



# ELECTRIC CARS AND THEIR INTEGRATION INTO MODERN POWER NETWORKS

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**Abstract:** Electric vehicles are becoming more widespread in modern times; however, with this green technology comes a new challenge of supporting charging requirements and integrating said requirements into our current power networks. In this paper, we will explore the modern technologies and concepts that are being considered for the enhancement of various power networks around the world, as well as the challenges of integrating a growing number of electric vehicles into the networks. We will also review the immense rise of electric vehicle sales in modern times to showcase why a seamless integration into the power networks is required and how big the industry has become. We will also highlight various guidelines being put in place by the three main markets to ease this complex process.

**Keywords:** Electric cars; Power networks; Challenges; Integration

## 1 INTRODUCTION

Global energy demand is increasing each year. Still, the primary source of energy supply comes from dirty fossil fuels. Burning and utilising these fossil fuels greatly impacts our environment and global climate change. This constant pollution will lead to unsustainable conditions; therefore, a shift to more renewable energy sources is needed.

Nowadays, the automotive industry is turning to greener solutions for most vehicles. One of those solutions is electricity. More regions, such as the European Union and the United States, are creating regulations limiting greenhouse gas emissions from automobile manufacturers [1][2], so the electric vehicle industry is developing technologies at an ever-increasing pace.

Earlier versions of various electric vehicles were not perfect. In many ways, a conventional combustion engine would still outperform them daily. However, with larger batteries being developed, leading to more significant ranges, and newer electric motors delivering more power, the vehicle industry began to change.

These vehicles have fewer moving parts, reducing their maintenance cost and rate of failure compared to conventional combustion engines. When we also consider the many electric vehicle incentives governments worldwide offer [3], an increasing number of drivers nowadays choose electricity over conventional combustion engines.

With this massive shift in the industry, many cities face the challenge of integrating a new network of stations capable of drawing enough power to charge various electric vehicles. Reducing emissions and creating a greener future is only possible if the infrastructure required for battery charging is created.

The number of electric vehicles is increasing year after year [4], and there is a real possibility of overloading numerous city power networks. Effective grid management will prove vital for integrating these vehicles.

### 1.1 The rise of electric vehicles

Electric vehicles (EVs) are steadily increasing, especially in Asian countries like China. Current trends suggest that the rise in numbers will not stop soon. Only about 17000 electric vehicles were being driven in 2010. However, that number rose to over 40 million cars in 2023, shown in Figure 1.

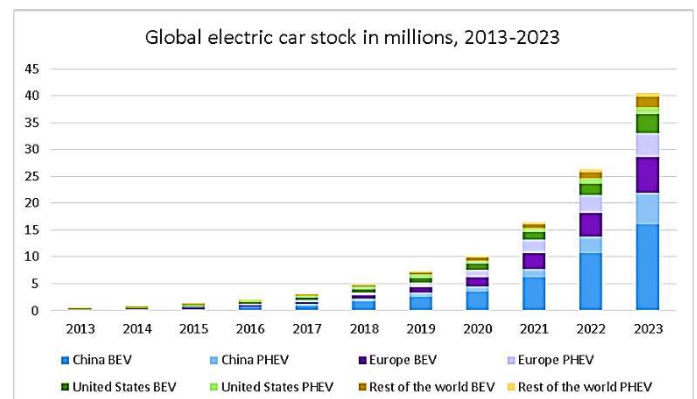


Figure 1: Number of electric vehicles around the world from 2010 to 2023 showcased in millions [4].

The chart showcases the number of BEVs (battery electric vehicles) and PHEVs (plug-in hybrid vehicles) on the road in the last 13 years and includes passenger cars only. It shows the meteoric rise of electric vehicles, especially between 2015 and 2019, where the number of battery vehicles went from 720000 in 2015 to 4.8 million in 2019. As we can see from the chart, China is the biggest battery and hybrid electric vehicle market, with the country having around 16 million battery cars and almost 6 million hybrid vehicles in 2023. Europe comes second with 6.7 million battery cars and 4.5 million hybrid cars in 2023. The United States had the lowest number of electric vehicles in the three big markets, with 3.5 million battery and 1.3 million hybrid cars registered in 2023. In the rest of the world, around 2 million battery and 700000 hybrid cars will be driven in 2023 – totalling around 28 million battery vehicles and 12 million hybrid cars on the road worldwide in 2023.

The chart clearly shows that the current trends in the electric vehicle industry are exceptional.

The three main markets, especially China, exhibit stable growth with no signs of stopping anytime soon. Those markets are the main driving force in yearly sales; however, they are not the only ones having a meteoric rise in the last few years. Many Southeast Asia and Latin American countries show significant yearly growth in electric vehicle sales. Vietnam had only 100 electric vehicles on the roads in 2021; however, by 2022, that number skyrocketed to 7000 vehicles and, in 2023, to 30000 cars.

Countries like Malaysia and Thailand are also tripling and quadrupling their year-on-year sales. The constant growth can also be seen in Brazil, Mexico, Colombia, and many European countries [5]. The increasing number of electric vehicles can also be seen in 2024, with the first quarter of 2024 showcasing more sales than the first quarter of 2023. This growth can be seen in the following chart, which shows the quarterly sales of electric vehicles between 2021 and 2024.

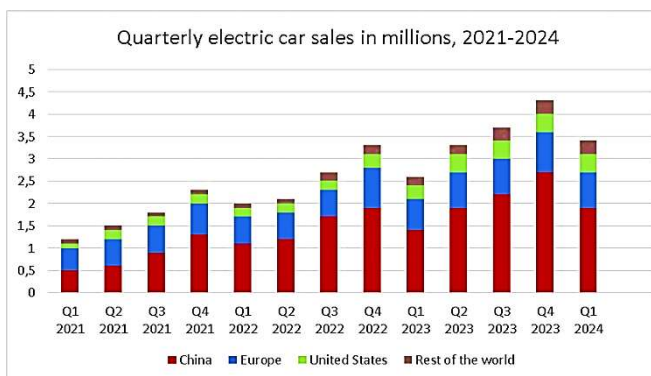


Figure 2 Number of electric cars sold quarterly from 2021 to 2024 showcased in millions [6]

As we can see from Figure 2, quarterly sales kept increasing steadily in the last 3 years. Sales increased from just above 1 million electric cars sold in the first quarter of 2021 to over 4 million in the previous quarter of 2023. China is the market that has the most sales in every quarter after the first two quarters of 2021, in which Europe and China were tied on the numbers of electric vehicles sold. Europe is currently the second largest market, with the region selling 800000 cars in the first quarter of 2024. The United States comes third in quarterly sales, with the region selling 400000 vehicles in the first quarter of 2024. The rest of the world covers countries like Malaysia, Thailand, Mexico and Colombia. Those countries are exhibiting an increase in quarterly sales as well. However, the number is still smaller, with the sales in the first quarter of 2024 reaching 300000 vehicles.

The number of electric vehicles on the road and quarterly sales in the last few years shows that electric car sales are increasing year after year. Because of this, various power networks must prepare for a realistic scenario in which electric vehicles overtake classic fossil-fueled cars.

Networks will need to find a way to seamlessly support hundreds of thousands of new vehicles registered worldwide each year. In the next section of the paper, we will examine the evolution of power grid technologies and various guidelines being developed to prepare for the integration process in multiple world regions.

## 2 RESEARCH OF POWER NETWORKS AND THE INTEGRATION OF ELECTRIC VEHICLES

As seen in the previous section, the number of electric vehicles keeps increasing worldwide. This growing fleet of cars will impact the current power networks with their growing demand for electric power. As more people own these vehicles, they need to charge them naturally. Networks must handle this additional load without overloading or creating potential power outages. Because of this, careful planning and preparation are required so the inevitable rise of EVs does not impede electricity delivery from producers to consumers. Many areas, like China and various European countries, face this reality. We will look at the positive and negative impacts of EVs, multiple challenges of integration and how different regions are reacting to the growing number of electric vehicles.

Introducing electric vehicles to the grid will be a big test for power suppliers. Vehicles will impact the grid positively and negatively [7]; however, the integration can be successful with careful planning. At the end of the process, the positive impacts can be better power management, improved power quality, frequency regulation and integration support for renewable energy. The negative consequences are the inevitable increase in load demand, the possibility of overloading and overall reduction of stability, phase and voltage unbalance, and an increase in power loss and current harmonics. Although these problems might occur with the widespread integration of electric vehicles, they can be solved using different power strategies. One of those strategies is making use of synchronous loading. This strategy would make a charging schedule for electric vehicles. It would lower the chance of instability and overloading at the cost of restrictive charging at certain times of the day. For instance, the cars would be charged between 10 pm and 7 am, which is the time when consumers use the power grid less. For this strategy to be effective, incentives need to be created that motivate users to charge their vehicles during off-peak hours.

Furthermore, coordinating scheduled off-peak charging on the household level is much more complicated. The impact of expected charging hours on household power bills is relatively small, while grid operators and charging stations have much stronger incentives to charge during off-peak hours. This scenario poses significant challenges, as an entire street or neighbourhood may experience many electric vehicles charging simultaneously. Uncoordinated charging could cause many power grids to suffer overloading issues or blackouts.

Wireless power transfer is a ground-breaking solution for charging vehicles without physical contact. With this technology, vehicles could be charged by inductive coupling, using a magnetic field to transfer power between coils of wire [8]. Wireless power transfer is creating quite a stir in the charging of devices from home appliances to vehicles to public transport.

Several advanced technologies are shaping the future of power grids. One of those is implementing high-voltage direct current (HVDC) power lines that could replace the much more common alternating current (AC) transmission system. This technology offers efficient electricity transmission over long distances with lower losses than traditional AC systems. It also stabilises the grid and makes it more economical due to the ability to exchange power between previously incompatible networks.

High-voltage direct current powerlines are usually used for long-distance transmission, costing less per kilometre than traditional AC lines. They are partly used because HVDC cables are usually smaller than AC cables, as they have less heat loss, so less material is needed.

The most significant benefit of HVDC systems is the ability to interconnect asynchronous grids and integrate more renewable

energy sources [9]. Another benefit is the ability for these cables to be installed underwater, connecting locations separated by seas. With this transmission system already being used on many overseas lines worldwide and many new lines being constructed [10], the system's power could alleviate the stress of integrating many electric vehicles into the power networks.

With the rise of innovative technologies, power grids that use sensors and special software to cover the demand for electricity in real time can be created. Modernising and digitalising current power networks can vastly improve their capabilities while minimising costs and maintaining stability and reliability. Smart grids can more efficiently control power usage by reducing the functions of non-critical devices during peak power usage and returning them during non-peak hours. It will optimise the time for EV charging during off-peak hours, balance loads on a grid, and mitigate overload due to risk during charging. EVs can act as distributed energy resources supplying back power to the grid, enhancing resiliency and rewarding owners economically.

An electric vehicle (EV) charging system will be optimised for off-peak hours, balancing power loads and reducing the risk of grid overload. Electric cars can also act as distributed electric energy resources supplying power back to the grid, thus enhancing resiliency and providing an economic incentive to owners.

With smart meters, electricity suppliers could get valuable data about electricity consumption and voltage levels in real time. Data might be used to monitor the stability of the network and warn the supplier about any issues that could lead to system disruption and blackouts. Consumers would also benefit from using smart meters. The rise of electric vehicles will lead to more accurate energy billing and better demand management. Users can also use these precise readings to monitor their power usage more carefully and lower the energy consumed, leading to lower power bills and less strain on the network. Smart power grids also tend to use more renewable energy sources, decreasing the number of fossil-fueled power plants and replacing them with clean solar, wind and hydro energy.

Improving battery storage capabilities is necessary for backup at peak load conditions and stabilising the grid. Microgrids are self-sufficient energy systems that can operate independently and will further heighten reliability, especially for remote regions. These microgrids allow local energy management, thus helping reduce outage hazards while increasing efficiency. These strategies will strengthen our energy infrastructure and future-proof it for electric vehicles.

As one of the biggest markets for electric vehicles, China needs to integrate millions of cars being bought every year. In January 2024, China's National Development and Reform Commission (NDRC), with the help of the National Energy Administration (NEA), the Ministry of Industry and Information Technology (MIIT) and the State Administration for Market Regulation (SAMR), released guidelines meant to smooth out the integration of electric vehicles into their current power grids [11]. These guidelines aim to enhance core systems used in the EV industry.

One of the guidelines calls for advancements in core vehicle-to-grid (V2G) technologies. Battery technology is still imperfect, with current batteries withstanding a limited number of bidirectional charging and discharging cycles before their battery capacity degrades. The policy calls for battery technology enhancements to achieve 3000 charge cycles. A robust V2G system architecture and an efficient bidirectional charging system must be feasible.

The policy also calls for better standardisation of these systems, focusing on interfaces, communication protocols, power regulation, and charging technology.

Another essential guideline proposed in the policy calls for optimising electric vehicle charging fees. Plans are underway to unveil differentiated pricing models for residential and household charging to effectively manage the ever-increasing demand posed by electric vehicles on the grid and to advance its sustainability goals. These charging tariffs would encourage EV owners to charge their cars during off-peak hours, for instance, late at night, when electricity demand is at its lowest.

Multiple efficient electric vehicle integration models are also proposed in different scenarios and locations, such as residential areas or industrial parks. The government will prioritise bidirectional charging technology for multiple public sector vehicles, primarily rental and public vehicles. Enhancements of charging facilities are also one of the policy's key guidelines. It calls for creating intelligent charging facilities and upgrading existing charging facilities. A management system for residential area charging will also be established, and the policy will define responsibilities and rights for users and power grid companies.

Finally, the policy calls for reinforcing support and assurance for power grid companies. Grid operators will be supported in integrating vehicle-to-grid management with brand-new load systems. Existing systems such as metering and grid connections will also be improved, while grid clearing will be optimised.

Some of these guidelines can already be seen in 2024, with the Chinese economic planning agency setting up multiple nationwide vehicle-to-grid system trials in which many electric vehicles feed power into the grid during peak hours [12]. These trials can show if cars can be used to smooth out rough peaks in electricity supply and demand. The prosecution also set up different pricing for charging in residential properties and daily charging, as called for in the policy set out a few months ago.

Europe also faces the formidable challenge of integrating many electric vehicles. According to data from the European Environment Agency (EEA), the projected share of electric cars by 2050 will reach 80%[6]. Additional energy will be required for this projected scenario.

Although power grids are not expected to have significant challenges in supplying the electricity required for charging these vehicles until 2030, by 2050, the percentage of electricity used by various European countries to charge the predicted stock of electric cars will vary from 3% to 25%. This demand in power supply needs to be fulfilled. With the rising integration of green energy sources such as solar, hydro or wind energy, many countries will look at these solutions to meet the demand for the proposed vehicles. These solutions will vary depending on the country's climate, with many sunny countries such as Greece or Spain harvesting solar power to smooth out the peak hours of charging during the day. Other countries with multiple extensive wind farm integrations, such as Germany or the United Kingdom, might choose this type of energy.

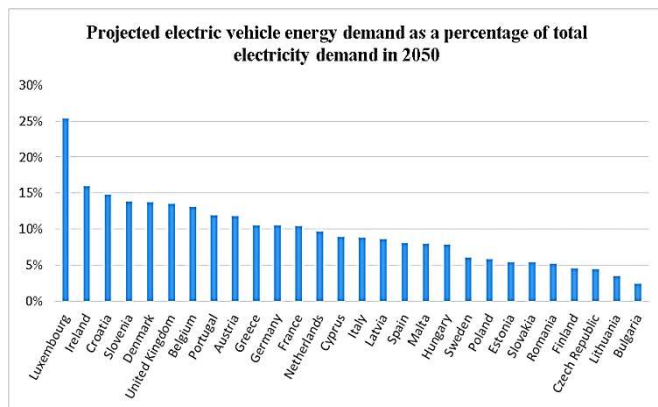


Figure 3 percentage of total electricity demand in 2050 (assuming the predicted 80% share of electric vehicles in 2050) [13]

As seen from the chart, by 2050, in 12 European countries, charging electric vehicles will take away more than 10% of distributed power. This chart assumes the 2050 electric vehicle share prediction is correct, with the prediction being calculated from current trends of electric vehicle stock around the world. Further implementation of green energy solutions is also required, as even though the CO<sub>2</sub> emissions will lower because of the rise of electric vehicles, the current power network infrastructures worldwide still use a lot of fossil fuels for power generation. Even though vehicle emissions still outweigh the emissions created in the power industry, further creation of solar, wind and hydro energy farms would generate more energy while lowering pollution.

As the third largest market, the United States is also planning better integration in the coming years to facilitate more than five million electric vehicles driven on the road in the region, growing steadily.

Because of these numbers, the U.S. Department of Energy (DOE) published a document covering the future of vehicle grid integration as part of its EV Grid assists initiative. This initiative aims to assist stakeholders in making progress towards their electrification goals by using data, tools, and real-world cases.

The department's document demonstrates technologies that can solve everyday challenges and create stronger stakeholder coordination. Good integration can lead to cheaper electricity rates and cost-effective charging with clean energy resources, and the document highlights the main points to achieve this through five objectives [14].

The first objective covers required investments in infrastructure to facilitate electric vehicle charging and enhance grid stability.

The second objective focuses on lowering the pollution of the power grids while also increasing the utilisation of charging assets to limit peak load impacts that are created.

The third objective suggests better standardisation of electric vehicle chargers and a more explicit statement of power grid requirements to allow easier innovation of technologies and integration into a more stable, compatible environment.

With the fourth objective, the document calls for more customer-centred options, such as multiple products or services to fulfil their charging needs and offering compensation for any services given to the grid.

The final objective highlights the need for well-built cyber and physical systems that handle the connections between the vehicle, charger, and power grid without severe manufactured or natural disruptions, making the system more robust.

With automakers Mercedes-Benz, Stellantis, Honda, Hyundai, Kia, BMW, and General Motors also uniting to create modern high-powered charging networks across the continent, the future of integration seems bright. Users will be more incentivised to choose electric over fossil-fueled cars [15].

### 3 CONCLUSION

In this paper, we analysed the rise of electric vehicles, modern technologies being applied to the current power grids, and various guidelines to ease the future integration of cars. The vehicle industry is changing drastically. Electric vehicles transformed from a concept for the future to a reality in just a couple of decades. Although the rising number of electric vehicles creates a challenging test for the stability of current power networks worldwide, many countries are investing in modernising various power grid systems. This process benefits users and distributors as it will lead to more significant implementation of green energy sources into the grid. With the evolution of innovative technologies happening rapidly, ordinary power networks could be transformed into smart ones, decreasing the energy price for consumers while making the networks more stable using multiple sensors and innovative technologies. Countries like China have proven that they can transform their vehicle fleet from fossil-based to electric without overloading their power networks. With the government gaining millions of electric vehicles per year, they are investing in more robust and modern power systems to prepare for the inevitable future of electric vehicles.

Although China and many richer European countries are upgrading their power grids, many countries still do not have sufficient systems to integrate these vehicles without issues. Without proper investment from these countries, travelling the continent can become problematic for electric vehicle users. Some countries have excellent infrastructure and plenty of charging stations, while their neighbours will have barely enough to support one city. Because of this, in many countries, the future of electric vehicles will be determined by their infrastructure and the prices of electricity that distributors set. One thing is certain: electric cars are rising in numbers in many countries, and if the trend doesn't waver, countries will have to accommodate the charging requirements that come with them.

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