SmartCharge: Cutting the Electricity Bill in Smart Homes with Energy Storage

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Buildings are Heavy Power Consumers

- Consumes 48% of total energy and 76% of electricity
- Making buildings energy efficient important problem
Our Sensor Deployment (I)

- **Building-level Sensors**
  - eGauges
    - Measures aggregate consumption
    - Measurements every second
  - TED

- **Outlet-level Sensors**
  - Insteon meters/switches
    - Polled every 10 seconds
    - AC-power lines and RF communication
  - Z-Wave devices
    - Control appliances wirelessly
    - Use low-power radio waves (900 MHz)
  - Kill-A-Watt
Our Sensor Deployment (II)

- Current deployment
  - Three homes instrumented with eGauges
  - ~35 outlets instrumented with Insteon switches
- Weather and solar data deployment
  - Three weather stations
Demand-Side Energy Management

- Techniques to control building’s energy footprint
  - Respond to energy availability
    - Manual
    - Automatic

- Components of DSEM
  - Load monitoring
  - Load shedding
  - Load shifting
    - Reduce peak usage
Benefits of Peak Load Reduction

- For utilities:
  - Infrastructure savings
  - Lower operating cost
  - Less carbon emissions
  - Transmission & distribution
    \[(\text{loss} \approx \text{current}^2)\]

- For consumers:
  - Cost savings
  - Reliable grid
Incentivizing Peak Reduction

- An attempt to reduce peak demand
- Examples: Ontario, CA and Illinois, US
Using Dynamic Pricing to Shave Peak

- Push usage to off-peak
  - Limited utility
  - User discomfort

- Energy Storage
  - Charge during off-peak
  - Use in peak periods
Problem Statement

- Advent of dynamic electricity pricing
  - Opportunity to reduce bills, demand peaks

- Requires user involvement
  - Need to monitor and plan consumption
  - Users don’t want to plan usage

- Can we lower electricity bills w/o any user involvement?
Outline

- Motivation
- SmartCharge Overview
- Cost Minimization Algorithm
- Evaluation
  - How much can we save
  - Cost-Benefit Analysis
- Conclusions
SmartCharge: Battery as Energy Store

- **Key idea:** charge battery at off-peak hours
  - Use off-peak rates
  - Use stored energy at peak to reduce grid draw

![Graph showing Illinois Real-time Hourly Rate and Grid Power with and without SmartCharge](image-url)
**SmartCharge: Challenges**

- **Goal:** optimize energy bills and reduce peaks
  - *When to charge?*
    - Need to know the price of electricity
  - *When to use?*
    - At any instant, must determine if power should be consumed from grid vs. battery

- Must account for battery inefficiencies
  - ~20% of stored energy is lost
  - Price differential must override inefficiencies
**Key idea:** Linear Programming Formulation

- Minimize price
- Electricity prices from day ahead market
- Predict consumption

**Inputs**

- Known
  - Electricity Prices
- Predict
  - Next Day Demands

**Outputs**

- When & how much to Charge Battery
- When & how much to Discharge Battery
**SmartCharge: LPF**

1. **Objective**
   \[
   \min \sum_{i=1}^{T} m_i
   \]

2. **Energy charged \( \geq 0 \)**
   \[
   s_i \geq 0, \forall i \in [1, T]
   \]

3. **Energy discharged \( \geq 0 \)**
   \[
   d_i \geq 0, \forall i \in [1, T]
   \]

4. **Max charging rate**
   \[
   s_i \leq C/4, \forall i \in [1, T]
   \]

5. **Charge conservation**
   \[
   \sum_{t=1}^{i} d_t \leq e \times \sum_{t=1}^{i} s_t, \forall i \in [1, T]
   \]

6. **Capacity constraint**
   \[
   \left( \sum_{t=1}^{i} s_t - \sum_{t=1}^{i} \frac{d_t}{e} \right) \times I \leq C, \forall i \in [1, T]
   \]

7. **Price calculation**
   \[
   m_i = (p_i + s_i - d_i) \times I \times c_i, \forall i \in [1, T]
   \]
SmartCharge: ML-Based Demand Prediction

- Predict future energy usage
  - Model includes many data features
    - Weather (temperature + humidity)
    - Time (month, day, weekend, holiday)
    - History (previous day)
  - 70 days of training period, 40 days of testing

- Best predictions with SVM-Poly
  - ~5.75% of real usage
  - Better at night (within 4%)
System Architecture Overview

- Electric Grid
- Battery Array
- Charge Control
- Inverter
- Power Transfer Switch
- Gateway
  - Control I/O
  - Energy Level Monitor
  - Consumption Monitor
- Panel Meter
- Energy Flow
  - Monitor Flow
  - Control Flow
1) A real home’s power consumption

2) Data from 435 anonymous homes

3) Ontario’s TOU, ISO-NE dynamic prices

4) Use CPLEX to solve LPF
Evaluation: Household Savings

- 10-15% savings
- Within 8-12% of Oracle
- Savings flatten >24kWh
- Charging not a limitation
Evaluation: Battery Sharing

- Savings increase with No of homes
- Homes peak at different times
Evaluation: Grid-scale Effects

- Significant grid peak reduction
- Lower prices for everyone!

![Graph showing % Peak Reduction vs % Homes with a 20% reduction indicated.]
Evaluation: Grid-scale Effects

- Increases peak at scale
  - Pricing not incentive-compatible
  - Motivates new pricing plans

% Peak Reduction

20% reduction!

Peak doubles!
Evaluation: Cost-Benefit Analysis

- +ROI if already use energy storage
  - Photovoltaics, electric vehicles, UPSs, etc.
- -ROI today to install energy storage, but...
  - ...battery advancements (lead-carbon)
  - ...better pricing plans (distribute cost)
  - ...time (rising prices and ratios)
Conclusions

- Presented SmartCharge
  - Stores cheap energy, uses during peak
  - ML model for demand prediction
  - LPF for charging-discharging decisions
  - Lowers bills transparently

- 10-15% cost savings

- 20% peak reduction in grid peak

- Potential for EVs as energy storage
Thank You!

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