A Grid-Friendly Electric Vehicle Infrastructure

The Korean Approach

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KOREA HAS DEPLOYED VARIOUS CHARGING infrastructure, from multiple-outlet ultrafast dc charging stations to built-in metering ac outlets, to relieve range anxiety and improve accessibility. The Korean government raised electric vehicle (EV) and renewables targets to realize carbon neutrality by 2050. The government is also making efforts to utilize EV batteries as a flexible resource to help with the grid connection of massive renewables. Time-of-use (TOU) tariffs and a demand response (DR) program have been introduced to facilitate more daytime charging from

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photovoltaic (PV) generation and reduce solar curtailment. An ac vehicle-to-grid (V2G) system is also a reality and is being applied to mass produce EVs, and demonstrations are underway. As the introduction of more EV models and the supply chain normalize, EV sales will increase rapidly. Consequently, now is the time for Korea to prepare for and fully embrace a more grid-friendly charging infrastructure for the future.

Korean Goals for Emissions Reduction and EV Adoption

The Korean government has revised its 2030 greenhouse gas emission reduction target to 40% from its previous goal of 26.3%, compared to 2018, to speed up its carbon-neutral push under a pledge to have net-zero carbon emissions by 2050. Since the transportation sector uses more than 20% of Korea's fossil fuels, the government plans to reduce greenhouse gas emissions in the transportation sector from 98.1 million carbon dioxide equivalent tons in 2018 to 2.8 million in 2050. To achieve the net-zero goal by 2050, Korea is seeking to dramatically phase out coal-fired power generation while ramping up renewable and nuclear generation. The 2022 peak demand in Korea was approximately 94.5 GW, with an installed capacity of 137.8 GW. By 2030, the planned installed capacity of renewables will be greater than 70 GW, according to Korea's 10th Basic Plan for Power Supply and Demand. A significant investment in flexible resources, such as pumped hydropower plants and battery storage systems, is often considered to manage power grids with a large share of renewables. However, as suggested by the International Energy Agency (IEA), the future fleet of EVs could be the most useful and largest asset for power system flexibility in the years to come. In Korea, almost all vehicles sold after 2040 will be electric. To achieve this, the country aims to have 1.15 million EVs on the road by 2025 and 4.2 million by 2030, as shown in Figure 1.

Incentivizing EV Uptake and Charging Infrastructure

The first mass-produced EV was registered in Korea in 2011, and by 2022, the number of registered EVs in the country had increased to 389,855. Of those, 81,263 are light-duty trucks (LDTs). Korea has seen a rapid increase in sales of electric LDTs thanks to an innovative policy that incentivizes the adoption of EVs for commercial use. In terms of energy, 80,000 LDTs require as much as 480,000 passenger cars. Therefore, a good public charging infrastructure should not only cater to passenger vehicles but also to trucks.

Korea supports the uptake of EVs through several measures, including subsidies and rebates on national and local vehicle purchase taxes and 50% lower highway tolls and public parking fees. Korea also gives priority to zero-emission vehicles in public procurement programs. In 2022, the tax rebate per EV was capped at ₩5.3 million (approximately US$4,200), and subsidies per EV were capped at a maximum of ₩15 million.

The number of public charging points (CPs) in Korea reached 193,000 in 2022, of which 10.6% were dc fast chargers. Nearly 83,000 chargers were installed in 2022. Korea had the best EV-per-CP ratio (2 EVs/CP) among 20 countries included in the IEA "Global EV Outlook 2023" report. The world average was 10 EVs/CP. Korea also had the highest average charger capacity-(in kilowatts)-per-EV ratio, with 7 kW/EV, while the worldwide average stood at 2.4 kW/EV. At the end of 2022, there were 102,662 customers that had installed EV chargers, and the total contract demand was 2,866 MW, as illustrated in Figure 2.

In addition to financial incentives, charging infrastructure deployment policies are essential to reduce charging anxiety and increase EV adoption. To meet EV and charging infrastructure targets, Korea increased subsidy funding for slow chargers from ₩24 billion in 2021 to ₩74 billion in 2022. Funding for fast chargers also increased from ₩4.5 billion to ₩37 billion. Regulatory measures were implemented in 2022 to ensure EV readiness in apartment blocks, public buildings, and parking lots. New apartment buildings must install chargers for at least 5% of their total number of parking spaces, and existing apartment buildings are required to install them for at least 2% of their spaces.

Facilitating a Better Charging Experience

Charging Standards

Back in 2010, the dc "Charge de Move" ("CHAdeMO") and Society of Automotive Engineers J1772 ac charging systems were used by the BlueOn, the first EV in Korea. Then, until 2017, three different fast charging standards [CHAdeMO, Combined Charging System (CCS) type 1, ac three-phase) were used to support early EV models. In 2018, Korea selected the CCS type 1 combo [International Electrotechnical Commission (IEC) 62196-3] as the recommended standard for dc fast charging. As for ac slow chargers, the J1772 (IEC 62196-2 type 1) has been used since 2009. Only Tesla has used its own connector type and charging network since its introduction in 2016.

DC Ultrafast Charging Station

Being able to charge an EV very quickly is an important factor when charging in the middle of a long-distance trip. Recently introduced EVs, such as the IONIQ 5, EV6, and Taycan, can have a charging power of up to about 225 kW, which is equivalent to 18 km/min. To support these faster-charging EVs, in 2021, Hyundai Motor Group and the Ministry of Environment established 32 ultrafast charging stations with a total of 152 CPs, each with up to 400 kW of charging power. An ultrafast charging station typically consists of a power conversion unit of 1,000 kW and four to six charging outlets of 200 or 400 kW, as demonstrated in Figure 3(b). With increasing use of electric buses for public transit in urban areas, the construction of charging stations >1 MW are becoming a concern for distribution system planning and operation.

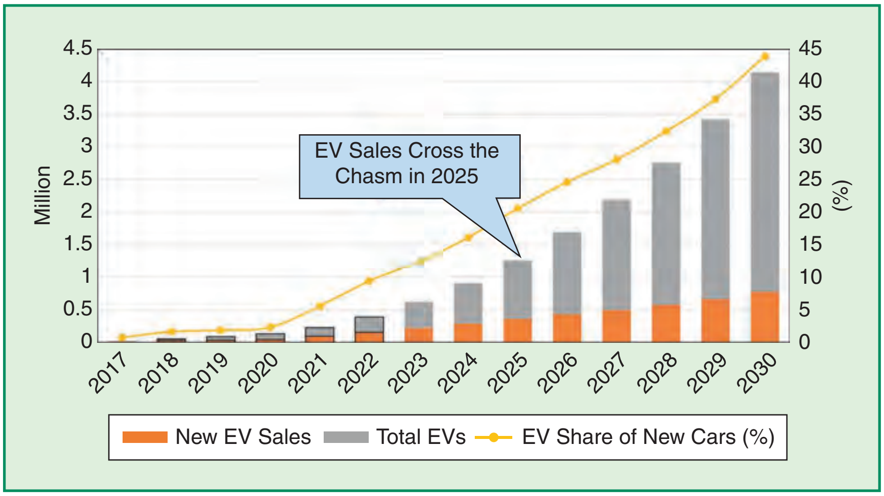

figure 1. The battery EV sales record (~2022) and forecast (2023~2030). "EV sales Cross the Chasm in 2025" implies that EV sales are expected to transition from an early market to a mass market in 2025.

Plug-and-Charge Service

The most recent charging standard, ISO/IEC 15118, introduces plug-and-charge (PnC) as a method to verify user identity seamlessly.

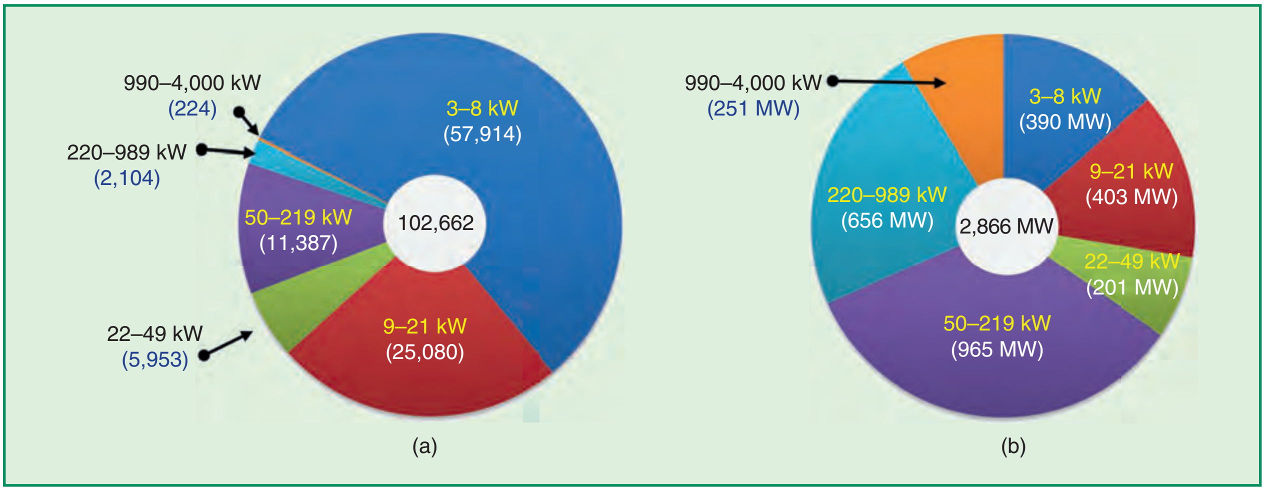

figure 2. The distribution of (a) EV charge rate customers and (b) contract demand, by segment. The numbers in parentheses show the number of registered customers and the sum of the contract demand for each segment. The kilowatt ranges in these figures are related to the features of the charging environment at each location. The group of 3–8 kW contains mostly stand-alone EV chargers owned by private customers, the group of 9–21 kW consists of charging stations where two or three slow chargers are installed and owned by CSPs or businesses, the group of 22–49 kW includes charging stations where three to seven slow chargers are installed and owned by CSPs, the group of 50–219 kW is made up of charging stations where one to four fast chargers are installed and owned by CSPs, the group of 220–989 kW involves charging stations where ultrafast chargers are installed, and the group of 990–4,000 kW includes EV bus charging stations at city bus garages.

figure 3. (a) A typical 50-kW three-plug (CHAdeMO, CCS type 1, ac three-phase) fast charger. (b) A 100-kW CCS type 1 charger. (c) An ultrafast charging station with 400-kW chargers.

What sets it apart is its automatic process of authentication and authorization of user identity when a user plugs it in. The PnC feature can be realized by installing a digital certificate in a vehicle. This certificate is issued through public key infrastructure technology, which is used for authentication. Thanks to public key infrastructure, it is possible to have communication security between an EV and a charger as well as a charger and back-end servers. In 2020, the Korea Electric Power Corporation (KEPCO) completed development of PnC service and has been preparing for its rollout.

Roaming Service and Charging Data Management

As the EV market and charging infrastructure began to expand in 2018, many charging service providers (CSPs) rushed to provide services independently. Having many providers meant that EV users had to create several accounts to use the chargers of different CSPs. To improve the user experience and support CSPs, KEPCO launched a real-time roaming service, ChargeLink, in 2020. The roaming service has simplified the complexities associated with payments among CSPs, as explained in Figure 4. Currently, more than 30 CSPs facilitate membership roaming and additional services, such as billing management, business-to-business settlement, and so on.

An increasing demand exists for sharing and utilizing EV charging data for the construction and operation of cost-effective charging infrastructure, demand flexibility, and new services. Korea makes it mandatory to provide charging station status data to the public as a condition of subsidies for public charging infrastructure, and everyone can access the data, which include the location of charging stations, charger types, and statuses (charging, standby, failure, and so on), through a government EV information portal. CSPs, power utilities, and EV and battery manufacturers are all interested in using data to develop new energy services, battery life management, and battery reuse.

EV Charge Pricing

At the beginning of the EV market, KEPCO introduced a discount program to support government policy and promote EV adoption in Korea. In 2016, EV owners could charge their vehicles at a 50% discount rate and with no demand charge. However, the discount rate for EV charging has been gradually reduced every year since 2020 according to a phase-out policy. From July 2020 to June 2021, 50% of the demand charge (won/kilowatt-hour) and 30% of the energy charge (won/kilowatt-hour) were discounted. In July 2021, the discount rates decreased to 25% and 10%, respectively. The program was intended to end to recover KEPCO's losses, but the government decided to extend it to 2022, in the face of strong backlash from EV owners and the industry. However, the program terminated on 30 June 2022 since the government and KEPCO agreed on the abolition of the discount program amid KEPCO's swelling deficit. As the discount of electricity rates for EV charging decreased, the charging price at public stations rose. The typical charge rate for dc fast chargers was ₩260/kWh until June 2021, and it increased to ₩293/kWh in July 2021. Since the discount disappeared in July 2022, EV owners pay ₩313/kWh for fast charging.

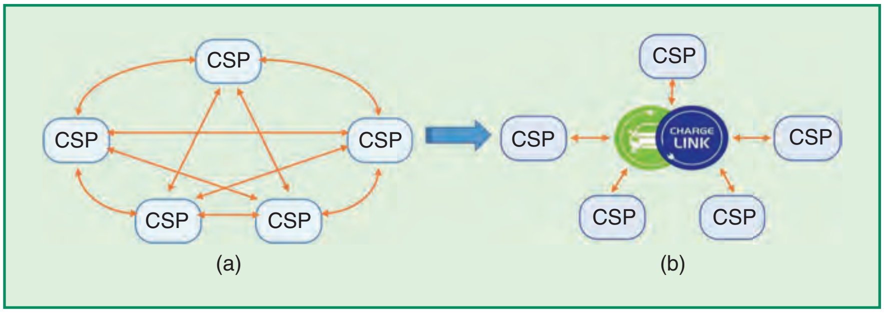

figure 4. KEPCO's ChargeLink roaming platform reduces the complexity of the (a) existing N–N data exchange network structure among CSPs to a (b) simple N–1–N structure.

table 1. The KEPCO TOU EV charging rates for low-voltage private customers, in won per kilowatt-hour.

<table>
<tr><th></th><th colspan="24">Off Peak / Midpeak / On Peak</th><th></th></tr>
<tr><th>Season/Hour</th><th>0</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>10</th><th>11</th><th>12</th><th>13</th><th>14</th><th>15</th><th>16</th><th>17</th><th>18</th><th>19</th><th>20</th><th>21</th><th>22</th><th>23</th><th>Maximum/ Minimum</th></tr>
<tr><td>Spring (March~May)</td><td colspan="8">85.4</td><td colspan="3">97.2</td><td>102</td><td>97.2</td><td colspan="5">102.1</td><td colspan="4">97.2</td><td colspan="2">85.4</td><td>1.2</td></tr>
<tr><td>Summer (June~August)</td><td colspan="8">84.2</td><td colspan="3">172</td><td>259</td><td>172</td><td colspan="5">259.2</td><td colspan="4">172</td><td colspan="2">84.2</td><td>3.08</td></tr>
<tr><td>Fall (September and October)</td><td colspan="8">85.4</td><td colspan="3">97.2</td><td>102</td><td>97.2</td><td colspan="5">102.1</td><td colspan="4">97.2</td><td colspan="2">85.4</td><td>1.2</td></tr>
<tr><td>Winter (November~February)</td><td colspan="8">107.4</td><td>155</td><td colspan="3">217.5</td><td colspan="4">154.9</td><td colspan="3">217.5</td><td colspan="3">154.9</td><td colspan="2">107.4</td><td>2.03</td></tr>
<tr><td colspan="26">₩1,300 = US$1.</td></tr>
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TOU Tariffs

One way to minimize peak load impacts is to use TOU tariffs, where unit prices for electricity consumption vary by period and season. As the default tariffs for EV charging in Korea, TOU tariffs have a three-tiered rate structure, where the rate ratios of peak to off-peak hours range from 1.2 to 3.1, as evident in Table 1. Even though KEPCO imposes electricity bills for EV chargers based on the TOU, customers using public fast charging services usually pay a flat rate. In the case of slow charging, half of the CSPs offer TOU tariffs, while the rest insist on a flat rate. Therefore, the impact of load shifts via TOU tariffs is considered limited for public charging.

EV Charging and Grid Flexibility

The Korean government aims to increase the share of the renewable energy supply to 20% by 2030. However, in 2022, renewables accounted for just 7.5% of Korea's generation mix. Jeju Island, which lies about 90 km off the southwestern coast of the Korean peninsula, has a different trajectory in renewables, with an 18.3% renewable energy share and a 49% installed renewable capacity in 2022. The increased use of renewable energy has made it more challenging to match electricity production with demand on the island, as the power system is not synchronized with the mainland and is linked via limited high-voltage dc lines.

Renewable Generation Curtailment on Jeju Island

The Jeju grid operator started to curtail wind power generation when it exceeded electricity demand. The number of curtailments increased from three in 2015 to 132 in 2022. Jeju has a vision of becoming a carbon-free island by 2030. To achieve this, it plans to install 1,411 MW of PV power and 2,345 MW of wind power. The island's plan will almost double the current capacity and lead to more curtailment. Jeju Island is trying to minimize curtailments by upgrading grid infrastructure, developing new flexible resources, securing additional energy storage resources, and adding a high-voltage dc back feed.

Plus DR With EVs

Attempts have been made to solve the curtailment problems of the Jeju power system through increasing electricity demand flexibility that can respond to balancing needs. In March 2021, Jeju Island launched a demand flexibility service, Plus DR, to solve the curtailment problem. Plus DR provides a reward to participants for increased electricity consumption during periods when an excessive supply of renewable energy is expected to occur. As of 2022, 16 resources of 73.5 MW were registered in the Plus DR market. However, the number of Plus DR events was only three, and the amount of bidding was still low.

In June 2022, the Jeju grid operator changed the conditions for a Plus DR event from a day ahead to three hours of notification. In addition, several attempts were made in parallel to grow the market by recruiting various customers with a high potential to increase their load. Among those customers, EV users are in the spotlight as a flexible resource for Plus DR participation. The proportion of EVs among the total registered vehicles on the island was 4.8% in 2022, which was significantly higher than the national average of 1.5%. With the collaboration of the Jeju Provincial Office, KEPCO implemented a Plus DR pilot project utilizing EV chargers. In the pilot project, a total capacity of 15 MW of 521 public chargers (282 fast and 239 slow chargers) was registered for the service.

Smart Charging Demonstration

The KEPCO Research Institute conducted a demonstration program on unidirectional smart managed charging (V1G) using regular EVs to assess their value as a demand resource for the power system. Through this program, users connect their

EVs to an ac V1G charger and utilize an app on their smartphone to set their desired battery charging level [the state of charge (SOC), expressed as a percent] and departure time. The V1G control and management system, considering user inputs and TOU rate information, generates a charging schedule and initiates charging accordingly. In the event of a control command issued by the operator or an external DR signal, a revised charging schedule is created and executed. To achieve a customer's specified target SOC and departure time, precise knowledge of the battery's SOC value is crucial. Unlike the V2G system, the charger does not obtain the vehicle's battery SOC through the charging cable; instead, KEPCO utilized a dongle attached to the onboard diagnostic port of the vehicle to retrieve the SOC value. By March 2022, 135 EVs of 18 different models had actively participated in the demonstration, which came to a close. Initially, only four vehicle types (Kona, 64 kWh; Niro, 64 kWh; Bolt, 57 kWh, and IONIQ, 38 or 28 kWh) were eligible, due to limitations in acquiring SOC data from vehicles. However, enhancements to the SOC acquisition method allowed newly launched EV models to take part. The total charger installation encompassed 100 units across 33 individual charging stations, five for workplaces, 14 for KEPCO offices, and two for the test bed.

During the 12-month demonstration, there were 8,531 charging sessions, which consumed a total of 168,150 kWh. Charge control actions involving load reduction were executed 330 times, with a cumulative control time of 197.6 h, with 1,245 kWh of energy. It is worth mentioning that participants set the SOC target to more than 90% during 67% of the charging sessions. This result seems to reflect users' preference for a higher SOC, due to limited battery capacity and mileage anxiety. The majority of the charging sessions were observed between 8 a.m. and 7 p.m., as shown in Figure 5, with a high proportion of the chargers installed at work or business sites (70% of the units), leading to connection start and end times being concentrated during business hours. An ex post survey revealed that 70.4% of the participants expressed satisfaction with the smart charging experiment, while 14.8% were dissatisfied. Of the satisfied respondents, 26.3% highlighted the cost saving benefits of automated charging at lower rates. The primary sources of dissatisfaction were charger malfunctions and communication errors, affecting 37.5% of the dissatisfied participants.

AC V2G System and Its Demonstration in Real Environment

A bidirectional charging, or reverse power transfer-capable, EV connected to the grid or a V2G system, such as an energy storage system (e.g., a pumped hydropower plant), could move abundant PV generation from the daytime to the evening; otherwise, expensive gas peaks start when demand ramps up. To utilize the potential of a V2G system, KEPCO started research and development activities in 2015. KEPCO developed a 3.3-kW ac V2G system prototype in 2017 and demonstrated V2G charging/discharging using an experimental EV. Based on this, starting in 2018, with the goal of applying it to mass-produced vehicles, KEPCO started to develop a 7-kW ac V2G system based on the ISO/IEC 15118 standard, with the collaboration of the best research groups in Korea, such as Hyundai, the Korea Automotive Technology Institute (KATECH), the Korea Electrotechnology Research Institute, and Ulvac Korea. In 2021, this ac V2G technology was implemented in mass-produced EVs and commercial-grade chargers, and V2G demonstrations began for individual customers who purchased the IONIQ 5. V2G demonstrations have shown that the vehicle's discharge output stabilizes within a maximum of 20 s from the time of the V2G discharge command. This level of response can be utilized by grid operators to maintain stability or provide flexibility, depending on grid conditions.

AC V2G Versus dc V2G

V2G charging and discharging can be done using an ac or a dc method, as depicted in Figure 6. In the ac method, a bidirectional onboard charger (OBC) is used to convert the battery's 300~800 V of dc into 220-V ac, which is connected to the power distribution system through the charger. DC V2G was commercialized as a CHAdeMO plug standard a few years ago. The external charger has a bidirectional dc-to-ac converter that converts dc from the EV battery into ac power. DC V2G chargers are estimated to cost five to 20 times more than ac chargers, due to the power conversion devices they require.

Components of the AC V2G System

As displayed in Figure 7, the ac V2G system consists of several key components, such as a V2G management system; V2G EV supply equipment (EVSE), i.e., the charger; an EV with a bidirectional V2G OBC; and a user charging app. The V2G control and management system manages the charging schedules of every charger, based on the driver's setting, the TOU tariffs, and grid needs, such as DR. It automatically

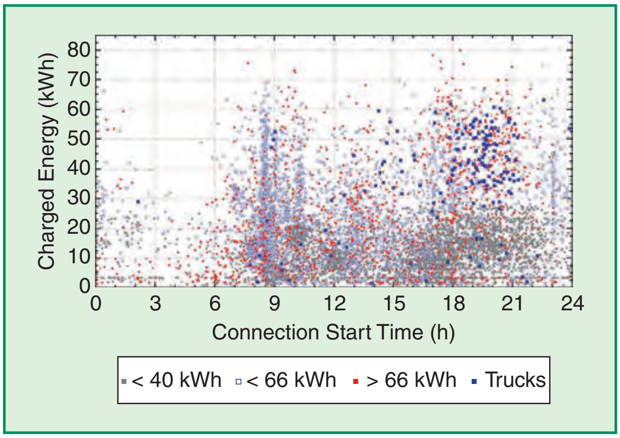

figure 5. The charger connection start time and charged energy (in kilowatt-hours) for EVs of different battery sizes and LDTs. It is evident that < 40-kWh vehicles charge around 20 kWh, < 66-kWh vehicles start charging around 9 a.m. (the beginning of the business day), > 66-kWh vehicles are evenly distributed across all hours except late night, and trucks have a high concentration of connections in the evening after 6 p.m.

participates in DR by adjusting the charging and discharging time within a range where the charging target set by the customer can be achieved. Customers may change the departure time or target SOC at any time. This system was used for a smart charging control demonstration with legacy EVs and a V2G demonstration using IONIQ 5 EVs.

Protocols for EV, EVSE, and Management System

A vehicle and charger communicate according to the ISO/IEC 15118-20 standard. At the time when KEPCO's V2G demonstration began, the standard was not yet finalized. Therefore, the company implemented a control sequence and messaging based on the July 2019 draft of the standard. In April 2022, the standard was finalized, and it will be implemented in V2G EVs and chargers of the near future. Communication with the V2G control system and chargers follows the "KEPCO Protocol" established by the company. When a user starts charging, the charger communicates with the EV and delivers the vehicle's current SOC to the control system. Charge and discharge schedules are dynamically modified according to utility or operator needs within user-set target values.

V2G OBC and ac V2G EVSE

Hyundai developed a bidirectional OBC with electrical ratings of 11 kW for charging and 5 kW for discharging and applied it to the IONIQ 5 EVs produced after August 2021. To enable the V2G function, customers who participated in the demonstration program received a firmware upgrade for their EV. Together with Ulvac Korea, KEPCO developed a type 1 ac V2G EVSE. The ac V2G EVSE connects the EV to the grid, and the battery can charge at 7 kW and discharge at 5 kW. After a long-term test of how the IONIQ 5 charger and V2G control system worked together, KEPCO deployed the system as part of its V2G demonstration program.

Control Performance of V2G System With Aggregated EVs

To use EVs to their full potential in the power grid as a flexibility resource, they need to be able to work together as a single large battery, or virtual energy storage system. Achieving this requires simultaneous control of all chargers and the ability to respond quickly. The effectiveness of the system's flexibility was evaluated by measuring the simultaneous charge and discharge control of multiple vehicles. In the test bed experiments, the aggregated transition time from charge to discharge or discharge to charge for five EVs with ac V2G chargers was approximately 6 s, as displayed in Figure 8.

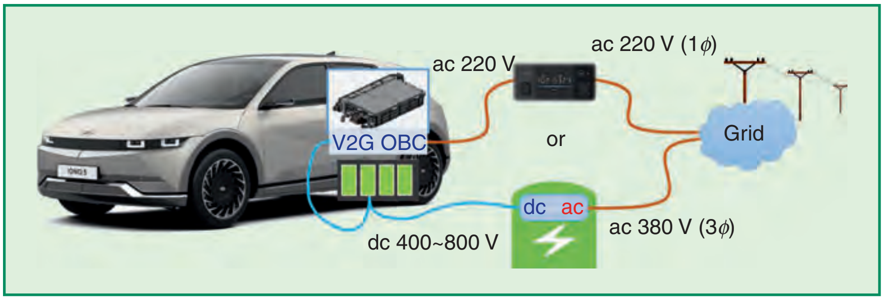

figure 6. AC versus dc V2G methods. In ac V2G, dc-to-ac power conversion is performed in a bidirectional onboard charger (OBC) in a vehicle, and in dc V2G, dc-to-ac power conversion is performed in an external charger.

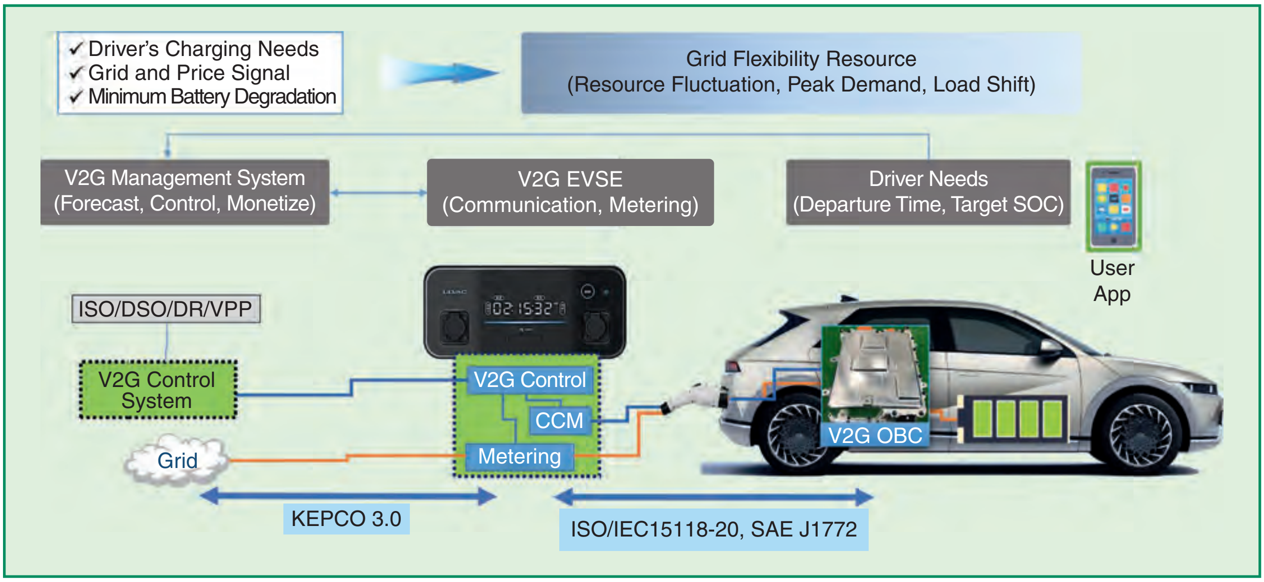

figure 7. The components of an ac V2G system. EVSE: EV supply equipment; ISO: independent system operator; DSO: distribution system operator; VPP: virtual power plant; CCM: communication control module; SAE: Society of Automotive Engineers. (Source: KEPCO Research Institute, Hyundai Motor Group, and Ulvac Korea; used with permission.)

V2G Demonstration Program for IONIQ 5 Customers

KEPCO recruited customers who drove an IONIQ 5 produced after August 2021 and could install a dedicated charger. KEPCO built V2G charging infrastructures for participants from all across the country and conducted empirical studies of V2G control functions, the convenience of user apps, and usage patterns in everyday life. One hundred chargers were installed for individual customers (51), KEPCO vehicles (12), a car rental service provider (12), participating organizations, and the test bed (25). From July 2022 to March 2023, there were 3,105 charging sessions of 72,163 kWh and 117 control sessions of 2,361 kWh. The longer an EV is connected to a V2G charger, the longer it can be used as an energy storage resource. Load reduction tests have been performed regularly to study the availability and effectiveness of V2G EVs. An ex post analysis report on the V2G demonstration will be made public after the completion of the experiments.

Willingness to Participate in the V2G Program

In a survey of 1,971 EV drivers conducted in 2022, KEPCO found that a smart charging service that controls the charging speed while matching the target SOC and departure time is positively perceived by a majority of EV drivers. Out of the total, 28.9% of the respondents answered that they would actively participate because it was a desirable service, and 46.6% said they would participate when the benefits or incentives were reasonable. The percentage of consumers who positively perceive smart charging is about 75%. In another survey intended for V2G, as presented in Figure 9, 70.3% of the respondents said they were willing to participate in the V2G program, and only 8.1% of the respondents showed no interest.

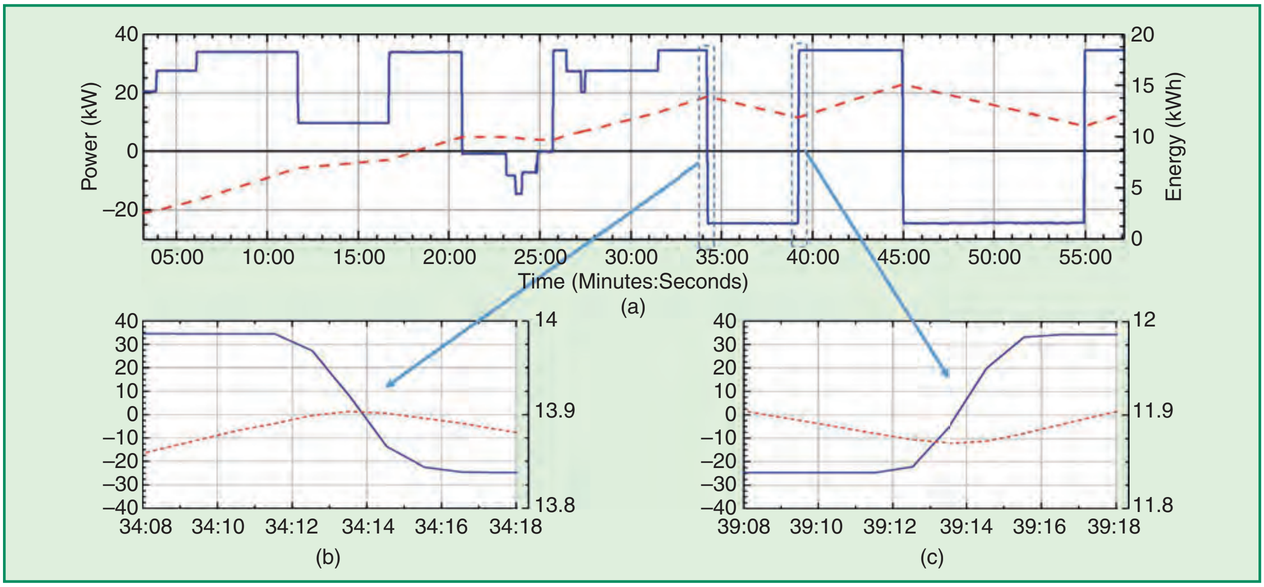

figure 8. The charge-to-discharge and discharge-to-charge transition control of five IONIQ 5 EVs charging and discharging power of 7 and 5 kW, respectively. Negative numbers indicate that power is being discharged. Red dotted lines show charged or discharged energy. (a) Power and energy profile for a 50-min charge and discharge control session, with magnified views of (b) the charge to discharge control and (c) the discharge to charge control.

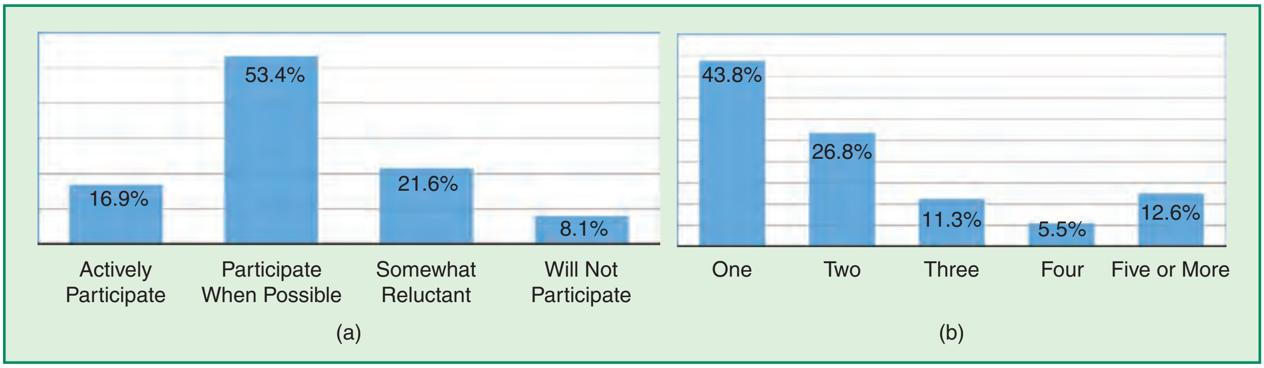

figure 9. The survey of EV owners' (a) willingness to participate in V2G services and (b) desired number of V2G events per week. The reason why five events or more per week accounted for a higher percentage than three or four per week is likely due to respondents expecting that the more they participated in V2G, the greater the rewards would be.

Assessment of V2G Impact on Battery Life

The impact on battery life caused by frequent charge-and-discharge cycles due to V2G control is always a question for EV owners, fleet operators, insurance providers, manufacturers, and V2G service providers. To answer the question, KEPCO and KATECH studied the battery state of health through thousands of charge-and-discharge cycles. A long-term continuous comparative test is in progress for conventional dumb charging, managed charging (V1G), and charging and discharging control (V2G) using battery modules identical to those in the IONIQ 5. A battery charge-and-discharge test equivalent to about 350,000 km of driving shows a difference of less than 2% among the comparison groups (see Figure 10).

Transition to Business as Usual

Supply Chain Recovery and Preparation for Rapid EV Adoption

Despite dwindling inventories of EVs due to supply chain constraints, EV demands continue to grow. The government's carbon-neutral policy and the introduction of a variety of new car models based on the EV-only platform will expand consumer choice and lead to a rapid increase in the number of EVs. Electric buses and trucks will continue to grow in number to reduce downtown particulate matter emissions and greenhouse gas emissions. Consequently, megawatt-class dc fast charging stations will also increase in number for vehicles equipped with high-capacity batteries. As new EV models' single-charge mileage increases, the fast charging infrastructure will transform into a large-scale centralized ultrafast type that provides a faster charging experience for long-distance travel.

With sufficient power resources, adequately equipped transmission and distribution networks are necessary to support the increased load from EVs. In addition to more demand, system operators are facing the challenge of balancing an increasing proportion of variable renewables at the transmission and distribution levels, requiring network upgrades and storage. In general, PVs, with a long queue for connection, need more network upgrades compared to EV charging or other newly electrified loads. Effective DR measures related to EV charging will be necessary to avoid frequent peak load events and disproportionate investment in grid upgrades. Faster approval times for grid upgrades are essential to ensure adequate charging networks. Establishing and upgrading grid connections is a complex task involving multiple stages of planning, approval, and procurement, each of which requires significant lead times in many countries. It is of prime importance that the required grid upgrades are put in place as promptly as possible while reflecting the legitimate claims of all stakeholders.

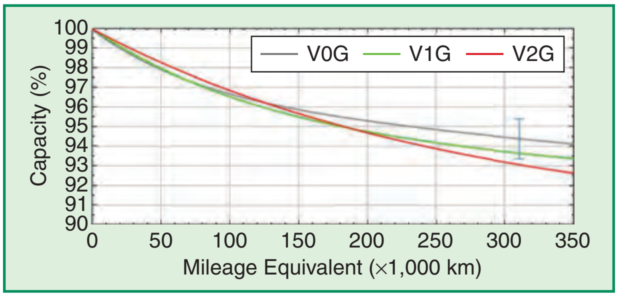

figure 10. The battery capacity degradation due to charge control (V1G, green line) and V2G (red line) compared with dumb charging (V0G, gray line), with a mileage equivalent of ~350,000 km. (Source: KEPCO and KATECH; used with permission.)

Maximizing the Value of EVs for Grid Flexibility

Unmanaged EV charging risks are compounding concerns for grid operators that must balance supply and demand, and they place additional pressure on networks. Coordinated smart EV charging has the potential to help smooth increases in peak demand. TOU tariffs can facilitate DR by engaging consumers through price signals to shift charging to off-peak periods. Ultimately, the development and deployment of EV grid integration technologies will enable vehicles to be plugged into smart chargers to contribute to balancing the system. In this manner, EVs will contribute to grid stability rather than being a source of balancing needs. V2G-capable charging infrastructure has the advantage of being able to expand quickly because it has less environmental impact and lead time than other grid flexibility resources (such as pumped hydro plants, utility-scale battery storage, and so on) and does not require the construction of new transmission lines (Table 2). It is encouraging that the KEPCO demonstration confirmed the technical validity of EV charging as a flexible resource for grid service and that most of the participants showed interest and willingness to join. Smart charging and V2G technology are on the way to evolving into commercialization in a few years. However, for successful implementation as a profitable business providing a flexible resource for system operation, cooperation among various stakeholders and prompt market creation are required.

The finalization of the ISO/IEC 15118-20 standard triggered the introduction of ac V2G-capable EVs from major EV manufacturers, and the first ISO/IEC 15118-20 ac V2G-ready EV was released in 2023. Ensuring that markets and regulations reflect the value of flexibility options for the system is a cornerstone of boosting bidirectional charging adoption. Consumer-provided flexibility services will incur costs, for instance, in terms of battery degradation and space for parking, that must be appropriately valued. This value can be reflected at every level of the power exchange market. Furthermore, it is necessary to secure the economic deployment of V2G chargers on a large scale before EV proliferation. The technology needs to progress to ensure the secure and stable control of large-scale bidirectional charging infrastructure with millions of connected EVs that can be used as a resource in the power grid. All these efforts will lead to the transformation of EV charging infrastructure into a grid-friendly one.

table 2. A comparison of grid-scale flexible resource characteristics.

Category	Pumped Hydro	Lithium-Ion Battery Storage	AC V2G EV
Unit capacity	200~400 MW	0.1~4 MW	7~10 kW
Occupied area (m^2/MW)	1,109	25	1,785*
Environmental impact	High	Low	**Very low**
Construction time	>7 years	>6 months	**<1 month**
Construction cost† (million won/MW)	934 (7 h)	870 (1 h)	**186 (~4 h)**
Ramp rate	<100 MW/min	~Megawatts/millisecond	~Kilowatts/second‡
Round-trip efficiency	72~81%	>81%	**>84%**
Data source	Yecheon P.H. plant	KEPCO	KEPCO

*Size of a standard parking lot.
†Construction cost excludes transmission and distribution infrastructure cost.
‡Per vehicle.

Conclusions

Higher shares of variable renewables in the generation mix are contributing to the transition needed to meet policy-stated decarbonization targets. New sources of flexibility can help to ensure that the power system is in balance at all times. As the IEA projects, to reach net zero in the energy sector by 2050 globally, flexibility in electric grids needs to quadruple in that period. EVs and their batteries could provide a huge reservoir of flexibility to facilitate the energy transition. If we aggregate 500,000 EVs capable of V2G at 10 kW, for example, they can be a very flexible power storage resource of 5 GW without network upgrade and storage investment.

This article briefly presented the recent uptake of Korean EV and charging infrastructure, policies, and smart charging pilot projects, including the first ac V2G charging using a commercial EV. It is very important that the government and the public sector promote consistent policies that give accurate signals to the market. Korea, which establishes a comprehensive road map for overall infrastructure, EVs, rates, and regulations and promotes policies, is a notable case. It is also exemplary that the operation status of all public chargers is open to the public through the government so that EV users can easily access it via a smartphone apps. It is necessary to prepare for the soon-to-be-expected expansion of charging demand in old apartments in downtown areas and to improve regulations and standards for the integration of V2G resources. For the time being, there is no problem with the charging power supply, but after 2030, we need to prepare for grid operation when renewable power generation and EV numbers increase. It is important for countries in the early stage of EV deployment to set clear goals for infrastructures and EVs, establish road maps, and promote consistent policies. In particular, national standards for charging infrastructure should be established at an early stage. Even if a new battery technology comes out that can be fully charged in minutes at a megawatt level, the current power system will fully support the charging demand.

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For Further Reading

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