


ENERGY MANAGEMENT FOR A COMMUNITY SHARED SOLAR PV-STORAGE SYSTEM UNDER UNCERTAINTIES

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April 10th, 2018

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Overview

- Coordination of Renewables in Power Systems
- Modern Power Systems: Challenges and Opportunities
- Energy Management for a Single Household
- Energy Management for a Community
- Final Comments

Coordination of Renewables in Power Systems

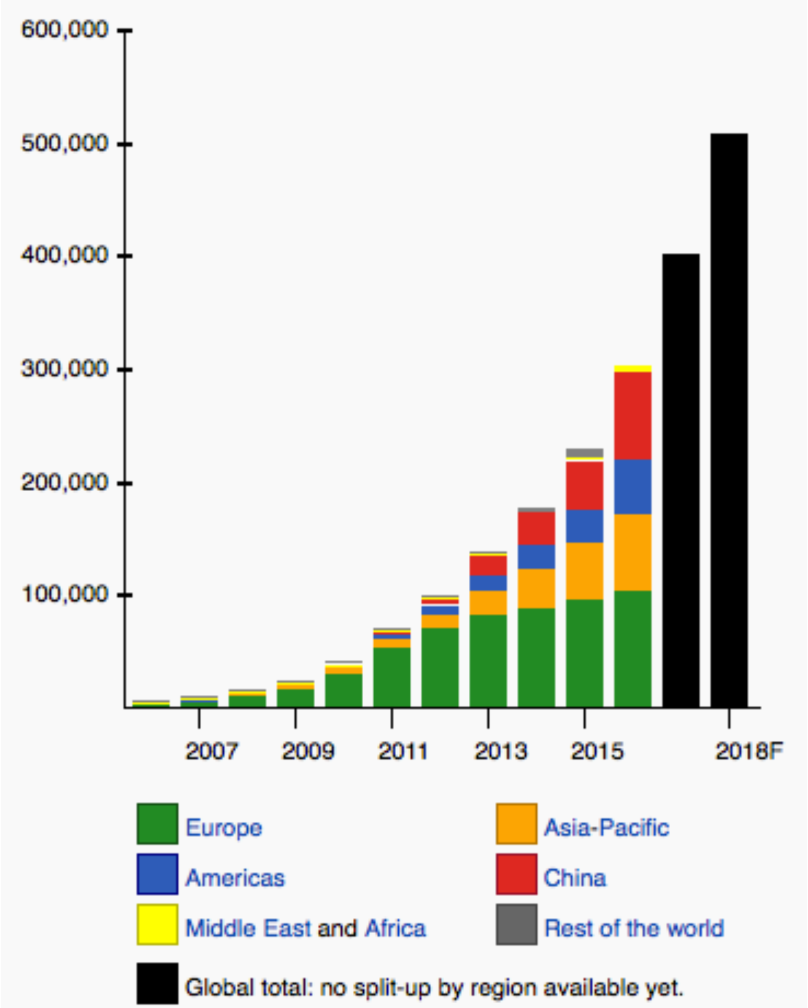
Introduction

- The main problem with renewable power is its **dependence on natural resources** (**may not be available when necessary**)
- Countries such Norway, Canada, Brazil, England, USA regions (BPA concession area, Western Texas, North Carolina) present **significant amounts of renewable generation resources**
- Hydropower is an exception of these restrictions, since **reservoirs can store water and control generation**
- **Other technologies associated with** energy management emerged over the years *e.g.* **static batteries and electric vehicles**
- In this context, **how to properly coordinate** the use of resources and manage energy use is a very important question

Solar Generation: An Energy Breakthrough

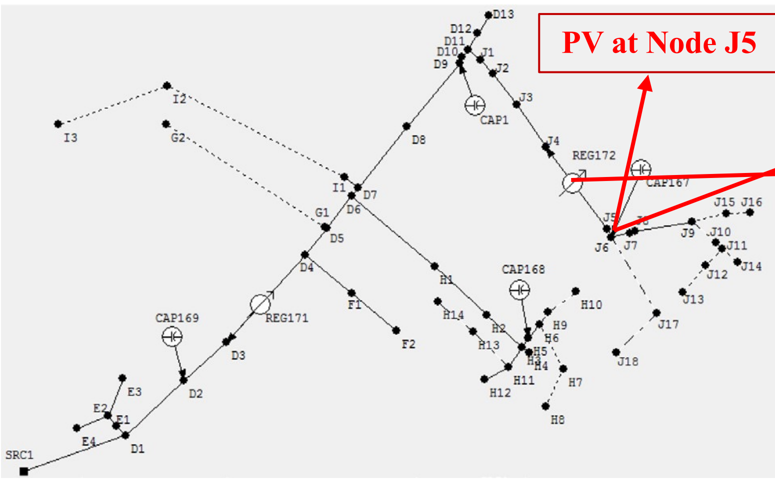
- **Solar energy is the most abundant energy resource on earth** – 173,000 terawatts of solar energy strikes the Earth continuously. That is **more than 10,000 times** the world's total energy use (http://energy.gov/)
- Life cycle greenhouse **gas emissions** from solar energy is **~ 5-10% compared to non-renewable sources** (http://www.nrel.gov/)
- Price dropping to ~$2/W (expected to be < $1/W by 2025)

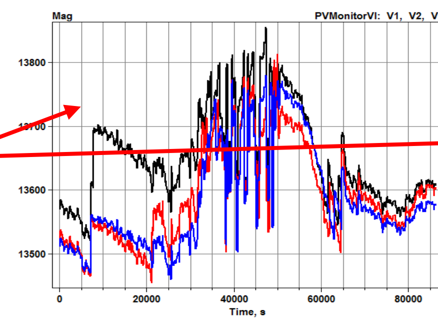
Installation



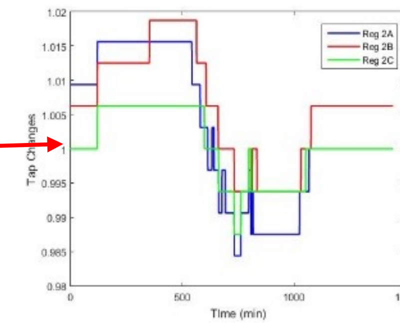
Global Installed Capacity of Solar PV [MW] (*IEA*)

Challenges to the Solar Deployment

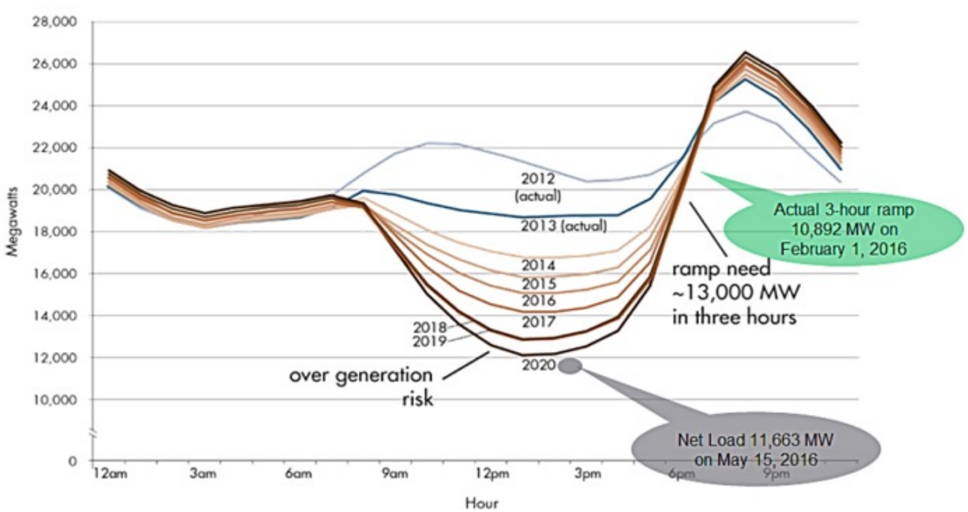




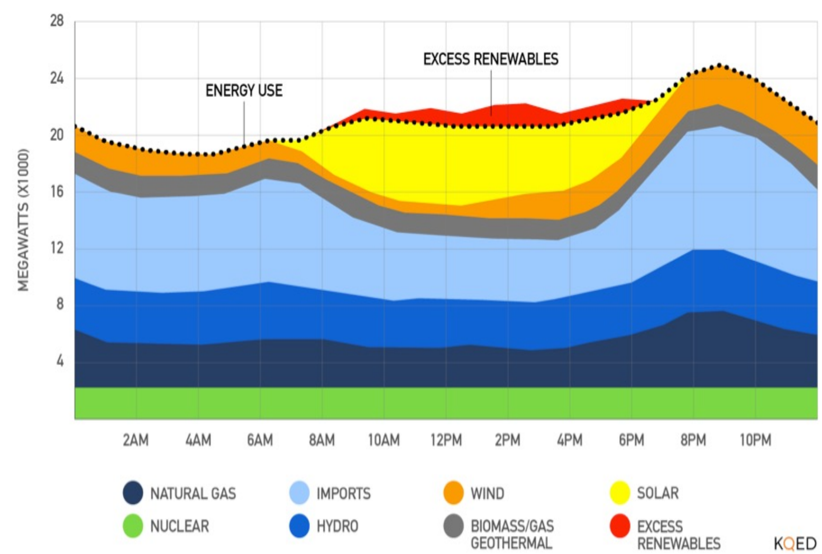
Voltage at Node J5



Regulator Switching Condition

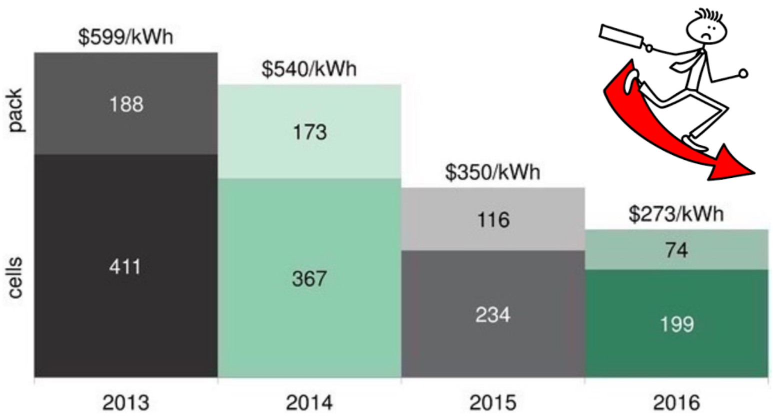


CAISO Duck Curve *(Source: CAISO)*

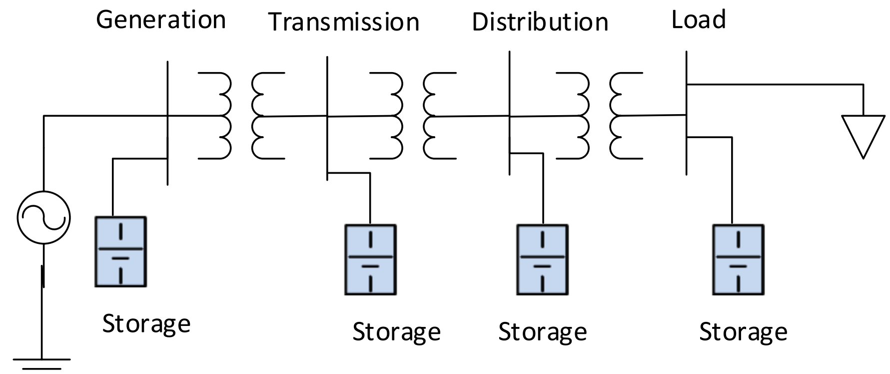


On a sunny day in March 2017, some solar farms had to shut down *(Source: CAISO)*

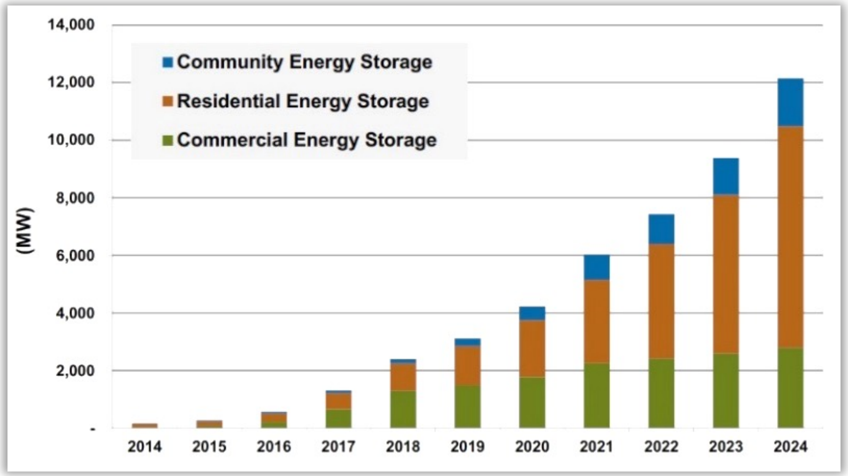
Energy Storage: Key to Overcome Grid Challenges



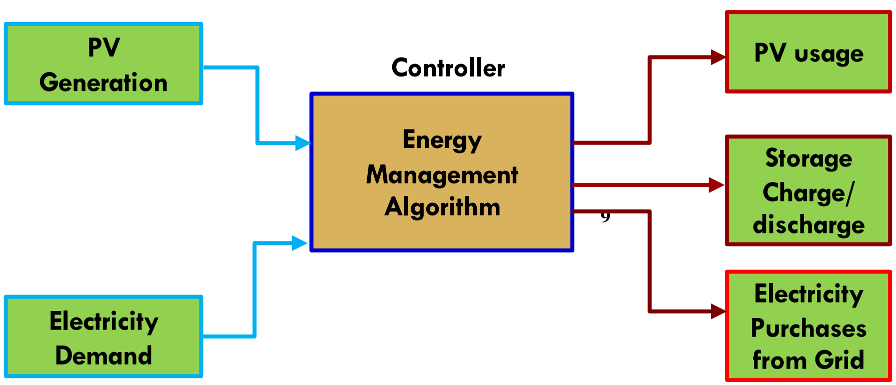
Prices per Kilowatt-hour of Storage (*Bloomberg New Energy Finance*)



Storage deployment in different levels of power system



Projections of Energy storage growth in U.S.A in different levels (*source: Navigant Research*)



Flow diagram of PV-based storage control

Mathematical Model Formulation

$$\min \quad z = \sum_{t=1}^{T} [P_{grid,t} \cdot C_t]$$

$P_{grid,t}$: Electricity from grid

C_t: ToU Rate

subjected to:

Equality constraints:

(i) Power Balance: **Input and output power should be equivalent**

- $P_{grid,t} - P_{b_{ch},t} + P_{b_{disch},t} - P_{slack,t} = P_{load,t} - P_{PV,t}^{\omega_t}$; $(\forall t \in T)$

$P_{b_{ch},t}$: Charge

$P_{b_{disch},t}$: Discharge

$P_{load,t}$: Actual Demand

$P_{PV,t}^{\omega_t}$: PV

(ii) Charge Balance: **State of charge will change based on charging/ discharging power**

- $SOC_t = SOC_{t-1} + \frac{P_{b_{ch,t}} \cdot \eta_b^C}{Q_b \cdot \Delta t} - \frac{P_{b_{disch,t}}}{Q_b \cdot \Delta t \cdot \eta_b^C}$; $(\forall t \in T)$

SOC_t: State of charge for storage device

Defining Boundary Conditions

Inequality Constraint:

- Storage device will be charged only from PV-generated power

$$P_{b\,ch,t} \leq P_{PV,t}^{\omega_t} \,, \forall t \in T$$

- Storage device will deliver power only to the household

$$P_{b\,disch,t} \leq P_{load,t} \,, \forall t \in T$$

- There will be no back-feeding of power to the grid

$$P_{grid,t} \geq 0 \,, \forall t \in T$$

Upper and lower bounds:

- $SoC_{b,min} \leq SoC_{b,t} \leq SoC_{b,max} \,, \forall t \in T$
- $P_{b_{ch}}^{min} \leq P_{b\,ch,t} \leq P_{b_{ch}}^{max} \,, \forall t \in T$
- $P_{b_{disch}}^{min} \leq P_{b\,disch,t} \leq P_{b_{disch}}^{max} \,, \forall t \in T$

Uncertainty generation:

$$P_{PV,t}^{\omega_t} = P_{PV,t} \pm \rho_t^{\omega_t} P_{PV,t};\ \omega_t \epsilon \forall \Omega_t \,, \forall t \in T$$

Uncertainty: A Challenge

Linear programming

or Dynamic

Programming could

solve the problem

→

But PV generation

is not fixed

→

How to deal uncertainty

with PV generation?

↓

Stochastic Dynamic programming

ensures global minimum

↓

Face 'Curse of dimensionality'

Requires a lot of time to calculate

Require Huge memory

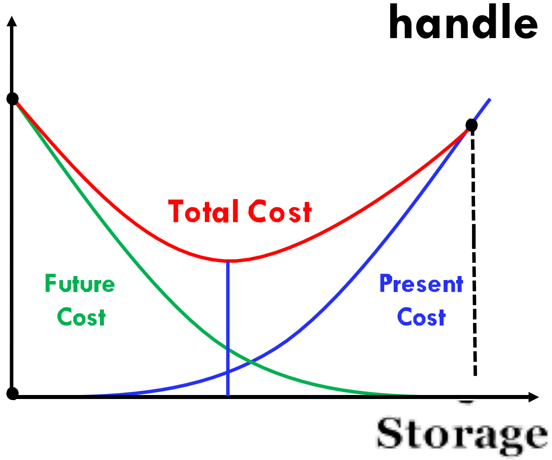
↖

Stochastic Dual

Dynamic

Programming can

handle the issue



Stage-t Benders' Master Problem

- Suppose we are at stage t under ω and we have:

$$\min_{x_t,\theta_t} \; c_t x_t + \theta_t$$
$$\text{s.t.} \quad A_t x_t = B_t x_{t-1} + b_t \; : \pi_t$$
$$-\vec{G}_t x_t + e\,\theta_t \geq \vec{g}_t \; : \alpha_t$$
$$x_t, \theta_t \geq 0$$

Benders' cuts → $-\vec{G}_t x_t + e\,\theta_t \geq \vec{g}_t$

$$\max_{\pi_t,\alpha_t} \; \pi_t (B_t x_{t-1} + b_t) + \alpha_t \vec{g}_t$$
$$\text{s.t.} \quad \pi_t A_t - \alpha_t \vec{G}_t \leq c_t$$
$$e^T \alpha_t = 1$$
$$\alpha_t \geq 0$$

$$b_t = R_{t-1} b_{t-1} + \eta_t$$ → **uncertainty**

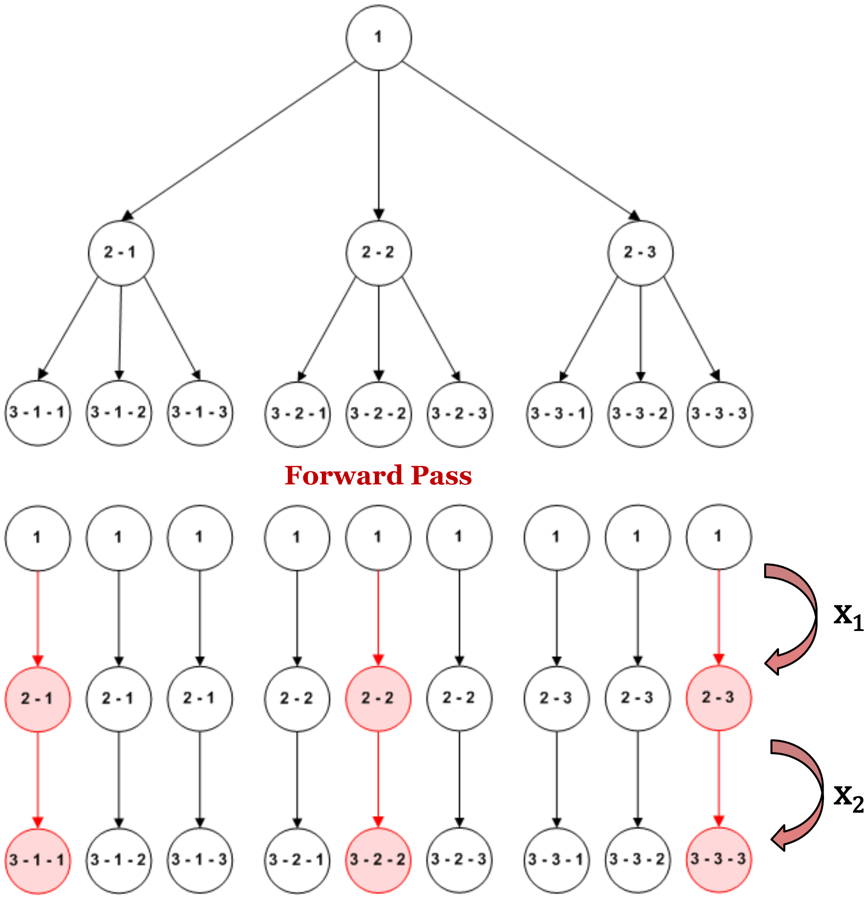
$\mathrm{vec}(\eta_t, c_t, B_t, A_t), t = 2, \ldots, T$ **are** $\perp\!\!\!\perp$

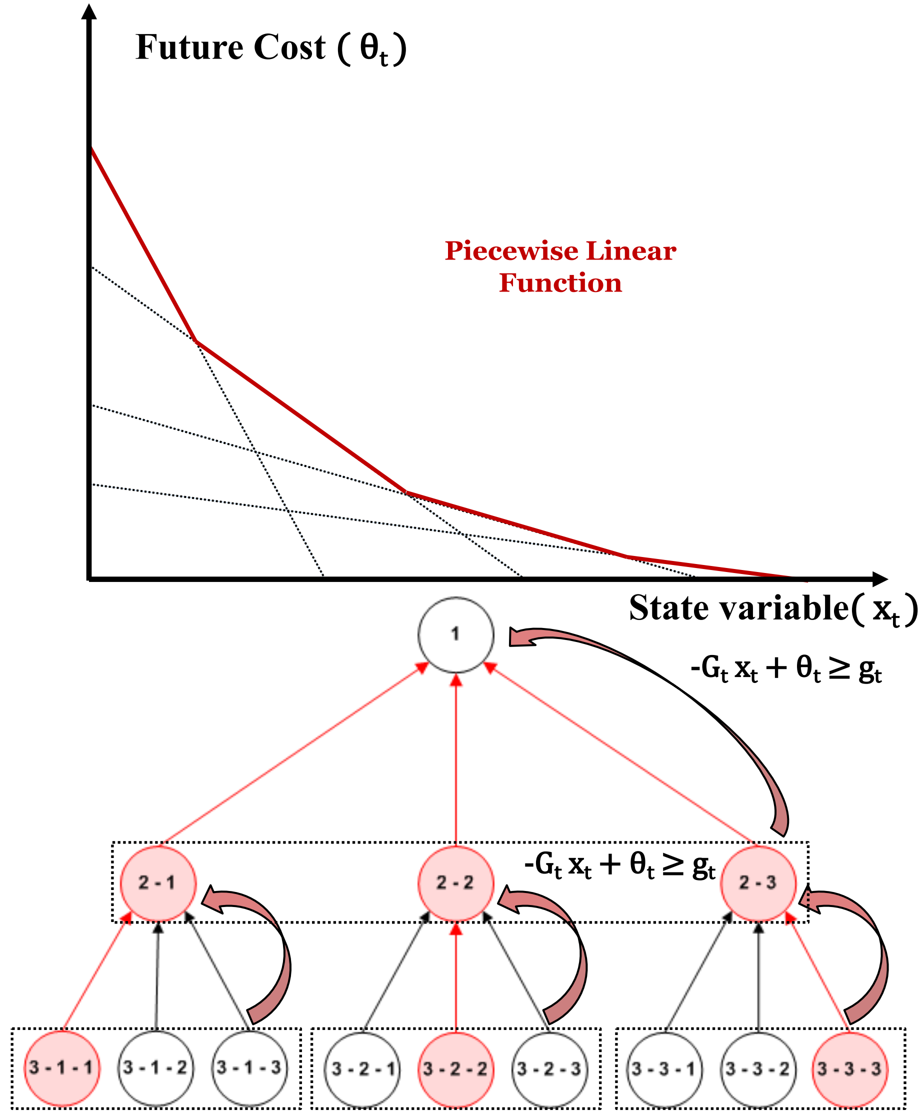
cut-intercept vector

$$G_t = \sum_{\omega_{t+1} \in \Delta(\omega_t)} p^{\omega_{t+1}|\omega_t} \pi_{t+1}^{\omega_{t+1}} B_{t+1}$$ → **cut-gradient matrix**

$$g_t^{\omega_t} = \sum_{\omega_{t+1} \in \Delta(\omega_t)} p^{\omega_{t+1}|\omega_t} \pi_{t+1}^{\omega_{t+1}} b_{t+1}^{\omega_{t+1}} + \sum_{\omega_{t+1} \in \Delta(\omega_t)} p^{\omega_{t+1}|\omega_t} \alpha_{t+1}^{\omega_{t+1}} \vec{g}_{t+1}^{\omega_{t+1}}$$

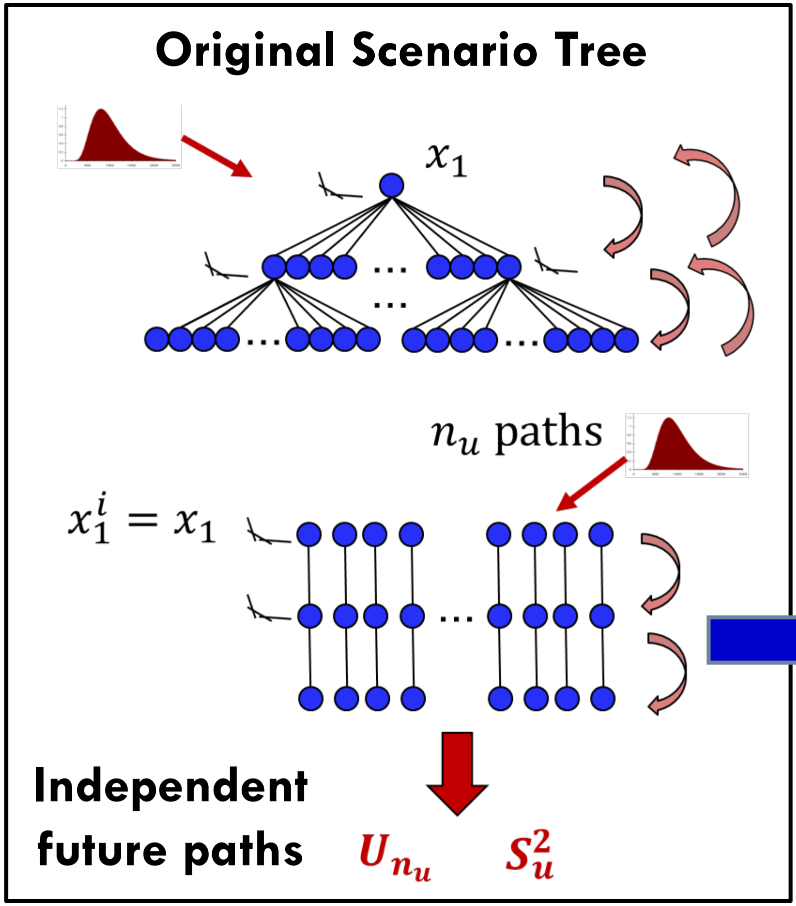
Sampling-based Decomposition Algorithm





de Queiroz, A.R., Morton, D.P., (2013) Sharing Cuts under Aggregated Forecasts when Decomposing Multi-stage Stochastic Programs, Operations Research Lett, 41(3): 311-316

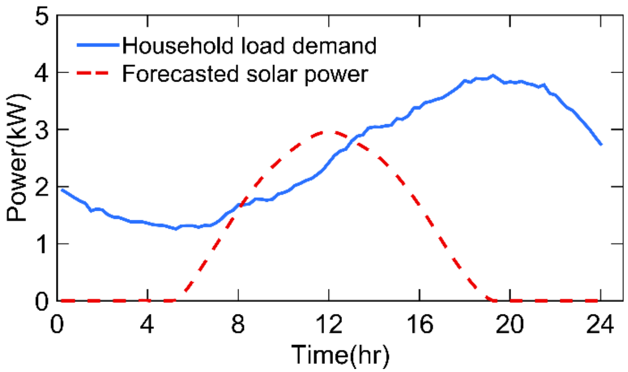
Control Scheme Evaluation



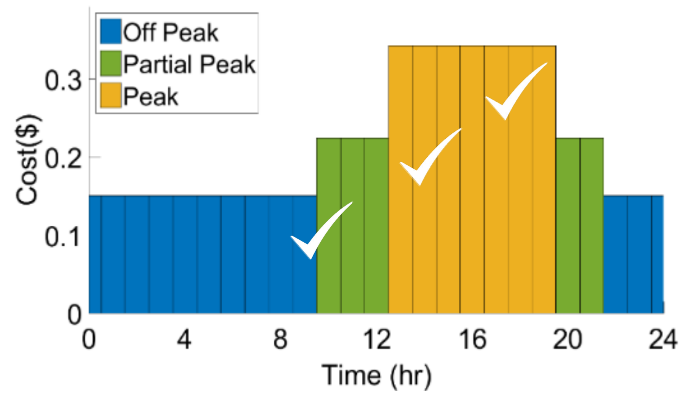
How show that the results are better using this approach?

They are used to test other kinds of control schemes as well

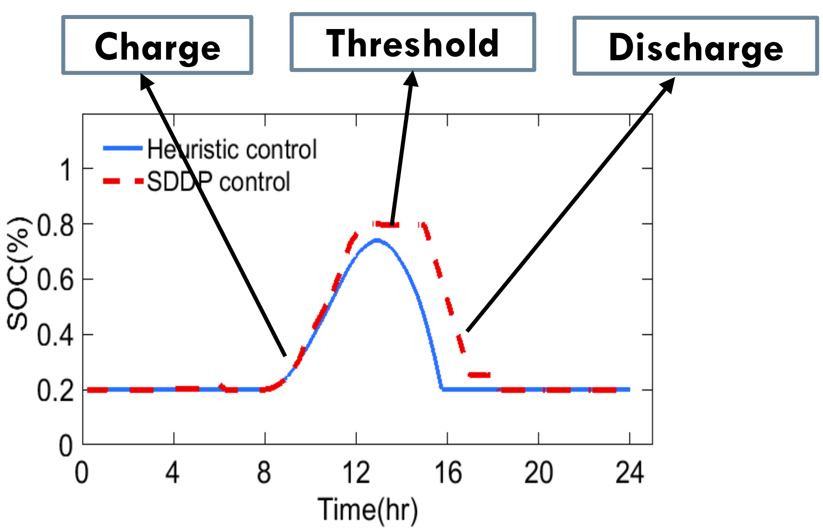
SDDP Control for a Summer Day- PV Usage Policy



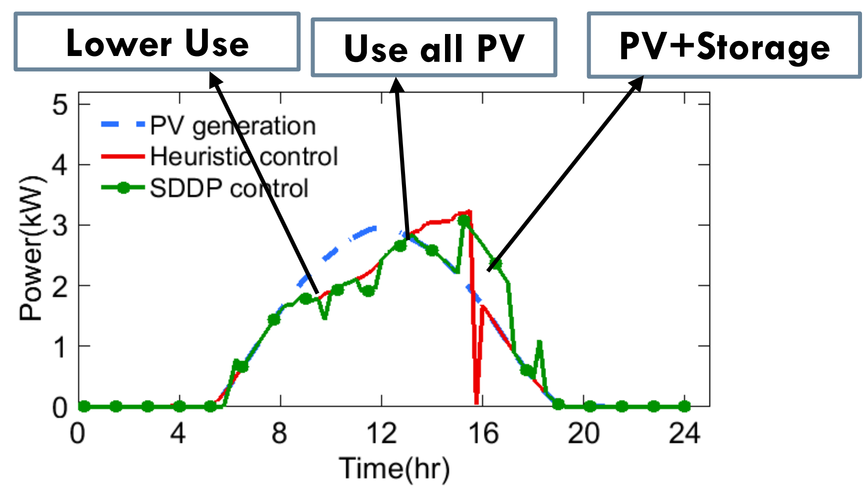
Household and solar generation profiles



ToU rate

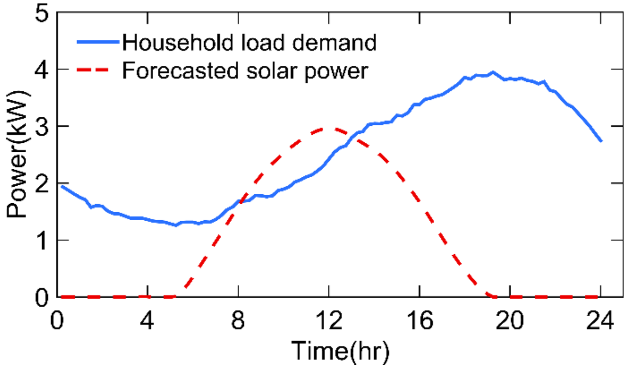


SOC profiles

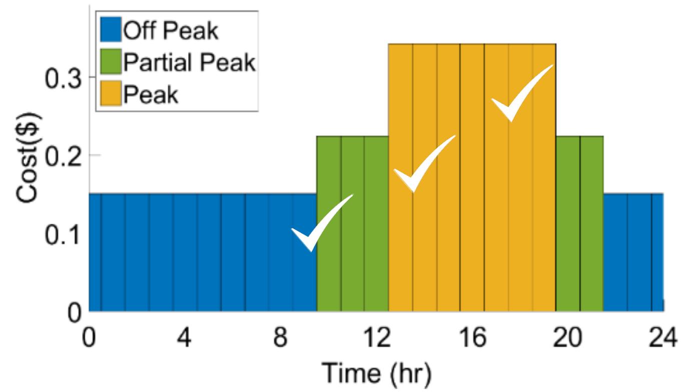


PV usage profiles

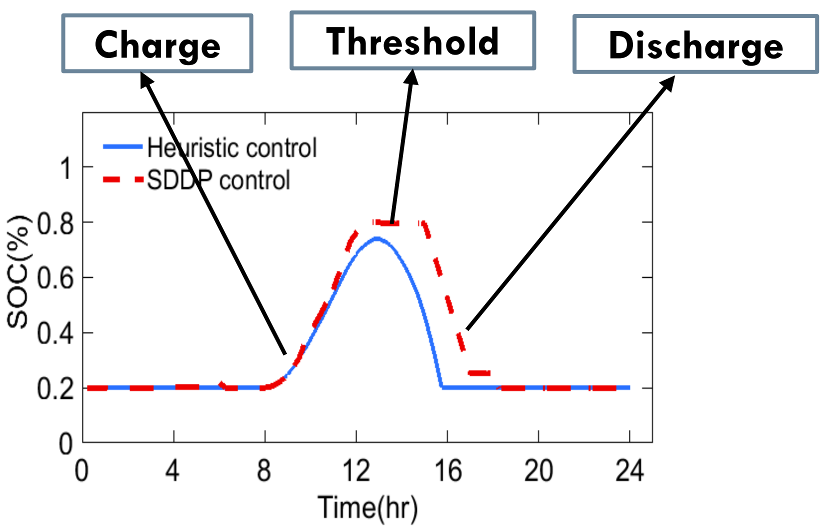
SDDP Control for a Summer Day- Electricity Purchases from Grid



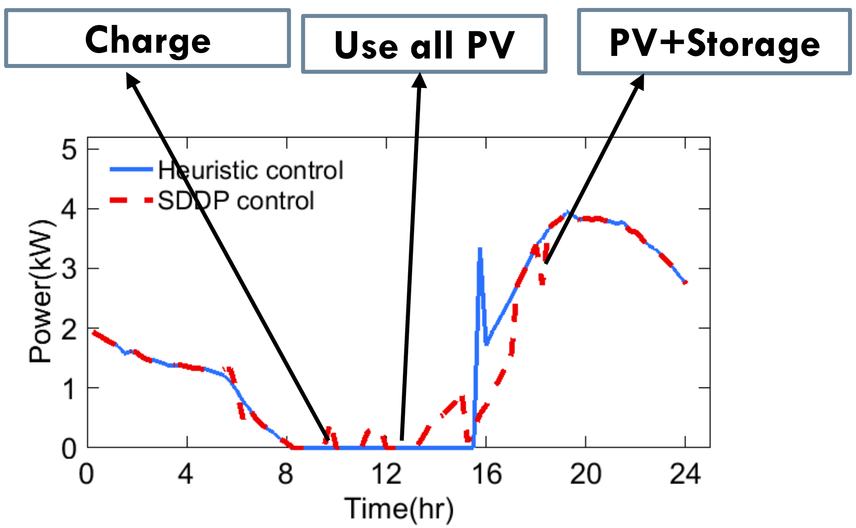
Household and solar generation profile



ToU rate



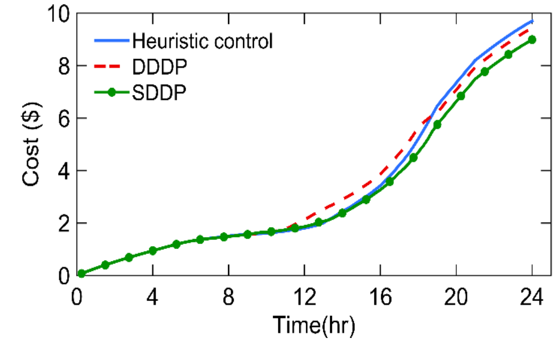
SOC profiles



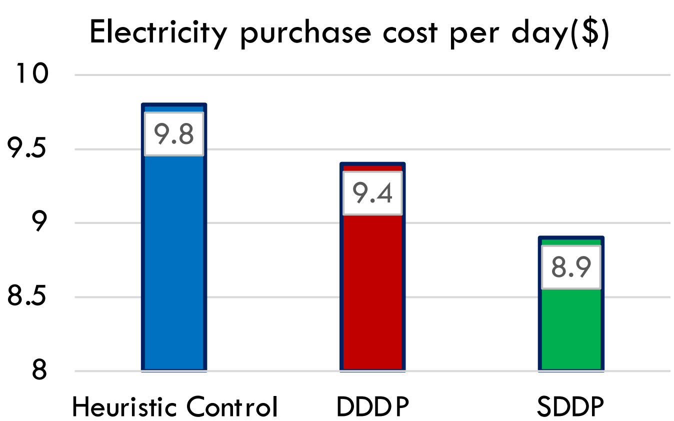
Electricity demand from grid

Is the Proposed Approach Better?

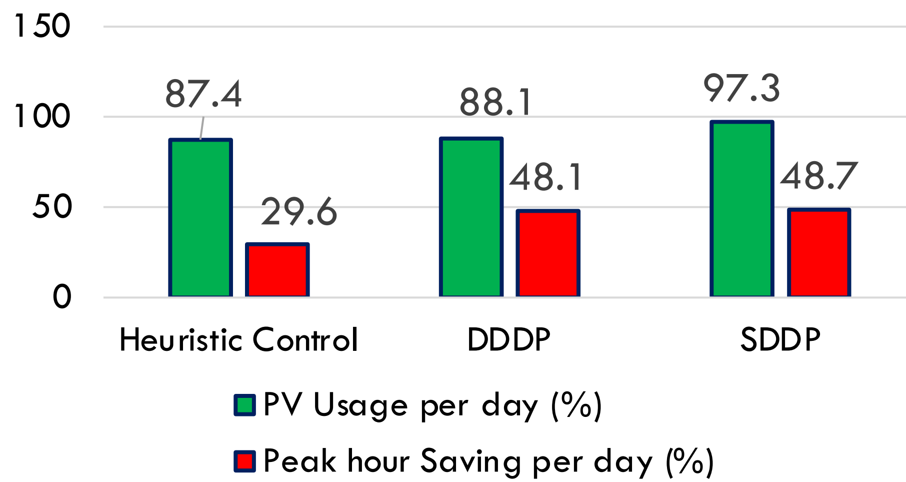
- Randomly independent scenarios to test the performance of the different control policies in out-of-sample cases
- Then the average costs across the scenarios are computed for each control strategy



Policy evaluation of overall cost



Cost savings: $25.8/month

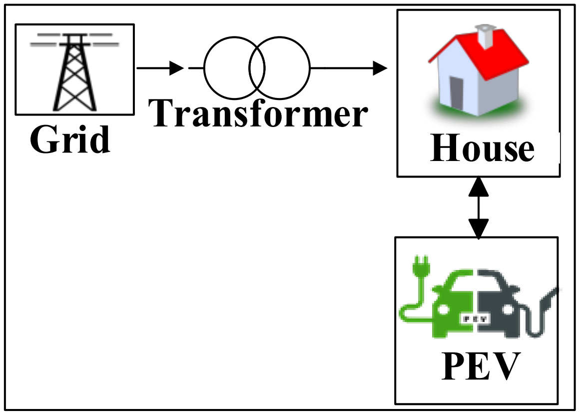


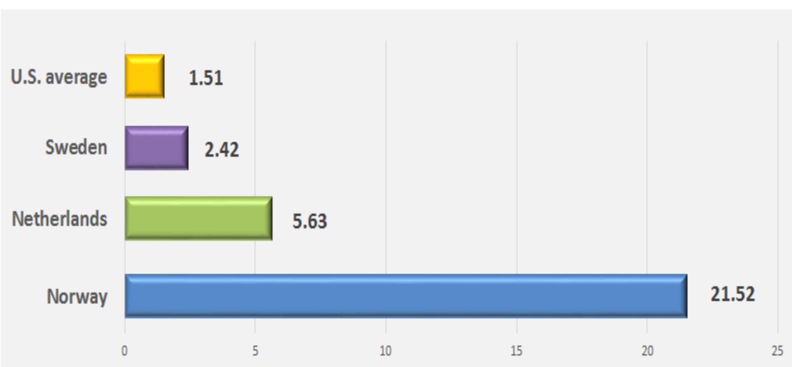
Improvement in PV usage and Peak hour savings

Hafiz, F., de Queiroz, A.R., Husain, I.,

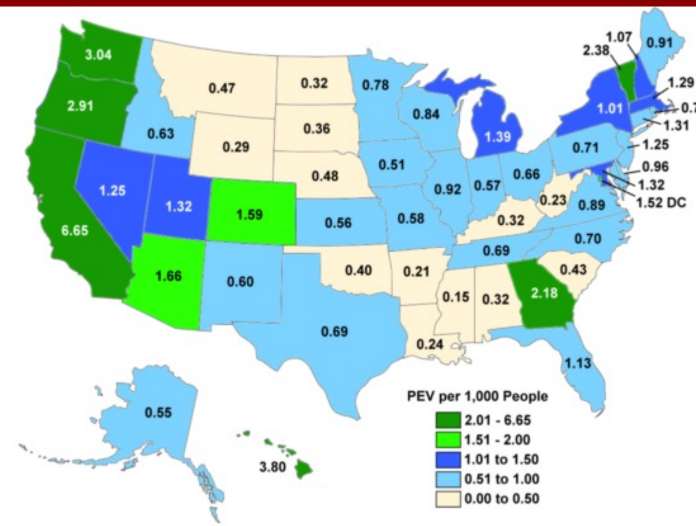
Multi-stage Stochastic Optimization for a PV-Storage Hybrid Unit in a Household, **Proceedings of the IEEE-IAS Conference, 2017**

PEV: Introduction of a New Source of Storage

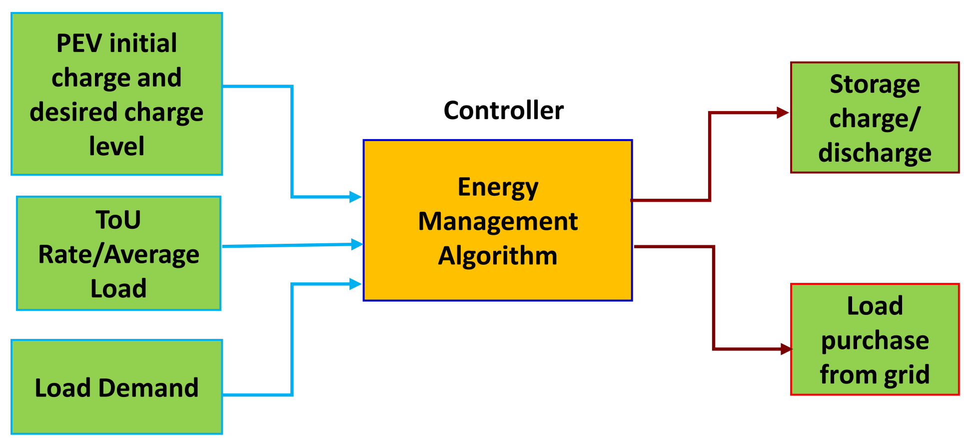




Usage of PEV per 1000 people in different countries



Usage of PEV per 1000 people in US - 2016 (Clean Technica)



Flow diagram of PEV-based storage control

Hafiz, F., de Queiroz, A.R., Husain, I., Fajri, P., Charge Scheduling of a Plug-in Electric Vehicle Considering Load Demand Uncertainty based on Multi-stage Stochastic Optimization, **Proceedings of the IEEE North American Power Symposium (NAPS), 2017**

Existing Methods, Limitations and Motivation

[P. Tian, 2016] → **No uncertainty consideration**
No Storage sizing method

[W. Tushar et al, 2016] → **No uncertainty consideration**
No Storage sizing method
Central storage is considered

[S. El-Batway et al., 2017] → **A central community energy storage sizing method is proposed**
Distribution network's reliability and flexibility are considered

[G. Ye et. al, 2017] → **Two different methods for optimal decision and revenue division is considered**
No storage sizing method is considered

P. Tian, X. Xiao, K. Wang, and R. Ding, "A Hierarchical Energy Management System Based on Hierarchical Optimization for Microgrid Community Economic Operation," *IEEE Trans on Smart Grid*, vol. 7, no. 5, pp. 2230–2241, Sept. 2016.

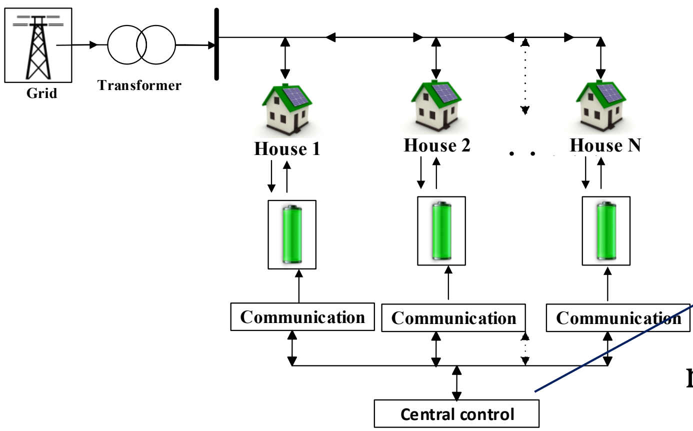
W. Tushar, B. Chai, C. Yuen, S. Huang, D. B. Smith, H. V. Poor and Z. Yang, "Energy Storage Sharing in Smart Grid: A Modified Auction-Based Approach," *IEEE Trans on Smart Grid*, vol. 7, no. 3, pp. 1462–1475, May 2016.

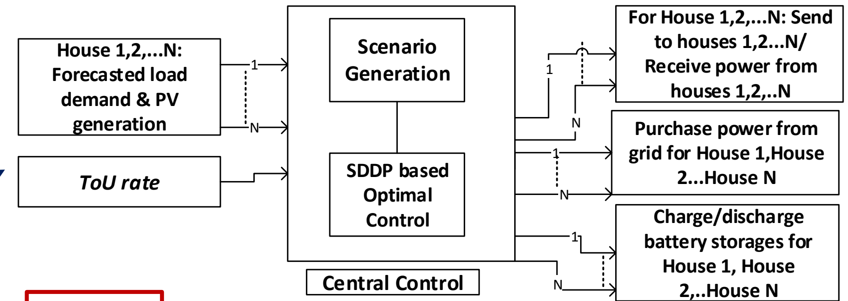
S. El-Batway, and W. G. Morsi, "Optimal Design of Community Battery Energy Storage Systems with Prosumers Owning Electric Vehicles," *IEEE Trans on Ind. Informatics*, Sept. 2017.

G. Ye, G. Li, D. Wu, X. Chen, and Y. Zhou, "Towards Cost Minimization With Renewable Energy Sharing in Cooperative Residential Communities," *IEEE Access*, vol. 5, pp. 11688–11699, 2017.

What is the exact size of storages e optimal control scheme to be used in a scheme with several houses???

Cost Effective Energy Management for a Shared Community





$$\min J = \sum_{t=1}^{T}\left[C_t \cdot \sum_{i=1}^{N} P_{g,t}^{i}\right]$$

Electricity purchases from grid for House 1,2…N

Power balance equation for the individual houses:

$$P_{g,t}^{i} = P_{dem,t}^{\omega_L^i} - P_{PV,t}^{\omega_{PV}^i} + P_{C,t}^{i} - P_{D,t}^{i} + \sum_{j=1,j\neq i}^{N} P_{i-j,t}^{j} - \sum_{j=1,j\neq i}^{N} P_{j-i,t}^{j} + P_{def,t}^{i}, \forall t \in T$$

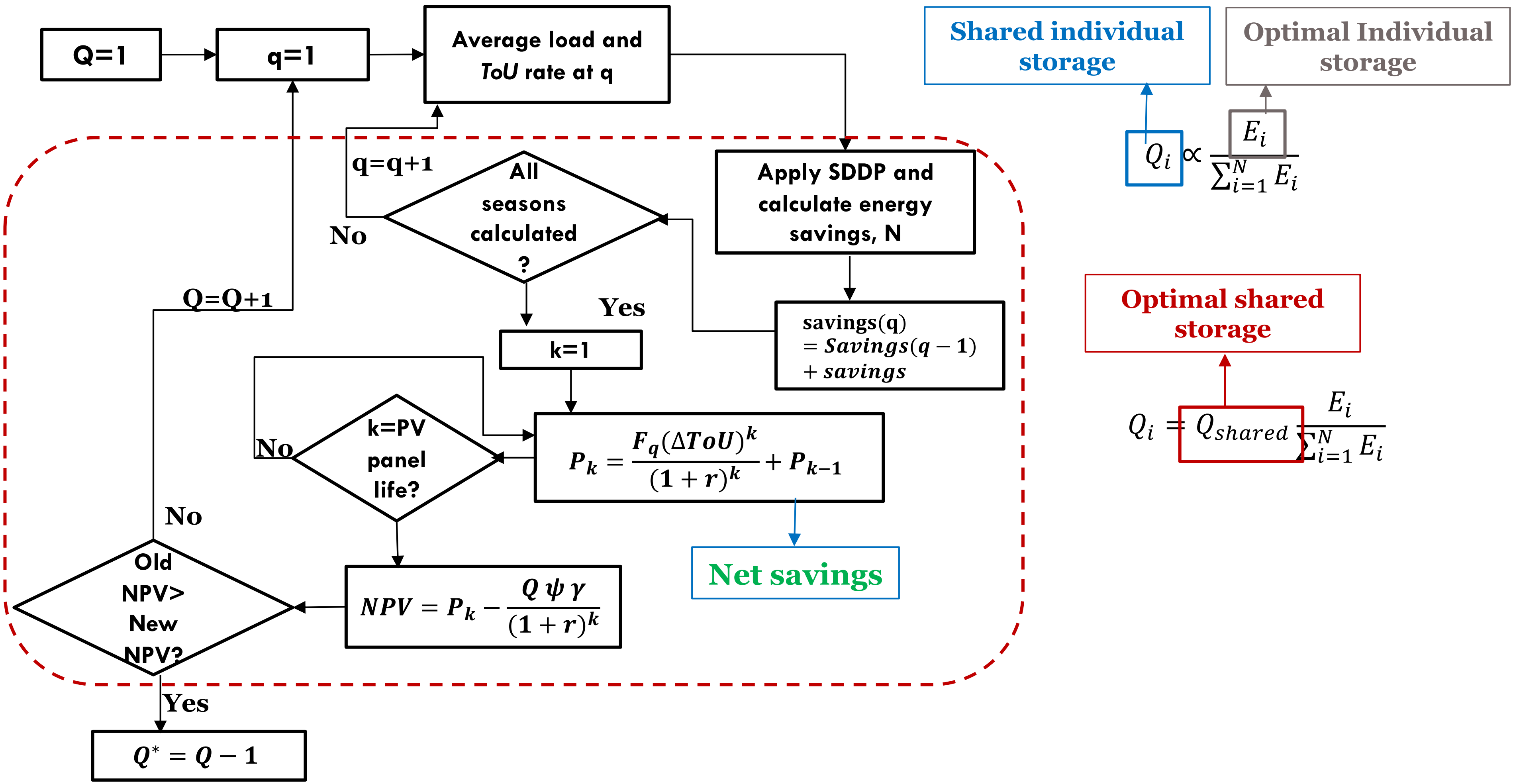
Receiving from other Houses

Sending to other Houses

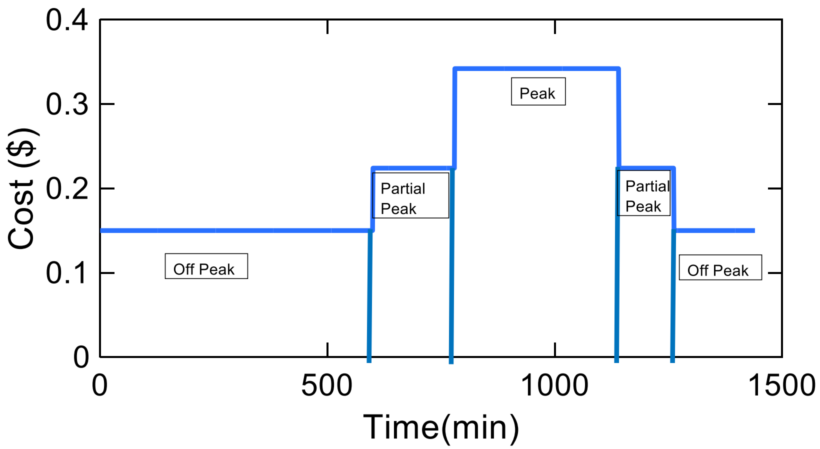
Charge balance constraint for the individual houses:

$$SOC_t^i = SOC_{t-1}^i + \frac{P_{C,t}^i \eta}{Q_i\,\Delta t} - \frac{P_{D,t}^i}{Q_i \eta \Delta t} + \frac{\sum_{j=1,j\neq i}^{N} P_{i-j,t}^{j}\,\eta}{Q_i\,\Delta t}, \forall t \in T$$

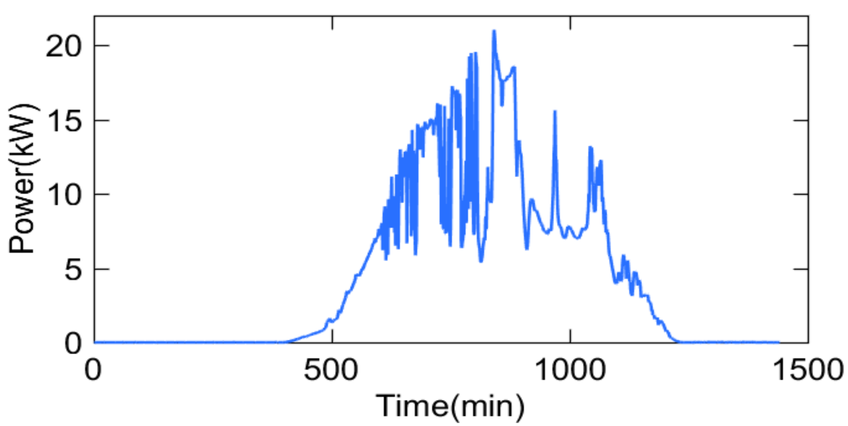
Storage Capacity Sizing for Individual houses in a Shared Community



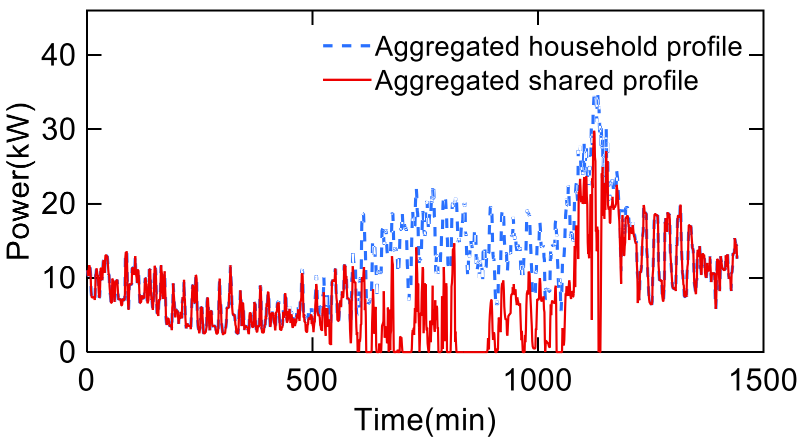
Shared energy community system vs individual system



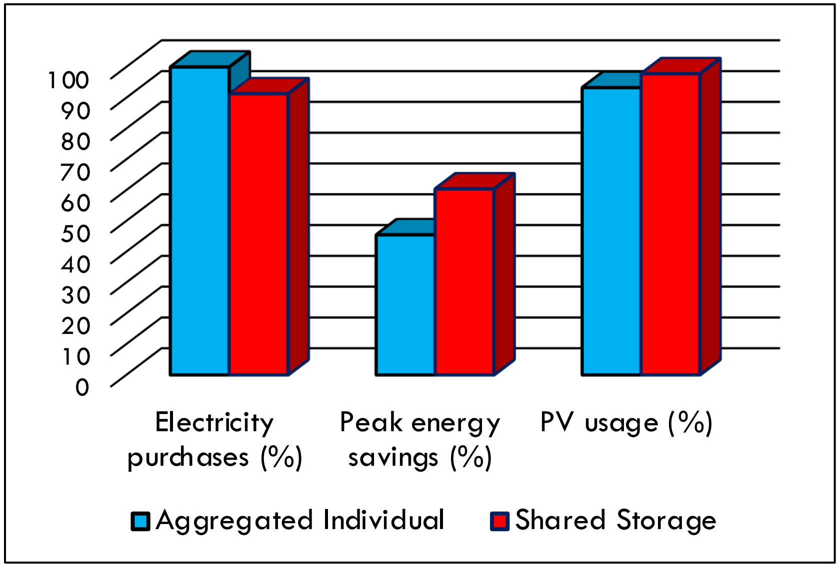
Summer *ToU* rates



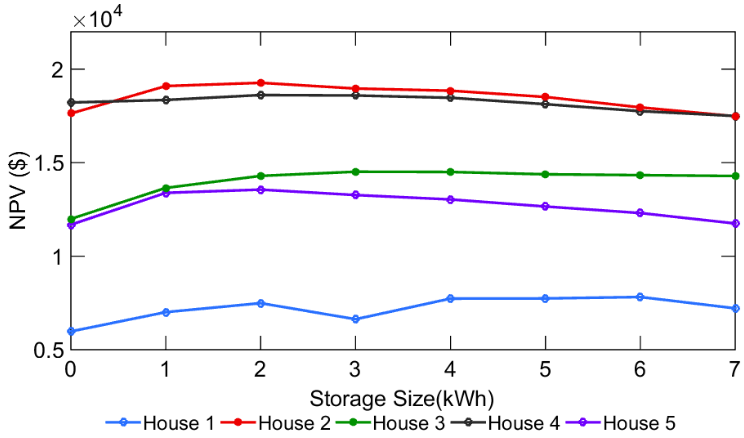
Aggregated solar generation of all houses



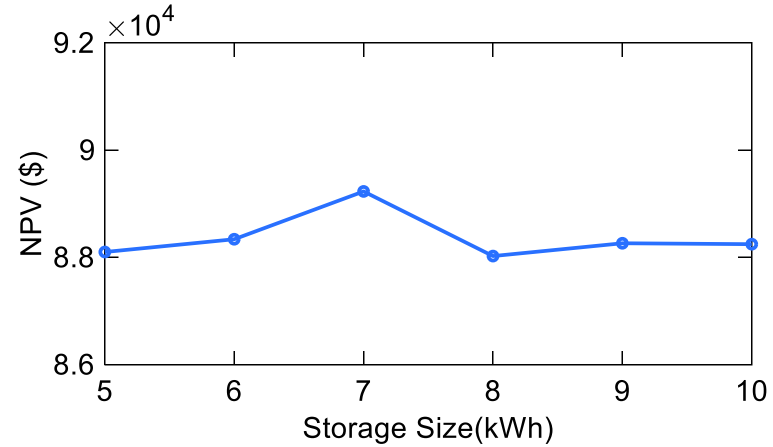
Community profile with and without control



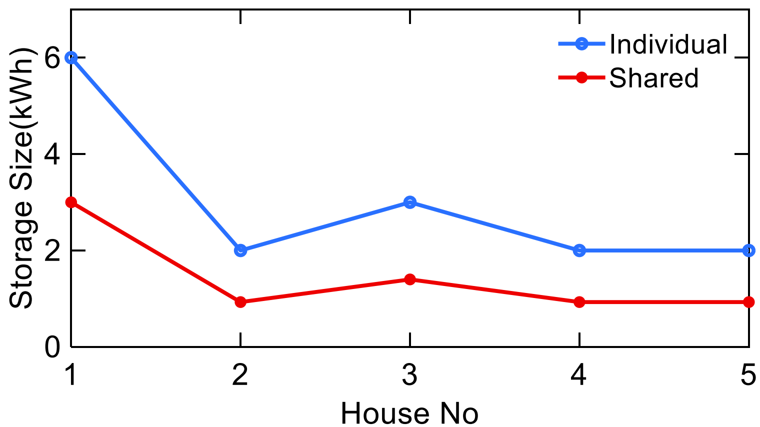
Shared energy community system vs individual system



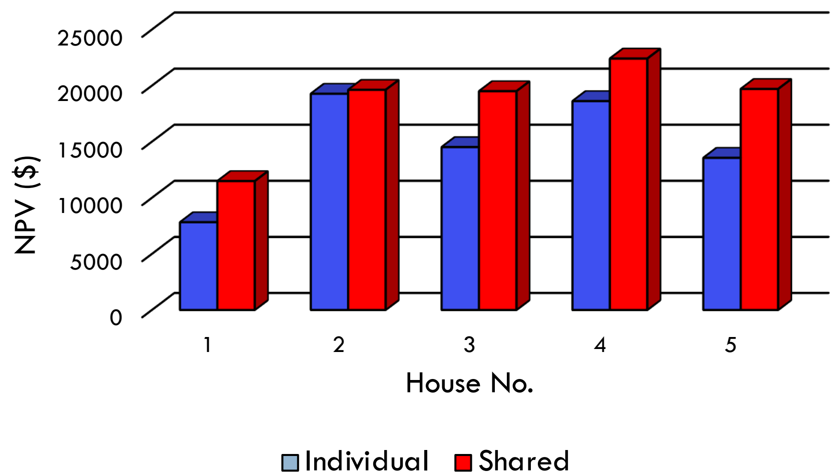
NPVs of five houses for different storage size



NPVs of different storage sizes for shared strategy



Comparison of optimal storage sizes for different houses for individual and shared controlled strategies



Comparison of NPVs for different houses for individual and shared controlled strategies

Final Comments

- A shared based control strategy for a community system is proposed
- Solar power generation and electricity demand uncertainties are considered
- A method of capacity sizing of storages for the shared scheme
- Improvement on critical parameters such as electricity purchase costs, peak savings and PV usage on daily basis and reduction of the requirement of storage capacity

Final Comments - Integrated Vision

Present/Future Systems have to be highly Flexible, Resilient and Connected where Resources are Optimized

References

1) De Queiroz, Anderson Rodrigo, and David P. Morton. "Sharing cuts under aggregated forecasts when decomposing multi-stage stochastic programs." *Operations Research Letters* 41.3 (2013): 311-316.
2) Hafiz, F., de Queiroz, A. R., Husain, I., & Fajri, P. (2017, September). Charge scheduling of a plug-in electric vehicle considering load demand uncertainty based on multi-stage stochastic optimization. In 2017 North American Power Symposium (NAPS) (pp. 1-6). IEEE.
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5) Hafiz, F., de Queiroz, A. R., & Husain, I. (2018). Solar generation, storage, and electric vehicles in power grids: Challenges and solutions with coordinated control at the residential level. IEEE Electrification Magazine, 6(4), 83-90.

Thank You !

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