

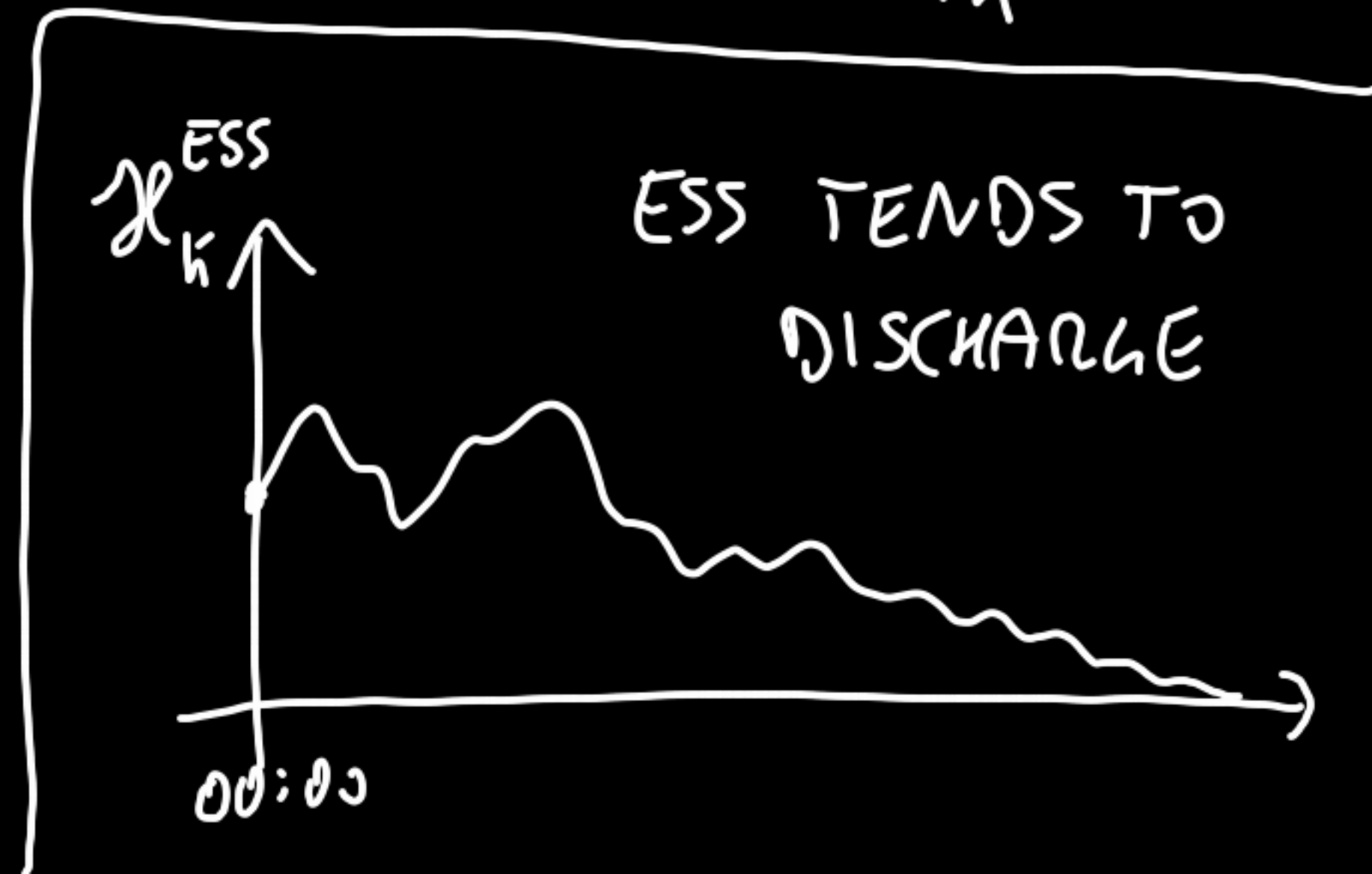
21/10/2026 - BMS CONCLUSIONS + EXAMPLE ON LARGE-SCALE PEV CHARGING

$$J^{\text{cost}} = \sum_{i=0}^{N-1} \left[C_{i|k}^{\text{IN}} \cdot (T P_{i|k}^{\text{IN}}) - C_{i|k}^{\text{OUT}} (T \cdot P_{i|k}^{\text{OUT}}) \right]$$

$$J^{\text{depr}} = \sum_{i=0}^{N-1} C^{\text{depr}} \left[\underbrace{P_{i|k}^{\text{IN}} + P_{i|k}^{\text{OUT}}}_{\text{ENERGY ESS CHARGES/DISCH. AT } i|k} \cdot T \right]$$

ENERGY ESS CHARGES/DISCH. AT $i|k$

$$J^{\text{ref}} = \sum_{i=0}^{N-1} \left(x_{i|k}^{\text{ESS}} - x_{i|k}^{\text{ref}} \right)^2$$



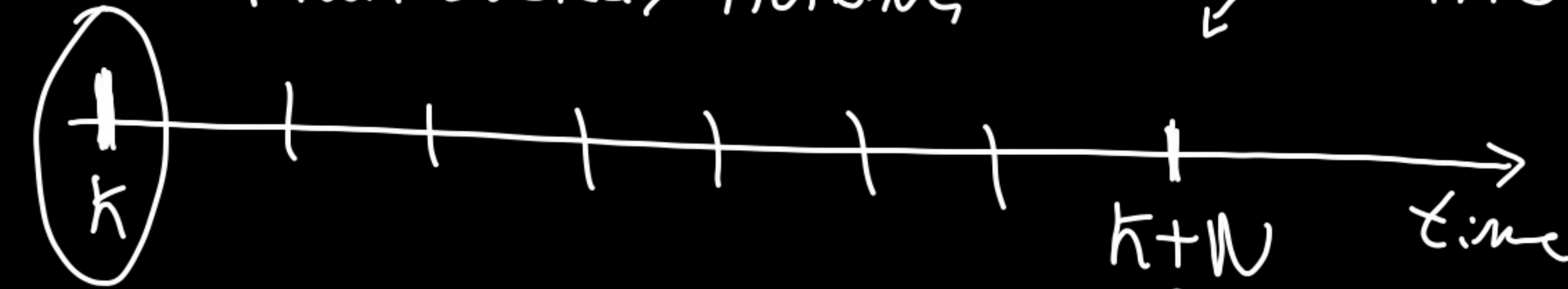
PREDICTION HORIZON

TOTAL VALUE MAXIMIZATION

COSTS (+) / PROFITS (-)
FROM ENERGY TRADING

TERMINAL
STATE

VALUE OF
TERMINAL STATE
OF ESS.



$V(x_k)$

$$\max \left(V(x_k) + \underbrace{\text{PROFITS} - \text{COSTS}}_{|||} + V(x_{N|k}) \right)$$

$$\min \left(-\cancel{V(x_k)} + \overset{|||}{J^{\text{COST}}} - V(x_{N|k}) \right)$$

$$J^{\text{COST, NEW}} = J^{\text{COST}} - \underline{V(x_{\text{KIN}})}$$

$V(x_{\text{KIN}})$ VALUE ASSIGNED TO THE ENERGY IN THE ESS
AT THE END OF PREDICTION WINDOW.

$$V(x_{\text{KIN}}) = \underline{\overset{\text{AVERAGE}}{C}} \cdot x_{\text{KIN}}$$

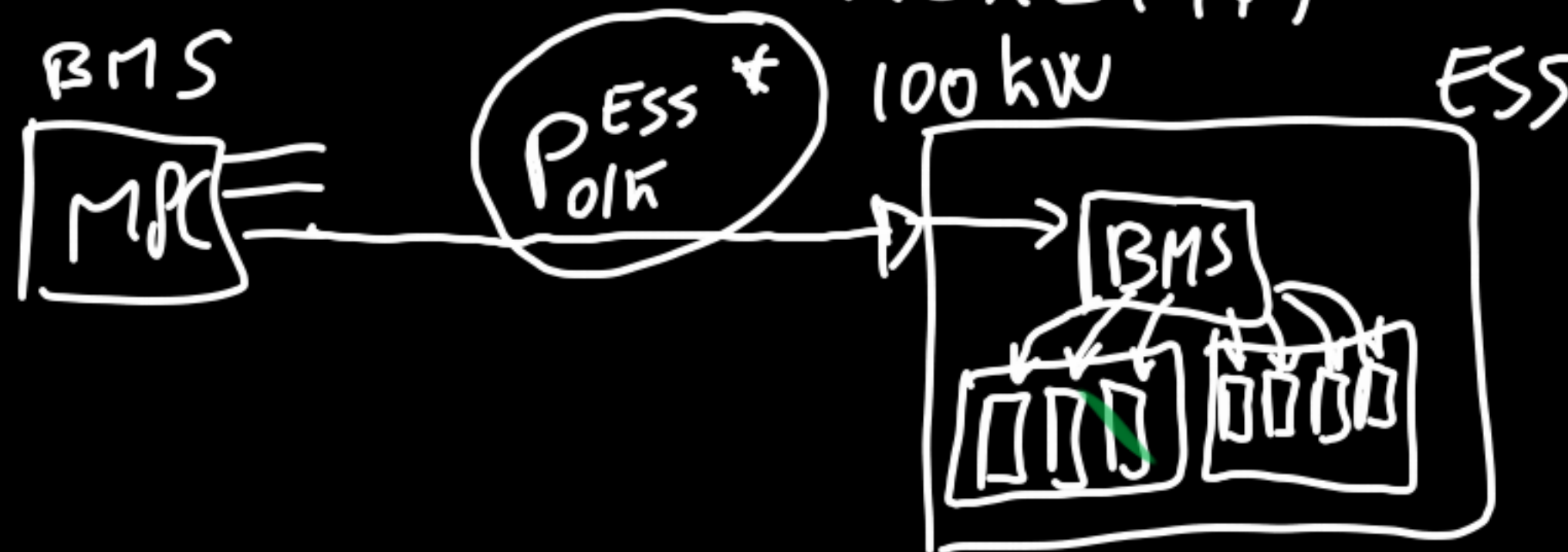
→ COULD BE SELECTED ADAPTIVELY DURING DAY WITH
RL.

FINAL CONSIDERATIONS

— WE FOCUSED ONLY ON ELECTRICAL PART

+ FOCUS ON SOC (%) . $x_{i+1k}^{ESS, SOC} = \dots$

+ SOM (STATE OF HEALTH) — CELL BALANCING



$$x_{i+1k}^{ESS, SOM} = \dots f(\text{temp}, x_{i1k}^{ESS, SOC} \dots)$$

+ SOP (STATE OF POWER) MAX. POWER BATTERY CAN PROVIDE IN THE NEAR FUTURE (VERY RELEVANT FOR VEHICLES).

$$P_{ESS, MAX} = 200 \text{ kW}$$

$$x_{i+1k}^{ESS, SOP} = f(\dots)$$

GOALS OF MAX SOM, SOP.

- SKIPPED THERMAL CONTROL PART

PARAMETERS OF BUILDING (BIM)

$$T_{i+1k}^{WALL,J} = T_{i1k}^{WALL,J} + f(T^{ext}, \underbrace{Q_{i1k}^{CONTROL}, Q_{i1k}^{LOSSES}, \dots}_{HVAC})$$

$$T_{i+1k}^{AIR, ROOM,J} = \dots$$

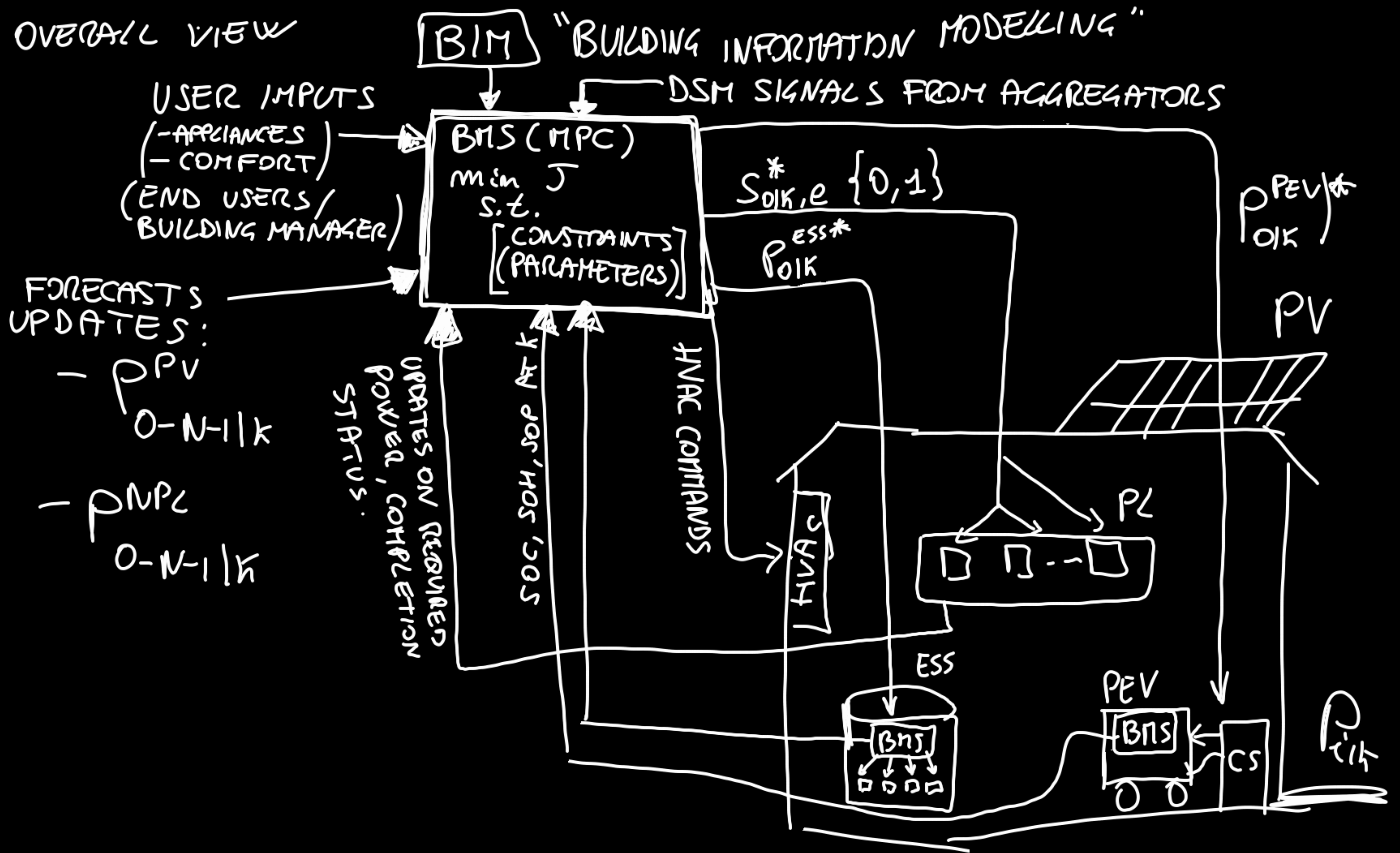
HUMIDITY, AIR QUALITY.

CONTROLS:

- NATURAL VENTILATION
- FORCED VENTILATION

NEW TERMS TO MAXIMIZE USER COMFORT

OVERALL VIEW



WITH BIM MODEL WE CAN UPDATE IN REAL TIME THE MODEL PARAMETERS TO MAKE SURE THEY ARE CONSISTENT WITH CURRENT BUILDING CONFIGURATION.

TUNING OF MPC.

PARAMETERS:

OBJ. FUNCTION: $J = \underbrace{\alpha_1 \cdot J^{\text{cost}}}_{\text{SINGLE OBJECTIVE}} + \underbrace{\alpha_2 J^{\text{reg}} + \alpha_3 J^{\text{track}} + \alpha_4 x_{\text{NIK}}}_{\text{MULTIPLE OBJECTIVES}}$

Diagram notes: In the equation, J^{cost} is bracketed and labeled 'SINGLE OBJECTIVE'. The terms $\alpha_2 J^{\text{reg}} + \alpha_3 J^{\text{track}} + \alpha_4 x_{\text{NIK}}$ are grouped by a large circle and labeled 'MULTIPLE OBJECTIVES'. An arrow points from the word 'AVERAGE' to the α_4 coefficient, and another arrow points from the word 'TERMINAL COST.' to the x_{NIK} term.

SINGLE
OBJECTIVE

MULTIPLE OBJECTIVES

SELECTION OF α_j PARAMETERS ESTABLISH THE TRADE OFF

BETWEEN DIFFERENT GOALS

d_J PARAMETERS CAN BE TAKEN :

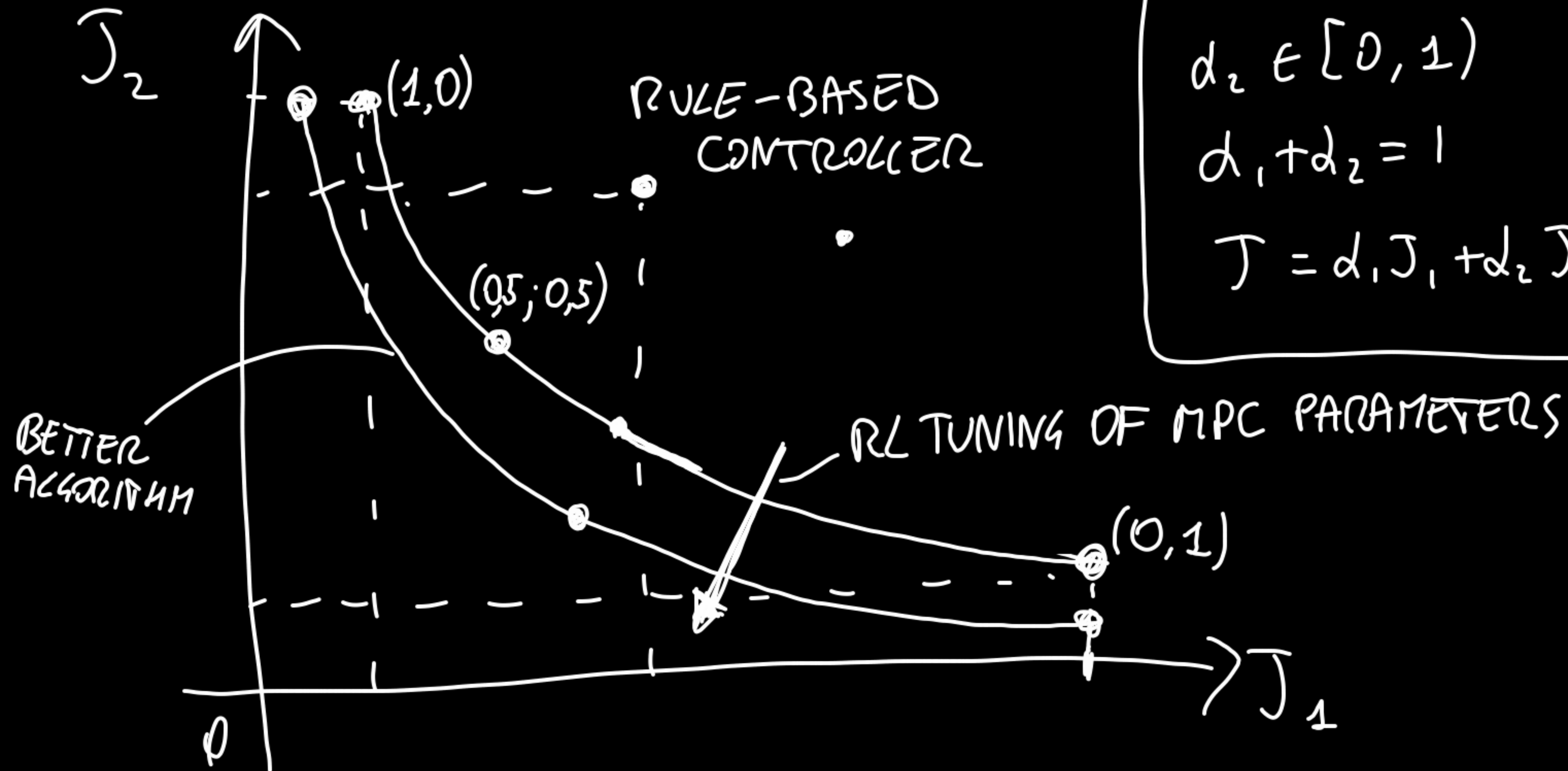
$$\left[d_J \in [0, 1] , \sum_J d_J = 1 \right]$$

$$\min(J = d_1 J_1 + d_2 J_2) \equiv \min\left(\frac{d_1}{(d_1 + d_2)} J_1 + \frac{d_2}{d_1 + d_2} J_2\right)$$

(SOLUTION)

TUNING CAN BE DONE WITH RL.

PARETO FRONTIER (FOR MIN PROBLEMS)



$$d_1 \in [0, 1]$$

$$d_2 \in [0, 1]$$

$$d_1 + d_2 = 1$$

$$J = d_1 J_1 + d_2 J_2$$

MPC FOR PEV AGGREGATORS

DSM - DEMAND SIDE MANAGEMENT.

MARKETS ;

WHOLESALE

- ENERGY MARKETS : BUY/SELL ELECTRICITY FOR CONSUMPTION

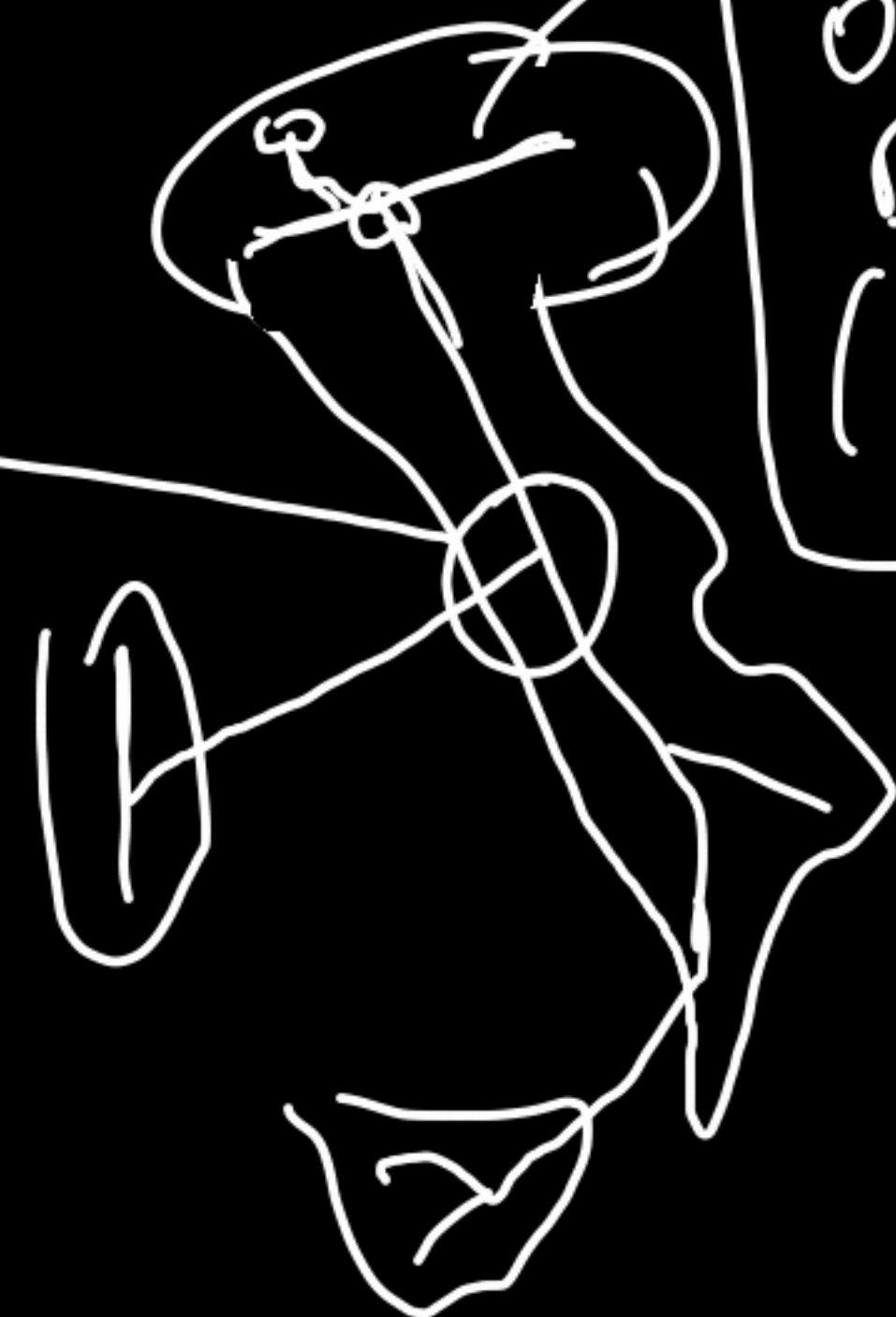
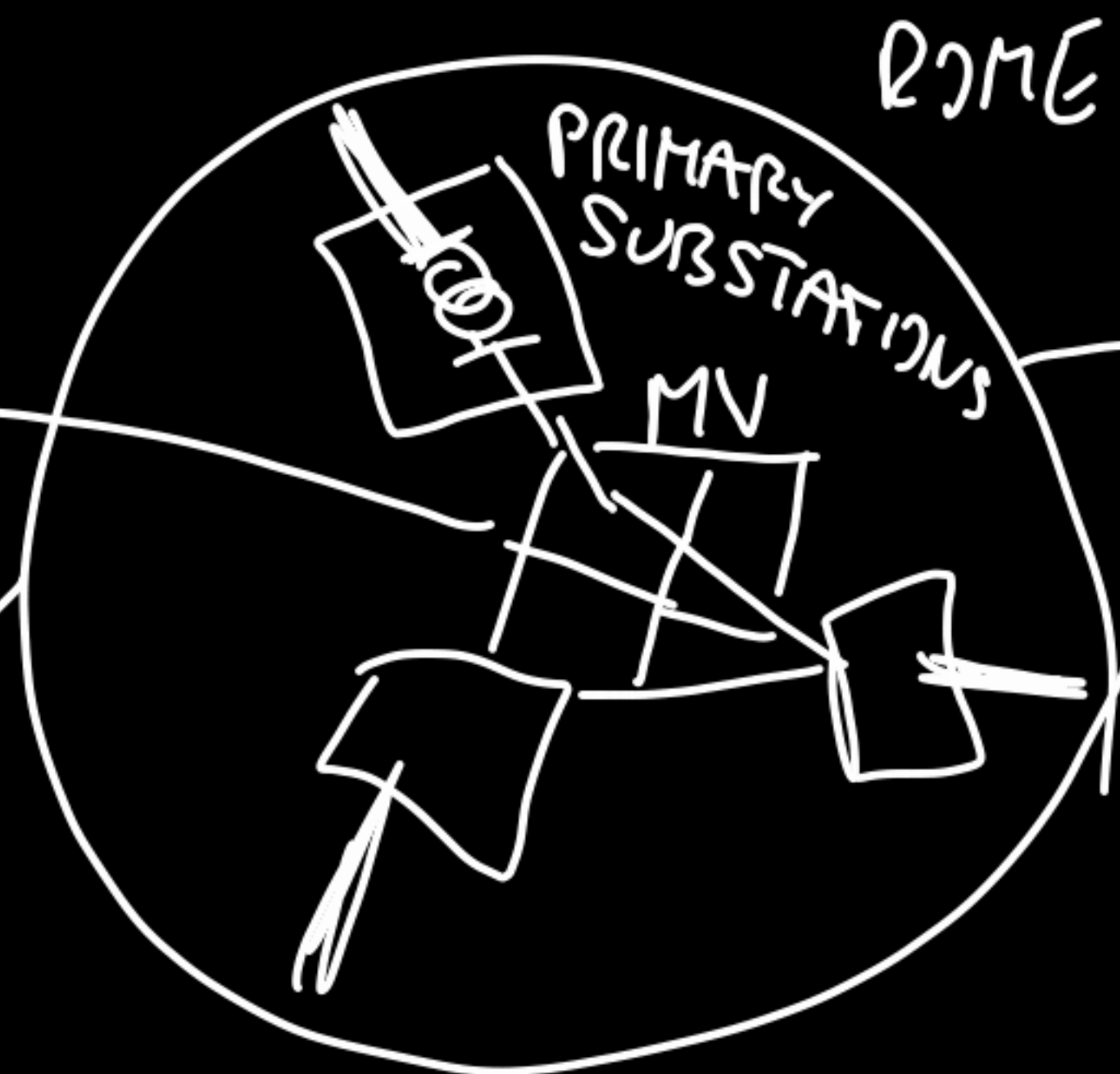
- GENCO : GENERATION COMPANIES (SELL ENERGY)
- RETAILERS : BUY ENERGY AND SELL TO FINAL CUSTOMERS
- COMPANY RUNNING MARKET (ACCORDING TO RULES)

● ANCILLARY MARKETS / FLEXIBILITY MARKETS

- TSO (TRANSMISSION SYSTEM OPERATORS)
- DSO (DISTRIBUTION SYSTEM OPERATORS)
- FLEXIBILITY PROVIDERS

1 MW

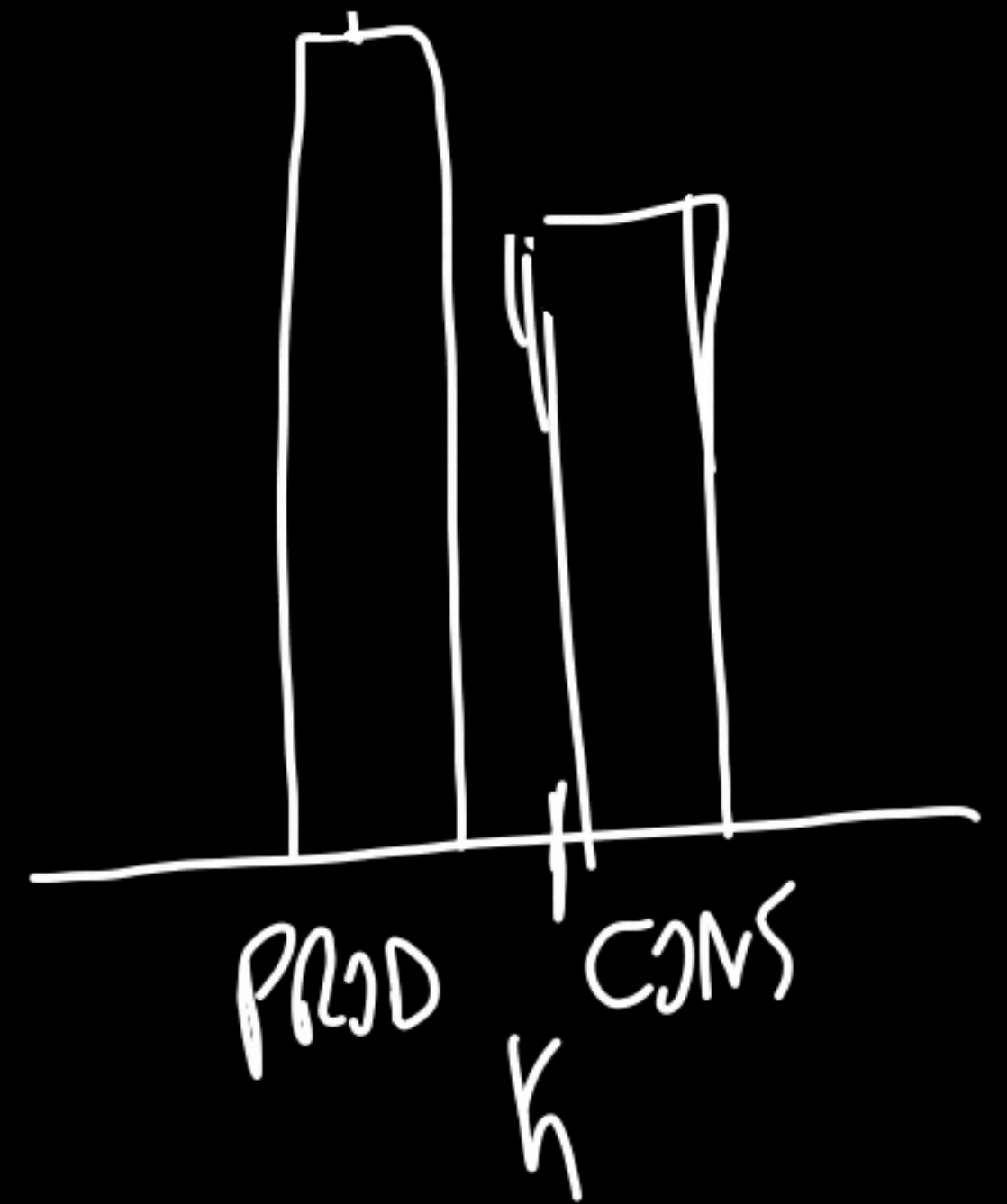
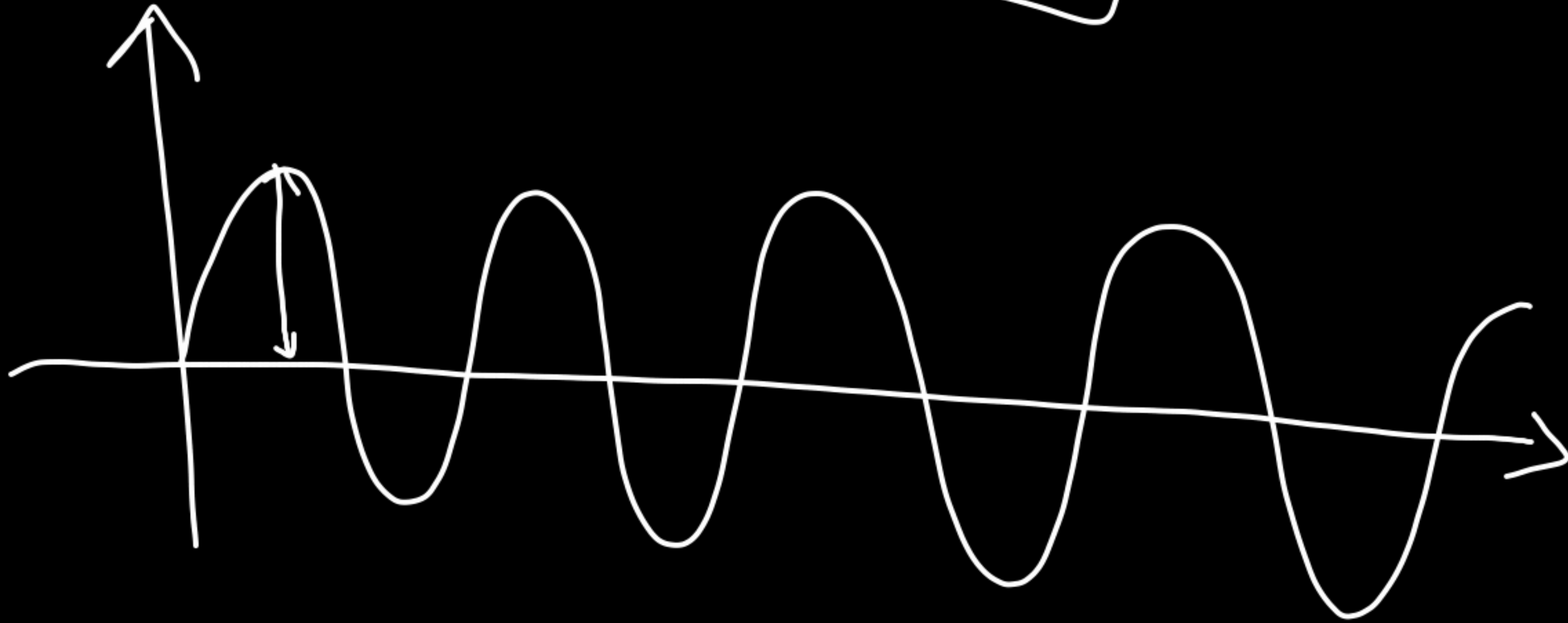
MV
GRID / DISTRIBUTION
GRID
DSO (ACEA IN
ROME)



HV GRID
TRANSMISSION
GRID
500 kV
OPERATED
BY TSO
(TERNA)

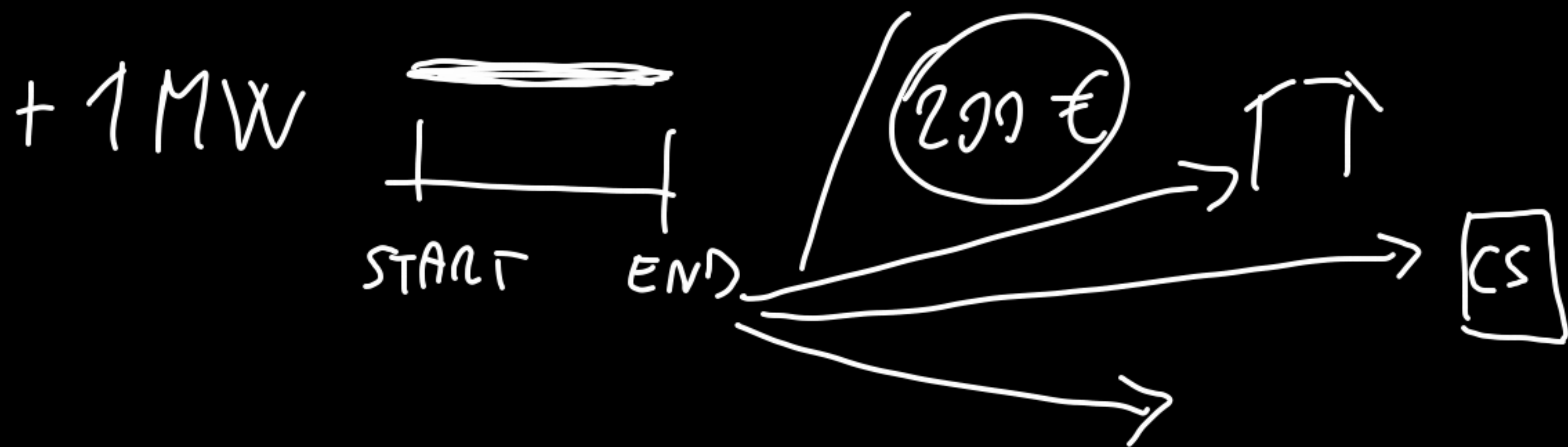
TO KEEP GRID OPERATION SAFE, GRID FREQUENCY AND VOLTAGE NEED TO BE REGULATED AT REFERENCE VALUES.

$$f^{\text{ref}} = 50 \text{ Hz}, \quad V^{\text{ref}} = 10 \text{ kV}$$



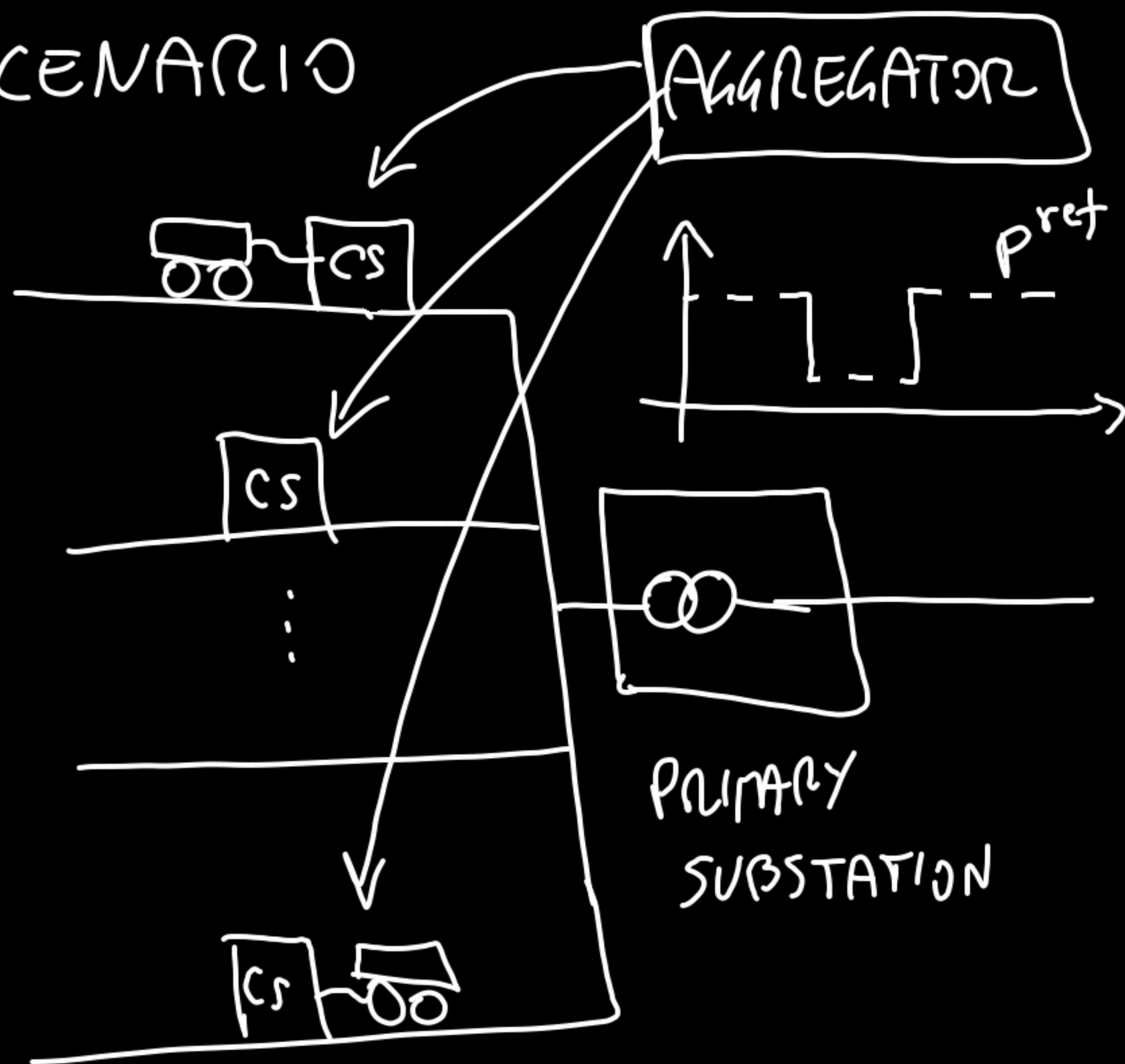
FLEX. PROVIDERS

- BIG CONSUMERS (INDUSTRIES)
- AGGREGATORS OF SMALLER ENTITIES, MANAGED AS IF THEY WERE ONE LARGE ENTITY (MINIMUM BIDDING SIZE)



MPC FOR PEV AGGREGATION:

SCENARIO



CONTROL GOALS:

- AGGREGATION: TOTAL PEV POWER TRACKS p^{ref}
- (USER CHARGING PREFERENCES ARE RESPECTED.)

MODELING

PEV:

- $P_{k,p}$ [KW] POWER CHARGED/DISCHARGED BY PEV p AT k ;
- $x_{k,p}$ [kWh] ...

USER PREFERENCES:

- F_p DESIRED FINAL TIME FOR CHARGING PEV p .
- x_p^{ret} DESIRED FINAL SOC.

- P_k TOTAL CH/DISCH POWER AT TIME k .

- P_k^{ret} DESIRED REFERENCE FOR TOTAL POWER.

$$P_{ik,p}^{ch} \geq 0, \quad i=0,1,\dots,N-1; \quad \forall p \in PEV_{ik} \rightarrow \text{SET OF PEV CONNECTED AT } ik.$$

$$P_{ik,p}^{dis} \geq 0, \quad i=0,1,\dots,N-1; \quad \forall p \in PEV_{ik}$$

$$P_{ik,p} = P_{ik,p}^{ch} - P_{ik,p}^{dis}; \quad i=0,1,\dots,N-1; \quad \forall p \in PEV_{ik}$$

$$\delta_{ik,p}^{ch}, \delta_{ik,p}^{dis} \in \{0,1\}; \quad \forall i,p$$

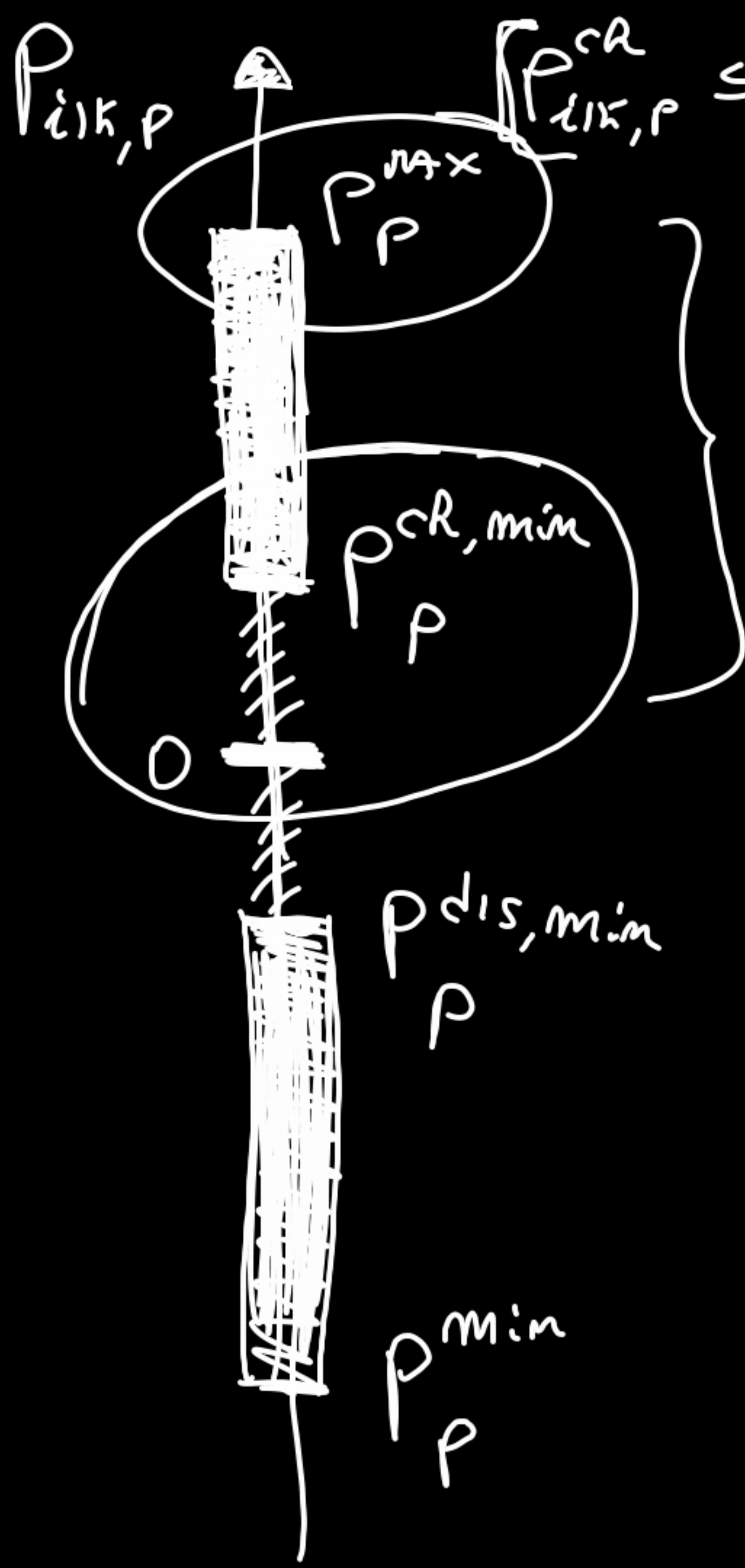
IND. CONSTRAINTS:

$$P_{ik,p}^{ch} \leq P_p^{max} \cdot \delta_{ik,p}^{ch}; \quad \forall i,p$$

$$P_{ik,p}^{dis} \leq |P_p^{min}| \cdot \delta_{ik,p}^{dis}; \quad \forall i,p$$

$$\delta_{ik,p}^{ch} + \delta_{ik,p}^{dis} \leq 1; \quad \forall i,p$$

MUTUALLY EXCLUSIVE CHARGING/DISCHARGING.



$$p_{ik,p}^{ch} \leq p_p^{max} \cdot \delta_{ik,p}^{ch}$$

SEMI-CONTINUOUS VARIABLE.

$$\text{IF } \delta_{ik,p}^{ch} = 1 \rightarrow p_p^{ch,min} \leq p_{ik,p}^{ch} \leq p_p^{max}$$

$$\delta_{ik,p}^{ch} = 0 \rightarrow p_{ik,p}^{ch} = 0$$

$$\delta_{ik,p}^{ch} = 1 \rightarrow p_p^{ch,min} \leq p_{ik,p}^{ch}$$

$$\delta_{ik,p}^{ch} \cdot p_p^{ch,min} \leq p_{ik,p}^{ch}$$

CHRS.

$$\delta_{ik,p}^{ch} \cdot P_p^{ch, min} \leq P_{ik,p}^{ch} \leq \delta_{ik,p}^{ch} \cdot P_p^{max}, \forall i, p$$

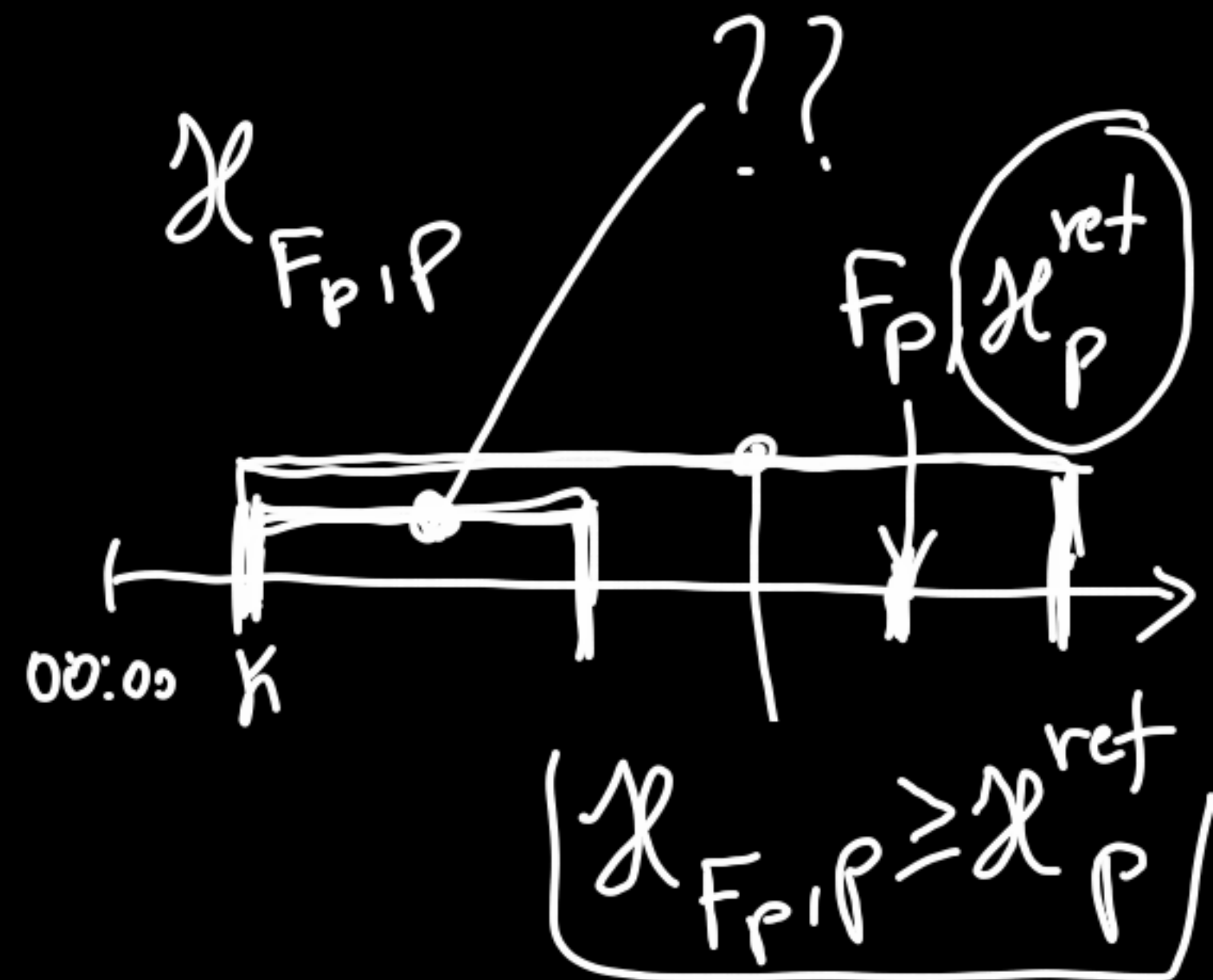
DISCH.

$$\delta_{ik,p}^{dis} \cdot |P_p^{dis, min}| \leq P_{ik,p}^{dis} \leq \delta_{ik,p}^{dis} \cdot |P_p^{min}|, \forall i, p$$

CONSTRAINTS OF SEMI-CONTINUOUS VARIABLE

USER PREFERENCES ON CHARGING

- F_p FINAL CHARGING TIME
- $\mathcal{X}_p^{\text{ret}}$ FINAL DESIRED SOC.



$$\mathcal{X}_{i+1k,p} = \mathcal{X}_{ilk,p} + \eta^{\text{ch}} T P_{ilk,p}^{\text{ch}} - \frac{1}{\eta^{\text{dis}}} T P_{ilk,p}^{\text{dis}}; \forall i, p$$

USER PREFERENCES?

$\forall p$, ENERGY IN BATTERY AT FINAL TIME F_p SHOULD

BE AT LEAST $\mathcal{X}_p^{\text{ret}}$