Data Center Power Optimisation

Hyperscale Cloud Case Study

Motivation

Modern hyperscale data centers are rapidly growing electricity consumers.
Key drivers:

- AI / GPU clusters
- Cloud computing demand
- Always-on services

Optimisation must jointly consider:

- Workload scheduling
- Cooling control
- Renewable integration
- Energy storage + grid interaction

Total Power Structure

Total facility power:

$$P_{total}(t) = P_{IT}(t) + P_{cool}(t) + P_{aux}(t)$$

Power Usage Effectiveness (PUE):

$$PUE(t) = \frac{P_{total}(t)}{P_{IT}(t)}$$

Hence:

$$P_{total}(t) = PUE(t) \cdot P_{IT}(t)$$

Typical hyperscale PUE:

$$1.1 \text{ to } 1.3$$

Cooling Power Model

Cooling modeled using Coefficient of Performance (COP):

$$P_{cool}(t) = \frac{P_{IT}(t)}{COP(t)}$$

COP depends on:

- Ambient temperature
- Cooling technology (air, liquid, immersion)
- Operating mode

Energy Sources

At time t, power may come from:

- Grid: $P_{grid}(t)$
- Renewables: $P_{ren}(t)$
- Battery discharge: $P_{bat}(t)$

Power balance:

$$P_{grid} + P_{ren} + P_{bat} = P_{IT} + P_{cool}$$

Optimisation Objective

$$\min \sum_{t} \left[c_{grid}(t) P_{grid}(t) + c_{bat} P_{bat}(t) \right]$$

Subject to:
Power balance:

$$P_{grid} + P_{ren} + P_{bat} = PUE(t) P_{IT}(t)$$

Constraints

Renewable availability:

$$0 \leq P_{ren}(t) \leq P_{ren}^{max}(t)$$

Battery dynamics:

$$E(t+1) = E(t) + \eta_c P_{ch}(t) - \frac{1}{\eta_d} P_{dis}(t)$$

Capacity:

$$0 \leq E(t) \leq E^{max}$$

Sustainability Constraint

Minimum renewable fraction:

$$P_{ren}(t) \geq \alpha P_{total}(t)$$

Interpretation:

- Carbon compliance
- Sustainability targets
- Green certification

Hyperscale Optimisation Principles

Workload-aware scheduling

- Renewable forecast
- Electricity price signals
- Grid carbon intensity

ML-based cooling

- Thermal prediction
- Cooling setpoint control
- Energy reduction

Grid interaction

- Demand response
- Battery dispatch
- Workload shifting

Research Directions

- Stochastic optimisation
- Carbon-aware scheduling
- Joint IT + thermal + electrical optimisation
- Hybrid classical + quantum optimisation

Battery Energy Model

Energy update:

$$E(t+1) = E(t) + \eta_c P_{ch} \Delta t - \frac{1}{\eta_d} P_{dis} \Delta t$$

Physical meaning:

- Current stored energy
- Plus effective charging energy
- Minus effective discharge energy

Battery Variables

t	Time index
$E(t)$	Stored energy (MWh)
P_{ch}	Charging power (MW)
P_{dis}	Discharge power (MW)
η_c	Charge efficiency
η_d	Discharge efficiency

Example Battery Calculation

Given:

- $E(t) = 5$ MWh
- $P_{ch} = 2$ MW
- $P_{dis} = 1$ MW
- $\eta_c = 0.95, \quad \eta_d = 0.90$

$$E(t+1) = 5 + 1.9 - 1.11 = 5.79 \text{ MWh}$$

Numerical Optimisation Problems

Decision variables:

- Grid import
- Renewable usage
- Battery charge/discharge

Time coupling via:

$$E(t+1) = f(E(t), P_{ch}, P_{dis})$$

Problem 1: Single-Hour LP

Given:

- $P_{IT} = 10$ MW
- $COP = 4$
- $P_{ren}^{max} = 6$
- $P_{dis}^{max} = 3$

Cooling:

$$P_{cool} = 2.5$$

Total:

$$P_{total} = 12.5$$