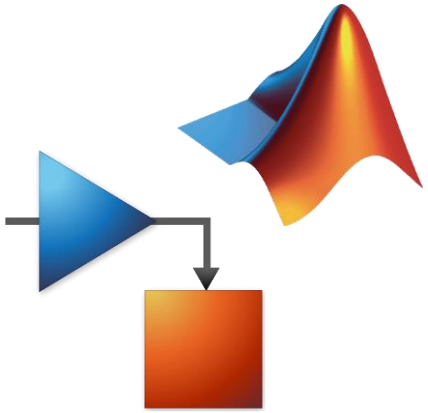
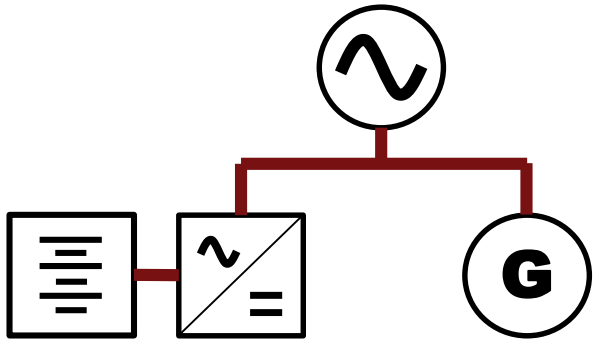
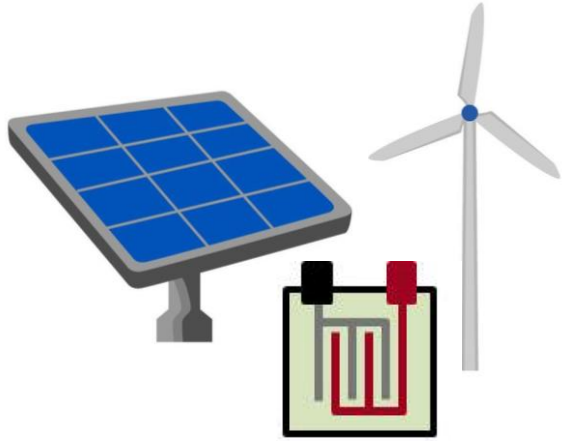
# Microgrid Energy Management System Development Using Optimization-based Methods





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# Demo – Microgrid EMS

## Using Model-Based Design and Optimization

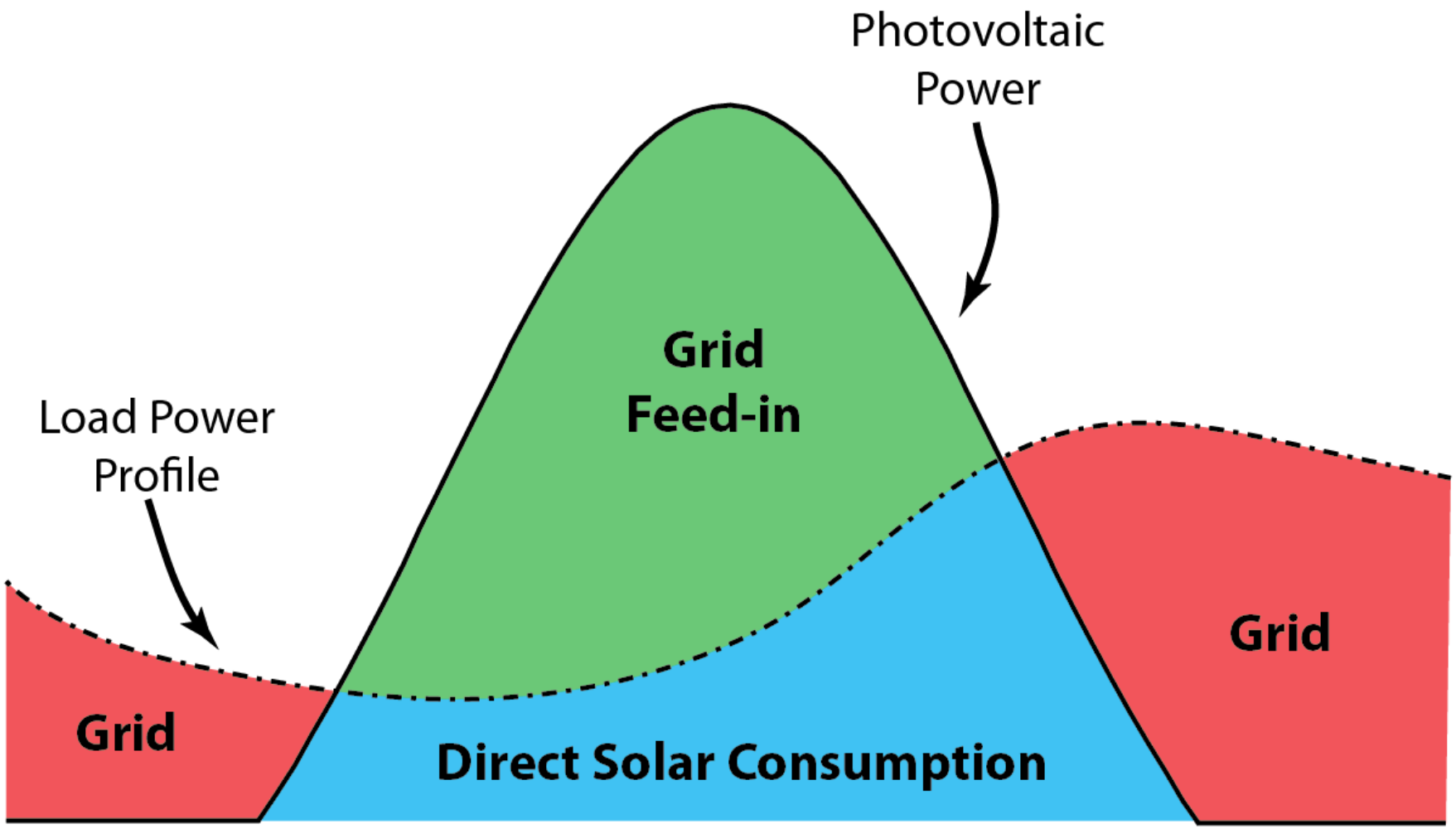
**HEMS example –** ***microgrid with loads***

**PV Panels**:
- MPPT Control
- Power electronics

**Decision Logic**:
- Store/draw power
- Use external grid
- Optimize energy

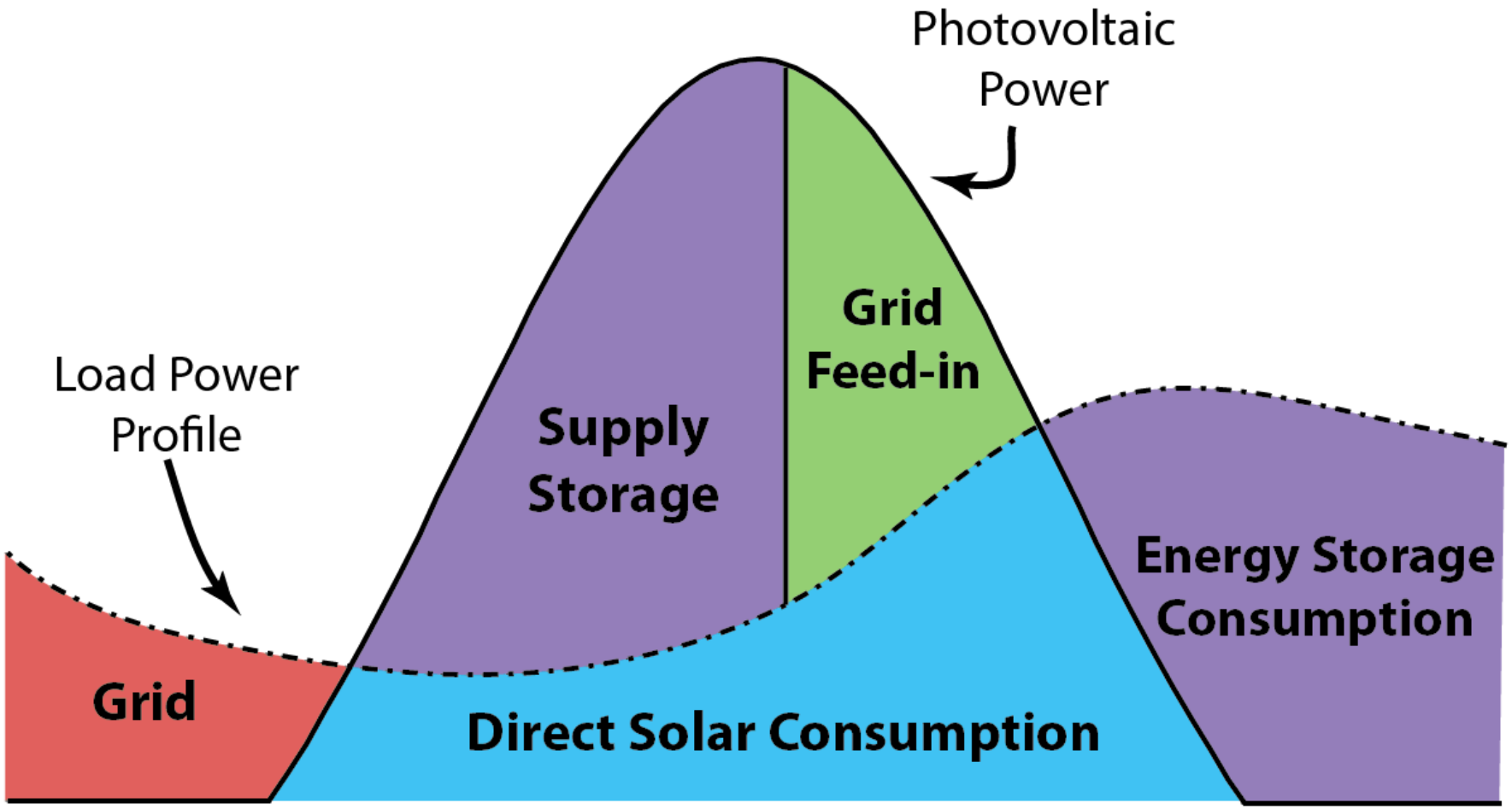
**Battery System:**
- Charge controls
- Discharge controls
- Power electronics

# Why energy storage with solar?




*Adapted from: Smart EnergySystems Website*
*http://www.smart-energy.ag/products/ac-gekoppelte-speicherlosung-smartenergy-ac/?lang=en*

# Peak Demand Shift using Energy Storage

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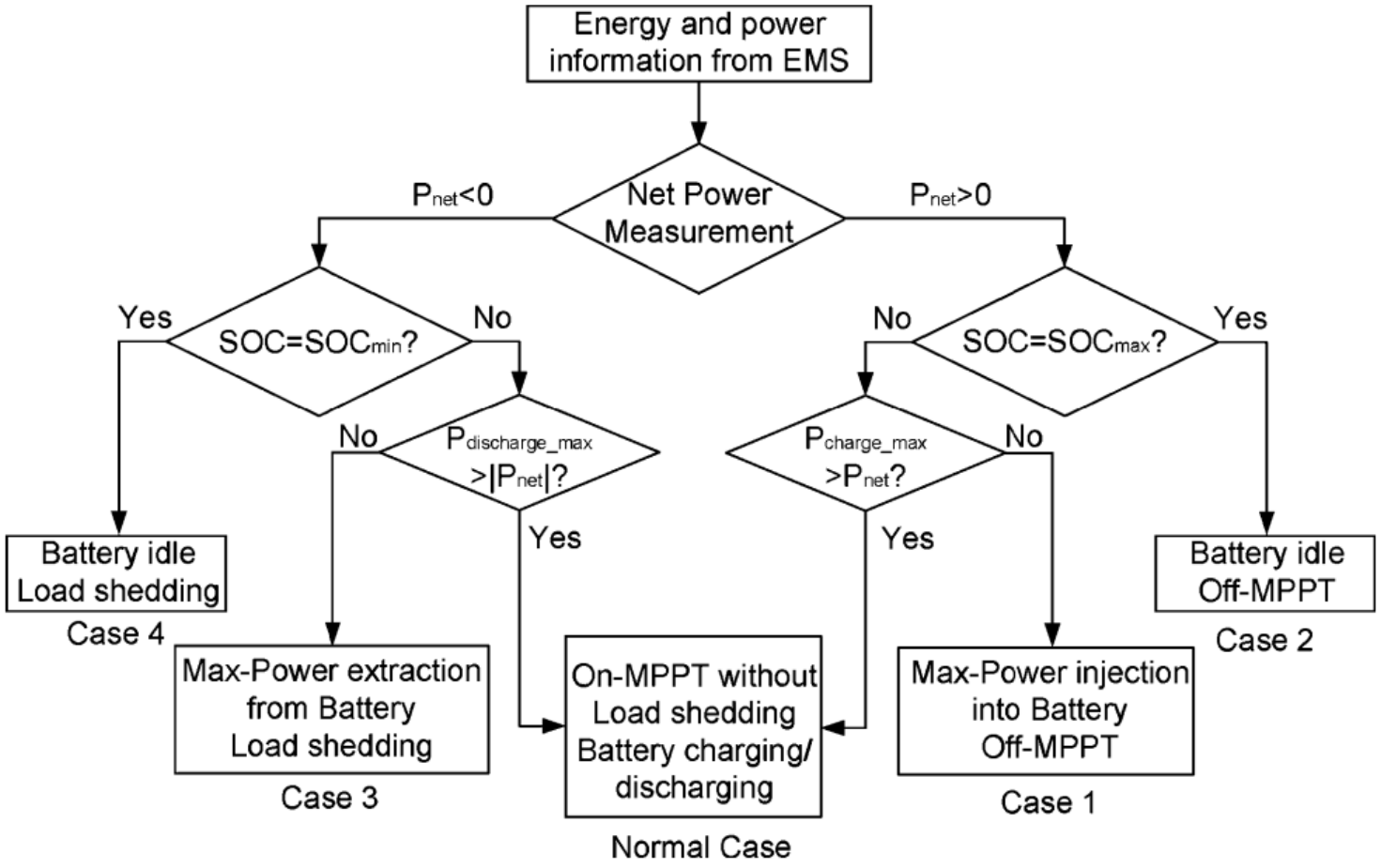
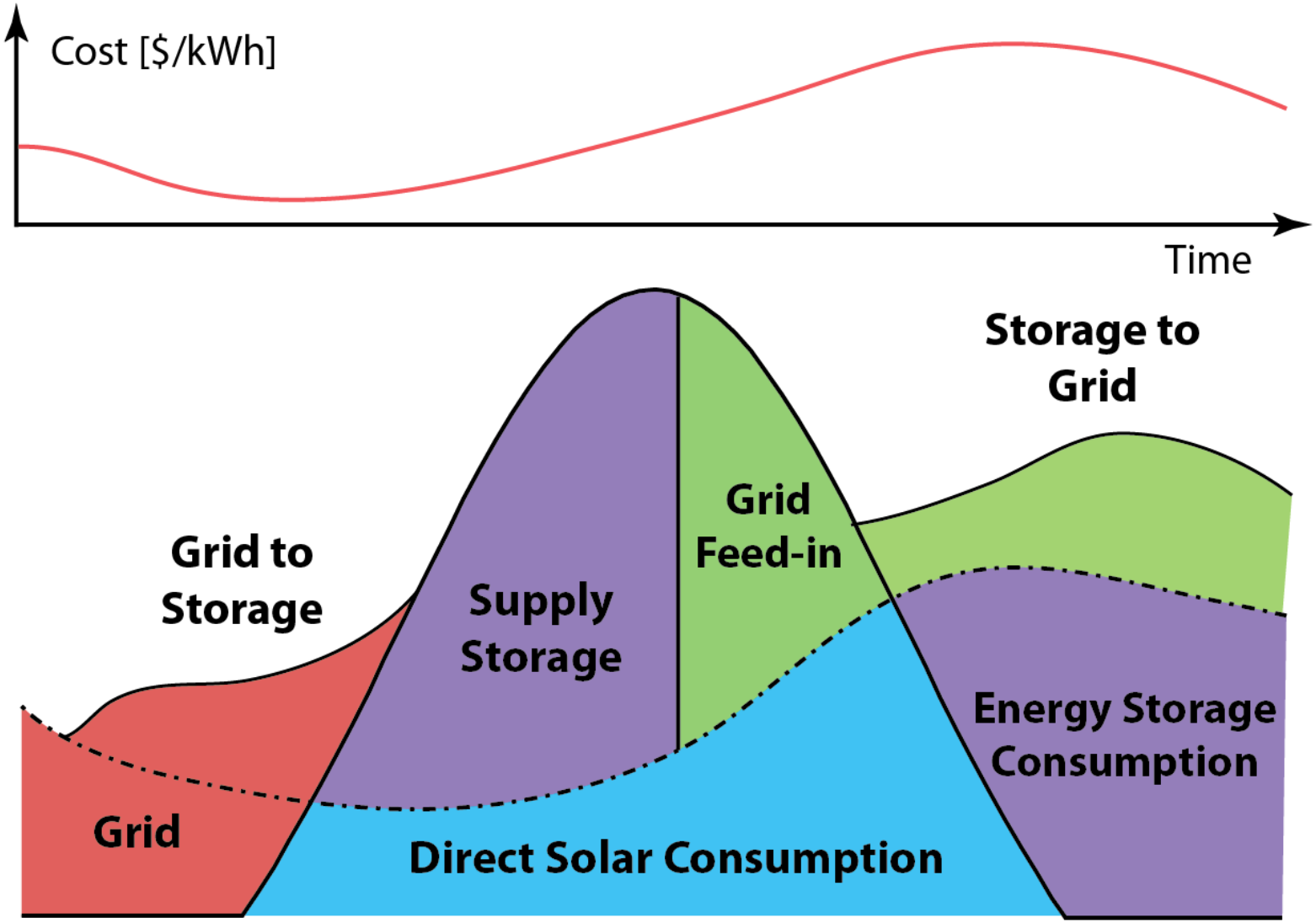
# Implementation of Energy Management Logic




*Ref: Liu 2011 - A Hybrid AC/DC Microgrid and Its Coordination Control*

# Factoring in Variable Electricity Cost




*Adapted from: Smart EnergySystems Website*
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# Optimization-based Peak Demand Shift

- Objective function: *what do we want to minimize/optimize?*
  - Minimize total cost of variable priced electricity

$$C_{tot} = \sum_{k=0}^{N} C_{grid}(k) \cdot E_{grid}(k)$$

- Constraints: *how does our system operate?*
  - Power input/output to battery

$$E_{batt}(k) = E_{batt}(k-1) + P_{batt}(k)\Delta T$$

  - Power balance

$$\underbrace{P_{pv}(k) + P_{grid}(k) + P_{batt}(k)}_{\text{Sources}} = \underbrace{P_{load}(k)}_{\text{Loads}}$$

# Linear program-based Optimization

- Standard form for the Linear program (LP) - linprog

$$\min_x f^T x \quad \text{such that} \quad \begin{cases} A \cdot x \leq b \\ A_{eq} \cdot x = b_{eq} \end{cases}$$

- Define states (x) necessary for LP optimization
  - $P_{grid}$(1:N) – Power from grid used from time step 1 to N
  - $P_{batt}$(1:N) – Power from battery
  - $E_{batt}$(1:N) – Energy stored in battery

$$x = [P_{grid}(1:N) \quad P_{batt}(1:N) \quad E_{batt}(1:N)]^T$$

# Linear program-based Optimization

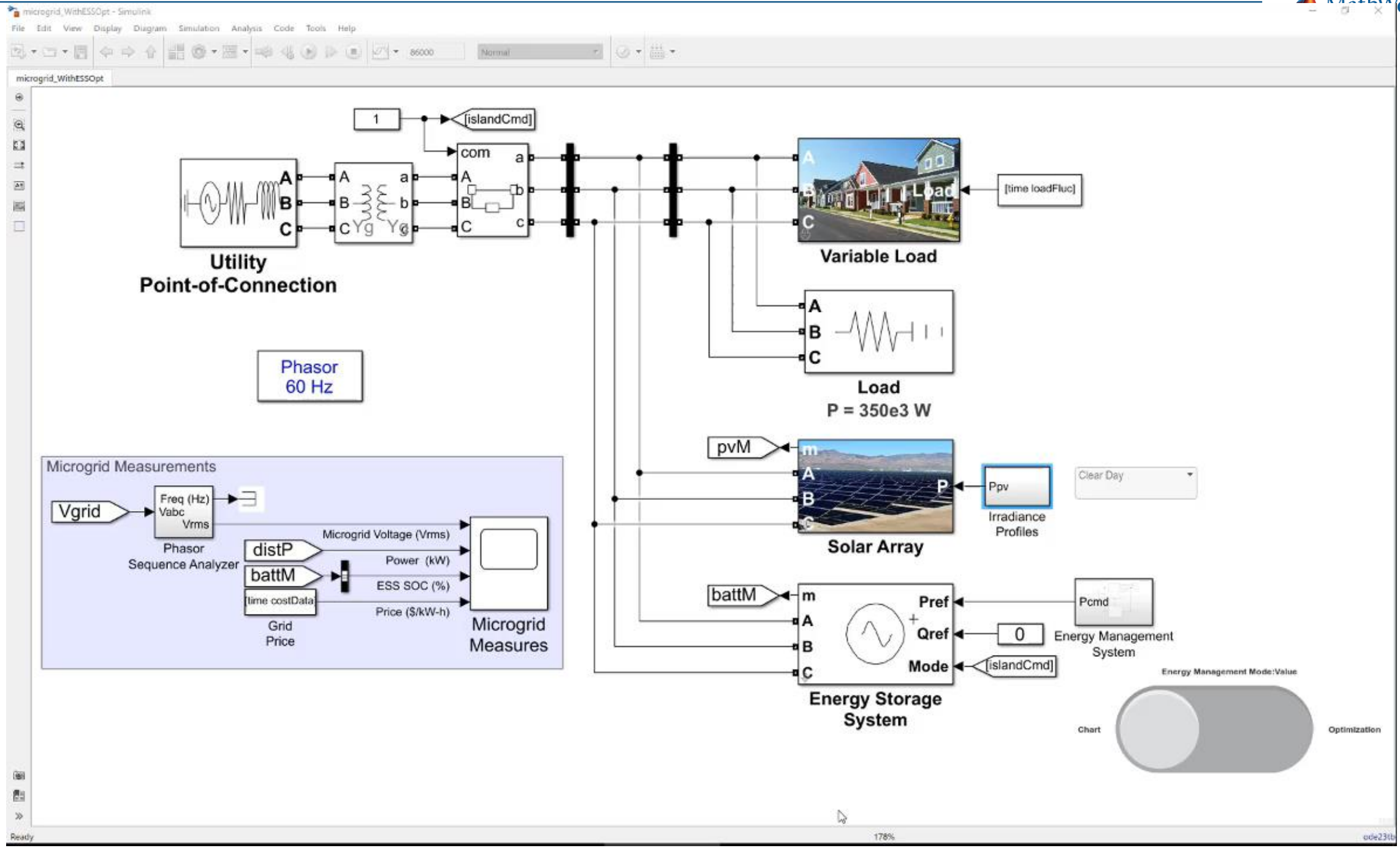
- Equivalent constraint

$$\underbrace{\begin{bmatrix} I_{N\times N} & I_{N\times N} & 0_{N\times N} \\ O_{N\times N} & \Upsilon_{N\times N} & \Phi_{N\times N} \end{bmatrix}}_{A_{eq}} \mathrm{x} = \underbrace{\begin{bmatrix} P_{load}(1:N) - P_{pv}(1:N) \\ E_{batt}(1) \\ 0_{N-1} \end{bmatrix}}_{b_{eq}}$$

$$\Upsilon_{3\times 3} = \begin{bmatrix} 0 & 0 & 0 \\ \Delta T & 0 & 0 \\ 0 & \Delta T & 0 \end{bmatrix} \qquad \Phi_{3\times 3} = \begin{bmatrix} 1 & 0 & 0 \\ -1 & 1 & 0 \\ 0 & -1 & 1 \end{bmatrix}$$

- Inequality constraints

$$\underbrace{\begin{bmatrix} O_{N\times N} & I_{N\times N} & O_{N\times N} \\ O_{N\times N} & -I_{N\times N} & O_{N\times N} \\ O_{N\times N} & O_{N\times N} & I_{N\times N} \\ O_{N\times N} & O_{N\times N} & -I_{N\times N} \end{bmatrix}}_{A} \mathrm{x} \geq \underbrace{\begin{bmatrix} P_{max} \\ -P_{min} \\ E_{max} \\ -E_{min} \end{bmatrix}}_{b}$$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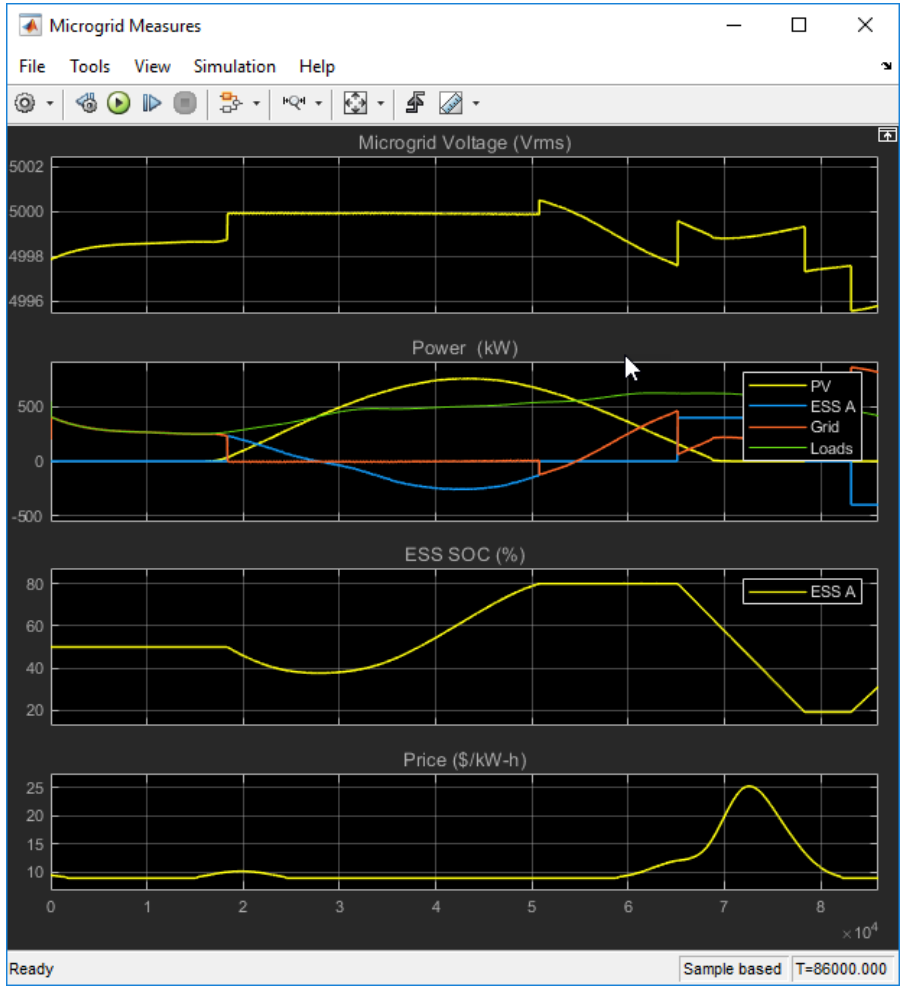
# Policy Comparison

## Heuristic




## Optimized