A Heuristic Approach to Resource Allocation in the Emerging Smart Grid

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MOTIVATION

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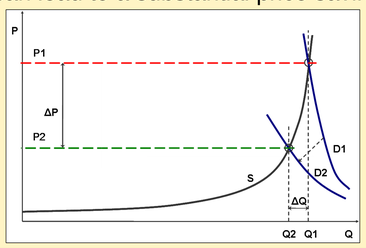
- **Physical**
  - according to the United States Department of Energy, growth in the peak demand for energy has exceeded transmission growth by 25% each year
    - given current trends, peak energy demands will exceed available transmission capability
    - can deal with this by creating distributed generation or by negative generation in the form of curtailing load
- **Economical**
  - a small reduction in consumption during peak times can lead to a substantial price savings



PROBLEM STATEMENT

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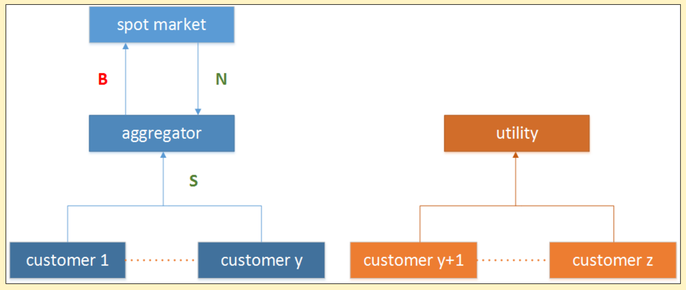
- **Given**
  - information about a set of customer schedulable loads
  - spot market pricing (forecast)
  - dynamic pricing (forecast)
- **Constraints**
  - customer asset availability
  - asset constraints
  - network constraints
  - system constraints
- **Objective**
  - using perceived correlation between aggregator profit and the peak to move the peak loads
  - find a **customer incentive vector** and **schedule loads** to maximize aggregator profit
    - aggregator incomes (selling negative load, ***N***, and selling electricity to customer, ***S***) minus costs (buying from spot market, ***B***)



SYSTEM MODEL

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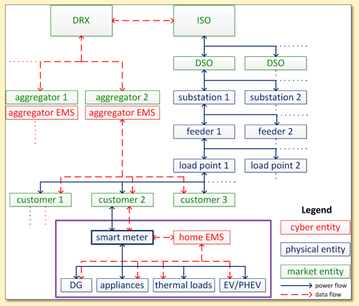

- **Enablers**
  - cyber-physical systems
  - dynamic pricing of electricity
  - control/communication infrastructure
  - end user willingness
- **Aggregator**
  - proposed entity in a deregulated market structure
  - to lower the peak, the aggregator has a set of participating customers and information about their schedulable loads
  - offers the end user the chance to engage in the spot market
- **Customer**
  - has a set of schedulable loads (e.g., smart appliances, PHEVs)
  - by offering their loads, the customer may pay less for electricity (the customer incentive vector instead of dynamic pricing)

RESULTS AND FUTURE WORK

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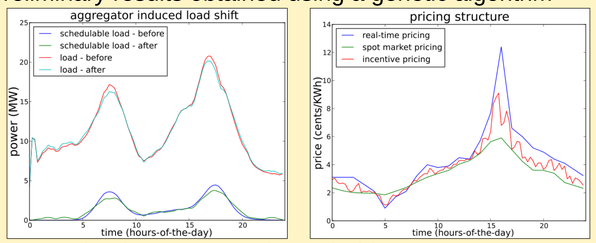
- **Results**
  - preliminary results obtained using a genetic algorithm



  - ~56,000 loads over 5,555 households
  - final objective value of $36,474.91 (one day)
- **Future Steps**
  - design, implement, and analyze other heuristics
  - explore scalability of the heuristics
  - explore spatial stochasticity of PHEVs and other uncertainties
  - interaction with power systems software
  - parallelize on Cray HPC System

Citation:

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SMART GRID RESOURCE ALLOCATION

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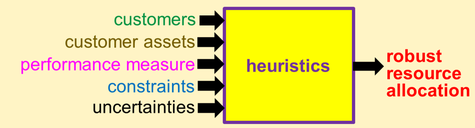
- **Smart Grid Complexity**
  - Smart Grid will contain many more **distributed** assets
  - schedulable assets with diverse roles
  - temporal and spatial stochasticity of assets



- **Bridge to Resource Allocation in Computing**
  - due to the computational complexity and inherent uncertainties of the problem, use a heuristic approach
  - optimize for aggregator profit with respect to the constraints in the face of the stochastic nature of the problem

HEURISTIC FRAMEWORK

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- **Schedulable Loads**
  - to move the peak, the aggregator has access to a set of schedulable loads (subset of the total load)
  - for each load i of a customer j
    - $\boldsymbol{\delta_i}$: duration
    - $\boldsymbol{p_i}$: power draw (in kW)
    - $\boldsymbol{t_{i,start}}$: customer scheduled start time
    - $\boldsymbol{j_i}$: customer that owns the load
- **Aggregator**
  - the aggregator knows
    - $\boldsymbol{\gamma(j, i, \hat{p}, t, \delta)}$: indicator (0,1) if customer j is offering load i to be scheduled at time t with duration δ and price vector $\hat{p}$
    - $\boldsymbol{s(t)}$: spot market price (cents/kWh)
  - the aggregator determines
    - $\boldsymbol{L}$: set of loads scheduled (*attempted*)
    - $\boldsymbol{t_{i,sch}}$: scheduled start time for load i
    - $\boldsymbol{\lambda(t)}$: customer incentive vector
- **Objective Function**
  - $\boldsymbol{N}$: income received for selling negative load
  - $\boldsymbol{S}$: income received for selling electricity to customer
  - $\boldsymbol{B}$: cost of buying spot market electricity
  - $\boldsymbol{P}$: aggregator profit (objective)

$$N = \sum_{i \in L} \left[\gamma\left(j_i, i, \{\lambda(t_{i,sch}) \dots \lambda(t_{i,sch} + \delta_i)\}, t_{i,sch}, \delta_i\right) \sum_{t=t_{i,start}}^{t_{i,start}+\delta_i} \frac{s(t)}{4} p_i \right]$$

$$S = \sum_{i \in L} \left[\gamma\left(j_i, i, \{\lambda(t_{i,sch}) \dots \lambda(t_{i,sch} + \delta_i)\}, t_{i,sch}, \delta_i\right) \sum_{t=t_{i,sch}}^{t_{i,sch}+\delta_i} \frac{\lambda(t)}{4} p_i \right]$$

$$B = \sum_{i \in L} \left[\gamma\left(j_i, i, \{\lambda(t_{i,sch}) \dots \lambda(t_{i,sch} + \delta_i)\}, t_{i,sch}, \delta_i\right) \sum_{t=t_{i,sch}}^{t_{i,sch}+\delta_i} \frac{s(t)}{4} p_i \right]$$

$$\boldsymbol{P = N + S - B}$$