Investment In Smart Homes

Consumer And Distributor Perspectives

Seyyedreza Madani

joint work with Pierre-Olivier Pineau

June 7, 2021

Rational behind V2G

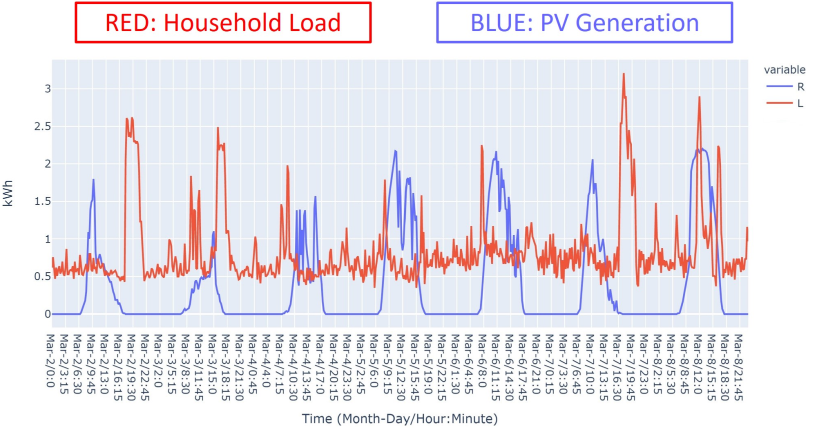


Figure 1: Generation and load in a sample week in March

Smart Home Management

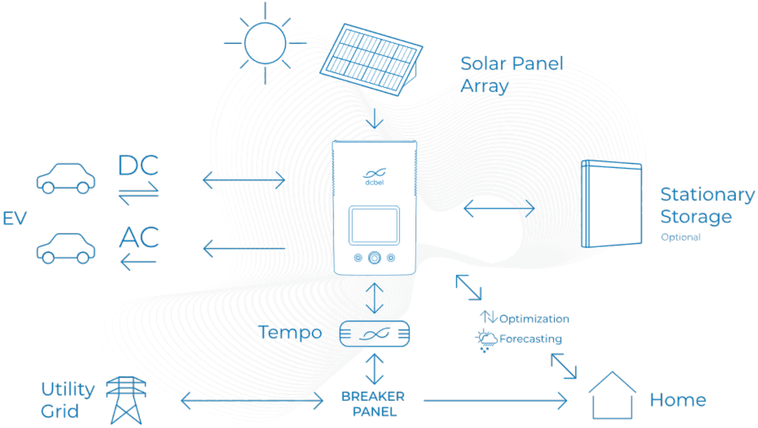


Figure 2: dcbel device

Previous studies

- The influences of Vehicle to Grid (V2G) system and its integration with RESs on the environment, society and economy [BTM21]

Previous studies

- The influences of Vehicle to Grid (V2G) system and its integration with RESs on the environment, society and economy [BTM21]
- Ownership challenge: Aggregators and Other Actors in the market [NZdRKS19]

Previous studies

- The influences of Vehicle to Grid (V2G) system and its integration with RESs on the environment, society and economy [BTM21]
- Ownership challenge: Aggregators and Other Actors in the market [NZdRKS19]
- Profitability of V2H [LP20]

Previous studies

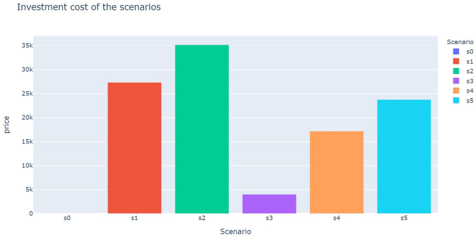
- The influences of Vehicle to Grid (V2G) system and its integration with RESs on the environment, society and economy [BTM21]
- Ownership challenge: Aggregators and Other Actors in the market [NZdRKS19]
- Profitability of V2H [LP20]
- Premium tariff rates for V2G [Ric13]

Previous studies

- The influences of Vehicle to Grid (V2G) system and its integration with RESs on the environment, society and economy [BTM21]
- Ownership challenge: Aggregators and Other Actors in the market [NZdRKS19]
- Profitability of V2H [LP20]
- Premium tariff rates for V2G [Ric13]
- Some case studies on the profitability of V2G: in the Netherlands [vdV20], China [LTL+20] and, India [LAAP+21]

Investment Scenarios

Scenario	Capacity of the stationary battery (kWh)	Capacity of the EV's battery (kWh)	Solar PV availability	Total cost (purchase and installation, USD)
0 – Status quo	❌	❌	❌	0
1 – Battery	40.5	❌	❌	27,300
2 – Battery + PV	27	❌	Yes	35,125
3 – EV	❌	36	❌	4,000
4 – EV + PV	❌	36	Yes	17,145
5 – Battery + EV + PV	10	36	Yes	23,724



Main problems

- Which agent? Profitability of investment in smart home for the distributor and the prosumer

Main problems

- Which agent? Profitability of investment in smart home for the distributor and the prosumer
- Which scenario? The best investment scenario for smart home technologies

Main problems

- Which agent? Profitability of investment in smart home for the distributor and the prosumer
- Which scenario? The best investment scenario for smart home technologies
- Which rate? Effects of different tariff structures on profitability of smart home technologies

Main problems

- Which agent? Profitability of investment in smart home for the distributor and the prosumer
- Which scenario? The best investment scenario for smart home technologies
- Which rate? Effects of different tariff structures on profitability of smart home technologies
- Consequences? Effects of different scenarios on the annual cost and monthly peak-loads

1. Introduction
2. Mathematical Models
3. Results and Insights
4. Conclusion

Assumptions

- All parameters are deterministic and given in the beginning

Assumptions

- All parameters are deterministic and given in the beginning
- Real consumption and generation records are used (provided by the Green Mountain Power (GMP) distribution company in Vermont)

Assumptions

- All parameters are deterministic and given in the beginning
- Real consumption and generation records are used (provided by the Green Mountain Power (GMP) distribution company in Vermont)
- The same charge/discharge limitation and efficiency rates are used for battery and EV

Assumptions

- All parameters are deterministic and given in the beginning
- Real consumption and generation records are used (provided by the Green Mountain Power (GMP) distribution company in Vermont)
- The same charge/discharge limitation and efficiency rates are used for battery and EV
- In GMP's model, Real-Time Locational Marginal Price (RTLMP) ($/kWh) in Vermont is used. The buying and selling prices are equal.

Rates

In prosumer model, five tariff structures are used:

Rate Name	Fixed charge ($/day)		Rate ($/kWh)
Flat (FX)	0.492	Usage	0.16859
Time-of-Use (TOU)	0.651	Peak-Load Usage	0.26771
		Off-Peak Usage	0.11411
FX for home & TOU for EV	0.651	General Usage	0.16859
		Off-Peak EV Usage	0.12831
RTLMP	0	price updates every	5 minutes
Buying at TOU from grid & Selling at RTLMP back to grid	0.651	Peak-Load Usage	0.26771
		Off-Peak Usage	0.11411
		price updates every	5 minutes

Indexes

$$t \in \{\mathcal{T}\} \qquad \text{episode } t \text{ in horizon } [1, 2, 3, ..., T]$$
$$k \in \{\mathcal{K}\} \qquad \text{month } k \text{ in horizon } [1, 2, 3, ..., K]$$

- A full year (8,760 hours) with 15 minutes time-steps (t) is considered here.[1]

[1] Note that when 1 kWh is used during this time interval means that 4 kW of power/capacity are being used

Parameters

$$B^{max} = \text{capacity (kWh) of battery}$$
$$B^{min} = \text{minimum allowed electricity (kWh) in battery}$$
$$E^{max} = \text{capacity (kWh) of EV}$$
$$E^{min} = \text{minimum allowed electricity (kWh) in EV}$$
$$U^{c} = \text{charging capacity (kWh) of battery/EV during the interval}$$
$$U^{d} = \text{discharging capacity (kWh) of battery/EV during the interval}$$
$$1 - \eta^{c} = \text{charging loss rate}$$
$$1 - \eta^{d} = \text{discharging loss rate}$$

Parameters cntd.

$$P^{rns} = \text{cost coefficient (\$/kW) of RNS}$$
$$P^{cap} = \text{cost coefficient (\$/kW) of capacity}$$
$$P_t^{buy} = \text{electricity price (\$/kWh) to buy from grid at time } t$$
$$P_t^{sell} = \text{electricity price (\$/kWh) to sell to grid at time } t$$
$$L_t = \text{load (kWh) at time } t$$
$$A_t = \text{availability of EV at time } t \text{ under the chosen scenario}$$
$$V_t = \text{EV usage (kWh) (for vehicle riding) at time } t \text{ under the chosen s}$$
$$R_t = \text{electricity generation (kWh) from solar panel } t$$
$$I^{trade} = \text{indicates if it is allowed to sell electricity to grid}$$

Decision Variables

x_t^{GL} = electricity (kWh) from grid to load at time t

x_t^{GB} = electricity (kWh) from grid to battery at time t

x_t^{GE} = electricity (kWh) from grid to EV at time t

x_t^{RL} = electricity (kWh) from solar panel to load at time t

x_t^{RB} = electricity (kWh) from solar panel to battery at time t

x_t^{RE} = electricity (kWh) from solar panel to EV at time t

x_t^{RG} = electricity (kWh) from solar panel to grid at time t

Decision Variables cntd.

$$x_t^{BL} = \text{electricity (kWh) from battery to load at time } t$$
$$x_t^{EL} = \text{electricity (kWh) from EV to load at time } t$$
$$x_t^{BG} = \text{electricity (kWh) from battery to grid at time } t$$
$$x_t^{EG} = \text{electricity (kWh) from EV to grid at time } t$$
$$x_k^{peak} = \text{maximum electricity (kWh) taken from grid in an episode in mont}$$

State variables

$$b_t^B = \text{available electricity (kWh) in stationary battery at time } t$$
$$b_t^E = \text{available electricity (kWh) in EV battery at time } t$$

Distributor's Model I

objective function

$$
\begin{aligned}
\min \sum_{t=1}^{T} \Big(P_t^{buy} (x_t^{GL} + x_t^{GB} + x_t^{GE}) & \qquad \text{buying cost} \\
- P_t^{sell} (x_t^{RG} + \eta^d x_t^{BG} + \eta^d x_t^{EG}) \Big) & \qquad \text{selling revenue} \\
+ 4 \sum_{k=1}^{12} (P^{rns} + 1.35 P^{cap}) x_k^{peak} & \qquad \text{network charge} \qquad (1)
\end{aligned}
$$

Distributor's Model II

Subject to:

Covering load

$$x_t^{GL} + \eta^d (x_t^{BL} + x_t^{EL}) + x_t^{RL} \geq L_t \qquad \forall t \qquad (2)$$

Distributor's Model III

availability of EV and stored energy limitation

$$x_t^{BL} + x_t^{BG} \leq b_t^{B} \qquad \forall t \qquad (3)$$

$$x_t^{EL} + x_t^{EG} \leq b_t^{E} A_t \qquad \forall t \qquad (4)$$

$$x_t^{GE} + x_t^{RE} \leq E^{max} A_t \qquad \forall t \qquad (5)$$

Distributor's Model IV

charging and discharging limits

$$x_t^{BL} + x_t^{EL} + x_t^{BG} + x_t^{EG} \leq U^d \qquad \forall t \qquad (6)$$

$$x_t^{GB} + x_t^{GE} + x_t^{RB} + x_t^{RE} \leq U^c \qquad \forall t \qquad (7)$$

Distributor's Model V

stored energy limitations

$$B^{min} \leq b_t^B \leq B^{max} \qquad \forall t \qquad (8)$$

$$E^{min} \leq b_t^E \leq E^{max} \qquad \forall t \qquad (9)$$

Distributor's Model VI

PV generation

$$x_t^{RL} + x_t^{RB} + x_t^{RE} + x_t^{RG} \leq R_t \qquad \forall t \qquad (10)$$

Distributor's Model VII

State transition

$$b_t^B + \eta^c(x_t^{GB} + x_t^{RB}) - (x_t^{BL} + x_t^{BG}) = b_{t+1}^B \forall t \qquad (11)$$

$$b_t^E + \eta^c(x_t^{GE} + x_t^{RE}) - (x_t^{EL} + x_t^{EG}) - \frac{V_t}{\eta^d} = b_{t+1}^E \forall t \qquad (12)$$

Distributor's Model VIII

peak load calculation

$$x_t^{GL} + x_t^{GB} + x_t^{GE} \leq x_k^{peak} \forall t \in k, k \tag{13}$$

Distributor's Model IX

domain of the decision variables

$$\begin{aligned} x_t^{RL}, x_t^{RB}, x_t^{RE}, x_t^{RG}, x_t^{BG}, x_t^{EG}, x_t^{BL}, \\ x_t^{EL}, x_t^{GL}, x_t^{GB}, x_t^{GE}, x_k^{peak}, b_t^{B}, b_t^{E} \geq 0 \end{aligned} \qquad \forall t \qquad (14)$$

Prosumer's Model I

objective function

$$\min \sum_{t=1}^{T} \Big(P_t^{buy}(x_t^{GL} + x_t^{GB} + x_t^{GE}) - P_t^{sell}(x_t^{RG} + \eta^d x_t^{BG} + \eta^d x_t^{EG})\Big) \tag{15}$$

Prosumer's Model II

Subject to:
Constraints 2 to 12

Trade allowance

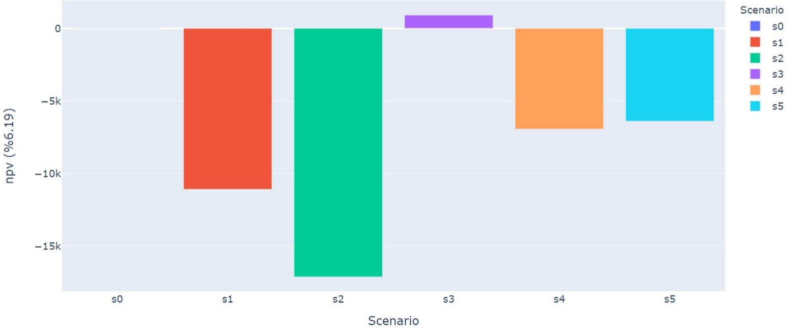
$$x_t^{RG} + x_t^{BG} + x_t^{EG} \leq (U^d + R_t)I^{trade} \qquad \forall t \qquad (16)$$

Prosumer's Model III

domain of the decision variables

$$
\begin{aligned}
x_t^{RL}, x_t^{RB}, x_t^{RE}, x_t^{RG}, x_t^{BG}, x_t^{EG}, x_t^{BL},& \\
x_t^{EL}, x_t^{GL}, x_t^{GB}, x_t^{GE}, b_t^{B}, b_t^{E} \geq 0& \qquad \forall t \qquad (17)
\end{aligned}
$$

NPV of scenarios when system is controlled by GMP



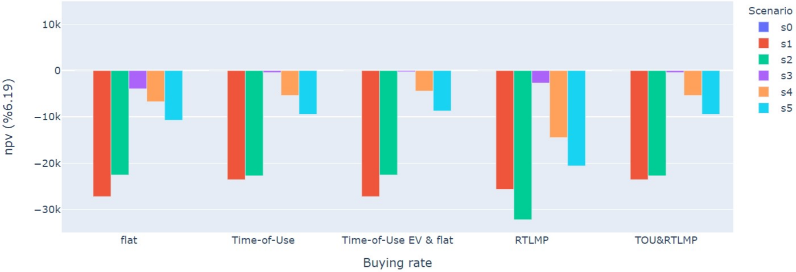
- Scenario #3 (having only EV) is the only profitable (+$909.3) investment scheme for the distributor. ($i = 0.0619$, $N = 15$)

Peak-Loads when GMP controls the system

- Peak-load shaving under different investment scenarios

NPV of scenarios when system is controlled by PRO

V2H, selling back to grid is NOT allowed



- All scenarios under any rate structure yield negative NPVs.

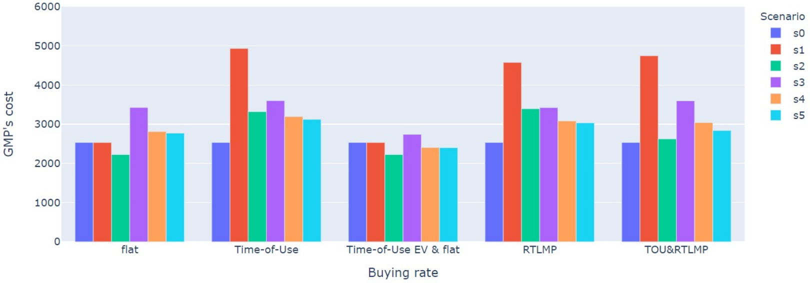
NPV of scenarios when system is controlled by PRO

V2G, selling back to grid is allowed

- RTLMP and TOU&RTLMP rate structures make any investment scenario UNPROFITABLE.
- S1 (Battery) and S2 (Battery+PV) are always UNPROFITABLE.

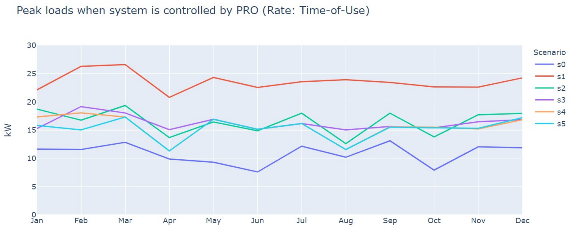
GMP's cost when system is controlled by PRO

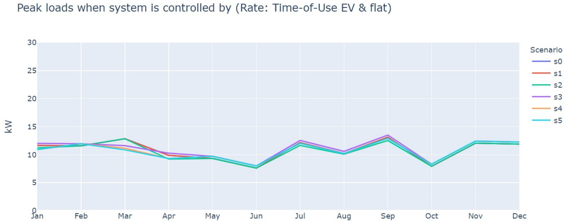
V2G, selling back to grid is allowed



- Choosing Time-Of-Use-EV&Flat yields the least cost for GMP, regardless of the PRO's investment scenario.

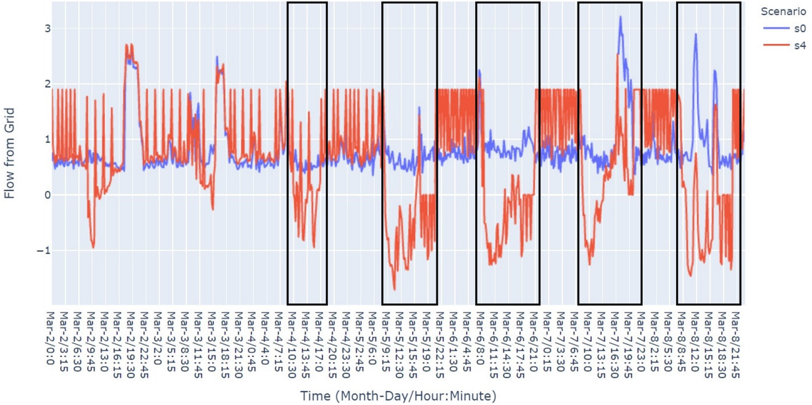
Peak-Loads when system is controlled by PRO (selling is allowed)





Flow from Grid when system is controlled by PRO (in 15-minutes time-steps)

rate is *TOU-for-EV-and-FX* and selling back to grid is allowed



1. Introduction
2. Mathematical Models
3. Results and Insights
4. Conclusion

Who should invest?

- The optimal investment strategy for the distributor's investment returns the NPV of $909.32
- The optimal investment strategy for the prosumer's investment returns the NPV of up to $11,728.92 (under proper tariff structure)
- A proper investment by the prosumer can save in both prosumer's and distributor's yearly costs.

What investment scenario to choose?

- The one and only profitable investment scenario for the distributor is scenario #3 (EV)
- (Under proper tariff structure) the best investment scenarios for the prosumer are scenario #4 (EV+PV), scenario #3 (EV), and, scenario #5 (Battery+EV+PV), respectively.

What tariff to impose?

- If selling back to grid is NOT allowed (v2H), all investment scenarios are UNPROFITABLE
- investment made by the prosumer usually increases the distributor's costs, however, TOU-for-EV&FX cuts the yearly costs of both agents.

Future works

- Developing a dynamic model with uncertain parameters
- Investigating collective investment scenarios (allowing local sharing)
- Considering effects of mass smart home technology adaption consequences on loads and prices

References

[BTM21] Bijan Bibak and Hatice Tekiner-MoÄ§ulkoÃğ.
A comprehensive analysis of vehicle to grid (v2g) systems and scholarly literature on the application of such systems.
Renewable Energy Focus, 36:1–20, 2021.

[LAAP+21] K. Logavani, A. Ambikapathy, G. Arun Prasad, Ahmad Faraz, and Himanshu singh.
Smart Grid, V2G and Renewable Integration, pages 175–186.
Springer Singapore, Singapore, 2021.

[LP20] JosÃľe-Lise Leheutre and Pierre-Olivier Pineau.
Profitability of a vehicle-to-home system in different electricity tariff contexts.
Rapport dâĂŹÃľtude de la Chaire de gestion du secteur de lâĂŹÃľnergie, 03, 2020.

[LTL+20] Xinzhou Li, Yitong Tan, Xinxin Liu, Qiangqiang Liao, Bo Sun, Guangyu Cao, Cheng Li, Xiu Yang, and Zhiqin Wang.
A cost-benefit analysis of v2g electric vehicles supporting peak shaving in shanghai.
Electric Power Systems Research, 179:106058, 2020.

[NZdRKS19] Lance Noel, Gerardo Zarazua de Rubens, Johannes Kester, and Benjamin K. Sovacool.
The Economic and Business Challenges to V2G, pages 91–116.
Springer International Publishing, Cham, 2019.

[Ric13] David B. Richardson.
Encouraging vehicle-to-grid (v2g) participation through premium tariff rates.
Journal of Power Sources, 243:219–224, 2013.

[vdV20] MT van der Ven.
Vehicle to grid in utrecht: Integrating electric vehicles into the energy system of utrecht.
Master's thesis, 2020.

Thanks!