Demand shaping through load shedding and shifting using day-ahead and real-time prices

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IEEE PES Power & Energy Society®

Overview

- Demand-Response
- System description
- Problem formulation
- Numerical results

Demand-Response

- Demand-Response enables automatic curtailment of electricity
- It is used when demand is expected to exceed the normal capacity
- Consumers agree to reduce the the use of A/C, water pumps, etc, during critical time intervals of very hot days in summer
- This reduction generates extra capacity, which is used to meet peak demand
- In return consumers receive certain incentives/benefits proportional to the loads they shed
- Reduces the risk of brownouts and blackouts
- Can lower electricity bills
- May reduce the emissions from fossil-based fired power plants

System description

- We consider three types of electricity load:

  1. Sheddable load, 2. Shiftable load, 3. Non-moveable load

- Sheddable load example: increase the target temperature of A/C
- Shiftable load example: Washing machine rescheduling time
- Non-moveable load example: Refrigerators running at the lowest viable temperature
- q_{it}: total load of user i at time t
- $q_{it}^{(d)}$: sheddable load
- $q_{it}^{(s)}$: shiftable load
- $q_{it}^{(n)}$: non-moveable load

$$q_{it} = q_{it}^{(d)} + q_{it}^{(s)} + q_{it}^{(n)}$$

System description (cont)

- y_{it}: actual sheddable load ($y_{it} \leq q_{it}^{(d)}$)
- $D_i(y_{it})$: discomfort of customer when shedding load of y_{it})
- $p_{it}^{(d)}$: incentive price per unit of load shed
- $[\alpha_{ij}, \beta_{ij}]$: time interval of use for appliance j
- x_{ijt}: consumption of appliance j ($x_{ijt} = 0, \forall t \notin [\alpha_{ij}, \beta_{ij}]$)
- $B_{it}^{f}(q)$: billing structure for shiftable and sheddable loads
- $B_{it}^{s}(q)$: billing structure for non-moveable loads
- $C_t^{dam}(q)$: cost of purchasing energy in day-ahead market
- $C_t^{rtm}(q)$: cost of purchasing energy in real-time market

Problem formulation

Utility's problem:

$$
\begin{aligned}
\max_{x,y,q_t^{(n)}} \quad & \sum_t \sum_i (B_{it} - p_t^{(d)} y_{it} - C_t) \\
s.t. \quad & q_{it}^{(s)} = \sum_j x_{ijt}, \forall t, i \\
& \sum_t x_{ijt} = x_{ij}^{max}, \forall i, j \\
& x_{ijt} = 0, \forall t \notin [\alpha_{ij}, \beta_{ij}] \text{ and } \forall i, j \\
& \leq y_{it} \leq q_{it}^{(d)}, \forall t, i \\
& x_{ijt}^{min} \leq x_{ijt} \leq x_{ijt}^{max}, \forall i, j, t
\end{aligned}
$$

$$C_t^f(q) = \min\left\{C_t^{dam}(q), C_t^{rtm}(q)\right\}$$

$$C_t = C_t^f(Q_t^{(d)} - Y_t + Q_t^{(n)pred}) + C_t^{rtm}(Q_t^{(n)real} - Q_t^{(n)pred})$$

$$B_{it} = B^f(q_{it}^{(s)} + q_{it}^{(d)} - y_{it}) + B_t^s(q_{it}^{(n)})$$

Problem formulation (cont)

Consumer's problem:

$$\begin{aligned}
\min_{x,y} \quad & B_{it} + D_{it}(y_{it}) - p_{it}^{(d)} y_{it} \\
s.t. \quad & q_{it}^{(s)} = \sum_j x_{ijt}, \forall t \\
& \sum_t x_{ijt} = x_{ij}^{max}, \forall j \\
& x_{ijt} = 0, \forall t \notin [\alpha_{ij}, \beta_{ij}] \text{ and } \forall j \\
& 0 \leq y_{it} \leq q_{it}^{(d)}, \forall t \\
& x_{ijt}^{min} \leq x_{ijt} \leq x_{ijt}^{max}, \forall j, t
\end{aligned}$$

Consumers try to minimize their losses

The algorithm alternates between solutions of the Utility problem and the Consumer problem, until convergence is achieved.

Numerical results

Data generation:

- We used 18 months of hourly electricity consumption data obtained from residential homes in Texas
- We generated demand data for $n = 1000$ consumers
- We randomly split the loads of each consumer to shiftable, shedable and non-moveable for each hour
- We obtained DAM and RTM energy prices from ERCOT
- We consider the discomfort function $D_i(y_{it}) = a_{it}y_{it}^2 + b^f y_{it}$
- Base case: Utility will purchase all forecasted energy from DAM, and the remaining from RTM.

Numerical results (cont)

Base case

Total Procurement Cost: $406,577.11
Flat Electricity Rate to Consumers: $29.80/*unit*

Algorithmic solution

Total Procurement Cost: $356,750.68

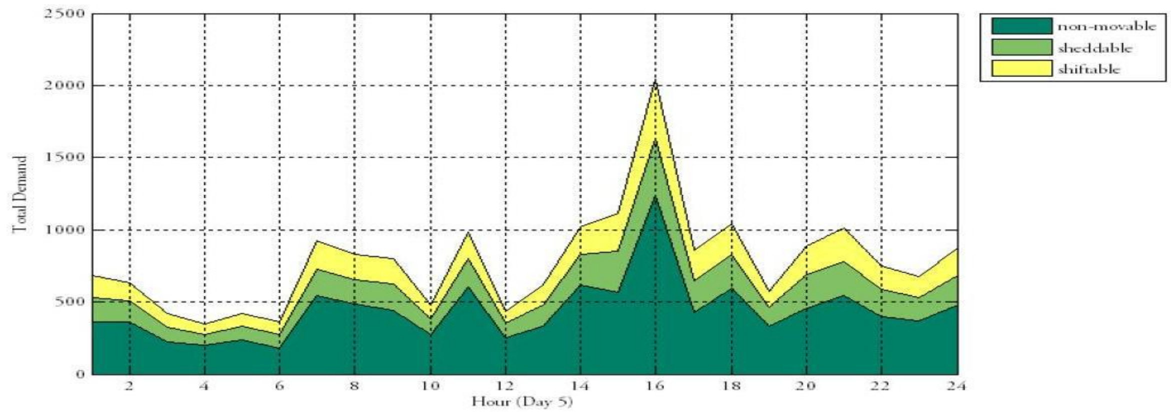
Improvement: 12.2551%

Hourly Rate to Consumers:

Time	Cost ($)	Time	Cost ($)	Time	Cost ($)	Time	Cost ($)
01:00	27.1531	07:00	32.2719	13:00	31.6678	19:00	46.4729
02:00	27.1531	08:00	37.2521	14:00	37.2501	20:00	32.1254
03:00	27.1531	09:00	36.6841	15:00	37.1531	21:00	24.5637
04:00	27.1531	10:00	35.5590	16:00	37.1531	22:00	23.9760
05:00	27.1531	11:00	35.8228	17:00	37.1531	23:00	24.3407
06:00	24.7797	12:00	34.6187	18:00	37.1531	24:00	23.1531

Numerical results (cont)

Demand profile without Demand-Response ⟶



Demand profile using our Demand-Response algorithm ⟶