

# Microgrid Scheduling in NYC

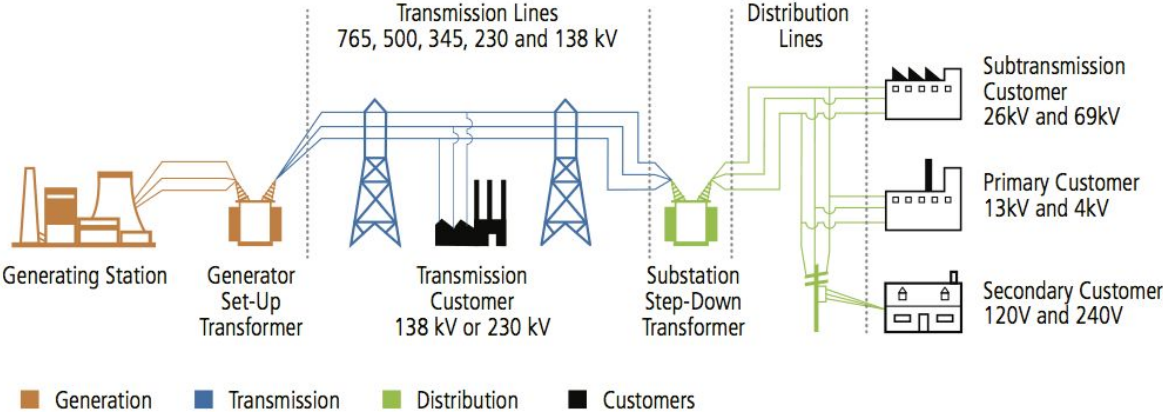
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By Maria, Sam, Vanessa, Wendy

# **Hurricane Sandy led to extended outages, especially for vulnerable populations**

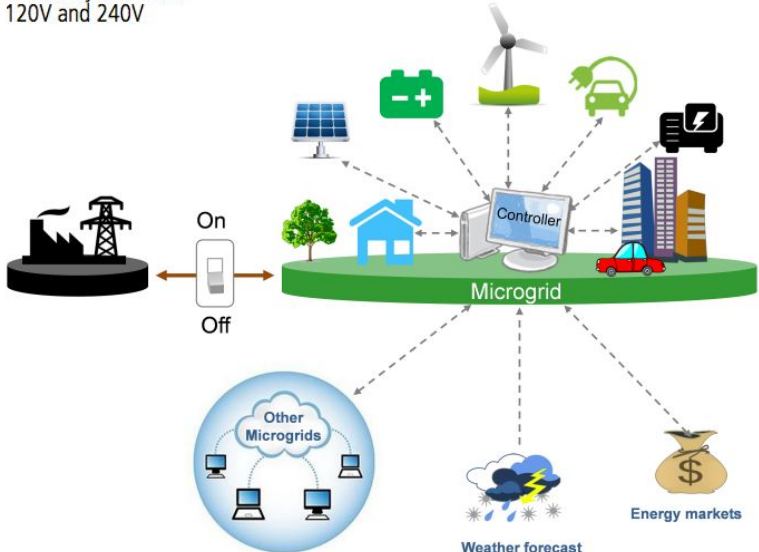


# Linear Grids vs. Microgrids



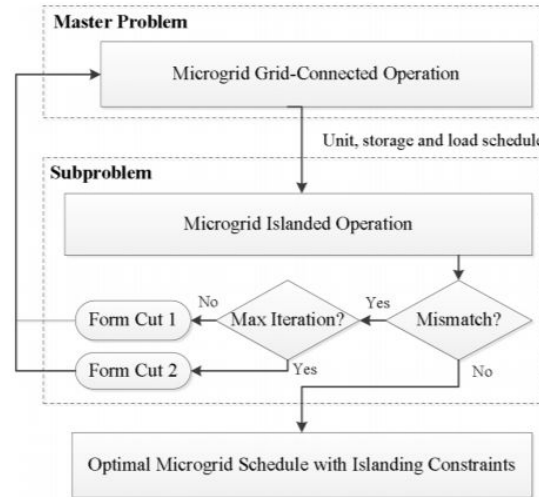
The electricity grid is designed linearly where if a portion breaks, the entire distribution network goes down

Microgrids solve this problem by creating self-sufficient units of electricity distribution



# Model 1: MIP with Benders Decomposition

Master problem:  
determines the optimal commitment & dispatch of available dispatchable units, charging and discharging schedules of energy storage systems, schedule of adjustable loads.



Subproblem:  
confirms an uninterrupted supply of loads for a variety of islanding scenarios

# Model 1: MIP

Minimizes the microgrid total operation cost

$$\text{Min} \sum_t \sum_{i \in G} [F_i(P_{it})I_{it} + SU_{it} + SD_{it}] + \sum_t \rho_t P_{M,t}. \quad (1)$$

$$\sum_i P_{it} + P_{M,t} = \sum_d D_{dt} \quad \forall t \quad (2)$$

$$-P_M^{\max} \leq P_{M,t} \leq P_M^{\max} \quad \forall t \quad (3)$$

$$P_i^{\min} I_{it} \leq P_{it} \leq P_i^{\max} I_{it} \quad \forall i \in G, \forall t \quad (4)$$

$$P_{it} - P_{i(t-1)} \leq UR_i \quad \forall i \in G, \forall t \quad (5)$$

$$P_{i(t-1)} - P_{it} \leq DR_i \quad \forall i \in G, \forall t \quad (6)$$

$$T_{it}^{\text{on}} \geq UT_i (I_{it} - I_{i(t-1)}) \quad \forall i \in G, \forall t \quad (7)$$

$$T_{it}^{\text{off}} \geq DT_i (I_{i(t-1)} - I_{it}) \quad \forall i \in G, \forall t \quad (8)$$

$$P_{it} \leq P_{it}^{\text{dch,max}} u_{it} - P_{it}^{\text{ch,min}} v_{it} \quad \forall i \in S, \forall t \quad (9)$$

$$P_{it} \geq P_{it}^{\text{dch,min}} u_{it} - P_{it}^{\text{ch,max}} v_{it} \quad \forall i \in S, \forall t \quad (10)$$

$$u_{it} + v_{it} \leq 1 \quad \forall i \in S, \forall t \quad (11)$$

$$C_{it} = C_{i(t-1)} - P_{it} \quad \forall i \in S, \forall t \quad (12)$$

$$0 \leq C_{it} \leq C_i^{\max} \quad \forall i \in S, \forall t \quad (13)$$

$$T_{it}^{\text{ch}} \geq MC_i (u_{it} - u_{i(t-1)}) \quad \forall i \in S, \forall t \quad (14)$$

$$T_{it}^{\text{dch}} \geq MD_i (v_{it} - v_{i(t-1)}) \quad \forall i \in S, \forall t \quad (15)$$

$$D_{dt}^{\min} z_{dt} \leq D_{dt} \leq D_{dt}^{\max} z_{dt} \quad \forall d \in D, \forall t \quad (16)$$

$$\sum_{t \in [\alpha_d, \beta_d]} D_{dt} = E_d \quad \forall d \in D \quad (17)$$

$$T_{dt}^{\text{on}} \geq MU_d (z_{dt} - z_{d(t-1)}) \quad \forall d \in D, \forall t. \quad (18)$$

Subject to:  
generating unit,  
energy storage system,  
and load constraints

$$\text{Min } w_s = \sum_t (SL_{1,ts} + SL_{2,ts}) \quad (19) \quad \text{Minimizes power mismatches}$$

$$\sum_i P_{its} + P_{M,ts} + SL_{1,ts} - SL_{2,ts} = \sum_d D_{dts} \quad \forall t \quad (20)$$

$$I_{its} = \hat{I}_{it} \quad \lambda_{its} \quad \forall i \in G, \forall t \quad (21)$$

$$u_{its} = \hat{u}_{it} \quad \mu_{its}^{\text{dch}} \quad \forall i \in S, \forall t \quad (22)$$

$$v_{its} = \hat{v}_{it} \quad \mu_{its}^{\text{ch}} \quad \forall i \in S, \forall t \quad (23)$$

$$z_{dts} = \hat{z}_{dt} \quad \pi_{dts} \quad \forall d \in D, \forall t \quad (24)$$

$$-P_M^{\max} U_{ts} \leq P_{M,ts} \leq P_M^{\max} U_{ts} \quad \forall t \quad (25)$$

$$P_i^{\min} I_{its} \leq P_{its} \leq P_i^{\max} I_{its} \quad \forall i \in G, \forall t \quad (26)$$

$$P_{its} - P_{i(t-1)s} \leq UR_i \quad \forall i \in G, \forall t \quad (27)$$

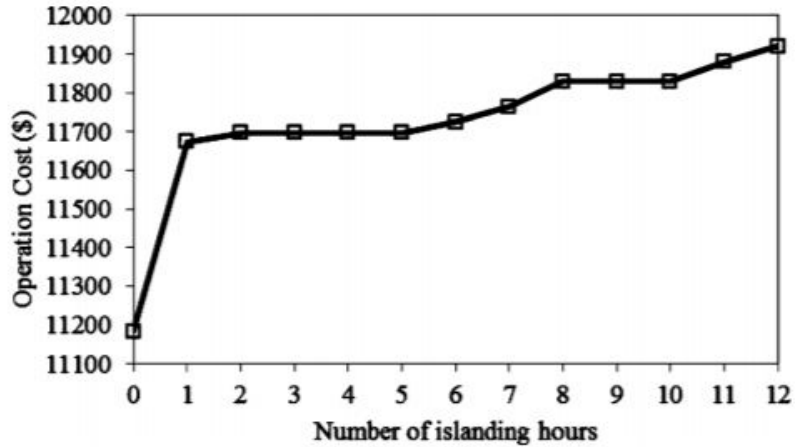
$$P_{i(t-1)s} - P_{its} \leq DR_i \quad \forall i \in G, \forall t \quad (28)$$

$$P_{its} \leq P_{its}^{\text{dch,max}} u_{its} - P_{its}^{\text{ch,min}} v_{its} \quad \forall i \in S, \forall t \quad (29)$$

$$P_{its} \geq P_{its}^{\text{dch,min}} u_{its} - P_{its}^{\text{ch,max}} v_{its} \quad \forall i \in S, \forall t \quad (30)$$

$$C_{its} = C_{i(t-1)s} - P_{its} \quad \forall i \in S, \forall t \quad (31)$$

# Model 1: Pros vs Cons



- 1) Low Operational Cost
- 2) Seamless islanding
- 3) Computationally efficient
- 4) Reduces peak load effectively
- 5) Model scalability and flexibility

# Model 2: MILP with Zone Structure

- Power structure divided into zones
  - Each zone has specific electricity demand
  - Can exchange electrical energy with main-grid during surplus/shortage
- Trade-off Relationship demonstrates higher costs are tied to an even larger proportional emissions reductions

$$\begin{aligned}
 & \overbrace{\sum_{i \in I} \sum_{z \in Z} \sum_{rd \in RD} \text{Fuel}_{i,rd} * \text{tfuel}_{z,rd} * \text{dur}_{rd}}^{\text{Fuel cost}} \\
 & \quad \quad \quad \text{Electricity discharge cost} \\
 & + \overbrace{\sum_{t \in T} \sum_{z \in Z} \sum_{rd \in RD} \text{Bdisp}_{rd,t} * \text{bdischarge}_{rd,t,z} * \text{dur}_{rd}}^{\text{Electricity purchases cost}} \\
 & + \overbrace{\sum_{t \in T} \sum_{rd \in RD} \text{Np}_{rd,t} * \text{ebuyn}_{rd,t} * \text{dur}_{rd}}^{\text{Electricity sales revenues}} \\
 & \text{Min}\{ \\
 & \quad \quad \quad \overbrace{- \sum_{t \in T} \sum_{rd \in RD} \text{Nprofit}_{rd,t} * \text{etonn}_{rd,t} * \text{dur}_{rd}}^{\text{Annualized investment cost (thermal units)}} \\
 & \quad \quad \quad \overbrace{+ \sum_{i \in I} \sum_{z \in Z} \text{CRF}_i * \text{Totcost}_i * \text{Cap}_i * \text{yinst}_{i,z}}^{\text{Annualized investment cost (renewable units)}} \\
 & \quad \quad \quad \overbrace{+ \sum_{j \in J} \sum_{z \in Z} \text{CRF}_j * \text{Totcost}_j * \text{Cap}_{ren}_{j,z}}^{\text{Annualized investment cost (renewable units)}} \\
 & \quad \quad \quad \left. \right\}
 \end{aligned}$$

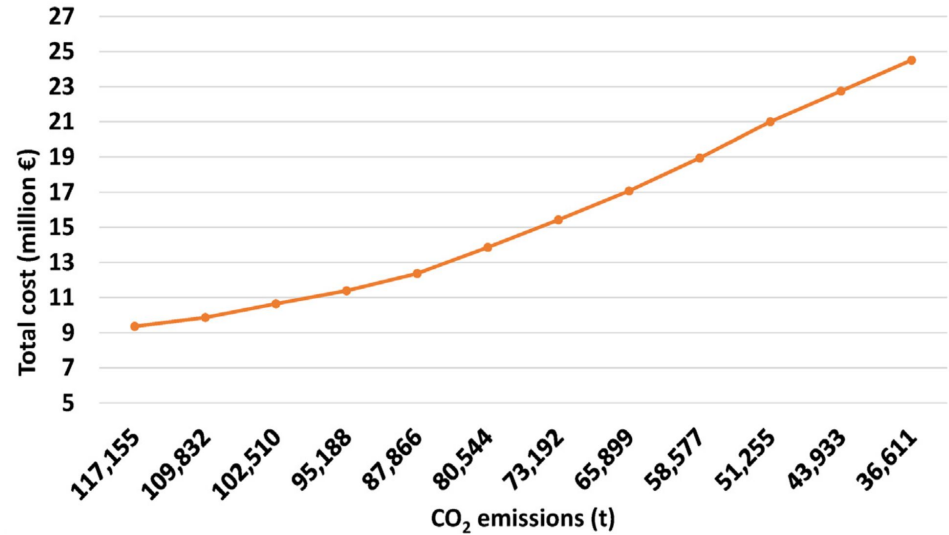
# Model 2: Pros & Cons

## Pros:

- Can install electricity production resources according to each zone's specific demand requirements
- Zonal structure enables better utilization of electricity produced, via exchanges between zones in cases of surplus/shortage

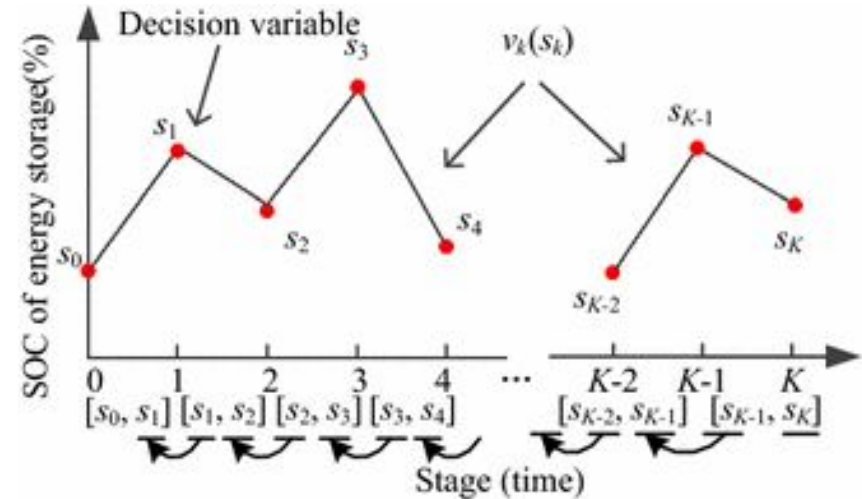
## Cons:

- Cost trade-off for emission reductions may not sufficient prior to carbon regulation



# Model 3: Dynamic Programming

- From the current stage, it selects the lowest cost next step from the set of reachable energy states
  - Based on energy production & demand forecasts
- Searches for shortest path (lowest operational cost) while satisfying demand
  - Segment length = period's operating cost
  - node = period's energy state



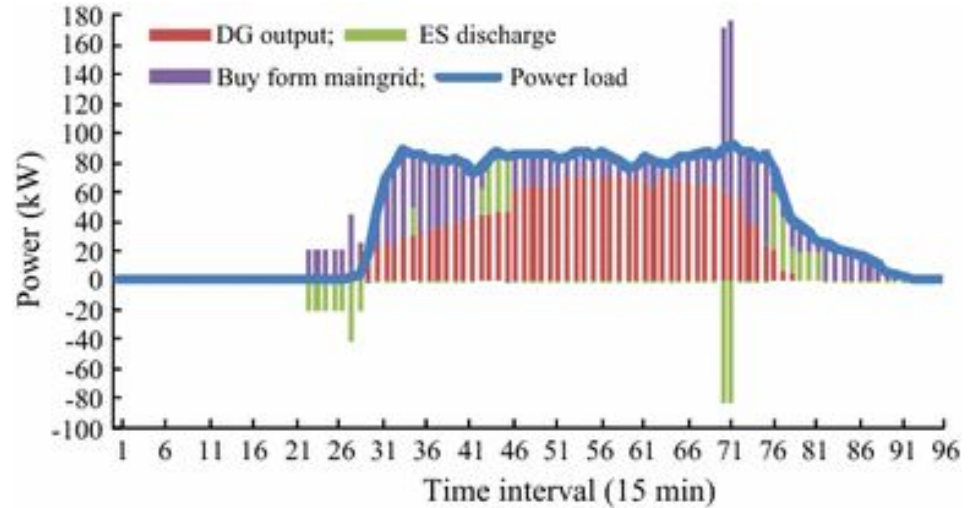
# Model 3: Pros & Cons

## Pros:

- Successful at reducing peak load
  - reduces cost & meets demand
- Low computational & memory needs
- Integrates energy storage operational costs (charging/drawdown)

## Cons:

- Paper did not quantify the approach in comparison to other methods
- Did not address islanding performance



# Model 4: Two Stage Stochastic Programming

- Resiliency oriented
- Objective function minimizes expected social cost
- Assigns probability distribution function (PDF) to each random parameter
- Day-ahead scheduling horizon

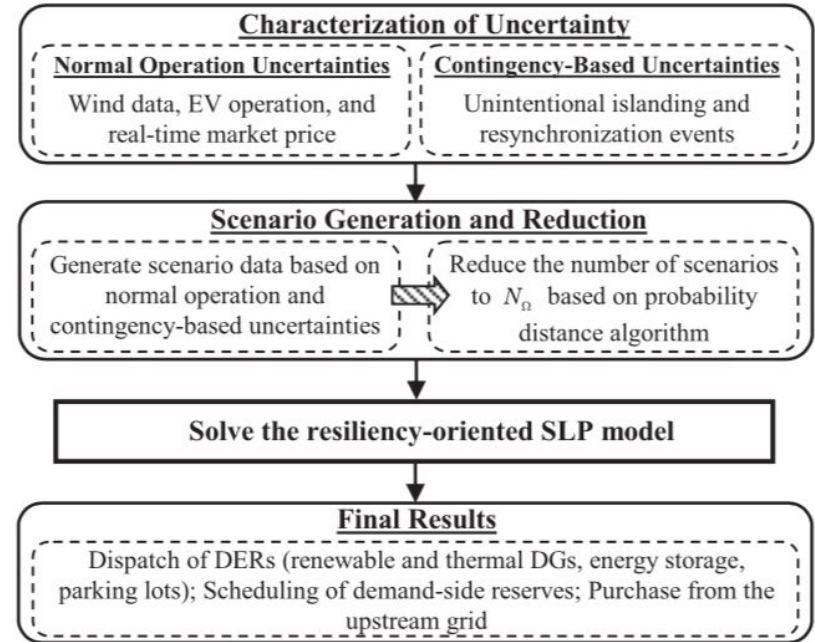


Fig. 2. Framework for resiliency-oriented MG scheduling.

# Model 4: Pros & Cons

## Pros:

- Effectively schedules reserves and flexible loads
- Low load shedding cost
- Conservation voltage regulation (CVR) enhances resilience following voltage sag during islanding

## Cons:

- High operational cost during islanding

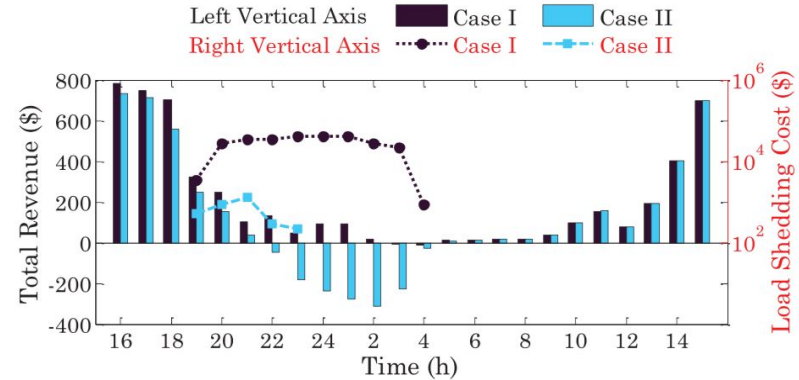


Fig. 7. Hourly cost analysis of MG schedules.

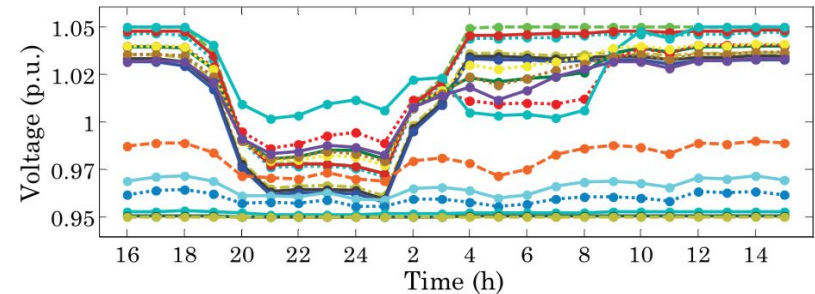


Fig. 9. CVR effect on bus voltages during the scheduling horizon.

# New York City Needs

- Good at islanding during emergencies
- Excellent at reducing peak load
  - Electricity in NYC is very costly, especially during peak hours
- Computationally efficient
- Adaptable to any regulatory environment (ex. low-cost in the case of a carbon tax)



# Recommendation

## Main model:

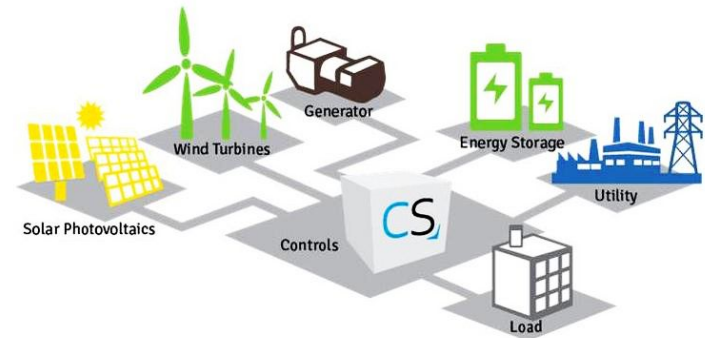
- MIP with Bender's Decomposition
  - Computationally efficient for high numbers of adjustable loads
  - Successfully islands at low marginal cost
  - Effectively reduces load from main-grid during most expensive hours

## Additional aspects to integrate:

- Integrate battery storage costs to operational cost function
- Allow linking between microgrids to share resources (like the zones in Model 2)

## Risks:

- Possibly not possible to scale a microgrids to all of NYC
  - Not enough space for local energy resources
  - If microgrid boundaries are too large then it might become too complex



**Thank you!**