# Study on development of EV charging services coupled with power system conditions using IoT technology

*Masaki* Imanaka [1] , *Hiroyuki* Baba [1], *Kazuhiko* Ogimoto [1] and *Jun* Matsumura [2].

[1]The University of Tokyo, Institute of Industrial Science, 4-6-1 Komaba, Meguro-ku,Tokyo, Japan
[2]IoT-EX, Kanda Business Cube 3F 5-1 Kanda-Toyama-cho, Chiyoda-ku, Tokyo, Japan

**Abstract.** Deployment of electric vehicles (EVs) has been accelerated in many countries. However, for further deployment of EVs and their contribution to electrical power systems, various new services need to be implemented related to EVs and their charging, called “Place of Use” (PoU) services. The combined menu of the charging services has been proposed which bundles EV charging fees with home electricity bills. Settlement will be needed for such combined menu. This paper proposes the combined menu of EV charging with settlement of electricity. Technical feasibility of the settlement has been tested by EV charging testbed with the IoT-HUB technology. IoT-HUB is the virtual infrastructure which interconnects various connected devices and application by using “drivers” for each device. This paper also proposes a forecast method of EV charging demand for the settlement after the charging starts. The proposed method has reduced the forecast error of total charged energy compared to the simple method, but some of the forecast error has remained because of the variability of the charging time at the final step of state of charge.

## 1 Introduction

Deployment of electric vehicles (EVs) has been accelerated in many countries [1] in order to reduce the greenhouse gas emissions from the transportation sectors. EVs are also focused on as one of the major flexibility resources needed for electrical power systems with high penetration of variable renewable energy sources (RES), like photovoltaics (PVs) and wind turbines, because of a large capacity of EV batteries. However, for further deployment of EVs and their contribution to electrical power systems, various new services need to be implemented related to EVs and their charging, especially for countries where the EV deployment speed is still slow, like Japan.

EV’s electrical demand is different from the traditional demands in the point that EV’s demand essentially moves geographically. Historically, electrical demands are immovable and are contracted according to their location. However, EVs move with their electric energy storages and charge (and discharge in some condition) outside. Also, values of electricity for charging EVs have been added such as “flexible”, “green” or “generated by oneself” etc.. Therefore, new services for EVs need to be developed to realize such values. The authors have proposed a high-level concept of “Place of Use (PoU)” services, which highlights new customer services for EVs and their charging [2][3]. The phase of “Place of Use (PoU)” is coined from “Time of Use (ToU)” rates.

The combined menu of the charging services, which bundles the charging fees with the home electricity bill, has begun to be focused. For example, the office for Zero Emission Vehicles of the United Kingdom funds the project of “Home & Roam EV charging app” from 2021[4]. The authors consider that the combined menu of the charging services is an important example of the PoU services because the combined menu has the potential of enhancing daytime charging outside. The daytime charging coupled with the power system conditions can mitigate the challenges related to the oversupply of PV output [5].

Some settlement process will be needed for the combined menu if the electricity retailer of the house differs from the electricity retailer of the building the charger existing. Normally, settlement will be done by money, but this paper proposes the “settlement by electricity” in order to enhance the utilization of the daytime PV output. Forecast of the charging demand will be important for the settlement by use of electricity.

This paper proposes a combined menu of EV charging outside and household electricity bill, as an example of PoU, with the settlement by electricity. Technical feasibility of the settlement by electricity has been tested by EV charging testbed. The IoT-HUB technology [6] enables the EV charging monitoring and operation in the testbed. This paper also shows an example of charging EV charging power and proposes a forecast method of EV charging demand for the settlement after the charging starts.

## 2 Combined menu of charging service

### 2.1 Challenges for de-carbonized EV charging

EV charging with coordination of de-carbonized electricity is not a simple problem but can be seen in different ways according to stakeholders [2]. Suppose that the main RES of the power system is PV and the proportion of other RESs is still small, like in Japan. In such case, the ratio of RES is high in the daytime but small at night. In the daytime in spring or autumn, some of the PV may be curtailed because of either the power network restrictions or preventing the over-supply on the power system.

Consider that you want to charge your EV from 100% RES. If your home electricity is contracted with electricity retailer’s 100% renewable menu, legally it is charged by 100% renewable electricity whenever you charge at home, typically in the evening when you come back home. However, from the viewpoint of the power system, if an EV is charged in the evening, the total generation mix at that time is not renewable rich in such PV-rich power grid.

On the contrary, EV charging outside around the noon is fit to the PV generation in the power system. However, it is not legally regarded as renewable energy, or “green” charging, unless the charger spot is contracted with some 100% renewable menu.

Of course, if you charge at isolated EV charger system of which power sources are only RES, it is clearly RE 100% EV charging [7]. However, it is not easy to make such EV charging spots, at least in densely populated sections.

## 2.2 Concept of the combined service

The challenge of green charging can be solved if the EV can be charged outside around the noon with the EV owner’s contracted retail menu. Therefore, the combined menu of the home electricity supply and outside EV charging is proposed.

Table 1 shows an image of electricity bill used for the combined menu. In addition to the kWh tariff and ampere tariff of home electricity, kWh tariff and basic tariff of outside EV charging is added.

**Table 1.** Image of electric bill for combined menu.

| Service item | Used amount | Unit | Fee (yen) |
|---|---|---|---|
| Energy at home | 368 kWh | 31.2 yen/kWh | 11,481 |
| Basic tariff at home | | 1,500 yen (40 A) | 1,500 |
| Energy outside EV charging | 53.9 kWh | 46.1 yen/kWh | 2,484 |
| Basic tariff for outside EV charging | | 100 yen | 100 |
| Total | | | 15,565 |

Ofgem’s report includes similar combined menu scenario called “Home and roam” with the description that “Domestic consumers may want to receive a single bill for when they charge their EV at home and on-the-go” [8]. The proposed combined menu is expected to reduce consumers’ task for settlement. Though “Home and roam” is positioned as “non-energy product” [8], our proposed settlement by electricity has a possibility to make the combined menu “energy product”.

## 2.3 Ways for settlement

If the electric retailer of the EV charger the consumer use is different from the retailer the consumer contracts, some settlement between the retailers will be needed. Assume that Consumer Y is contracted to the Retailer B’s 100% renewable and the combined menu. Consumer Y comes to an EV Charger C of Consumer X. Consumer X is contracted with Retailer A with non-renewable menu. In this situation, some settlement between Retailer A (or Consumer X) and Retailer B is needed because Consumer Y pays for the charging only to Retailer B.

Fig. 1 shows an overview of the settlement by money. Retailer B pays an electricity fee for Retailer A. For the de-carbonized charging, Retailer B needs to obtain tradable green certificate etc..

Instead of the money settlement, settlement by electricity has been proposed [2]. Fig. 2 shows an overview of the settlement by money. If Retailer B has supply contracts from plenty of PV systems, they can use the PV output directly.

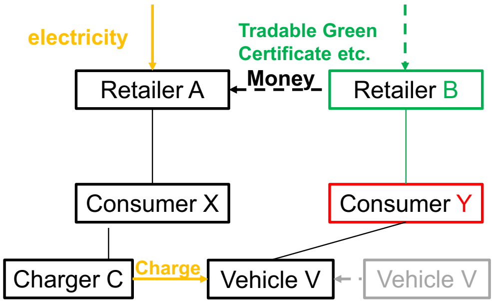

**Fig. 1.** Settlement by money.

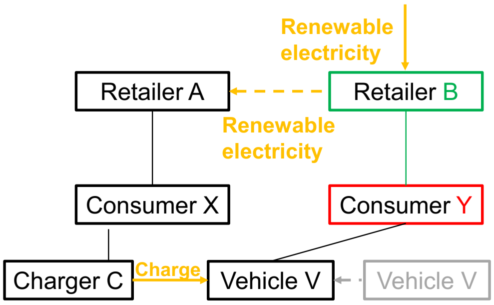

**Fig. 2.** Settlement by electricity.

## 2.4 Sequence of electrical settlement

Fig. 3 shows the example of the settlement sequence by electricity. The sequence is made partially referred to Japanese “partial supply rule”, in which multiple electricity retailers supplies the electricity for single supply point [9]. The operation starts when Consumer Y reads the QR code at the charger, choose the charging menu and connect the EV to the EV charger.

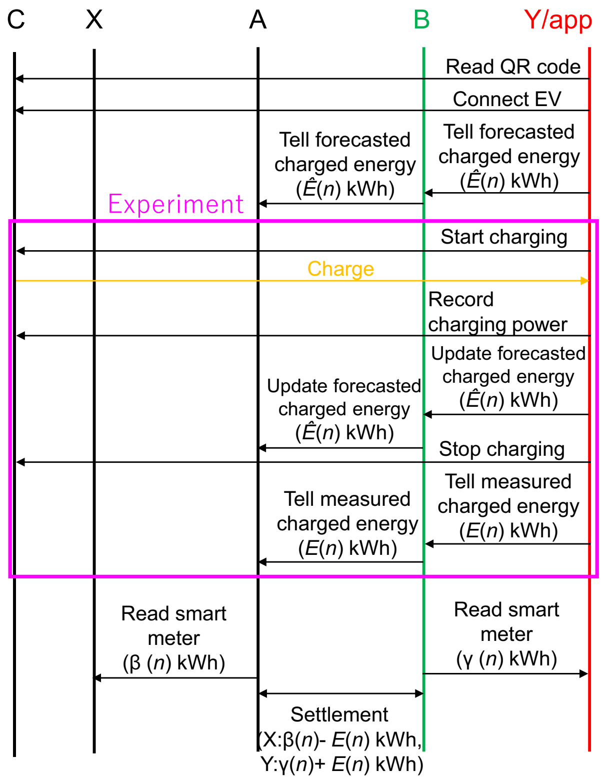

**Fig. 3.** Sequence chart of settlement by electricity

The challenging point of this settlement is to tell the forecasted and measured EV charged energy from Retailer B to Retailer A. It is important for the retailers to forecast the EV charging electricity in order to adjust their supply-demand plan, especially when the EV charging power becomes not negligible portion for the retailers. For example, the partial supply rule in Japan orders the load-following retailer to tell both forecasted power and actual power to the base retailer with 30 min. resolution. Therefore, the time resolution of the EV charging demand forecast also set to 30 min. in this sequence.

During the charging, the application renews the forecasted power and tells Retailer A and Retailer B.

After the charging finishes, the application tells the measured power consumption to Retailer A and Retailer B. Retailer A subtracts the electrical demand of the EV charging from consumer X's total demand, and Retailer B adds the EV charging demand to Consumer Y's total demand. In other words, Retailer A will "transfer" the EV charged electricity demand to Retailer B.

Experiments has been conducted from the starting of charging to the telling the measured charged energy. Instead of telling the forecasted and measured energy to the retailer, the experimental application recorded the values in the experiment.

## 3 Experimental methods

### 3.1 EV charging testbed

Fig. 4 shows the overview of the testbed. The testbed is existing at the parking area in Komaba Research campus, the University of Tokyo. The EV charger is Nichicon's EV power station VCG-666CN7. The EV charger connects to the EV with the connector using CHAdeMO (charge de move) protocol. Though the rated power of the EV charger is 5.9 kW, the maximum power in this experiment is 3.0 kW because of the restriction of the testbed. The EV's rated battery capacity is 62 kWh.

**Fig. 4.** Photo of testbed.

Nichicon's EV power stations normally cannot connect to the Internet directly. Therefore, the EV charger of the testbed is enabled to connect to the Internet using the IoT HUB technology [6]. IoT-HUB is the virtual infrastructure which interconnects various connected devices and applications by using "drivers" for each device with any communication protocol. E-roaming (e.g., the option for EV drivers to charge their vehicles at all non-private charger stations) [10] can be accelerated by the IoT-HUB. Note that the EV charger can obtain the EV's information like state of charge (SOC) only after the EV is connected to the charger and only when the charging protocol can handle the information.

Fig. 5 shows the schematic diagram of the overall of ICT (Information and Communication Technology) connection of the testbed. The EV charger gateway (GW) is connected to the experimental application via

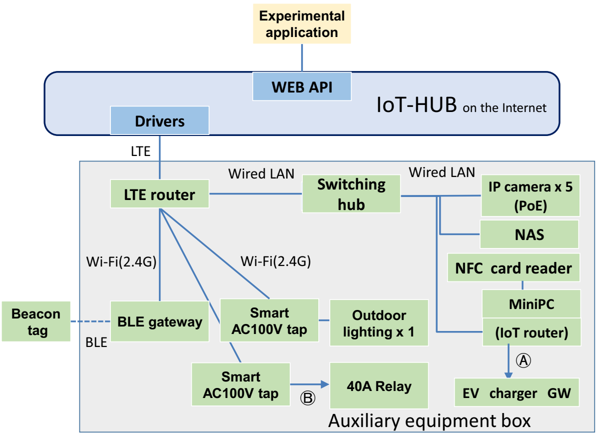

**Fig. 5.** Schematic of ICT connection of testbed.

IoT-HUB, LTE (long term evolution) router and the IoT router. The experimental application for this research runs at a laptop PC, which can send commands for the EV charger and record the responses from the EV charger, via IoT-HUB. Other equipment like BLE (Bluetooth low energy) gateway, IP camera, NAS (network attached storage), NFC (near field communication) card reader are also connected for related research.

### 3.2 Forecast methods of EV charged energy

As mentioned in **2.4**, the forecasted charged energy needs to be calculated and be updated for the retailers' adjustment of the supply-demand plan. Two forecast methods, simple method and proposed method, were tested in experiments.

#### *3.2.1 Simple method and its problems*

In the simple method, the $\widehat{SOC}(n)$ [%] and $\hat{E}(n)$ [kWh/30min.], the forecasted SOC and charged energy at time slot *n*, respectively, will be calculated using from eq. (1) to eq. (4). $\mathrm{C_b}$ [kWh] is the total capacity of the EV battery obtained by the command from the experimental application at the start of the charging, which is different from the rated capacity. T is the length of the time slot; 30 min. in these experiments. $SOC(1)$ is the initial measured SOC. $P_{\max}$ is the maximum chargeable power; 3.0 kW. $SOC_{\max}$is the maximum SOC; 100%. $T_{\mathrm{ini}}$ [min.] is the length of charging time at the first time slot.

$$\widehat{SOC}(n+1) = \widehat{SOC}(n) + 100\hat{E}(n)/\mathrm{C_b} \tag{1}$$
$$\widehat{SOC}(1) = SOC(1) \tag{2}$$
$$\hat{E}(n+1) = P_{\max}\mathrm{T}/60\ (\widehat{SOC}(n) < SOC_{\max}) \tag{3}$$
$$\hat{E}(1) = P_{\max}T_{\mathrm{ini}}/60 \tag{4}$$

However, the simple method has the following problems. The detail will be shown in **4.2**.

-The measured SOC is integer. Hence, the SOC has some rounding error.

-Actual SOC increases slowly than eq. (1) because of the energy loss etc..

-When the SOC gets close to 100%, actual charging power decreases in order to protect the battery.

-SOC estimation by the car itself has some error.

#### *3.2.2 Proposed method*

The proposed method is constructed in order to solves the first three of the previous problems. Eq. (5) to eq. (11) is the calculation of the proposed method.

In the proposed method, the SOC and charged power is forecasted with the time-resolution of 1 min.. *t* [min.] is the time and $\widehat{SOC_t}(t)$ [%] is the forecasted SOC with the time resolution of 1 min.. $\hat{P}(t)$ [kW] is the charging power. *K(t)* is the co-efficient for the compensation of SOC increase. $\tau_I$ [min.] and $\tau(t)$ [min.] are the time with the initial SOC and time with the latest SOC, respectively.

$$\widehat{SOC_t}(t+1) = \widehat{SOC_t}(t) + K(t)\hat{P}(t)/0.6\mathrm{C_b} \tag{5}$$
$$K(t) = \frac{SOC(t) - SOC(0) - 1}{t - \tau_I - \tau(t)} \tag{6}$$

$\hat{P}_{\mathrm{trans}}(t)$ [kW] is the declined power when the SOC get close to 100%. In this paper, $SOC_{\mathrm{th1}}$and $SOC_{\mathrm{th2}}$ is set to 99.3% and 99.8%, respectively. Fig. 6 shows the relationship between $\widehat{SOC_t}(t)$ and $\hat{P}(t)$.

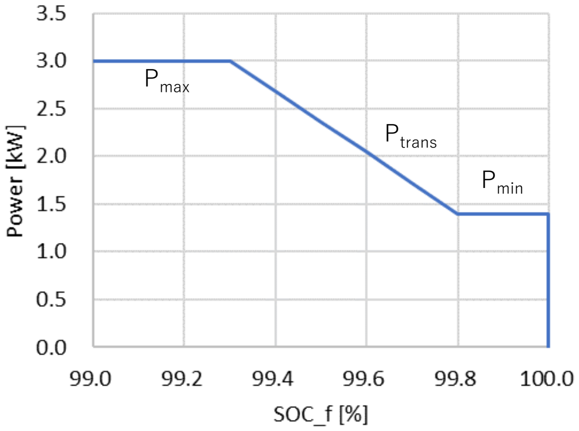

**Fig. 6.** Relationship between forecasted SOC and forecasted power in the proposed model.

$$\hat{P}(t) = \begin{cases} P_{\max} \quad (if\ \widehat{SOC_t} < SOC_{\mathrm{th1}}) \\ \hat{P}_{\mathrm{trans}}(t) \quad (if\ SOC_{\mathrm{th1}} < \widehat{SOC_t} < SOC_{\mathrm{th2}}) \\ P_{\min} \quad \left(if\ SOC_{\mathrm{th2}} < \widehat{SOC_t} < SOC_{\max}\right) \\ 0\ (if\ SOC_t = SOC_{\max}) \end{cases} \tag{7}$$
$$\hat{P}_{\mathrm{trans}}(t) = \frac{P_{\max} - P_{\min}}{SOC_{\mathrm{th1}} - SOC_{\mathrm{th2}}}\left(\widehat{SOC_t}(t) - SOC_{\mathrm{th1}}\right) + P_{\mathrm{rate}} \tag{8}$$

$\widehat{SOC}(n)$ and $\hat{E}(n)$ are calculate by eq. (9) to eq. (11).

$$\widehat{SOC}(n) = \widehat{SOC_t}((n-1) * T + T_{\mathrm{ini}}) \tag{9}$$
$$\hat{E}(n) = \sum_{t=(n-2)*T+T_{\mathrm{ini}}+1}^{(n-1)*T+T_{\mathrm{ini}}} (\hat{P}(t)T/60)\ \ (n > 1) \tag{10}$$
$$\hat{E}(1) = P_{\mathrm{rate}}T_{\mathrm{ini}} \tag{11}$$

## 4 Experimental Results

### 4.1 Procedure of the experiment

The experimental application starts the EV charging through the Internet. The application collects the information of the EV charging like charging power, cumulative charged energy and SOC of the EV, once in a minute. The application forecasts the forecasted SOC and the charged energy, $\widehat{SOC}(n)$ and $\hat{E}(n)$.

### 4.2 Experiment 1: With simple forecast

Fig. 7 shows the time series data of the measured and forecasted power, measured charged energy and measured and forecasted SOC. The forecasted power ends faster than the measured power because the forecasted SOC increases faster than the measured SOC.

The main reason of the over-forecast of the SOC is that though the power is 3.0 kW, the measured SOC increases smaller speed. The possible reason of the slow SOC increase is the energy loss of charging. Fig. 8

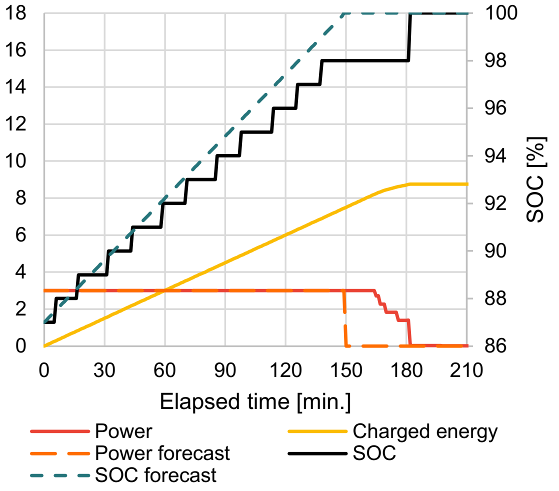

**Fig. 7.** Time series data of power, charged energy and SOC.

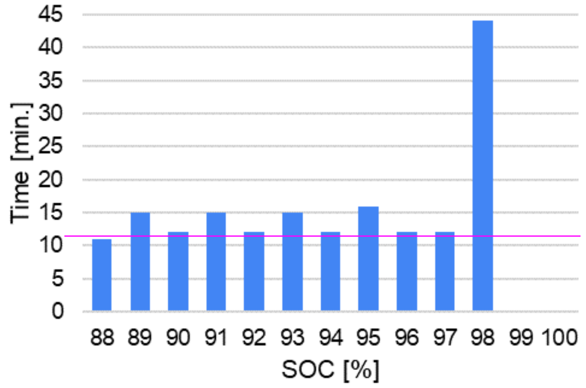

**Fig. 8.** Staying time at each SOC.

shows the staying time at each SOC. The total capacity of the EV battery responded from the EV charger was 57.5 kWh, which was smaller than the rated capacity, 62 kWh. Hence, according to (1), the SOC will increase 1% in every 11.5 min.. However, as shown in Fig. 8, the actual SOC increases 1% in every 12-15 min. (average 13.2 min.) except when the SOC is 98%. When the SOC is 98%, it takes 44 min. to increase the SOC, but the next SOC is not 99% but 100%.

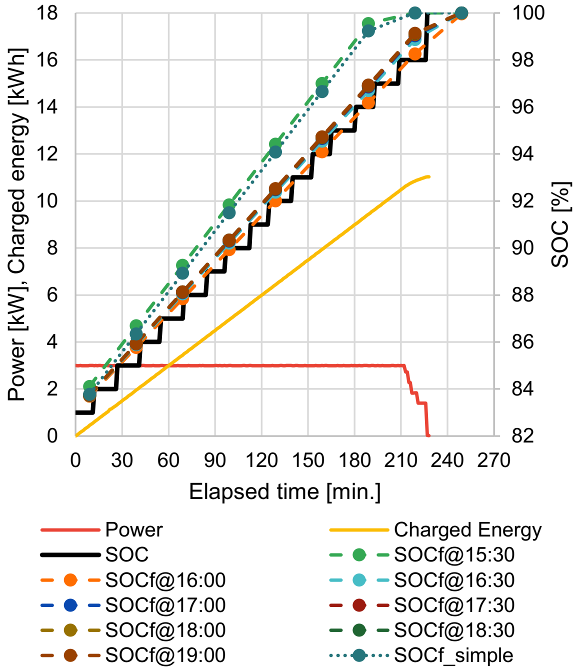

**Fig. 9.** Measured power, charged energy, SOC and forecasted SOC (Only "SOCf_simple" is not calculated in real time but lined for comparison.).

### 4.3 Experiment 2: With proposed forecast

Fig. 9 shows measured power, cumulative charged energy, SOC and forecasted SOC. Note that only "SOCf_simple" is not calculated in real time but lined for comparison. The power, the charged energy and the SOC are measured every one min.. The "SOCf@15:30" etc. are the SOC trends forecasted at 15:30 etc. by the application in real time. The forecasted SOC was used for the calculation of the forecasted EV charging energy in every 30 min..

SOC forecast with simple method (SOCf_simple) over-estimates the SOC. "SOCf@15:30" also over-estimates the SOC because K was not calculated at 15:30 with (6) but equals to one. After 16:00, the forecasted SOC is close to the measured SOC, except

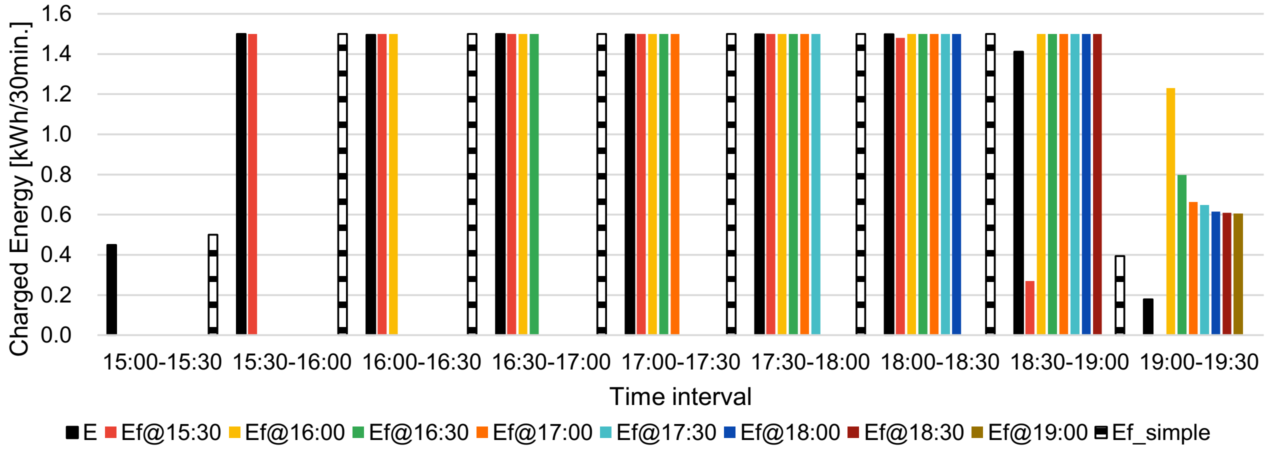

**Fig. 10.** Measured and forecasted charged energy. (Only "SOCf_simple" is not calculated in real time but lined for comparison.).

the timing that the SOC has reached to 100%. This timing forecast problem will be discussed at **4.4**.

Fig. 10 shows the measured and forecasted charged energy in every 30 min.. Both the simple method and forecast at 15:30 largely under-estimated the charged energy from 18:30 to 19:30. Compared to them, the charged energy forecasted after 16:00 had only 0.09 kWh error at 18:30-19:00. However, the charged energy forecasted after 16:00 had still from 0.42 kWh to 1.04 kWh error at 19:00-19:30. This error causes because of the time forecast problem when the SOC has reached to 100%.

Fig. 11 shows the error of total charged energy in each forecast. Compared to the simple method, the proposed method has reduced more than half of the error after 17:00 forecast.

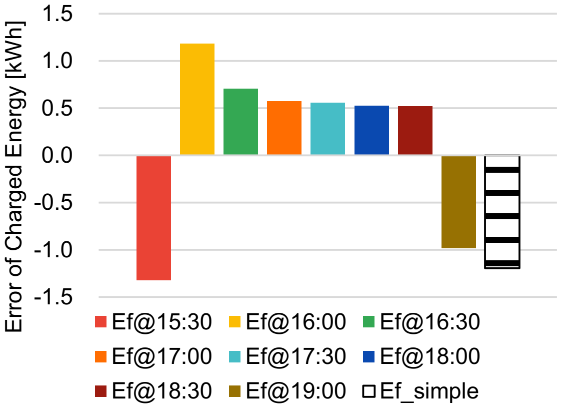

**Fig. 11.** Error of total charged energy.

### 4.4 Discussion

Fig. 12 shows the measured and forecasted charging power after the SOC reaches 98% in three experiments (Experiment 3 is the additional experiment). The charging duration time with 3 kW differs largely in these three experiments; 26 min. in experiment 1, but only 3 min. in experiment 2. The proposed method forecasted that the 3 kW charging continues 18 min., which is the average in Experiment 1 and 3, but is 15 min. smaller than in Experiment 2. The variability and error of this duration time at the final step of SOC is the main factor for the remaining error of the forecasted method. Improvement of the forecast considering this variability is the future work.

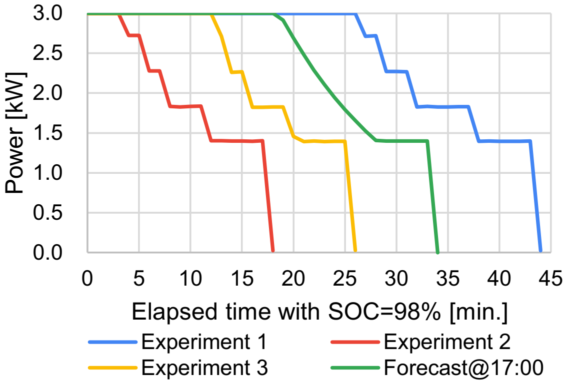

**Fig. 12.** Measured and forecasted power when SOC is 98%.

Compared to the variability of the duration time with 3 kW charging, the variability when the charging power is smaller than 3 kW is relatively small, and the forecasted power curve is also similar to the measured curve.

## 5 Summary

This paper proposes a combined menu of EV charging power, as an example of Place of Use (PoU) services; the attractive services for the movable electrical demand. The technical feasibility of the settlement by the electricity for the combined menu is tested.

A forecast method for EV charging energy in each time slot for the settlement is also proposed and tested. From the third timeslot, the proposed method has reduced more forecast error of total charged energy compared to the simple method. However, some of the forecast error partially remains because of the variability of the charging time at the final step of SOC.

Future work includes improvement of the forecast considering the variability of the full power charging time when the SOC reaches close to 100%. Confirmation tests with other combinations of EVs and EV chargers is also important.

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