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(REVIEW ARTICLE)

A comprehensive review on Vehicle-to-Home integration based on home and industrial perspective

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Abstract

Exchanging power between vehicles and other electric appliances in bidirectional flow is known as Vehicle-to-Anything (V2X) technology in home and industrial regions. The V2X technology involves Vehicle-to-Home (V2H), Vehicle-to-Vehicle (V2V), and Vehicle-to-Grid (V2G) that enables the bi-directional flow of energy between Electric Vehicles (EVs) and homes or industrial buildings. However, there are challenges associated with V2H integration, including the development of standardized communication protocols, smart grid infrastructure, and ensuring cybersecurity. Regulatory frameworks and interconnection standards also need to be established to ensure the safe and seamless integration of V2H systems into existing energy networks. Conversely, excess energy from renewable sources like solar panels or wind turbines can be stored in the EV battery for later use or to sell back to the grid. The integration of V2H technology offers several advantages such as allowing for increased energy resilience, as EVs can provide backup power during grid outages or natural disasters. Besides, V2H systems can contribute to load balancing by supplying energy to homes or industrial facilities when the demand is high, thereby reducing strain on the electrical grid. This study is considered a reference to the researchers in the field.

Keywords: V2X; V2H; V2V; EV

1. Introduction

Vehicle-to-Home (V2H) integration based on home and industrial settings represents a promising approach to enhancing energy efficiency [1]. Besides, resilience, and sustainability by leveraging the capabilities of EV batteries for both transportation and stationary energy applications [2]. However, V2H integration usually refers to the ability to connect Electric Vehicles (EVs) to homes and industrial settings to optimize energy usage and provide various benefits [3]. This integration involves using EVs as energy storage devices, allowing them to store excess electricity from renewable sources and feed it back into the grid or use it to power homes during peak demand periods [4]. It aims to maximize the utilization of EV batteries for both transportation and stationary energy applications [5]. Various benefits can be achieved by integrating EVs with home and industrial energy systems [6]. In a V2H system, the EV battery acts as a decentralized energy storage device that can be used to power homes or industrial buildings during peak energy demand periods or in emergency situations [7].

The state-of-the-art is considering various studies and applications on the Vehicle-to-Home worldwide [8]–[10]. This can potentially lead to cost savings and improved grid stability. Additionally, V2H integration promotes the use of

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renewable energy sources by optimizing the energy flow between EVs and buildings. It enables the storage and utilization of surplus renewable energy generated during off-peak periods, which would otherwise go to waste. As a result, it enhances the overall sustainability and efficiency of the energy system. A researcher in [11], conducted a study for the on-grid system using an integration system based on RESs. Similar study considering different site in order to reduce the cost by using PHEV [12]. The smart operation of integrating V2X technologies has been compared and classified as grid support services are discussed in [13].

This article is sharing the contribution to the knowledge by proving a comprehensive review of the technology of V2H in home and industrial regions. The rest of the article is organized in various sections that stating with general introduction in Section 1. The methods and materials of V2H integration from the application, sustainable, and classification perspective in the home and industrial sectors are discussed in Section 2. The various topologies of V2X technology are listed in Section 3. Section 4 is discussing the main benefits of the utilization of V2H technology. The main roles of V2H technology figured out in Section 5. The discussion section of exploited technology is discussed in Section 6. Finally, the article is ending with a summary conclusion and a list of related references.

2. Material and Methods

Based on various forms of EVs as presented forms in Figure 1 (a-d) are indicates as the main structure or forms of EVs for the purpose of charging and discharging [14]. The aforementioned references comprehensively discussed the main and sub-classification of EV along with the standards. While the structure of Internal Combustion Engine Vehicle (ICEV) is presented in Figure 2 which the main causes of pollution that recommended to be switched into EV [15]. Moreover, integrating vehicles with home systems allows for smarter home automation [16]. For instance, a vehicle can communicate with the home through a connected platform, enabling it to automatically adjust the thermostat, turn on/off lights, or activate appliances based on the homeowner's preferences or the vehicle's schedule [17]. This integration enhances convenience and energy efficiency in managing household activities [9]. From an industrial perspective, vehicle-to-home integration can contribute to reducing the strain on the electric grid [18]. By utilizing idle EVs as temporary energy storage units, the integration can support grid stabilization during peak energy demand [13]. This concept is known as Vehicle-to-Grid (V2G) enables bi-directional energy flow between vehicles and the grid, benefiting both the grid's reliability and the EV ecosystem's sustainability [19].

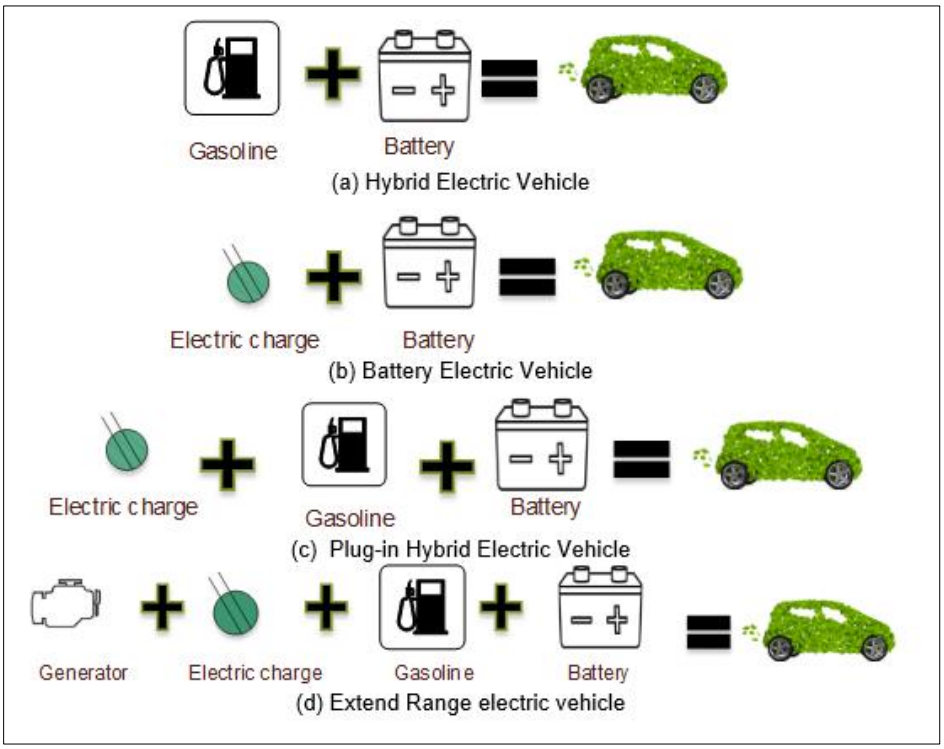

Figure 1 Classification of electric vehicles [20]–[23]

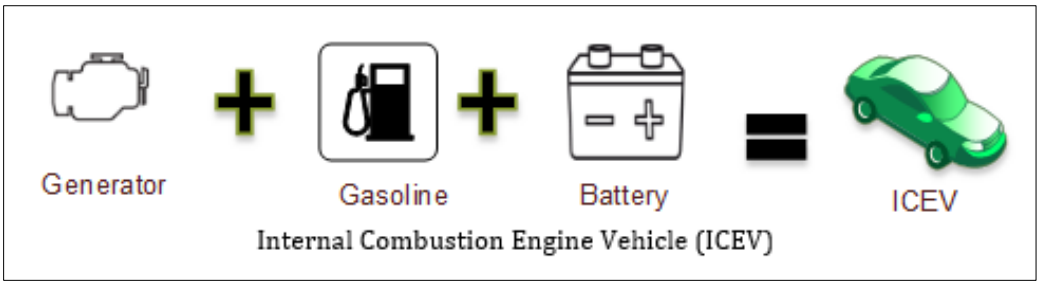

Figure 2 Internal Combustion Engine Vehicle

2.1. V2X topologies

The transportation sector is one of the most important sectors that use EV to meet the consumer's need of electricity and exchange the power between the EV and other electric appliances [24]. The V2X (Vehicle-to-Everything) is representing the aforementioned operation that refers to the exchange of information between vehicles and various entities such as other vehicles (V2V) [2], infrastructure (V2I) [25], pedestrians (V2P) [26], and others [27]. There are several topologies that can be used for V2X communication as presented in Table 1. The choice of V2X topology depends on various factors such as the intended application, geographic location, infrastructure availability, and network coverage [28]. Different regions or countries may adopt different V2X topologies based on their specific requirements and technological capabilities [28].

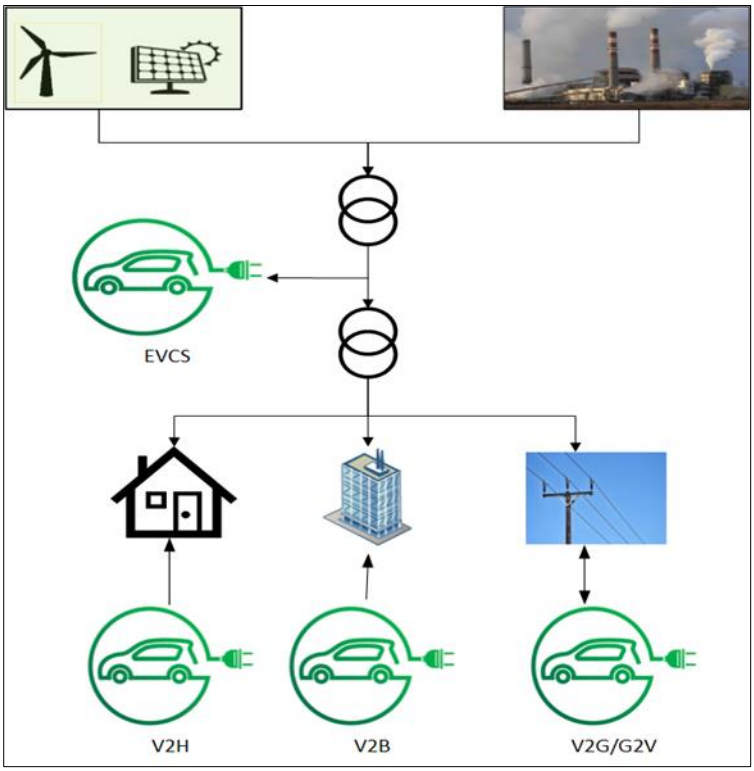

Figure 3 Electric Vehicle integration forms

Table 1 V2X topologies [25], [29]–[33]

Topologies	Features
Point-to-Point (P2P)	Vehicles directly communicate with each other or with specific infrastructure nodes. It allows for direct communication between two entities without the need for relays or intermediaries.
Cellular-based	This topology relies on cellular networks to enable V2X communication. Vehicles transmit and receive information through cellular infrastructure, similar to how mobile phones communicate. This allows for wide coverage but can be limited by network availability and bandwidth.
Infrastructure-based	vehicles communicate with a central infrastructure, which acts as a relay or coordination point. The infrastructure then distributes the information to other vehicles or entities as needed. It enables efficient data sharing but relies heavily on the presence of infrastructure nodes.
Hybrid	This topology combines elements of both infrastructure-based and cellular-based communication. It leverages infrastructure nodes when available but also utilizes cellular networks for wider coverage. This allows for more flexibility and reliability in V2X communication

2.2. Vehicle-to-Home benefits

Vehicle-to-home (V2H) integration refers to the process of using electric vehicle (EV) batteries as a power source for homes [27]. Some of the benefits that homeowners can derive from V2H integration in terms of energy management are tabulated in Table 2. It's important to note that while V2H integration offers these benefits, its availability and implementation may vary depending on the specific EV models, home energy management systems [34], and local regulations [33].

Table 2 Benefits of Vehicle-to-Home

Benefits	Features	Ref
Backup Power Supply	During power outages or emergencies, an EV battery can serve as a backup power supply for the home. Homeowners can draw power from their EV to keep essential appliances running, maintain heating or cooling systems, or charge communication devices. This can provide greater resilience and peace of mind during unforeseen events.	[35]
Energy Cost Savings	With V2H integration, homeowners can take advantage of Time-of-Use (TOU) rates to save on energy costs. They can charge their EVs during low-demand or off-peak periods when electricity rates are cheaper, and then use the stored energy during peak times when rates are higher. This flexibility can help reduce electricity expenses.	[36]
Demand Response Participation	V2H integration allows homeowners to participate in demand response programs. During periods of high demand on the grid, utility companies often request homeowners to curtail their electricity usage to balance the load. By utilizing the energy stored in their EV batteries, homeowners can contribute to grid stability and potentially earn incentives or credits from the utility company.	[17]
Renewable Energy Optimization	V2H integration enables homeowners to optimize their use of renewable energy. They can charge their EVs when renewable sources like solar or wind power are plentiful, ensuring that the stored energy in their EVs comes from sustainable sources. This promotes the utilization of clean energy and reduces reliance on fossil fuels.	[37]

Grid Support	In regions with high EV adoption, V2H integration can support the overall grid infrastructure. By allowing EVs to discharge power back to the grid when needed, homeowners contribute to grid resiliency and balancing electricity supply and demand. This bi-directional flow of electricity can help integrate renewable energy sources more efficiently and reduce strain on the grid.	[38]

2.3. V2h role for sustainability in home and industrial sectors

Vehicle-to-home (V2H) integration is a crucial aspect of achieving a sustainable and flexible energy grid for both homes and industries [39]. By enabling bidirectional energy flow between EVs and the power grid, V2H technology allows EV owners to utilize their vehicle batteries as portable energy storage systems. This process has several benefits as shown in Figure 4 along with further explanation tabulated in Table 3.

Figure 4 Vehicle-to-Home roles [8], [29], [40], [41]

V2H integration plays a key role in achieving a more sustainable and flexible energy grid by improving energy resilience, load balancing, grid stabilization, and the integration of renewable energy [40], [42]. It leverages the growing fleet of EVs as a distributed energy resource, benefiting both homes and industries in terms of energy reliability, efficiency, and environmental impact [43], [44].

Table 3 Explanation of Vehicle-to-Home roles in the home and industrial sectors

Roles	**Remarks**	**Ref**
Energy Resilience	During power outages or periods of high demand, V2H integration allows EV owners to use their vehicle batteries to supply electricity to their homes or businesses. This enhances energy resilience by providing a backup power source and reducing reliance on centralized power infrastructure.	[45]
Load Balancing	V2H integration allows for the efficient balancing of energy supply and demand. During peak demand periods, EV batteries can supply electricity to the grid, reducing stress on the power infrastructure. Conversely, during low-demand periods, excess renewable energy (such as solar or wind) can be stored in EV batteries, making better use of renewable energy resources	[46]
Renewable Energy Integration	V2H integration accelerates the integration of renewable energy sources into the grid. EV batteries can store excess energy generated from renewable sources, such as solar panels, and release it back to the grid when renewable generation is low. This helps to reduce curtailment of renewable energy and promotes a cleaner energy mix.	[47]
Grid Stabilization	V2H integration can help stabilize the grid by absorbing fluctuations in energy supply and demand. By utilizing EV batteries as distributed energy storage units, excess energy can be stored during times of surplus and supplied back to the grid when needed, reducing strain on the power infrastructure.	[48]

3. Discussion

Besides the aforementioned discussion and classification of the V2H integration, the V2H concept involves EVs as a power source for homes and industrial applications. It enables the bi-directional flow of electricity between a vehicle's battery and the electrical grid, allowing the vehicle to act as a mobile energy storage unit. When it comes to home integration, V2H technology can offer several benefits.

Firstly, it provides a backup power supply during emergencies or power outages. In such situations, an EV's battery can be used to power essential appliances or even an entire home for a limited period of time. This can improve resilience and energy security. Moreover, V2H integration promotes increased usage of renewable energy sources. Homeowners can charge their EVs during off-peak hours when renewable energy generation is high, and then use the stored energy during peak hours when demand is typically higher. This helps balance the grid and reduces stress on power generation infrastructure.

In an industrial setting, V2H integration can be even more impactful. Electric fleets used for delivery services or company transportation can not only transport goods or people but also function as a decentralized energy storage system. This can optimize energy usage within industrial complexes, reduce peak demand, and provide additional revenue streams through energy trading or grid stabilization services. However, the widespread adoption of V2H integration faces several challenges. One major obstacle is the development of appropriate charging infrastructure and protocols to enable efficient power flow between vehicles and buildings. Additionally, battery degradation and warranty concerns should be addressed to ensure the longevity and reliability of both EVs and home appliances. Despite these challenges, V2H integration holds great potential for a more sustainable and resilient energy system. As technologies advance, and the adoption of EVs and renewable energy sources increases, we can expect to see further development and deployment of vehicle-to-home integration solutions.

4. Conclusion

To conclude that the V2H technology from both home and industrial perspectives offers numerous benefits. It allows for efficient energy management, increased convenience, and environmental sustainability. From a home perspective, integrating vehicles with the home energy system enables optimized energy usage. This integration enables the vehicle to serve as a mobile energy storage unit, capable of charging during off-peak hours when electricity rates are lower, and then supplying power back to the home during peak demand periods. This not only reduces energy costs but also helps to stabilize the grid by balancing energy supply and demand. Furthermore, industries can utilize vehicle-to-home integration to foster renewable energy adoption. Excess renewable energy generated during low-demand periods can be stored in connected electric vehicles, increasing the overall utilization of renewable sources. This integration promotes a greener energy mix by reducing reliance on conventional power sources, resulting in reduced carbon emissions.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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