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Thème

STUDY OF DIFFERENT TYPES OF CHARGING SYSTEMS FOR ELECTRIC VEHICLES

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Dedication

"

I dedicate this precious work to the dearest people in the world, to whom I express my love and affection for their encouragement, understanding and patience, who understood me and pushed me to learn, I am talking about you, my dear parents ***Abdelkader*** *and* ***REGUIEG Nassima****. To my brother* ***Saber*** *and sisters* ***Sara*** *and* ***Anfel*** *and all the family:* ***"RAKIK"*** *without exception.*

To all my friends who have always supported me, and all my friends of the Electrotechnical Engineering Class of 2019.

Without forgetting my partner ***MOUISSAT Mohammed Issam Eddine*** *with whom I have developed my end of study project.*

Finally to all those who appreciate me at my true value.

Thanks.

"

-RAKIK, Mohamed Akram

Dedication

"

*A special feeling of gratitude to my loving parents, **Djamel** and **SAHNINE Abbasia** whose words of encouragement and push for tenacity ring in my ears. My sisters **Abir**, **Souha** and **Kawthar** have never left my side and are very special.*

*I also dedicate this work to all my friends who have always supported me throughout the process, and all the family **MOUISSAT** and **SAHNINE** without exception.*

*Without forgetting my partner **RAKIK Mohamed Akram** with whom I have developed my end of study project.,*

Finally to all those who appreciate me at my true value. To all my loved ones, to all of you.

Thanks.

"

-MOUISSAT, Mohammed Issam Eddine

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In closing, I would like to thank anyone who has contributed directly or indirectly to this work.

Abstract

This project presents a study of different charging systems for electric vehicles, the purpose of this project is to present a state of art for the EV's than present all the methods of charging with all their different modes, then do a techno- economic study in order to determine which mode is the best for the consumers and rank all the modes. Using an algorithm of decision making (MCDM) called TOPSIS, which gives us the most balanced alternative as number 01.

The final techno-economic study showed that the best alternative is the dynamic wireless. And demonstrate that the WPT is way better that the plug-in system. So, there has to be development in this mode to a large deployment.

Keywords : Electric vehicles, charging system, charging station, plug-in charging, wireless charging, techno-economic study.

Résumé

Ce projet présente une étude des différents systèmes de charge pour les véhicules électriques. Le but de ce projet est de présenter un état de l'art pour les VE, de présenter toutes les méthodes de recharge avec tous leurs différents modes, puis de faire une étude technico-économique afin de déterminer quel mode est le meilleur pour les consommateurs et de classer tous les modes. En utilisant un algorithme de prise de décision (MCDM) appelé TOPSIS, qui nous donne l'alternative la plus équilibrée en numéro 01.

L'étude technico-économique finale a montré que la meilleure alternative est la technologie dynamique sans fil. Et démontrer que le WPT est bien meilleur que le système plug-in. Donc, il doit y avoir un développement dans ce mode pour un large déploiement.

Mots clés : Véhicules électriques, système de recharge, station de recharge, recharge par branchement, recharge sans fil, étude technico-économique.

ملخص

تقدم هذه الأطروحة دراسة لأنظمة الشحن المختلفة للسيارات الكهربائية والغرض منها هو تقديم حالة فنية للمركبات الكهربائية عبر تقديم جميع أساليب الشحن بجميع أشكالها المختلفة ، ثم إجراء دراسة اقتصادية تقنية من أجل تحديد الوضع الأفضل للمستهلكين وترتيب جميع أشكال الشحن. باستخدام خوارزمية صنع القرار MCDM) (تسمى TOPSIS ، والتي تمنحنا البديل الأكثر توازناً كرقم 01..

وأظهرت الدراسة التقنية الاقتصادية النهائية أن أفضل بديل هو اللاسلكي الديناميكي. وأثبتت أن النظام اللاسلكي أفضل بكثير من السلكي.لذلك، يجب أن يكون هناك تطور في هذا الوضع إلى انتشار كبير.

كلمات مفتاحية : السيارات الكهربائية، نظام الشحن، محطة الشحن، الشحن السلكي، الشحن اللاسلكي، دراسة تقنية-إقتصادية.

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Liste des sigles et acronymes

EV	*Electric Vehicle*
BEV	*Battery Electric Vehicle*
HEV	*Hybrid Electric Vehicle*
PHEV	*Plug-in Hybrid Electric Vehicle*
FCEV	*Fuel Cell Electric Vehicle*
IC	*Internal Combustion*
HC	*Combustion of Hydrocarbon*
R/P	*Reserves-to-Production Ratio*
ISO	*International Organization for Standardization*
IEC	*International Electrotechnical Commission*
RCD	*Residual Current Devices*
PWM	*Pulse-Width Modulation*
ENV	*Electric Networked Vehicle*
OSI	*Open System Interconnection*
RFID	*Radio Frequency Identification*
GSM	*Global System for Mobile communication*

CHAdeMO *"CHArge de MOve," equivalent to "charge for moving," and is a pun for "O cha demo ikaga desuka." in Japanese, meaning "Let's have a cup of tea while charging."*

V2G *Vehicle To Grid*

WPT *Wireless Power Transfer*

WEVCS *Wireless Electric Vehicle Charging System* Society of Automotive Engineers

SAE *Society of Automotive Engineers*

V2V *Vehicle To Vehicle*

MED *Mobile Energy Disseminators*

EMF *ElectroMagnetic Fields*

ICNIRP *International Commission on Non-Ionizing Radiation Protection*

MCDM *Method for Multiple-Criteria Decision Making*

TOPSIS *Technique for Order Preferences by Similarity to an Ideal Solution*

CAGR *Compound Annual Growth Rate*

OEM *Original Equipment Manufacturer*

ICPT *Inductive Coupling Power Transfer*

EPRI *Electric Power Research Institute*

ESS *Energy Storage System*

PCS *Power Conversion System*

BOP *Balance Of Plant*

IEEE *Institute of Electrical and Electronics Engineers*

General introduction

As the effects of global warming are increasingly felt, many people are looking for ways to reduce their carbon footprint. Electric vehicles are one way to do this, and in some parts of the world, they're becoming more popular with everyday consumers.

But, before the introduction of Electric vehicles, there's the need of charging stations (battery chargers) dedicated to this type of vehicles, which will encourage consumers to head to EV's more than the classic vehicles.

Battery chargers play a critical role in the development of EV's. Charging time and battery life are linked to the characteristics of the battery charger. A battery charger must be efficient and reliable, with high power density, low cost, and low volume and weight. Its operation depends on components, control, and switching strategies. Charger control algorithms areimplemented through analog controllers, microcontrollers, digital signal processors, and specific integrated circuits depending upon the rating, cost, and types of converters.

An EV charger must ensure that the utility current is drawn with low distortionto minimize power quality impact and at high power factor tomaximize the real power available from a utility outlet. IEEE, IEC, and the U.S. National Electric Code standards limit the allowable harmonic and dc current injection into the grid, and EV chargers are usually designed to comply.

With the increasing EV's deployment all over the world, lot of charging methods has been invented, firstly with the plug-in which has different levels and modes of charging. Then, wireless charging system (WPT) has seen the light recently with two modes, the static and the dynamic, so we can say that the last technology is still under development.

The main problem for the consumers is to choose the kind of charging method suit better the car and to his economic stat and his health and well being.

The objectives of the project are:

- Give a basics, historical background, fundamentals of working and the environmental impact of EV's.
- Have a detailed view of all the charging methods and their different modes.

- Do a technical-economic study of the different modes which we detailed in order to figure the best mode of charging using a method of multi-criteria.

This thesis is organized into four chapters:

The first chapter **Generalities about electric vehicles** has an objective to present a brief history, some generalities on electric vehicles, and to study its functioning as well as its different architectures and the elements constituting.

The second chapter **Plug-in charging system** will talk about the plug-in charging system and its history, identify the charging power levels, talk about conductive charging modes and the accessories of charging (station side and vehicle side), as well as the communication issues. Then, we're going to end the chapter with the advanced technology for plug-in charging which is V2G.

The third chapter **Wireless charging system** will show the newest technology of charging EV's is the wireless (WPT) which don't need cables or plugs to charge, but there's some concerns about the amount of power, yield of the process.

This chapter will clarify the theory of the resonance coupling WPT, talk about the different modes of the WPT (static and dynamic), Safety of the process on the human being and the new technologies in the way of development concerning the wireless systemes (G2V, V2V, MED).

The fourth chapter **Comparison of the different charging systems** will touch the study of the different charging systems of the electric vehicle seen in the previous chapters (plug-in normal charge, plug-in semi-fast charge, Plug-in fast charge, stationary wireless charging and the dynamic wireless charging) using one of the method of making decisions (Method for Multiple-Criteria Decision Making MCDM).

After seeing a lot of methods, we decided to use TOPSIS method because it using simple mathematical method and algorithm, using both quantitative and qualitative data, u have a clear differentiation of all the alternative and the decision making is easy.

Next thing we have to determine the criterias then find the right data for all the alternatives.

Chapter 1

Generalities about electric vehicles

1.1 Introduction

Today, the electric vehicle appears as a lever for recovery and modernization. Finally, the technological maturity of the lithium-ion battery opens up prospects for the large-scale development of electric vehicles.

The objective of this first chapter is to present a brief history, some generalities on electric vehicles, and to study its functioning as well as its different architectures and the elements constituting.

1.2 Basics

Generally, an electric vehicle (EV) is a motor vehicle that uses electricity to power its wheels. EV's can be powered by battery packs; an off-board source of electricity (i.e., a powerhouse).
Specifically, EV's is an automobile powered by one or many electric motors for propulsion (traction motors). It can be powered by a collector system, with electricity from extravehicular sources, or it can be powered autonomously by a battery which requires recharging. Although prototype electric vehicles (EVs) were invented in the 1800s and various models were built in the 1900s, the EV industry only began in earnest after the turn of the 21st century.

There are 4 (four) types of electric cars, with the following outline [11]:

- Battery Electric Vehicle (BEV)
- Hybrid:
  - Hybrid Electric Vehicle (HEV)
  - Plug-in Hybrid Electric Vehicle (PHEV)
- Fuel Cell Electric Vehicle (FCEV)

1.3 Historical background

1.3.1 History of EV's [1]

1828-1835: First small-scale electric car: Horses and carriages are the primary means of transportation, but innovators in Hungary, the Netherlands and the United States are thinking ahead and developing the first small electric cars.
1832: First crude electric vehicle is developed: Around 1832, Robert Anderson

developed the first simple electric cars, but these did not become practical until the 1870s or later. The picture here is of an electric car built by a British inverter in 1884.
1889-1891: First Electric Vehicle debuts in the U.S: William Morrison of Des Moines built the first successful electric car in the United States. His car was nothing more than an electric car, but it sparked interest in electric vehicles.
1899: Electric cars gain popularity: Compared to the gasoline and steam-powered cars of the day, electric cars were fairly easy to drive and didn't emit any odorous pollutants - which quickly became popular with city dwellers, especially women.
1900-1912: Electric cars reach their heyday: By the turn of the century, electric vehicles were all the rage in the United States, making up about a third of all vehicles on the road.
1901: Edison takes on Ev's batteries: Many innovators are noticing high demand for electric vehicles and are looking for ways to improve the technology. Thomas Edison, for example, believed that electric cars were a superior mode of transportation and worked to make better batteries.
1901: World's first hybrid electric car is invented: Ferdinand Porsche, founder of the sports car of the same name, created the Lohner-Porsche Mixte, the world's first hybrid electric car. The vehicle is powered by electricity stored in a battery and gas engine.
1908-1912: Model T deals a blow to electric vehicles: The introduction of electric starters helped to further increase sales of gas-powered vehicles. Pictured above is Henry Ford's first Model T, the 1,000,000th in the U.S., which made gasoline easy for rural America and led to the growing popularity of gasoline-powered cars.

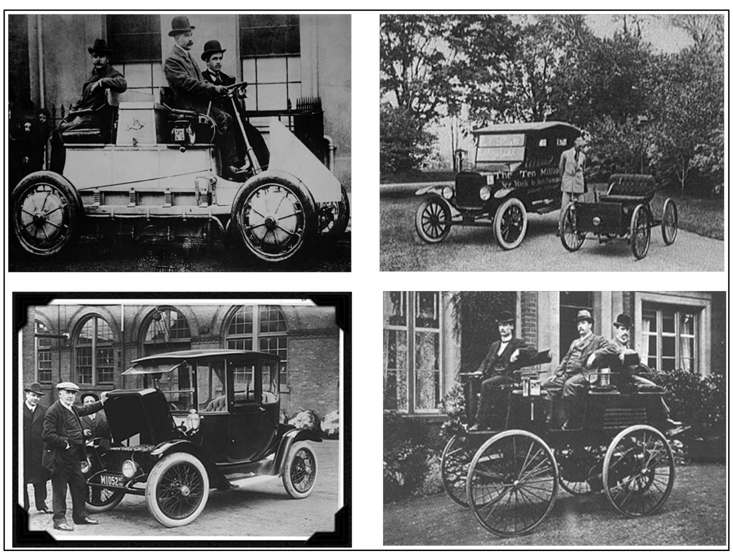


Figure 1.1: Old models of EV's

1920-1935: Decline in electric vehicles: better roads and the discovery of cheap Texas crude are leading to a decline in electric vehicles. In 1935 they all disappeared. Pictured here is one of the gas stations popping up across the U.S., supplying rural America with gasoline and leading to the growing popularity of gasoline-powered vehicles.
1968-1973: Gas prices soar: Over the next 30 years or so, cheap, abundant gasoline and continued improvements in the internal combustion engine left little need for alternative fuels in cars. But in the 1960s and 1970s, soaring gasoline prices reignited interest in electric vehicles.
1971: Over the moon with EV's: Around the same time, the first manned spacecraft landed on the moon. NASA's lunar rover runs on electricity and is helping to raise the profile of electric vehicles.
1973: The next generation of EV's: Many automakers large and small are beginning to explore alternative fuel vehicle options. General Motors, for example, is developing a prototype of an electric city car, which it showed at the first Low Emissions Energy System Development Symposium in 1973.

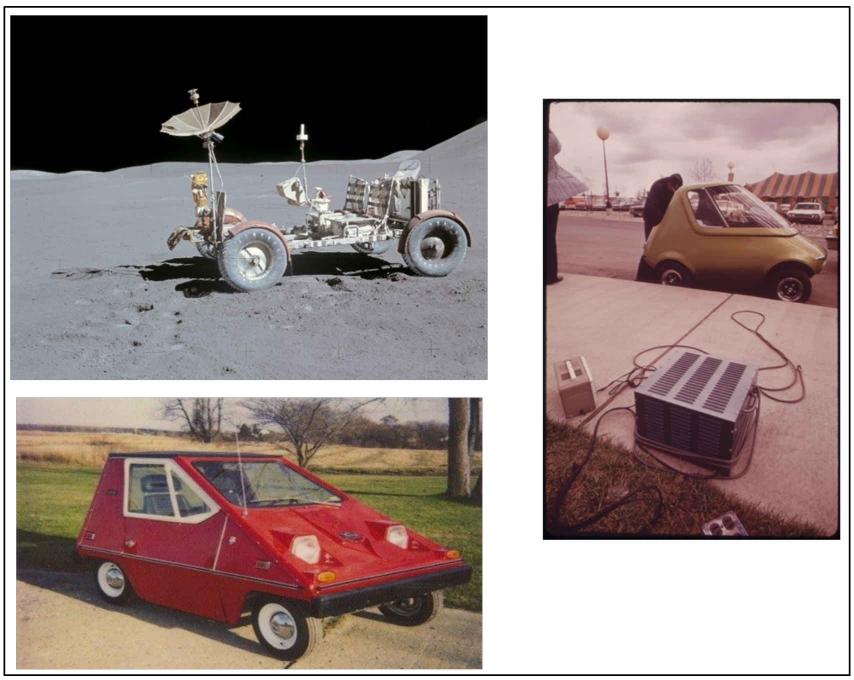


Figure 1.2: New utilisations for EV's

1975-1977: Leader in EV's vehicle sales: The current successful EV is Sebring-Vanguard's Citi Car. The company makes more than 2,000 Citi Cars - wedge-shaped compact cars with a range of 50 to 60 miles. By 1975, its popularity made Sebring-Vanguard the sixth-largest U.S. automaker.
1979: Interest in Ev's fades: Electric vehicles currently have disadvantages such as limited power and range compared to gasoline-powered vehicles, which has led to a renewed waning of interest in electric vehicles.
1990-1992: New regulations renew Ev's interest: New federal and state regula-

tions are reviving interest in electric vehicles. As a result, automakers are starting to convert popular models to electric vehicles, bringing their speed and performance closer to gasoline-powered vehicles.

1996: EV1 gains a cult following: General Motors has unveiled the EV1, an electric vehicle designed and built from the ground up. The EV1 quickly gained cult status.

1997: First mass-produced hybrid: With the Prius, Toyota introduced its first production hybrid. In 2000, Toyota launched the Prius around the world, and it became an instant celebrity, boosting its popularity (and electric vehicle popularity).

1999: Building a better electric car: Scientists and engineers are working behind the scenes to improve electric vehicles and their batteries. Seen here is a researcher at the Department of Energy's National Renewable Energy Laboratory testing an electric vehicle battery.

2006: Silicon Valley startup takes on electric cars: Silicon Valley startup Tesla Motors has announced it will build a luxury electric sports car with a range of more than 200 miles. Other automakers are taking notice and are accelerating work on their own electric vehicles.

2009-2013: Developing a nation-wide charging infrastructure: To help consumers charge their vehicles on the go, the Department of Energy is investing in a nationwide charging infrastructure, installing 18,000 residential, commercial and public chargers. Including chargers installed by automakers and other private companies, there are 8,000 public charging stations in the U.S. today.

2010: First commercially available plug-in hybrid for sale: General Motors introduces the Chevrolet Volt, making it the first commercial plug-in hybrid. The Volt uses battery technology developed by the power sector.

2010: Nissan launches the LEAF: In December 2010, Nissan will launch the LEAF, a pure electric vehicle with zero tailpipe emissions. In January 2013, thanks to a loan from the Department of Energy, Nissan began assembling the LEAF in Tennessee for the North American market.

Figure 1.3: New generation of EV's

2013: EV's battery costs drop: The battery is the most expensive component in an electric vehicle. Thanks to an investment from the U.S. Department of Energy, battery costs will drop by 50 percent in just four years, helping make electric vehicles more affordable for consumers.

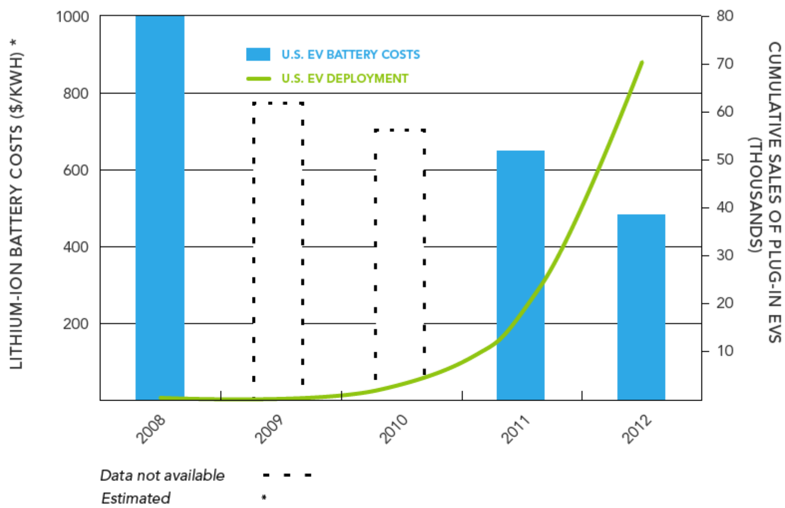


Figure 1.4: Deployment and cost for EV's and batteries between 2008-2012

2014: EV's and multitude of choice: Consumers now have a variety of options when shopping for electric vehicles, including hybrids, plug-in hybrids, and fully electric vehicles. Today, there are currently 23 plug-in electric vehicles and 36 hybrid models to choose from.

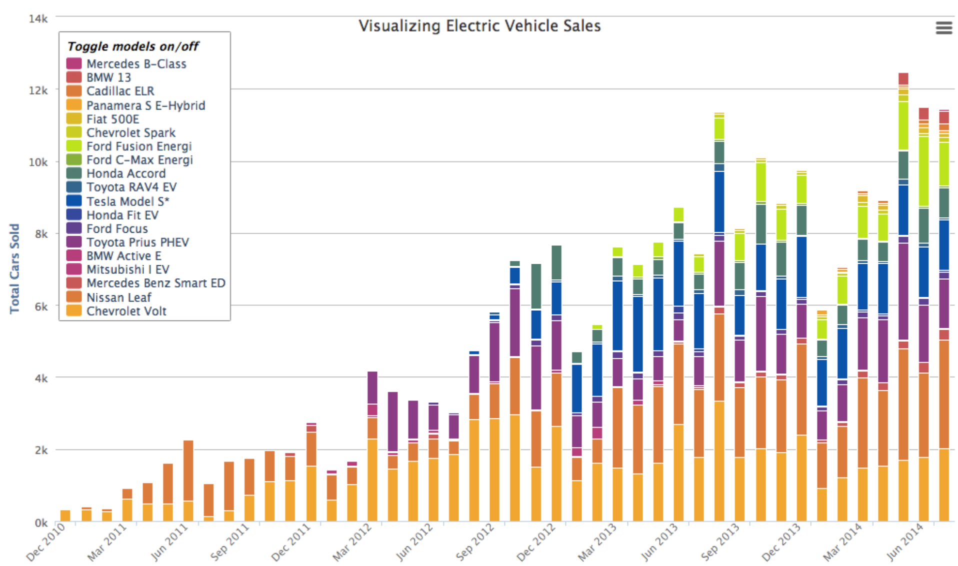


Figure 1.5: Variety of choice for Ev's nowdays

2015: The future of electric cars: Electric vehicles have enormous potential to help the world create a more sustainable future. If the world switched all light commercial vehicles to hybrid or plug-in electric vehicles, we could reduce the carbon footprint of the transportation sector by up to 20%.

Figure 1.6: Appearance of new charging systems for EV's

1.4 Fundamentals of Electric vehicles

In Electric vehicles internal combustion engine and fuel tank are replaced with and electric motor and a battery pack, a modern electric train is illustrated as follow:

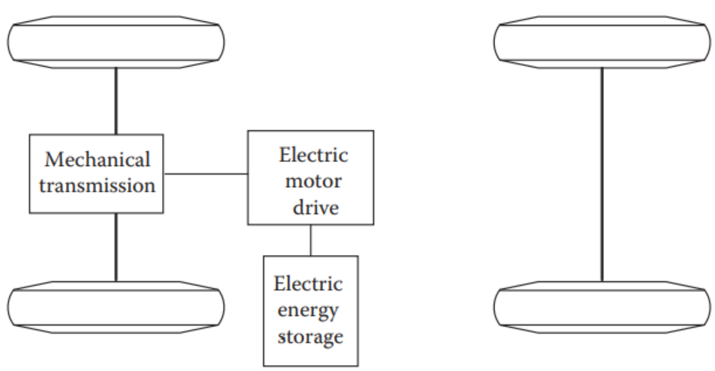


Figure 1.7: Primary electric vehicle power train

The drive train consists of three major subsystems: electric motor propulsion, energy source, and auxiliary. The electric propulsion subsystem comprises the vehicle controller, power electronic converter, electric motor, mechanical transmission, and driving wheels. The energy source subsystem involves the energy source, the energy management unit, and the energy-refueling unit. The auxiliary subsystem consists of the power steering unit, the hotel climate control unit, and the auxiliary supply unit.

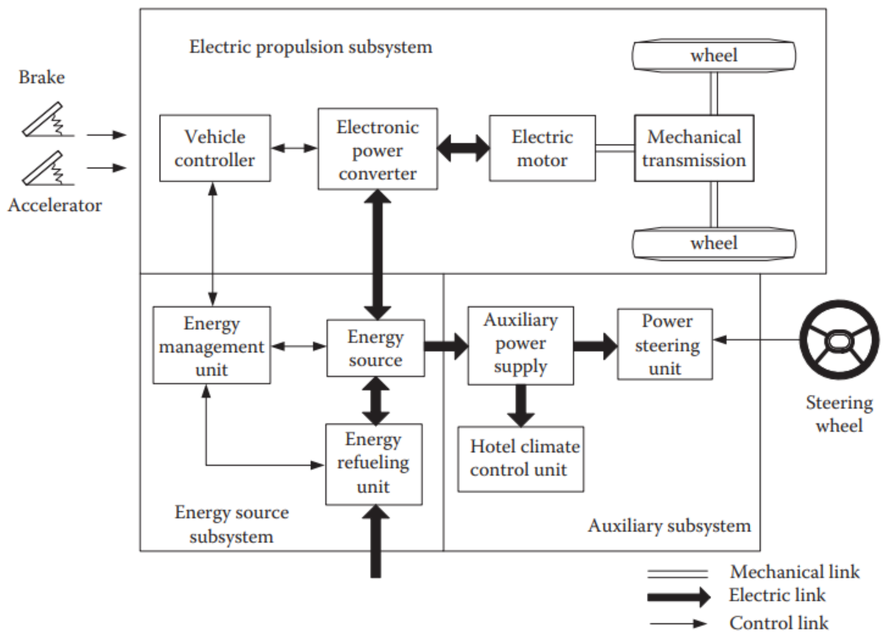


Figure 1.8: Conceptual illustration of general EV configuration

Based on control inputs from the accelerator and brake pedals, the vehicle controller appropriate control signals are provided to an electronic power converter for regulating the flow of power between the electric motor and the energy source. Regenerative braking of electric vehicles produces lagging power electric current, and this recovered energy can be recovered Enter energy, provided the energy is acceptable. The same goes for most EV batteries super capacitors and flywheels easily have the ability to absorb regenerative energy. This the energy management unit controls the regenerative energy together with the vehicle controller braking and its energy recovery. It can also be controlled together with the power supply unit Refueling device and for monitoring energy availability. Auxiliary power provides the necessary power for all electric vehicle auxiliary equipment, especially hotel air conditioning and power steering, with different voltage levels.

EV configuration very due to the variation in electric propulsion characteristics and energy source as shown:
a.In this configuration, an electric propulsion replaces the internal combustion engine of a conventional vehicle train. It consists of an electric motor, a clutch, a gearbox and a differential. The clutch is used to connect and disconnect the power coming from the

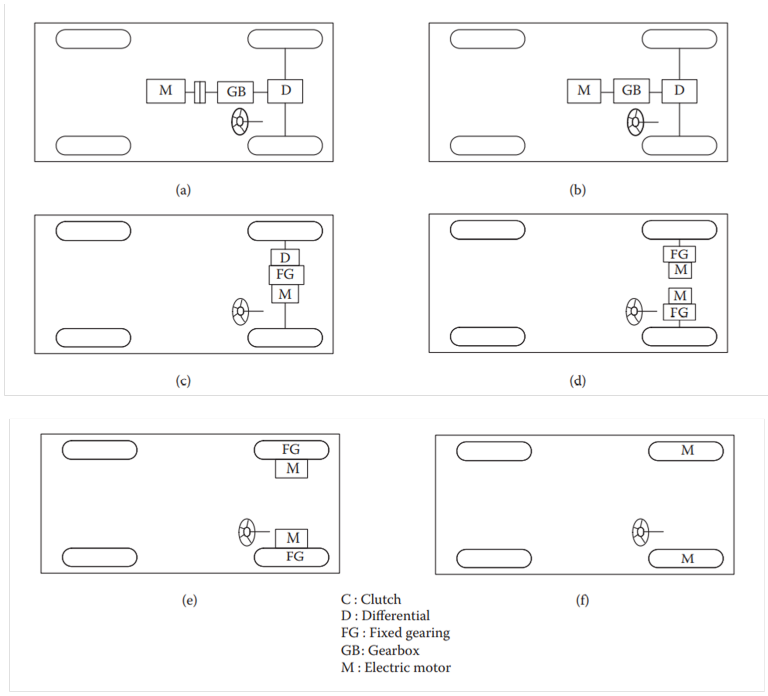


Figure 1.9: Possible EV configurations

electric motor, the gearbox provides a set of gear ratios to change the speed-power profile to match the load requirement, the differential will enable the wheels of both sides to be driven at different speeds when the vehicles run along a curved path.
b.Using an electric motor that has constant power in long speed range, a multispeed gearbox can be used to reduce the need for a clutch. This configuration not only reduce the weight of the mechanical transmission system, it also simplifies the drive control because gear shifting is not needed.
c.The electric motor, the fixed gearing and the differential can be further integrated into one single assembly bock, the whole driven train is further simplified and assembled and compacted.
d.The mechanical differential is replaced by using two traction motors, when the vehicle is running along curved path, each one of the motors will drive at different speed.
e.The traction motor can be placed inside a wheel. This arrangement is called in-wheel drive, a thin planetary gear set may be employed to reduce the motor speed and torque, the ting planetary gears set offers the advantage of high-speed reduction ratio.
f.By fully abandoning any mechanical gearing between the electric motor and the driven wheels, the out rotor of the electric motor is directly connected to the driving wheels. This arrangement requires the electric motor to have a higher torque, to start and accelerate the vehicle.[12]

1.5 Environmental Impact

1.5.1 Environmental Impact of Modern Transportation

The development of internal combustion (IC) engine vehicles, and especially automobiles, is one of the greatest achievements of modern technology. Automobiles have made great contributions to the growth of modern society by satisfying many of the needs for mobility in everyday life. The rapid development of the automotive industry, unlike that of any other industry, has prompted the progress of human beings from a primitive security to a highly developed industrial one. The automobile industry and the other industries that serve it constitute the backbone of the world's economy and employ the greatest share of the working population. However, the large number of automobiles in use around the world has caused and continues to cause serious problems for environment and human life. Air pollution, global warming, and the rapid depletion of the Earth's petroleum resources are now problems of paramount concern. In recent decades, the research and development activities related to transportation have emphasized the development of high-efficiency, clean, and safe transportation. Electric vehicles (EVs), hybrid electric vehicles (HEVs), and fuel cell vehicles have been typically proposed to replace conventional vehicles in the near future. This chapter reviews the problems of air pollution, gas emissions causing global warming, and petroleum resource depletion. It also gives a brief review of the history of EVs, HEVs, and fuel cell technology.

Air Pollution

At present, all vehicles rely on the combustion of hydrocarbon (HC) fuels to derive the energy necessary for their propulsion. Combustion is a reaction between the fuel and the air that releases heat and combustion products. The heat is converted to mechanical power by an engine and the combustion products are released to the atmosphere. An HC is a chemical compound with molecules made up of carbon and hydrogen atoms. Ideally, the combustion of an HC yields only carbon dioxide and water, which do not harm the environment. Indeed, green plants "digest" carbon dioxide by photosynthesis. Carbon dioxide is a necessary ingredient in vegetal life. Animals do not suffer from breathing carbon dioxide unless its concentration in air is such that oxygen is almost absent.
Actually, the combustion of HC fuel in combustion engines is never ideal. Besides carbon dioxide and water, the combustion products contain a certain amount of nitrogen oxides (NOx), carbon monoxides (CO), and unburned HCs, all of which are toxic to human health.

Nitrogen Oxides:

Nitrogen oxides (NOx) result from the reaction between nitrogen in the air and oxygen. Theoretically, nitrogen is an inert gas. However, the high temperatures and pressures in engines create favorable conditions for the formation of nitrogen oxides. Temperature is by far the most important parameter in nitrogen oxide formation. The most commonly found nitrogen oxide is nitric oxide (NO), although small amounts of nitric dioxide (NO2) and traces of nitrous oxide (N2O) are present. Once released into the atmosphere, NO reacts with the oxygen to form NO2. This is later decomposed by the Sun's ultraviolet radiation back to NO and highly reactive oxygen atoms that attack the membranes of living cells. Nitrogen dioxide is partly responsible for smog; its brownish color makes smog visible. It also reacts with atmospheric water to form nitric acid (HNO3), which dilutes in rain. This phenomenon is referred to as "acid rain" and is responsible for the destruction of forests in industrialized countries. Acid rain also contributes to the degradation of historical monuments made of marble.

Carbon Monoxide:

Carbon monoxide results from the incomplete combustion of HCs due to a lack of oxygen. It is a poison to human beings and animals who inhale/breathe it. Once carbon monoxide reaches the blood cells, it fixes to the hemoglobin in place of oxygen, thus diminishing the quantity of oxygen that reaches the organs and reducing the physical and mental abilities of affected living beings. Dizziness is the first symptom of carbon monoxide poisoning, which can rapidly lead to death. Carbon monoxide binds more strongly to hemoglobin than oxygen. The bonds are so strong that normal body functions cannot break them. People intoxicated by carbon monoxide must be treated in pressurized chambers, where the pressure makes it easier to break the carbon monoxide–hemoglobin bonds.

Unburned HCs:

Unburned HCs are a result of the incomplete combustion of HCs. Depending on their nature, unburned HCs may be harmful to living beings. Some of these unburned HCs may be direct poisons or carcinogenic chemicals such as particulates, benzene, or others. Unburned HCs are also responsible for smog: the Sun's ultraviolet radiations interact with the unburned HCs and NO in the atmosphere to form ozone and other products. Ozone is a molecule formed of three oxygen atoms. It is colorless but very dangerous, and is poisonous because as it attacks the membranes of living cells, causing them to age prematurely or die. Toddlers, older people, and asthmatics suffer greatly from exposure to high ozone concentrations. Annually, deaths from high ozone peaks in polluted cities have been reported.

Other Pollutants:

Impurities in fuels result in the emission of pollutants. The major impurity is sulfur: mostly found in diesel and jet fuel, but also in gasoline and natural gas. The combustion of sulfur (or sulfur compounds such as hydrogen sulfide) with oxygen releases sulfur oxides (SOx). Sulfur dioxide (SO2) is the major product of this combustion. On contact with air, it forms sulfur trioxide, which later reacts with water to form sulfuric acid, a major component of acid rain. It should be noted that sulfur oxide emissions originate from transportation sources but also largely from the combustion of coal in power plants and steel factories. In addition, there is debate over the exact contribution of natural sources such as volcanoes. Petroleum companies add chemical compounds to their fuels in order to improve the performance or lifetime of engines. Tetraethyl lead, often referred to simply as “lead,” was used to improve the knock resistance of gasoline and therefore allow better engine performance. However, the combustion of this chemical releases lead metal, which is responsible for a neurological disease called “saturnism.” Its use is now forbidden in most developed countries and it has been replaced by other chemicals.

Global Warming

Global warming is a result of the “greenhouse effect” induced by the presence of carbon dioxide and other gases, such as methane, in the atmosphere. These gases trap the Sun’s infrared radiation reflected by the ground, thus retaining the energy in the atmosphere and increasing the temperature. An increased Earth temperature results in major ecological damages to its ecosystems and in many natural disasters that affect human populations Considering the ecological damages induced by global warming, the disappearance of some endangered species is a concern because this destabilizes the natural resources that feed some populations. There are also concerns about the migration of some species from warm seas to previously colder northern seas, where they can potentially destroy indigenous species and the economies that live off those species. This may be happening in the Mediterranean Sea, where barracudas from the Red Sea have been observed. Natural disasters command our attention more than ecological disasters because of the amplitude of the damages they cause. Global warming is believed to have induced meteorological phenomena such as “El Niño,” which disturbs the South Pacific region and regularly causes tornadoes, inundations, and dryness. The melting of the polar icecaps, another major result of global warming, raises the sea level and can cause the permanent inundation of coastal regions and sometimes of entire countries. Carbon dioxide is the result of the combustion of HCs and coal. Transportation accounts for a large share (32% from 1980 to 1999) of carbon dioxide emissions. The distribution of carbon dioxide emissions is shown in Figure 1.10. Figure 1.11 shows the trend in carbon dioxide emissions. The transportation sector is clearly now the major contributor to carbon dioxide emissions. It should be noted that developing countries are rapidly increasing their transportation sector, and these countries represent a very large share of the world population. Further discussion is provided in the next subsection. The large amounts of carbon dioxide released into the atmosphere by human activities are believed to be largely responsible for the increase in the global Earth temperature observed during the last decades (Figure 1.12). It is important to note that carbon dioxide is indeed digested by plants and sequestrated by oceans in the form of carbonates. However, these natural assimilation processes are limited and cannot assimilate all of the emitted carbon dioxide, resulting in an accumulation of carbon dioxide in the atmosphere.

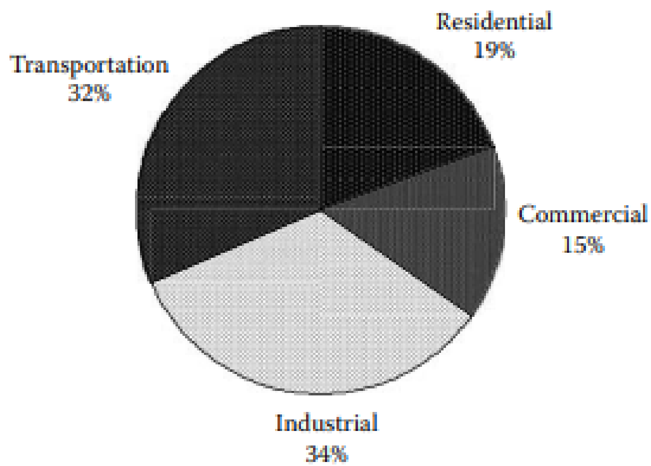


Figure 1.10: Carbon dioxide emission from 1980 to 1999

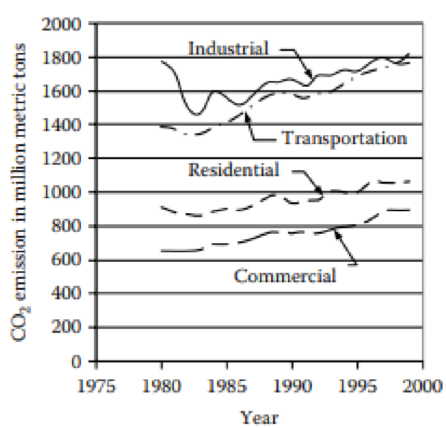


Figure 1.11: Evolution of CO2 emission[2]

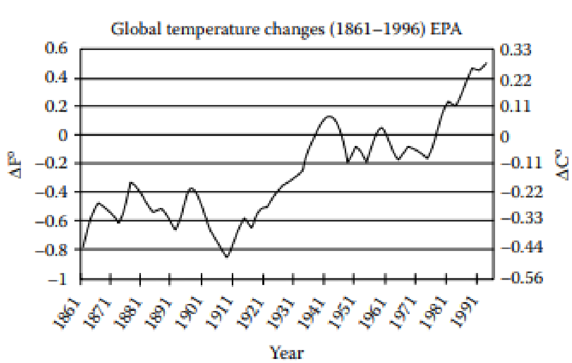


Figure 1.12: Global earth atmospherie [2]

Petroleum Resources

The vast majority of fuels for transportation are liquid fuels originating from petroleum. Petroleum is a fossil fuel, resulting from the decomposition of living matters that were imprisoned millions of years ago (Ordovician, 600–400 million years ago) in geologically stable layers. The process is roughly the following: living matters (mostly plants) die and are slowly covered by sediments. Over time, these accumulating sediments form thick layers and transform to rock. The living matters are trapped in a closed space, where they encounter high pressures and temperatures and slowly transform into either HCs or coal, depending on their nature. This process takes millions of years to accomplish. This is what makes the Earth's resources in fossil fuels finite. The oil extracted nowadays is the easily extractable oil that lies close to the surface, in regions where the climate does not pose major problems. It is believed that far more oil lies underneath the Earth's crust in regions such as Siberia, or the American and Canadian Arctic. In these regions, the climate and ecological concerns are major obstacles to extracting or prospecting for oil. The estimation of the total Earth's reserves is a difficult task for political and technical reasons. A 2000 estimation of the undiscovered oil resources by the US Geological Survey is given in Table 1.1.

Table 1.1: U.S. Geological survey estimate of undiscovered oil in 2000

Region	Undiscovered Oil in 2000 in Billion Tons
North America	19.8
South and Central America	14.9
Europe	3.0
Sub-Saharan Africa and Antarctic	9.7
Middle East and North Africa	31.2
Former USSR	15.7
Asia Pacific	4.0
World (potential growth)	98.3 (91.5)

Although the R/P ratio does not include future discoveries, it is significant. Indeed, it is based on proved reserves, which are easily accessible to this day. The amount of future oil discoveries is hypothetical, and the newly discovered oil will not be easily accessible. The R/P ratio is also based on the hypothesis that the production will remain constant. It is obvious, however, that consumption (and therefore production) is increasing yearly to keep up with the growth of developed and developing economies. Consumption is likely to increase in gigantic proportions with the rapid development of some largely populated countries, particularly in the Asia-Pacific region. Figure 1.13 shows the trend in oil consumption over the last 20 years. Oil consumption is given in thousand barrels per day (one barrel is about 8 metric tons). Despite the drop in oil consumption for Eastern Europe and the former USSR, the world trend is clearly increasing, as shown in Figure 1.14 The fastest growing region is Asia Pacific, where most of the world's population lives.

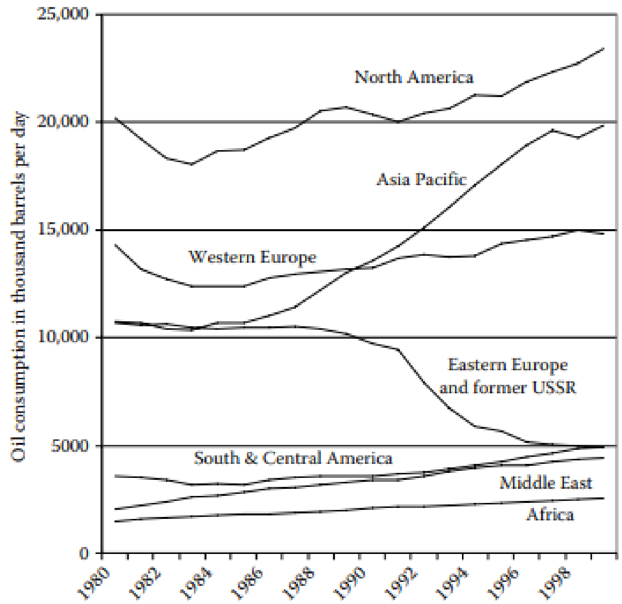


Figure 1.13: Oil consumption per region

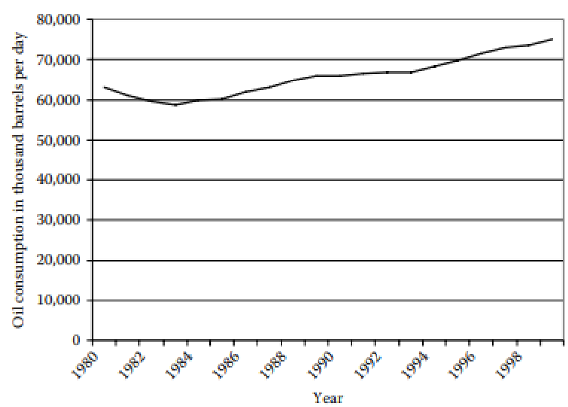


Figure 1.14: World oil consumption

Induced Costs

The problems associated with the frenetic combustion of fossil fuels are many: pollution, global warming, and foreseeable exhaustion of resources, among others. Although difficult to estimate, the costs associated with these problems are huge and indirect, and may be financial, human, or both.

Costs induced by pollution include, but are not limited to, health expenses, the cost of replanting forests devastated by acid rain, and the cost of cleaning and fixing monuments corroded by acid rain. Health expenses probably represent the largest share of these costs, especially in developed countries with socialized medicine or health-insured populations. Costs associated with global warming are difficult to assess. They may include the cost of the damages caused by hurricanes, lost crops due to dryness, damaged properties due to floods, and international aid to relieve the affected populations. The amount is potentially huge. Most of the petroleum-producing countries are not the largest petroleum consuming countries.

In searching for a solution to the problems associated with oil consumption, one has to take into account those induced costs. This is difficult because the cost is not necessarily asserted where it is generated. Many of the induced costs cannot be counted in asserting the benefits of an eventual solution. The solution to these problems will have to be economically sustainable and commercially viable without government subsidies in order to sustain itself in the long run. Nevertheless, it remains clear that any solution to these problems— even if it is only a partial solution—will indeed result in cost savings, which will benefit the payers.[13]

1.5.2 Benefits of electric cars on the environment

Research has shown that electric cars are better for the environment. They emit fewer greenhouse gases and air pollutants than petrol or diesel cars. And this takes into account their production and electricity generation to keep them running.

The major benefit of electric cars is the contribution that they can make towards improving air quality in towns and cities. With no tailpipe, pure electric cars produce no carbon dioxide emissions when driving. This reduces air pollution considerably.

Put simply, electric cars give us cleaner streets making our towns and cities a better place to be for pedestrians and cyclists. In over a year, just one electric car on the roads can save an average 1.5 million grams of CO2. That's the equivalent of four return flights from London to Barcelona.

EVs can also help with noise pollution, especially in cities where speeds are generally low. As electric cars are far quieter than conventional vehicles, driving electric creates a more peaceful environment for us all.

Making electric cars does use a lot of energy. Even after taking battery manufacture into account, electric cars are still a greener option. This is because of the reduction in emissions created over the car's lifetime The emissions created during the production of an electric car tend to be higher than a conventional car. This is due to the manufacture of lithium-ion batteries which are an essential part of an electric car. More than a third of the lifetime CO2 emissions from an electric car come from the energy used to make the car itself. As technology advances, this is changing for the better.

Reusing and recycling batteries is also a growing market. Research into the use of second-hand batteries is looking at ways to reuse batteries in new technologies such as electricity storage. One day we could all have batteries in our homes being used to store our own energy. Opportunities like this will reduce the lifetime environmental impact of battery manufacture.[14]

1.6 Batteries and energy storage for EV's

1.6.1 Definition

A battery is a device that converts the chemical energy contained in its active materials directly into electric energy by means of an electrochemical oxidation-reduction reaction. In the case of a rechargeable system, the battery is recharged by a reversal of the process. This type of reaction involves the transfer of electrons from one material to another through an electric circuit. In a non-electrochemical redox reaction, such as rusting or burning, the transfer of electrons occurs directly and only heat is involved. As the battery electrochemically converts chemical energy into electric energy, it is not subject, as are combustion or heat engines, to the limitations of the Carnot cycle dictated by the second law of thermodynamics. Batteries, therefore, are capable of having higher energy conversion efficiencies.

Figure 1.15: Car battery

1.6.2 Types

Electrochemical cells and batteries can be classified in two big categories, primary (non-rechargeable) and secondary (rechargeable), depending on their capability of being electrically recharged these are some types of electrochemical batteries:

Primary cells or batteries

Primary batteries cannot be easily or effectively recharged, it is designed to be used once and discarded. Primary cells in which the electrolyte is contained by and absorbent where

there is no liquid electrolyte are called “dry cells”.
Primary batteries are usually inexpensive, lightweight, and it is a source of power for portable electrical and electronic devices, the advantages of the primary batteries are the good life shelf, high energy density at a low discharge rates and ease of use.
Small capacity batteries applications are lighting, photographic equipment, toys...etc., although large high-capacity primary batteries are used in military applications, standby power systems, and many other applications.

Figure 1.16: A variety of standard of primary cells and batteries

Secondary or rechargeable cells or batteries

Secondary batteries can be recharged to their original state by passing current in the opposite direction to that of the discharge current, this type of batteries is called “storage batteries” or “accumulators “.
There are two main categories of secondary batteries applications:

- The first category is in which the battery is used as an energy storage device.
- The second category is in which the battery is used as a primary battery or a primary source of energy.

Secondary batteries are characterized by high power density, high discharge rate, flat discharge curves, and good temperature performance, their energy density is lower than of the primaries.
Rechargeable batteries applications are automotive and air craft systems, emergency no-fail and standby power systems, hybrid and fully electric vehicles.[15]

1.6.3 Batteries used in electric vehicles

The types and number of applications requiring improved or advanced rechargeable batteries are constantly expanding one of the applications of these batteries are electric and hybrid vehicles, in addiction the performance the performance, life and cost requirement for the batteries used in many of these new and existing applications are becoming increasingly more rigorous.

Figure 1.17: A rechargeable lithium polymer mobile battery

Commercially available batteries may not be able to meet these performance requirements. Thus, a need exists for both conventional battery technology with improved performance and advanced battery technologies with characteristics such as high energy and power densities, long life, low cost, little or no maintenance, and a high degree of safety.
Battery performance applications depend on the application, for examples:

- High specific energy and energy density to provide adequate vehicles driving range.
- High power density to provide acceleration.
- Capability of accepting high power.
- Long cycle life with little maintenance.
- Low cost.

1.7 Conclusion

In this chapter, we have presented a state of the art on electric vehicles, a brief history and the elements that compose this kind of vehicle was presented first, the advantages and disadvantages were also discussed. Electric vehicles, being ecological and clean, will certainly be the new means of transportation that will take an increasingly important place in the market in the near future, and will therefore replace in the coming years the thermal cars that are much too polluting, and especially not eternal. The production of energy necessary for the operation and manufacture of electric vehicles, take part in global warming, which allows us to say that finally the electric car is not as ecological, unless it is produced from renewable energy, such as solar or hydraulic energy. Several architectures of electric vehicles are currently possible and present various performances and functionalities. The points that block the complete arrival of the electric vehicle are now known, the manufacturers offer very efficient solutions in terms of technology and power despite this, some points still need to be improved to allow the real immersion of the electric vehicle in the populations, especially regarding the autonomy, the price and the infrastructure necessary for its expansion, so which do not seem to be possible in the short term.

Chapter 2

Plug-in charging system

2.1 Introductrion

In urban traffic, due to their beneficial effect on environment, electrically propelled vehicles are an important factor for improvement of traffic and more particularly for a healthier living environment. The operation of the electrically propelled vehicle is dependent on the availability of efficient electric energy storage devices: the traction batteries. To allow the use of cheap and clean electric energy from the grid, recharging infrastructure shall be available to transfer electric energy from the distribution grid to the battery. This transfer can be done either by conduction or by induction, the first system being the most widely used. This chapter will present the current evolution in the field of charging infrastructure, the problems involved, the ongoing standardization efforts and the accessories of charging (station side and vehicle side). Then, we're going to end the chapter with the advanced technology for plug-in charging which is V2G.

2.1.1 Definition

A plug-in electric vehicle (PEV), also known as a new energy vehicle (NEV) in China, refers to any road vehicle that can store energy inside it using an external power source, such as a wall socket connected to the grid. The rechargeable on-board battery pack then powers the electric motor and helps drive the wheels. PEVs are a subset of electric vehicles, including full electric/battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs). In December 2008, the first mass-produced plug-in car went on sale with the introduction of the BYD F3DM plug-in hybrid, followed by the all-electric Mitsubishi in July 2009 i-MiEV, but global retail sales only picked up after the December 2010 launch of the all-electric production car Nissan Leaf and plug-in hybrid Chevrolet Volt.
Charging an electric car or plug-in hybrid is mainly done at home.Home charging accounts actually for 80% of all charging done by EV drivers.

2.1.2 Historical background

The need for the availability of suitable charging infrastructure already arose in the first golden age of the electric vehicle in the early 20th century. The first ever standard to be developed for electric vehicles concerned in fact the charging plug, a standard sheet for which was presented in 1913 [16] , which would be adopted on an international level as British Standard 74 [17]. Infrastructure needs also had their implications on the design of the vehicles. As d.c. distribution networks were still in widespread use in that period, particularly in the United States, standard battery voltages have been chosen allowing direct charging from a 110V d.c. supply. This corresponds to the final charging voltage for a 40-cell lead–acid battery having a nominal voltage of 80V [16]; this standard voltage was used up to the present time for battery-electric industrial vehicles.
The development of compact and efficient power electronic converters allowed electric ve-

hicles to be fitted with on-board chargers, to be connected directly to the a.c. distribution network, thus greatly enhancing the flexibility of use for the vehicle.

2.1.3 Battery charging

Let us first consider the process of battery charging, which typically involves two phases:

- the main charging phase, where the bulk of energy is recharged into the battery.
- the final charge phase, where the battery is conditioned and balanced.

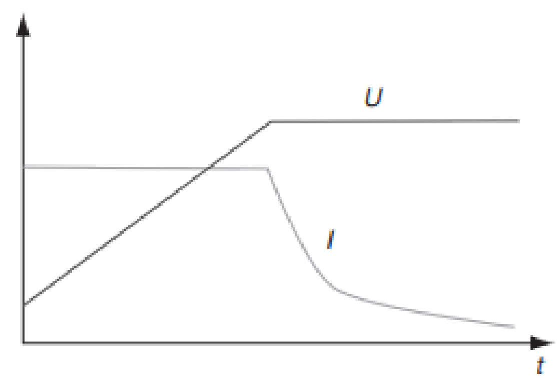


Figure 2.1: IU charging characteristic

Most chargers in use today use the so-called IU characteristic, where a constant current I is used for the main charge and a constant voltage U for the final charge (figure 2.1). The duration of the main charge phase is dependent on the available current and the rating of the charger, whereas the final charge, which only needs a small current, typically takes several hours. Opportunity charging, the partial charging used in public stations, mostly involves the main charge phase only. However, for a good upkeep of most types of battery, a periodical full charge is advisable.

2.2 Charging power levels

2.2.1 Energy usage

Background

The power rating of the charging connection will depend on the energy consumed by the vehicle and the time needed for a charge.

The energy consumption of an electric vehicle, measured at the grid, can be obtained by integrating the immediate power at the wheels needed to propel the vehicle over time, taking into account the immediate efficiencies of all elements of the drive train:

$$E = \int_0^t \frac{P_w}{\eta_t \eta_m \eta_p \eta_b \eta_c}.dt \tag{2.1}$$

with the efficiencies:

η_t of the mechanical transmission
η_m of the electric motor
η_p of the power electronics
η_b of the battery
η_c of the charger This power P_w must be available to deliver the tractive force equal to the forces acting on the moving vehicle :

$$F = F_a + F_d + F_f + F_s \tag{2.2}$$

where:
F_a =m'.a is the acceleration force
F_d =$\frac{1}{2}.\rho.S.c_x.v^2$ is the drag force
F_f =$m.g.f_r.cos(\alpha)$ is the rolling friction force
F_s =$m.g.sin(\alpha)$is the force to overcome the slope The power,and thus the energy consumption, will depend on the vehicle characteristics (mass m, including rotating masses m , front surface S,and drag coefficient c_x , the road characteristics(friction coefficient fr and slope *alpha*, the speed v, and the acceleration a. The influence of the acceleration force will be reflected through the followed drive cycle and the driving style.
Urban traffic, with its frequent accelerations, will yield much higher consumption values than constant speed driving. In extreme cases, such as postal distribution services, the energy consumption may double the value measured in standardized tests based on "urban" driving schedules, as defined in international standards such as ISO 8714.

Estimated consumption and practical example

A good approximation of the grid consumption of a battery-electric vehicle with current technology in mixed city traffic can be given by the empirical formula:

$$E_s = 80 + 80/m$$

where:
E_s is the specific energy consumption in Wh/Tkm.
m is the mass of the vehicle in tons.

For example, a typical medium-sized vehicle weighing 1500 kg would have an energy consumption of

$$E = 1.5 \times (80 + \frac{80}{1.5}) = 200\frac{Wh}{Km}$$

To drive this vehicle over a distance of 50 km, a typical urban range for battery-electrics or plug-in hybrids, the following amount of energy would be needed from the grid:

$$E = 50Km \times 200\frac{Wh}{Km} = 10kWh$$

Charging time and "charging speed"

The time needed for charging the 10 kWh from the example above will depend on the power available and on the rating of the charger: with 2 kW available, 5 h would be needed, whereas a 10 kW outlet would deliver this power in just 1h. To illustrate the time needed for charging, one could define the notion of charging speed, corresponding to the distance covered by the amount of electrical energy charged during 1 h.
For the example, the charging speed would be 10 km/h for the 2 kW charger and 50 km/h for the 10 kW charger.

2.2.2 Defining power levels

Several power levels can be defined according to the power taken from the grid and the associated charging speed possible. However, one should be aware that the use of terms like "semi-fast" or "fast" in this context refers to the charging of typical vehicles like cars or small delivery vans as in the example of equation 2.3. For smaller vehicles such as motorcycles, the power of a standard 16A outlet may already allow a "fast" charge, whereas for a full-size bus a 22 kW connection will just be a "normal" charge.

"Normal" charging

Normal charging can be understood as using a power level corresponding to the standard power outlets typically available in residential installations. This concept corresponds to the Level 1 charging defined in the United States.
The rating of standard power outlets varies in different areas of the world. In most European countries, the standard outlet is often rated 230V, 16A, yielding up to 3.7 kW which allows the 10 kWh from the example above to be recharged in less than 3 h. In some countries, however, the standard outlets have lower ratings (e.g., the United Kingdom 13 A, Switzerland 10 A).
With a corresponding "charge speed" of 18.5 km/h, the "normal" charging at 230V, 16A is thus offering a somewhat acceptable opportunity charging alternative, with adequate power for overnight charging which is typical practice for both private and commercial

electric vehicles.
In North America, on the other hand, the supply of 120V is still in general use. The standard power outlets are rated 120V, 15A ,which corresponds to a maximum power of up to 1.8 kW. This voltage only allows a poor charging performance: with only 1.8 kW available, charging the vehicle from the example of equation 2.3 would take nearly 6 h. With a range of 50 km, one could define a "charge speed" of 9 km/h.

"Semi-fast" charging

Semi-fast charging is to be understood as making use of current levels exceeding those of a standard domestic outlet, but which could be readily made available in a typical residential or commercial setting. This corresponds to Level 2 charging in the United States.
In Europe, three-phase distribution is in general use. The most common system is a four-wire distribution as shown in Figure 2.2, with a phase voltage of 230V and a line

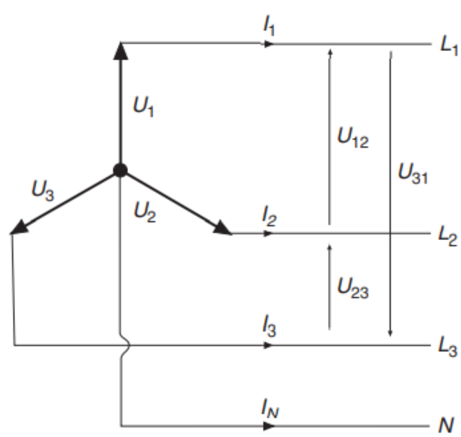


Figure 2.2: Four-wire Three-Phase distribution

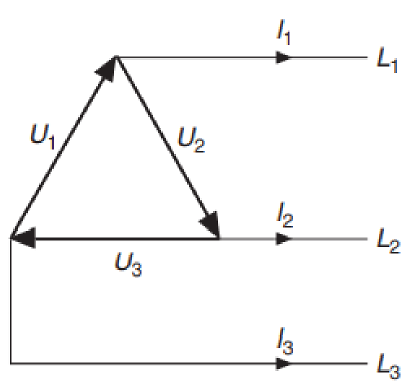


Figure 2.3: Three-wire Three-Phase distribution

voltage of 400V. In some countries such as Belgium, three-wire 3 × 230V networks Figure 2.3 with a phase voltage of 230V can be found, particularly in older installations. The neutral is not used here, its use being phased out with the demise of the former 127/220V system. For a given current, available power levels with this system are a factor lower than with a 3 × 400V system.
The way the three-phase power is distributed to individual customers is however strongly dependent on historical developments and on the cultural tradition of every single country and its electricity distributors.
Some countries tend to allow residential connections to single phase only, even for higher power. France, for example, provides single-phase connections up to 80A (18.4 kW). In such areas, a 230V, 32A connection can be readily made available, allowing 7.4 kW charge power.
On the other hand, in other areas three-phase power distribution is the norm. Switzerland mandates three-phase connections for all currents >16 A, whereas a standard residential connection in Germany is 3 × 400 V, 63A.
This three-phase connection allows considerably higher power for a modest current: with just 16A per phase, one can get:

$$P = \sqrt{3} \times 400 \times 16 \times cos(\phi) = 11.1kW(cos(\phi) = 1) \quad (2.3)$$

This allows charging the example vehicle in just under 1 h for a range of 50 km, or a “charge speed” of 55 km/h.
With a current of 32A, even up to 22.2 kW becomes available. This is already pretty fast charging for small- and medium-sized vehicles, using current levels which can be implemented more easily than the high single-phase current of nearly 100 A, which would be required to deliver this power. The use of three phases has the further advantage to be more beneficial for the load spreading of the electric network. The on-board battery charger of the vehicle shall of course be configured to accept a threephase connection. In North America, the three-wire split phase system illustrated in Figure 2.4 allows a 240V supply, effectively doubling the available power for a given current; this 240V is indeed used for high-power devices such as cooking ranges. A 240V, 30A connection would give a power up to 7.2 kW. Three-phase distribution is found only where asynchronous electric motors are used.

2.2.3 Overview of power levels

An overview of the available power for normal and semi-fast charging is given in Table 2.1. The last two columns give the section of copper needed for the cable (based on the standard ratings of 16A for 2.5 mm^2 wire and 32A for 6 mm^2 wire, and not including neutral or earth conductors) and the relationship between power and copper section. It can clearly be seen that the use of higher voltages, particularly in three phases, allows a much better utilization of the conductors, and hence the use of lighter cables and

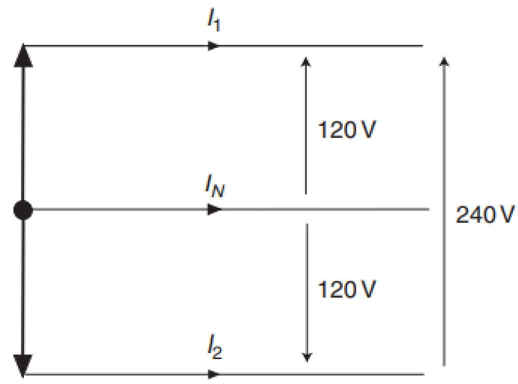


Figure 2.4: Three-wire split-wave distribution

accessories.

Table 2.1: Power Levels for charging (cosφ)=1

	Voltage(V)	Phases	Current(A)	Power(kW)	Copper(mm2)	Kw/mm
EU Standard	230	1	16	3.7	5	0.74
EU semi-fast	230	1	32	7.4	12	0.62
EU semi-fast	400	3	16	11.1	7.5	1.48
EU semi-fast	400	3	32	22.2	18	1.23
N.A Level 1	120	1	15	1.8	5	0.36
N.A Level 2	240	1	30	7.2	12	0.60

N.A: North America

2.3 Charging modes for conductive charging

The preceding section has dealt with the power levels for charging, but one should also consider the actual infrastructure used for connecting the vehicle. This leads to the definition of the so-called charging modes, introduced in the international standard IEC 61851-1.

2.3.1 Mode 1 charging

Mode 1 charging refers to the connection of the electric vehicle to the a.c. supply network (mains) utilizing standardized socket outlets (i.e., meeting the requirements of any national or international standard), with currents up to 16A. This corresponds to non

dedicated infrastructure, such as domestic socket outlets, to which electric vehicles are connected for charging. These socket outlets can easily and cheaply deliver the desired power, and due to their availability, Mode 1 charging is the most common option for electric vehicles, particularly when existing infrastructure is to be used.
However, a number of safety concerns must be taken into account. The safe operation of a Mode 1 charging point depends on the presence of suitable protections on the supply side: a fuse or circuit breaker to protect against overcurrent, a proper earthing connection, and a residual current device switching off the supply if a leakage current greater than a certain value (e.g., 30mA) is detected. Without proper earthing, a hazardous situation for indirect contact could occur with a single earth fault within the vehicle (Figure 2.5)
In most countries, residual current devices (RCDs) are now prescribed for all new electric installations. However, still a lot of older installations are without RCD, and it is often difficult for the electric vehicle's user to know, when plugging in the vehicle, whether or not an RCD is present. Whereas some countries leave this responsibility to the user, Mode 1 has therefore been outlawed in a number of countries such as the United States. Furthermore, some countries like Italy do not allow Mode 1 charging for charging places accessible to the public and limit its use to private premises, out of concern that live standard socket outlets in public places may be exposed to the elements, vandalism or unauthorized access. In countries where the use of Mode 1 charging is allowed, it will

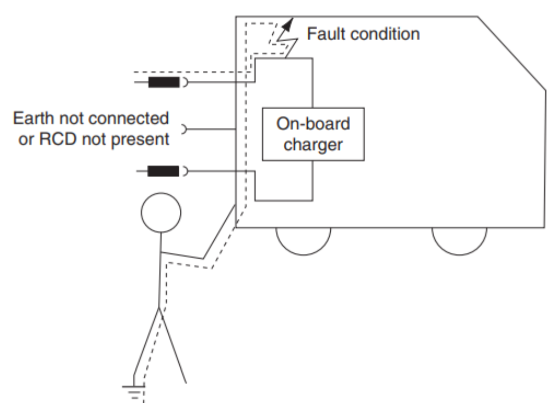


Figure 2.5: Hazardous situation without RDC

remain the most widespread charging mode for private premises (including residential garages as well as corporate parking lots) due to its simplicity and low investment cost. With a proper electrical installation including RCD, Mode 1 allows charging in full safety. However, the uncertainty faced by the user about the presence of an RCD when plugging in the electric vehicle in an arbitrary standard outlet results in a potential hazard. For this reason, vehicle manufacturers tend to steer away from Mode 1 charging in the long term.

2.3.2 Mode 2 charging

Mode 2 charging connection of the electric vehicle to the a.c. supply network (mains) also makes use of standardized socket outlets. It provides however additional protection by adding an in-cable control box with a control pilot conductor (see Section 2.3.3) between the electric vehicle and the plug or control box.
The introduction of Mode 2 charging, mainly aimed at the United States, reflected the American infrastructure process which developed electrical standards and code language that were adopted by the National Electrical Code, to ensure that personnel protection and other safety considerations were implemented in all charging systems utilized. Mode 2 was initially considered a transitional solution particularly for the United States, although it has received some new interest for replacing Mode 1 for charging at non dedicated outlets.
The main disadvantage of Mode 2 is that the control box protects the downstream cable and the vehicle, but not the plug itself, whereas the plug is one of the components more liable to be damaged in use.

2.3.3 Mode 3 charging

Definition

Mode 3 charging involves the direct connection of the electric vehicle to the a.c. supply network utilizing dedicated electric vehicle supply equipment. This refers to private or public charging stations. The standard IEC 61851-1 mandates control pilot protection between equipment permanently connected to the a.c. supply network and the electric vehicle.

Control pilot conductor

For Mode 3 charging, the IEC 61851-1 standard foresees additional protection measures to be provided by the so-called control pilot, a device which has the following functions mandated by the standard:

- verification that the vehicle is properly connected
- continuous verification of the protective earth conductor integrity
- energization and deenergization of the system
- selection of the charging rate

In the first edition of the standard, the control pilot is defined as an extra conductor in the charging cable assembly, in addition to the phase(s), neutral, and earth conductor. However, IEC 61851 does not specify normative requirements for the operation of the

control pilot circuitry.
An example of control pilot circuit is given in Figure 2.6, showing the operation of the system. A small current is sent through the control pilot conductor, which is connected to the vehicle body by a resistor. The current returns to the charging post through the earth conductor. When the pilot current flows correctly, the contactor in the charging post is closed and the system is energized. When no vehicle is connected to the socket

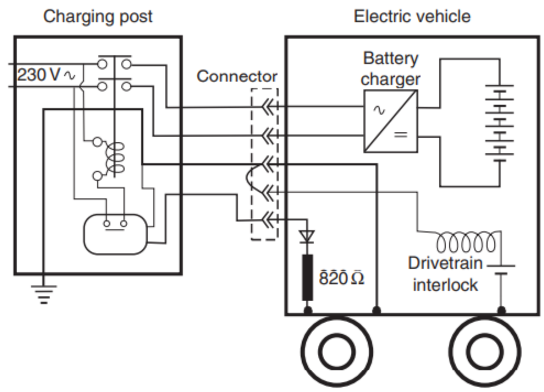


Figure 2.6: Control Pilot Conductor

outlet, the socket is dead. This provides a key safety advantage particularly for publicly accessible charging points. Power is delivered only when the plug is correctly inserted and the earth circuit is proved to be sound.
The connection process shall be such that the earth connection is made first and the pilot connection is made last. During disconnection, the pilot connection shall be broken first and the earth connection shall be broken last. This sequence also ensures that the current is interrupted at the contactor and not at the power contact pins of the plug, thus eliminating arcing and prolonging the service life of the accessories.
The use of a control pilot conductor in charging equipment was first proposed around 1990 for charging stations for electric boats deployed in the Norfolk Broads in England.The use of a control pilot function with fourth wire is also included in the Society of Automotive engineers (SAE) standard J1772 (which is now under revision).

Control Pilot Alternatives

The use of a dedicated conductor for the control pilot necessitates an extra conductor and thus the use of special cables and accessories.
The new version of the standard 61851-1 has introduced the concept of control pilot function, mandatory for Mode 3 charging, which has to perform the same functions as the control pilot conductor described in the previous section, but which can be realized by other means than the extra pilot conductor. The use of a physical control pilot conductor remains an option of course.
Alternative means to implement control pilot functionality include various wireless data

transfer systems as well as power-line communication. An interesting implementation of the latter has been developed by Electricité de France .The principle is illustrated in Figure 2.7 The control pilot signal is a common-mode signal between the phase wires and the

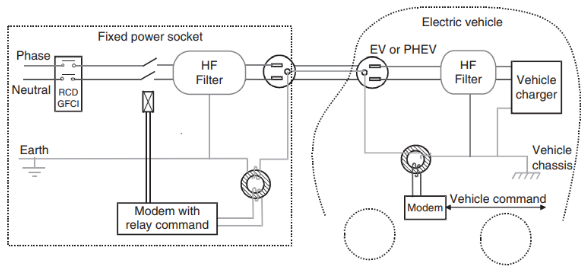


Figure 2.7: Control Pilot function with power-line communication

earth conductor, using a 110 kHz carrier frequency. This signal is generated by the vehicle electronics and transmitted to the earth wire through a transformer (ferrite torus).Filter circuits are present to avoid the unwanted transmission of data signals from the charging system to the mains, and to be compliant with relevant standards concerning electrical equipment to be connected to the grid, which proscribe any earth-line communication upstream of the electric vehicle supply equipment. The associated components are small and low cost.
The system is able to perform all control pilot functionalities over a three-wire connection. This basic protection can be implemented using a cheap and minimal set of electrical components and thus would also be suited for light vehicles like electric motorcycles, where the extra cost of special accessories should be avoided. The proposed system presents however several other interesting opportunities, since it is able not only to carry the control pilot signal but also to perform data exchange functions to be used in smart charging and billing (see also Section 2.4).

2.3.4 Mode 4 charging

Mode 4 charging is defined as the indirect connection of the electric vehicle to the a.c. supply network (mains) utilizing an off-board charger where the control pilot conductor extends to equipment permanently connected to the a.c. supply.
This pertains to d.c. charging stations, which are mostly used for fast charging. As the charger is located off-board, a communication link is necessary to allow the charger to be informed about the type and state of charge of the battery, so as to provide it with the right voltage and current.

2.4 Communication Issues

The communication between the vehicle and the charging post can be developed in several ways, with increasing sophistication.
In Mode 1 or Mode 2 charging, where standard, nondedicated socket outlets are used, there is no communication at all.

2.4.1 Control pilot communication

Mode 3 introduces communication through the control pilot function. In its most basic way of operation, the control pilot only fulfills its essential safety function. The signal can be just a current sent through the control pilot loop to ensure the vehicle is properly connected and the earth connection is sound.
More functionality can be added by using a pulse-width modulation (PWM) signal in the control pilot circuit. The PWM signal can convey information through the variation of its duty cycle Dc (Figure 2.8)

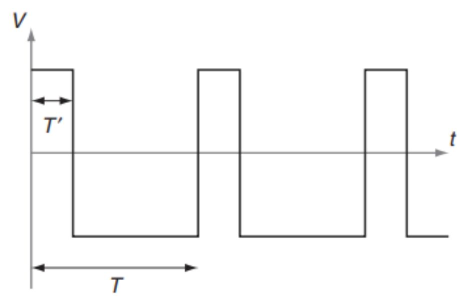


Figure 2.8: PWM signal

$$D_c = \frac{T'}{T} \times 100 \tag{2.4}$$

The duty cycle can be used to define the ampacity of the charger. This feature presents several operational benefits:

- The charger can adjust itself to the maximum allowable current that can be delivered by various charging points, for example, a standard value of 16A and a higher value of 32 A for semi-fast charging points. The standard value of 16A will usually be the default value.
- The charging point can control the amount of current absorbed by the charger, in the framework of a smart grid load management, or to optimize the billing of the electric energy.

The solution that will be proposed in the new IEC 61851-1 uses a PWM signal at a level of ± 12V at a frequency of 1 kHz and defines the current level by a constant of 0.6 × DcA for values of the duty cycle between 10 and 85%, and 2.5 × (Dc – 64)A for values between 85 and 96%, which will thus yield a current between 6 and 80A, encompassing the whole range of normal and semi-fast charging.
A duty cycle 5% conveys the message that charging current is controlled through advanced serial communication; for duty cycles 97%, charging is impeded.

2.4.2 Advanced communication

Off-board chargers (Mode 4)

Off-board chargers, which supply a d.c. to the vehicle battery, must communicate with the vehicle in order to supply the battery with the correct voltage and current. This is particularly the case with nondedicated chargers as used in public charging stations, which should be able to supply vehicles with varying battery voltages and chemistries.
The communication protocol for this data link was intended to be the part 24 of IEC 61851. The document was never published by IEC however, and the European pre-standard ENV 50275-2-4, which the IEC standard would supersede, was transferred in 2006 to Technical Specification 50457-2.
The proposed protocol is largely based on the ISO road vehicle diagnostic standards as defined in ISO 14229 a nd ISO 14230. These concern requirements for diagnostic systems implemented on a serial data link layer, which allows a tester to control diagnostic functions in and on vehicle electronic control unit.
The protocols were specifically adapted for the selected application: after the initialization phase by the off-board charger, the vehicle's charge control unit controls the charging process of the off-board charger. Contrary to the standard communication according to ISO 14230 where the server and the client are fixed during all the session, their roles are definitively reversed after the initialization phase.
This Thesis however is to be superseded by the new standards now under development and discussed next.

Communication for grid management

The development of new concepts such as "smart grid" or "vehicle to grid" has created the need for an appropriate communication protocol for electric vehicle charging beyond the mere safety functions of the control pilot, in order to provide functionalities such as:

- vehicle identification and billing, allowing payment for charging at public charging stations, but also individual billing of used energy to the user's account when the vehicle is charged at any outlets connected to a smart meter.

- charge cost optimization by choosing the most appropriate time window where electricity rates are the lowest.
- grid load optimization by controlling charger ampacity in function of grid demand.
- peak-shaving functionality by using electric vehicles connected to the grid as a spinning reserve (vehicle-to-grid).
- appropriate billing and user compensation functions for vehicle-to-grid operation.

The development of such a communication protocol involves several actors, including both vehicle manufacturers and utilities. To this effect, the standardization of this issue is being addressed by a joint working group uniting ISO TC22 SC3 (electric equipment on road vehicles, including on-board communication systems), ISO TC22 SC21 (electric road vehicles), and IEC TC69 (electric road vehicles).
The standard to be developed by this joint working group will describe the communication, in terms of data format and message content, between the electric vehicle and the electric vehicle supply equipment (charging post), as well as message content and data structure to enable billing communication and grid management. Provisions for additional communication aspects (like vehicle charge status information and configuration) will also be considered to allow for interoperability of all vehicles with all charging stations.
The communication protocols are based on the well-known seven-layer Open System Interconnection (OSI) reference model (Figure 2.9). In order to define the implementation

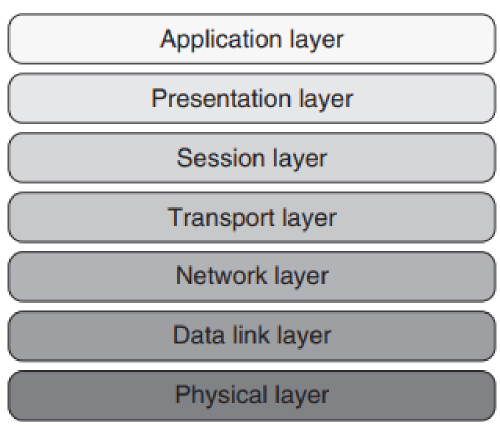


Figure 2.9: Open System Interconnection layers

of the communication in the lower layers, it is first necessary to analyze the real communication needs and the information to be transferred by the different "actors" involved in the charging process. These actors include physical devices such as the charging post or the vehicle controller, entities such as electricity suppliers or grid operators, and last but not least the vehicle user. An overview of actors potentially involved and the communication links between them is shown in Figure 2.10. The local or remote communication system may have the function of a “clearing house” for the authentication, collecting and consolidation of grid and billing parameters from the actors as well as transmitting charging process information to the respective actors. Not all such functions are necessarily required for the basic charging functions, and some may be performed locally or remotely. The system can thus become rather complex, and several issues are still to be resolved. All envisageable charging processes have to be contextualized in so-called “use cases,”

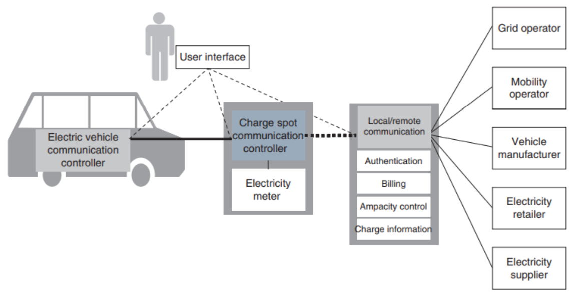


Figure 2.10: Actors involved in charging process

where three main categories can be discerned:

- charging with no communication: this is the classical Mode 1 or 2 charging, also Mode 3 charging with only the basic control pilot safety functions.
- charging with minimal communication: Mode 3 charging with ampacity control to adapt to local physical limits or to perform dynamic grid optimization.
- charging with maximum communication, including automatic billing and grid control and process information.

Functionalities to be implemented are illustrated in Figure 2.11; the increase of user convenience necessitates an extension of data structures to be exchanged.
For each use case, different scenarios are to be defined, relating to the desired control of charging by the grid operator, to the used billing scheme, and to the communication system for the user. Several systems are now under consideration and/or used in experimental fleets:

- use of a radio frequency identification (RFID) tag
- communication over the control pilot conductor
- communication (at low or high data rate) through power-line communication with the vehicle’s CAN-Bus system
- wireless communication through Bluetooth or ZigBee devices via mobile phone

One typical example scenario (“plug and charge”) could be described as follows:

- The user plugs his vehicle into the charge spot without having to perform other manipulations.
- The vehicle sends its identification ID to the charge spot to get authenticated by the clearing house through GSM.
- Authentication is successfully processed.
- Grid and tariff parameters are negotiated.
- Charging process starts automatically.

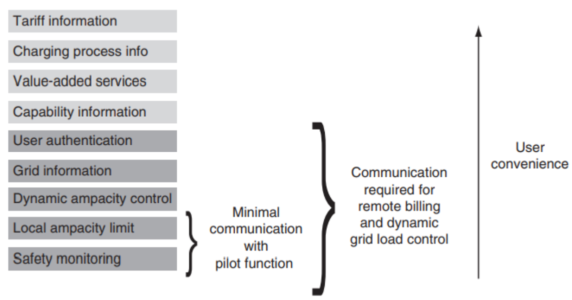


Figure 2.11: Communication and use cases

In order to define the communication messages, every such scenario shall be translated into a sequence diagram in unified modeling language. It is clear that considerable standardization work remains to be performed in this field, and that a generally applicable standard shall be draft which does not encompass proprietary protocols so it can be used by all concerned parties, enabling a true global solution.

Billing

The practice of charging electric vehicles at public charging stations raises the problem of billing the user for the energy consumed. Payment systems can make use of coins (vulnerable to vandalism), credit cards (creating the necessity of communication systems and involving transaction costs) or dedicated access devices (cards or RFID).
As the value of the electricity typically charged in one opportunity charging session is quite low compared to the parking cost in city center environment, one can consider to charge the user according to time rather than energy used, which dispenses the need for (more expensive) electricity counters. Some legal issues have also to be considered here, as in some countries the sale of electricity as such is heavily regulated.
The new developments in communication will allow a more sophisticated approach of this issue, with user identification and communication using wireless devices or mobile phones, differential billing according to time of the day and grid load, as well as compensation for energy returned to the grid. Furthermore, vehicles being charged at varying locations in a

"smart grid" environment will charge the user in a transparent "roaming" way: wherever the user charges his vehicle, it will be charged on his own bill.

2.5 Accessories for Charging

2.5.1 Connection cases

The connection of the cable between the vehicle and the charging outlet can be carried out in three ways as defined in IEC 61851-1:

- Case "A" – where the cable and plug are permanently attached to the vehicle. This case is generally found only in very light vehicles.
- Case "B" – where the cable assembly is detachable and connected to the vehicle with a connector. This is the most common case for normal and semi-fast charging.
- Case "C" – where the cable and vehicle connector are permanently attached to the supply equipment. This arrangement is typically used for fast charging (Mode 4), so that drivers do not have to carry heavy cables around. Public charging stations using this case are however at a higher risk of copper theft.

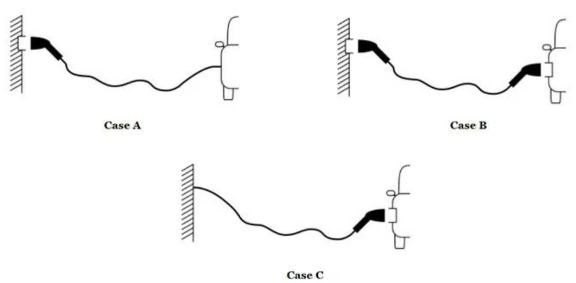


Figure 2.12: Connection cases

2.5.2 Standard accessories

For Mode 1 charging, and also for Mode 3 charging with power-line communication, standard plugs and sockets can be used encompassing only phase, neutral, and earth contacts. In most areas, this will usually be the standard domestic plugs as described in various national standards, and typically rated 10–16A.
One has to recognize however that these domestic plugs, particularly not the low cost versions mostly used on consumer grade equipment, are not really suited for the heavy-duty operation of electric vehicle charging, characterized by

- long-time operation at near rated current.

- frequent operation, including disconnection under rated load.
- exposure to outdoor conditions.

This leads to a shorter lifetime of the accessories and to contact problems which may cause hazardous situations.

A better alternative is to use industrial plugs and sockets as defined by the international standard IEC 60309-2. These plugs (in standard blue color for 230V, red for 400V) are widely used, particularly in Europe, for industrial equipment but also for outdoor uses like camping sites, marinas, etc., where they function in an operation mode comparable to an electric vehicle charging station. Both plugs/sockets and connector/ inlets are available in the IEC 60309-2 family. These accessories are easily found on the market and are inexpensive, making them the preferred choice for Mode 1 charging; they can also be used for Mode 3 charging where power-line communication is used.

2.5.3 Dedicated accessories

The use of a physical control pilot conductor necessitates the introduction of specific accessories for electric vehicle use. Such plugs and sockets are described in the international standard IEC 62196 "Plugs, socket-outlets, vehicle couplers and vehicle inlets-Conductive charging of electric vehicles."
Part 1 of this standard gives general functional requirements; it is based on the general standard IEC 60309-1, adapted with the requirements of IEC 61851-1. As the latter standard is currently being revised, a new version of IEC 61982-1 will also be drafted.
This part of the standard however states no physical dimensions of the accessories. These will be treated in part 2, which is currently under preparation.

Early proprietary developments

Vehicle couplers for early battery-electric vehicles used either standard accessories or proprietary connectors. One popular example of such coupler, produced by the Maréchal company, was widely used on European battery-electric vehicles, in the 1990s.
This coupler was foreseen for both Mode 1 or Mode 3 charging at 230Va.c., 16A and Mode 4 d.c. charging at 200 A. One common vehicle inlet could accommodate connectors in both a lightweight version for a.c. connection and a heavier version for highcurrent d.c. charging. However, despite its relatively wide use, it was never adopted as an international standard sheet.
A similarly built vehicle coupler, albeit with a different arrangement of contacts, was proposed by Avcon in the United States.

Adaptation of standard accessories

A connector accommodating both Mode 1 and Mode 3 charging has been proposed by the German company Mennekes. It makes use of modified IEC 60309-2 accessories, with sliding side contacts added for the pilot connection, while maintaining intermateability with standard IEC 60309-2 socket-outlets. A vehicle can thus be charging in Mode 1 on a non-dedicated outlet (e.g., private garage) and in Mode 3 on a public charging station. This system has seen use in Germany and Switzerland.

New standardization proposals

With the new interest for battery-electric and plug-in hybrid vehicles since 2006, standardization work has started toward a global coupler design to be used for all vehicles in all countries. Parallel developments and differing needs in several regions have led however to the proposal of three distinct designs for the vehicle coupler which will feature in IEC 61982-2, with some other proposals having been abandoned.

- Single-phase connector. A first proposal represents the solution which is based on the proposals made for the new forthcoming version of SAE J1772 and on a proposal made by the Japanese company Yazaki. This plug is rated for 250V and 32A (30A in the United States and Japan). It is fitted with two extra contacts: one for the control pilot (CP) and one for an auxiliary coupler contact (CS) which can be used to indicate the presence of the connector to the vehicle and to signal the correct insertion of the vehicle connector into the vehicle inlet. With a diameter of 44 mm, this connector is made in a compact way.

- Three-phase connector. The connector proposed in the former paragraph is single phase only. The advantages of three-phase connections and the availability of three phase supply in most European countries led to a second proposal based on a prototype developed by the German company Mennekes. The connector is rated for currents up to 63A and has two auxiliary contacts. One interesting feature of this proposal is that the same device is designed to be used both as plug and vehicle connector (Figure 2.13) - if national regulations permit such use - with a supplementary insulation of contact pin tips to prevent direct contact with live conductors.

- Italian national standard plug. Based on the first edition of IEC 62196-1, a national standard was drafted in Italy for a single-phase plug with pilot contact. These accessories are in widespread use in Italy, particularly for light electric vehicles such as motorcycles. Based on this standard, a third proposal has been drafted, with either one or two auxiliary (pilot) contacts. This accessory comes with a rating of either 16A or 32A; the dimensions of the plug housing and the contacts are actually identical for both, but a different keyway is provided to disallow introduction of a

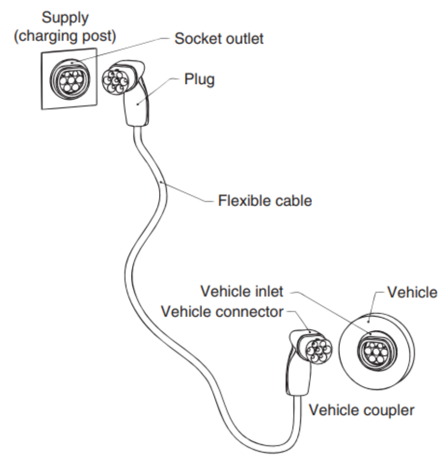


Figure 2.13: Proposed three-phase connector with nomenclature of accessories

32A plug in a 16A socket outlet. A three-phase version of this concept is also being proposed.

2.5.4 Battery connectors

Battery connectors are widely standardized for use in industrial electric vehicles. Functional requirements are given in the European standard EN 1175-1. Several families of connectors in use conform to this standard, such as the so-called Euroconnectors and the “Anderson” connectors. These connectors are available with or without auxiliary contacts, for d.c. currents up to 350 A.
Although such connectors are sometimes found in electric road vehicles for internal connections, their use for (Mode 4) charging of road vehicles is not advisable, particularly by the general public, as they are designed neither for the higher battery voltage levels now in use nor for connecting to cable assemblies. Furthermore, they lack earth conductors and are not designed to break a load.

2.6 ”Fast” Charging

For “fast” charging (called Level 3 charging in the United States), higher power levels are used which create the need for specific infrastructure beyond standard domestic or industrial socket outlets. The charging can be performed with either a d.c. or an a.c. connection between the vehicle and the charging post.
In the d.c. case, a fixed battery charger (rectifier) is connected to the battery, and more heavy and expensive fixed infrastructure is thus needed, whereas for a.c. fast charging the rectifying is done on-board the vehicle, most commonly using the traction inverter which is able to recharge the battery at a high current (for regenerative braking) and can also be fed by the grid (Figure 2.14)

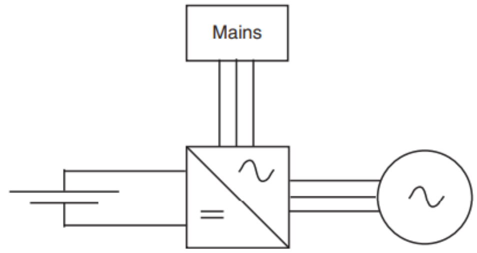


Figure 2.14: Charging with inverter

Fast charging infrastructure is being proposed for power levels up to 250 kW , claiming to be able to charge an electric vehicle in less than 10 min, comparable with the refueling time of a gasoline-powered legacy vehicle.
The enhancing of the user flexibility associated with this fast charging comes however with a number of drawbacks:

- The high cost of the fixed infrastructure involved compared with semi-fast charging.
- The need for heavy cables, which for practical purposes are usually fixed to the charging station (Case “C”), exposing them to copper thieves.
- The high burden on the distribution network if point loads of this level are introduced, and the high cost of the electric energy particularly at peak times. This can be alleviated by providing an energy buffer such as a stationary battery at the charging station (which would be charged overnight at low rates), but such solution increases the investment cost even more while introducing additional losses due to battery and charger efficiencies.
- The fast charging cycle provides only opportunity charging and does not allow final charge which takes a certain time at a low current; periodical (overnight) charging will thus remain necessary.

It thus seems likely that the mainstay of the infrastructure will make use of normal or semi-fast charging points located both at private locations (residential garages or corporate parking places) and at publicly accessible charging points.
The presence and availability of fast charging stations however provides a psychological advantage to electric vehicle drivers, allowing them to fully exploit the range envelope of their vehicle and to overcome “range anxiety.” A few well-located fast charging stations in an urban area can fulfill this need. They will be accessed mostly for “emergency” uses or in case of an unexpected change in mission, with the bulk of the electric energy delivered to the vehicles by cheap overnight charging.
The psychological advantage of the fast charging stations is comparable in fact to the plug-in hybrid vehicle, where the presence of an auxiliary power unit gives users the confidence to use the full range of their battery, overcoming the range anxiety typical for

many battery electric drivers who do not have specialist knowledge of the behavior of their battery.
The high power connection of the “fast” charging station makes it furthermore particularly interesting for “vehicle-to-grid” applications.[18]

2.7 Summarizing

2.7.1 Charging levels

Figure 2.15 will summarize charging levels:

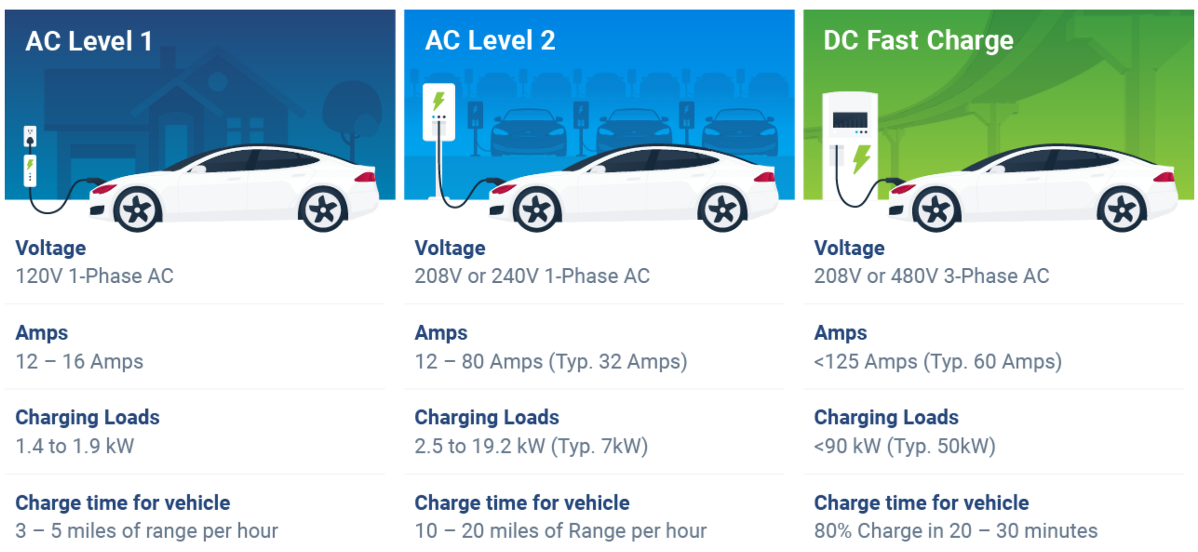


Figure 2.15: Different charging levels for plug in charging system

2.7.2 Recharging terminals

we can see in this figure different types of recharging terminals:

2.7.3 Charging outlets (vehicle side)

There is five types of plug in the vehicles side:

Type 01 plug

The type 1 plug is a single-phase plug which allows for charging power levels of up to 7.4 kW (230 V, 32 A). The standard is mainly used in car models from the Asian region, and

Figure 2.16: Charging terminals

is rare in Europe, which is why there are very few public type 1 charging stations[3].

Type 02 plug

The triple-phase plug's main area of distribution is Europe, and is considered to be the standard model. In private spaces, charging power levels of up to 22 kW are common, while charging power levels of up to 43 kW (400 V, 63 A, AC) can be used at public charging stations. Most public charging stations are equipped with a type 2 socket. All mode 3 charging cables can be used with this, and electric cars can be charged with both type 1 and type 2 plugs. All mode 3 cables on the sides of charging stations have so-called Mennekes plugs (type 2)[3].

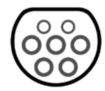
Combination Plugs (Combined Charging System, or CCS)

The CCS plug is an enhanced version of the type 2 plug, with two additional power contacts for the purposes of quick charging, and supports AC and DC charging power levels (alternating and direct current charging power levels) of up to 170 kW. In practice, the value is usually around 50 kW[3].

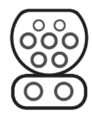
CHAdeMO plug

This quick charging system was developed in Japan, and allows for charging capacities up to 50 kW at the appropriate public charging stations. The following manufacturers offer electric cars which are compatible with the CHAdeMO plug: BD Otomotive, Citroën, Honda, Kia, Mazda, Mitsubishi, Nissan, Peugeot, Subaru, Tesla (with adaptor) and Toyota[3].

(a) Type 01 plug



(b) Type 02 plug



(c) Combo plug(CCS)

(d) CHAdeMO plug

(e) Tesla supercharger

Figure 2.17: Different charging outlets for electric side [3]

Tesla Supercharger

For its supercharger, Tesla uses a modified version of the type 2 Mennekes plug. This allows for the Model S to recharge to 80% within 30 minutes. Tesla offers charging to its customers for free. To date it has not been possible for other makes of car to be charged with Tesla superchargers[3].

2.8 Vehicle-to-grid ”V2G”

Vehicle-to-grid (V2G) technology is one of the advanced solutions that uses electric vehicles (EV) to balance electricity demand in the power system. It can be particularly useful in analyzing and then mitigating the risk of not delivering electricity to the end user.

2.8.1 Definition

Vehicle to grid (V2G) technology can be defined as a system in which there is a capability to control, bi-directional flow of electric energy between a vehicle and the electrical grid. The integration of electric vehicles into the power grid is called the vehicle-to-grid system. Any electric-drive vehicle, has within them the energy source and power electronics combining making it capable to drive the power requirements of homes and offices. It has been calculated that 92% of the total vehicles remain parked even during the peak hours. When a vehicle is not being operated, the on-board battery is connected to a nearby electrical grid via appropriate communication devices. The idea is to use the power from the idle vehicles to provide load-shedding and peak shaving and many other functions. The vehicle batteries can be fully charged during low-demand hours and the flow can be reversed at any time according to the requirements. This can be fulfilled by utilizing the concept of 'smart grid' which is an electricity network capable of processing the information, manages the electricity flow to fulfil the end users varying power demand and is able to provide communication between generation sources and end users. This concept works on the balance the 'off-peak' and 'peak' demand. The Vehicle can get charged during off-peak hours and can sell it back to the grid during peak hours.[19]

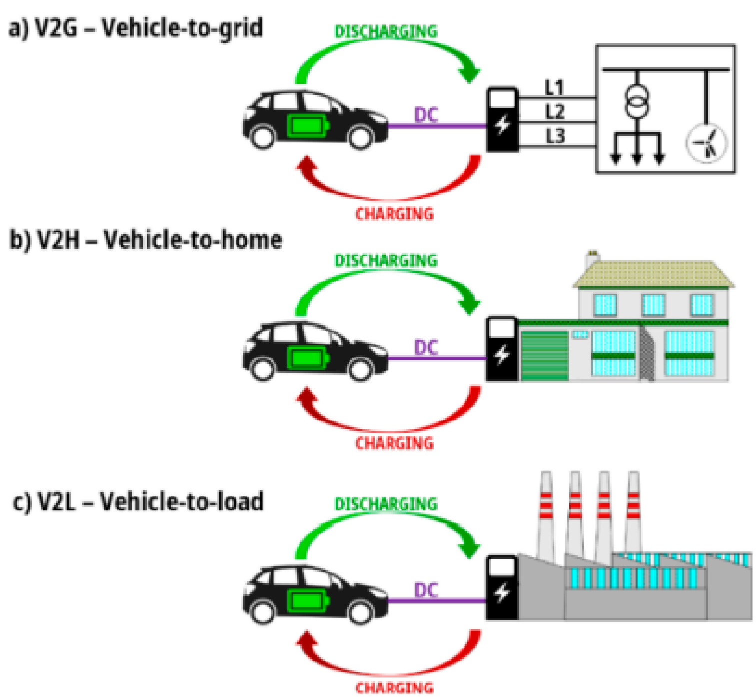


Figure 2.18: Various forms of vehicle-to-X technology[4]

2.8.2 Advantages

PHEVs can be operated as a load while charging, a distributed storage, including services like reactive regulation, motor starting or a standalone energy source such as peak shaving. Although care has to be taken while discharging the on-board batteries as excessive discharge might affect the battery life and its expectancy. PHEV fleet is large enough and if a particular portion of the vehicle's stored energy could be tapped while parked, it would provide the power grid with large amounts of energy at a given time of the day. This section concentrates on the benefits of using PHEVs as a distributed storage.[19]

- Peak shaving and other electrical benefits.
- Ancillary and Regulation Services.
- Renewable Energy Integration.
- Spinning reserves.
- Backup during power outage.[18]

2.9 Conclusion

Battery-electric and plug-in hybrid vehicles can be charged on several levels.
"Normal" charging, making use of standard domestic socket outlets, can be used potentially anywhere but is limited in power. It remains suitable for overnight home charging or improvised opportunity charging. On private premises, Mode 1 charging can be done in perfect safety with a properly fitted electrical installation, making use of standard accessories, preferably of the IEC 60309-2 type.
"Semi-fast" charging allows a higher charging power, up to 22 kW, which is very suitable for most vehicles. It makes use of power levels which are easily delivered by existing distribution networks and will be the mainstay for dedicated electric vehicle charging points in both private and public settings. The use of three-phase supply allows a considerable increase in the charging power available. Dedicated accessories are being standardized to allow a flexible operation of the system including power management and vehicle to grid.
"Fast" charging needs a more expensive infrastructure, particularly where a d.c. connection with off-board charger is used and may thus be less interesting for routine charging, but the availability of selected fast charging stations provides opportunities for enhancing the operational flexibility of the vehicles, as well as high-power bidirectional energy transfer.
Battery-electric and plug-in hybrid vehicles should be considered equally for their infrastructure needs, both depending on the electric grid for their energy supply; it is in fact to be expected that most plug-in hybrids will mainly be operated in electric mode, allowing the use of cheaper (and cleaner!) electric energy.

Intensive work is now being performed by international standardization committees in order to realize unified solutions which will be a key factor in allowing the deployment of electrically propelled vehicles on a global level.[18]

Chapter 3

Wireless charging system

3.1 Introduction

The newest technology of charging EV's is the wireless (WPT) which don't need cables or plugs to charge, but there's some concerns about the amount of power, yield of the process.

This chapter will clarify the theory of the resonance coupling WPT, talk about the different modes of the WPT (static and dynamic), Safety of the process on the human being and the new technologies in the way of development concerning the wireless systemes (G2V, V2V)

3.2 Theory of resonance coupling WPT

The following are different ways to achieve WPT, such as: B. Far-field type (Microwave WPT), Magnetic induction type and coupled resonance type. From a ”coupling” and ”resonance” perspective, they can be classified as shown in Figure 3.1. For far-field types, the load impedance on the receiver (Rx) side does not apply Affects the state of the transmitter (Tx) side. So there is coupling between Tx and Rx.Far-field antennas may have a resonant mechanism (eg, a half-wave dipole) or not (eg, a horn). coupled resonance type and magnetic induction type for near field area. In this type, the load impedance on the Rx side affects the state on the Tx side. Therefore, the coupling between Tx and Rx is stronger. Coupled resonance type has Magnetic induction type has no resonance mechanism

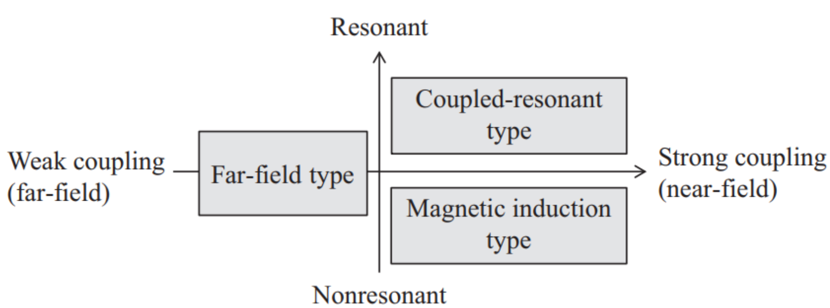


Figure 3.1: Classification of WPT systems by aspect of coupling and resonance

Resonant WPT technology is divided into electric field coupling and magnetic field coupling, as shown in Figure 3.2. To understand near-field WPT, it is best to consider coupling and resonance mechanisms separately. If only E-field coupling or H-field coupling is used, an external reactive device is required for resonance. On the other hand, self-resonant antennas have both E-field coupling and H-field coupling, because resonance occurs at frequencies where the amount of stored electrical energy and stored magnetic energy are equal,the following figure shows coupling mechanism,resonant mechanism, and impedance matching mechanism for various kinds of WPT:

		Coupling mechanism		Resonant mechanism	Impedance matching mechanism (feeding mechanism)	Schematic
		E-field	H-field			
Type 1	Electrostatic induction	Yes	No	Power factor compensation may be considered as a resonant circuit	Not active following for load impedance	
	Magnetic induction	No	Yes			
Type 2	Coupled-resonant using electrostatic induction	Dominant	Negligible	Discrete reactance device is necessary for resonance	According to the load impedance or transmission distance, active following by circuit parameter in impedance matching circuit or transmission frequency is necessary to achieve simultaneous conjugate matching	
	Coupled-resonant using magnetic induction	Negligible	Dominant			
Type 3	Coupled-resonant with self-resonant coupler (E-field dominant)	Dominant	Small, but not negligible	Coupler acts as resonator		
	Coupled-resonant with self-resonant coupler (H-field dominant)	Small, but not negligible	Dominant			
Type 4	Far-field type	Coupling in far-field. Ratio of E-field to H-field is 377 Ω		Tx and Rx antennas resonate independently	Tx/Rx antennas are matched to the source/load independently	

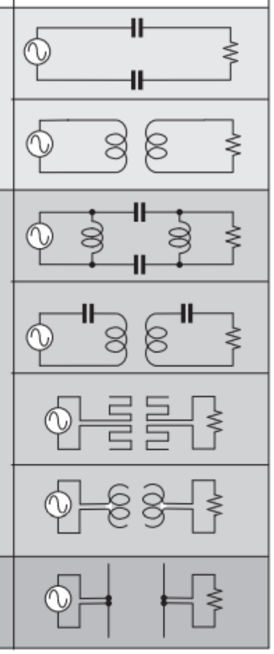


Figure 3.2: Coupling mechanism, resonant mechanism, and impedance matching mechanism for various kinds of WPT

The unified model of the coupled resonant WPT is shown in Figure 3.3. This model allows us to interpret coupled resonant WPTs in terms of ”resonance” and ”coupling”, the same applies to power electronics-based WPTs and RF-based WPTs

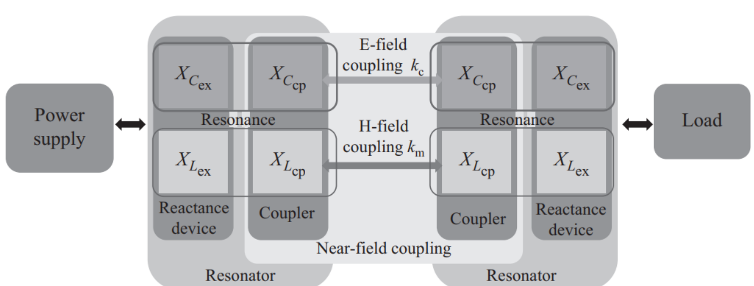


Figure 3.3: Unified model for coupled-resonant WPT

As seen in the previous figure, the unified model of the of coupled-resonant WPT,. This model enables us to explain coupled-resonant WPT from the viewpoint of ‘‘resonance’’and ‘‘coupling’’. The transmitting resonator is connected to the power supply,and the receiver resonator is connected to the load. The resonator consists of a coupler and a reactive element. Couplers are defined in the previous section. A reactive element is a device that has a reactive impedance but is not designed to interact between air and an electrical circuit. For example, a coupling coil is a coupler, but a coil in a matching circuit is a reactive element. The term resonance-coupling has is compound of two words, resonance and coupling, each word is a phenomena that explain as follow:
Resonance: The inductive reactance of the resonator consists of XLex and XLcp. The capacitive reactance of the resonator consists of XCex and XCcp. Resonance occurs at frequencies where the inductive and capacitive reactances are equal. ”Resonance” is defined as the amount of magnetically stored energy, and the electrical energy stored in the resonator becomes equal. The reactive device keeps the stored energy in the enclosed space, while the coupler keeps it in the open space
Coupling: The capacitive reactances of the Tx resonator and the Rx resonator are coupled by the electric field, and the electric field coupling coefficient is kc. The inductive reactances of the Tx resonator and the Rx resonator are coupled by the magnetic field, and the magnetic field coupling coefficient is km.

3.3 Circuit theory of wireless coupling

A passive device that delivers electric power to a remote point across a space is called a wireless coupler, A well-known example is a magnetic field coupler consisting of twin loops, solenoidal, or spiral coils placed at a distance from each other as shown in Figure 3.4

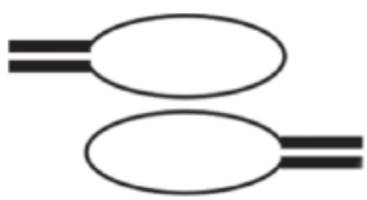


Figure 3.4: Inductive wireless couplers

Another example is an electric field coupler consisting of two pairs of metal solid or mesh plates normally facing each other across a space as shown in Figure 3.5

Figure 3.5: Capacitive wireless couplers

wireless couplers are usually made from passive material such as conductive metals or dielectric insulators,Once the coupler of interest is characterized with an equivalent circuit, characteristics of wireless power transfer could be evaluated using key factors that are the coupling coefficient k and the quality factor
In the case of inductive coupling,The coupler is assumed to have a symmetrical shape between the input and output. Therefore, it corresponds to the one-to-one transformer shown in Figure 3.6, where two identical coils exchange RF energy with each other via flux linkage,the coils of transformer are characterized by self inductance L and mutual inductance M.

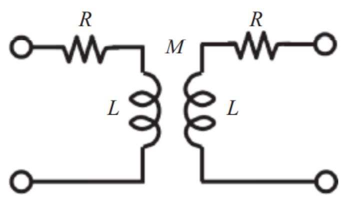


Figure 3.6: Inductive coupler equivalent circuit

To use couplers in wireless power transfer (WPT) systems, the primary coil is excited by radio frequency current. The current creates a magnetic flux around it. Some of the flux goes to the secondary coil and the rest leaks out. The ratio of the primary to secondary series flux is called the coupling coefficient, denoted as k. About element parameters

$$k = \frac{M}{L} \tag{3.1}$$

Where L designate self inductance and M designate mutual inductance,
In a stand-alone coil d that has inductance L and resistance R in series, the quality factor

is defined as follow:

Also clutch. This applies not only to Q, but also to coupling

$$Q = \frac{\omega L}{R} \tag{3.2}$$

Not only for inductors, Q also applies to other passive components as a quality factor and single-port active devices such as resonators and oscillators. what do we do next Learn in this section that Q works like an inductor even for a two-port system Also clutch. This applies not only to Q, but also to coupling coefficient k
The WPT system main concern of in efficiency, which is defined as followed:

$$\eta = \frac{P_{out}}{P_{in}} \tag{3.3}$$

3.4 Static wireless electric vehicle charging system

WEVCS opens another door to provide consumers with a user-friendly environment (and avoid the safety concerns associated with plug-in chargers), Static WEVCS can easily replace the plug in charger with minimal driver participation, and it solves associated safety issues such as trip hazards and electric shock,Figure 3.7 shows the basic layout of a static WEVCS.

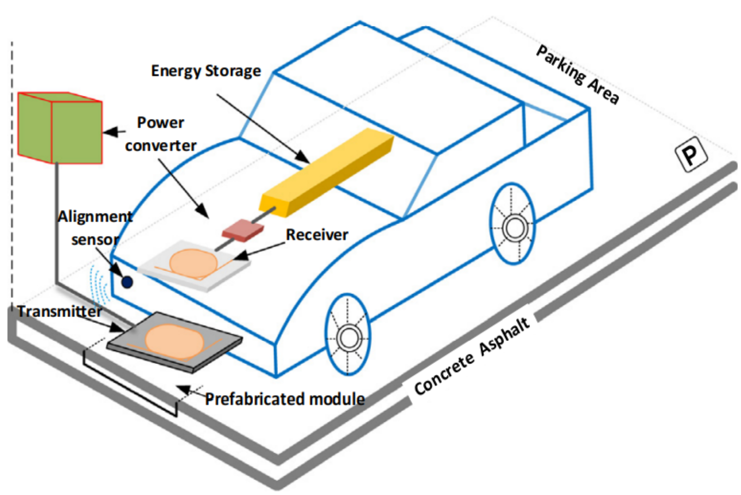


Figure 3.7: Inductive coupler equivalent circuit

The primary coil is installed in the street or underground, with additional power converters and circuits underneath. The receiver coil or secondary coil is Typically installed under the front, rear or center of the EV. The received energy is converted from AC to DC using a power converter and transferred to the battery pack, the charging time depends on some factors that are source power level, charging pad sizes, and air-gap distance between the two windings,The average distance between light weight duty vehicles is approximately 150–300 mm. Static WEVCS can be installed in many places like parking areas, car parks, homes, commercial buildings, shopping centres, and parks., many prototypes have been developed by universities at research level and commercial level,their price vary from 2500-13000 USD, depending on charging levels by international SAE standards (J2954),including frequency range 80-90 kHz

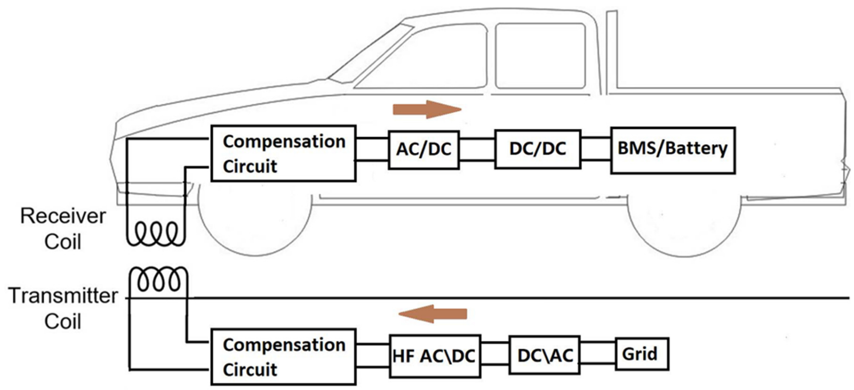
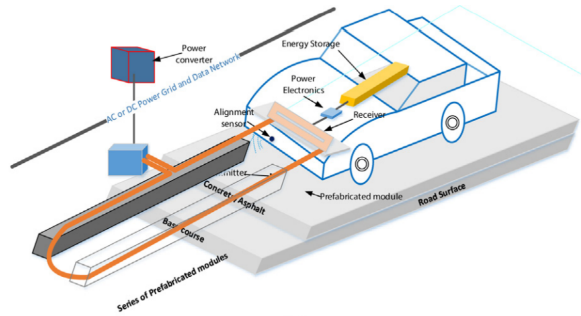


Figure 3.8: Block diagram of the wireless static EV charging system

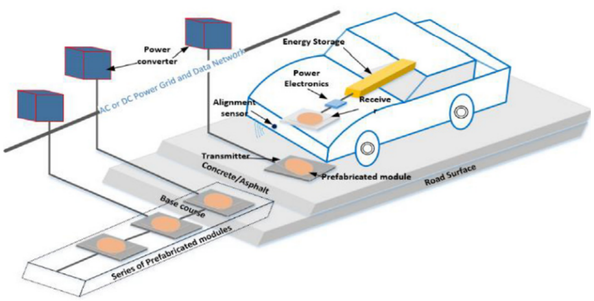
A typical wireless electric vehicle charging platform is shown in Figure 3.8. It has multi-level wireless control of electric vehicles. The coupling between two wires can be increased by twisting them together and bringing them closer together with a common axis, so the magnetic field of a single coil passes through the other coil. The mutual inductance of 2 conductors can be used to evaluate the amount of inductive coupling between them. The two coils may be contained in one unit, such as the secondary and primary windings of a transformer, or may be separate. Pairing can be unintentional or intentional. Accidental inductive coupling can cause a signal in one circuit to trigger directly into a nearby circuit, so this is called cross-talk, also a form of electromagnetic interference.[20]

3.5 Dynamic wireless electric vehicle charging system

Plug-in or BEVs face two major hurdles - cost and range. To increase range, EVs either need to be recharged fairly frequently, or larger battery packs need to be installed (which brings additional issues such as cost and weight). Furthermore, it is not economical to



(a)



(b)

Figure 3.9: different dynamic wpt structures

charge the vehicle frequently. Electric Vehicle Dynamic Wireless Charging System (D-WEVCS) is a promising technology that can reduce the problems associated with the range and cost of electric vehicles. It is the only solution for the automation of future electric vehicles.[21]

As with static WEVCS, the secondary coil is mounted under the vehicle. When the electric car passes the transmitter, it picks up the magnetic field through the receiver coil and converts it to DC to charge the battery pack using the power converter and BMS. Frequent charging of EVs can reduce total battery demand by about 20% compared to current EVs. Dynamic WEVCS requires the installation of transmitter pads and power segments at specific locations and predefined routes. The power supply section is mainly divided into centralized and separate power supply

frequency schemes, as shown in Figure 3.9. Power supply centrally, install a large coil (about 5-10m) on the road, use several small charging pads. Compared with the segmented scheme, the centralized scheme has higher losses, lower efficiency, including high installation and higher maintenance costs.
Overall, installing the initial infrastructure for this technology is expensive. In the future, with the help of self-driving cars, it will help to achieve perfect alignment between the transmitting coil and the receiving coil, which will greatly improve the overall power transmission efficiency. Dynamic-WEVCS can be easily integrated into many electric vehicle transportation applications such as: B. Light Commercial Vehicles, Buses, Rail and

Rapid Transit.

There is many models that could be applied on dynamic wireless electric vehicle charging system, we will discuss about Grid-to-vehicle (G2V) and vehicle to vehicle (V2V) model for wireless charging.
For G2V, primary coil is in the form of inductive coil laid along the road is powered by grid mains through rectifiers, high frequency inverters and power factor corrector. they work together to create a magnetic field that link the first coil and the second coil of the electric vehicle, to assure power transfer from grid to vehicle as shown in figure 3.10 [22]

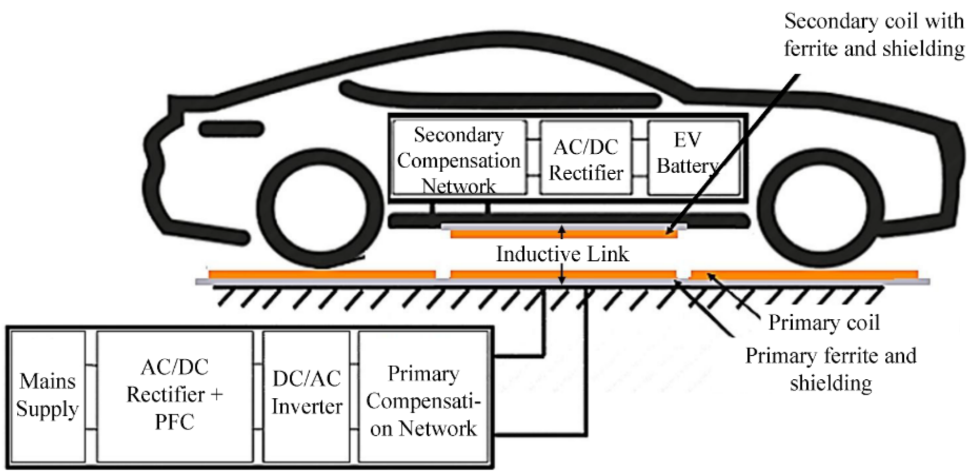


Figure 3.10: Block diagram of the wireless dynamic EV charging system

The V2V is another way of dynamic wireless power transfer to increase the distance covered by EV drivers.This utilizes vehicles that have large battery bank for wirelessly transfer power to electric cars in surrounding and are power deficit. These vehicles have primary coil fitted at the front and secondary coils are held at the back of receiving vehicle. Energy transfer takes place as shown in the Figure 3.11 [22]

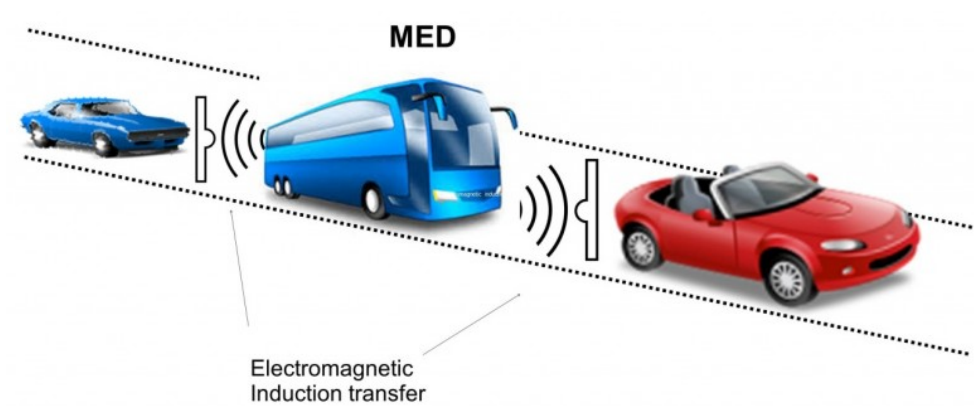


Figure 3.11: Dynamic charging via Vehicle to Vehicle (V2V) model

This concept is also called as mobile energy disseminators (MED). Care must be taken to avoid accident between vehicles transmitting and receiving the energy. So MEDs limits the development of new DWS enabled roads hence reduce the cost. The mobile energy disseminators (MEDs) are utilized for the optimizatio of route taken by EVs. Then, for optimization a restricted shortest path is considered upon the presence of MEDs on that road segment and premeditated time of ravel. The optimization function now has following parameters total distance travelled, time of journey and the energy consumed during the journey by electric vehicle.

3.6 Safety concerns relative to wireless charging system

Electric charge is a fundamental property of matter. Interactions between charged objects are mediated by electromagnetic fields (EMFs). EMF propagates infinitely in all directions from all charged matter. Electromagnetic (EM) interactions are responsible for nearly every physical, chemical, and biological phenomenon we encounter every day. EMF can be thought of as a combination of the electric field created by the charge and the magnetic field (also called current) created by the motion of the charge. The electric and magnetic fields produced by charged objects can be further divided into two parts: the reaction field, which is produced by a constant charge and current, and the radiative field, which is produced by the time-varying distribution of the charge and current. Conductors carrying alternating current (AC) generate reactive and radiated fields.[23]

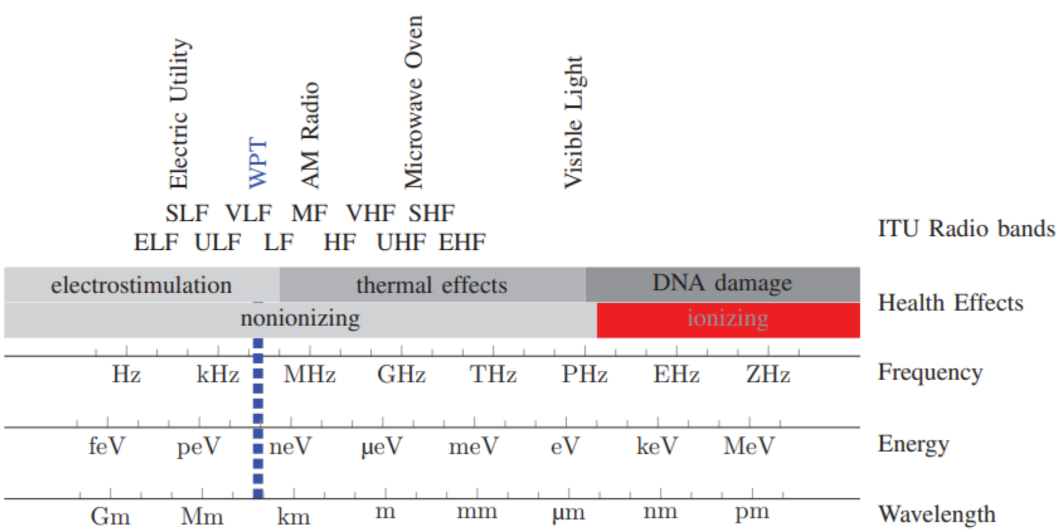


Figure 3.12: The electromagnetic spectrum organized horizontally on a logarithmic scale in terms of increasing frequency

The reactive field dominates in the ”near field” range and is responsible for capacitive and inductive coupling effects. Reactive fields store electromagnetic energy that is not

lost or radiated into the environment. If an adjacent object is capacitively or inductively coupled to a passive source, a charge or current can be induced in it. This induction is the only known process by which energy can be transferred through a reactive field. The strength of the reaction field decreases relatively quickly with distance. For example, the field of a magnetic dipole (a good approximation of any closed current loop over a distance of a characteristic length) decreases as the cube of the distance to the dipole.
The radiation field propagates outward from its source at the speed of light. These fields may also be referred to as electromagnetic radiation. The electromagnetic spectrum diagram in Figure 3.12 illustrates the full range of propagating electromagnetic fields, their alternate names, and their interaction properties. Radiated fields do not decay like reactive fields, but rather ”spread” as they move away from their source. This results in an effective inverse square relationship between distance and field strength.
As wireless charging systems operate at higher and higher power levels, up to 100 kW for high-power EV applications,the EM fields generated between or around charging pads should be measured to ensure safe areas for humans. Induced voltages can also damage electronic equipment. In addition, heating effects on the metal should also be considered.[24]
human exposure to EM fields is the greatest safety concern for EV wireless charging systems, since the EM fields generated can produce direct effects on the human body. Two guidelines were formulated for human exposure to EM fields: one publication from the ICNIRP, and the other publication, issued by the International Committee on Electromagnetic Safety under the Institute of Electrical and Electronic Engineers (IEEE), was IEEE C95.1. The basic restrictions on EM exposure from 10 kHz to 100 kHz published by the ICNIRP are much more conservative than those in IEEE C95.1. The ICNIRP reference level for general public exposure to time-varying EM fields is 6.25 mT, which is much lower than the IEEE level of more than 100 mT.Nowadays, inductive EV charging standards including SAE J2954, UL2750 and ISO/IEC PT61980 employ the ICNIRP guidelines to define the limits on human exposure to EM fields. SAE J2954, issued by SAE International, is an operating and safety standard for wireless charging of electric and plug-in hybrid vehicles. In addition, the ICNIRP guidelines have been adopted by many European and Oceanic countries. Although standards have been proposed regarding human exposure to EM fields, the scope of this study is limited to a study on the possible health effects of EM fields in EV wireless charging using ICNIRP guidelines.[24]

3.7 Conclusion

Despite the WPT for EV's is a new technology, there's lot of development in this field. As we have seen in this chapter, the principal of the inductive coupling and the different ways thet circuit is coupled. Then we have seen the two modes of the WPT which are the static wireless EV charging system (WEVCS) with its cost, frequency and structure. And the dynamic wireless electric vehicle charging system (DWEVCS) with its structures along with the new advanced technologies which are the future perspective of the WPT (V2V, ...).

We ended the chapter with assuring the concerns and fears about if the inductive coupling is safe or not by mentioning the safe electromagnetic field of WPT systems.

Chapter 4

Comparison of the different charging systems

4.1 Introduction

In this chapter we will touch the study of the different charging systems of the electric vehicle seen in the previous chapters (plug-in normal charge, plug-in semi-fast charge, Plug-in fast charge, stationary wireless charging and the dynamic wireless charging) using one of the method of making decisions (Method for Multiple-Criteria Decision Making MCDM).

After seeing a lot of methods, we decided to use TOPSIS method because it using simple mathematical method and algorithm, using both quantitative and qualitative data, u have a clear differentiation of all the alternative and the decision making is easy.

Next thing we have to determine the criterias then find the right data for all the alternatives.

4.2 TOPSIS Method

4.2.1 Introduction

The Technique for Order Preferences by Similarity to an Ideal Solution (TOPSIS) method was proposed by Hwang and Yoon (1981)[25]. The main idea came from the concept of the compromise solution to choose the best alternative nearest to the positive ideal solution (optimal solution PIS)[26] and farthest from the negative ideal solution (inferior solution NIS)[26]. Then, choose the best one of sorting, which will be the best alternative.

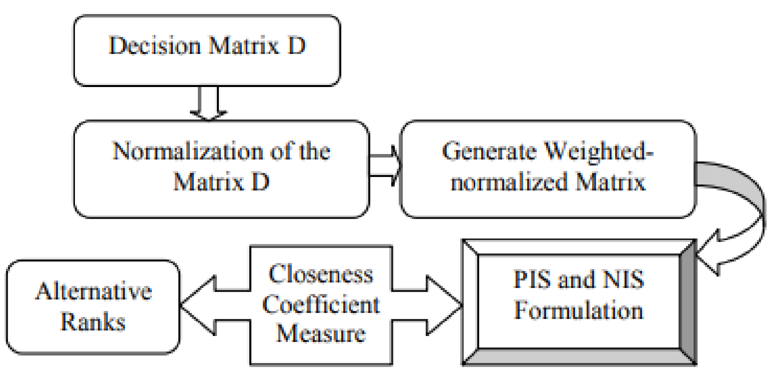


Figure 4.1: TOPSIS Procedure [5]

4.2.2 Procedure

In the classical TOPSIS method we assume that the ratings of alternatives and weights are represented by numerical data and the problem is solved by a single decision maker.

The idea of classical TOPSIS procedure can be expressed in a series of following steps [27] [28]

Step 1. Construct the decision matrix and determine the weight of criteria.

Let $X = x_{ij}$ be a decision matrix and $W = [w_1, w_2, ..., w_n]$ a weight vector, where $x_{ij} \in \mathfrak{R}$,$w_j \in \mathfrak{R}$ and $w_1 + w_2 + ... + w_n = 1$.

Criteria of the functions can be: benefit functions (more is better) or cost functions (less is better).

Step 2. Calculate the normalized decision matrix.

This step transforms various attribute dimensions into non-dimensional attributes which allows comparisons across criteria. Because various criteria are usually measured in various units, the scores in the evaluation matrix X have to be transformed to a normalized scale. The normalization of values can be carried out by one of the several known standardized formulas. Some of the most frequently used methods of calculating the normalized value n_{ij} are the following:

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{4.1}$$

$$n_{ij} = \frac{x_{ij}}{max_i \quad x_{ij}} \tag{4.2}$$

$$\begin{cases} n_{ij} = \frac{x_{ij} - min_i \quad x_{ij}}{max_i \quad x_{ij} - min_i \quad x_{ij}} & if \quad C1 \quad is \quad a \quad benefit \quad criterion \\ n_{ij} = \frac{max_i \quad x_{ij} - x_{ij}}{max_i \quad x_{ij} - min_i \quad x_{ij}} & if \quad C1 \quad is \quad a \quad cost \quad criterion \end{cases}$$

for i = 1, … , m; j = 1, … , n.

Step 3. Calculate the weighted normalized decision matrix.

The weighted normalized value v_{ij} is calculated in the following way:

$$v_{ij} = w_j n_{ij} \quad for \quad i = 1, ..., m; j = 1, ..., n. \tag{4.3}$$

where w_j is the weight of the j-th criterion, $\sum_{j=1}^{m} w_j = 1$

Step 4. Determine the positive ideal and negative ideal solutions.

Identify the positive ideal alternative (extreme performance on each criterion) and identify the negative ideal alternative (reverse extreme performance on each criterion). The ideal positive solution is the solution that maximizes the benefit criteria and minimizes the cost criteria whereas the negative ideal solution maximizes the cost criteria and minimizes the benefit criteria.

Positive ideal solution A^+ has the form:

$$A^+ = (v_1^+, v_2^+, ..., v_n^+) = \left(\left(max_i \quad v_{ij} \quad \mid j \in I\right), \left(min_i \quad v_{ij} \mid j \in J\right)\right) \tag{4.4}$$

Negative ideal solution A^- has the form:

$$A^- = (v_1^-, v_2^-, ..., v_n^-) = \left(\left(min_i \quad v_{ij} \quad \mid j \in I)\right), \left((max_i \quad v_{ij} \mid j \in J)\right)\right) \tag{4.5}$$

where I is associated with benefit criteria and J with the cost criteria,

i = 1,..., m; j = 1,..., n.

Step 5. Calculate the separation measures from the positive ideal solution and the negative ideal solution.

In the TOPSIS method a number of distance metrics can be applied.

The separation of each alternative from the positive ideal solution is given as:

$$d_i^+ = \left(\sum_{j=1}^{n} (v_{ij} - v_j^+)^p\right)^{\frac{1}{p}}, i = 1, 2, ..., m. \tag{4.6}$$

The separation of each alternative from the negative ideal solution is given as

$$d_i^- = \left(\sum_{j=1}^{n} (v_{ij} - v_j^-)^p\right)^{\frac{1}{p}}, i = 1, 2, ..., m. \tag{4.7}$$

Where $p \geq 1$.For p= 2 we have the most used traditional n-dimensional Euclidean metric.

$$d_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2, i = 1, 2, ..., m.} \tag{4.8}$$

$$d_i^- = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^-)^2}, i = 1, 2, ..., m. \tag{4.9}$$

Step 6. Calculate the relative closeness to the positive ideal solution.

The relative closeness of the i-th alternative A_j with respect to A^+ is defined as:

$$R_i = \frac{d_i^-}{d_i^- + d_i^+}, \tag{4.10}$$

where $0 \leq R_i \leq 1, i = 1, 2, ..., m.$

Step 7. Rank the preference order or select the alternative closest to 1.

A set of alternatives now can be ranked by the descending order of the value of R_i.

4.3 Data for plug-in charging system

4.3.1 Charging infrastructure technologies

There are no standards yet for charging infrastructure for electric vehicles.The specifications for the types of charging points (voltage, shape of plugs and connectors, etc.) vary from one country and manufacturer to another. We provide here a classification based on the work of the the work of Jean Louis Legrand's interministerial working group (Working Group on the development of infrastructure for electric or rechargeable hybrid vehicles - sub-group on the economic model, 2009).[29]

The normal charge

It is so called because it is based on the standardised voltage of the low voltage network.

- **Power(kW):** 3
- **Charging time for a 25kWh battery:** 8 to 10 hours
- **Uses:** This type of charging is intended for all home charging and for the vast majority of charging points at workplaces and private car parks. Majority of charging points at workplaces and private car parks. Slow charging can also be used for be used for on-street charging.
- **Current:** Single-phase nominal voltage of 230 V between phase and neutral and current of 16A. alternating current.

- **Advantages:** No impact on the size of the supply network. In addition, this type of moreover, this type of charging uses widely available equipment, is inexpensive and does not have a negative impact on the life of the lithium ion battery[29].
- **Disadvantage :** Slow charging.

Semi-fast and fast charging

- **Power(kW):** from 20 to 50. A distinction is made between semi-fast charging (24kW) and fast charging (42kW).
- **Charging time for a 25kWh battery:** At 42 kW the battery is charged to 80% in 25 minutes, in about one hour on a semi-fast charge.
- **Uses:** Unlike normal charging, this technology can only be used in public car parks, on the road or in or in dedicated stations.
- **Current:** The current is three-phase to benefit from the 400V voltage between phases. The current is from 32 to 63A at the network level and 100A at the wiring level. A rectifier charger is integrated directly in the terminal to supply direct current to the vehicle.
- **Advantages:** Speed of charge.
- **Disadvantage :** The plugs and connectors for this type of charging are not yet industrialised on a large scale. As of April 2009, the only public fast charging station in operation was the Dutch NRGspot (City of Westminster, 2009). The cost of a fast charging station is obviously a major drawback[29].

Very fast charging

This technology is currently being developed. It supplies the vehicle directly with three-phase alternating current through the vehicle's power train rectifier. This system injects a power of 50 to 250 kW into the vehicle and allows a 50% charge of the battery in 10 to 15 minutes. This system has never been deployed in pilot projects and is currently being developed by a few charging station manufacturers. This charging system is designed for dedicated stations[29].

Other processes are imagined, such as battery exchange[29], which would take place in dedicated stations, for a exchange time of around five minutes. While some countries are banking on this system (Better Place project in Denmark).This process, however, is hindered by the fact that EV batteries are not standardized for varying vehicle models [7] and it seems that its economic and technical viability remains to be proven. Such projects are not taken into account in the present prospective study, as a significant development of this type of system is not yet possible.

4.4 Data for wireless charging system

The global wireless electric vehicle charging market was valued at $6,857.80 thousand in 2020, and is projected to reach $207,415.10 thousand by 2030, growing at a CAGR of 41.4% from 2021 to 2030[6].

The OEMs (Original Equipment Manufacturer) and governments emphasize on electric vehicles usage as an effort to reduce tail pipe emissions. With the increase in demand for electric vehicles, the requirement for charging stations is expected to significantly increase in the near future. As the plug-in charging stations take longer hours for charging, the on-the-go wireless electric vehicle chargers can cater to the need and provide range extension. The wireless charging has high applications for cars as well as for commercial fleets; thus, fostering the growth of the wireless electric vehicle charging market[6].

Figure 4.2: Attractive Opportunities in the wireless charging market for electric vehicles[6]

we can see in Figure 4.3 the benefits of the WPT system in the charging operation and it's impact on the battery cost.

4.4.1 Stationery wireless charging

Some companies are already rolling it out in the UK. Charging companies Char.gy, Qualcomm, and Sprint Power have all developed their own charging pads and are in the process of trialling them in public. Some larger companies, including BMW [8], have also started to offer static wireless charging systems.

The county of Nottinghamshire is even taking part in a trial, which will analyse nine electric taxis using wireless charging, as part of the WiCET project [9] – a £4.47 million

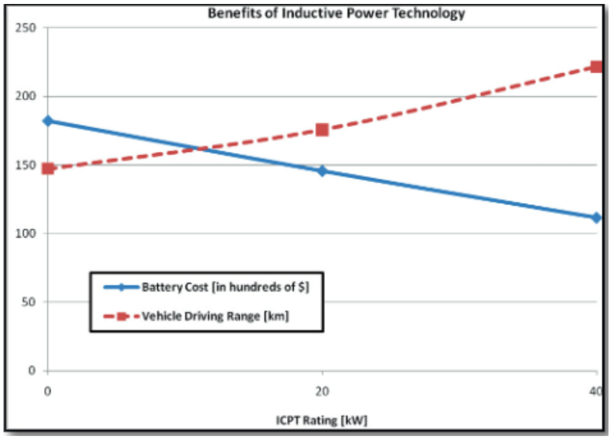


Figure 4.3: Benefits of WPT in EV Charging Operations[7]

initiative which will hopefully demonstrate the successes of wireless charging for electric vehicles[30].

Figure 4.4: BMW e530 charging wireless [8]

Figure 4.5: BMW wireless pad [8]

As with any new technology, there's a lot of mixed opinions on whether wireless EV charging is as good as standard EV charging.
However, in terms of efficiency, wireless charging is currently in the range of 90% to 93%. This means it does as good a job of transferring electricity from the charger to a car's battery as standard charging does – and since no charging rate is 100% yet, we'd say that's pretty good[30].
Again, since wireless charging is still relatively new, it's more common for it to be introduced to taxi and bus services rather than domestic vehicles (Figure 4.6).
"Before you get to electric cars, there are an awful lot of vehicles, such as buses and taxis and vans, that have to go electric," Andrew Daga, chief executive of Momentum Dynamic, told The Financial Times.
Currently, it costs $30,000 (£22,483) to add four to six pads to a bus, but the company Momentum Dynamic is aiming to cut that to less than $1,000 (£749) once it is producing at scale.
This means that wireless pads could cost between $5,000-$7,500 (£3,747-£5,246) for an individual pad.

4.4.2 Dynamic wireless charging

The greatest benefit of a dynamic ICPT (inductive coupling power transfer) system is that it eliminates the energy storage shortcomings of EVs by allowing them to charge while driving without the additional waiting time. The ultimate goal is to extend the EV driving range to distances of over 500 kms while also significantly decreasing the size and cost of the EV battery.

Figure 4.6: New Electric Taxi Livery for UK's first Wireless Charging Trial[9]

As EV battery size continues to decrease, the cost will begin to shift from the electric vehicle to the complex infrastructure needed to charge such vehicles while in-motion. Public agencies, like state DOTs and electric utility companies, will have to invest significant costs constructing, maintaining, and operating EV charging infrastructure[7].

Figure 4.7: Charging plates under the asphalt[10]

Infrastructure cost

According to the Electric Power Research Institute (EPRI)[31],an ICPT system, or what they refer to as an integrated energy storage system, consists of three major components: energy storage system (ESS), power conversion system (PCS), and balance of plant (BOP). This section of the paper will give an in-depth literature review of the major costs incurred due to installing ICPT infrastructure for EVs, including capital, maintenance, and operational. As agencies begin investing in such infrastructure, they must be cautious in estimating the costs of ICPT infrastructure as history has proven that the costs associated with PCS and ESS systems are heavily under-estimated[31]. In addition, it must also be taken into consideration that transferring large amounts of energy requires suitable batteries, which can also be very costly[7].

Capital Cost Issues Associated with Dynamic ICPT Infrastructure Construction:

The current estimate of the construction and commissioning of ICPT infrastructure is at $235,790 /lane km, for power requirement of 400KW/km in one direction [32]. However, the cost of the grid converter(s) would have to be taken into account depending on the power level of the system. In determining the cost of these large utility power converters, the EPRI [31] report was used to estimate the cost of grid-level power conversion system (PCS) installations. The PCS includes all components necessary to deliver the electrical energy from the power strips to the ESS on the EV as well as to discharge stored energy to the utility grid. For dynamic ICPT charging, it was determined that this would be Type III PCS for prompt discontinuous operation, which is a short duration power quality (SPQ) application. Although the converter must remain utility connected and powered up in order to energize the roadbed transmit coils when needed, the Type III PCS will have very low standby losses as it is not required to be constantly energized. In other words, the PCS would remain idle until an EV passed over the transmit coils. The PCS can also be used to provide grid reactive power support during its idle time. The total cost of the PCS was estimated using Equation 4.11, obtained from EPRI [31] report, which was developed from historical data of PCS vendors, and for this case, a pulse factor (P_f) of 3.5, which was the middle value of the typical 2 to 5 pulse factor range, was assumed. Therefore, the total cost of the PCS would amount to 185 $/kW. So, a 400KW grid converter for ICPT would be approximately $70,000 fully installed, without including the additional costs associated with the grid point of common connection (PCC) transformer[31].

$$TYPE \quad III \quad PCS \quad = 365 \times p_f^{-0.54} \tag{4.11}$$

Cost Issues Associated with Dynamic ICPT Infrastructure Maintenance: Typically, public agencies, like the DOT (department of transportation), are not only responsible for road construction (highway development programs) but also for road maintenance (rehabilitation programs). With ICPT infrastructure being introduced into the scenario, however, there are a number of added costs associated with the maintenance of the highway infrastructure. The initial problem in dealing with the ICPT infrastructure is that the DOT's pavement management schedules and costs will significantly change. Significant levels of coordination will be required between the DOT's pavement management schedules and the electric utility's power strip management schedules. It will take significant amounts of costs to train employees in managing the complex ICPT system as well as additional time and costs in efficiently merging both management database systems used to monitor the pavement and the ICPT infrastructure.

ICPT infrastructure in the pavement itself consists of the transmission coils in the roadbed, which is used to provide power to the passing EVs. Although these transmission coils can be installed in both asphalt and concrete pavements, most previous work has investigated application in concrete pavement. These works have found that transmission coils should be installed directly above any re-bar to minimize parasitic losses from the inductance of adjacent metals. As a result, losses appear to the grid converter as a continuous loss during energized periods which is directly comparable to the line losses on transmission and distribution lines that utilities currently face, which is simply a cost of doing business[7]. Other studies have found that these roadway embedded coils, or continuous system cables, should be suitable for the life cycle of the concrete roadbed. Typically, the coils are installed as long sections of pre-stressed and reinforced concrete modules having transmit coils and attachment cables and then are typically overlaid with synthetic concrete or some plasticizer, much like the interconnected pre-stressed sections of guide way used in China's construction of the Shanghai MAGLEV train. These sections, while not protected by the roadbed reinforcement rods, are not installed in the lane wheel ruts left by large over-the-road trucks, and thus, may not require significant amounts of maintenance or replacement. Therefore, while it may appear that typical maintenance costs will remain low for the dynamic ICPT infrastructure itself, costs may begin to accumulate for DOTs in training existing staff and in hiring more personnel to monitor the pavement infrastructure for potentially harmful conditions such as debris. Furthermore, ICPT systems are complex and require advanced expertise acquired only through intensive training; therefore, the stakeholders must implement training programs to educate their personnel, something that will be very time consuming and expensive. Other operational issues which may increase maintenance costs will include resilience to freeze-thaw cycles in colder regions, additional equipment to heat ICPT components in winter and cool them in summer in order to protect the system from adverse weather conditions.

Cost Issues Associated with Dynamic ICPT Infrastructure Operations: When dealing with the operational costs of the dynamic ICPT infrastructure, both DOT and utility companies will have numerous cost issues to consider. A stable grid will have balanced power generation throughout normal and abnormal conditions; a reliable grid will be able to handle unexpected demands without failing and be able to quickly recover if failure does occur for some unforeseen reason[33]. The utility companies' major costs will arise in distribution system expansion costs in order to ensure stability and reliability within the electric grid. The estimated full cost of upgrades to the grid network in order to bring the generation on line is approximately $700/kW for transmission and distribution (TD) costs and $70/kW-yr in peak generation costs [34]. In order to anticipate the scale of such costs, utilities must perform what is known as power system planning. The objective of such efforts is to strategically plan for the long-range expansion of the generation, transmission, and distribution systems in order to meet the added energy demand that EVs place on the utility grid. The goal is to supply adequate amount of ICPT infrastructure capable of meeting the predicted future load forecast while also minimizing infrastructure expansion. The utility companies must account for both economic factors and load requirements in calculating distribution system expansion costs[35]. The major issue that arises here is that the future electrical load is very difficult to predict as many variables will determine how quickly and to what extent EVs will penetrate the transport sector. Smart-charging management is one strategy that the utility companies may consider while trying to ensure that the electric grid is able to meet EV energy demands. This can reduce peak demand through processes such as time of-use rates and load control [34]. Time-of-use rates is a type of demand response control in which EVs are charged a higher $/kW rate during peak hours in order to control the load and to avoid severe situations like the North-eastern United States blackout in 2003 [36], which resulted in billion dollar losses. In addition, electric utilities can use load scheduling, a process allowing utility companies to balance energy supply and demand in real-time. This method can also allow utilities to reduce energy costs by using more renewable energy sources as load scheduling matches charging demand to irregular renewable generation supply, such as wind and solar energy [34]. The utility companies can also encourage vehicle-to-grid (V2G) enabled

EV owners to participate in the grid ancillary services by applying a charge scheduling model to lower the investment in both operational and maintenance cost[37]. Pricing schemes like these will help utility companies reduce their new generation, transmission, and distribution costs.

4.5 Study application (TOPSIS)

4.5.1 Remarks

Some remarks we need to mention:

- Results for wpt static system will be taken from our ingeniorat project [Wireless charging system for electric vehicles].
- Cost will include investment cost, connection cost and maintenance cost.
- Time of charging is the time awaited while charging the battery's vehicle from 0% to 100%.
- Time of charging is estimated for a battery of 25kWh.
- The steps of TOPSIS Method are calculated using Microsoft Excel.
- For more details about the table 4.1 check sections 4.3 and 4.4.

4.5.2 TOPSIS steps

Step 1. Construct the decision matrix and determine the weight of criteria.

The weight of each criteria will be 0.2.
0.2+0.2+0.2+0.2+0.2=1

Table 4.1: Decision matrix

Criterias / Modes	**Power(kW)**	**Charging time(h)**	**Installation cost($)**	**Availability**	**Risk**
Normal	3	7	3 800	Excellent	Yes
Semi-Fast	22	1	7 171	Good	Yes
Fast	43	0,5	56 650	Medium	Yes
Static WPT	9	3	4 000	Below average	No
Dynamic WPT	100	0	70 000	Low	No

Now we have to transform the qualitative data into a quantitative data:

Table 4.2: Use of 5 scale points for qualitative data

Qualitative	**Quantitative**
Excellent	5
Good	4
Medium	3
Below average	2
Low	1

And for the risk:
Yes $\rightarrow 1$
$No \rightarrow 0$

So, the final decision matrix will be :

Table 4.3: Final decision matrix

Criterias / Modes	**Power(kW)**	**Charging time(h)**	**Installation cost($)**	**Availability**	**Risk**
Normal	3	7	3 800	5	1
Semi-Fast	22	1	7 171	4	1
Fast	43	0,5	56 650	3	1
Static WPT	9	3	4 000	2	0
Dynamic WPT	100	0	70 000	1	0

Step 2. Calculate the normalized decision matrix.

Table 4.4: The normalized decision matrix

Criterias / Modes	Power(kW)	Charging time(h)	Installation cost($)	Availability	Risk
Normal	0,026925329	0,909397723	0,041986808	0,674199862	0,577350269
Semi-Fast	0,197452409	0,12991396	0,079233527	0,53935989	0,577350269
Fast	0,385929709	0,06495698	0,625934916	0,404519917	0,577350269
Static WPT	0,076288431	0,389741881	0,04419664	0,269679945	0
Dynamic WPT	0,897510951	0	0,773441203	0,134839972	0
$\sqrt{\sum_i (x_{ij})^2}$	111,4192533	7,697402159	90504,61724	7,416198487	1,732050808

Step 3. Calculate the weighted normalized decision matrix.

Table 4.5: The standardized decision matrix with consideration of criteria weights

Weighted	0.2	0.2	0.2	0.2	0.2
Criterias / Modes	**Power(kW)**	**Charging time(h)**	**Installation cost($)**	**Availability**	**Risk**
Normal	0,005385066	0,181879545	0,008397362	0,134839972	0,115470054
Semi-Fast	0,039490482	0,025982792	0,015846705	0,107871978	0,115470054
Fast	0,077185942	0,012991396	0,125186983	0,080903983	0,115470054
Static WPT	0,015257686	0,077948376	0,008839328	0,053935989	0
Dynamic WPT	0,17950219	0	0,154688241	0,026967994	0

Step 4. Determine the positive ideal and negative ideal solutions.

Table 4.6: The positive ideal and negative ideal solutions

Criterias	Power(kW)	Charging time(h)	Installation cost($)	Availability	Risk
$V_j(+)$	0,17950219	0	0,008397362	0,134839972	0
$V_j(-)$	0,005385066	0,181879545	0,154688241	0,026967994	0,115470054

Step 5. Calculate the separation measures from the positive ideal solution and the negative ideal solution.

Table 4.7: Calculation of positive Euclidean distance d^+

Criterias / Modes	Power(kW)	Charging time(h)	Installation cost($)	Availability	Risk	d^+
Normal	0,0303	0,03308	0	0	0,01333	0,2770
Semi-Fast	0,0196	0,0006	5,5E-05	0,0007	0,01333	0,1854
Fast	0,0104	0,0001	0,0136	0,0029	0,01333	0,2012
Static WPT	0,0269	0,0060	1,9E-07	0,0065	0	0,1989
Dynamic WPT	0	0	0,02140	0,01163	0	0,1817

Table 4.8: Calculation of negative Euclidean distance d^-

Criterias / Modes	Power(kW)	Charging time(h)	Installation cost($)	Availability	Risk	d^-
Normal	0	0	0,0214	0,0116	0	0,1817
Semi-Fast	0,0011	0,0243	0,0192	0,0065	0	0,2264
Fast	0,0051	0,02852	0,0008	0,0029	0	0,1935
Static WPT	9,E-05	0,0108	0,0212	0,0007	0,0133	0,2150
Dynamic WPT	0,0303	0,0330	0	0	0,0133	0,2770

Step 6. Calculate the relative closeness to the positive ideal solution.

Table 4.9: The relative closeness to the positive ideal solution P_i

	d_i^+	d_i^-	$d_i^+ + d_i^-$	P_i
Normal	0,277002302	0,181761891	0,458764192	0,396198949
Semi-Fast	0,185457496	0,226471639	0,411929135	0,549783009
Fast	0,201294886	0,193540661	0,394835547	0,490180438
Static WPT	0,198992101	0,215015506	0,414007607	0,519351582
Dynamic WPT	0,181761891	0,277002302	0,458764192	0,603801051

Step 7. Rank the preference order or select the alternative closest to 1.

Table 4.10: Alternatives final ranking

	P_i	**Ranking**
Normal	0,396198949	5
Semi-Fast	0,549783009	2
Fast	0,490180438	4
Static WPT	0,519351582	3
Dynamic WPT	0,603801051	1

4.5.3 Result and comments

The Topsis method showed that the Dynamic wireless is the best charging system followed by the semi-fast, static WPT , then, the fast plug-in and the normal plug-in comes at the end.

- The dynamic WPT ranked in the first place due to its high power and 0 time of charging with a cost near the Fast plug-in charging. But we can't rely 100% on it. Because the consumption of the car is higher than the charging system, so there have to be a point where the driver needs to stop to charge the car with another method of charging.
- We remark that the WPT systems (stationery and dynamic) are well ranked despite they're newer than the plug-in systems, and that goes back to the zero risk in the process, the good power/infrastructure cost ratio compared to those of the plug-in.
- Despite the normal charging is ranked the fifth, but it still good alternative because it's used in the houses, doesn't need big changes in the infrastructure and it's used the most at night.

4.6 Conclusion

We have seen in this chapter the different alternative for charging an EV, we have seen also their advantages and disadvantages alongside with all the data and information needed on each one of them.
We used a method of multi criteria decision making (TOPSIS) to determine which one of the alternative is the best, and to ranked them one by one.
We have found at the end that the dynamic WPT is the best alternative for now, but it can't used by itself, it has to be another alternative with it. so, we will go with the

Semi-Fast charging.
Lot of development and progress is made and marked in this field which will push consumers to head towards the EV's. The final decision of the TOPSIS can change with the change of the data, which will change certainly with this development.

General conclusion

The work presented in our final study project concern the different charging system for electric vehicles. we've studied the two method of charging an EV (plug-in and wireless) with all their modes (Normal, Semi-Fast and Fast for plug-in) and (Static and Dynamic for WPT). Since no-renewable resources are being replaced by renewable resources due to their advantages and the environmental impacts, electric vehicles aim to replace internal combustion engine vehicles due to their clean effect on the environment. one of the problems that face electric vehicles that we treated on our project is charging process that represent a big problem due to the autonomy, time charging, cost of electricity. And of course the lack of resources because of modernity of the subject.

We used a method of multi criteria decision making (TOPSIS) to determine which one of the alternative is the best, and to ranked them one by one.
We have found at the end that the dynamic WPT is the best alternative for now, but it can't used by itself, it has to be another alternative with it. so, we will go with the Semi-Fast charging.
Lot of development and progress is made and marked in this field which will push consumers to head towards the EV's. The final decision of the TOPSIS can change with the change of the data, which will change certainly with this development.

Our perspective for the project is to normalize the charging process. We aim to make the EV's hybrid with two charging methods, dynamic WPT alongside with semi-Fast plug-in.

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Abstract :

This project presents a study of different charging systems for electric vehicles, the purpose of this project is to present a state of art for the EV's than present all the methods of charging with all their different modes, then do a techno- economic study in order to determine which mode is the best for the consumers and rank all the modes. Using an algorithm of decision making (MCDM) called TOPSIS, which gives us the most balanced alternative as number 01.

The final techno-economic study showed that the best alternative is the dynamic wireless. And demonstrate that the WPT is way better that the plug-in system. So, there has to be development in this mode to a large deployment.

Keywords: Electric vehicles, charging system, charging station, plug-in charging, wireless charging, techno-economic study.

Resumé:

Ce projet présente une étude des différents systèmes de charge pour les véhicules électriques. Le but de ce projet est de présenter un état de l'art pour les VE, de présenter toutes les méthodes de recharge avec tous leurs différents modes, puis de faire une étude technico-économique afin de déterminer quel mode est le meilleur pour les consommateurs et de classer tous les modes. En utilisant un algorithme de prise de décision (MCDM) appelé TOPSIS, qui nous donne l'alternative la plus équilibrée en numéro 01.

L'étude technico-économique finale a montré que la meilleure alternative est la technologie dynamique sans fil. Et démontrer que le WPT est bien meilleur que le système plug-in. Donc, il doit y avoir un développement dans ce mode pour un large déploiement.

Mots clés : Véhicules électriques, système de recharge, station de recharge, recharge par branchement, recharge sans fil, étude technico-économique.

ملخص :

تقدم هذه الأطروحة دراسة لأنظمة الشحن المختلفة

للسيارات الكهربائية والغرض منها هو تقديم حالة فنية للمركبات

الكهربائية عبر تقديم جميع أساليب الشحن بجميع أشكالها المختلفة ، ثم إجراء دراسة اقتصادية تقنية من أجل تحديد

الوضع الأفضل للمستهلكين وترتيب جميع أشكال الشحن. باستخدام خوارزمية صنع القرار (MCDM) تسمى TOPSIS

، والتي تمنحنا البديل الأكثر توازناً كرقم 01

وأظهرت الدراسة التقنية الاقتصادية النهائية أن أفضل بديل هو اللاسلكي الديناميكي. وأثبتت أن النظام اللاسلكي أفضل بكثير من السلكي.لذلك، يجب أن يكون هناك تطور في هذا الوضع إلى انتشار كبير

كلمات مفتاحية :

.السيارات الكهربائية، نظام الشحن، محطة الشحن، الشحن السلكي، الشحن اللاسلكي، دراسة تقنية-إقتصادية