Optimal Sizing of Microgrid:
The Skagerak Stadium, Norway

- Emmanuel Mompremier
- Nuril Hidayati
- Olamilekan Olugbayila

The Skagerak Stadium, Norway

Microgrid Details

- Power generation: Photovoltaic
- Energy Storage: Battery
- PV + Battery is connected to the grid to export energy

Objective Function

- **Minimizing the investment cost** of energy production to **supply the load** demand of the stadium **without importing energy** from the grid

Expected Optimization Output

- Number of PV panels
- Number of battery cells
- Initial state of charge of the battery
- Overall investment cost
- Yearly revenue (coming from selling excess electricity to the grid)
- Payback period

Methodology

- Data collection and cleaning
- Variable definition
- Constraint definition
- Mathematical modeling of objective function

Methodology

Variable Definition

- **PV generator output:**

$$P_{PV}(t) = N_{PV} \cdot \eta_{PV} \cdot P_{STC} \cdot \frac{GSR(t)}{G_{STC}} \cdot \left(1 - C_T \cdot (T(t) - T_{STC})\right)$$

  - N_{PV} is number of panels; η_{PV} is the panel efficiency
  - P_{STC} is the nominal power under standard test conditions
  - G_{STC} is Global solar radiation (1kW)
  - C_T is the temperature coefficient
  - T_{STC} is 25°C

- **Maximum number of PV panels:**

$$N_{PV\,max} = \frac{(Total\ Available\ Surface\ area\ for\ PVs)}{Surface\ area\ for\ one\ PV\ panel}$$

Variable Definition

- **Battery Cells**

$$SOC(t+\Delta t) = SOC(t) - \eta_{Bat} \cdot \frac{P_{Bat}}{N_{Cell} \cdot C_{Cell}} \cdot \Delta t$$

  - SOC is the state of charge
  - η_{Bat} is the battery efficiency
  - P_{Bat} is the battery power
  - N_{Cell} is the number of cells
  - C_{Cell} is the battery cell capacity

Constraint

1. **Bounds on the variables**:
   - The maximum available area for PV panels: $N_{PV\ max}$
   - Battery cells size: 100 min and 25,900 cells max

2. **No unsupplied Load**
   - Always supply the load demand of the stadium either by supply from PV generation or battery capacity

3. **$SOC_{min} \leq SOC \leq SOC_{max}$**
   - State of charge: 5% - 95%

4. **SOC (end of day) ≥ SOC (beginning of day)**

Objective Function

$$\min_{\mathbf{x}} \; Cost^{inv}(\mathbf{x})$$

subjected to:

$$\mathbf{x^l} \leq \mathbf{x} \leq \mathbf{x^u}$$

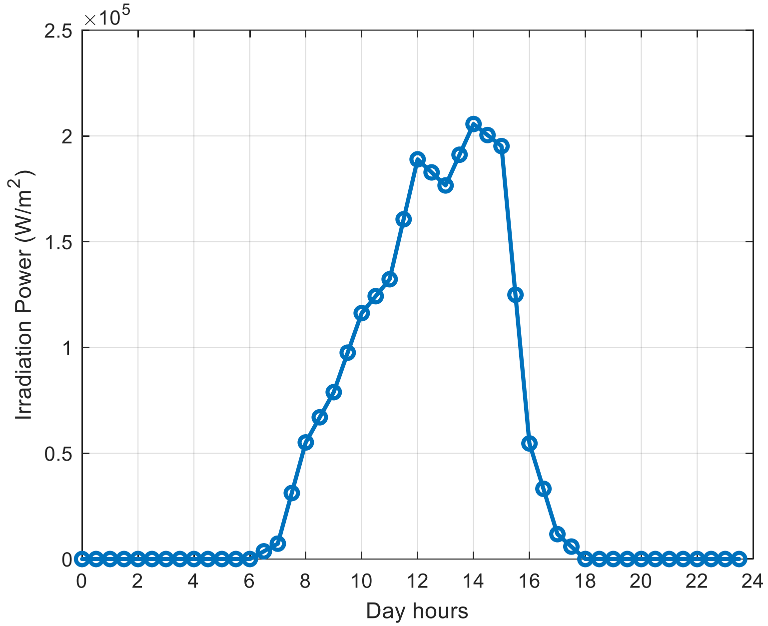
$$SOC_{min} \leq SOC(\mathbf{x}, t) \leq SOC_{max}, \; \forall \, t \in \text{Day}$$

$$P_{unsup}(\mathbf{x}, t) = 0, \; \forall \, t \in \text{Day}$$

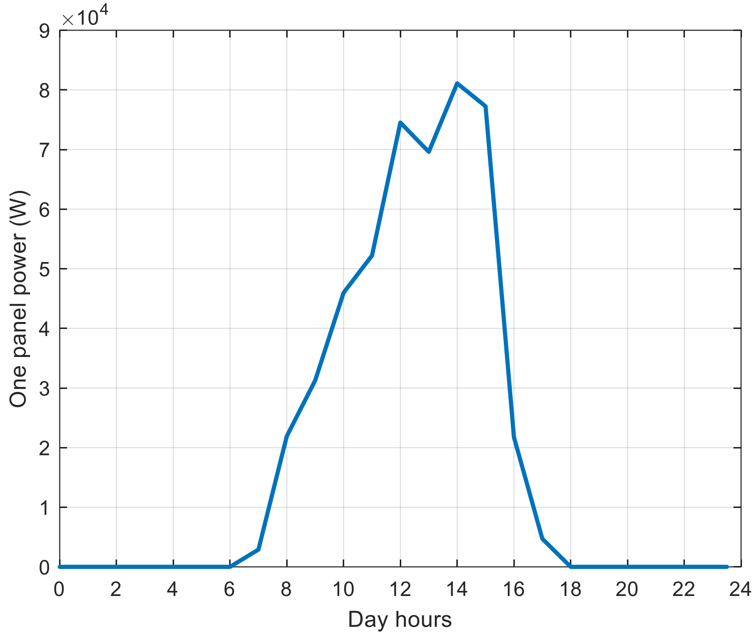
$$SOC(\mathbf{x}, t_{final}) \geq SOC(\mathbf{x}, t_{start})$$

Parameters of PV panel, Battery, Grid

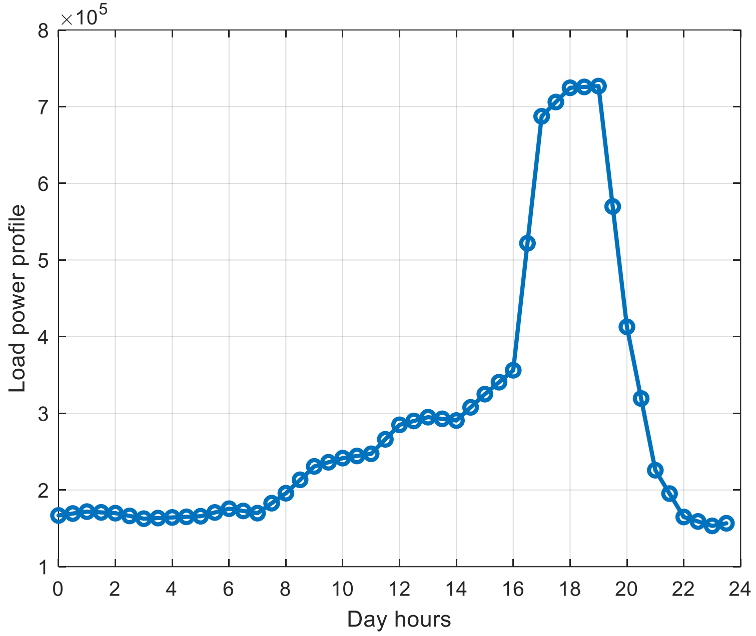
Simulation Parameters	
Parameter	**Value**
Solar panels	
PV array rated power in standard test conditions (STC)	380 W
Solar radiation under STC	$1000\ \frac{W}{m^2}$
Temperature coefficient	$-0.34 \cdot 10^{-2}$ / °C
Temperature STC	25 °C
Electrical Efficiency of PV Panels	0.95
Price of PV	7400 €/kW
Battery System Specifications	
Cell Capacity	30 Ah/3.6 V
Charging Efficiency	0.95
Minimum SOC	0.05
Maximum SOC	0.95
Minimum amount of cell	100
Maximum amount of cell	25900
DC/DC Efficiency	0.98
AC/DC Efficiency	0.95
Price of cell	470 €/kWh
Grid	
Export Price	$0.04 \cdot 10^{-3}$ €/kWh



Solar Irradiance



Power Generated by 1 PVPanel



Load Profile

Utilized data

All utilized data for 11 March 2018, date of the largest demand

Algorithm – Cost Minimization

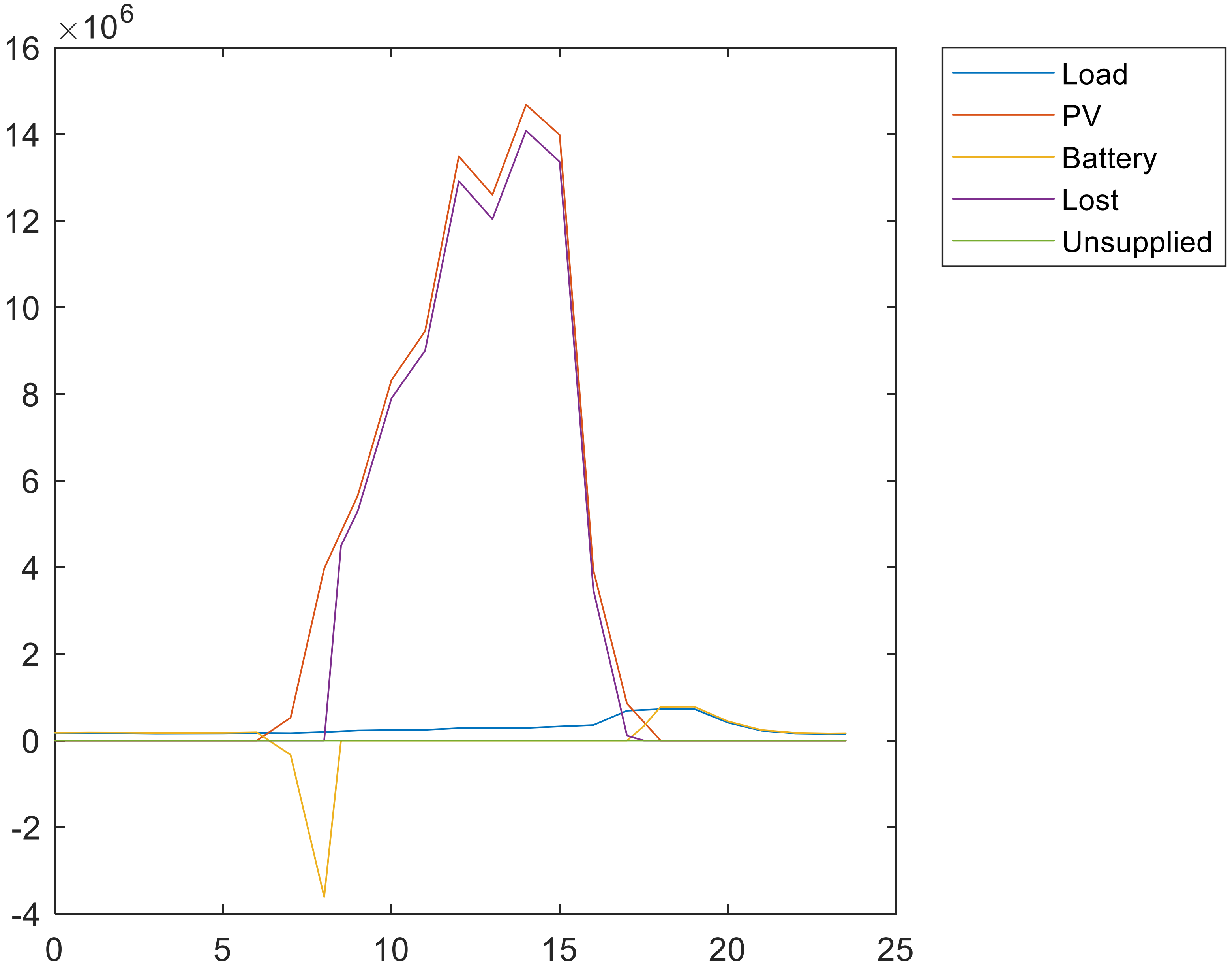
SOC_{bat}, Battery SOC in %
P_L , Load demand in kW
P_{PV} , PV generation in kW
P_{bat_c} , Power stored in the battery system in kW
P_{bat_d} , Power discharged from the battery system in kW
P_{lost} , Power generated but not used (subsequently sold to the grid) in kW
$P_{unsupplied}$, Unsupplied power in kW
$P_{unsupplied} = P_L - P_{PV}$

for t=1:number of solar generation data points **do**
  if $P_{unsupplied} < 0$ and $SOC_{bat} < 95$ **then**
    $P_{bat\_c} = -P_{unsupplied}$
  else if $P_{unsupplied} < 0$ and $SOC_{bat} = 95$ **then**
    $P_{lost} = -P_{unsupplied}$
  else if $P_{unsupplied} > 0$ and $SOC_{bat} > 0$ **then**
    $P_{bat\_d} = P_{unsupplied}$

Results & Discussion

Optimal Design Result

- Number of PV panels: 181
- Number of battery cells: 2589
- Initial SOC of batter: 62%
- Total investment cost: € 1.82 million
- Yearly revenue: € 1.15 million
- Payback period: 19 months



Power Profile (kW) of the optimizely sized microgrid

Thank you for your attention