Integration and Extension of Direct Load Management of Smart Loads

Anna Scaglione, UC Davis

GRA: Mahnoosh Alizadeh

Project objective

- Invent methods to “store” load demand for
  - Real-time “generation following”
  - Integration of load reserves as dispatchable assets in the Energy Market
- Architecture for virtual “reserves” (queues) of electrical load demand
  - Watts to Job mapping (analysis)
    - Captures digitally the service requirements
      - Equal service type = Equal queue
  - Job to Watts mapping (synthesis)
    - Allows to optimally schedule the load profile

Major technical accomplishments

- Centralized model: *Digital Direct Load Scheduling (DDLS) – Year 1-Year 2*
  - M. Alizadeh, A. Scaglione, R.J. Thomas and D.C. Callaway, "Information Infrastructure for Cellular Load Management in Green Power Delivery Systems", IEEE SmartGridComm 2011, Oct. 2011, pp. 13-18.
  - M. Alizadeh, Z. Wang and A. Scaglione, "Demand Side Management Trends in the Power Grid", IEEE CAMSAP 2011, Dec. 2011, pp. 141-144.
  - M. Alizadeh, A. Scaglione, and R.J. Thomas, "From Packet to Power Switching: Digital Direct Load Scheduling", IEEE Journal on Selected Areas in Communications: Smart Grid Communications Series, Vol 30, No. 4, July 2012.
- Decentralized: *Collaborative Home Energy Management (Co-HEMS) – Year 2 (still ongoing)*
  - T.H. Chang, M. Alizadeh, and A. Scaglione, "Real-Time Power Balancing via Decentralized Coordinated Home Energy Scheduling", IEEE Transactions on Smart Grid, March 2012 (under revisions)
- Wide area: *Stochastic model for PHEV deferrable load and market integration of DDLS – Year 2 (still ongoing)*
  - M. Alizadeh, A. Scaglione, J. Davies, and K.S. Kurani, "Scalable Simulation, Telemetry and Forecasting for Electric Vehicle Charging Demand", IEEE Transactions on Smart Grid, July 2012 (submitted)

Proposed Modeling Approach

<u>Load Classification</u>

Load Type 1: Deferrable

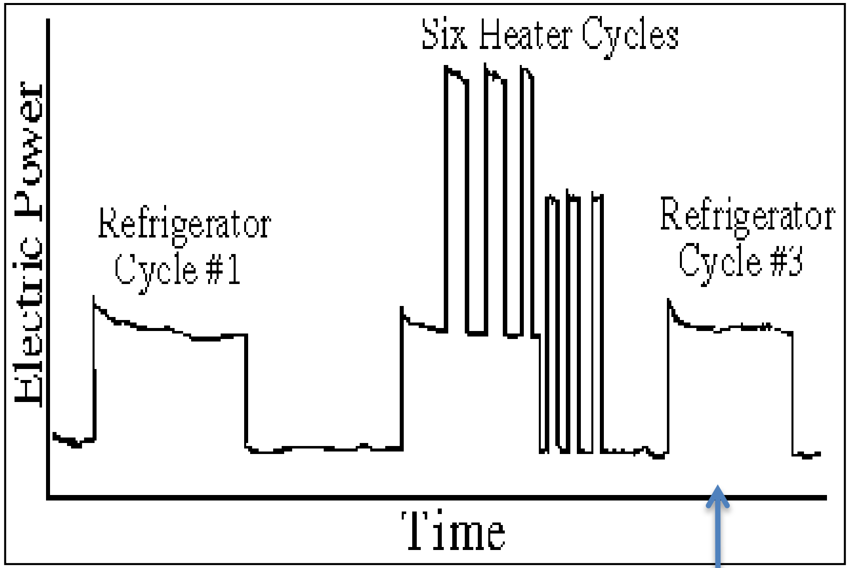
- activation random, known duration
  - PHEV and EVs, washer, dryer

Load Type 2: Delay sensitive

- activation random, duration unknown
  - Lighting

Load Type 3: Control loops

- recurrent automatic activation, duration unknown
- Heating and cooling



LOAD CONTINUOUS MODEL

$g(t;C)$

$$L(t) = \sum_i g(t - t_i^a; C_i^a)$$

AD conversion: Watts to Jobs

- Load Analysis each load maps to (t_i^a, C_i^a, χ_i^a)

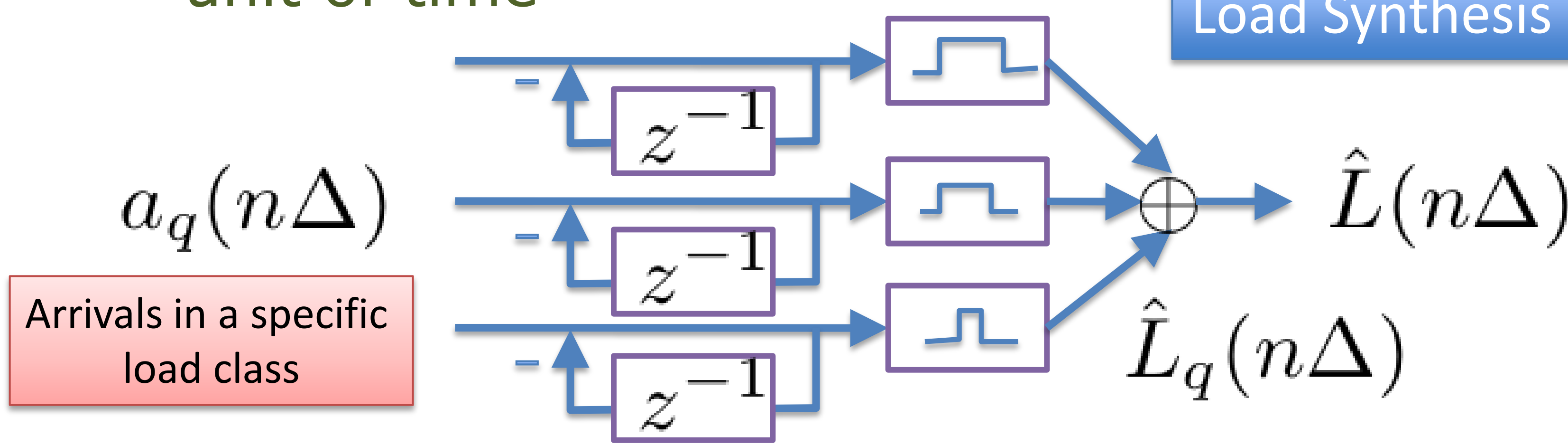
  arrival · shape · laxity

- Digital signature
  - Quantize C_i^a into codes $\hat{C}_1, \ldots, \hat{C}_Q$

$$\hat{C}_q \mapsto \hat{g}_q(t)$$

  - Record $a_q(n\Delta)$: loads arrived per class and unit of time

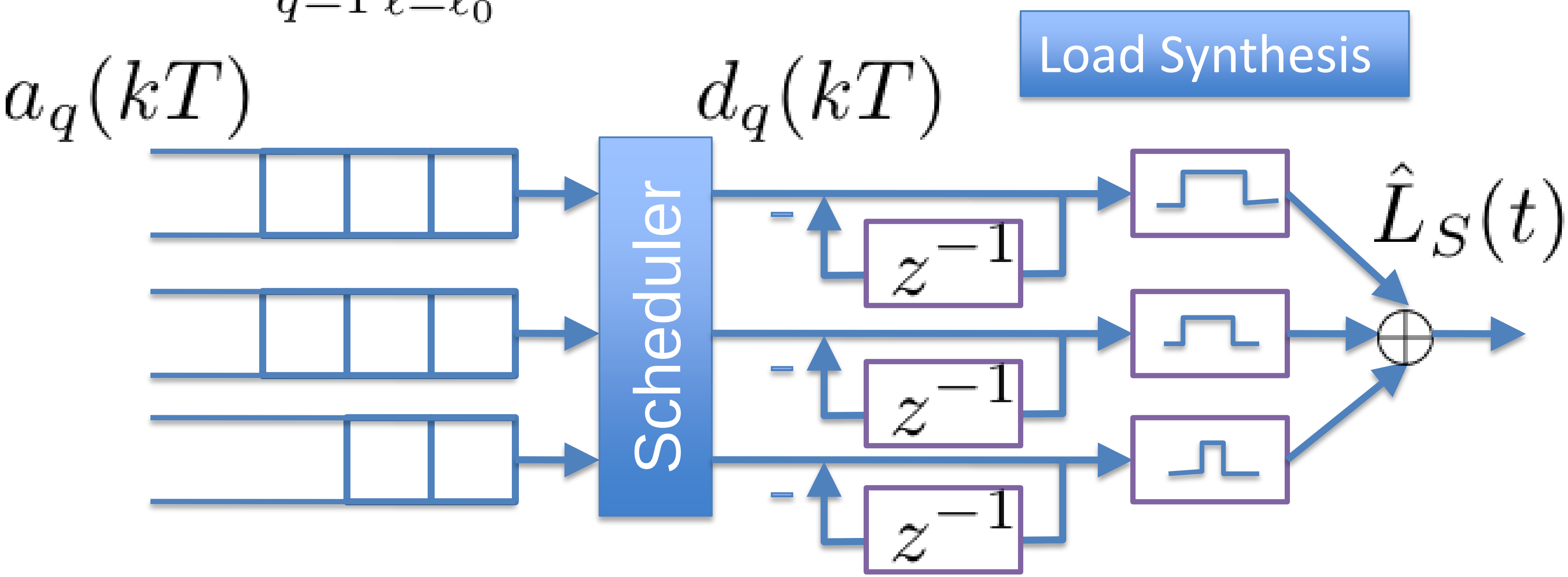
Load Synthesis



Queuing model: Jobs to Watts

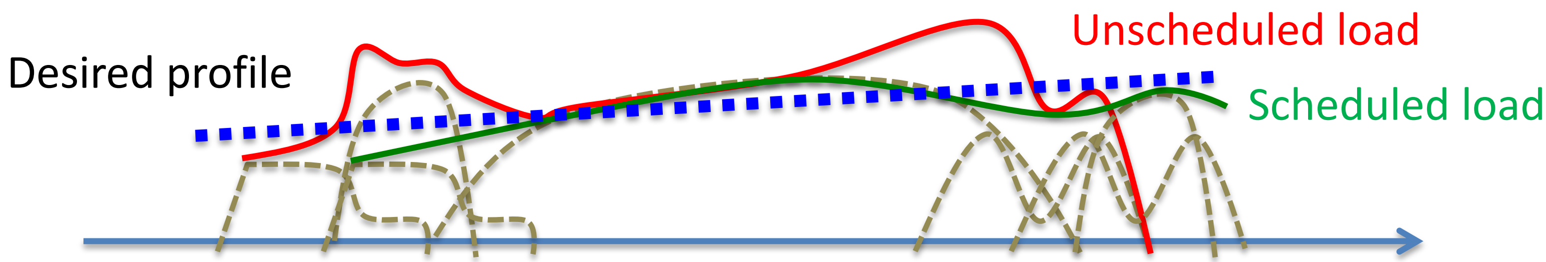
Decide $d_q(kT)$ =loads x class x time to activate at kT. The scheduled load is

$$\hat{L}^S(t) = \sum_{q=1}^{Q} \sum_{\ell=\ell_0}^{\infty} [d_q(\ell T) - d_q((\ell - 1)T)] g(t - \ell T; \hat{C}_q)$$



Objective of real-time scheduling

- Follow a profile of "cheaper" power
  - Paid for in the market + local renewable power



- Collecting load arrival information $a_q(kT)$
- Using a Model Predictive Controller to decide the schedule $d_q(kT)$
- **Scalability** → Complexity function of the number of queues not the number of loads managed

Objectives of the Market Integration

- Valley filling
- Lowering generation reserve requirements
- Risk management for renewable integration
- Solution proposed
  - Use DDLS description to model load flexibility in the Unit Commitment and Optimal Power Flow problems
  - Aggregator can operate differently!

Work completed this year

Additional publications:

- M. Alizadeh, X. Li, Z. Wang, A. Scaglione, and R. Melton, “Demand Side Management in the Smart Grid : Information Processing for the Power Switch", **IEEE Signal Processing Magazine**, Special Issue on Signal Processing Techniques for Smart Grid, Sep. 2012

- M. Alizadeh, Z. Wang, A. Scaglione, Chen Chen and Shalinee Kishore, “On the Market Effects of Queuing Energy Requests as an Alternative to Storing Electricity", **IEEE Power Engineering Society General Meeting**, July 2012.

- Chen Chen, Shalinee Kishore, Z. Wang, M. Alizadeh, A. Scaglione, “A Cournot Game Analysis on Market Effects of Queuing Energy Request as Demand Response", **IEEE Power Engineering Society General Meeting**, July 2012.

- M. Alizadeh, T.H. Chang, A. Scaglione, C. Chen, and S. Kishore, “The Emergence of Deferrable Energy Requests and a Greener Future: What Stands in the Way?", 5th International **ISCCSP**, May 2012, Rome, Italy.

- T.H. Chang, M. Alizadeh, A. Scaglione, Chen Chen and Shalinee Kishore, “Coordinated Home Energy Management for Real-Time Power Balancing", **IEEE Power Engineering Society General Meeting,** July 2012.

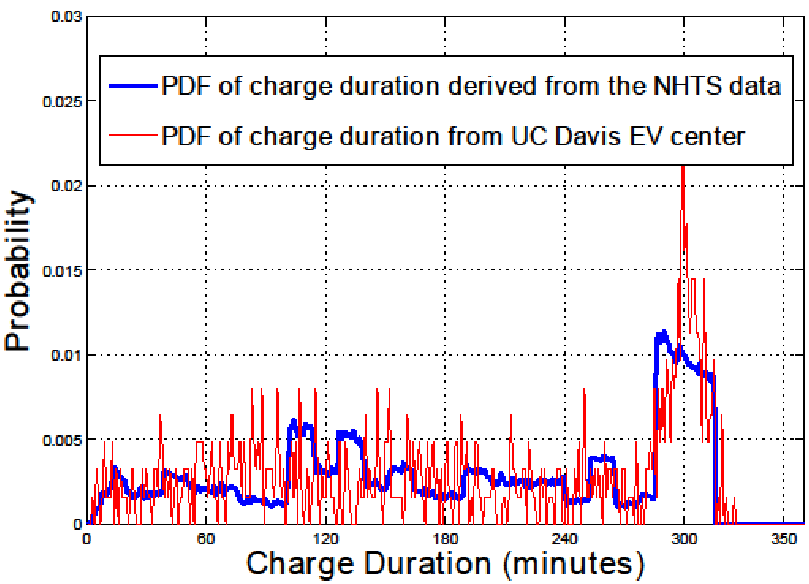
- M. Alizadeh, T.H. Chang, and A. Scaglione, “Grid Integration of Distributed Renewables through Coordinated Demand Response", **IEEE CDC 2012**, to appear.

- M. Alizadeh, T.H. Chang, and A. Scaglione, ”Marketing the Demand Flexibility of Deferrable Loads Under a Best-Effort Service Model", submitted to **IEEE HICSS 2013**.

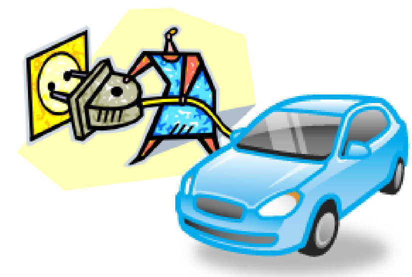
Stochastic model for PHEV

- We have statistics for charge duration, arrival process and laxity of PHEVs

Charge Duration



Probability of plugging the car:

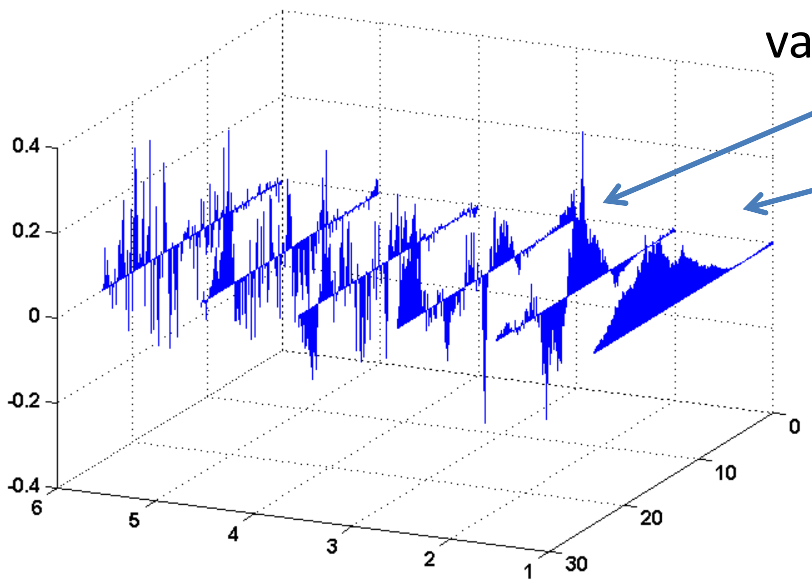


$$P_{\text{plug}}(M_i) = \begin{cases} 0.05, & M_i < 1.5 \\ 0.1, & 1.5 < M_i < 8 \\ 0.5, & 8 < M_i < 16 \\ 1, & 16 < M_i \end{cases}$$

$$F_S^{\text{PHEV}}(s) = \frac{1}{0.78\sqrt{2\pi s}} \exp^{-\frac{(\ln s - 5.03)^2}{2 * 0.78^2}}$$

Arrival Process

- Non-stationary Poisson arrivals a good fit
- 6 principal components account for 96% of the variance of all hourly arrival count vectors generated from NHTS ICEV



Weekends variations

The most significant principal component (weekday variations)

Forecast using time series analysis

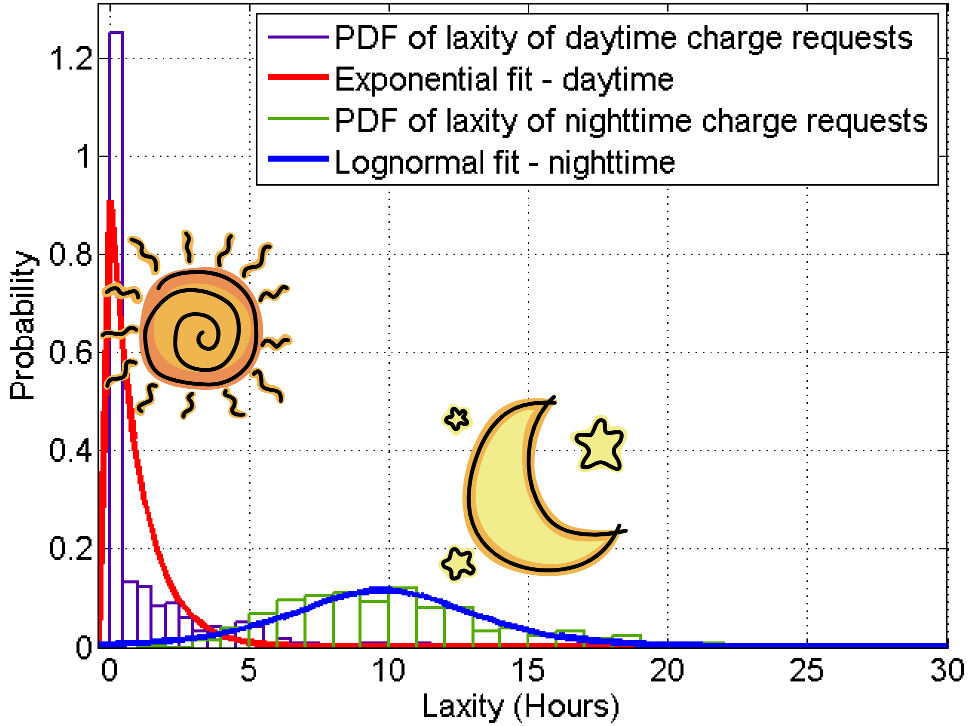
Principal components

Arriva count vector for day j

$$c_j \approx \sum_{i=1}^{K} \alpha_i(j) u_i$$

Laxity - night and day

- The amount of flexibility for recharging– separated for day and night hours



PDF fits:

Daytime:
Exp(1.08)

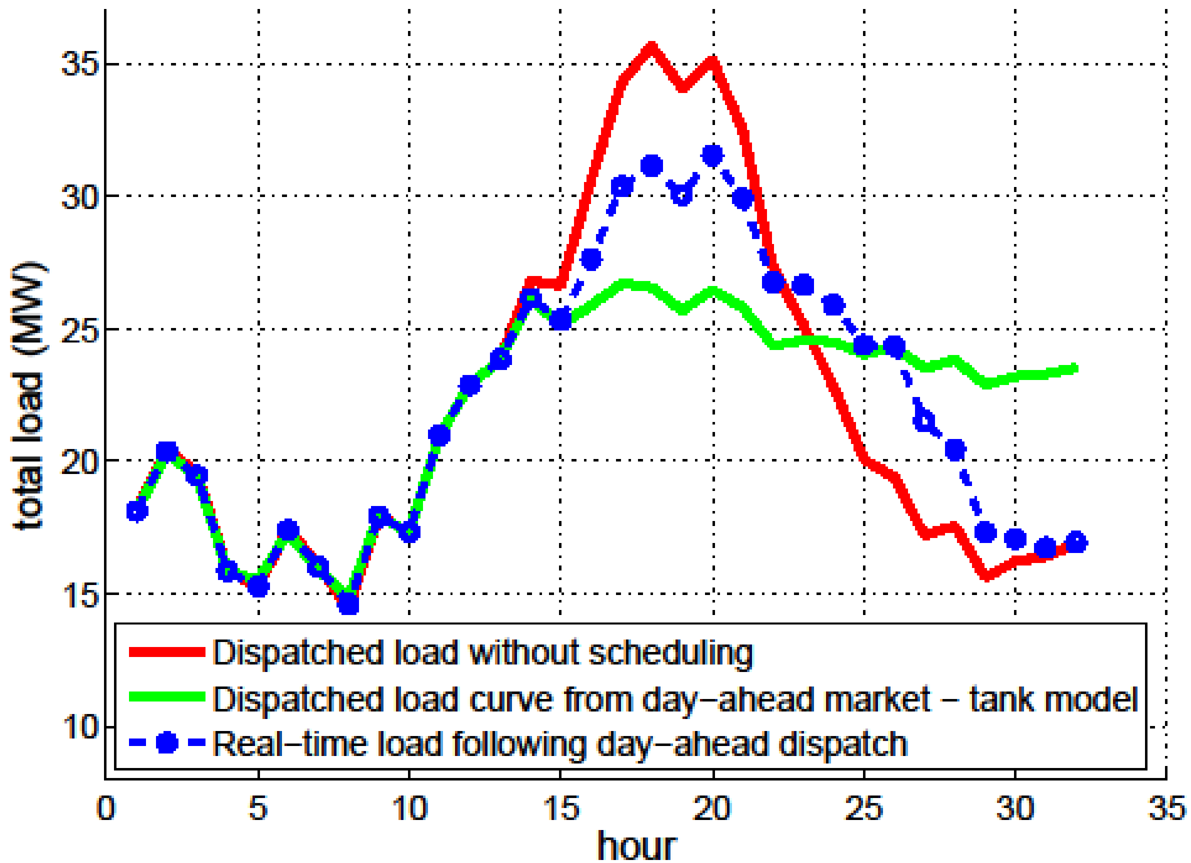
Nighttime:
$\ln N(2.25, 0.4^2)$

Market Integration

- The demand is the sum of contributions from many many appliances – how can we model the flexibility in the wholesale dispatch?
- Previous work can be divided into 3 groups:
  - **Very detailed:** Model the contribution of every individual appliance
  - **Very coarse:** Represent the deferrable demand as a large tank that has to be filled by a deadline
  - **No model at all:** back and forth exchanges of Local Marginal Prices with the customers

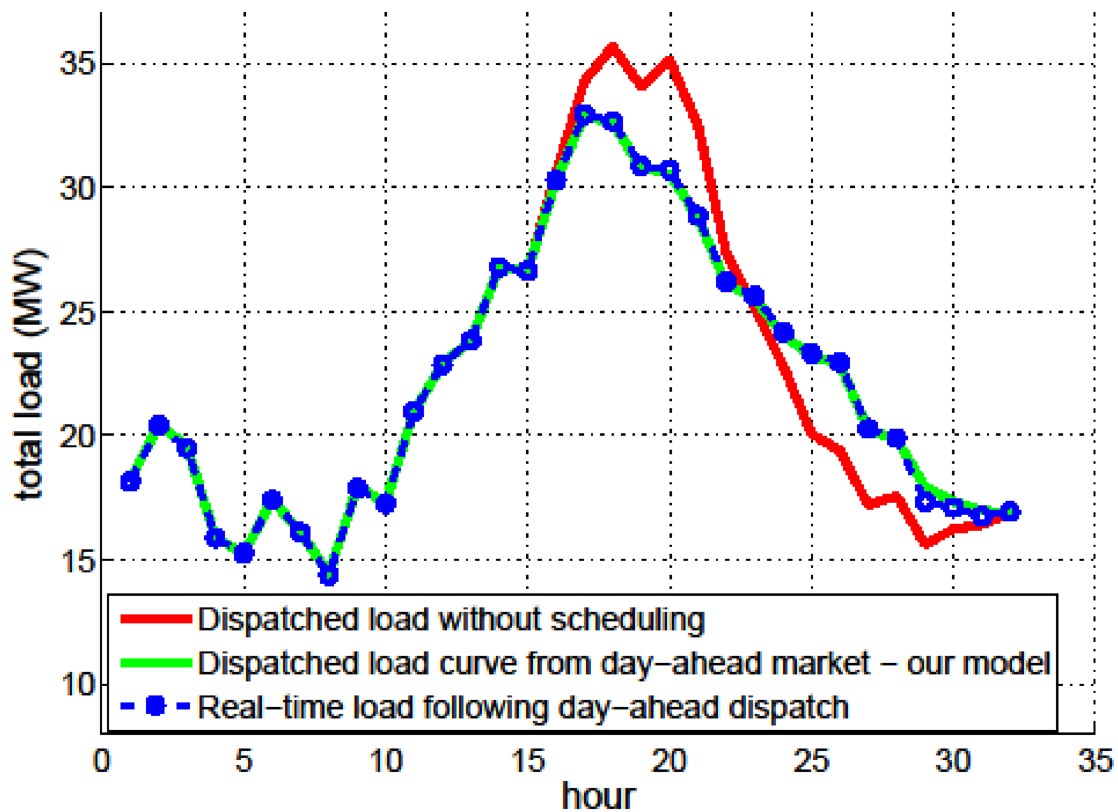
Simulation results

Tank Model



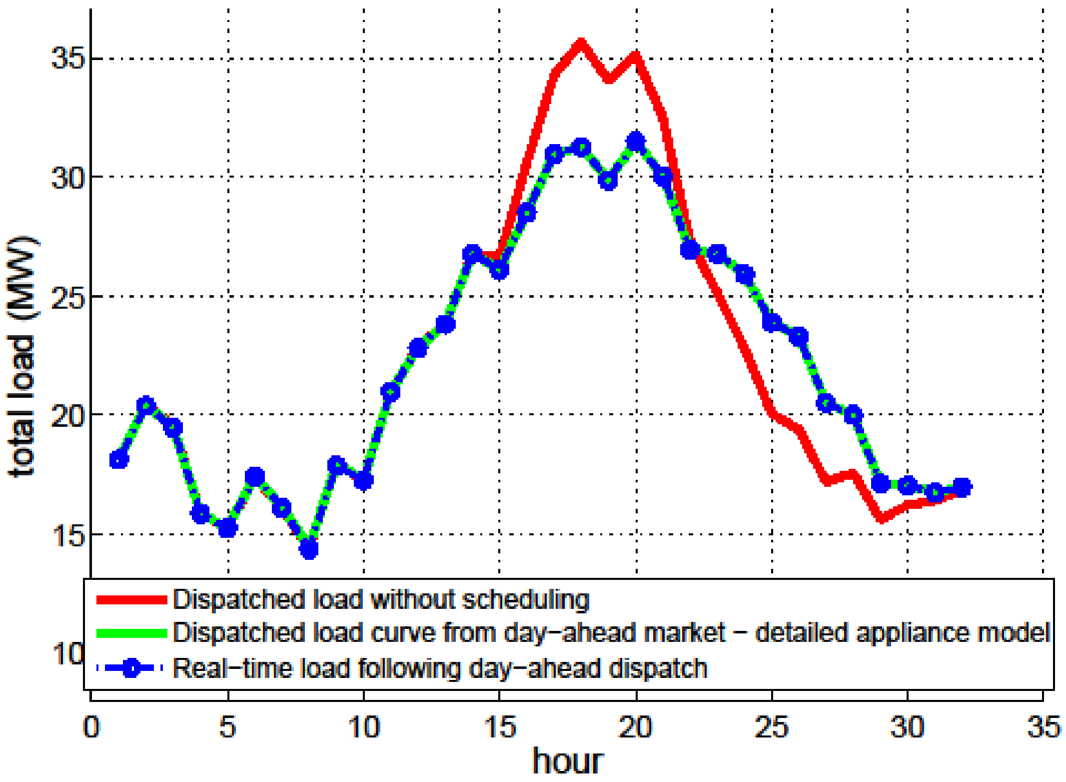
Simulation results

DDLS Model



Simulation results

Detailed Model



Deliverables and schedule for activities under FY12 funding

under FY12 funding

- Analysis of Market equilibrium with the addition of Load Aggregators offering deferrable load service
  - C. Chen, M. Alizadeh, S. Kishore, and A. Scaglione, “A Cournot Game Analysis on the Markets Eects of Demand Response", in preparation.
- Additional work on stochastic model for EV loads (work under review)
- Analysis of renewable integration using current Central Cooling System with Thermal Energy Storage (data from UCD utility)

Risk factors

- Risks affecting timely completion of planned activities
  - We may not be able to combine load scheduling with renewable generation management in the energy market, because of intrinsic difficulties
- Risks for movement through RD&D cycle
  - What is the customer for our software solutions and architectures?
    - PHEV, EV charging only? Home Energy Management software application?
    - Market Integration?
  - Mitigation of risk: Analyzing current EMS systems and develop software for load scheduling opportunity in that space

Possible follow-on work for FY13

- Further develop the demand response model for Central Cooling System with Thermal Energy Storage
- Investigate software integration with current EMS
- Improve protocols for decentralized Home Energy Management and the market integration of demand response
- DDLS type models for Market Integration of Thermostatically Controlled devices
  - Dilemma: Homes and brand new EMS or EMS for Building complexes like the UCD utility?