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EV CHARGING INFRASTRUCTURE AND V2G CONCEPT

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ABSTRACT

The increasing concern over climate change requires the widespread deployment of electric vehicles (EVs). The adoption of electric vehicles involves the establishment of a charging infrastructure. This thesis presents a review of the current EV situation in world, including infrastructure, standards, and the effects of EVCS to the grid. Examining the situation in Azerbaijan, the research investigates the country's ambitious efforts to create a electric vehicle production facility. It assesses the current status of EVs in Azerbaijan, taking into account significant Government initiatives and private companies initiatives like Azpetrol, Elcar.az, Charge.az and the rise of local manufacturers and resellers of fast chargers. This study also conducted an in-depth analysis of pricing of charging of EVs in Azerbaijan. Using a Tesla Model S battery with a capacity of 75 kWh as a reference, I computed the cost of charging and charging time of electric vehicles with this type of battery using several charging options, ranging from a 120 kW level 3 fast charger to a 3.5 kW level 1 charger. The next part analyzes the complex incorporation of EV into the power grid, delving into sophisticated concepts such as EV aggregators, Virtual Power Plants (VPPs), and the architectural details of EVs outfitted with vehicle-to-grid (V2G) systems. This research reveals the potential for significant changes, offering valuable understanding of the changing energy environment and the interactive connection between EVs and the electrical grid. This study also analyzed the prospective effects of EVs on the power grid, and evaluated both the positive and negative consequences. The research offers a comprehensive approach to predict the import of EVs and Hybrid Electric Vehicles (HEVs) into Azerbaijan. This is done by analyzing historical data and use linear regression models to estimate trends from 2019 to 2030. The exploration concludes with analysis of MATLAB Simulink simulations, providing realistic results from situations, such as Grid-to-vehicle (G2V), Vehicle-to-grid (V2G), and a combined G2V-V2G system. This simulation examines the relationship between voltage and current in a single-phase electric vehicle charging system. It analyzes the state of charge (SOC), voltage, and current of the EV battery. These simulations increase understanding of the practical effects of integrating EVs with the power system. To sum up this thesis offers a complete and detailed explanation of the dynamic interaction between Electric Vehicles and the power grid. It includes a thorough examination of worldwide trends and localized initiatives primarily in Azerbaijan.

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LIST OF ABBREVIATIONS

AC	Alternative current
AEV	All-electric vehicles
BEV	Battery electric vehicle
BSS	Battery swapping station
CS	Charging Station
DC	Direct Current
ESS	Energy Storage System
EV	Electric vehicle
EVGI	Electric vehicle grid integration
FC	Fuel cell
FCEV	Fuel Cell Electric Vehicle
FCHEV	Fuel Cell Hybrid Electric Vehicle
G2V	Grid to vehicle
GHG	Green House Gases
HEV	Hybrid electric vehicle
ICE	Internal Combustion Engine
ICEV	Internal combustion engine vehicle
IEA	International Energy Agency
IGBT	Insulated-Gate Bipolar Transistor
MPG	Miles per gallon
PHEV	Plug-in hybrid electric vehicle
PWM	Pulse Width Modulation
RES	Renewable energy source
SOC	State of the charge
TSO	Transmission system operators
V2B	Vehicle to building
V2G	Vehicle to grid
V2H	Vehicle to home
V2L	Vehicle to load
V2V	Vehicle to vehicle
WPT	Wireless power transfer

LIST OF CONTENT

CHAPTER ONE

Introduction

1.1 Introduction

Due to the environmental and socioeconomic advantages of EVs, the electrification of the transportation industry is quickly becoming a worldwide trend. This effective mode of transportation lowers the strain of high fuel prices and the uncertainty issues related to fossil fuel resources. It also minimizes greenhouse gas (GHG) emissions. The best alternative to fossil fuel-based engines is an electric car. Electric vehicles are described as being more environmentally friendly, emitting fewer hazardous gases, requiring minimal maintenance, producing less noise, and performing better [1]. The likelihood of them raising their penetration levels in the foreseeable future is therefore very high. Therefore, power system engineers need to be aware of any potential difficulties that EV may present for their networks. While waiting for renewable energy sources (RES) to stabilize, the flexibility of EV charging requirements can be taken advantage to achieve that goal. Even if the EV grid integration is good for the environment and can enable more RES to be integrated into power systems, the impact of EV grid integration needs to be examined in order to find the power system problems for the EV grid integration and test various charging scenarios. Since their release, electric vehicles have developed rapidly. Plug-in hybrid electric vehicles (PHEV), battery electric vehicles (BEH), fuel cell electric vehicles (FCEV) and hybrid electric vehicles (HEV) are some of the various forms of electric vehicles [2]. As the number of EVs rises, so do the amount of charging stations and electricity demand also rises. Therefore, the distribution system is seriously impacted by these charging stations, which may cause voltage instability, voltage collapse, harmonic distortion, a considerable drop in actual power and reactive power, etc. [3].

1.2 Motivation

EVs have become essential for sustainable transportation due to the critical need for innovative solutions for mitigating climate change. This thesis investigates the complex interaction between cars and the electrical infrastructure in Azerbaijan. Gaining a comprehensive understanding of the intricate factors that influence the adoption of EVs is crucial, given the worldwide need to fight with climate change, which in turn leads to the extensive implementation of EVs.

1.3 Thesis structure

The thesis progresses through a methodical examination, beginning with Chapter One that shows the necessity of tackling climate change by widely embracing EVs. The Literature Review thoroughly examines the worldwide EV situation, with a specific emphasis on infrastructure, standards. Chapter three analyzes the present condition of electric vehicles in Azerbaijan, investigating the efforts made by both the government and commercial sector. This includes a focus on important entities such as Azpetrol, Elcar.az, and Charge.az, as well as the rise of local EV manufacturers and fast charger resellers. This chapter also thoroughly examines the pricing patterns of cars charging in Azerbaijan, using a Tesla Model S battery as a benchmark. Chapter four examines the complex integration of electric cars into the power grid, including topics such as EV aggregators, Virtual Power Plants, and the technology components of Vehicle-to-Grid systems. In Chapter five, historical data and linear regression models are utilized to forecast the import of EV/HEV into Azerbaijan between 2019 and 2030, also the exploration reaches its peak with MATLAB Simulink simulations. These simulations provide realistic insights into scenarios like Grid-to-Vehicle, Vehicle-to-Grid, and a combined G2V-V2G system. They analyze the relationship between voltage, current, and state of charge in a single-phase EV charging system. In last chapter, the extensive exploration culminates with a detailed overview of the research findings, and future suggestions.

CHAPTER TWO

Literature overview

2.1 General Information about Electrical Vehicle (EV)

In the EV market, a wide range of vehicles are being introduced, including sedans, sport utility vehicles (SUVs), pickup trucks, motorcycles, even buses and public transportation. There are EVs that are battery operated only, while there are also plug-in hybrids that are powered by both an electric motor and an internal combustion engine. A short overview of the various types of EVs and the different types of charging infrastructure is provided in this section.

In general, there are 2 groups: **All-Electric Vehicles (AEVs)** and **Hybrid Electrical Vehicles (HEVs).** The only motors on an AEV are electric ones that run on electricity. AEVs are further divided into Fuel Cell EVs (FCEVs) and Battery EVs (BEVs). You don't need an external charging system to use an FCEV. But a BEV's storage unit can only be charged externally using grid electricity. One kind of HEV that has the ability to refuel its energy source from the electric-grid is the plug-in hybrid electric vehicle (PHEV) [4]. Figure 2.1 classifies several EV kinds, whereas Figure 2.2 illustrates general structure of BEV and PHEV.

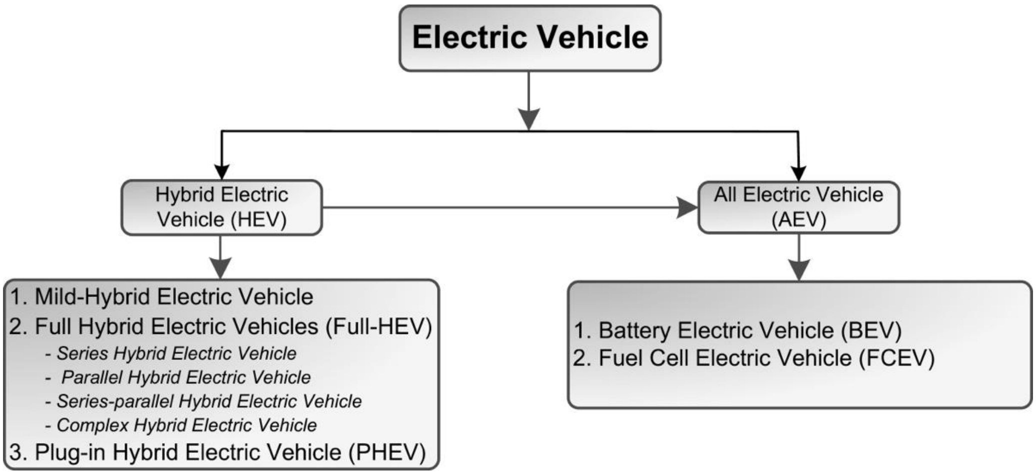


Fig 2.1 Electrical Vehicle classification [5].

As it can clearly observed from Fig 2 BEV has only electric motor as a main source of power, whereas PHEV also has internal combustion engine (ICE) to power up EV.

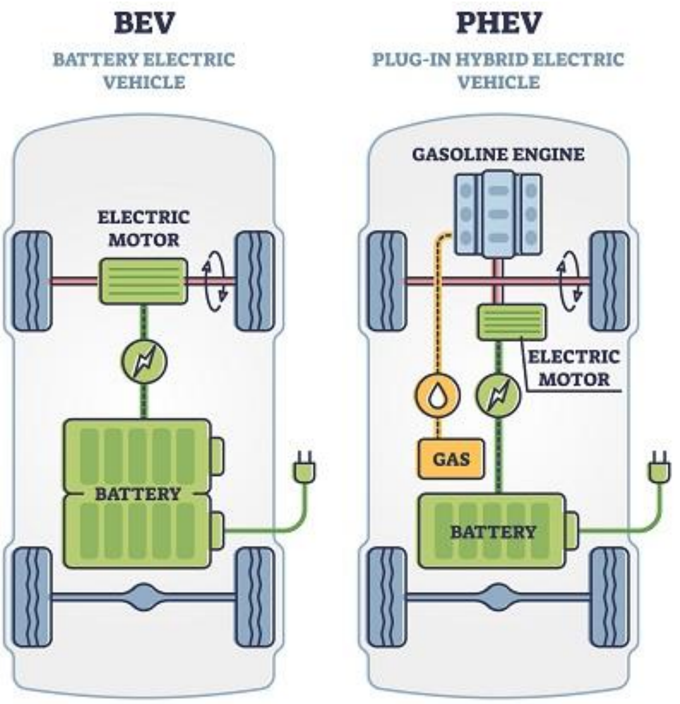


Fig 1.2 General structure of BEV and PHEV [4].

According to [6] in 2021, the average range of BEV was 349 kilometers, or roughly 216.86 miles. Although the range of electric vehicles has been growing over the past few years, it has not kept up with consumer expectations. Fig 3 illustrates the global average EV range by type from 2017 to 2021.

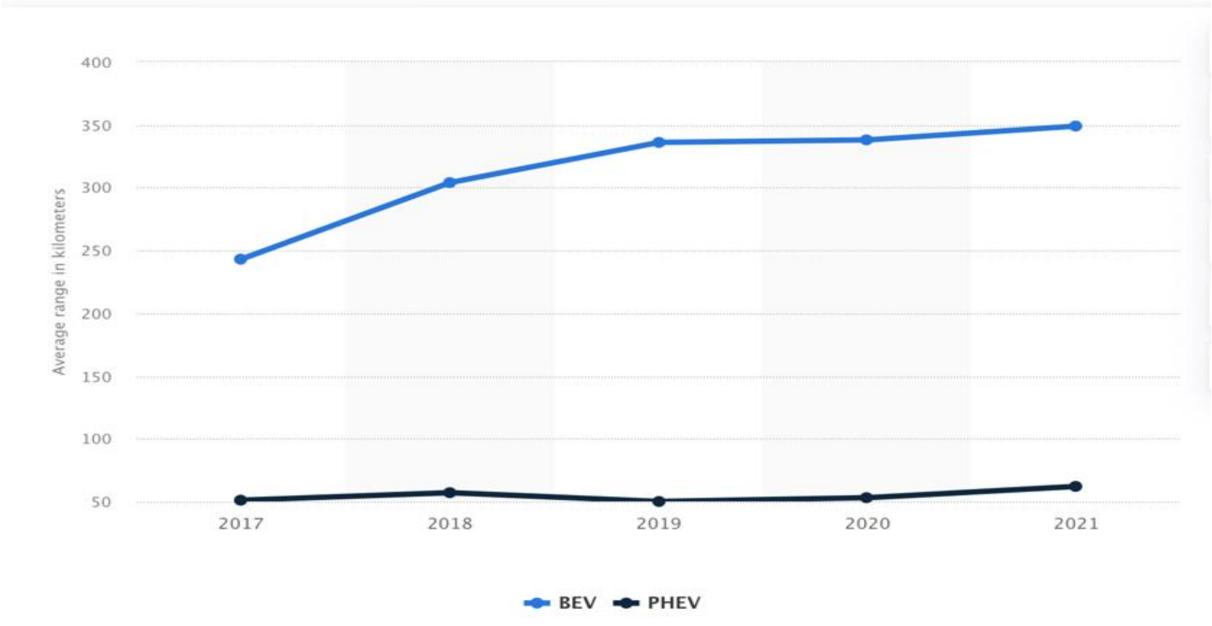


Fig 2.2 Worldwide average EV range from 2017-2021 in km [6].

2.2 Market share and size of electric cars worldwide

With zero emissions targets set for 2050, electric vehicles (EVs) are expected to play a major role, and the industry is preparing accordingly. The 2022 ushered in a record-breaking year. Over 10 million EVs were sold, accounting for 14% of all new car sales. This represents a significant increase from the 9% in 2021 and less than 5% in 2020. In consequence, there were more than 26 million electric vehicles on the road in the world in 2022, a 60% increase from 2021. According to Fig 2.4 there are 13.8 million EVs in China, which makes it worldwide leader [7].

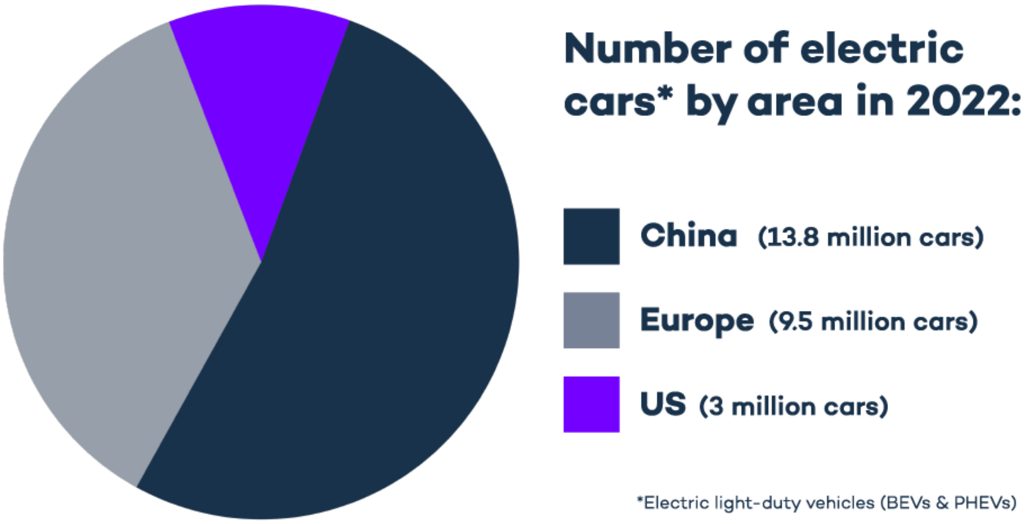
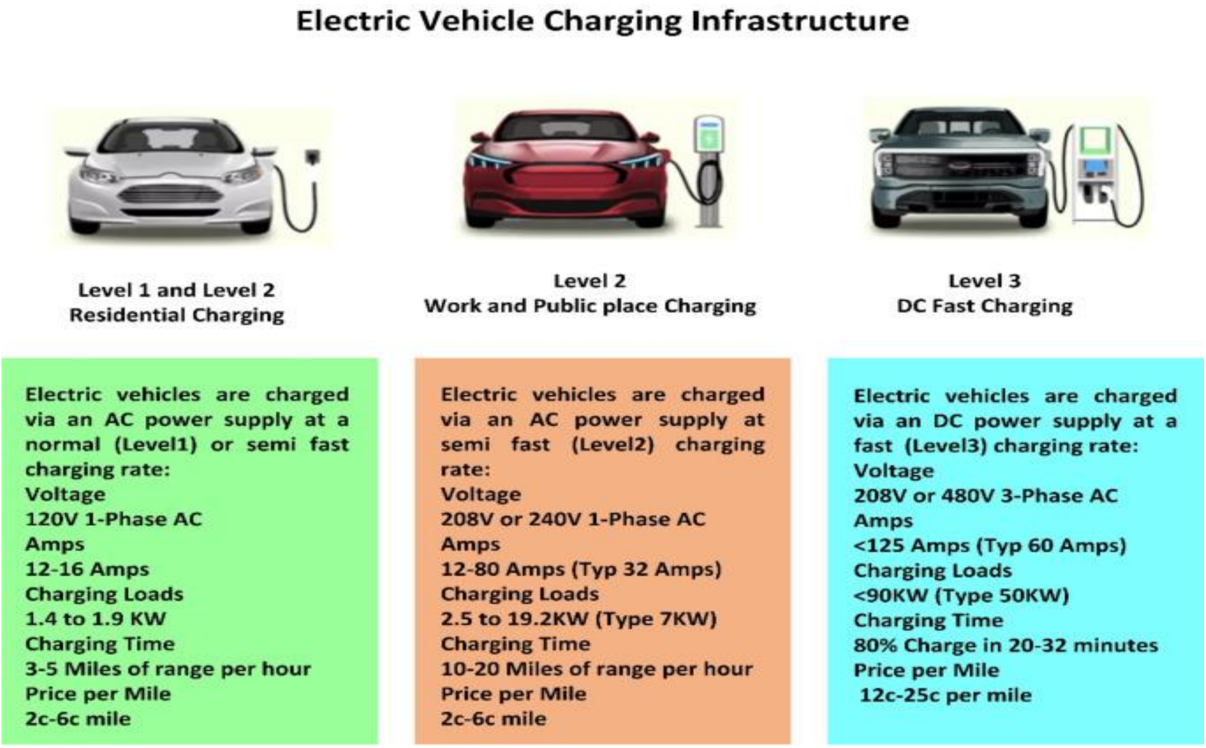


Fig 2.3 Market share and size of electric cars worldwide [7].

2.3 EV Charging Levels

Both slow and fast charging are supported by the installed CS, which can be categorized into private and public categories. Although slow charging ports make up the majority of EV charging, next generation CSs are expected constructed at public locations to serve as EVCSs with a variety of charging port types [8]. There are three charging levels L1, L2 and L3. The simplest and slowest kind of charging is called level 1. It usually uses a portable charging wire that comes with the car and a regular 110–120-volt AC home electrical socket. This charging level is useful for gradually topping off the car's battery; it typically adds two to five miles of range every hour. At home, level 1 charging works best when done overnight. Level 2 charging offers greater versatility and speed. It is powered by a 240-volt AC power supply, which is frequently available at public charging stations or can be installed in residential buildings. Depending on the battery capacity of the car and the power output of the charging device, level 2 chargers can cover anywhere from 10 to 60 miles per hour. Level 2 charging is frequently utilized for everyday charging and is appropriate for usage in both commercial and residential settings. The quickest way to charge an electric car is through level 3 charging, also referred to as DC fast charging. It may supply the vehicle's battery with a significant quantity of electricity using direct current (DC), enabling quick charging. Usually located at public charging stations, DC fast chargers can provide 60–80% of a charge in 20–30 minutes, which makes them ideal for short-term top-ups or long-distance travel [9].


Electric Vehicle Charging Infrastructure

Level 1 and Level 2
Residential Charging

Electric vehicles are charged via an AC power supply at a normal (Level1) or semi fast charging rate:
Voltage
120V 1-Phase AC
Amps
12-16 Amps
Charging Loads
1.4 to 1.9 KW
Charging Time
3-5 Miles of range per hour
Price per Mile
2c-6c mile

Level 2
Work and Public place Charging

Electric vehicles are charged via an AC power supply at semi fast (Level2) charging rate:
Voltage
208V or 240V 1-Phase AC
Amps
12-80 Amps (Typ 32 Amps)
Charging Loads
2.5 to 19.2KW (Type 7KW)
Charging Time
10-20 Miles of range per hour
Price per Mile
2c-6c mile

Level 3
DC Fast Charging

Electric vehicles are charged via an DC power supply at a fast (Level3) charging rate:
Voltage
208V or 480V 3-Phase AC
Amps
<125 Amps (Typ 60 Amps)
Charging Loads
<90KW (Type 50KW)
Charging Time
80% Charge in 20-32 minutes
Price per Mile
12c-25c per mile

Fig 2.4 EV Charging Levels [9].

2.4 EV charger connectors

Plugs for electric vehicle chargers are essential for making charging electric cars easier. The safe and effective passage of electrical power from the charging station to the vehicle's battery is guaranteed by the design of these connectors. Their sizes and shapes vary, and they are frequently standardized to fit in with varied voltages, charging capacities, and geographical areas. An overview of a few popular EV charger plugs is provided here [10].

The J1772 connector is a commonly utilized Level 1 and Level 2 connector in the United States and Canada. It is well-known for its locking mechanism and other safety features, and it works with most electric vehicles that aren't Teslas.

The Mennekes Type 2 Connector (IEC 62196-2) is a type of connector that is frequently found in Europe and is utilized for Level 2 charging.

Combining extra DC pins for Level 3 rapid charging with the J1772 connector for AC charging is known as the **CCS (Combo Connector)**. Being able to charge at a high speed has made it more and more popular in North America and Europe.

CHAdeMO Connector: Level 3 DC rapid charging uses these Japanese-designed connectors. They are frequently found in Nissan and Mitsubishi EVs and have a unique circular plug shape.

Tesla Supercharger Connector: Available only in V2 and V3 variants, these connectors are unique to Tesla automobiles. These connectors are an essential part of Tesla's exclusive charging network and enable quick DC fast charging [12]. Fig 2.6 illustrates EV charging connector types [11], and Table 2.1 shows detailed information about this connectors[10, 11, 12].

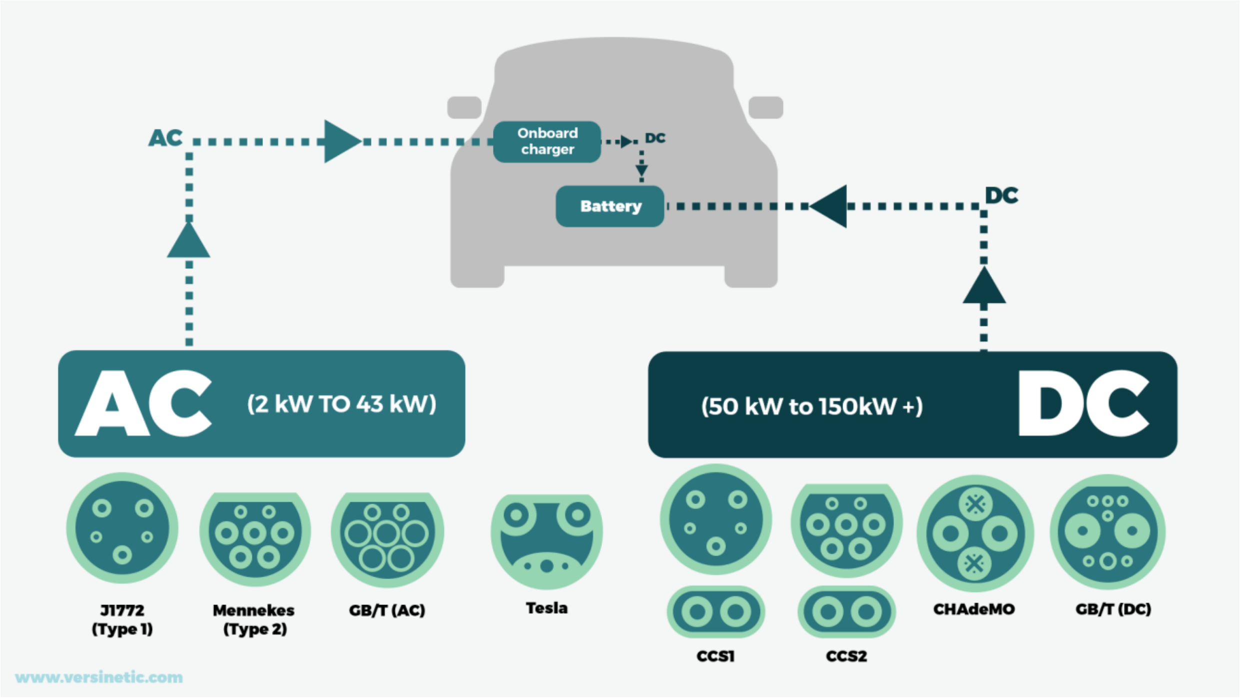


Fig 2.5 Most common EV charging connector types [11]

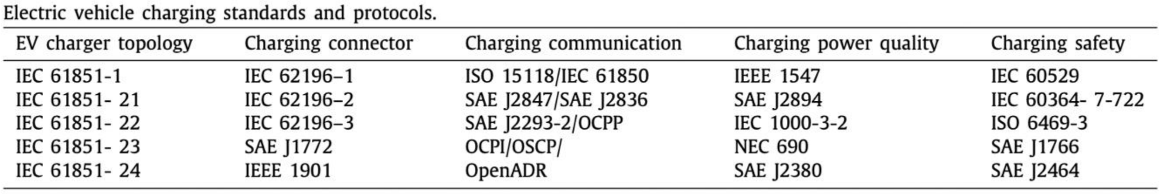
Table 2.1 Common Electric Vehicle Charger Connectors [10, 11, 12]

Charging Port Type	Charging Level	Voltage	Power Output Range	Typical Charging Time for 100 Miles of Range (Approx.)
Standard Household Outlet (NEMA 5-15)	Level 1	110-120V AC	1.3-1.9 kW	20-30 hours
Dedicated Level 1 Charger (NEMA 5-20)	Level 1	110-120V AC	1.4-1.9 kW	20-30 hours
Type 1 Charger (J1772)	Level 2	208-240V AC	3.7-19.2 kW	3-15 hours
Mennekes Type 2 Connector (IEC 62196-2)	Level 2	208-240V AC	3.7-22 kW	2-8 hours
CCS (Combo Connector)	Level 3 (DC Fast Charging)	Varies (typically 400-800V DC)	Up to 350 kW	15-40 minutes
CHAdeMO Connector	Level 3 (DC Fast Charging)	Varies (typically 400V DC)	Up to 400 kW	20-60 minutes
Tesla Supercharger (V2 & V3)	Level 3 (DC Fast Charging)	Varies (typically 400-800V DC)	Up to 250 kW (V2) or 250-350 kW (V3)	15-30 minutes (V2) or 10-20 minutes (V3)

2.4 Charging techniques for electric vehicles

A battery may be charged, and its current can be regulated in several ways. Rectifiers are used in electric vehicles to transform AC into DC for battery fueling. Charge can be transferred via several methods, such as battery switching, conductive charging, and inductive charging [13, 14, 15]. Table 2.2 displays a comparison of the charges made by various charging stations. Fig 2.7 shows that there are two types of conductive charging: overnight charging and pantograph charging, which also divides into 2 categories: bottom-up and top down.

Table 2.2 EV Charging protocols and standards [10,11,12]



Electric vehicle charging standards and protocols.

EV charger topology	Charging connector	Charging communication	Charging power quality	Charging safety
IEC 61851-1	IEC 62196–1	ISO 15118/IEC 61850	IEEE 1547	IEC 60529
IEC 61851- 21	IEC 62196–2	SAE J2847/SAE J2836	SAE J2894	IEC 60364- 7-722
IEC 61851- 22	IEC 62196–3	SAE J2293-2/OCPP	IEC 1000-3-2	ISO 6469-3
IEC 61851- 23	SAE J1772	OCPI/OSCP/	NEC 690	SAE J1766
IEC 61851- 24	IEEE 1901	OpenADR	SAE J2380	SAE J2464

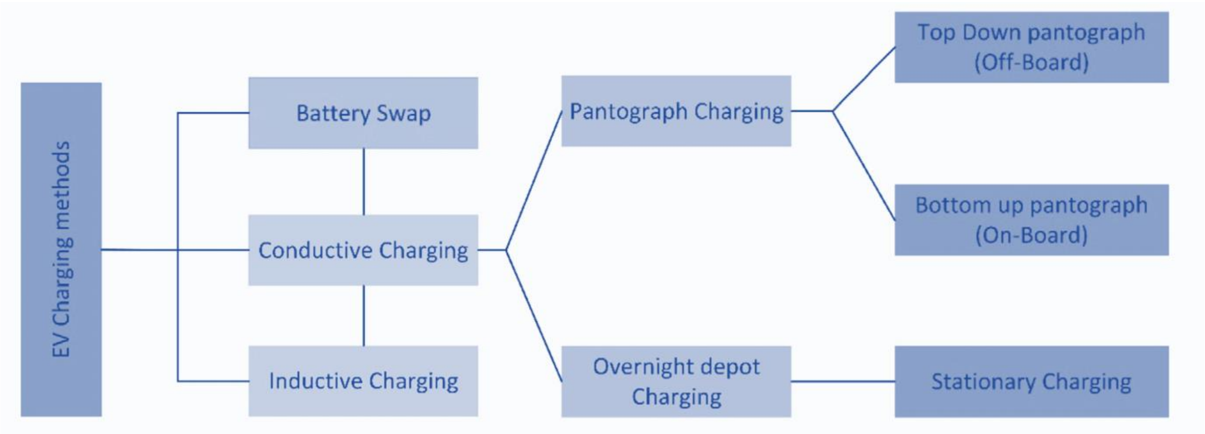


Fig 2.6 EV charging methods

Conductive Charging: The advantages of this technique are its high efficiency, affordability, speed of charging, and ease of use. Apart from the onboard and offboard charging systems, there are further classifications for conductive charging [16]. AC-DC converters and other onboard chargers are often sluggish chargers that use internal current to fully charge EV. Conversely, fast charging is possible with offboard chargers. Another way to extend an EV's range is to use offboard chargers to reduce the vehicle's weight [17]. As disused earlier conductive charging is divided into two categories: Overnight depot charging and Pantograph charging.

Overnight charging: Both slow and rapid refueling options are available. This method is the most beneficial as it has the least negative effects on the distribution system [18]. On the other hand, applications requiring fast charging and large battery capacities are best suited for the Pantograph charging approach.

Pantograph Charging: There are several charging choices available with this charging technique. This charging infrastructure is usually utilized for vehicles like buses and lorries that need larger batteries with more power. Bus batteries require less investment thanks to this charging approach, which lowers investment costs but raises the expenses of the charging infrastructure [19].

Top-down Pantograph: This technique, which has already been tested in Germany, Singapore, and the United States, generates high power using direct current [20]. **Bottom-up Pantograph:** Since buses come pre-installed with charging hardware, using this charging technique is suitable in cases when the equipment is already there.

Wireless Charging: This electromagnetic induction-based technique makes use of a two-coil setup. Once the installation is finished, the charging pads is set up on the outside and the receiving pad is put inside the car. Recent developments in Wireless power transfer structure have generated enthusiasm for the use of electric vehicles by enabling convenient and safe car recharging. The charger can be used while driving and doesn't require a standard connector [21]. Nevertheless, the efficiency of inductive power transfer is low. The distance between the transmitter and receiver coils should be approximately 20 and 100 cm [22]. Eddy current loss in the WPT can potentially be a problem and there might be a small communication lag [23]. Fig 2.8 illustrates this in action.

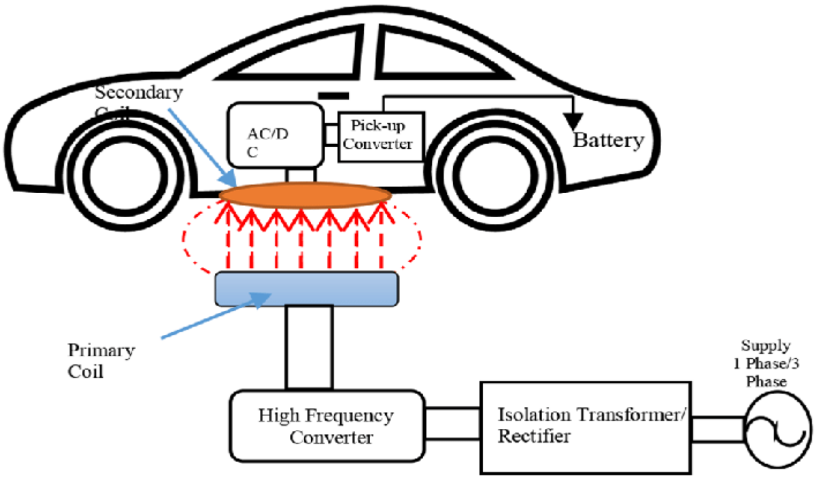


Fig 2.7 Wireless EV charger structure [24]

Battery Swap Station (BSS):

A process known as "Battery Exchange" is used to exchange batteries. Battery life is extended, and the charging process is slowed down by the BSS [25]. It is simple to include locally produced RES like solar and wind power into the BSS. By using this method, the user can swiftly replace the batteries without having to get out of the automobile. The fact that this battery supports the V2G project is an additional benefit [26]. Fig 2.9 illustrates the hybrid switch station's two distinct charging procedures.

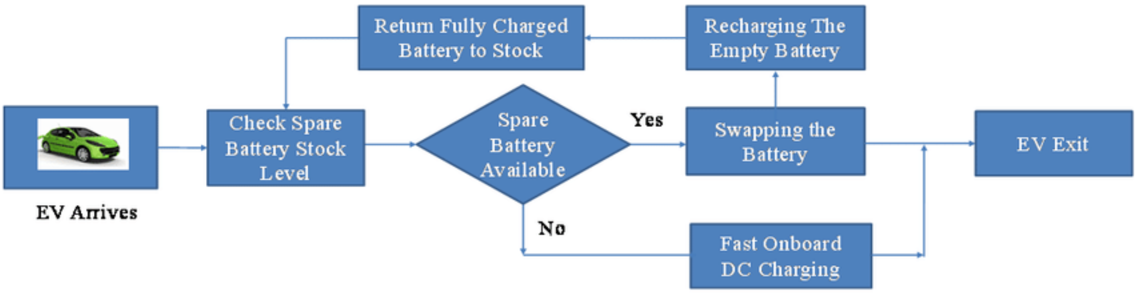


Fig 2.8 Operational principle of battery swapping station with onboard fast charging [27].

2.5 EV Charging Infrastructure (CI)

As shown in Fig 2.10 an entire EVCI consists of energy frame, management, and communication structure, and EVCSs.

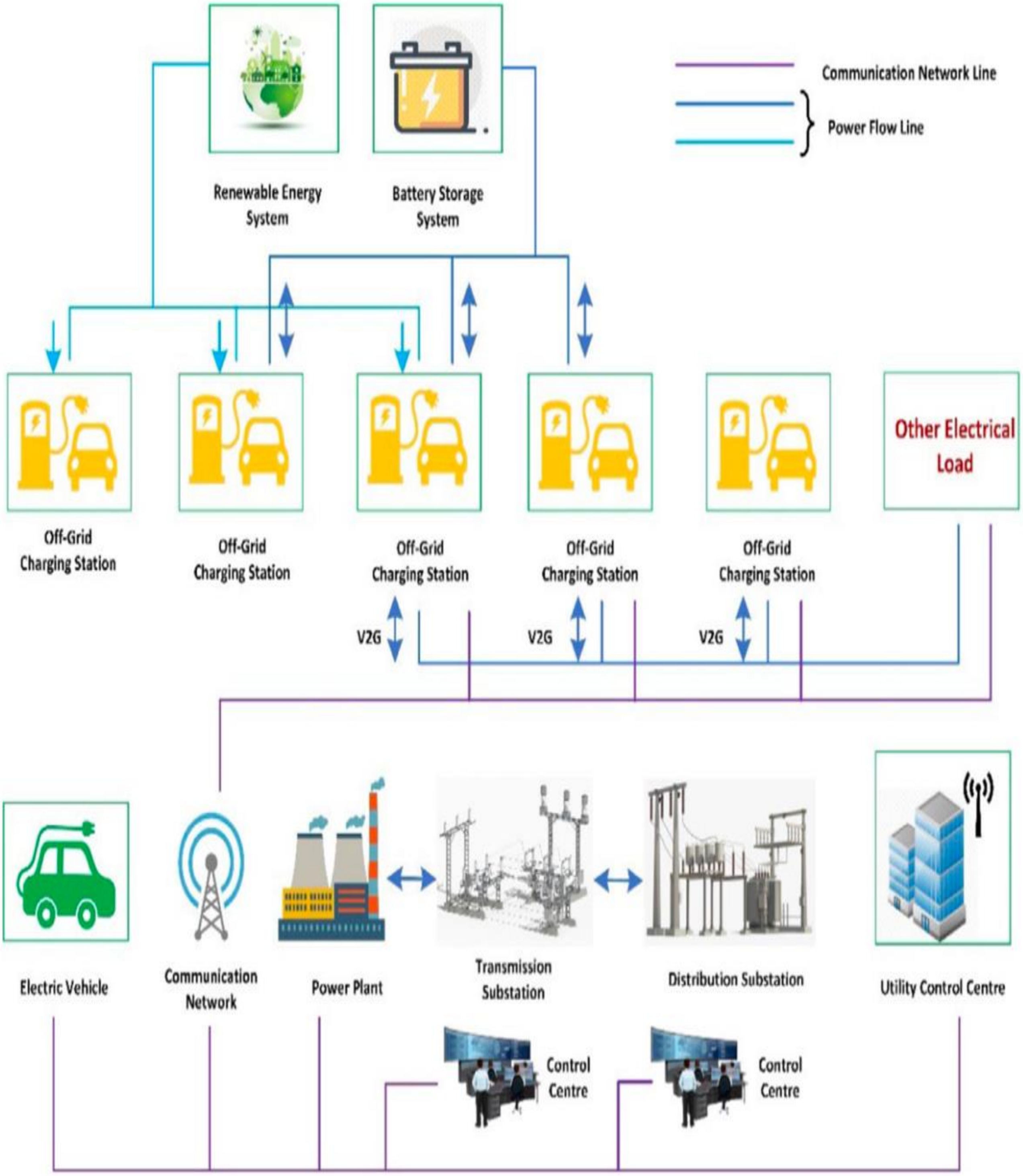


Fig 2.9 Schematic illustration of the infrastructure used for electric vehicle charging [28].

Figure 2.11 displays the entire EV infrastructure, including charging power levels and on- and off-board charging devices.

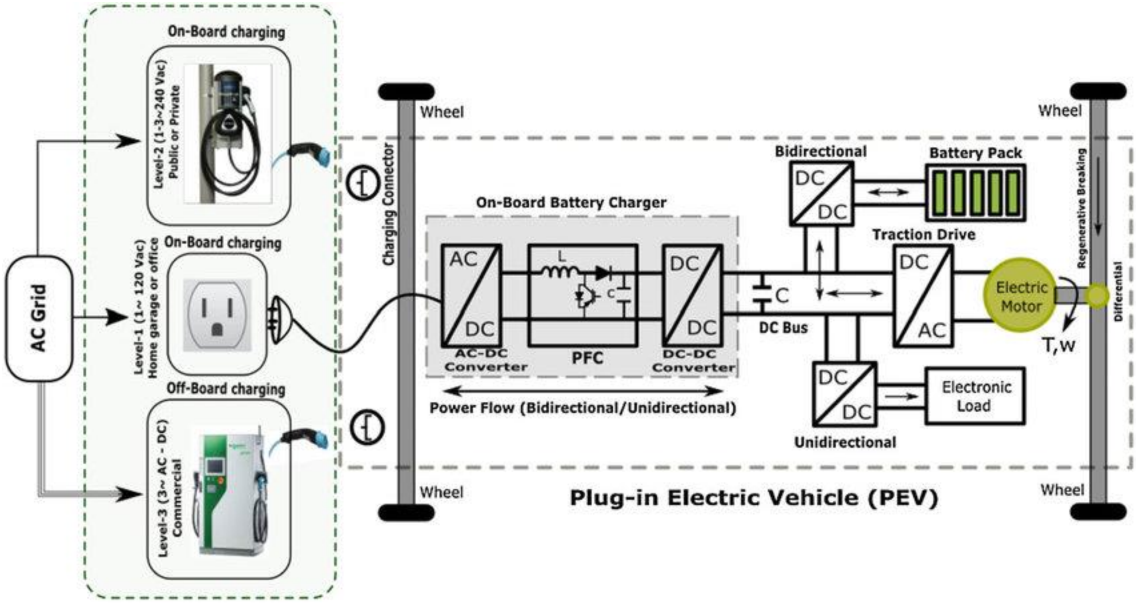


Fig 2.10 EV infrastructure with charging levels [29].

Power Type

Electricity sources for EV charging might be AC or DC. The voltage and frequency levels of AC charging vary depending on the electrical grid of the nation in concerned. Levels 1, 2, and 3 of AC charging correspond to different voltage levels; L3 has the highest voltage. While L3, which require distinct wiring and require approval from utility companies to set up, L1 and L2 usually in nonresidential places. DCFC L3 is the most rapid and powerful charging level [9].

Physical Interaction

The CS can be separated into traditional and wireless charging based on the point of physical contact. While a wireless CSs deliver energy in the absence of any cables, a standard method keeps a standard charging cable [30].

There are two types of conductive charging: fast charging (Level 3 or DCFC) and regular L1 and L2. The most recent CS employ DCFC to power the cars, which is essential to EVs becoming more and more popular [31]. Problems like time needed for charging [32], accessibility for the public, integration of RES [33] and so forth must be fixed in order for it to be the finest solution on the market.

WPT technology is usually used in contactless charging systems to charge the battery. WPT systems have a power rating approximately 3-25 kW and can function in L1,L2,L3. Up to 90% efficiency has been recorded [34, 35, 36].

Accommodation of charging circuit

Accommodation is divided into 3 categories: Onboard, Offboard and Wireless. The charger might be installed in a CS or inside a vehicle. Anywhere there is a power source, individuals can refuel their vehicle using an onboard charger. Its limited power supply capacity to EVs results in a increased refueling time despite its small size, light weight, and low cost. On the other hand, off-board EV chargers are less bulky and weigh less and support both rapid and slow charging inside the one device. In addition to on-board and off-board chargers, a third kind of charging system is wireless charging, which can have 2 pads to charge battery wireless [18,19,20,21,22].

Power Flow Direction

There are 2 groups of chargers bidirectional and unidirectional according on the direction of power transfer, as illustrated in Fig 2.12 [37].

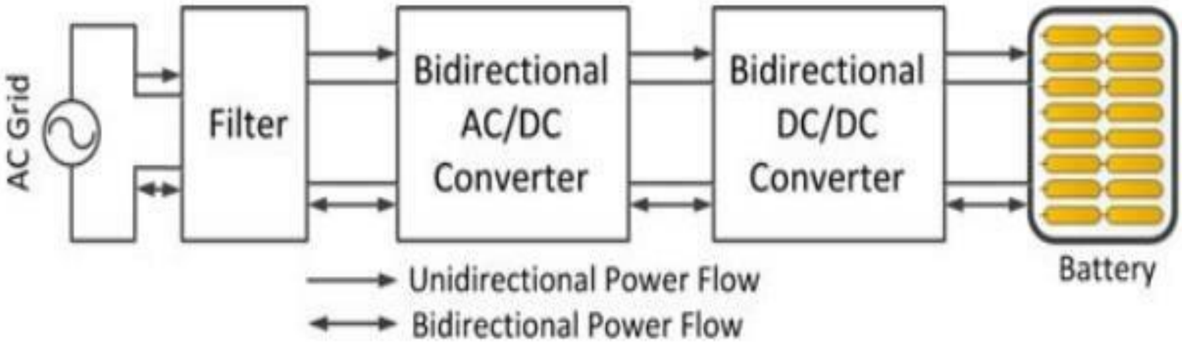


Fig 2.11 General unidirectional and bidirectional topology.

A unidirectional DC-DC converter and a diode rectifier are used by an EV charger with a unidirectional architecture to control charging [37]. The simplicity of the unidirectional charger makes it simple to operate. Compared to bidirectional varieties, it has fewer connecting problems and reduces battery degradation. Nevertheless, the majority of grid ancillary services cannot be delivered by unidirectional chargers [38].

A bidirectional AC-DC/DC-DC converter are components of a bidirectional EV charger [39]. Because this type of CS can function in both charging/discharging modes, EVs are able to provide the grid a variety of extra services. Yet, the lifespan of an EV battery can be shortened by often cycling the electricity back to the grid. The procedure is further complicated by the metering and grid stability lawsuits, which entail purchasing and selling energy from suppliers.

2.6 EV Control and communication system

The control and communication system serves as a crucial component in facilitating real-time monitoring and control of electric vehicle charging [40]. Despite the fact that electric vehicle charging imposes an extra load on the power system, it is possible to mitigate this by implementing effective scheduling strategies. By managing and coordinating EV charging stations in conjunction with the grid, peak demand can be reduced, resulting in lower charging costs [41].

Figure 2.13 illustrates the manner in which the control of electric car charging is executed. The management of electric vehicle (EV) charging includes the coordination and regulation of several components, including the power system, EVCS, and vehicles.

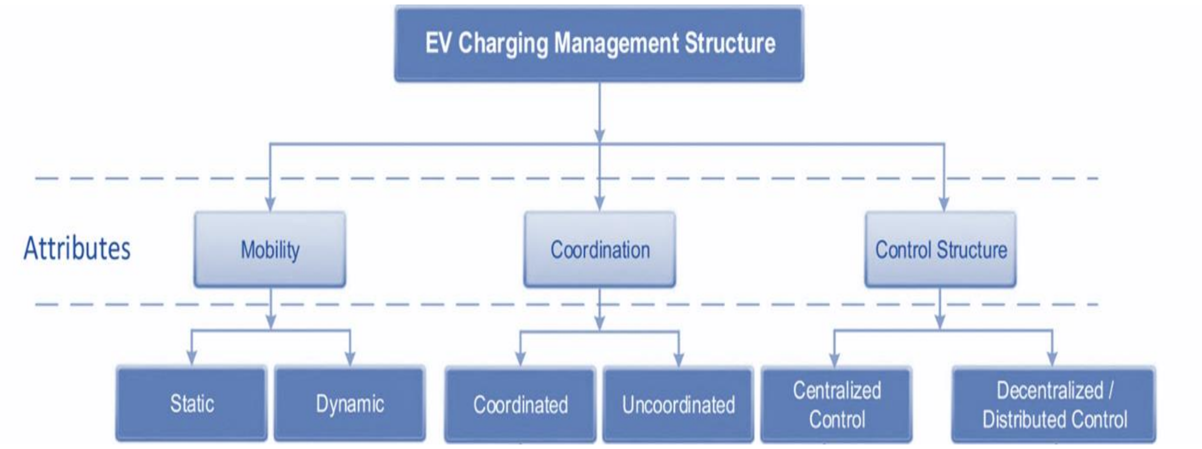


Fig 2.12 EV charging management structure

Considerations for Vehicle Mobility: In this regard, the infrastructure for electric vehicle charging could separate two types: **static charging and dynamic charging**. During the process of static charging, the vehicle is seen as being stationary at a designated charging station while undergoing the charging procedure. In contrast, the dynamic or mobility-aware charging scheme takes into account various temporal factors, including the timing of vehicle arrival and departure, the historical patterns of trips, and any unforeseen instances of electric vehicle arrival or departure [42]. This approach is more realistic as it considers the spatiotemporal relationships of EVs. However, it is also more complicated and involves the implementation of sophisticated control systems [43]. Fig 2.14 illustrates static and dynamic charging structure [44].

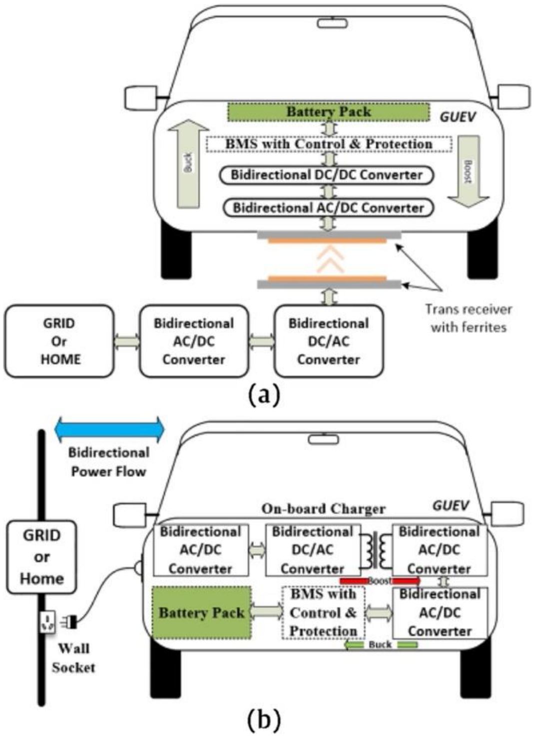


Fig 2.13(a) dynamic charging system (b) static charging system [44].

The concept of charging coordination: Uncoordinated and coordinated charging control are two techniques to electric car charging. Lack of coordination in electric car battery charging leads in rapid charging upon connection or delayed start dependent on customer choices. In all circumstances, charging continues until batteries are full or unplugged [45]. Unsynchronized charging operations have a tendency to elevate the demand during peak hours, potentially resulting in excessive loads on distribution transformers and cables. This can lead to greater power losses and declined grid resilience [46]. Certain utility providers provide a dual tariff option, which includes discounted rates during nighttime hours, specifically targeting electric vehicle owners. This initiative is implemented with the intention of mitigating peak loads [47]. In contrast, coordinated or smart charging strategies have been shown to effectively optimize both time and power demand [48]. Additionally, these strategies have demonstrated the ability to reduce many factors such as daily energy expenses voltage changes, line currents, and transformer load spikes [45]. One example of a coordinated charging approach is known as off-peak charging, which involves the charging of electric vehicles during a designated period when the demand on the power grid is at its lowest. This solution partially addresses the problem of overloading. However, it is necessary to obtain precise time information from utility providers to fully resolve the issue [45,47,49].

Consider the control structure. The EV charging stations exhibit a geographical spread inside the distribution grid. In order to effectively regulate and monitor the transfer of electrical power to and from EVCS, two distinct approaches might be implemented: the decentralized strategy and the centralized strategy [50]. Fig 2.15 illustrates both control systems.

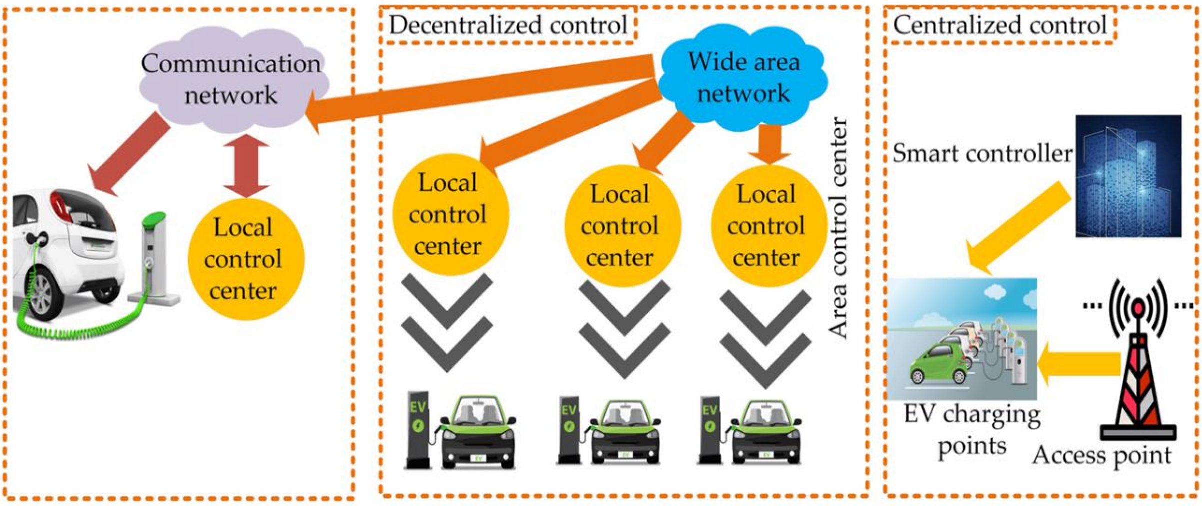


Fig 2.14 EV charging system with centralized control and decentralized control.

Centralized Control

In centralized charging, the master control engine sets electric car charging schedules and rates. This control system uses electric car data to make charging decisions. The scaling of the optimization issue, which increases with vehicle density, limits the practicality of centralized charging. According to [51], every group is equipped with a local controller responsible for managing the allocation of power to its individual electric vehicles. On the other hand, the central controller is solely responsible for handling the demands of the entire group. The utilization of the hierarchical control approach leads to enhancements in communication and computation needs. Centralized structures also facilitate the implementation of additional control mechanisms, such as online control [52], and real-time pricing [53]. The design depicted in Figure 2.16 is the centralized EV charging control [54].

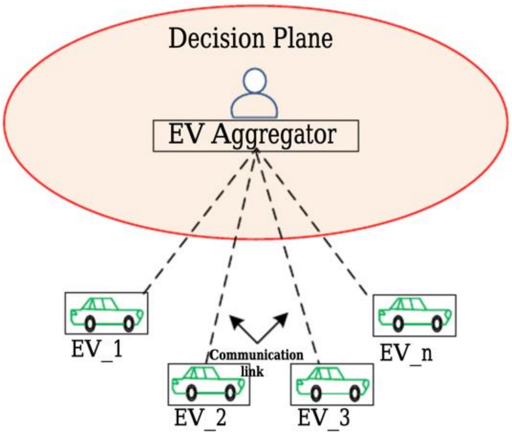


Fig 2.15 Centralized control [54].

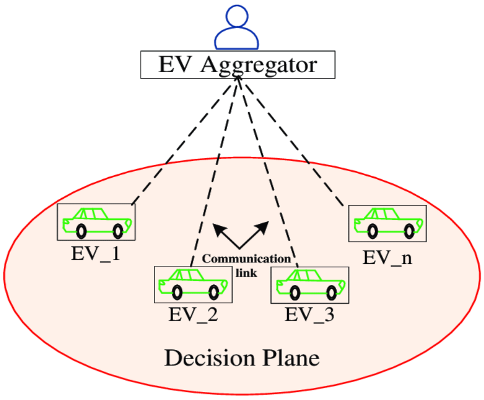


Fig 2.16 Decentralized control [55]

Decentralized Control

Is a strategic approach wherein electric vehicle customers autonomously determine their preferred charging schedules. The primary determinants for making charge decisions in this particular form of control are the cost of electricity and the convenience for customers. The absence of centralized control in determining the charging patterns of electric vehicle users has limitations on achieving the most effective solution for the entire system. Nevertheless, through the implementation of an electricity tariff structure and the cultivation of responsible conduct among electric vehicle users, it is possible to align the EV loads with the demands of the grid [55], Fig 2.17 illustrates decentralized control.

CHAPTER THREE

Situation Of EV Charging Infrastructure In Azerbaijan

Azerbaijan has been an active contributor in the worldwide endeavor to achieve sustainable transportation solutions, particularly in the context of the paradigm shift towards electric mobility. The Azerbaijani government has implemented several measures to encourage the use of EVs and facilitate the establishment of essential charging infrastructure, acknowledging the advantageous environmental and economic aspects associated with such vehicles.

Government initiatives: Azerbaijan has demonstrated its dedication to mitigating carbon emissions and promoting energy sustainability, aligning itself with prevailing worldwide patterns. According to the most recent statistics, governmental efforts have consisted of a combination of regulatory policies and incentive programs aimed at promoting the use of EVs. Various incentives such as tax benefits, subsidies, and exemptions are implemented to incentivize customer engagement and promote a seamless transition towards the use of electric vehicles.

3.1 Azerbaijan aims to establish a cutting-edge EV manufacturing facility.

The government of Azerbaijan is now engaged in efforts to establish a cutting-edge EV manufacturing facility with the aim of diminishing the nation's reliance on fossil fuels, particularly oil and gas. The plant will be constructed and built with the assistance of China, as the country has a keen interest in fostering and growing bilateral collaboration.

Azerbaijan is a nation abundant in energy resources, relying significantly on the exportation of oil and gas to generate cash. Considering the recent decline in fossil fuel prices, Azerbaijan has been actively seeking avenues to enhance the diversification of its economy. Azerbaijan seeks to establish an EV manufacturing facility with the objective of producing electric automobiles of superior quality.

3.2 EV number statistics in Azerbaijan

Referring to the State Customs Committee, it is reported that the number of electric cars imported this year has increased more than 6 times. During the initial four-month period of 2023, a total of 568 electric cars were imported into Azerbaijan, with a cumulative value amounting to 23,771,000 dollars. Between January and April 2022, a total of 92 electric vehicles, with a collective value of 2,920,000 dollars, were imported into the country of Azerbaijan. Referring to the State Customs Committee, it is reported that the number of electric cars imported this year has increased more than 6 times. In the previous year, the total count of hybrid vehicles, characterized by a manufacturing duration not exceeding three years and an engine capacity of 2,500 cubic centimeters or less, reached a quantity of 3,026 units. However, in the year 2021, this figure decreased significantly to 805 units. As of February 20th, of the current year, the total number of imported automobiles reached a quantity of 673 units.

3.3 EV charging infrastructure in Azerbaijan

During a conference on the subject of "Operation of environmentally friendly cars and a clean environment in Azerbaijan," Rauf Gurbanov, a representative of the Ministry of Energy of Azerbaijan, stated that there are presently 33 charging stations available for electric vehicles in the country. Based on his statement, there are a total of 22 charging stations situated in Baku, while an additional 11 charging stations are distributed throughout other locations such as Ganja, Guba, Kurdamir, and others. The projected expansion of electric cars in Azerbaijan is expected to result in a corresponding rise in the number of charging stations. According to the advice put forward by Tokyo Electric Power Company (TEPSCO), it is advisable to build charging stations at a maximum radius of 25 kilometers from one another. According to Gurbanov, our ministry is now contemplating the earlier suggestion. As per a spokesperson from the ministry, it is feasible to employ RES to power CS in various areas of Azerbaijan.

3.4 Azpetrol initiative.

At the gas stations operating under the brand name "Azpetrol," to be exact at "H. Aliyev Avenue 105," "H. Aliyev Avenue 108," "K. Marks," "Spartak," "Mayak," "Mayak-2," "Babak," "Nobel," "Ganjlik," "Mardakan," "Kalaba," "Sumgait-1," "Alat," and "Salyan-2," there are 14 "Terra-54" models of electric car charging stations manufactured by "ABB" in Italy, which installed in 2019 .

The Terra 54 facilitates uninterrupted charging at a rate of 50 kilowatts, while also supporting high voltage charging at a maximum of 920 volts direct current. The Terra 54 has the option of being configured with either CCS1-only capabilities or both CCS and CHAdeMO functionality. Table 3.1 shows the technical characteristic of Terra 54 fast DC charger.

Table 3.1 Terra 54 technical specification.

Specifications	Terra 54
Max Output Power	50 kW continuous
AC Input Voltage	480Y / 277 VAC +/- 10 %
AC Input Connection	3-phase: L1, L2, L3, GND
Nominal Input Current	64 A
Input Power Rating	54 kVA
Recommended Circuit Breaker(s)	80 A
Power Factor	> 0.96
Current THD	IEEE 519 Compliant; 5%
Short Circuit Current Rating	65 kA; 10 kA optional
DC Output Voltage (CCS1)	200 - 500 VDC
DC Output Voltage (CHAdeMO)	50 - 500 VDC
DC Output Current	125 A
Efficiency	95%

3.5 EV fast charger manufacturer in Azerbaijan

The "Ilab" MMC company in Azerbaijan has commenced the manufacturing of electric charging stations known as "Charge Box". According to Zaur Bunyatov, who is responsible for overseeing Marketing and Advertising at the firm, power supply stations are manufactured using imported components sourced from Italy and China. The cost of indoor electric feeding stations begins at 4,000 manats, while the cost of the outdoor variant, designed to withstand rain, wind, and impact, starts at 6,500 manats. The rates provided encompass the cost of installation services. The first presentation of "Charge Box" electric power stations took place during the Electric Vehicle Exhibition hosted inside the Park Bulvar shopping center in Baku. Below illustrated the map of charging stations near of the capital Baku, Azerbaijan, however Google maps does not include the new fast charger locations.

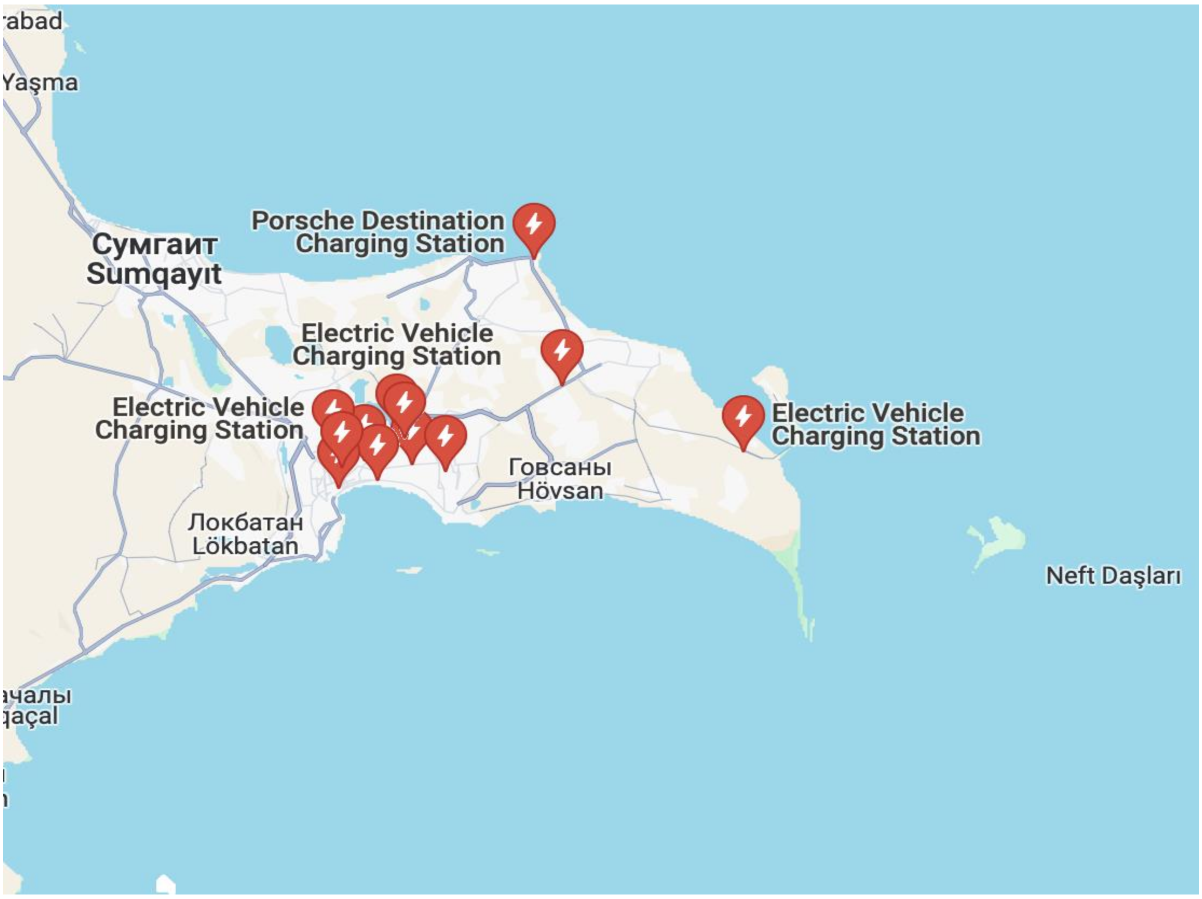


Fig 3.1 EV charging station locations in Baku and nearby areas [Google Maps].

3.6 Electric vehicle charging cost in Azerbaijan.

Several newly established companies in Azerbaijan are engaged in the sale of EV charging equipment and have developed their own charging infrastructure. Here is a compilation of them. E-lektra.az, Elcar.az, Charge.az, Estation.az, EVsun.az, and more similar companies. Charge.az and E-lektra.az are the two businesses with the largest infrastructure. Both companies have more than 10 EV charging stations around the country, and the number of charging stations is continuously growing. Both of them provide a range of chargers with varying power capacities and prices for charging.

In this part, I will provide an informative calculation of the charging costs for different stations. Table 3.2 shows the power ratings of Fast chargers and their corresponding prices per kilowatt-hour (kWh) in AZN.

Table 3.2 EV Charging price per kWh (AZN)

COMPANIES	CHARGING POWER (kW)	COST PER kWh (AZN)
ELEKTRA.AZ 120 KW	120	0,3
CHARGE.AZ 60 KW	60	0,19
ELEKTRA.AZ 40 KW	40	0,25
AZPETROL 50 KW	50	0,12

From the table, it is evident that the lowest price is found at the 50 kW azpetrol station, charging 0.12 AZN per kW, while Elektra 120 kW is the costliest option. The charging station has a power output of 120 kilowatts and the cost is 0.30 Azerbaijani manat per kilowatt. This charger is one and only 120 kW fast charger located in Azerbaijan. Fig 3.2 illustrates the photo of this 120 kW FCS.

Fig 3.2 120 kW Elektra.az charger

Here are standard formulas for cost calculation:

$$Cost = Charging\ Power\ (kW) \times Charging\ Time\ (hours) \times Cost\ per\ kWh(AZN) \quad (1)$$

Formula for finding charging time

$$Charging\ Time = \frac{Battery\ Capacity}{Charging\ Power} \quad (2)$$

For example, to find a charging time for 75 kWh battery via 120 kW Eletra.az fast charger

$$Charging\ Time = \frac{75\ kWh}{120\ kW} = 0{,}625\ hours\ or\ 0{,}625 * 60 = 37{,}5\ minutes$$

$$Cost = 120\ kW \times 0{,}625\ hours\ \times 0{,}3\ AZN = 22{,}5\ AZN$$

I have calculated the duration and expenses associated with charging using different chargers, based on a battery capacity of 75 kWh. The findings are illustrated below.

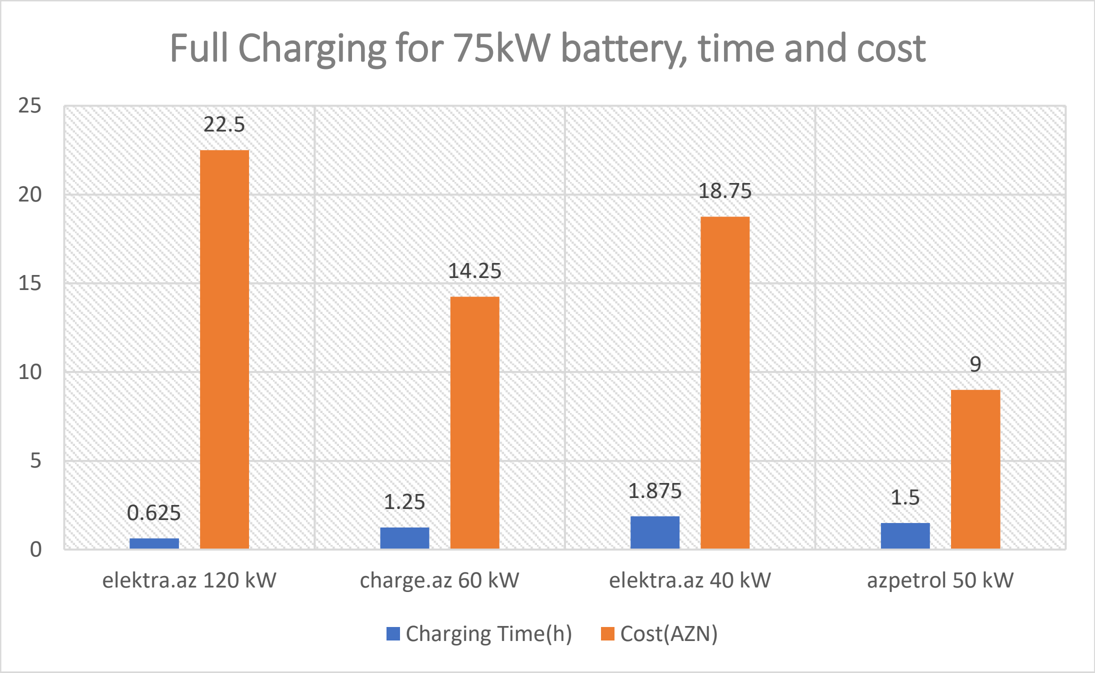


Fig 3.3 Full charging Time and Price chart for 75 kW battery

According to the calculation, charging a 75-kW battery at a 120 kW fast charger will cost the client 22.5 AZN and take around 0.625 hours, which is equivalent to around 37,5 minutes. This battery can provide a range of approximately 400 km. This charger is the most efficient and costly charger in Azerbaijan, in comparison to other chargers. For example, if a customer charges the same battery with a capacity of 75 kW at the Azpetrol 50 kW fast charger, customers will spend 9 AZN and it will take 1.5 hours or 90 minutes to fully charge the battery. This is almost 2.5 times cheaper compared to other options, but it will also take 2.5 times longer to fully charge the vehicle's battery.

It is noteworthy that EV owners typically do not fully charge their EVs at fast charging stations. Therefore, I have also taken into account another situation where the State Of Charge (SOC)% ranges from 20% to 80%. The figure 3.4 illustrates the calculation results for this scenario.

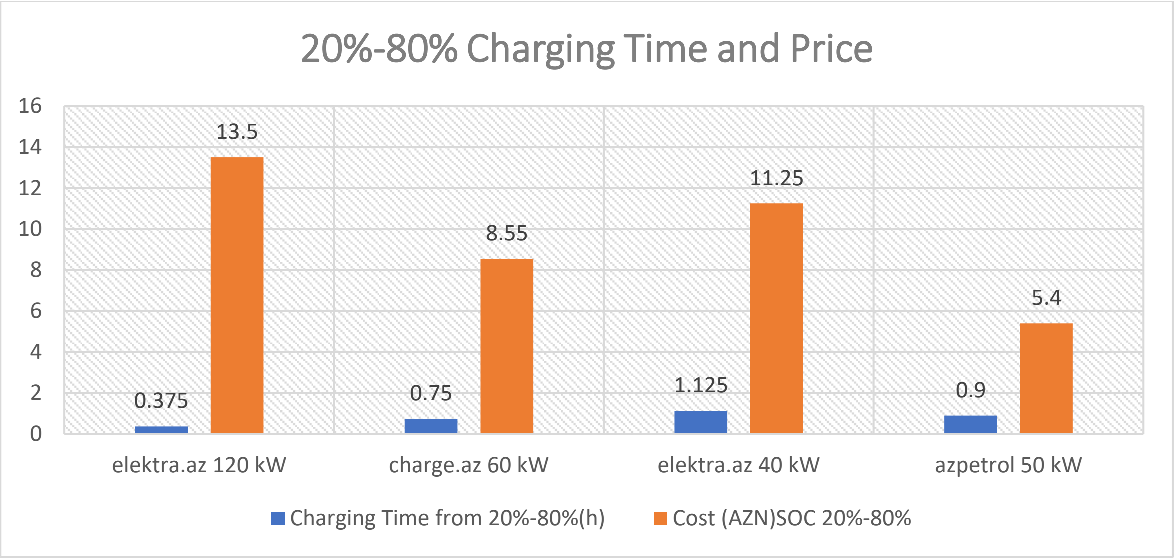


Fig 3.4 Charging Time and Cost for 20%-80% SOC

For this situation, when a 75-kW battery is being charged using a 120 kW fast charger, the EV owner will need to wait around 0.325 hours or 19.5 minutes and incur a cost of nearly 13.5 AZN. The Azpetrol 50 kW station will need 0.9 hours or 54 minutes to complete and will have a cost of 5.4 AZN.

Additionally, there are companies in Azerbaijan that specialize in selling charging equipment for private use. One notable example is Elcar.az. Below is a comprehensive list of available chargers along with their corresponding prices.

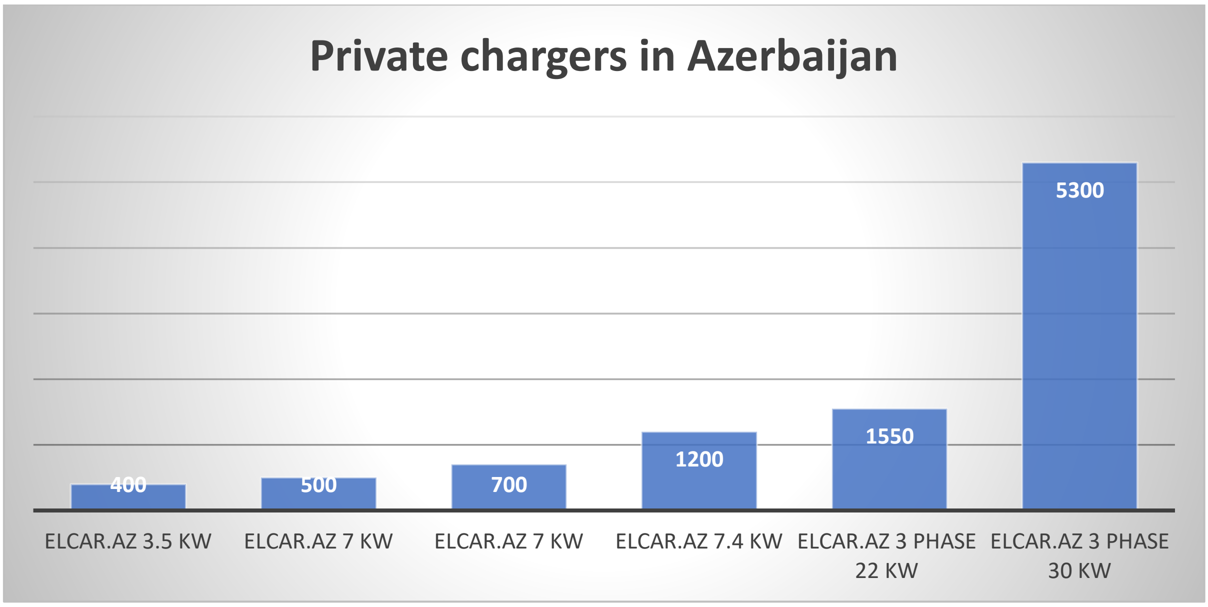


Fig 3.5 Private charger prices in Azerbaijan.

According to Elcar.az, the price for a level 1 charger with a power of 3.5 kW is 400 manats. For a level 2 charger with a power of 22 kW, the price is 1550 AZN. Lastly, the price for a fast charger with a power of 30 kW is 5300 AZN.

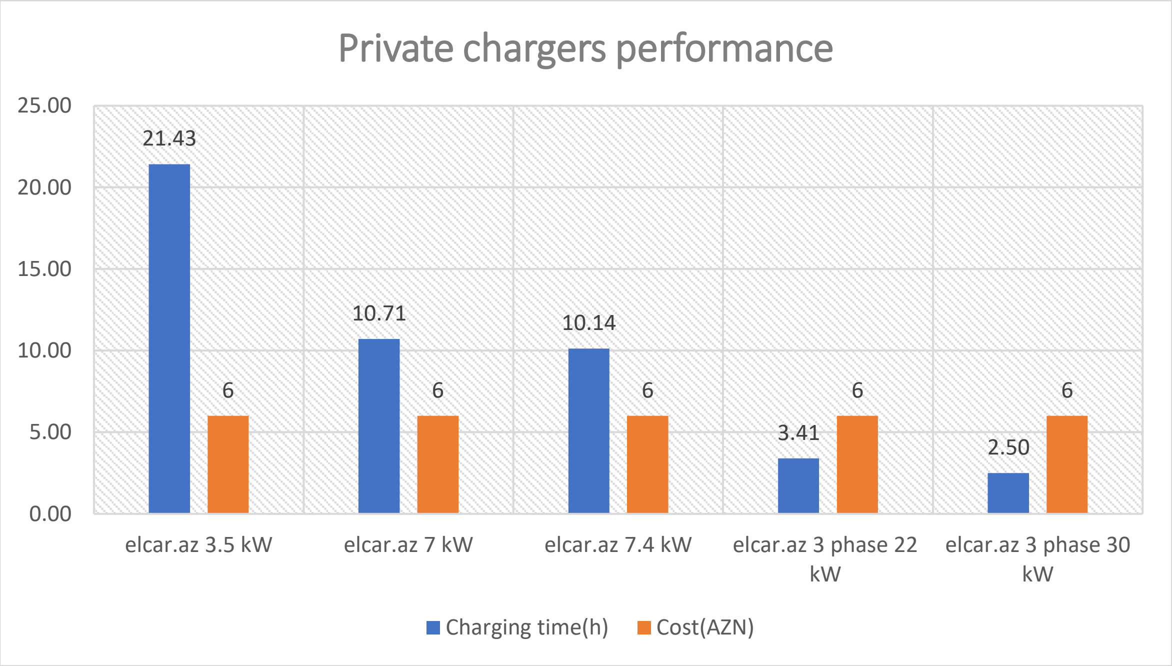


Fig 3.6 the private chargers charging time and price

From this chart, it is evident that the 3.5 kW charger has the longest charging time 21,43 hours, while the 3 Phase 30 kW charger has the shortest time 2,5 hours. However, the price remains the same 6 AZN because the consumption does not exceed 75 kW in any case, and the price per kW in Azerbaijan is 0.08 AZN (if the limit is not exceeded).

Fig 3.7 illustrates the Chage.az fast charger locations, fig 3.8 illustrates the Electra.az charging stations in Azerbaijan.

Fig 3.7 Charge.az EV FCS locations

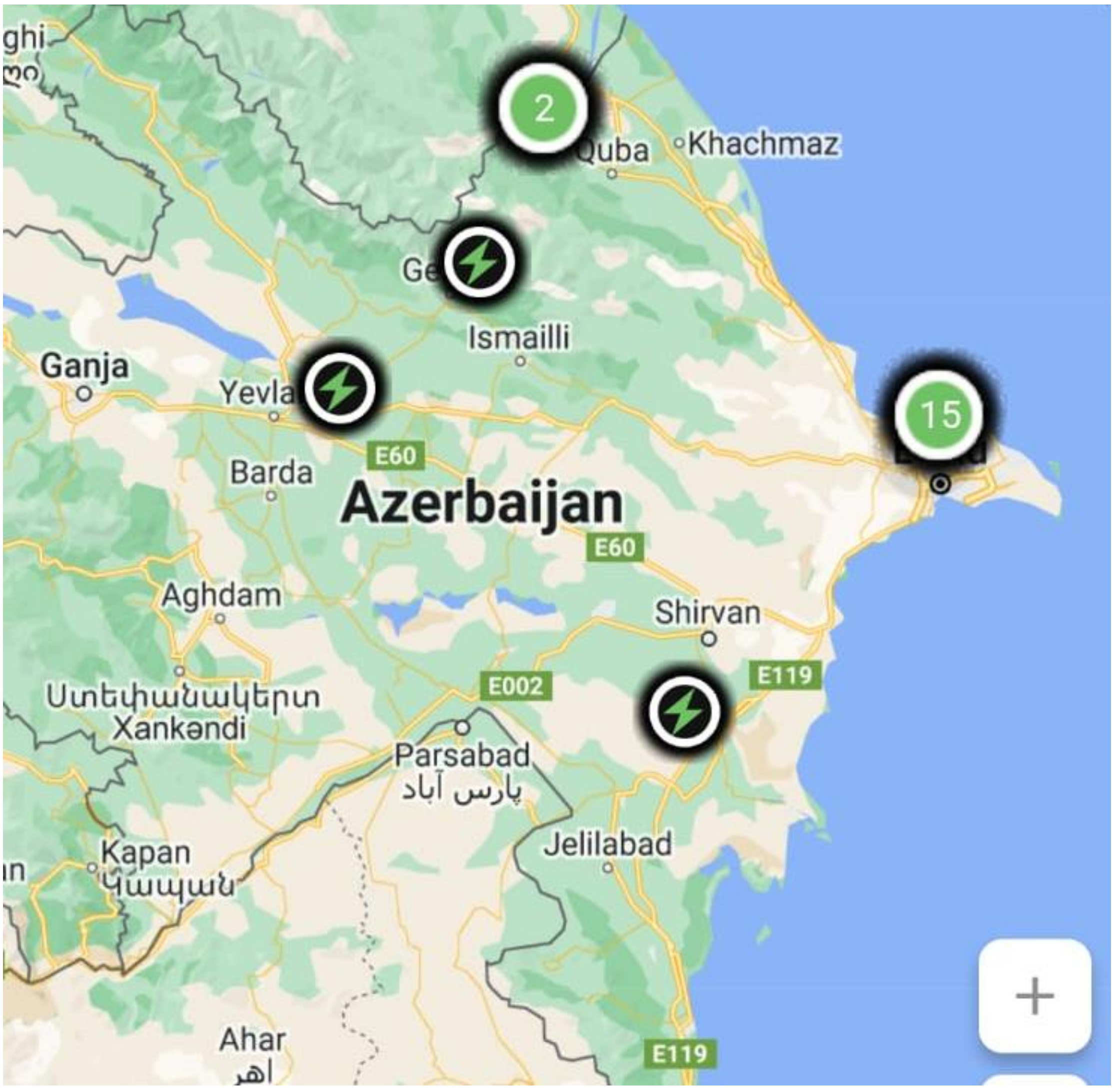


Fig 3.8 Electra.az EV FCS locations.

CHAPTER FOUR

The Integration Of EV To The Power Grid

The installation of a significant quantity of electric vehicles into the electric power system is a significant obstacle that necessitates a thorough evaluation and monitoring of its economic implications, as well as the operational and control advantages under ideal circumstances. Numerous academic papers have examined the effects of electric vehicles on the distribution power system [56], while others have delved into various application concepts that facilitate the EVGI [57]. According to most recent research, most of the EV charging infrastructures are projected to be completed at home. However, it is anticipated that the majority of electric vehicle charging would occur at public, commercial, or workplace charging stations [58]. Hence, it is anticipated that the effects of EV charging will have a direct impact on the electric power distribution system. The consequences encompass a spectrum of outcomes, including the overheating of power transformers and the necessitation of additional investments in power distribution infrastructure. Nevertheless, the implementation of electric vehicles has the potential to significantly enhance the performance, effectiveness, and the quality of power of the electric grid. The successful integration of a significant number of electric vehicles into the power grid can be achieved by careful planning and technical reorganization that adheres to established operating standards [59].

4.1 EV aggregators and Virtual Power Plants

Academic articles have proposed many methods to determine the practical benefits of adding a large fleet of electric vehicles to the electric grid. This situation relies on the EV owner and utility company. Both parties can communicate with the system, but they must give up advanced control and operational considerations. The architecture that is most frequently encountered in the literature clearly includes the **EV aggregator**, which has garnered significant attention from researchers in recent years. EV aggregators serve as intermediaries between the electrical grid and electric vehicles, utilizing smart meters as a means of communication. These aggregators gather information regarding the power demand for charging and the duration of the charging sessions from EV drivers, subsequently transmitting this data to grid operators. Moreover, electric vehicle aggregators offer comprehensive data regarding the locations of charging stations as well as the corresponding electricity tariffs, which is made available to car users. In a competitive “Bazar” with several aggregators, electric vehicle owner would benefit from choosing the aggregator that aligns most closely with their specific needs and preferences. In conjunction with the DSO, the aggregators engage in the prediction of the forthcoming day's energy consumption and thereafter formulate their respective purchase and sale prices. The aggregator is regarded as the central authority responsible for coordinating essential operational tasks, such as communication with the distribution system operator (DSO), transmission system operator (TSO), and energy service providers. Typically, the aggregator assumes the responsibility of facilitating the connection between participants in the energy market and electric vehicle owners [60]. Moreover, the implementation of electric vehicle integration can be conceptualized within the framework of a **virtual power plant (VPP).** Virtual Power Plants are comprised of interconnected clusters of compact energy generation and storage systems, such as solar panels and batteries, which are collectively harnessed to provide electricity to the grid. With the consent of the participants, utilities can harness their energy during periods of peak demand or store it for future utilization [62]**.** In this context, the EVs are grouped together and managed as a unified distributed energy resource. In the VPP design, the EVs are observable by the Distribution System Operator (DSO), Transmission System Operator (TSO), or Grid Operator (GO) via the aggregator, enabling them to effectively engage in the energy market [61]. Fig 4.1 illustrates the simple VPP system.

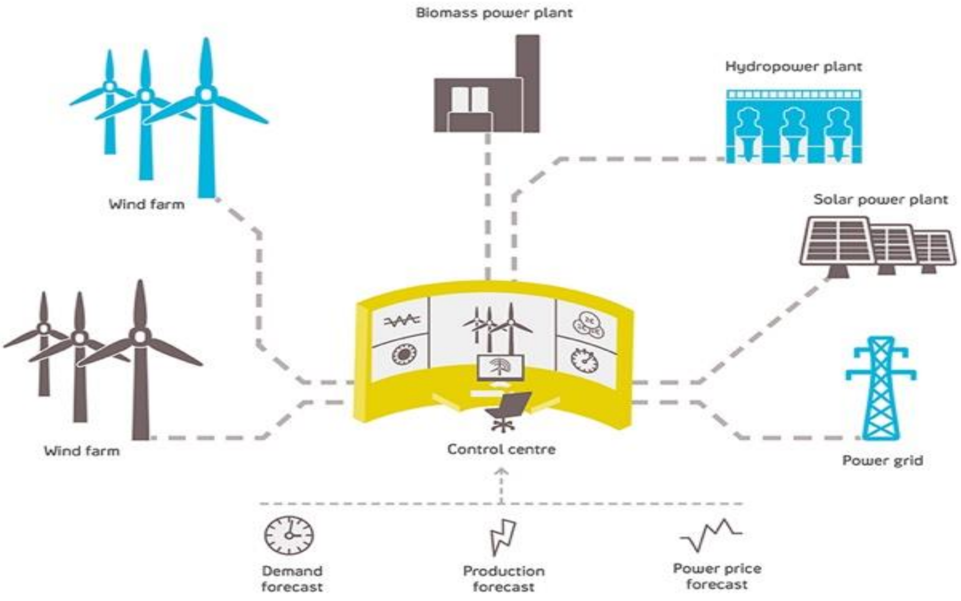


Fig 4.1 VPP structure [63].

Electric vehicles equipped with vehicle-to-grid system architecture.

The utilization of vehicle-to-grid technology enables an EV to transmit electrical power to the energy grid by means of a bidirectional charger that is regulated through a remote management system. Certain vehicles equipped with vehicle-to-grid technology possess the capability to provide auxiliary power in the event of a power outage. Nevertheless, it is important to note that V2G should not be conflated with Vehicle-to-Home (V2H) or Vehicle-to-Load (V2L) systems. In contrast to V2G, which involves the transfer of power from the vehicle to the grid, V2H and V2L systems utilize the vehicle's power to supply energy to a home or specific loads, respectively. V2G technology facilitates the integration of EVs with the electricity system, enabling them to establish synchronization and inject energy into the grid through the utilization of a specialized bidirectional charger. The advanced gadgets are equipped with intricate power converters that possess the capability to either recharge the electric vehicle's battery or transmit electricity back to the grid upon command. This functionality is particularly useful during periods of elevated power use, as it aids in the stabilization of the grid [64]. Fig 4.1 represent simple V2G concept.

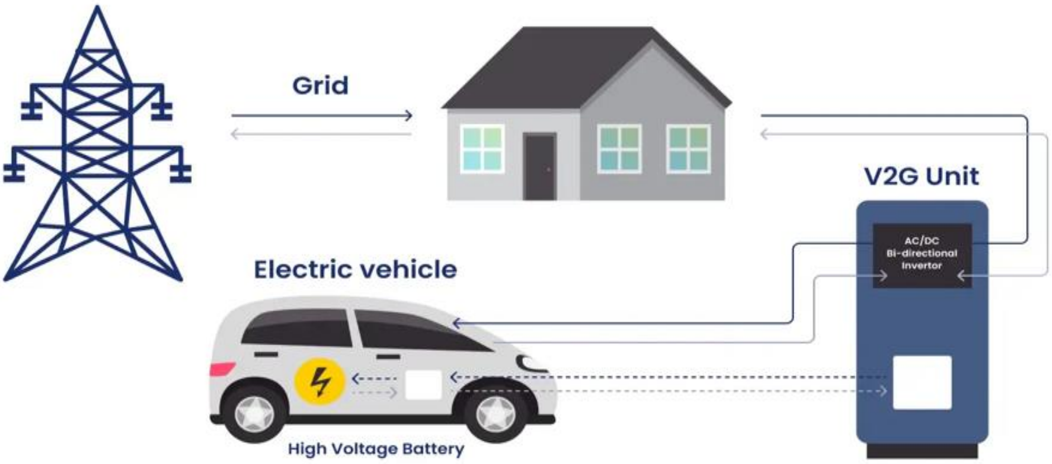


Fig 4.1 V2G working principle [65].

4.2 The Effects Of EVGI

The impact of integrating electric vehicles into the grid can be categorized into positive as well as negative elements. Fig 4.2 provides a more comprehensive delineation of these details. Electric vehicles pose substantial issues for electrical utilities. The extensive EVGI has a significant effect on the stability of the distribution grid. The unfavorable impact observed can be attributed to alterations in load profiles, imbalances in voltage and frequency, the injection of excessive harmonics, and loss of energy. The overintegration cars to the power grid can lead to power quality deterioration, peak load challenges. The problems might be effectively addressed through the utilization of sophisticated power management methodologies [66].

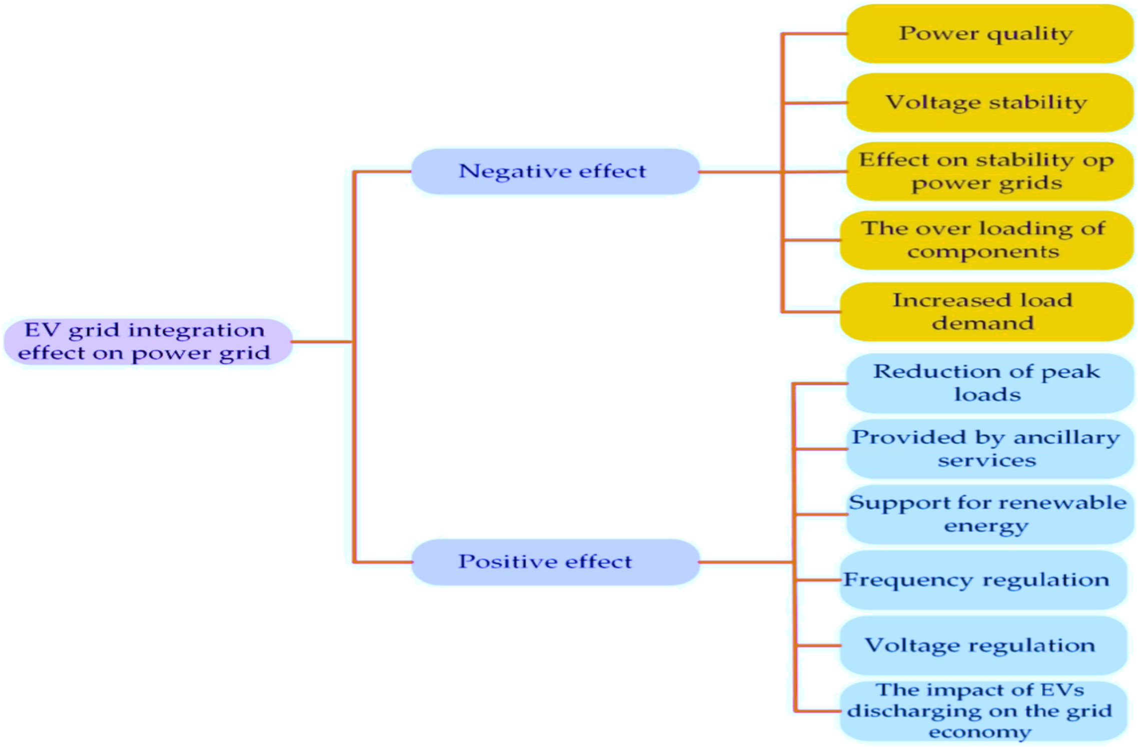


Fig 4.2 EVGI technical impacts

A number of scholars have conducted extensive research on the subject matter, and the following is a concise overview of their academic endeavors.

Negative Impacts

The impact on the stability of electricity grids: This study aims to examine the stability of a distribution power network that is connected with PHEVs. This study assumes that PHEVs may not necessarily require charging during periods of off-peak load consumption. The integration of additional electric vehicle loads into the existing system necessitates an assessment of IEEE33 bus system, considering both scenarios with CS included and without the incorporation of CS [67].

The components overloading effects: This article analyzes current EV technology advances, the probable consequences of broad electric vehicle use, and the many opportunities that result from EV adoption. A thorough investigation of overloaded components and grid effects was also done. The presence of extremely high levels of EVGI results in an increase in load demand, necessitating the generation and transmission of more electrical power. The current electric grid elements are not specifically engineered to accommodate the extra charges, resulting in potential overloading of components and potential impact on the lifespan of transformers [68].

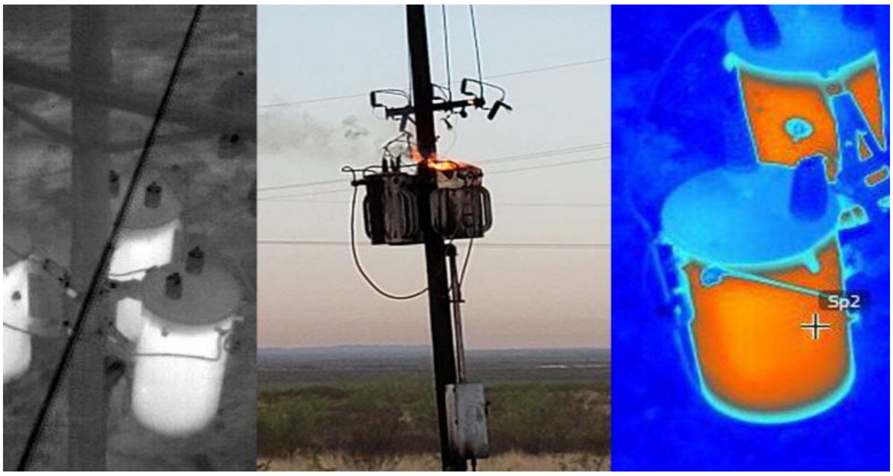


Fig 4.3 Transformer overloading consequences [71]

As depicted in Figure 4.3, the transformer experienced a significant rise in temperature because of overloading. This thermal stress ultimately resulted in the failure of the transformer, leading to severe and potentially disastrous effects, such as the occurrence of fire. Additionally, this failure may also trigger subsequent malfunctions in other interconnected components.

Power loss effects: This study presents a comprehensive methodology for assessing the effects of varying degrees of plug-in EV adoption on investment in distribution networks and the resulting increase in energy losses. The suggested methodology relies on the utilization of a comprehensive distribution planning model of significant magnitude, employed for the examination of two authentic distribution regions. The widespread integration of EVs into the electrical grid results in a significant increase in real power demand, thus leading to power losses within the distribution system. The loss of power experienced during off-peak hours can potentially increase by up to 40%[69].

Voltage imbalance effects: Case studies show that EV charging demand has little impact on urban distribution networks due to low EV adoption. As EV penetration rises, long-term network design must include them. Furthermore, the calculation findings have recognized the need and potential of "smart charging". The utilization of single-phase EV chargers has the potential to induce phase unbalance when a significant amount of cars are refueling concurrently on the one phase [70]. The primary source of voltage unbalance is the presence of current imbalances. The observed outcome may be attributed to an erroneous allocation of single-phase loads. In the context of a vulnerable power grid, such as on an EV, ensuring equitable allocation of loads across the different phases becomes particularly crucial. Figure 4.4 illustrates the disparity between balanced and imbalanced voltage, clearly demonstrating the observable phase shifts in voltage.

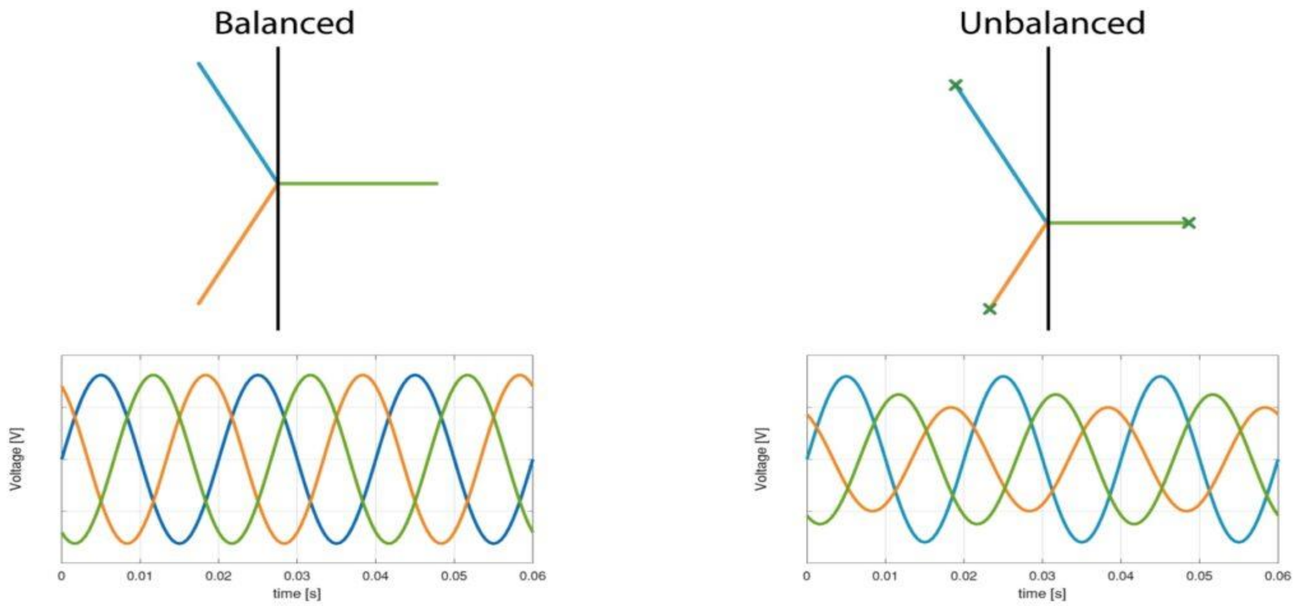


Fig 4.4 Balanced/Unbalanced Voltage difference [72].

Positive Impacts

EVGI has the potential to yield several benefits, encompassing ancillary services, congestion management, RES integration, reduction of peak loads and enhancement of power quality.

Ancillary services: The name "ancillary services" describes a range of functions offered by the power grid beyond just generating and distributing power. The provision of these services is essential for ensuring the uninterrupted transmission of energy, so ensuring that the supply consistently matches the demand, so assuring stability and security within the electricity system. At any given moment, the quantity of electricity generated by power plants that are linked to an electric grid must precisely correspond to the quantity of energy withdrawn from the grid by users, including residences, factories, buildings, and electric vehicles. If the nominal frequency of the grid exceeds a certain range, there is a potential chance of experiencing a blackout. This study aims to establish a connection between ancillary services and EV flexibility, CS and their optimal placement [73].

Frequency Regulation: A significant number of electric cars, which function as distributed energy storage units, are able to send input to the grid in the event that the grid is required to supply electricity and auxiliary services. For the purpose of this investigation, authors construct a model of a signal area power system as well as a linked two-area model that incorporates V2G. Based on the findings, it is evident that V2G has the capability to effectively decrease the frequency deviation and tie-line flow deviation, as well as the reserve capacity of the system [74].

Renewable energy sources: The integration of EVs with RES contributes to the advancement of environmental sustainability on a broader scale. In contrast to conventional cars powered by fossil fuels, electric vehicles charged using renewable energy sources have the potential to enhance air quality, mitigate air pollutants, and support efforts towards biodiversity conservation. It also enables the efficient control of the power grid. Smart charging solutions may effectively mitigate the unpredictable nature of renewable sources such as solar and wind. Electric vehicles have the potential to be charged during periods of increased renewable energy output, so aiding in load balancing and reducing strain on the electrical grid [75]. The schematic presented in Figure 4.5 illustrates the integration of a renewable energy distributed generation (DG) system and EVs at the point of common coupling (PCC). This integration occurs near the load, which is supplied by both the AC grid and the DG system. EVs are interconnected in parallel configuration, at the DC bus of the charger.

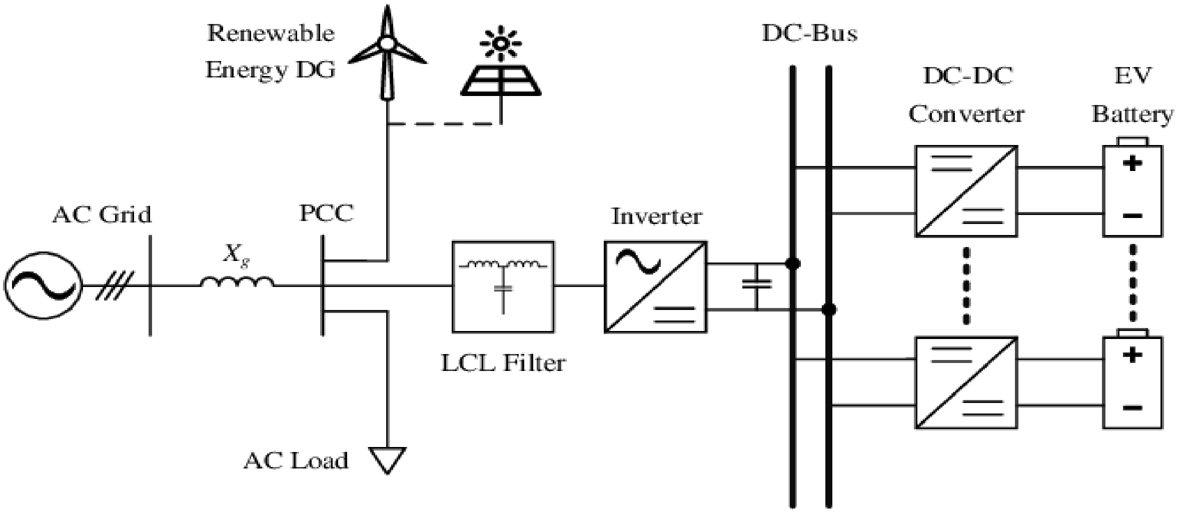


Fig 4.5 RES integration for EV charging simplified scheme.

Peak load reduction: In this study, authors have introduced a novel methodology aimed at mitigating the peak load experienced at public electric car charging stations. This approach is centered around the implementation of dynamic pricing mechanisms and incorporates considerations for uncertainties arising from client preferences. The utilization of simulations has demonstrated that including the peak demand into the scheduling of charging operations may yield a significant enhancement in the annual profit of the charging station operator [76].

G2V-V2G system for peak load reduction: This study presents a V2G optimization technique that aims to improve the power flow of grid-connected EVs by minimizing the variation in power grid demand. Fig 4.6 illustrates a generic power load curve on a daily basis. Moreover, the objective of achieving the intended grid loading is accomplished by the use of peak load shaving and load leveling techniques. These techniques aim to reduce the discrepancy between electricity grid charging and the goal loading, as seen in Fig 4.6. The V2G technique is executed by facilitating refueling in periods when the energy grid charging is below the desired level, also known as the G2V operation. In contrast, electric cars are obligated to release the stored electricity from their batteries at instances when the grid's demand exceeds the intended load, a process known as vehicle-to-grid operation [77].

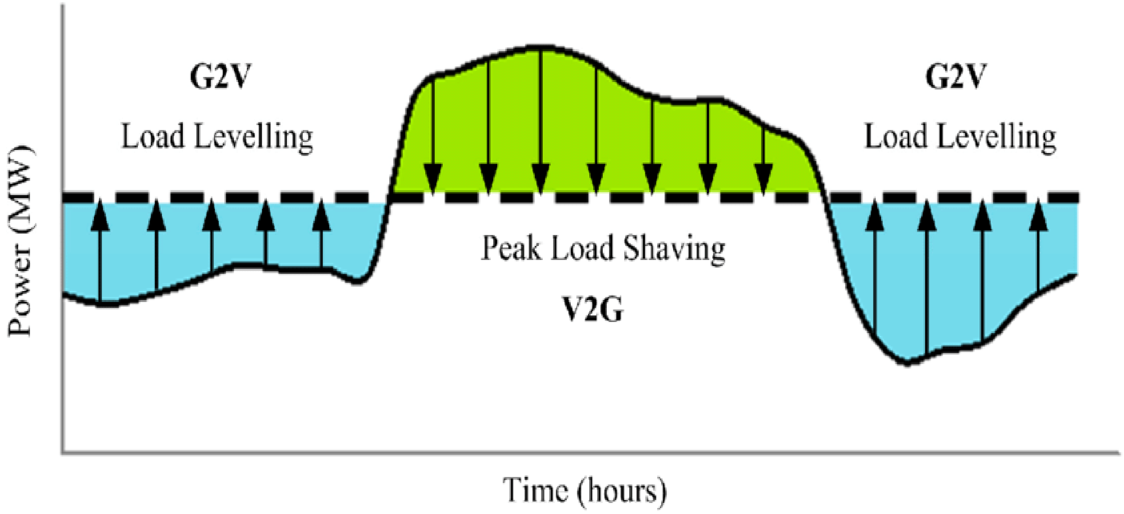


Fig 4.6 Peak load leveling with help of G2V-V2G-G2V method [77].

CHAPTER FIVE

Simulation

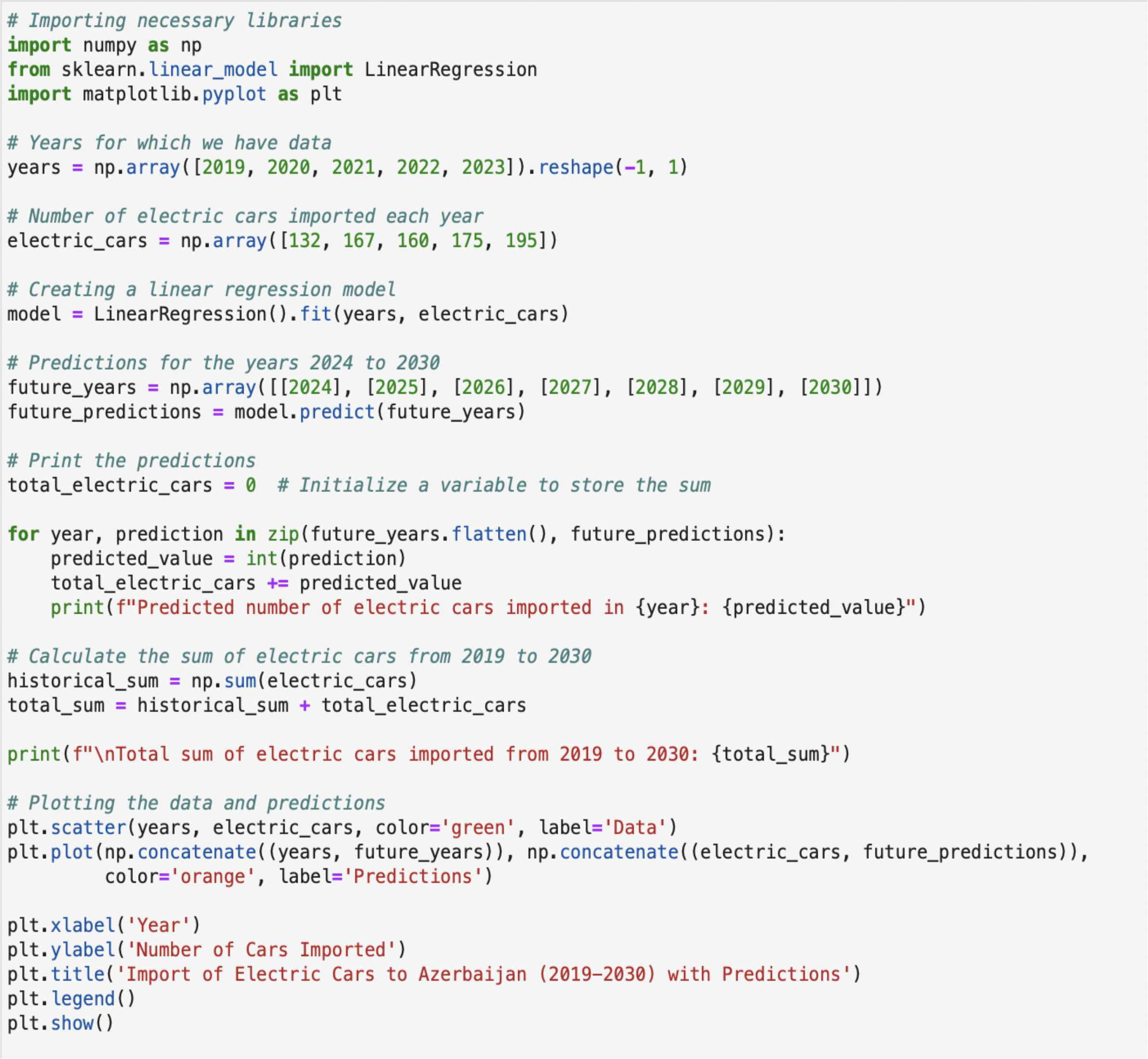
This chapter will examine some simulations conducted using Python and MATLAB Simulink as simulation tools. The initial simulation tool will be developed using the Python programming language. Its purpose is to anticipate the number of EVs that will be imported into Azerbaijan.

5.1 Forecasting EV Import to Azerbaijan (2019-2030) Using Linear Regression

The incorporation of EVs into the transportation infrastructure of Azerbaijan is a fundamental approach aimed at mitigating greenhouse gas emissions and fostering sustainability. Considering this transition, accurate forecasting of the future import of electric vehicles has significant importance in the realms of infrastructure development and energy management. This research utilizes a linear regression model to predict the import of electric automobiles to Azerbaijan from the years 2019 to 2030. The data related to the years 2019 to 2023 has been sourced from Ismail Huseynov, the First Deputy Chairman of Azerbaijan's State Customs Committee. The number of electric motor vehicles imported to Azerbaijan witnessed an increase from 132 cars in 2019 to 167 cars in 2020, followed by a little decrease to 160 cars in 2021, 175 cars in 2022. The number of imported hybrid automobiles in the year 2019 amounted to 3,645 units, followed by an increase to 5,081 units in 2020, and a further surge to 12,936 units in 2021. According to the speaker, as of February 20, 2023, the aggregate count of electric cars that were imported amounted to 195.

5.2 Methodology

Figure 5.1 depicts the Python code utilized for the prediction model.



```
# Importing necessary libraries
import numpy as np
from sklearn.linear_model import LinearRegression
import matplotlib.pyplot as plt

# Years for which we have data
years = np.array([2019, 2020, 2021, 2022, 2023]).reshape(-1, 1)

# Number of electric cars imported each year
electric_cars = np.array([132, 167, 160, 175, 195])

# Creating a linear regression model
model = LinearRegression().fit(years, electric_cars)

# Predictions for the years 2024 to 2030
future_years = np.array([[2024], [2025], [2026], [2027], [2028], [2029], [2030]])
future_predictions = model.predict(future_years)

# Print the predictions
total_electric_cars = 0  # Initialize a variable to store the sum

for year, prediction in zip(future_years.flatten(), future_predictions):
    predicted_value = int(prediction)
    total_electric_cars += predicted_value
    print(f"Predicted number of electric cars imported in {year}: {predicted_value}")

# Calculate the sum of electric cars from 2019 to 2030
historical_sum = np.sum(electric_cars)
total_sum = historical_sum + total_electric_cars

print(f"\nTotal sum of electric cars imported from 2019 to 2030: {total_sum}")

# Plotting the data and predictions
plt.scatter(years, electric_cars, color='green', label='Data')
plt.plot(np.concatenate((years, future_years)), np.concatenate((electric_cars, future_predictions)),
         color='orange', label='Predictions')

plt.xlabel('Year')
plt.ylabel('Number of Cars Imported')
plt.title('Import of Electric Cars to Azerbaijan (2019-2030) with Predictions')
plt.legend()
plt.show()
```

Fig 5.1 Python prediction model code

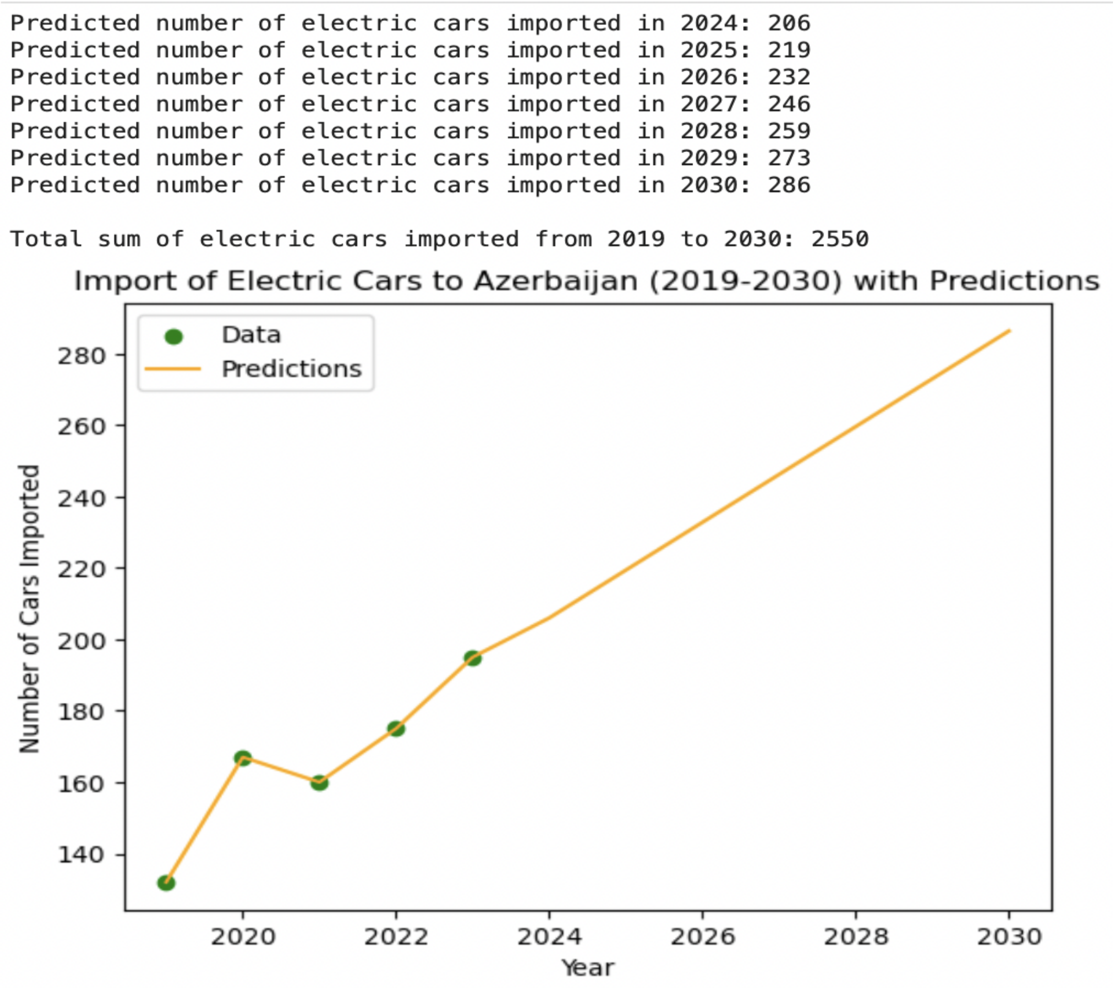
Importing libraries: ‘Numpy’ is imported as np for numerical operations. ‘LinearRegression’ from ‘sklearn’ is imported to create a linear regression model. ‘matplotlib.pyplot’ is imported as ‘plt’ for creating plots.

Data Collection: The collection of data encompassed records spanning from 2019 to 2023, specifically focusing on the yearly import figures of electric automobiles in Azerbaijan.

A linear regression model was constructed with the scikit-learn toolkit. The model received training using historical data to create a correlation between the years and the quantity of electric automobiles imported.

Prediction for Future Years: Predictions for the import of electric cars for the years 2024 to 2030 were made using the trained linear regression model.

Result: Prediction results are shown in the below Fig 5.2



```
Predicted number of electric cars imported in 2024: 206
Predicted number of electric cars imported in 2025: 219
Predicted number of electric cars imported in 2026: 232
Predicted number of electric cars imported in 2027: 246
Predicted number of electric cars imported in 2028: 259
Predicted number of electric cars imported in 2029: 273
Predicted number of electric cars imported in 2030: 286

Total sum of electric cars imported from 2019 to 2030: 2550
```

Fig 5.2 Prediction Results

The forecasts suggest a consistent upward trend in the import of electric vehicles to Azerbaijan over the projected period. This is consistent with the worldwide shift towards electric mobility and the increasing focus on environmentally friendly transportation. The use of a linear regression model offers an initial projection of the import of electric cars to Azerbaijan. Nevertheless, it is important to take into account that several real-world variables, including governmental regulations, economic circumstances, and improvements in EV technology, might potentially impact the actual figures pertaining to imports.

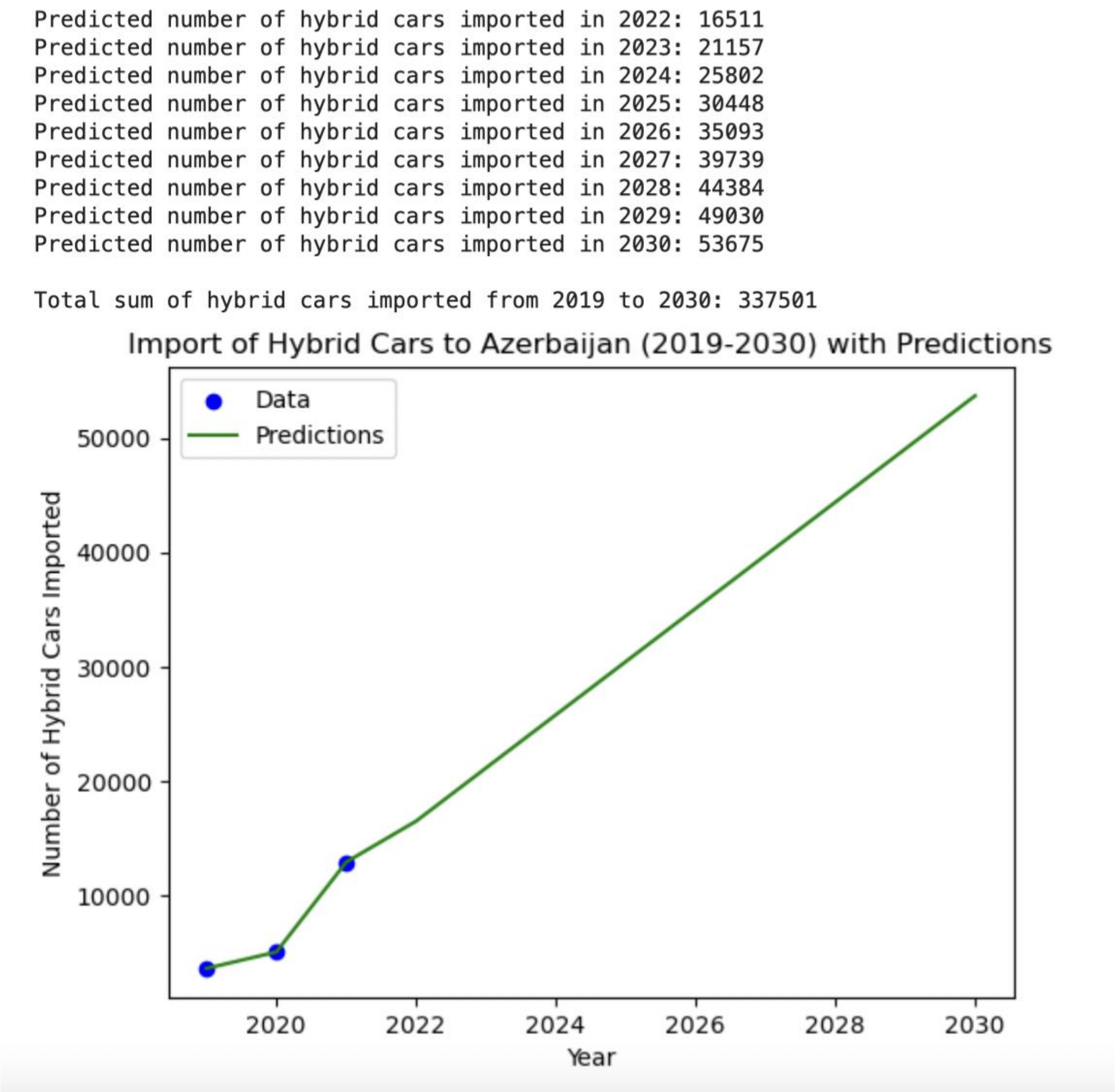
Forecasting HEV Import to Azerbaijan (2019-2030)

Fig 5.3 illustrates the python code for forecasting.

```
# Importing necessary libraries
import numpy as np
from sklearn.linear_model import LinearRegression
import matplotlib.pyplot as plt

# Years for which we have data
years_hybrid = np.array([2019, 2020, 2021]).reshape(-1, 1)

# Number of hybrid cars imported each year
hybrid_cars = np.array([3645, 5081, 12936])

# Creating a linear regression model
hybrid_model = LinearRegression().fit(years_hybrid, hybrid_cars)

# Predictions for the years 2022 to 2030
future_years_hybrid = np.arange(2022, 2031).reshape(-1, 1)
future_predictions_hybrid = hybrid_model.predict(future_years_hybrid)

# Print the predictions
total_hybrid_cars = 0  # Initialize a variable to store the sum

for year, prediction in zip(future_years_hybrid.flatten(), future_predictions_hybrid):
    predicted_value = int(prediction)
    total_hybrid_cars += predicted_value
    print(f"Predicted number of hybrid cars imported in {year}: {predicted_value}")

# Calculate the sum of hybrid cars from 2019 to 2030
historical_sum = np.sum(hybrid_cars)
total_sum = historical_sum + total_hybrid_cars

print(f"\nTotal sum of hybrid cars imported from 2019 to 2030: {total_sum}")

# Plotting the data and predictions
plt.scatter(years_hybrid.flatten(), hybrid_cars, color='blue', label='Data')
plt.plot(np.concatenate((years_hybrid.flatten(), future_years_hybrid.flatten())),
         np.concatenate((hybrid_cars, future_predictions_hybrid)),
         color='green', label='Predictions')

plt.xlabel('Year')
plt.ylabel('Number of Hybrid Cars Imported')
plt.title('Import of Hybrid Cars to Azerbaijan (2019-2030) with Predictions')
plt.legend()
plt.show()
```

Fig 5.3 Prediction model code for HEV

Applying the identical methodology to determine the quantity of hybrid electric vehicles will get the result depicted in Figure 5.4.



```
Predicted number of hybrid cars imported in 2022: 16511
Predicted number of hybrid cars imported in 2023: 21157
Predicted number of hybrid cars imported in 2024: 25802
Predicted number of hybrid cars imported in 2025: 30448
Predicted number of hybrid cars imported in 2026: 35093
Predicted number of hybrid cars imported in 2027: 39739
Predicted number of hybrid cars imported in 2028: 44384
Predicted number of hybrid cars imported in 2029: 49030
Predicted number of hybrid cars imported in 2030: 53675

Total sum of hybrid cars imported from 2019 to 2030: 337501
```

Fig 5.4 HEVs import prediction.

Result: The provided printed forecasts include a comprehensive analysis of the projected quantity of hybrid vehicles that will be imported annually throughout the designated period. This section provides a concise summary of the anticipated patterns and developments, offering a convenient means of gaining a rapid understanding of the forecasted trends.

However, this approach involves the utilization of simple linear regression, which implies that it is not entirely precise. Nevertheless, it may be employed as a rudimentary evaluation technique.

Conclusion: Based on the simulation, it is predicted that the quantity of AEVs between the years 2019 and 2030 would amount to 2550 vehicles. In contrast, the number of Hybrid Electric Vehicles (HEVs) anticipated to be imported during the same period is estimated to reach 337,501 cars. Predicting the quantity of fast charging stations in Azerbaijan is challenging due to the absence of historical statistical data. Nevertheless, it is evident that Azerbaijan is actively pursuing the advancement of its sustainable transportation sector, the incorporation of EV rapid charging infrastructure at gas stations, such as 'Azpetrol', represents a significant stride towards achieving a sustainable future with less environmental impact, various private firms, like ‘ElektraAZ’, ‘EVpointAZ’, 'EStationAZ', 'SolarWindAZ', 'ElcarAZ', ‘Ilab MMC’ among others, are actively involved in the development of a market for home-based charging stations, thereby indicating a probable upward trajectory in the number of fast charging stations. It is noteworthy to emphasize that this simulation is based on the "Linear regression" model. However, it should be acknowledged that this simulation can only serve as a reference. Real-world data is inherently complex and subject to many scenarios.

5.3 MATLAB Simulation

This simulation shows V2G and G2V model. Given that a significant proportion of EV owners in Azerbaijan has single phase charging outlets in their residences, this simulation focuses on the development of single-phase converters that possess bidirectional capabilities. This MATLAB Simulink model is designed to showcase the working principle of V2G and G2V modes in system. Vehicle-to-grid technology facilitates the exchange of energy in both directions between electric vehicles and the electric grid, enabling vehicles to function as portable energy storage units.

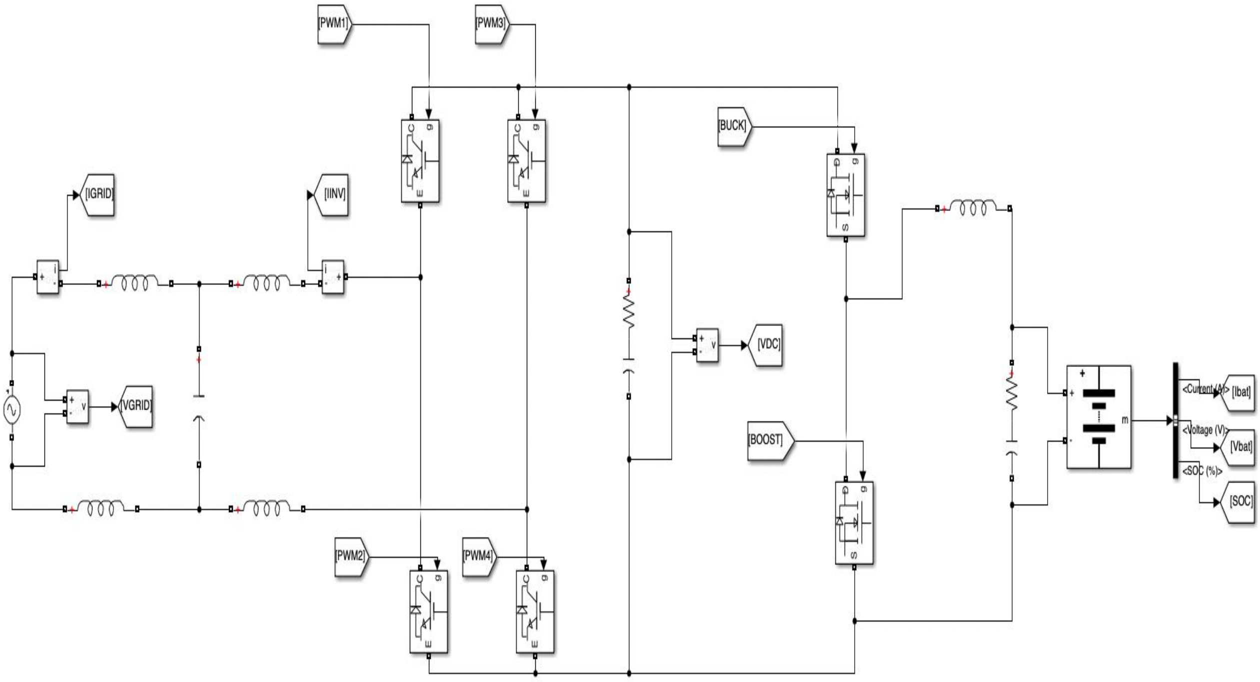


Fig 5.5 MATLAB Simulink Model Single Phase V2G-G2V Concept

The MATLAB Simulink model has several components, including a Grid, LCL filter, AC-DC/DC-AC converter active rectifier, DC-DC converter BUCK/BOOST, and Battery system. The voltage source produces a conventional one-phase voltage and frequency of 220V at 50 Hz, as often seen in Azerbaijan. The LCL filter employs conventional values for the purpose of filtering the output, resulting in enhanced smoothness. The single-phase pulse width modulation (PWM) active rectifier, implemented in a bridge configuration, is designed to convert alternating current (AC) to direct current (DC). This rectifier comprises four insulated-gate bipolar transistors (IGBTs) and effectively regulates the output voltage at around 400 V. The model incorporates a BUCK/BOOST bidirectional converter to facilitate the transition between V2G and G2V modes. The battery utilized in this particular model is a lithium-ion (Li-ion) battery, possessing a nominal voltage of 170 and a capacity of 120 Ah.

5.4 Case 1 G2V mode.

The simulation findings demonstrate that the grid voltage is consistently maintained at a stable level of 220 volts, which accurately represents the nominal voltage of the single-phase electrical grid. The maintenance of grid voltage stability is necessary in order to guarantee the optimal operation of electrical appliances and equipment that are interconnected with the grid. Concurrently, the grid current is measured around 20 amperes, serving the purpose of charging the electric vehicle's battery and restoring its energy storage for further utilization. Current and voltage are both having the same phase angle when the battery is being charged. Fig 5.6 displays source voltage and current in G2V mode.

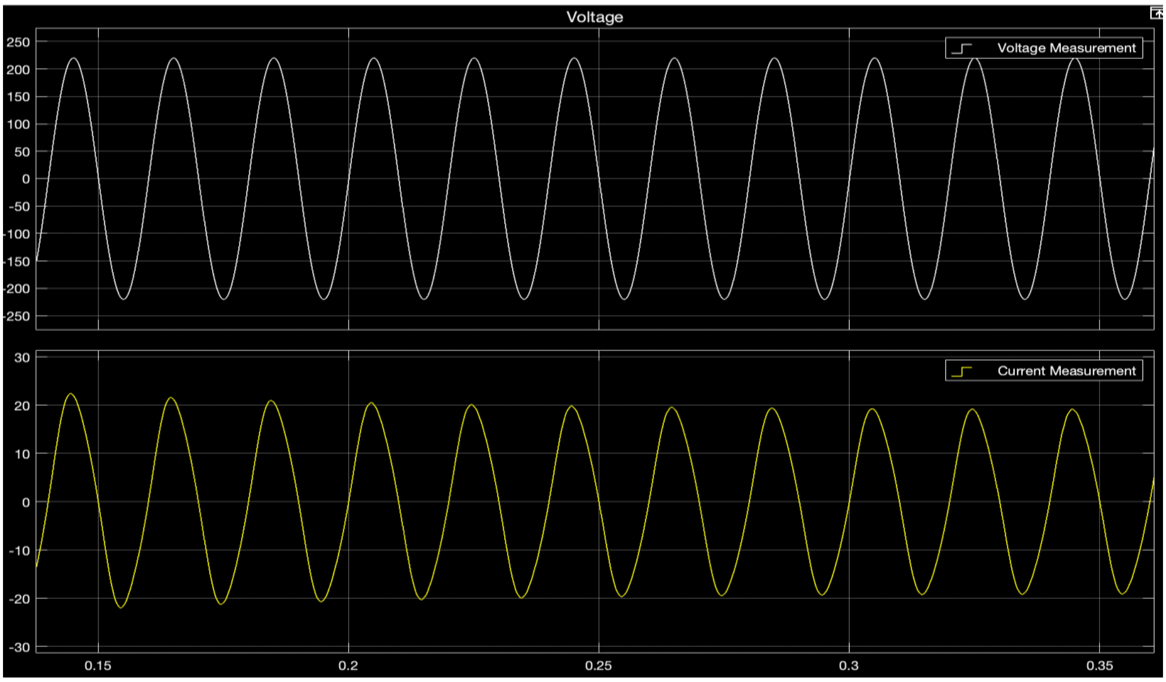


Fig 5.6 Voltage and Current in G2V mode.

The voltage at the DC bus is maintained at a controlled level of 400 volts during the V2G mode. Bellow Fig 5.7 shows the bus voltage at G2V mode.

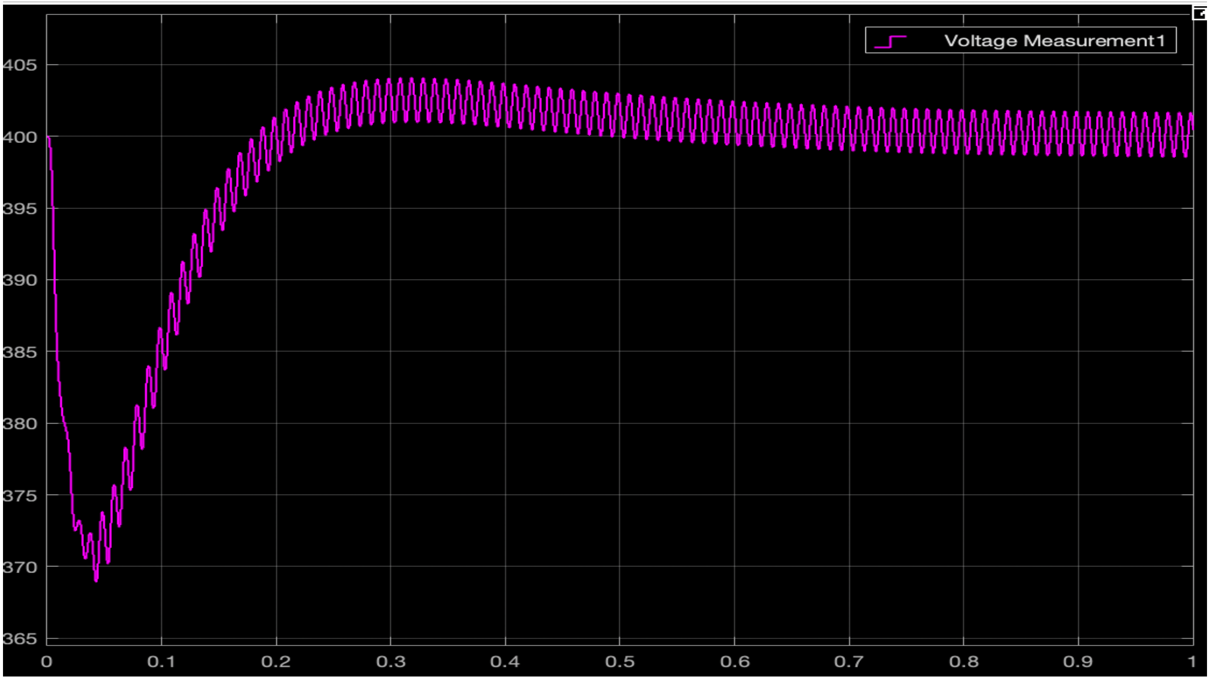


Fig 5.7 DC bus voltage at G2V mode.

The State of Charge (SOC) of the electric vehicle's battery plays a crucial role during G2V mode. According to the data presented in Figure 40, it can be observed that the state of charge of the battery displays an upward trend, indicating that the system is functioning in the G2V mode. Over a duration of one minute, the state of charge climbed marginally from 30.000% to 30.003%. The voltage has successfully reached a value of 171.2 V, indicating a favorable outcome. Additionally, the current is measured at -12 A, suggesting that the battery is drawing energy from the grid. The charging mechanism regulates the voltage to prevent over charging and ensure the battery's optimal health and performance. An optimally engineered G2V system guarantees that the battery voltage is in line with the charging profile, effectively regulating both voltage and current to facilitate efficient energy transfer.

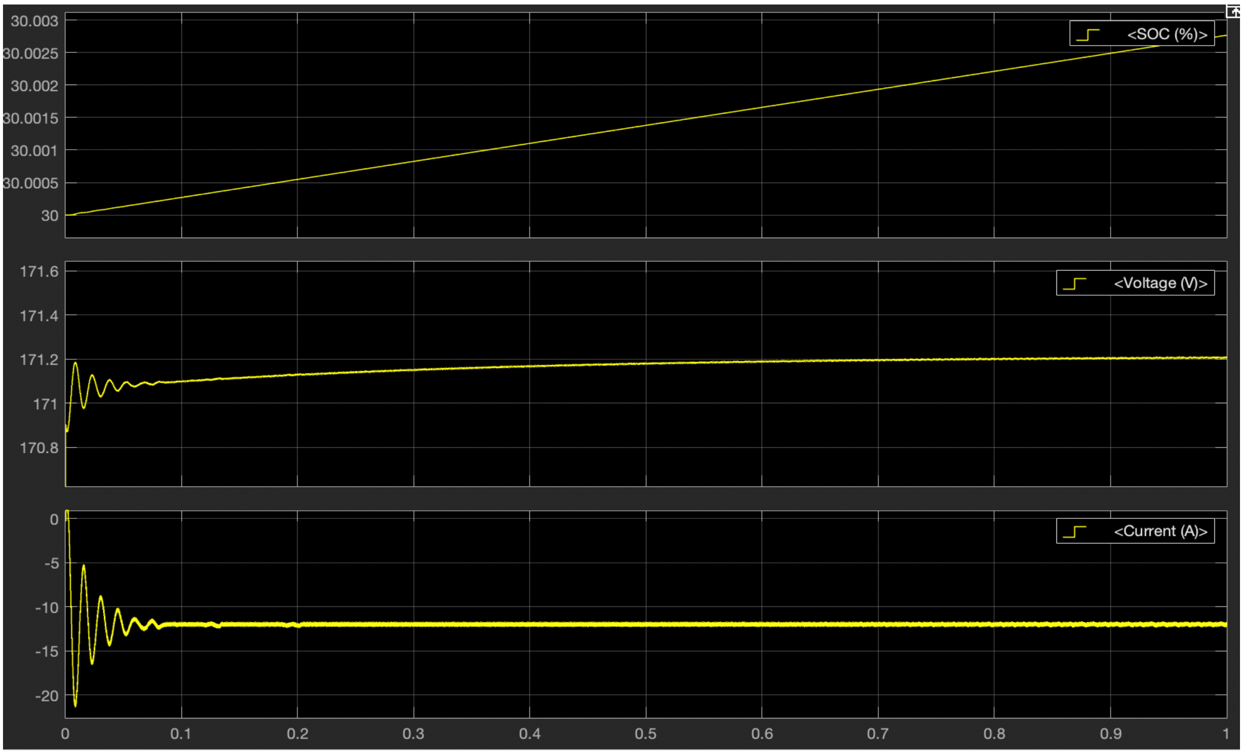


Fig 5.8 State of Charge SOC%, battery voltage, battery current results in G2V mode.

5.5 Case 2 V2G mode

The simulation aimed to evaluate the performance and efficiency of a V2G system functioning within a single-phase electrical grid. An analysis was conducted on key parameters, including voltage, current, and state of charge, to provide insight into the effects of bidirectional power flow between the electric car and the grid. The simulation demonstrated a clearly defined voltage waveform in V2G mode. While the electric car sent energy to the grid, the voltage nearly mirrored the frequency and amplitude of the grid. The V2G technology effectively demonstrated its capacity to adapt to grid requirements by maintaining voltage stability within acceptable ranges. Fig 5.9 illustrates Voltage and Current relation in V2G mode. The current waveform seen during V2G mode had an inverted shape 180 degrees phase difference in contrast to the voltage waveform, showing the power flow reversal from the electric car to the grid. The current waveform maintained sinusoidal characteristics, aligning with the grid frequency, and contributing minimal harmonic distortion.

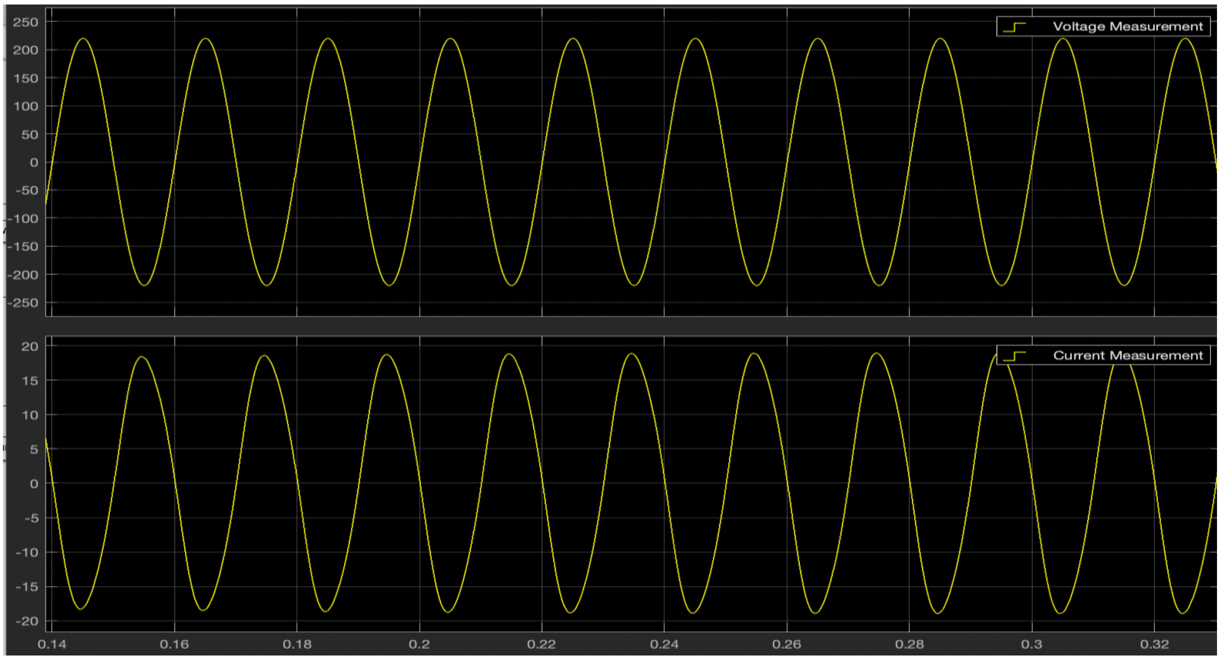


Fig 5.9 Voltage and Current relation in V2G mode

According to Figure 5.10, the converter system effectively maintains the battery voltage and stabilizes it at around 400 V, for further transfer.

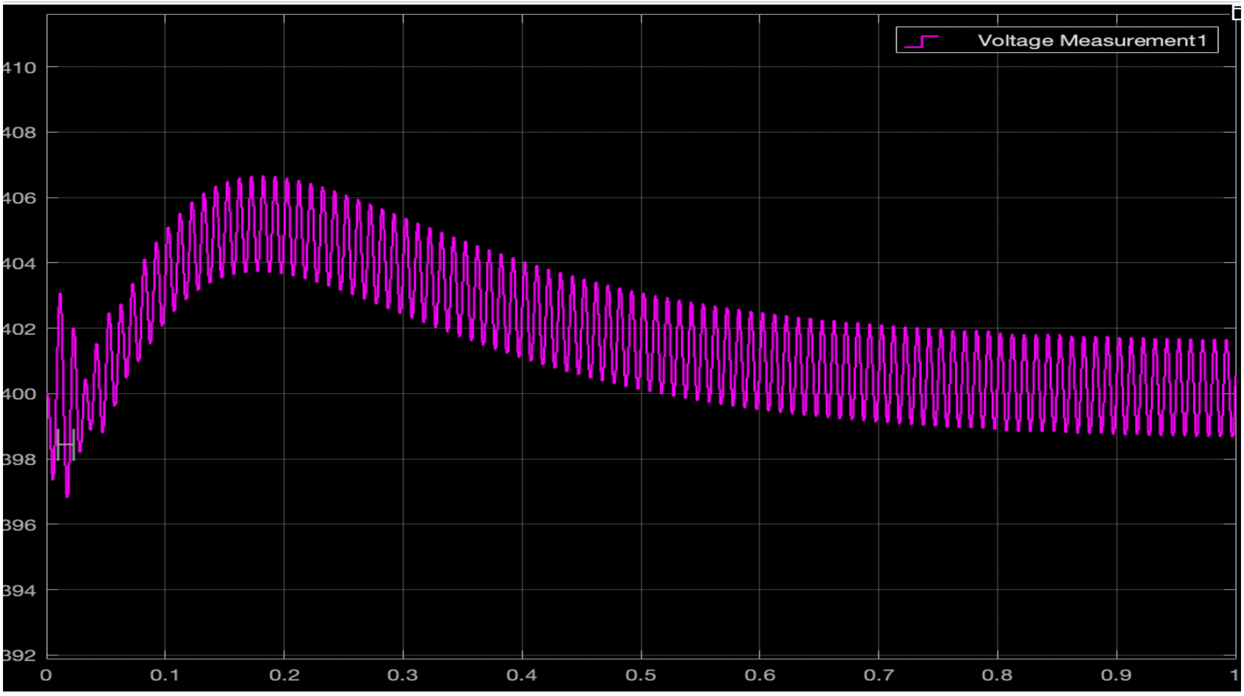


Fig 5.10 DC voltage at DC bus in V2G mode.

Fig 5.11 illustrates the SOC, voltage and current characteristic of battery in V2G mode. The electric vehicle's battery's SOC was continuously monitored during the simulation. During

V2G operation, the SOC of the battery steadily decreased as it transferred energy to the grid. The state of charge dynamics in line with the power flow demands, guaranteeing that the battery functioned within secure thresholds. SOC decreases from 80.000% to 79.997% throughout the 1-minute interval, indicating that the battery is supplying power to the grid. The voltage is being regulated at 173-172.5 V, while the current in the battery is 12 A, indicating that the battery is transferring energy from the battery to the grid.

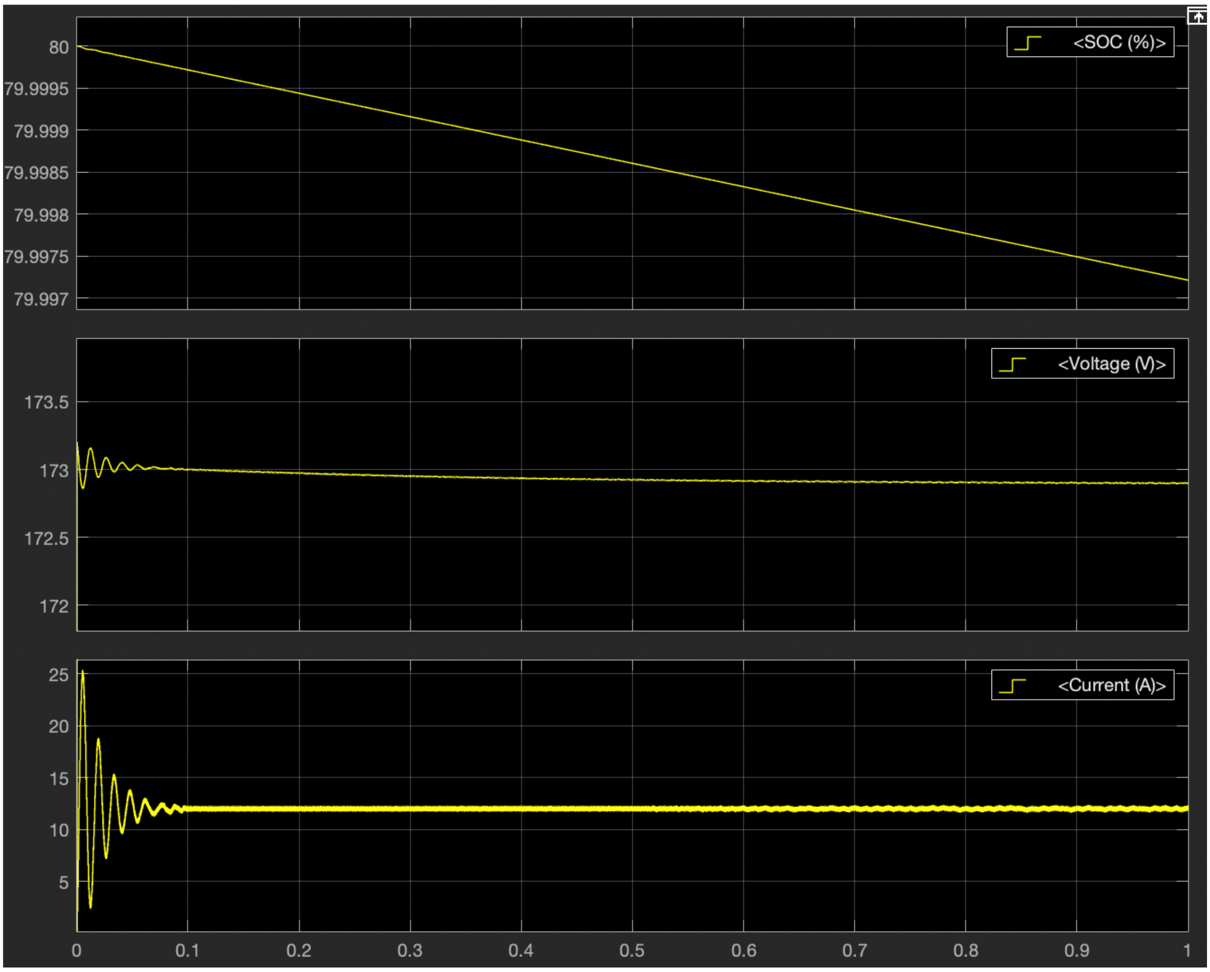


Fig 5.11 SOC, Voltage, and current parameters of battery in V2G mode.

5.6 Case 3 G2V-V2G merged system

The MATLAB Simulink simulation provides a thorough analysis of the interactions between the electrical grid and vehicles, both in terms of power flow from the grid to the vehicles and from the vehicles back to the grid in a single-phase electrical system. The integration of this simulation is essential for comprehending the bidirectional power exchange between an electric car and the grid, offering significant knowledge for the improvement and development of electric vehicle charging infrastructure.

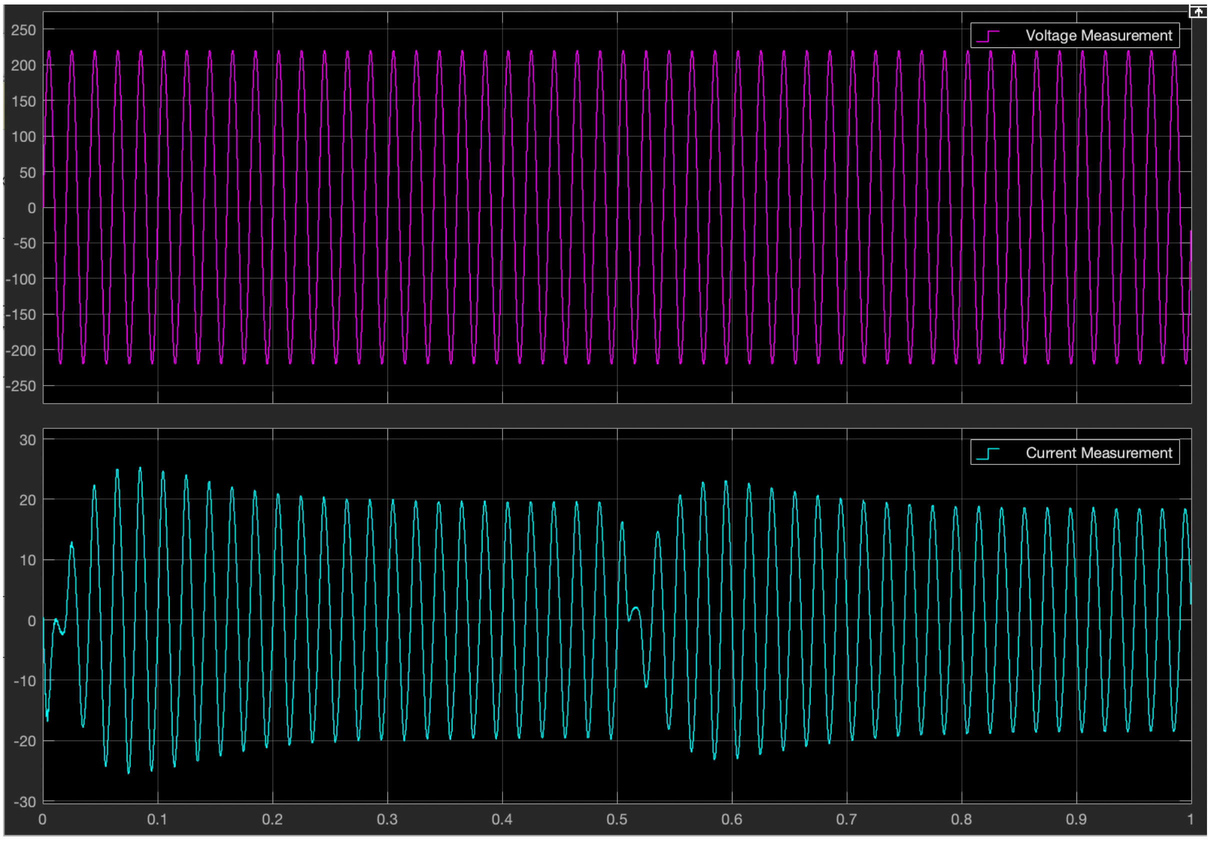


Fig 5.12 Grid voltage and source current.

Figure 5.12 indicates that there are no voltage imbalances during the transition. However, after half of the simulation time, when switching from G2V to V2G mode, there is a slight fluctuation in the current for about 2 or 3 cycles. Nevertheless, the system quickly stabilizes with the assistance of the system. In the first half, the voltage and current are in the same phase, indicating that the system is operating in G2V mode. In the second part, there is a phase change of 180 degrees, indicating that the system is now functioning in the V2G mode.

The following figure 45 depicts the relationship between the DC voltage in these two modes. At the start of the simulation, there is a small undershoot of approximately 0.1 units of time. However, the system quickly stabilizes. Around 0.5 units of time, there is an overshoot that lasts for a similar duration. This occurs when the system switches between G2V and V2G. The system promptly stabilizes itself. No other disturbances are observed during the simulation period.

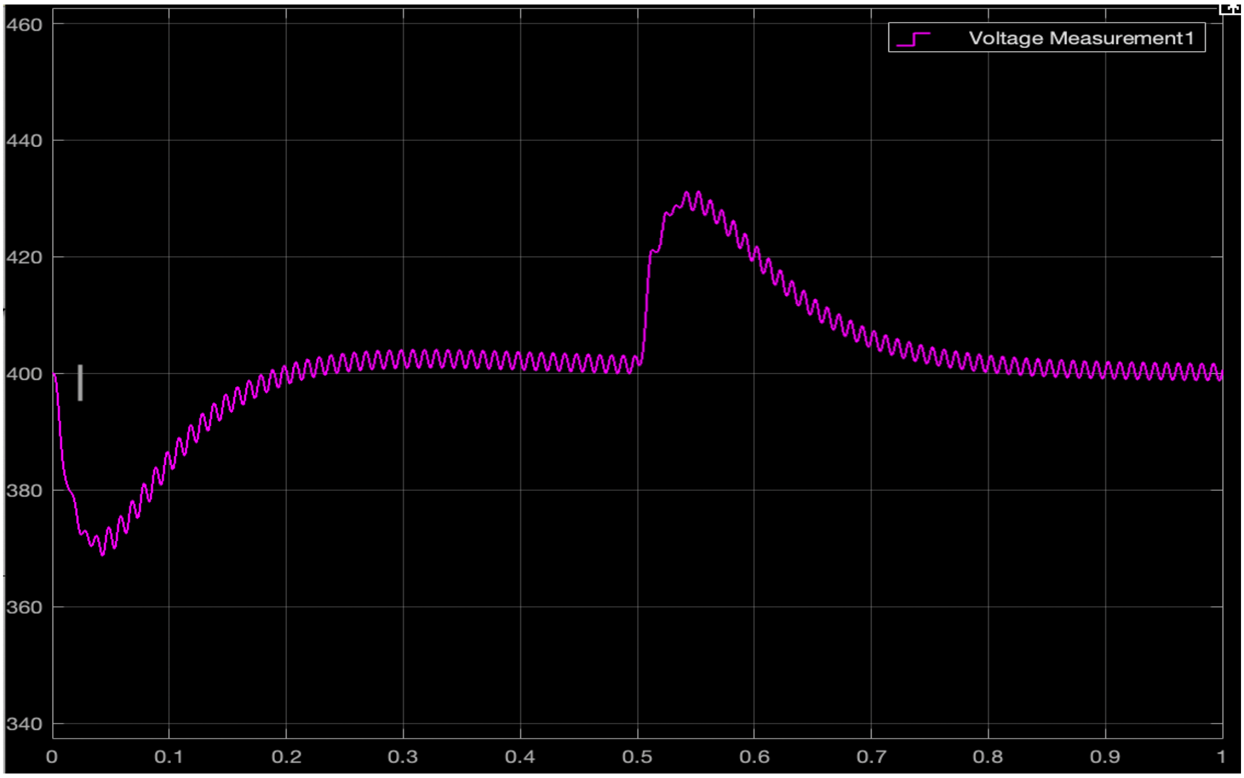


Fig 5.13 DC voltage on G2V-V2G switching mode.

Figure 5.13 depicts three common attributes shared by both systems: state of charge (SOC), battery voltage, and battery current. Observing the first half of the simulation, it is evident that the state of charge of the battery is increasing. The voltage initially oscillates but eventually stabilizes at 172.6V. The battery current also oscillates but becomes more consistent at -12A. However, at the midpoint of the simulation, when transitioning from grid-to-vehicle mode to vehicle-to-grid mode, the SOC begins to decrease. This indicates that the battery is transferring energy to the grid. After a brief while, the system experiences oscillations in voltage and current. However, it quickly stabilizes, with the voltage settling at around 172.2V and the current at 12A.

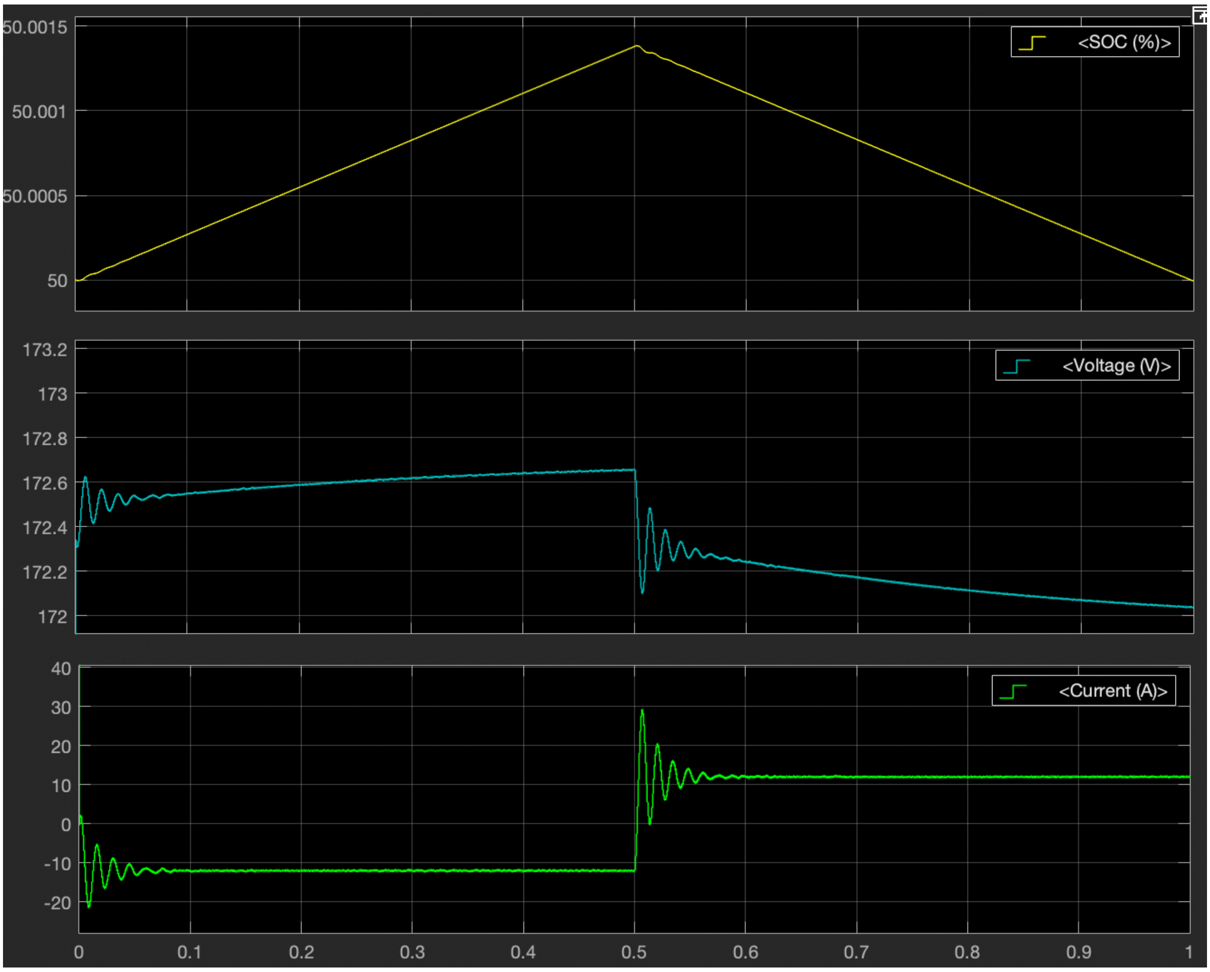


Fig 5.14 SOC%, battery voltage, battery current characteristics during the switching between G2V-V2G one phase system modes.

In conclusion, the Single-Phase V2G-G2V simulation conducted in MATLAB Simulink has provided valuable insights into the dynamics of bidirectional power flow between an electric vehicle and the electrical grid. This comprehensive study was undertaken to understand the interactions during both Grid-to-Vehicle and Vehicle-to-Grid modes.

Key findings.

Efficient Bidirectional Power Flow: The simulation demonstrated efficient bidirectional power flow, showcasing the capability of the system to seamlessly switch between charging and discharging modes.

Voltage and Current Stability: Voltage and current waveforms remained stable during both G2V and V2G modes, indicating a well-controlled power exchange between the EV and the grid.

Battery Health and SOC Management: Monitoring the State of Charge (SOC) dynamics throughout the simulation provided a clear understanding of the battery's charging and discharging behaviors.

CHAPTER SIX

Conclusion And Future Research

6.1 Conclusion

To summarize, this thesis has thoroughly examined the EV charging infrastructure, specifically highlighting the evolving situation in Azerbaijan. The global imperative to address climate change has propelled the widespread adoption of EVs, necessitating the establishment of a robust charging infrastructure, government regulations, and innovative technologies. The research has explored the present condition of the worldwide EV situation, including regulations, EVCI, and the wider influence of EVCI on the power grid. The specific case study on Azerbaijan has shed light on the ambitious endeavors within the country to establish an electric vehicle production facility. The case study on Azerbaijan has revealed the country's ambitious efforts to construct a factory for producing electric vehicles. Notable contributions from both the government and commercial sector groups including Azpetrol, Elcar.az, and Charge.az have been crucial in influencing the trajectory of EVs in Azerbaijan.

Furthermore, a detailed analysis of the pricing dynamics of EV charging in Azerbaijan has been presented, offering insights into the economic aspects of EV ownership. The investigation into various charging options, using a Tesla Model S with 75 kWh battery as a reference, has provided a nuanced understanding of the cost and time implications for EV users, The analysis reveals that the fastest way to charge an EV in Azerbaijan is through the use of a 120 kW "Electra.az" level 3 fast charger. This charger, located in Baku city near "Fevvareler meydani" at KFC parking, is the only one of its kind in the area. It can fully charge a 75-kWh battery in just 37.5 minutes, but this convenience comes at a cost of 22.5 AZN, making it the most expensive option available. The cheapest solution was Azpetrol's terra 54 DC fast charger rated 50 kW which can charge the same vehicle for 90 minutes only for 9 AZN. Additionally, calculations were conducted to thoroughly analyze the pricing and charging time for different public and private chargers. The thesis has also explored the intricate integration of EVs into the power grid, unraveling concepts such as EV aggregators, Virtual Power Plants (VPPs), and the technological aspects of Vehicle-to-Grid (V2G) systems.

Additionally, the study has employed historical data and linear regression models to forecast trends in EV and HEV adoption in Azerbaijan from 2019 to 2030. As a result, it has been found that the total forecasted number of EVs from 2019 to 2030 is 2550 units, whereas the number of HEVs is 337501 cars, which clearly indicating the outstanding number of HEVs over the BEVs. Nevertheless, it is important to take into account that several real-world variables, including governmental regulations, economic circumstances, and improvements in EV technology, might potentially impact the actual figures pertaining to imports.

MATLAB Simulink simulations have been employed to analyze scenarios like G2V, V2G and a combined G2V-V2G system. These simulations offer realistic insights into the voltage, current, and state of charge dynamics in a single-phase EV charging system. The simulation demonstrated efficient bidirectional power flow, showcasing the capability of the system to seamlessly switch between charging and discharging modes. Voltage and current waveforms remained stable during both G2V and V2G modes, indicating a well-controlled power exchange between the EV and the grid. Monitoring the SOC dynamics throughout the simulation provided a clear understanding of the battery's charging and discharging behaviors.

In summary, this thesis serves as a comprehensive resource providing valuable insights into the intricate relationship between EVs and the power grid. By combining a global perspective with localized initiatives in Azerbaijan, it offers a nuanced understanding of the challenges and opportunities presented by the EVGI into the energy ecosystem. The research findings make a valuable contribution to the continuing discussion on sustainable transportation and energy management and highlight the importance of continual collaboration among stakeholders to achieve a more resilient and environmentally friendly future.

6.2 Future Research

For future research it’s better to study new charging technology namely Ultra-Fast Charging. In recent years, the advent of ultra-fast charging (UFC) technologies has emerged as a transformative force in the realm of electric mobility. Future research could aim to explore the consequences of ultra-fast charging for EV infrastructure by examining the technological subtleties of UFC, such as high-powered charging stations and developments in battery technology. Studying the effects of UFC on the stability, distribution, and resilience of the grid will provide essential knowledge for sustainable planning and the smooth integration of ultra-fast charging into the changing electric mobility sector. With the increasing popularity of UFC, it is crucial to comprehend its influence on the adoption of electric transportation, the demand for energy, and the stability of the power grid. This knowledge is essential for designing a sustainable and efficient future for high-speed electric transportation. Furthermore, the model that I develop in MATLAB Simulink may be upgraded to include the 3-phase system and perform a more comprehensive analysis of its effects on the power grid. According to several studies, EVs have a positive effect on the power grid when combined with other RES like wind or solar power. There are several ways available for MATLAB or any other simulation program. Furthermore, my prediction model has the potential to be enhanced by the incorporation of more accurate data and the utilization of diverse prediction algorithms.

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APPENDIX A

Python Forecasting code for EV

```
# Importing necessary libraries
import numpy as np
from sklearn.linear_model import LinearRegression
import matplotlib.pyplot as plt

# Years for which we have data
years = np.array([2019, 2020, 2021, 2022, 2023]).reshape(-1, 1)

# Number of electric cars imported each year
electric_cars = np.array([132, 167, 160, 175, 195])

# Creating a linear regression model
model = LinearRegression().fit(years, electric_cars)

# Predictions for the years 2024 to 2030
future_years = np.array([[2024], [2025], [2026], [2027], [2028], [2029], [2030]])
future_predictions = model.predict(future_years)

# Print the predictions
total_electric_cars = 0  # Initialize a variable to store the sum

for year, prediction in zip(future_years.flatten(), future_predictions):
    predicted_value = int(prediction)
    total_electric_cars += predicted_value
    print(f"Predicted number of electric cars imported in {year}: {predicted_value}")

# Calculate the sum of electric cars from 2019 to 2030
historical_sum = np.sum(electric_cars)
total_sum = historical_sum + total_electric_cars

print(f"\nTotal sum of electric cars imported from 2019 to 2030: {total_sum}")

# Plotting the data and predictions
plt.scatter(years, electric_cars, color='green', label='Data')
plt.plot(np.concatenate((years, future_years)), np.concatenate((electric_cars, future_predictions)),
         color='orange', label='Predictions')

plt.xlabel('Year')
plt.ylabel('Number of Cars Imported')
plt.title('Import of Electric Cars to Azerbaijan (2019-2030) with Predictions')
plt.legend()
plt.show()
```

APPENDIX B

HEV forecasting code for python.

```python
# Importing necessary libraries
import numpy as np
from sklearn.linear_model import LinearRegression
import matplotlib.pyplot as plt

# Years for which we have data
years_hybrid = np.array([2019, 2020, 2021]).reshape(-1, 1)

# Number of hybrid cars imported each year
hybrid_cars = np.array([3645, 5081, 12936])

# Creating a linear regression model
hybrid_model = LinearRegression().fit(years_hybrid, hybrid_cars)

# Predictions for the years 2022 to 2030
future_years_hybrid = np.arange(2022, 2031).reshape(-1, 1)
future_predictions_hybrid = hybrid_model.predict(future_years_hybrid)

# Print the predictions
total_hybrid_cars = 0  # Initialize a variable to store the sum

for year, prediction in zip(future_years_hybrid.flatten(), future_predictions_hybrid):
    predicted_value = int(prediction)
    total_hybrid_cars += predicted_value
    print(f"Predicted number of hybrid cars imported in {year}: {predicted_value}")

# Calculate the sum of hybrid cars from 2019 to 2030
historical_sum = np.sum(hybrid_cars)
total_sum = historical_sum + total_hybrid_cars

print(f"\nTotal sum of hybrid cars imported from 2019 to 2030: {total_sum}")

# Plotting the data and predictions
plt.scatter(years_hybrid.flatten(), hybrid_cars, color='blue', label='Data')
plt.plot(np.concatenate((years_hybrid.flatten(), future_years_hybrid.flatten())),
         np.concatenate((hybrid_cars, future_predictions_hybrid)),
         color='green', label='Predictions')

plt.xlabel('Year')
plt.ylabel('Number of Hybrid Cars Imported')
plt.title('Import of Hybrid Cars to Azerbaijan (2019-2030) with Predictions')
plt.legend()
plt.show()
```