A thorough investigation of the systems supporting EV-vehicle charging stations and emerging trends

Neeraj Das | Amandeep Gill | Neha Karnik | Ranganathaswamy Madhalli Kenchappa

Abstract: The percentage of electric vehicles (EVs) in the automobile industry is increasing; yet, internal combustion engines (ICEs) remain a significant number of automobiles. The main barriers to EV use and environmentally friendly travel are their high price, short range, lack of battery charging infrastructure, and electricity pollution from EV chargers. These barriers need to be addressed. Energy storage systems (ESS) with a substantial amount of energy are expensive, which contribute to the expensive use of EVs. This article offers an analysis of EV technology, focusing on energy optimization, real-time execution and focused solution techniques.

Keywords: Electric Vehicle (EV), charging infrastructure, photovoltaic, smart charging

1. Introduction

The popularity of electric vehicles (EVs) has increased as a result of lower battery costs and stricter restrictions. Ten million EVs were affected at the end of 2020; by 2030, that number is predicted to reach 150 million. Approximately 20 nations declared that they would not be selling new conventional automobiles after 2040 to achieve the goal of having zero emissions from transportation (Cabrera-Tobar et al. 2022). The International Electrotechnical Commission, automobiles that use batteries, transformers, or sources of energy should be considered hybrid electric vehicles (HEVs) if at least one generates power (Chen et al. 2021). The next issue for urban mobility may be to concentrate on the transition from cars to bicycles. Reaching this goal would have two benefits: one for ecology and another for lowering the amount of urban land used for roads and traffic congestion. Simply switching from gas-powdered to electric cars might reduce emissions, but switching from automobiles electric or not to bicycles would result in less traffic, fewer health issues, and increasingly liveable communities (Nemoto et al. 2021). The first class includes offline energy management systems (EMSS) based on drive data, including those based on rule EMSS and global optimization-based EMSS. Forecasting, instantaneous optimization, and learning-based online emergency control systems make up the second group of EMSS. Numerous studies have been reviewed because the proposed system encompasses a variety of techniques for optimality, real-time execution and focused solution objectives (Zhang et al. 2020).

Currently, personal mobility choices such as micromobility and e-bikes minimize traffic while emitting no pollutants and facilitating people’s travel to their destinations. In addition, they may be utilized for extended urban commutes rather than standard bicycles, which reduces the amount of time and energy required for the user to use them. These e-bicycles have the potential to be drawn into a larger user base (Balacco et al. 2021). This study investigated the potential for reducing the total cost of EVs via energy oversight and efficient planning techniques. Mixed-integer linear programming (MILP) was developed to solve the powering schedule issue for an electric vehicle workforce equipped with a nearby photovoltaic system. For large-scale EVs, an effective recharging approach was proposed to fulfill the valley-filling role, and a centralized EMS that utilizes heuristics might mitigate the maximum energy induced by EVs, as shown in Table 1 (Wu et al. 2020)). The concept of employing electric vehicle batteries (EVBs) as energy storage devices (ESSs) allows them to draw energy from solar PV as required and supply it to the network when needed. By drawing electricity via home photovoltaic (HPV) structures, EVBs have the potential...
to reduce the dawn voltage spike issue, which can help to increase the amount of HPV saturation in the transmission network, which is currently constrained by elevated HPV saturation issues (Tran et al. 2019).

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<th>Table 1 Summary of energy management.</th>
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<td>References</td>
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<td>Electric vehicle and charging</td>
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Hemavathi and Shinisha (2022) reported that the use of EVs has increased over several years for a number of reasons, such as promoting the use of energy from natural sources, decreasing the supply of fossil fuels, and increasing carbon dioxide (CO2) emissions. To facilitate the switch from normal to electric automobiles, charging station expansion was crucial. Ma (2019) reviewed the development of electrical converter-based and energy interactions and other related topics that have been the primary focus of recent review articles on EVs that can be found in the public domain. This work presented a thorough assessment of important technologies, associated design approaches, computations, and current system settings for ECSs. Gupta et al. (2021) focused on standard fuel, which was rapidly depleted as a result of increased use by the automotive industry. The replacement of an engine that powers a vehicle with an EV has been observed in recent years. A thorough analysis of the existing EV situation, the facilities for charging EVs, the effects of EVs, and the best uses for EVs is mapped. Kurien et al. (2020) reported

The pollution hazard changes from the vehicle operating phase to the renewable energy generation phase with the spread of EVs in nations that predominantly rely on fossil fuels for power production. Alia and Deshmukh (2022) investigated EVs, which have become a blessing for the globe and are suffering from the severe environmental effects of burning fossil fuels since modern vehicles contribute significantly to pollution. Sivasankar et al. (2023) suggested an Internet of Things (IoT)-integrated solar power station for EVs, providing an effective solution to this issue. The technology employed at EV charging stations may be powered by solar energy, which lowers the production of greenhouse gases and promotes the use of green energy sources. Yashaswinibai et al. (2022) developed the project as a charger for electric vehicles that uses a solar panel and the IoT to display the maximum power that the module can generate.

The use of automobiles has increased together with population growth. The majority of modern cars run on fossil fuels such as gasoline, diesel, and LPG. Murthy and Nethravathi (2021) presented an empirical study aimed at analyzing fast-charging site assessment criteria concerning position and concrete manifestations. By including both present and future consumers of electric transportation technology, acceptability standards for the general public are found, along with a list of potential disadvantages. Li et al. (2020) investigated the broad state obtained for management in a low-torque and low-speed zone to reduce armature oscillations in multiphase switched-reluctance motors (SRMs). By investigating a larger range of options that were already available after careful consideration, the best options were discovered to reduce movement and noise from the surroundings while reducing characteristics such as resonance of torque, maximum power, and metallic copper loss. Battapothula et al. (2019) investigated the widespread installation of fast charging stations (FCSs) for EV promotion. Determining the best arrangement poses a serious obstacle to the responsibility of the administrator, particularly regarding the placement and dimensions of FCSs inside the electrical wiring system.

2. EV Technology

EV technology refers to a group of parts and mechanisms that are used to run and operate automobiles on electricity. The main problem with ICE is that they require fossil fuels, which raises questions about the reliability of the energy supply and the release of greenhouse gases. Regarding the demand for petroleum and coal, which increases CO2 emissions, electric EVs reduce the need for transportation powered by crude oil and the amount of greenhouse gases released into the atmosphere.
There are four main areas of vehicle technology, as shown in Figure 1. Left to right, electrification, which increases petroleum and diesel fuel combustion, is one of the main sources of global CO2 emissions from conventional cars. Therefore, hybrid vehicles emit fewer greenhouse gases than do vehicles with engines that burn fuel. Vehicles with zero emissions that use hydro energy sources or batteries make up the third and fourth categories described by Kumar et al. (2023):

2.1. *Fuel Cell of Electric Vehicle (FCEV)*

FCEV automobiles emit no hazardous pollutants since there are no exhaust fumes. The two main power train types are FCEVs and fuel cell hybrid electric vehicles (FCHEVs). An FCEV design schematic is shown in Figure 2. Prime prospects for FCEVs include forklifts, buses, trams, and other automobiles that require constant electricity at modest speeds. FCEVs use a variety of energy management techniques to create automobiles with outstanding performance that are efficient and fuel efficient, as explained by Muthukumar et al. (2021).

![Figure 2 Schematic diagram of an FCEV. Source: https://doi.org/10.3390/app13158919](https://doi.org/10.3390/app13158919)

2.2. *Hybrid Electric Vehicles (HEVs)*

ICE can power HEVs because it can also run on fossil fuels and renewable energy, making it a dual-power supply automobile. HEV appears to be the most economical option for a minimum of ten years. HEVs are in their infancy and appear to be the most economical option for at least the next ten years. HEVs are becoming much more economical and ecologically important due to their enhanced reliability and fuel efficiency. The electrical motor and ICE engine of the HEV are tuned to minimize the waste of renewable energy and pollution. The high initial cost of batteries is a drawback explained by Rajper and Albrecht (2020). Figure 3 shows the basic layout of the HEV.
2.3. Plug-in Hybrid Electric Vehicle (PHEV)

This type of car has an internal combustion engine (ICE) that can run either on diesel or gasoline, while electrical power is supplied by a battery. Greater powers of batteries are more frequently observed in PHEVs than in traditional HEVs. For shorter excursions, the automobile may run primarily on energy with a powerful battery pack. A PHEV may operate on fluid gasoline that is kept in its reservoir; thus, long trips are not required to deplete the battery. The basic configuration of a PHEV is shown in Figure 4 and explained by Arif et al. (2021).

2.4. Battery electric vehicles (BEVs)

The power supply pack is the electrical source for the electric car. In other words, in regard to lowering carbon dioxide halts and begins, which enable emissions and halt climate change, EVs outperform HEVs. Regenerative braking (RB) is a feature of EVs that transforms the motion energy generated when slowing downward into power that may be stored in the power pack. As a result of their constant ability to regain some of the energy that is consumed, EVs are better for city traffic. Figure 5 shows the basic configuration of a battery-powered vehicle explained by Faraz et al. (2021).

3. Methods of charging technology

Effective battery recharging requires the use of a proper battery, an appropriate recharging structure, and a suitable cost approach. This method intends to reduce the duration of charging without affecting the lifetime or effectiveness of the battery, and it also allows the battery’s defined safe operating conditions to follow. A succinct summary of the most commonly used charge methods is provided by Brenna et al. (2020).
3.1. Constant current (CC)

One common and easy-to-use method is the CC method. This guarantees that over the whole charging cycle, the power source keeps charging at a constant low C-rate. It is common practice to charge NiCd, NiMH, and Li-ion batteries using this technique. Determining the ideal charge voltage for a charging cable may be difficult because it must balance maximizing energy efficiency with reducing the duration of charging. The annoyance caused by longer charging times for EVs offsets the great capacity utilization caused by the low current of charge achieved by Sanguesa et al. (2021).

3.2. Constant Voltage (CV)

The CV charging technique is a simple choice that entails a constant electric current when recharging the battery. The primary benefit of using CV instead of CC is its capacity to lessen the negative consequences of overcharging, which can reduce battery life. While rapid CV expedites the process, it also shortens the battery's lifespan. The current being charged may exceed the appropriate limit when the power source has a low capacity. The conductive substance at the pole fractures as a result of the mesh frame collapsing under the high battery current (Tu et al., 2019).

3.3. Constant current–constant voltage (CC–CV)

The CV technique is a simple choice that entails a constant electric current when recharging the battery. In the first stage of the recharging procedure, CC recharging occurs. When the current rises beyond the maximum safe threshold, the process changes to CV charging. Energy is lost when the anode current decreases with rapid charging. Li electroplating is associated with a reduction in the longevity of batteries and efficient charging. Charging too little reduces the battery's capacity to store energy, while excessive charging permanently damages the cell. The increased temperature results from more heat loss during a stable period when the electrical charge is high (Sun et al., 2019).

3.4. Multistage Constant Current

The CV technique is a simple choice that entails a constant electric current when recharging the battery. Several phases of stable flow are involved in the process of charging, during which the current progressively drops until the voltage on the terminals reaches a preset limit. The MCC works with a variety of cell types, such as Li-ion, NiMH, and lead-acid batteries. It is evident by comparing the beginning currents of the two charging techniques that the MCC procedure takes longer (Das et al., 2020).

3.5. Pulse Charging (PC)

Rechargeable battery PCs did not gain widespread traction in the industry until the 1970s. **Spike Stage:** A high-current pulse is applied to the batteries. The pulse energy is considerably greater than the typical voltage used for power batteries. **Idle State:** The cell power is broken, and the power supply is turned off following each pulse. Sulfate granules disintegrate, and metabolic processes occur during this period. **Recurrent cycle:** According to the lifespan of the battery and the level of revitalization, several runs of pulse and rest can be necessary (Collin et al., 2019).

3.6. Trickle Charging
A battery is charged by applying a very low, constant voltage for a considerable amount of time, referred to as TC, followed by pausing and letting the battery run to its maximum capacity. Steady voltages are inexpensive and very simple to construct. Because they need human interaction from the person using them at the beginning and end of the charging procedure, these people are not regarded as adapters (Khalid et al., 2021).

4. Architecture of EV charging stations

Solar energy production is the main source for charging stations. By utilizing dual-directional power converters and the related DC/DC boost converter, energy may be drawn from the electrical grid. EVs can run in vehicle-to-grid (V2G) mode, where they release energy, if there is more accessible energy, to the network during periods of high load. Figure 6 depicts the architecture of the charging station. A typical DC bus, which is powered by either solar energy or an electrical arrangement based on accessibility and operational circumstances, provides the energy needed for EV charging. Essential elements of the complete system include reversible grid-interfaced potential conversion, a DC-DC boost converter with maximum power point tracking (MPPT) capability that provides solar energy to the oscillating DC bus, and a two-way DC-DC converter that charges EV batteries. A buck-boost converter is used for both EV charging and discharging. The subsequent subsections provide explanations for each of these elements. A controller is utilized to determine the path of electricity among the three system components based on variations in the DC bus voltage (Raendran et al., 2021).

5. Levels and Standards of the charging stations

The Society of Automotive Engineers (SAE) defines charging infrastructure and bases its development on several standards related to chargers and charging cables. Two standards that define electrical work, tangible and interpersonal protocols, are the American standard SAEJ1772 and the International Electro-Technical Commission’s IEC 61851. SAE J1772 should be followed for EV conversion and voltage stability standards Savio Abraham et al. (2021).
When utilizing off-board chargers for utility or microgrid-based charging, the SAWJ2293 criteria are met. SAEJ 2836 specifies the interaction necessities for system integration. Figure 7 displays the various level-based charger connections. EV chargers are categorized into three varieties based on the AC/DC voltage level; stage 1, stage 2, and stage 3 are shown in Table 2. The electric vehicle charging station equipment (EVSE), recharging duration, price, and electricity grid use are determined by the power for charging capabilities of the terminal, as discussed by Khalid et al. (2021).

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<thead>
<tr>
<th>Supply Type</th>
<th>AC</th>
<th>DC</th>
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<tbody>
<tr>
<td>Voltage Range (V)</td>
<td>120–240</td>
<td>200–600</td>
</tr>
<tr>
<td>Current Range (A)</td>
<td>13–16</td>
<td>80</td>
</tr>
<tr>
<td>Power Output (kW)</td>
<td>1.9–3</td>
<td>20</td>
</tr>
<tr>
<td>PEV Charging Time</td>
<td>7 h</td>
<td>3 h</td>
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Table 2 Levels of the charging stations.

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<thead>
<tr>
<th>Types of Chargers</th>
<th>AC</th>
<th>DC</th>
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<tbody>
<tr>
<td>EV Connector</td>
<td>J1772™/AC</td>
<td>CHAdeMO/DC</td>
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Source: https://doi.org/10.3390/electronics10161895

6. Challenges

There are several obstacles to the widespread acceptance and incorporation of EVs, both generally and technologically. The lack of a suitable system for refueling EVs is one of the primary barriers to their widespread adoption. Additional charging points must be placed in more convenient locations that are open to the public and that work with different makes and models of cars. Additionally, charging periods need to be decreased for easier use, and battery capacity deteriorates over time, affecting a vehicle's endurance and general effectiveness. Lowering expenses for maintaining and guaranteeing the lifespan of EVs depend on the development of robust and long-lasting batteries.

7. Future trends of EVs

Refueling an EV should be simple and rapid, as filling the vehicle with gas requires fast charging stations. Academic research on the reduction of sound, temperature, and electromagnetic interference in these kinds of charging facilities is desperately needed. Since EV batteries have a limited lifespan, meticulous preparation and research are necessary. Since cells have a limited lifespan, it is critical to focus on other problems, such as developing safer materials and sensors, developing cells and packs, enhancing the performance of solid-state batteries, and developing battery control mechanisms. It is necessary to create a reliable output conversion that incorporates a high-power solid-state converter, conditioning method, charging connection, and protection mechanism.

8. Final considerations

A variety of EV applications, charging frameworks, renewable source-based EVs, and grid-implemented EV technologies have emerged due to the expanding usage of various EVs. Due to advancements in technology, infrastructure for charging, and grid connections, the popularity of electric cars is predicted to increase over the next ten years. To maximize these advantages, EVs with centralized power sources require other technological advancements, such as intelligent charging facilities, dependable network connections, and synchronized charging technologies. Improved energy oversight systems and complete automation of the electrical network are possible with future grid technologies built on the energy network. This article presents a study of connecting grid facilities and EV charging. For EVs and the facilities supporting them to become widely used, global standards and conventions must be established. Furthermore, a thorough analysis of the benefits and drawbacks of many components of the current grid connectivity and charging infrastructure, such as supremacy, interactions, management, and synchronization, has been performed. This study offers ideas for research as well as perspectives on resolving present
issues. The debate on EV potential makes it clear that this subject needs to be reviewed. Researchers and engineers will have a thorough understanding of the present status of integrated grids and EV battery storage research after reading this paper.

Ethical Considerations

Not Applicable.

Conflict of Interest

The authors declare no conflict of interest.

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