Validation of Model Predictive Home Energy Management System Using Actual Equipment

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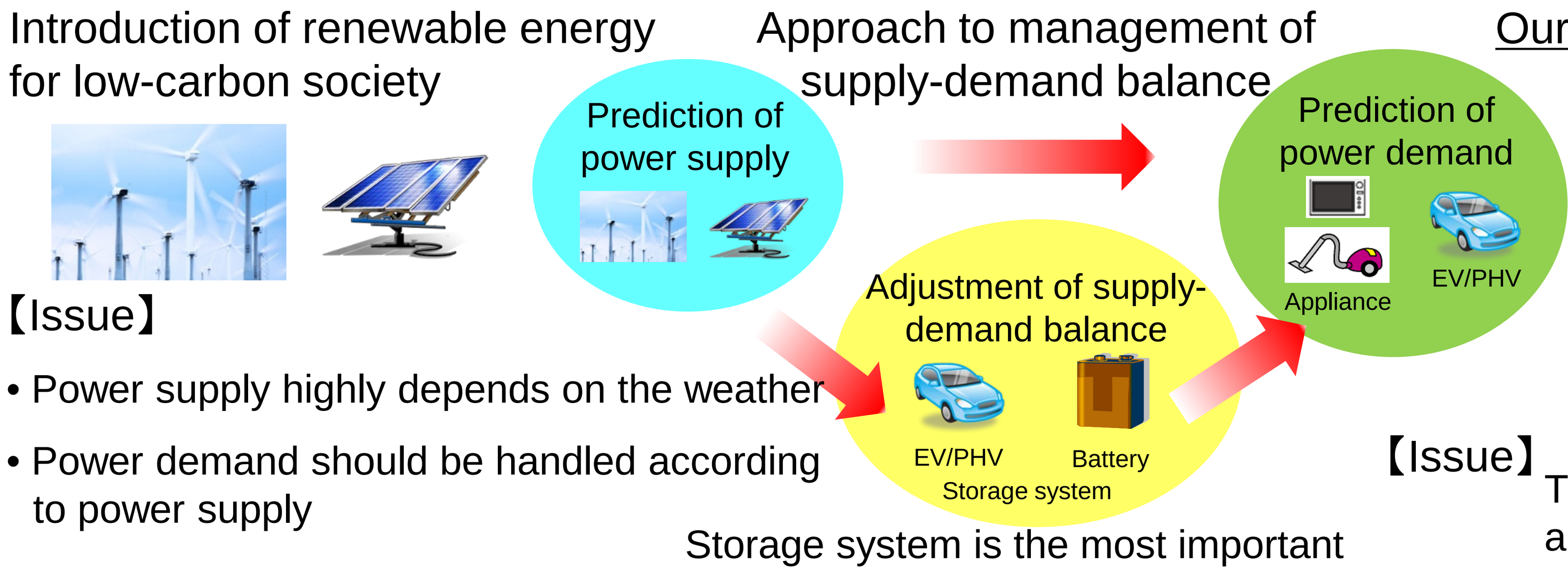
Background

Introduction of renewable energy for low-carbon society

Approach to management of supply-demand balance



【Issue】

- Power supply highly depends on the weather
- Power demand should be handled according to power supply

Storage system is the most important component

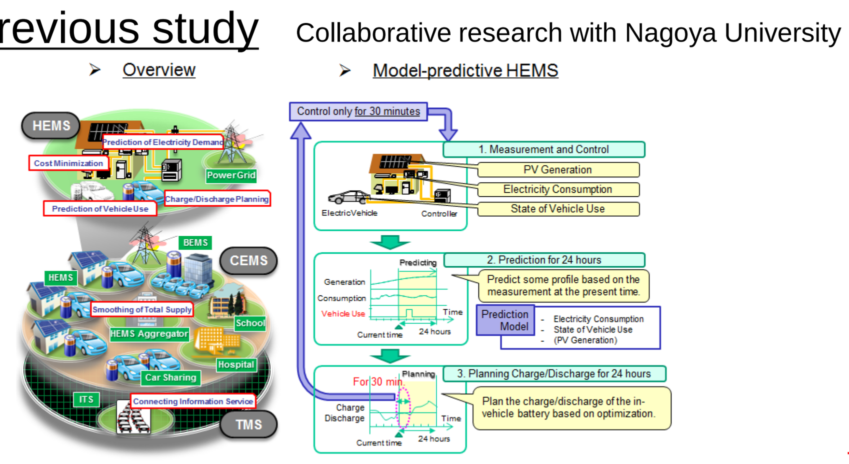
【Issue for storage system】

- Price
- Installation place

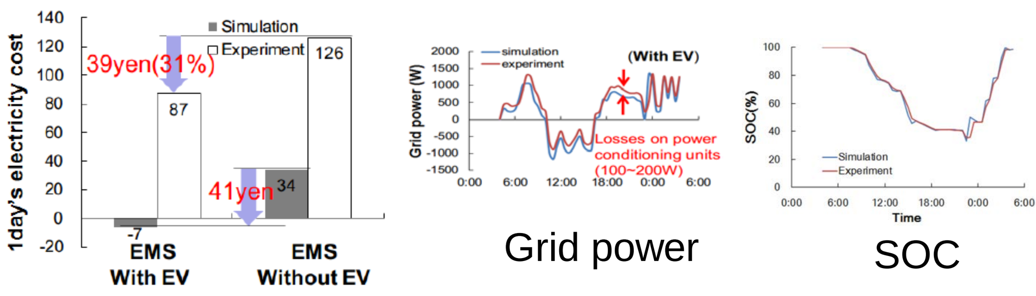
Products	Stationary battery (7.2kWh)	Electric vehicle (16kWh)
Price (Without tax)	¥2,040,000	¥2,628,000

Our goal is to develop an HEMS using in-vehicle batteries.

Our previous study — Collaborative research with Nagoya University



【Issue】 The large deviation between theoretical values and actual measurements

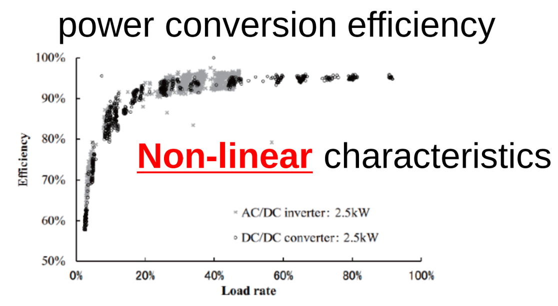


Grid power SOC

Power conditioner unit model

Dynamic characteristic model

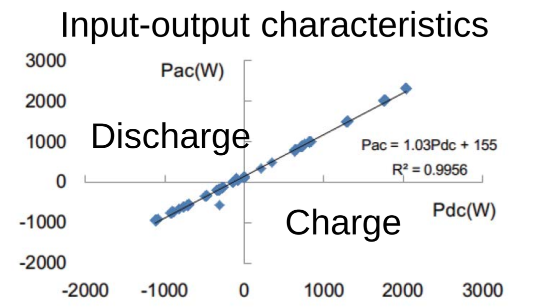
Load rate vs. power conversion efficiency



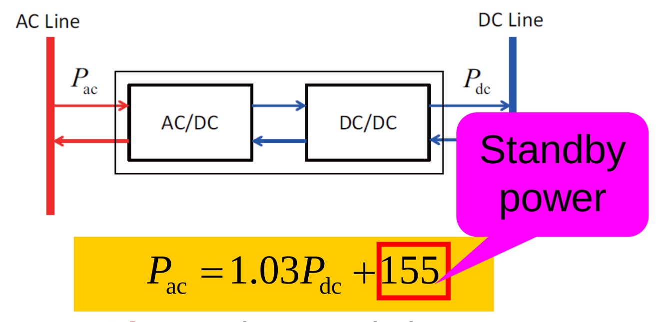
Modeling based on input-output characteristics

Proposed viewpoint

Input-output characteristics

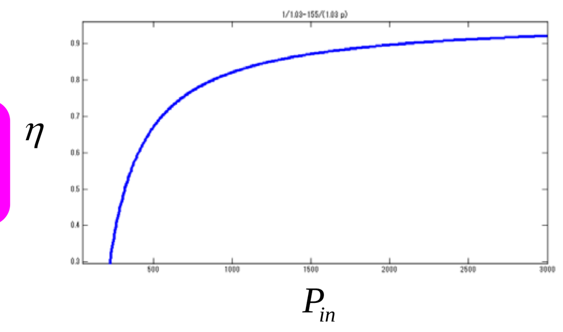


$$\eta = \frac{P_{out}}{P_{in}} = \frac{\alpha P_{in} - P^{standby}}{P_{in}} = \alpha - \frac{P^{standby}}{P_{in}}$$



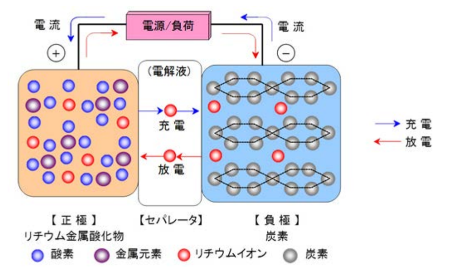
$$P_{ac} = 1.03 P_{dc} + 155$$

Linear characteristics



Battery model

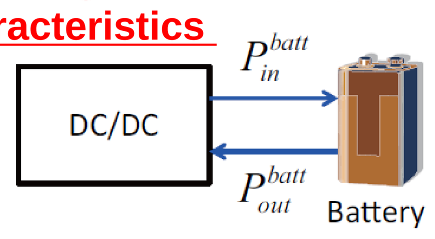
Chemical reaction model



(Source: Hitachi Chemical HP)

- Complexity
- Difficulty of implementation

Modeling based on input-output characteristics

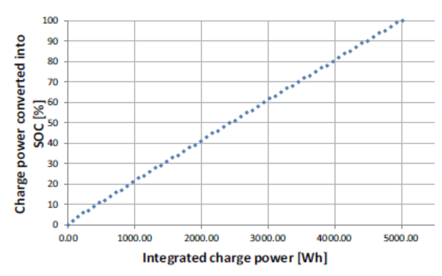


$$b_j^v(k+1|t) = b_j^v(k|t) + \{1-\tilde{\gamma}_j(k|t)\} H p_j^v(k|t)\Delta t - \tilde{\gamma}_j(k|t)\tilde{B}_j^{v,cons}(k|t)$$

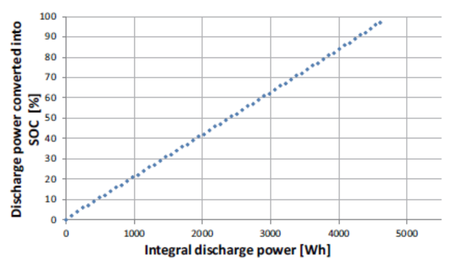
$$H = \begin{cases} \eta^{char} & p_j^v(k|t) \ge 0 \\ \eta^{dischar} & p_j^v(k|t) < 0 \end{cases}$$

Proposed viewpoint

Input-output characteristics



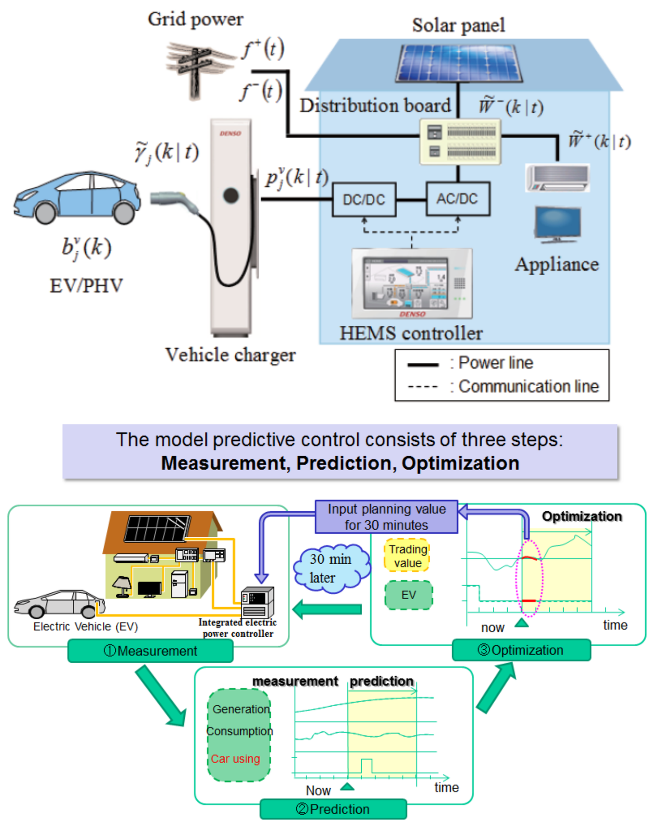
Charge characteristics



Discharge characteristics

Formulation of charge and discharge plan

Model predictive HEMS using in-vehicle batteries



- $\tilde{W}^+(k|t)$: Electrical power consumed in home [W]
- $\tilde{W}^-(k|t)$: Electrical power generated in home [W]
- $\tilde{\gamma}_j(k|t)$: Vehicle usage 1 : available, 0 : non-available
- $\tilde{B}_j^{v,cons}(k|t)$: Power consumption of vehicle [Wh]
- $f^+(t)$: Purchase price [Yen/kWh]
- $f^-(t)$: Sale price [Yen/kWh]
- W_{max} : Maximum instantaneous electrical power [W]
- J_{max} : Maximum electrical power [Wh]
- $P_j^{v,char}$: Maximum charging power [W]
- $P_j^{v,dis}$: Maximum discharging power [W]
- $b_j^v(k|t)$: Battery power of vehicle [Wh]
- $B_j^{v,max}(t)$: Upper bound of the amount of battery [Wh]
- $B_j^{v,min}(t)$: Lower bound of the amount of battery [Wh]
- $B_j^{v,init}$: Initial value of the battery power [Wh]
- η^{char} : Efficiency of charge
- η^{dis} : Efficiency of discharge
- η^{PV} : Efficiency of photovoltaic generation
- $P^{standby}$: Efficiency of conversion between AC and DC [W]
- $p_j^v(k|t)$: Charging or discharging power of vehicle [W]

Mixed integer programming problem

【Decision variable】

$p_j^v(k|t)$: Charging or discharging power of vehicle [W]

【Evaluation function】 Daily home electricity costs

$$Z = \sum_{k=t}^{t+T-1} F(k)\tilde{W}(k|t)\Delta t \qquad F(k) = \begin{cases} f^+(k) & \text{if } \tilde{W}(k|t) \ge 0 \\ f^-(k) & \text{if } \tilde{W}(k|t) < 0 \end{cases} \text{※}$$

【Constraint condition】

1. $\tilde{W}(k|t) = \tilde{W}^+(k|t) + \eta^{PV}\tilde{W}^-(k|t) + \eta^{acdc}\sum_{j=1}^{N} p_j^v(k|t) + P^{standby}$
2. $b_j^v(k+1|t) = b_j^v(k|t) + \{1-\tilde{\gamma}_j(k|t)\} H p_j^v(k|t)\Delta t - \tilde{\gamma}_j(k|t)\tilde{B}_j^{v,cons}(k|t)$, $\quad H = \begin{cases} \eta^{char} & p_j^v(k|t) \ge 0 \\ \eta^{dischar} & p_j^v(k|t) < 0 \end{cases}$ ※
3. $\tilde{W}(k|t) \le W_{max}$
4. $\sum_{k=t}^{t+T-1} \tilde{W}(k|t) \le J_{max}$
5. $p_j^v(k|t)\tilde{\gamma}(k|t) = 0$
6. $P_j^{v,dis} \le p_j^v(k|t) \le P_j^{v,char}$
7. $B_j^{v,min}(k|t) \le b_j^v(k|t) \le B_j^{v,max}$

※) We have to convert these expressions to the mixed logical dynamical system (MLDS).

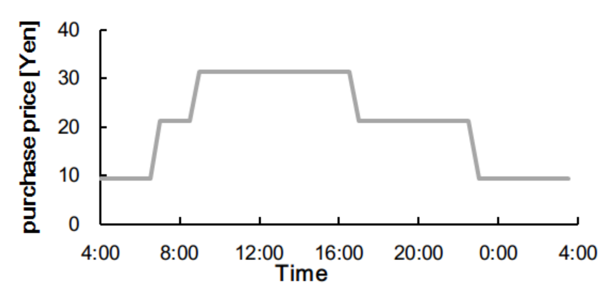
Experimental equipment and validation approach

Experimental equipment

Specification of the test equipment

Equipment	Specification
Solar panel (PV simulator)	5 kW
PV inverter	4.5 kW
Appliance (Electronic load)	2 kW
EV (Electronic load)	3 kW
In-vehicle battery	3 kWh
DC/DC converter	2.5 kW
AC/DC converter	2.5 kW

Electricity price setting



Validation approach

We performed 3 types of experiments to evaluate the proposed model.

(1) Without MPC※
→Validation of the effect of the proposed model

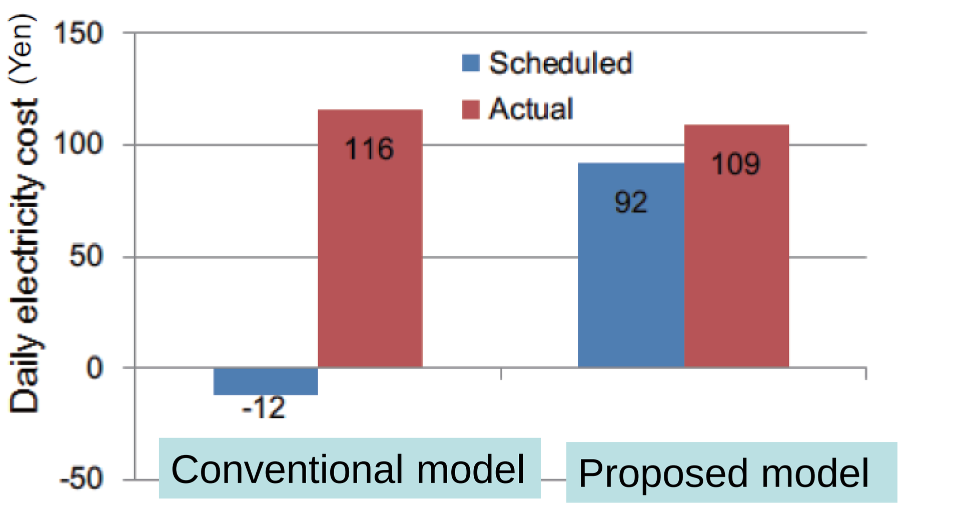
(2) With MPC
→Validation of the multiplier effect of the proposed model and MPC

(3) The number of charging and discharging
→Investigation of the proposed model's effect on battery behavior

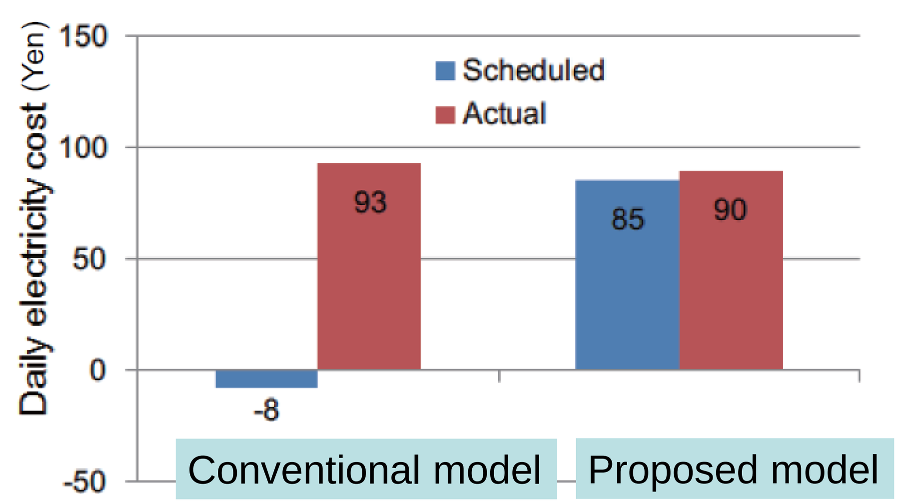
※MPC : Model Predictive Control

Experimental results

(1) Without MPC



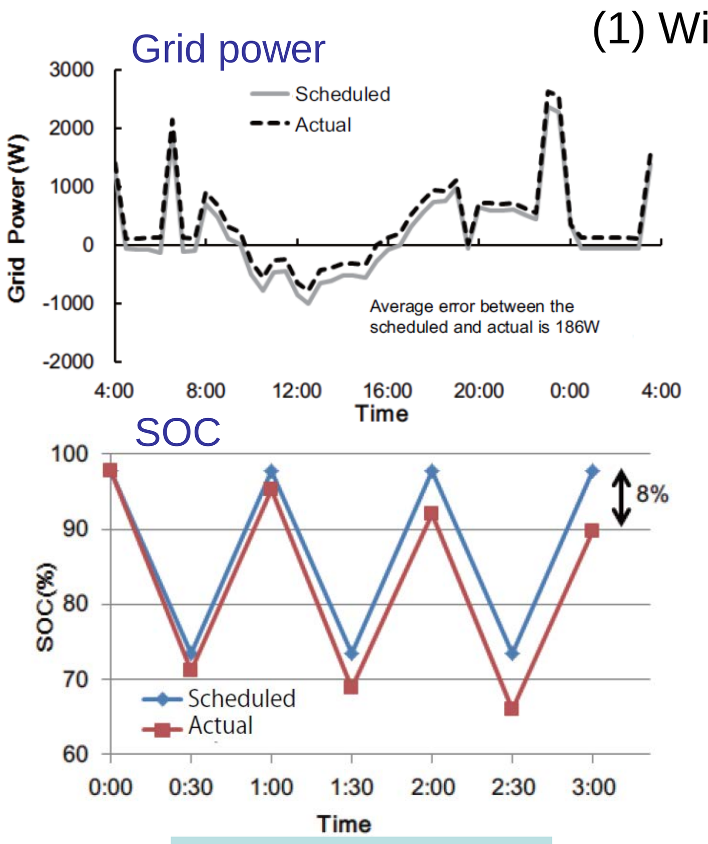
(2) With MPC



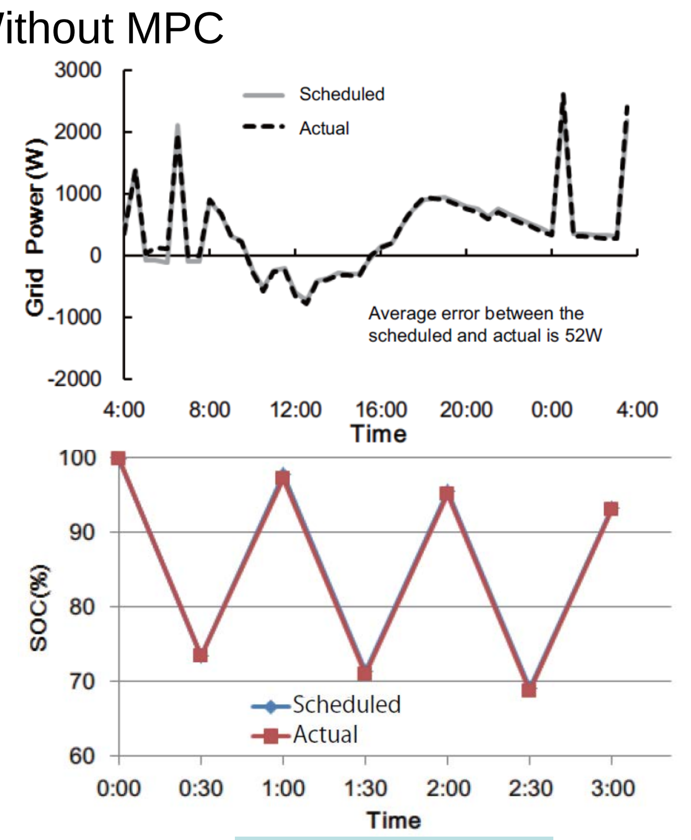
	Conventional model			Proposed model		
	Plan(Yen)	Actual(Yen)	Error(Yen)	Plan(Yen)	Actual(Yen)	Error(Yen)
Without MPC	-12	116	128	92	109	17
With MPC	-8	93	101	85	90	5

Experimental results

(1) Without MPC

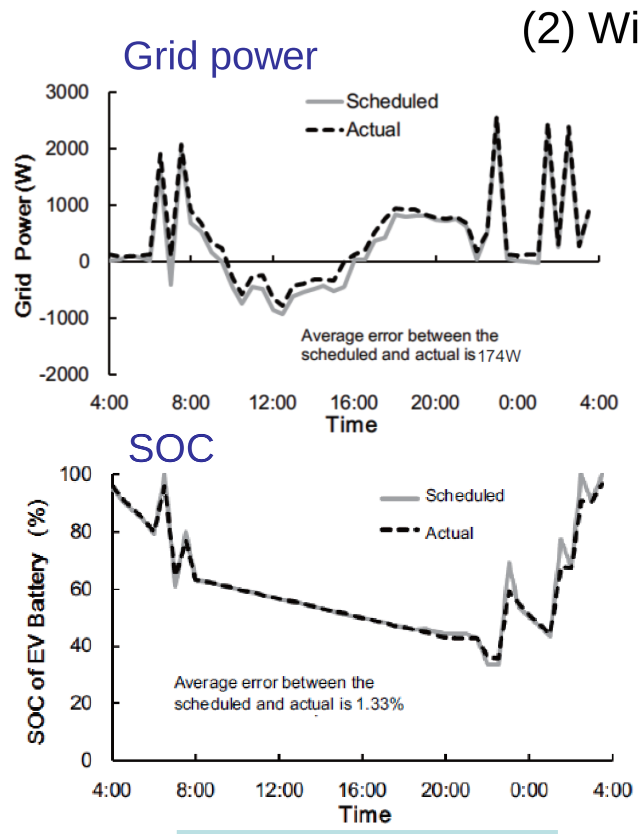


Conventional model

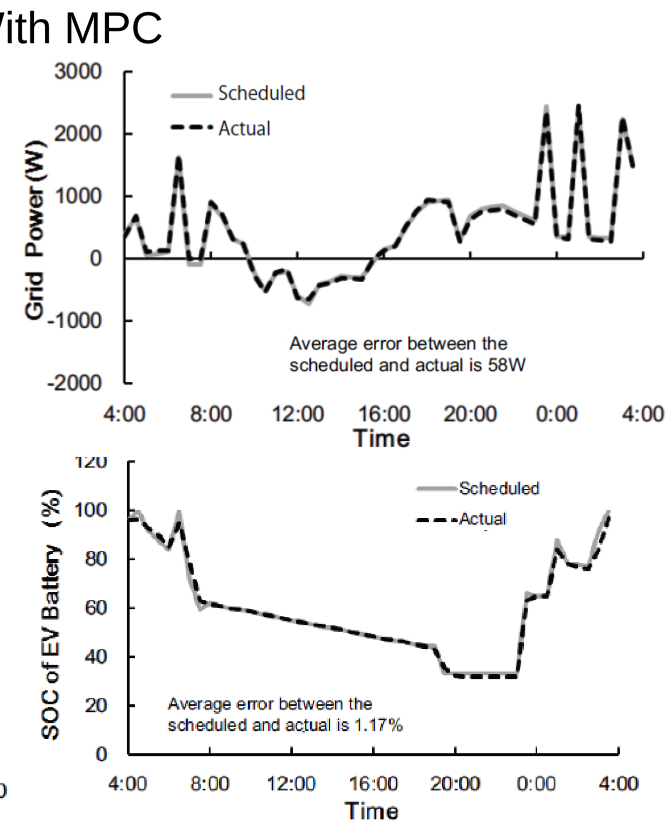


Proposed model

(2) With MPC



Conventional model



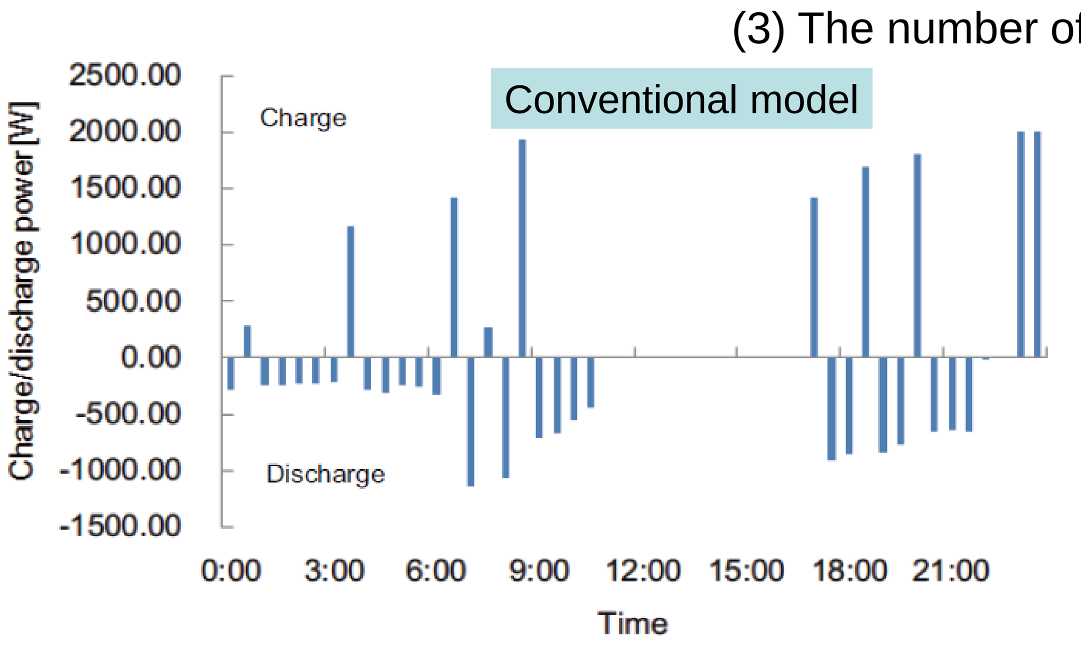
Proposed model

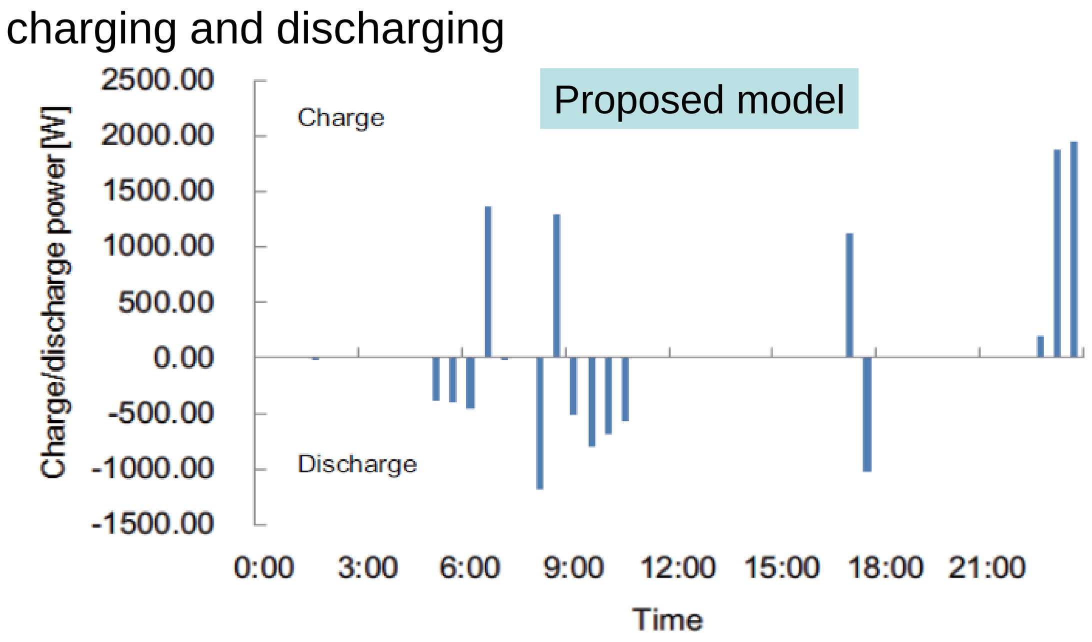
According to the experimental results of (1), the deviation can be reduced dramatically by applying the proposed model due to improvement the accuracy of the prediction of the grid power consumption.

As you can see from the experimental results of (2), the deviation can be reduced further by applying MPC due to the feedback structure.

Experimental results

(3) The number of charging and discharging





The proposed model makes the number of charging and discharging be reduced due to explicit consideration the efficiency.

Summary and future plan

Summary

We have proposed the simple models for power conditioner units and batteries. These model contribute to reduce the deviation between theoretical values and actual measurements.

Furthermore, application MPC to HEMS is effective for reducing the deviation.

Future plan

- Verification of the proposed model's extensibility when connecting a plurality of power conditioner units and batteries
- Development of a battery model taking into account an environmental condition