Examination of electric vehicle charging stations and V2G technology

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Abstract. With the rapidly increasing tendency towards electric vehicles in the world with the effect of global warming, the issue of charging the batteries of electric vehicles has gained importance. With the introduction of electric vehicles into our lives, existing networks have become insufficient. In order to meet the energy demanded by electric vehicles, it is possible to increase the grid efficiency by around 20 % by making the existing grid smart without building a new power plant. In this sense, the inclusion of electric vehicles in the smart grid is an important topic. An important element of the goal of transition to smart grids, which is a renewable and clean energy policy all over the world, is electric vehicle charging stations. In this study, a review was made by examining the methods of connecting electric vehicles to the grid. Among these methods, the types and levels of vehicle charging stations that provide one-way transmission are defined. Statistics on usage and infrastructure in the world and in Turkey are shared. In addition, vehicle-to-grid (V2G) technology, another method with bidirectional transmission, is analysed. The importance of this technology is emphasized by sharing data on its development and market share in the world and in Turkey. In the light of this information, suggestions have been made for the development of electric vehicle charging stations and V2G technology in Turkey.

Keywords: smart grid, charging stations, electric vehicle, V2G.

1. Introduction

In recent years, electric vehicles have been adopted on a global scale in line with increasing environmental concerns and energy efficiency targets due to emissions into the atmosphere. The widespread adoption of electric vehicles has necessitated the development of charging infrastructures and their integration with smart grid technologies due to the increasing demand for electrical power [1]. The majority of electric vehicles are parked 90-95 % of the day in facilities with charging infrastructure or in personal garages with charging infrastructure. Micro grids can contribute to alternative energy solutions for stationary applications such as parked electric vehicles, energy supply/demand. The integration of smart grids and renewable energy plants has made electric vehicles important not only in the transport sector but also in grid integration. Electric vehicles are critical elements of smart grids thanks to their energy charging and discharging capabilities while parked [2]. Charging stations are essential infrastructure elements for the widespread adoption of electric vehicles. Technological developments in recent years have increased the charging speeds of these stations, improved efficiency and enhanced user experience. Today, there are some challenges regarding the accessibility, standardization and grid integration of charging stations. By solving these problems, establishing a comprehensive, flexible and smart grid integrated charging station network accelerates the transition to sustainable transportation, reduces carbon emissions and increases the trend towards electric vehicle use [3]. In this framework, many studies in the literature emphasize the importance of the integration of electric vehicle charging stations with smart grids. In addition to many components included in smart grids, the advantages of charging stations as an alternative energy source are known. In addition to being an alternative energy source to smart grids, electric vehicles can also be considered as an alternative power source with the energy stored in their batteries during charging. This brings us Vehicle-to-Grid (V2G) technology. The V2G (Vehicle-to-Grid Systems) system is explained as follows. The basic concept of the system is based on increasing the reliability of the system during the hours of peak power demand by transmitting power from the battery of electric vehicles to the grid. Electric vehicles can also be used as a storage device. A network of easily and quickly accessible energy storage devices can be created that can provide power flow directly from electric vehicles to the distribution grid. These loads can be converted into new sources of electrical energy for the grid through their interaction with smart grids. Furthermore, electric vehicles operating in a V2G system can act as storage for the excess energy generated by the centralized renewable power plant, providing an additional power source to the energy generated by renewable sources such as wind and solar. In this study, studies in the literature on electric vehicle charging systems, infrastructure and V2G technology are examined and analysed in the world and in Turkey, and what kind of studies and technological developments are foreseen in the future [4].

2. Grid integration of electric vehicles

Two different methods are used for connecting electric vehicles to the grid. The first is to supply electricity from the grid to the vehicle. The batteries in electric vehicles are charged via charging stations. Since the batteries generally have DC voltage, they can be charged unidirectional with AC/DC converters and DC/DC converters from AC and DC charging stations. Another method is to feed the grid from the vehicles. Here V2G technology comes into play and the electrical energy stored in the vehicle battery can be fed to the grid when needed. These systems are bidirectional power transfer systems.

2.1. Electric vehicle charging systems

Today's technology offers three basic methods for charging electric vehicles: battery exchange, wireless charging and wired charging. The wired charging method is divided into two sub-categories: alternating current (AC) and direct current (DC) charging units. The vast majority of electric vehicles can charge their batteries via both AC and DC charging stations. Wireless charging method stands out as both a practical and safe alternative as it does not require any charging apparatus in the vehicles. In this method, the vehicle is charged by placing it on an electric field created by electromagnetic waves. However, today this system has not reached the desired level of efficiency. Studies are ongoing to charge the vehicles on the move. The battery replacement method is usually carried out at certain change points. Users who do not want to waste time during charging prefer this method. In this system, the discharged battery of the vehicle is quickly replaced with a full battery, and this process is completed in a short time at charging centers or authorized services [5]. SAE J1772, the recommended application document for charging systems of electric vehicles, divides electric vehicle charging stations into 3 levels. While defining these levels with SAE J1772, it also specifies the electrical connector types. Charging levels are defined as shown in Table 1 [6].

Table 1. Charging levels and characteristics

Charge level	Voltage	Maximum current	Maximum power
Level 1	120VAC	16A	1.9 kW
Level 2	208-240 VAC	80A	20 kW
Level 3	200-500 V DC	80A	40 kW
Level 3	200-500 V DC	200A	100 kW

2.1.1. Level 1 charging stations

Level 1 charging stations are AC (alternating current) powered charging stations only.

Charging is carried out through a device called "on-board charger" located inside the vehicle. They are generally preferred for vehicles with smaller battery capacity. These stations allow vehicles to be charged by connecting to standard household sockets. Depending on the energy capacity of the battery, the full charging time varies between approximately 8 and 10 hours. In Europe, this charging method is used with single-phase 230 VAC voltage and 12 or 16 A fuses. In the USA, it operates with 120 VAC single-phase power and a maximum current of 16 A. However, Level 1 charging is of limited use as it is a slow method and not efficient enough for short-term connections. Level 1 charging supports a maximum power capacity of 1.9 kW [7]. Due to its slowness, this type of charging stations are generally preferred in homes and car parks of large sites. The vehicle owner can charge the vehicle overnight due to the long charging time.

2.1.2. Level 2 charging stations

Level 2 charging is often the primary charging method used in both public and private facilities. Chargers in this category may have an in-vehicle design to minimize power electronics. Today's Level 2 chargers offer a maximum charging capacity of 80 A and 20 kW between 208 V and 240 V. Installation of these devices at home or in commercial spaces requires specialized equipment and professional installation. For example, electric vehicles such as Tesla are equipped with in-car power electronics and can only be charged by connecting them to a suitable outlet. Since most homes in the US have a 240 V power supply, Level 2 chargers can fully charge vehicle batteries, usually overnight. Electric vehicle owners prefer Level 2 due to the shorter charging times of these chargers and standardized connectivity with the vehicle [8]. Level 2 charging stations operate with alternating current like Level 1 charging stations. It transmits the grid electricity to the vehicle in a similar way as in Level 1. But it is faster than it. The charging time is almost half or less than the lower level 1. The user experience is improved thanks to the human machine interface (HMI). It has a structure that is more advanced in terms of hardware and can provide high voltage.

2.1.3. Level 3 charging stations

Level 3 charging is designed for commercial fast charging processes, allowing batteries to be fully charged in less than one hour. Such chargers can be placed in a similar way to petrol stations, usually at rest facilities on the motorway or at fuel stations in the city. Level 3 chargers are usually at a voltage of 480 V or higher. Charging is usually accomplished by the device supplying DC energy directly to the electric vehicle. These systems are generally not suitable for residential use [9]. It is seen as the technology of the future. It can convert the mains voltage into an upgraded DC voltage to provide high current. Of course, few vehicle batteries today are capable of supporting 500 V. For this reason, it will be used more widely in the future with the development of batteries. It is also equipped with complex electrical circuits as hardware.

2.1.4. Wireless charging system

Another method for charging electric vehicles is wireless charging, i.e. inductive charging systems, which is a safe and efficient new generation technology. These systems offer the user the convenience of wireless charging and eliminate cable clutter. Inductive power transfer systems transfer power in the kHz to MHz range using a non-radioactive magnetic field. This method is also called magnetic resonance because there are resonances in the circuit. Two planar coils generate a magnetic field, forming a loosely coupled transformer called a magnetic or inductive coupler. The receiving coil, usually mounted under the vehicle, converts the generated magnetic flux fields into high-frequency AA. This high frequency AA is then converted into a stable DA source and utilized by the on-board batteries. The energy is transmitted to the vehicle side through the secondary coil, which is reciprocally connected to the primary coil via the flux generated in the air gap by the primary coil current [10]. It is divided into two as static and dynamic charging. Dynamic charging systems allow electric vehicles to be charged while moving. In this way, the need for large and expensive batteries is eliminated and range limitations are avoided. In static wireless charging systems, the safety, durability and efficiency of the battery are at the forefront. Despite fluctuations in the charging state of the battery, constant current / constant voltage mode is used. Dynamic charging systems reduce the need for large batteries compared to static charging systems but require high initial costs [11].

2.1.5. Electric vehicle charging stations and infrastructure: global and Turkish perspectives

Charging your vehicle at home is more common than other methods. Home charging possibilities vary in many parts of the world. This varies in parallel with the country's technological development in this field. In addition, it will be seen that charging possibilities differ according to urban, rural and suburban areas, based on income level and facilities. In overpopulated megacities, access to charging at home is limited and charging in public spaces is more available. According to the data of the International Energy Agency, Korea takes the lead at this point. In 2023, public charging stations increased by 40 per cent.

In areas where the voltage of the electricity grid is 220V or above, EV owners can charge their vehicles overnight from a normal household socket. This is the most common situation and is the case in Europe, Australia, most of Latin America and most of Asia. The UK has one of the highest reported shares of access to home charging at 93 per cent, more than half of which are smart chargers. This is partly due to the UK being the first country to publish smart charging point regulations. In India, 55 per cent of consumers say they have access to home charging today. In areas where the voltage is lower, typically 100-120V, charging speeds from normal household sockets are much slower. Therefore, in countries with 100-120V electricity grids, the ability to charge in under ten hours requires the installation of a specialized charger. This is the case in some countries with high rates of EV charging at home, such as the United States (83 %) and Canada (80 %) [12]. Fig. 1 shows the statistics of charging stations in public and private areas for light-duty vehicles by energy rating and type for the years 2015-2023. On the other hand, since China is the leader in EV conversion in the automotive sector and has the highest market share, they are far ahead of the rest of the world in terms of the number and ratio of charging stations in both private (home etc.) and public areas. Chinese electric vehicle manufacturers are in a position to produce more than all of the electric vehicles produced by the rest of the world, in other words, they have produced more than half of the electric vehicles produced in the world. This directly affects the rate and development of charging stations.

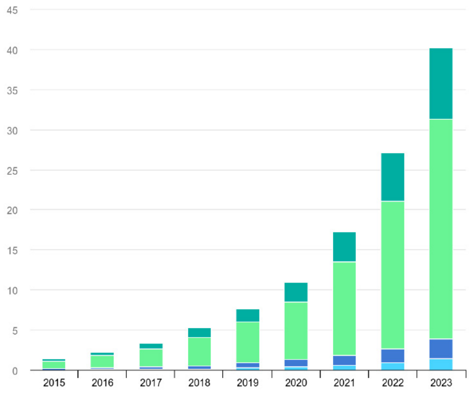

Fig. 1. Statistics of charging stations in public and private areas [12]

In Turkey, based on the Energy Market Regulatory Authority (EPDK) data, we can say that there are close to 168 thousand electric vehicles as of November 2024. This number is increasing day by day. The increase in the number of electric vehicles directly means an increase in electric vehicle charging stations. According to the data of Turkish Statistical Institute (TÜİK), there are 25 thousand AC and DC charging stations as of November 2024. The total installed power of charging stations is determined as 1644 MW. Fig. 2 shows the statistics of charging stations in the last 1-year period. It is predicted that this number will increase in parallel with the transformation to electric vehicles in the future.

An analysis has been made on the existing charging stations actively used based on the regions of Turkey. According to the results, the Marmara region stands out as the region with the most diverse charging types. These charging stations host CCS (Combined Charging System), CHAdeMO (CHArge de MOve), J-1772 (Type 1) and Type 2 connectors. The Mediterranean region also shows development in this sense. These charging stations continue to operate with CCS, CHAdeMO, J-1772 (Type 1) and Type 2 sockets. The Aegean region also follows the Mediterranean region, and the socket types are similar. The high charging power demand is met by CCS and CHAdeMO charging sockets. Currently, there are no charging stations in Turkey that can provide 250 kW or more. This is considered to be an underinvestment due to the lack of vehicles supporting high power levels. The medium level fast charging needs of EVs sold are met by CHAdeMO and CCS charging sockets. The wireless charging station infrastructure in Turkey is mainly used in shopping centres and underground car parks. Cable station structure is used for intercity roads [13].

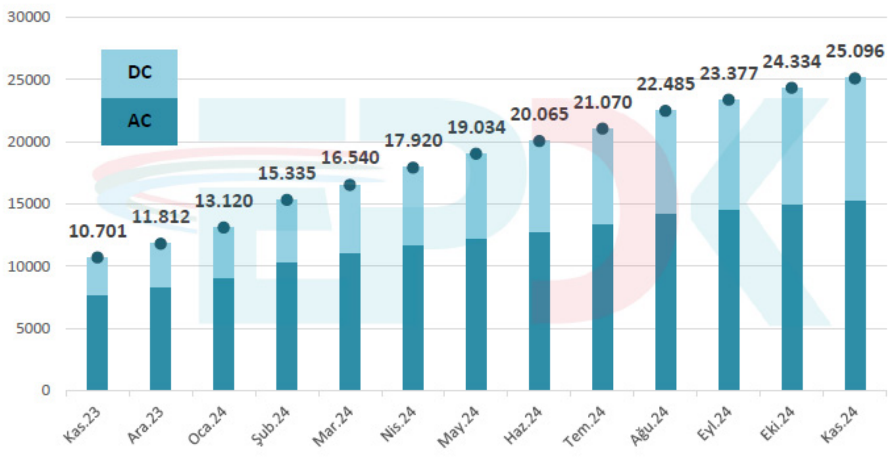

Fig. 2. Statistics of charging stations in Turkey [14]

2.2. Vehicle-to-Grid (V2G) technology

Vehicle-to-everything (V2X) communication technology is one of the key development steps for advanced autonomous driving in the future. V2X technology enables vehicles to communicate with other vehicles (V2V), infrastructure (V2I), network (V2G) and other road users and traffic participants (V2P, V2N) via cellular communication (C-V2X) or Dedicated Short Range Communication (DSRC). The main objective of V2X technology is to improve efficiency and safety for all road users [15]. Vehicle to Grid (V2G) systems represent the utilization of the power capacity of parked vehicles to generate electricity for the grid. The basic concept of V2G is based on transmitting energy from the battery of electric vehicles to the grid during peak power demand hours, thereby increasing the reliability of the system. Electric vehicles can also be used as a storage device. A network of easily and quickly accessible energy storage devices can be created that can provide power flow directly to the distribution grid with electric vehicles. These loads can be converted into new sources of electrical energy for the grid through their interaction with

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smart grids. Furthermore, electric vehicles operating in a V2G system act as stores of excess energy generated by the centralized renewable power plant, providing an additional power source to the energy generated by renewable sources such as wind and solar. The main components of a V2G system include charging infrastructure, aggregator, independent system operator (ISO), renewable energy sources, electricity service provider, electric vehicle and battery pack, unidirectional and bidirectional power flow, and ideally smart metering and control systems [4], [16]. Fig. 3 shows the schematic of the V2G installation:

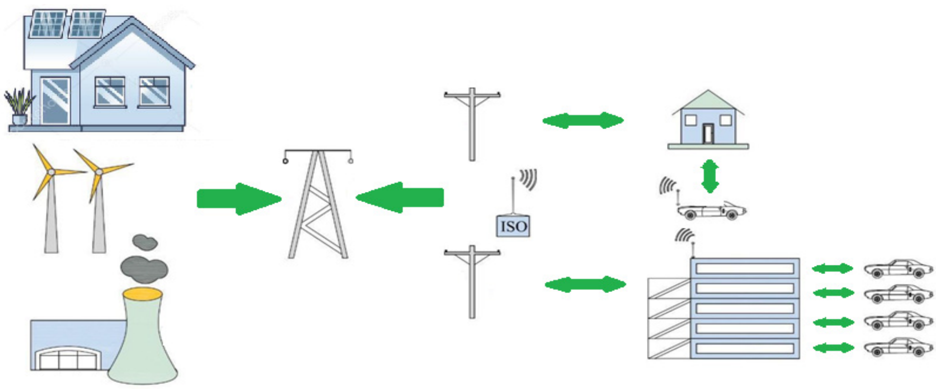

Fig. 3. V2G installation diagram [4]

Looking at the vehicle usage statistics, it is seen that vehicles are not used much during the day. Vehicles are kept in car parks or parking areas for long hours after going to work or home. In this case, the grid supply method called V2G (Vehicle-to-Grid) comes into play. The energy pre-stored in the vehicle batteries can be transferred back to the grid during the day when buildings need a high amount of energy and can support the energy demand. However, for this method to be applied, electric vehicles must meet certain requirements:

1) Electric vehicles support two-way energy transfer,
2) Ability to communicate with the electricity network,
3) Having battery control mechanisms on the vehicle [17].

V2G technology is poised for growth in the global market with government incentives and energy legislation, with the shift towards smart grids and the adoption of electric vehicles. More than 500 V2G pilot projects have been launched worldwide, and the market is expected to show significant growth. Experts expect the value of the market to reach $3.8 billion by 2030, with more than 50 million electric vehicles able to participate in V2G services. Infrastructure is also expanding rapidly, with around 10,000 bi-directional chargers installed worldwide, supporting the integration of vehicle energy back into the grid [18]. Although Turkey is a newcomer to V2G technology, various electricity distribution companies have been involved in various pilot projects supported by the European Union. It is expected that Turkey will also make a breakthrough in this field in the future.

3. Conclusions

The widespread use of electric vehicles with the goals of reducing carbon emissions, increasing energy efficiency and reducing dependence on fossil fuels has brought about the necessity of smart energy management and the expansion of charging infrastructure. When developed countries are analysed, it is seen that smart grids have a significant impact on welfare level and economic development. Thanks to the current technological advances, various projects and investments are being implemented to overcome the inadequacies in the electricity grid infrastructure [19]. As a result of this study, the following points are important:

1) Existing grids in Turkey should be transformed into smart grids to meet the demands of

electric vehicles with a smooth transition.

2) The number of charging stations in both public and private areas should be increased in Turkey and the world. Transition to Level 3 fast charging systems should be encouraged.

3) Government incentives for the inclusion of charging stations in smart grids should be increased. Legislation should be updated in this direction. Charging infrastructure installation incentives and low-cost financing models should be created for electric vehicle users. In addition, private sector participation for charging station operations should be supported.

4) Providing services such as reservation, payment and energy management by supporting charging infrastructure with digital platforms should improve the user experience.

5) Research and pilot projects on V2G technology, which will have a high market value in the future, should be supported and hardware and software that will allow bi-directional energy transfer of electric vehicles should be developed through supported companies.

6) Legal arrangements should be made to support the use of V2G technology. Legislation on issues such as electricity pricing, feedback tariffs and user incentives should be expanded.

V2G technology, the development of charging stations and smart grids have the potential to revolutionize the energy sector. However, in order to realize this transformation, infrastructure investments, R&D studies, legal regulations and user awareness need to be increased. The development of charging infrastructure and integration of V2G technology in Turkey offers great opportunities in terms of energy management and sustainability. The public and private sectors should act together to realize these innovative solutions.

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Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Author contributions

Mehmet Duran Menekşe drafted the article. İsmail Temiz supervised the article, reviewed it and indicated the parts to be added.

Conflict of interest

The authors declare that they have no conflict of interest.

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