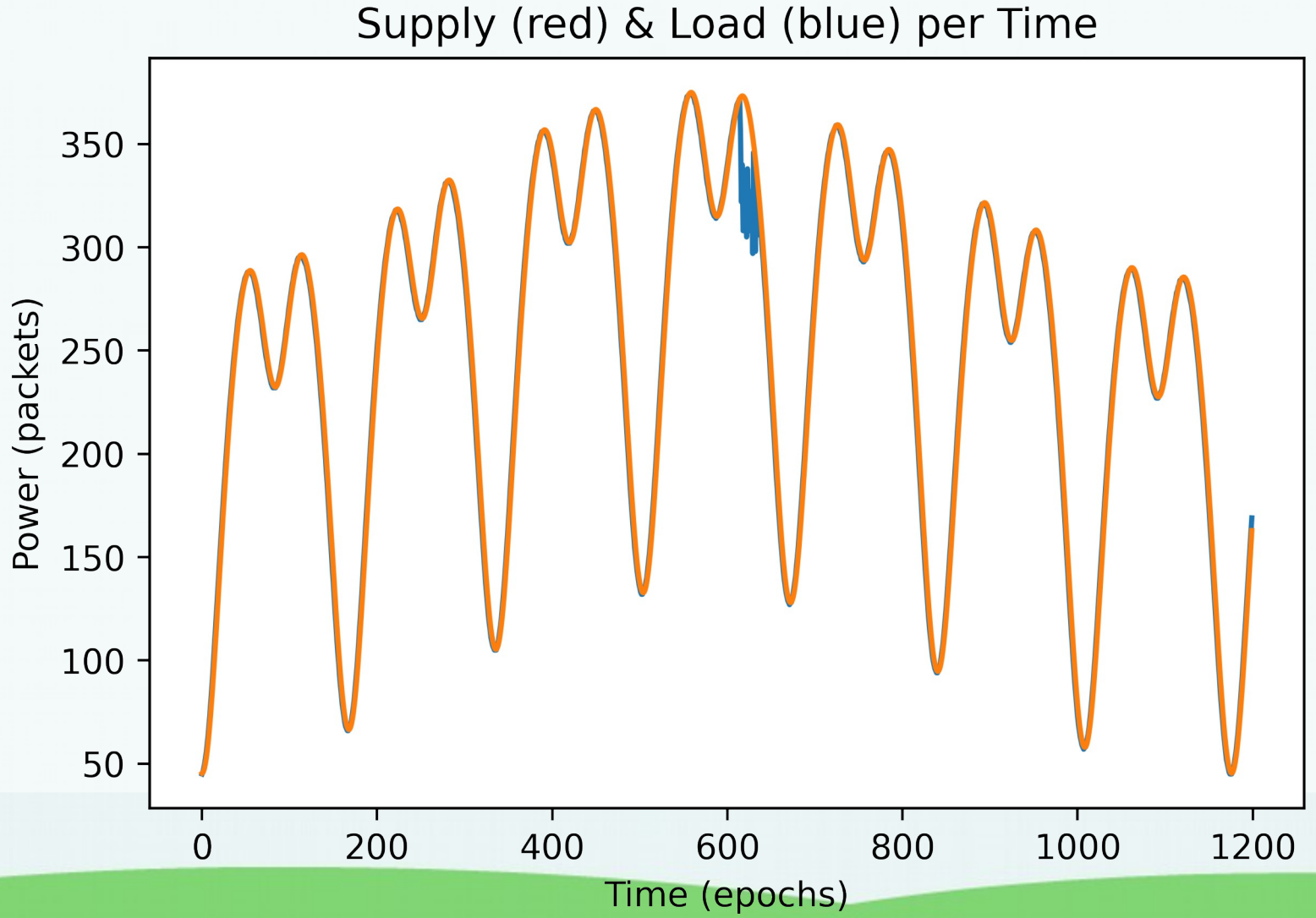
- Steady States

index	type	state	using	requesting
0	ewh	59.821244	False	True
1	ewh	59.986942	True	False
2	ewh	59.406641	True	False
3	ewh	59.612088	True	False
4	ewh	60.026281	False	False
5	ewh	60.213749	False	False
6	ewh	60.788079	False	False
7	ewh	57.540706	False	True
8	ewh	59.419203	False	True
9	ewh	59.809077	False	True
10	ewh	60.501564	False	False
11	ewh	61.242690	False	False
12	ewh	59.302513	True	False
13	ewh	60.681796	False	False
14	ewh	59.846769	False	True

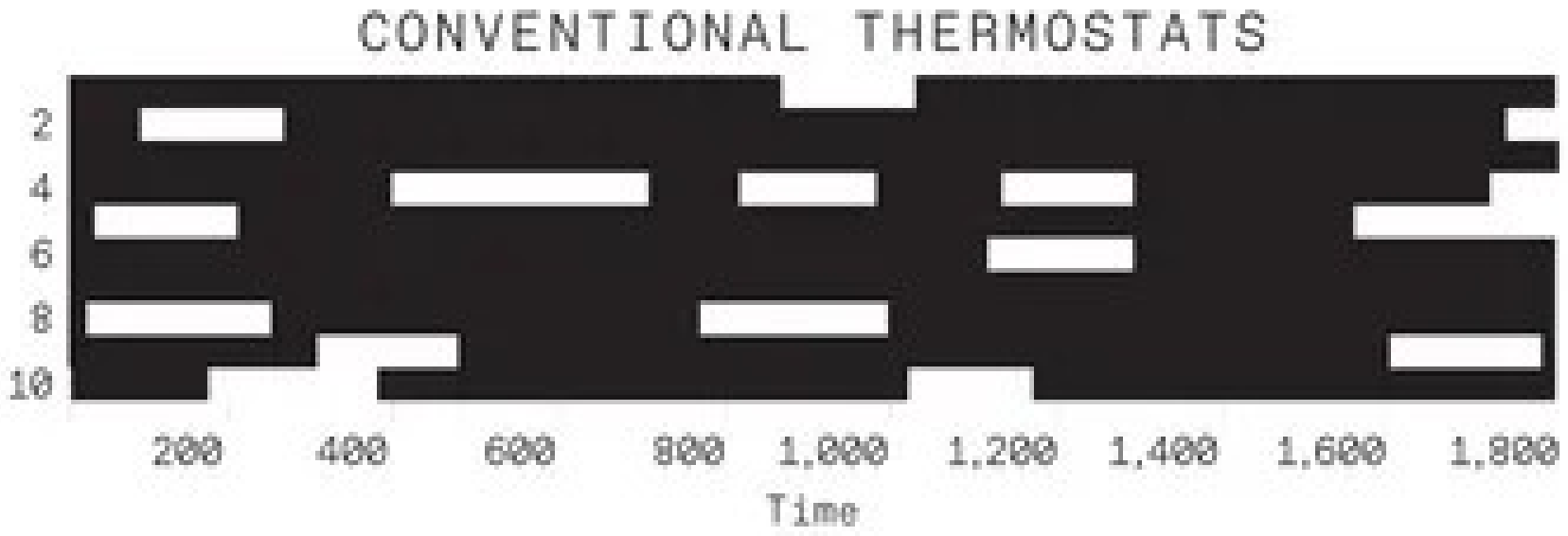
Results

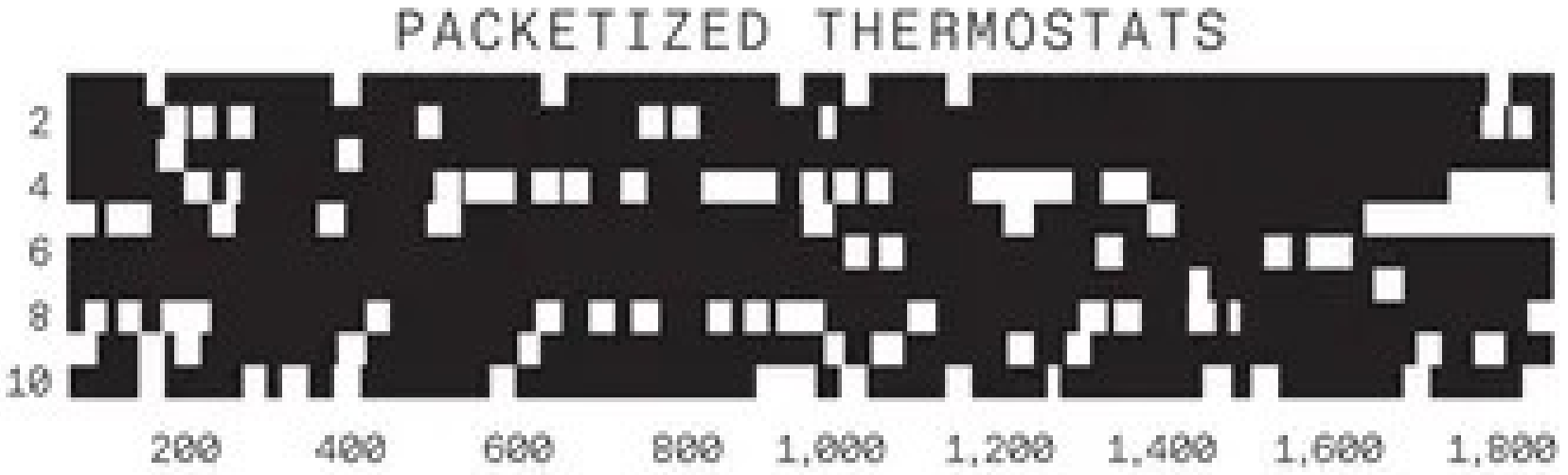
Matching Demand to Supply

- It works!!



On/Off For Individual Devices

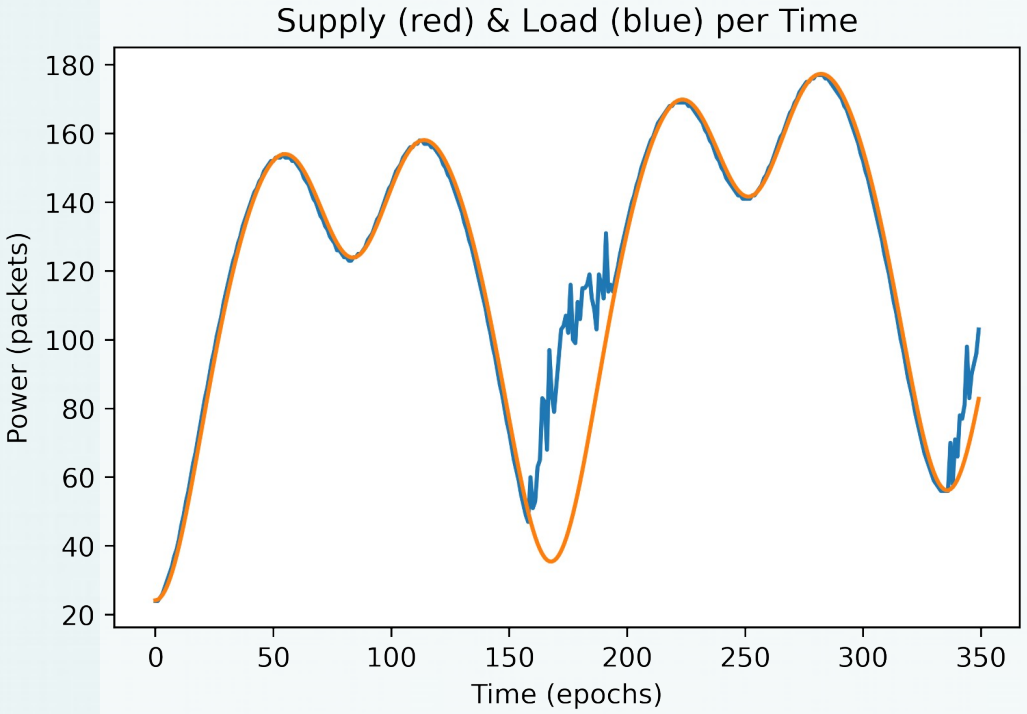


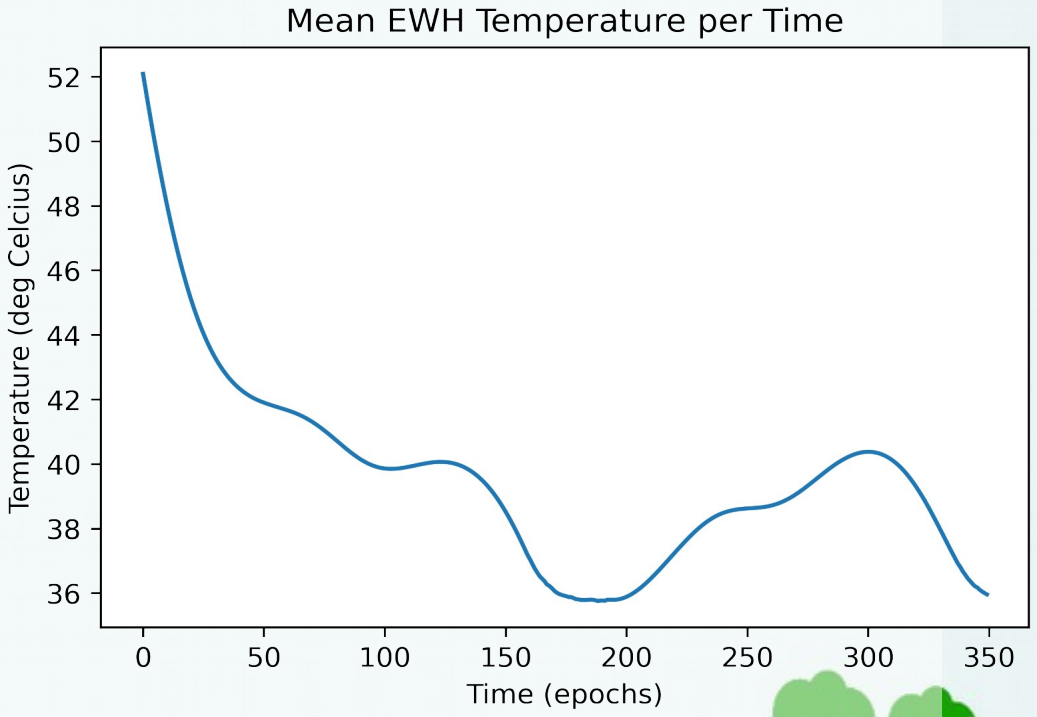


For the most part...

Undersupply & Recovery

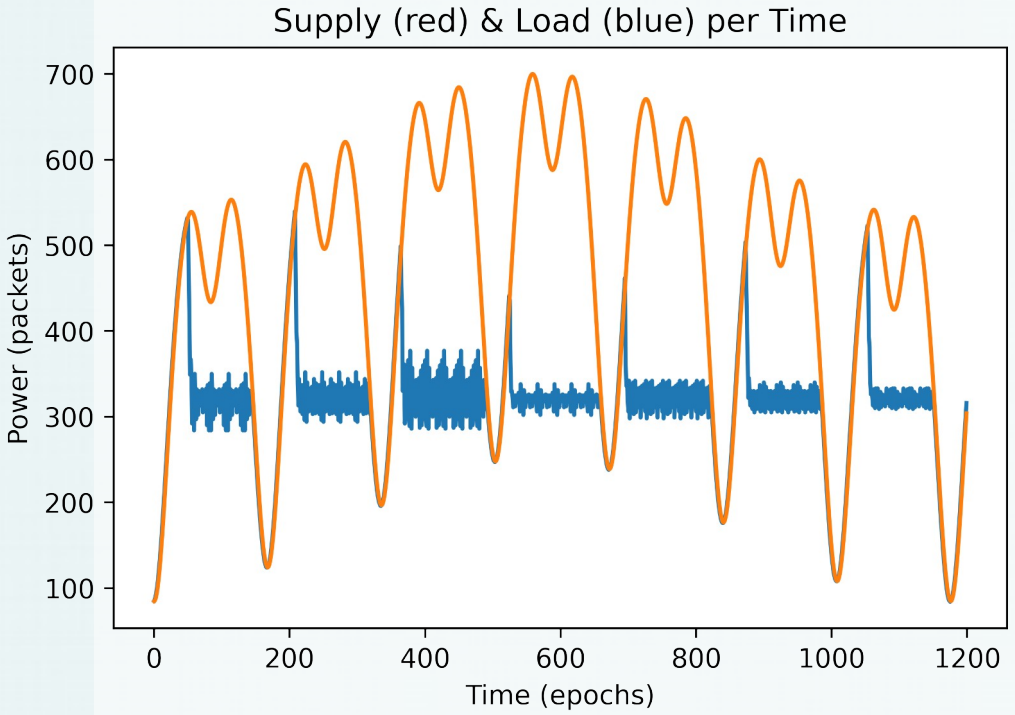
- There exists a domain in which packetized management is useful

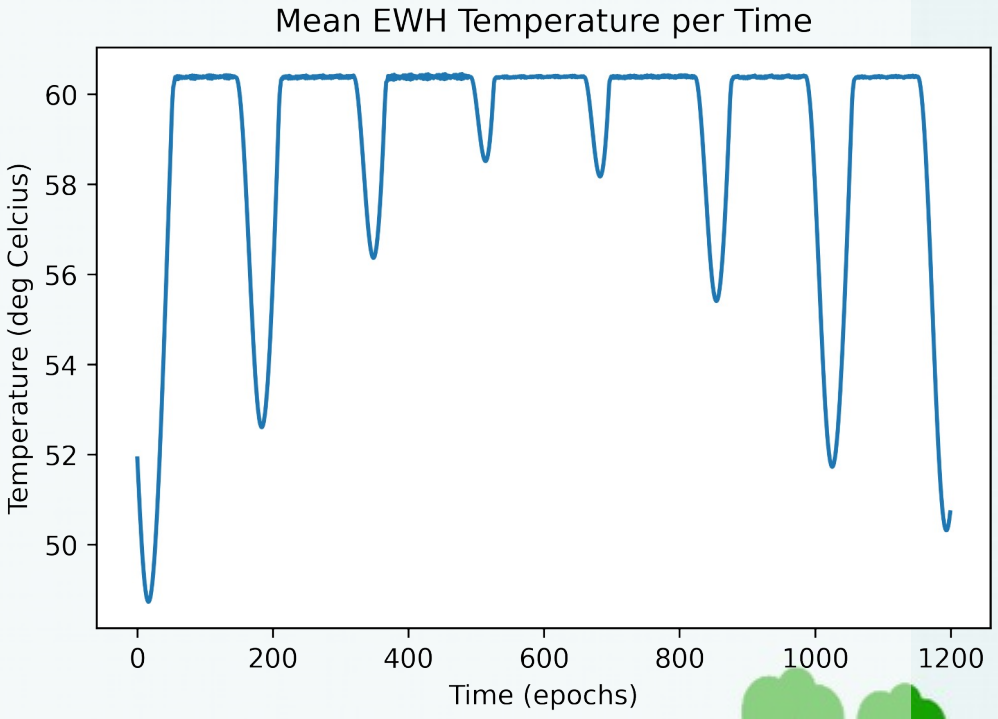




Oversupply & Recovery Spike

- Keeps demand from surpassing supply
- Creates predictable “return to baseline” spikes





Conclusion

- Grid size electrical loads can be reasonably managed
- Undersupply followed by oversupply leads to demand spike and steady state behavior
- Undersupply leads to grid failure

References

Almassalkhi, M., Frolik, J., & Hines, P. (2022, February 15). *How to prevent blackouts by packetizing the power grid*. IEEE Spectrum. Retrieved April 18, 2022, from https://spectrum.ieee.org/packetized-power-grid

Espinosa, L. A., Almassalkhi, M., Hines, P., & Frolik, J. (2018). Aggregate modeling and coordination of diverse energy resources under Packetized Energy Management. *2017 IEEE 56th Annual Conference on Decision and Control (CDC)*. https://doi.org/10.1109/cdc.2017.8263849

Espinosa, L. A., Khurram, A., & Almassalkhi, M. (2021). Reference-tracking control policies for packetized coordination of heterogeneous der populations. *IEEE Transactions on Control Systems Technology*, *29*(6), 2427–2443. https://doi.org/10.1109/tcst.2020.3039492

Frolik, J., & Hines, P. (2021, November 9). Systems and Methods for Random-Access Power Management.

Frolik, J., Hines, P., & Almassalkhi, M. (2021, October 19). Packetized Energy Management Control Systems and Methods of Using the Same.

Graber, G., Calderaro, V., Mancarella, P., & Galdi, V. (2019). Two-stage stochastic sizing and packetized energy scheduling of BEV charging stations with quality of service constraints. *Applied Energy*, *260*, 114262. https://doi.org/10.1016/j.apenergy.2019.114262

Nardelli, P. H., Alves, H., Pinomaa, A., Wahid, S., Tome, M. D., Kosonen, A., Kuhnlenz, F., Pouttu, A., & Carrillo, D. (2019). Energy internet via packetized management: Enabling Technologies and deployment challenges. *IEEE Access*, *7*, 16909–16924. https://doi.org/10.1109/access.2019.2896281

Rezaei, P., Frolik, J., & Hines, P. D. (2014). Packetized plug-in Electric Vehicle Charge Management. *IEEE Transactions on Smart Grid*, *5*(2), 642–650. https://doi.org/10.1109/tsg.2013.2291384

Zhang, B., & Baillieul, J. (2013). A packetized direct load control mechanism for demand side management. *2012 IEEE 51st IEEE Conference on Decision and Control (CDC)*. https://doi.org/10.1109/cdc.2012.6427392