Development of EV charging control technology for load peak shifting

Keisuke MORITA
Kansai Transmission and Distribution Inc. –Japan

Tetsuya HIRAYAMA
Kansai Transmission and Distribution Inc. –Japan

Sachiko MORIOKA
The Kansai Electric power company Inc. –Japan

Hiroki KURIYAMA
The Kansai Electric power company Inc. –Japan

Hiromi KATAOKA
The Kansai Electric power company Inc. –Japan

Yoshihiro KANEUCHI
The Kansai Electric power company Inc. –Japan

Shogo HIRAYAMA
The Kansai Electric power company Inc. –Japan

Contact email: morita.keisuke@a5.kansai-td.co.jp

Abstract

Reverse power flow of PVs is causing congestion problem on power system. EVs are expected to introduce drastically, and forward power flow of their charge could cause thermal overloads. On the other hand, flexibility services to control EV's charge has potential to improve power operation. With this background, the proposed system was developed to utilize control of EV's charge for load peak shifting.

In order to utilize control of EV's charge for load peak shifting, two technologies are needed. One is to command multiple EVs remotely and integratedly, the other is to control each EV to the command value accurately. For the remote and integrated control, the system was developed, which commands multiple EVs to charge or stop from a server remotely. For accurate control of each EV, the group control method which commands charge value by multiple group based on their use and the feedback control method which compensates actual charge value by two minute intervals were developed.

As a result of two 14-day demonstrations using actual EVs, we were able to control EVs accurately to the commands and confirm the effectiveness of the technologies.

1. Introduction

Reverse power flow of PVs is causing congestion problem on power system. For carbon neutrality, EVs are expected to introduce drastically, and forward power flow of their charge could cause thermal overloads and voltage dips. On the other hand, flexibility services of an aggregator to control EV's charge have potential to improve power operation. With this background, the proposed system was developed to utilize control of EV's charge for load peak shifting.

Most EVs in Japan are designed to be charged manually after the drive or at night when electricity rates are low, and do not have a remote control function. In order to utilize control of EV's charge for load peak shifting, two technologies are needed. One is to command multiple EVs remotely and integratedly, the other is to control each EV to the command value accurately.

In this paper, we introduce the demonstration result of the development for these technologies

2. Demonstration of the control system

2-1. Overall control method

As in Figure 1, the remote EV control system, which commands 101 EVs to charge or stop charging from EV server, was developed. The signals between EV server and each EV are communicated via a gateway, which control multiple EVs integratedly, installed at the parking location where EVs located. The communication protocols are MQTT[1] between EV server and a gateway and ECHONET Lite[2] between a gateway and EVs. The charge values for each EV are adjusted by the command from EV server.

The overall control method is as follows. At first, for 19 household's EVs, EV owners are asked to confirm whether or not they can participate for the remote control in advance with smartphone application to ensure convenient use of EVs. Next, the command value [kW] and time slot which can be set by each 30 minutes are commanded by the group control for each group divided by the parking location where EVs located. Before starting control, the system automatically selects which vehicles to charge preferentially by estimating the available charge amount based on the past charge result. Once the control is started, feedback control is performed at regular intervals so that the control is more accurate to the command value. During feedback control, each EV adjusts charging based on the command from EV server by the EV switch opening and closing and by an adjustment function of V2H vehicles.

EV switch installed on the vehicle was developed for this demonstration, which can start and stop charging by open and close the switch remotely. The 101EVs to be controlled are divided into 6 groups as shown in Table 1

Table 1. Breakdown of each group

Group	Location name	Number of EVs
Location1	Company A	10
Location2	Company B	20
Location3	Company C	46
Location4	House hold	19
Location5	Company D	3
Location6	Company E	3

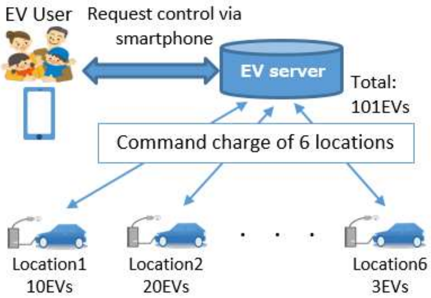


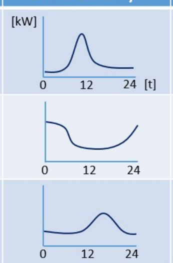
Fig.1 Overall control system

2-1-1. Group control by location

The command values are transmitted for each group divided into six locations. The sum of the command values of each group is identical to the overall command value.

The command value for each group is set based on the baseline and the calculation result of the controllable amount for the day predicted by the machine learning in EV server. The baseline is defined as the past 4 days charge value, which excludes holidays and one day when the past charge value is minimum during control duration, out of the nearest 5 days, and is calculated by averaging every 30 minute for the sum of the past charge value of each EVs.

Before starting control, the system automatically selects which EV to charge preferentially by estimating the available charge amount based on the past charge result.



Example for command value: From 11 to 14[h], 25kW

Group	Calculation results of machine learning	Base line(image) In the last 4 days	Command value
1	Upper limit: 24kW Lower limit: -1kW	[kW] 0 12 24 [t]	15kW
2	Upper limit: 4kW Lower limit: -8kW	0 12 24	0kW
3	Upper limit: 10kW Lower limit: -3kW	0 12 24	5kW
4	··	··	0kW
5	··	··	5kW
6	··	··	0kW
Total command value			25kW

Fig.2 Group control by location

2-1-2. Feedback control

Feedback control was developed for the accurate charging control of EV to the command. Once the control charging is started, the actual charge value is measured every one minute. The expected charge value is estimated in real time based on the actual charge value and the available charge amount. The number of charging EVs and charge value of V2H is adjusted at 5-minute intervals by comparing the expected charge value and the charge value to meet the success criteria which is within 10% between command value and actual charge value. For the convenient use of EV, EVs to be charged are re-selected every 30 minutes to reduce the unevenness of EVs to be charged. The priority of EVs to be charged is reduced after they were once selected.

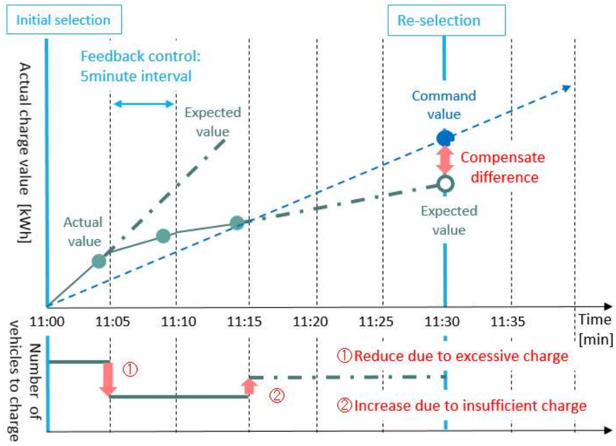


Fig.3 Feedback control

2-2. Results and Discussion

One hundred and one EVs at 6 locations participated in the demonstration, and the command to raise and lower charge were issued from the server at 68 time slot for a total of 14 days.

Figure 4 shows the command value, the achievement rate and the success judgment for each day. The achievement rate is the value obtained by dividing the actual charge value [kW] by the command value [kW]. The success criteria is defined within from 90% to 100% with the command to raise charge, and within from 100% to 110% with the command to lower charge.

As a result, only one slot met the success criteria out of 68 slots. In addition, the achievement rate for each day were also far from 100% on many days. Although the communication technology to command multiple EVs integratedly was functioned, the system could not control accurately and sufficiently.

The following section describes the details of the results of the raising and lowering charges on 7th and 5th February respectively, which clearly showed the problem.

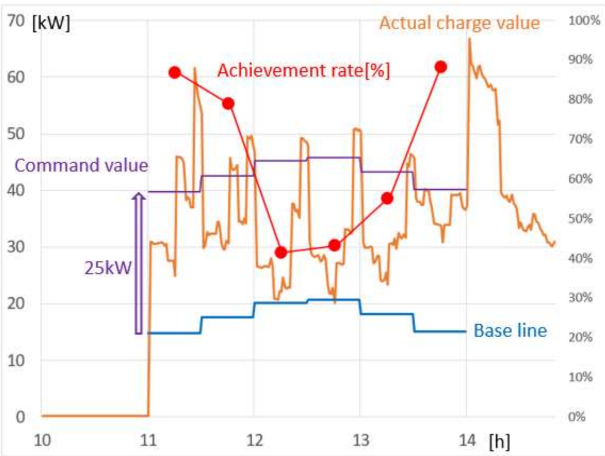
Results of the demonstration: From Dec.2019 to Feb.2020

Date	12/23	12/24	1/14	1/15	1/22	1/23	1/27
Time	14:00～17:00	11:00～14:00	12:00～14:00	14:00～16:00	14:00～16:00	13:00～15:00	15:00～16:00
Command value [kWh/30min]	-5.0	+20.0	+5.0	-20.0	-5.0	+20.0	-10.0
Achievement rate Min, Max[%]	Min:252.8 Max:379.1	Min:36.8 Max:199.1	Min:327.5 Max:390.0	Min:121.3 Max:160.4	Min:169.5 Max:188.4	Min:37.7 Max:51.4	Min:89.1 Max:92.3
Success judgement [Within 10%]	0/6slot	0/6slot	0/4slot	0/4slot	0/4slot	0/4slot	0/2slot
Date	1/28	1/30	1/31	2/5	2/7	2/10	2/13
Time	12:00～13:00	14:00～17:00	12:00～15:00	15:00～18:00	11:00～14:00	14:00～17:00	12:00～15:00
Command value [kWh/30min]	+15.0	-10.6	+7.5	-10.1	+12.5	-5.0	+26.3
Achievement rate Min, Max[%]	Min:20.2 Max:32.3	Min:63.8 Max:104.7	Min:102.5 Max:175.2	Min:112.1 Max:128.0	Min:41.5 Max:88.2	Min:194.7 Max:263.5	Min:55.0 Max:76.0
Success judgement [Within 10%]	0/2slot	1/6slot	0/6slot	0/6slot	0/6slot	0/6slot	0 /6slot

Fig.4 Results of demonstration

2-2-1. Raise charge result

On 7th February, the demonstration was conducted by the commands to raise 25 kW charge from 11:00 to 14:00.
As in Figure 5, the achievement rate for all six slots of 3 hours were a minimum of 41.5% and a maximum of 88.2%. None of the slots could not meet success criteria.
Since the 30-minute average actual charge value was lower than the command value in all slots, we considered the cause by focusing on the estimation method of available charge amount.
Although the system selected which EVs to charge preferentially in the initial selection of charged EVs by estimating the available charge amount based on the past charge result, we found that in this system the available charge amount was estimated lower than actual one, which was the cause of the low achievement rate. Therefore, we assumed that achievement rate could be improved if the initial selection method could be improved.
In addition, we assumed that shortening feedback intervals and changing comparison target with the command value to the actual charge value instead of the expected charge value could also improve achievement rate.



kWh/30min	7th February 2020						
	11:00 ～ 14:00						Ave.
Time	11:00 ～	11:30 ～	12:00 ～	12:30 ～	13:00 ～	13:30 ～	-
Control result	10.8	9.8	5.2	5.4	6.8	11.0	8.2
Command value	12.5						-
Achievement rate	86.8%	79.0%	41.5%	43.2%	55.1%	88.2%	65.6%
Success judgement (Within 10%)	×	×	×	×	×	×	-

Fig.5 Results of raise charge demonstration

2-2-2. Lower charge result

On 5th February, the demonstration was conducted by the command to lower 20.2 kW charge from 15:00 to 18:00.
As in Figure 6, the achievement rate for all six slots of 3 hours were a minimum of 79.3% and a maximum of 128.0%. None of the slots could not meet success criteria.
Since the 30-minute average actual charge value tended to be higher than the command value, the cause of the failure to respond to the command was considered.
Many of EVs that are charged at work such as commuting are fully charged by noon, and we found that it would be difficult for such EVs to be used to lower charge amount during the evening hours.
Since the method to command each group based on the location could not follow up other groups that do not achieve the command sufficiently, we assumed that the method to command groups reorganized based on the usage pattern of EV could improve achievement rate.

kWh/30min	5th February 2020						
	15:00 ～ 18:00						Ave.
Time	15:00 ～	15:30 ～	16:00 ～	16:30 ～	17:00 ～	17:30 ～	-
Control result	-8.0	-11.4	-11.6	-12.3	-12.0	-13.0	-11.4
Command value	-10.1						-
Achievement rate	79.3%	112.1%	114.7%	121.5%	118.3%	128.0%	112.3%
Success judgement (Within 10%)	×	×	×	×	×	×	-

Fig.6 Results of lower charge demonstration

3. Improvement of control method

Based on the four assumptions in the previous section, the group control, initial vehicle selection, and feedback control were improved.

3-1. Improved overall control method

The four improvements of overall control process are as follows. At first, the organization of groups was changed to three groups based on EV's usage. Next, in the initial selection of EV's charge, except for the EVs that cannot confirm the SOC, each EV is remotely tested to charge 10 minutes prior to the start of control to confirm the available charge amount. After control starts, feedback interval was shortened and its comparison target was changed.

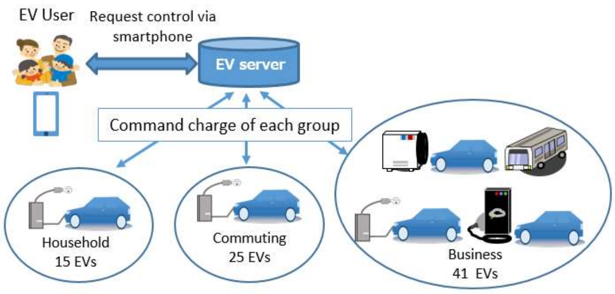


Fig.7 Improved overall control system

3-1-1. Group control by their use

Since the charge tendency for each EV varies by time of the day, we reorganized EVs into three groups based on their use, which are household, commuting, and business. By organizing groups with similar charging tendencies, each EV can follow up the over or under charge against the command in the same group.

For the consideration of 2-2-1, the method to confirm available charge amount at the initial selection was changed. The new method confirms it by remotely testing charge to all EVs 10 minutes prior to the start of control, instead of estimating it from the past charge result.

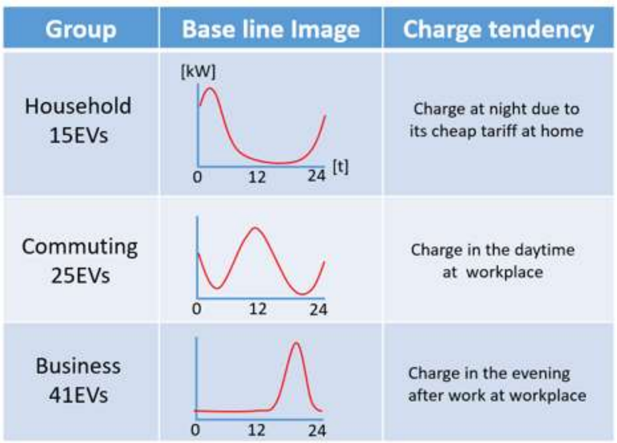


Fig.8 Charge tendency of three groups

3-1-2. Feedback control

To improve the achievement rate, the interval to adjust the number of charging EVs and charge value of V2H is shortened from five to two minute.

In addition, comparison target was changed to the actual charge value instead of the expected charge value.

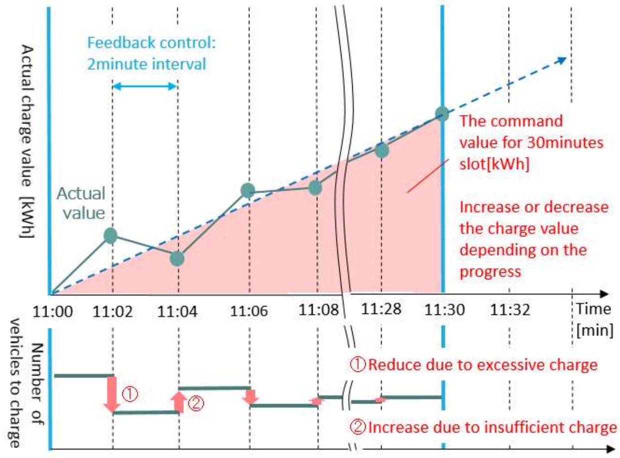


Fig.9 Improved feedback control

3-2. Results and Discussion of improvement

Eighty-one EVs, consisting of three groups which are 15 for household, 25 for commuting and 41 for business, and the commands to change charge amount were issued at 84 time slot for a total of 14 days.

As a result, 52 slots met the success criteria out of 84 slots, and we confirmed the effectiveness of the improvements. The following section describes the details of the results of the raising and lowering charges on 5th and 4th February respectively.

Results of improvement: From Dec.2020 to Feb.2021

Date	12/10	12/11	12/16	12/17	12/22	12/23	1/14
Time	15:00～18:00	11:00～14:00	15:00～18:00	13:00～16:00	15:00～18:00	12:00～15:00	15:00～18:00
Command value [kWh/30min]	-4.5	+9.0	-5.0	+14.0	-4.5	+10.0	-6.0
Achievement rate Min, Max[%]	Min:101.4 Max:152.1	Min:85.5 Max:95.2	Min:92.0 Max:107.8	Min:54.6 Max:93.8	Min:117.9 Max:183.2	Min:92.4 Max:107.1	Min:94.3 Max:107.8
Success judgement [Within 10%]	2/6slot	3/6slot	4/6slot	3/6slot	0/6slot	1/6slot	5/6slot
Date	1/19	1/20	1/25	2/2	2/4	2/5	2/9
Time	15:00～18:00	15:00～18:00	15:00～18:00	15:00～18:00	15:00～18:00	11:00～14:00	11:00～14:00
Command value [kWh/30min]	-3.0	-3.6	-4.4	-2.8	-2.8	+14.5	+13.4
Achievement rate Min, Max[%]	Min:103.7 Max:157.4	Min:18.2 Max:105.3	Min:70.8 Max:106.7	Min:104.7 Max:109.8	Min:103.8 Max:105.5	Min:94.4 Max:95.8	Min:94.8 Max:96.4
Success judgement [Within 10%]	3/6slot	2/6slot	5/6slot	6/6slot	6/6slot	6/6slot	6/6slot

Fig.10 Results of improvement

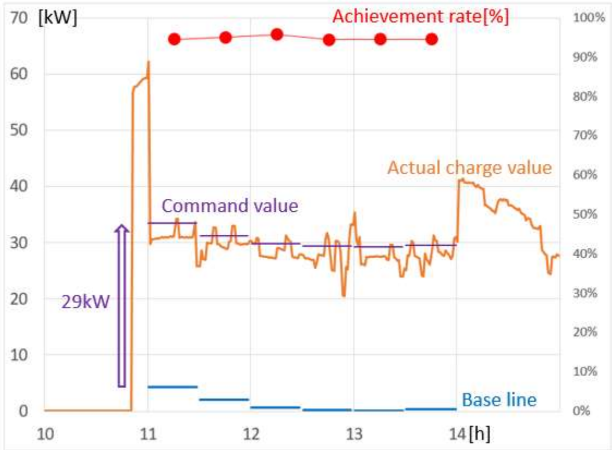
3-2-1. Raise charge result

On 5th February, the demonstration was conducted by the commands to raise 29 kW charge from 11:00 to 14:00.

The command value was set at 20.5 kW for commuting group of 25 EVs and 8.5 kW for household group of 15 EVs.

As in Figure 11, all slots could meet success criteria and the average achievement rate for all six slots of 3 hours was 94.8% which outperformed previous result of 65.6% significantly.

From this result, we confirmed the effectiveness of the improved group control and feedback control.

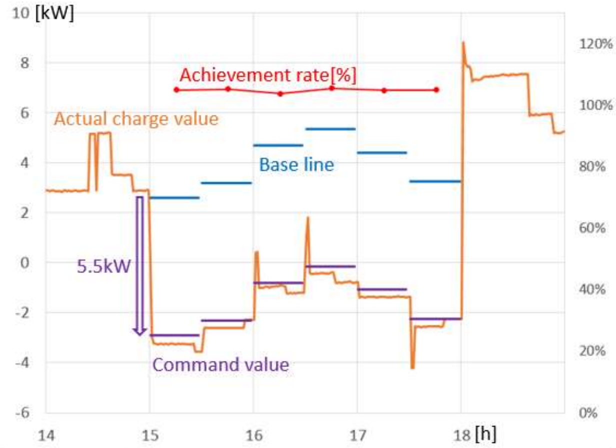


kWh/30min	5th February 2021						
Time	11:00～14:00						Ave.
	11:00～	11:30～	12:00～	12:30～	13:00～	13:30～	-
Control result	13.8	13.9	14.0	13.7	13.8	13.8	13.8
Command value	14.5						-
Achievement rate	94.5%	95.0%	95.8%	94.4%	94.5%	94.8%	94.8%
Success judgement (Within 10%)	✓	✓	✓	✓	✓	✓	-

Fig.11 Results of raise charge demonstration

3-2-2. lower charge result

On 4th Feb, the demonstration was conducted by the commands to lower 5.5kW charge from 15:00 to 18:00.
The command value was set at 5.5 kW for only business group of 41 EVs.
As in Figure 12, all slots could meet success criteria and the average achievement rate for all six slots of 3 hours was 104.9% which outperformed previous result of 112.3%.
From this result, we confirmed the effectiveness of the improved group control and feedback control.



kWh/30min	4th February 2021						
Time	15:00～18:00						Ave.
	15:00～	15:30～	16:00～	16:30～	17:00～	17:30～	-
Control result	2.9	2.9	2.9	2.9	2.9	2.9	2.9
Command value	2.8						-
Achievement rate	105.0%	105.2%	103.8%	105.5%	104.9%	105.0%	104.9%
Success judgement (Within 10%)	✓	✓	✓	✓	✓	✓	-

Fig.12 Results of lower charge demonstration

4. Conclusion

In this paper, we introduced technologies which can command multiple EVs remotely and integratedly, and control each EV to the command value accurately.
The group control and feedback control introduced in the demonstration improved the accuracy of the control, and we confirmed the effectiveness of these technologies.
In this demonstration, the command value was set manually as a time slot of 30 minutes. In the future, it is envisioned that the system is used for flexibility services, such as setting commands automatically linked to wholesale electricity prices.
In addition, we aim to develop technologies that can respond to fluctuations of raising and lowering control that meet market requirements to make it more practical. Also, we will work to develop these technologies that can be used for load peak shifting and flexibility services by increasing the number of EVs to participate in the demonstration.

REFERENCES

[1] Website, https://mqtt.org/
[2] Kodama, Hisashi. "The echonet lite specifications and the work of the echonet consortium." New Breeze-Quarterly of the ITU Association of Japan 27.2 (2015): 4-7.