REAL DATA ORIENTED QUANTITATIVE RESEARCH ON THE DEPLOYMENT OF ELECTRIC VEHICLE CHARGERS IN THE DISTRIBUTION NETWORK

A Thesis

by

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Submitted to the
Graduate School of Sciences and Engineering
In Partial Fulfillment of the Requirements for
the Degree of

Master of Science

in the
Department of Electrical and Electronics Engineering

Özyeğin University
June 2022

REAL DATA ORIENTED QUANTITATIVE RESEARCH ON THE DEPLOYMENT OF ELECTRIC VEHICLE CHARGERS IN THE DISTRIBUTION NETWORK

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To all my loved ones, who have never stopped supporting me.

ABSTRACT

It is very evident that the number of electric vehicles worldwide will increase and that the dominant mobility concept in the future will be at the center of EVs. As a requirement of e-mobility, EVs should be rechargeable anywhere and in any situation, and this will increase EV-based electrification. The effects of EV charging stations on the grid are very important in the increasing electricity demand level and the installation of EV charging stations on distribution transformers (DTs) should be balanced and should not have negative effects on the transformers. This thesis aims to determine the quantitative deployments of EV charging stations to be installed on distribution transformers in an optimized and safe manner. The data of 8361 distribution transformers in the Central Anatolian Region were collected and analyzed. Data verification was completed with data cleansing methods and an effective EV charging station installation modeling was developed. Three different risk level modeling allows the installation of different EV charging stations in the most optimized way by determining the current state of the distribution transformer. The general situation of DTs in the region was determined with the pilot region application. Basic data can be revealed by modeling which region should be improved for the EV infrastructure to advance.

ÖZETÇE

Dünya genelinde elektrikli araç sayısının artacağı ve gelecekte baskın mobilite konseptinin EV'lerin merkezinde olacağı çok açıktır. E-mobilitenin bir gereği olarak EV'lerin her yerde ve her durumda şarj edilebilir olması EV tabanlı elektrifikasyonu artıracaktır. Artan elektrik talep seviyesinde, EV şarj istasyonlarının şebeke üzerindeki etkileri oldukça önemlidir ve EV şarj istasyonlarının dağıtım trafoları (DT'ler) üzerine kurulması dengeli olmalı ve trafolara olumsuz etkileri olmamalıdır. Bu tez, dağıtım trafolarına kurulacak EV şarj istasyonlarının nicel açıdan dağılımlarını optimize ve güvenli bir şekilde belirlemeyi amaçlamaktadır. Orta Anadolu Bölgesinde bulunan 8361 dağıtım trafosunun verileri toplanmış ve analiz edilmiştir. Veri temizleme yöntemleri ile veri doğrulaması tamamlanmış ve etkin bir EV şarj istasyonu kurulum modellemesi geliştirilmiştir. Üç farklı risk seviyesi modellemesi ile, dağıtım transformatörlerinin mevcut durumunu belirleyerek en optimize şekilde farklı EV şarj istasyonlarının kurulumuna imkan vermektedir. Pilot bölge uygulaması ile DT'lerin bölgedeki genel durumu belirlenmiştir. Elektrikli araç altyapısının geliştirilmesi için hangi bölgenin iyileştirilmesi gerektiği modellenerek temel veriler ortaya çıkarılabilir.

ACKNOWLEDGEMENTS

I have always pursued knowledge and virtue in my education life until now. I believe that I have always achieved this in my academic career. First of all, I would like to thank my very esteemed advisor, Göktürk Poyrazoğlu, for his contribution to me on the path I pursued knowledge and virtue, and for the light, he shed on my path. His invaluable support has always been a mainstay in this master thesis and will be remembered for the rest of my life.

I would like to also express my gratitude to all of them; from my first teacher to my last professor, who contributed to me for providing the knowledge to carry out this study.

Thanks to Ozyegin University, the Department of Electrical and Electronics Engineering, and Vestel Electronics, which provided me with this master's education opportunity at this stage of my academic life.

Finally, of course, I would like to thank my beloved wife, my family, and all my loved ones, who have never stopped supporting me.

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CHAPTER I

INTRODUCTION

At the beginning of this thesis, it was thought that the motivation, which should be seen as the source of the study, the situation of the problem, the scope, and the contributions brought about by the subject should be mentioned.

1.1 Motivation and Problem Statement

It is very important today to contribute to the development of the developing electric vehicle concept more efficiently and more successfully. The advancement of EVs will bring benefits in many ways. As it is known, EVs are an environmentally friendly vehicle type thanks to their zero-emission features. The increase in the EV population in the world means removing the pollution caused by fossil fuel vehicles and using vehicles that are more beneficial to nature. In this direction, countries have turned their policies towards this and started to ban fossil fuel vehicles in the future. In fact, some countries such as Norway already have a very dense electric vehicle population and have started to provide electrification in vehicles. At this point, it is certain that electrification will increase on a global scale and that charging stations of EVs will begin to be more integrated into electricity grids. With this foresight, the main motivation of this thesis study is to ensure that the increasing number of electric vehicle charging stations can be installed in the electricity grid and especially in distribution transformers (DT) in the most optimized and risk-free way.

It is known that electric vehicle charging stations can come in a wide variety of powers. However, in a situation where the EV population is increasing day by day, the need for charging will increase the electricity demand of all users or drivers. This increased demand will probably overlap most of the time and cause a very serious demand explosion. At this point, it is extremely important that the electrical network infrastructure and especially the distribution transformers have sufficient capacity. If there is not enough capacity in DTs or if it cannot compensate when it is exposed to sudden demand attacks even if there is enough capacity, the transformers will overload. This will actually have a much bigger impact in the next step, perhaps EV charging actions will not be completed for a long time in the DT-connected region. This means that mobility is hit very seriously. Of course, smart charging actions or applications will prevent such sudden attacks or overlaps to a certain extent. Or maybe it will suggest not to charge in that region due to limited capacity, or it will prevent direct charging service. At the same time, although overlaps are prevented, the increase in the number of vehicles will expand the system after a while, and even if smart applications work in the most optimized way, they will be dragged into a blockage. All these situations are likely to harm mobility, and if a global EV conversion is aimed, such barriers should be removed, because users will not want to break the routine they currently have for ICE vehicles, perhaps EV conversion will be interrupted when faced with situations such as charging difficulties.

1.2 Scope of Thesis and Contributions

The main focus and scope of this thesis are to organize the installation of charging stations for electric vehicles in the electric network with determined modeling and to analyze the network data in this context. Within the framework of this scope, the situation of distribution transformers in the Central Anatolian Region was analyzed primarily. In order to make this analysis, certain methods have been applied for the meaningful and correctness of the data together with the real data collected. In addition, the future projection created according to the market data of electric vehicles within the scope of the literature review is also included in the scope of the thesis. Structural examination of EVs, analysis of important parts, examination of standards related to EV charging, evaluation of their requirements, and the situation on the basis of application has been studied. User behaviors and routines have been tried to be determined along with the evaluations related to the interaction of the EV networks of the electricity grid.

The modeling made together with these studies reveals the analysis of the situations that may occur with the establishment of EV charging stations in the electricity networks, especially in the distribution transformers, and will contribute to the prevention of possible problems in the infrastructure with more optimized installation scenarios. In addition to the numerical analysis of the DTs that are suitable for the installations, it will also enable the installations that may pose a problem to come to light. At the same time, the amount of installation of EV charging stations, both at the basic level and in-depth, is optimized through quantitative risk modeling, and the rated powers of distribution transformers are prevented from exceeding. Another gain that can be achieved within the scope of this study is the numerical data of the station installation with the test applications made on the existing DTs with modeling. As an advanced study and in order to achieve standardization, a policy was determined and a specific flow chart was developed by creating an algorithm.

CHAPTER II

LITERATURE REVIEW

In the thesis study, it was thought that starting from the historical development of electric vehicles and related technologies, the current situation and then the future projection should be looked at. This section contains details on the past, present, and future of EVs.

2.1 Origin and Backround of EVs

As a part of the general developments in the automotive field that started in the 19th century, vehicles that use electrical energy in the motion system have also emerged [1]. From this point of view, it can be said that electric vehicles, which are becoming more widespread every day, have a history of more than 100 years. In 1832, the first-crude EV electric carriage with a non-rechargeable battery structure was developed by Robert Anderson [2]. Developed by William Morrison in 1890, it was the first successful electric vehicle. Although this vehicle has a range of 80 km, it has a rechargeable battery structure [3]. In the automobile market dominated by different technologies in the late 1800s and early 1900s, electric vehicles are at a level that can compete with steam vehicles and gasoline vehicles, and it is considered the peak period of EVs for that period. Considering the distribution of vehicles in the United States in 1900, electric vehicles accounted for 38% of all vehicles [4]. In 1908, with Ford's mass production techniques and cost efficiency, the rise of vehicles using internal combustion engines (ICE) began. The prices of electric vehicles were twice as high as the Ford Model T in 1908 and 10 times in 1923. With the low price of petroleum products, the place of electric vehicles in the market disappeared from 1914 until the 1970s [1]. EVs, which came to the agenda again with the oil crisis in 1973, started to develop commercially again in the 90s with the agreements to reduce CO2 emissions. Tesla Motors, which emerged as a startup in 2006, launched the Tesla Roadster with a lithium-ion battery in 2008 [5]. In 2010, the first commercial plug-in hybrid vehicle, the GM Chevy Volt, was launched with the all-electric Nissan LEAF. Along with these developments, there have been developments in advanced technologies and infrastructures to be used for electric vehicles. EV charging infrastructure advanced significantly from 2009 to 2014 [6]. By 2019, the price of Li-ion batteries used in vehicles has decreased to 185USD/kWh [7]. In general, laws banning the use of fossil fuels from 2015 will mostly be implemented between 2025 and 2040, and the rise of EVs has accelerated after 2015 [8]. 3 million EVs were produced worldwide in 2017 [9]. However, the EV charging station infrastructure in 2019 reached 7.3 million [10]. By 2020, the cumulative number of EVs worldwide has exceeded 10 million [11]. Figure 1 shows a timeline of the evolution of EVs up to the present.

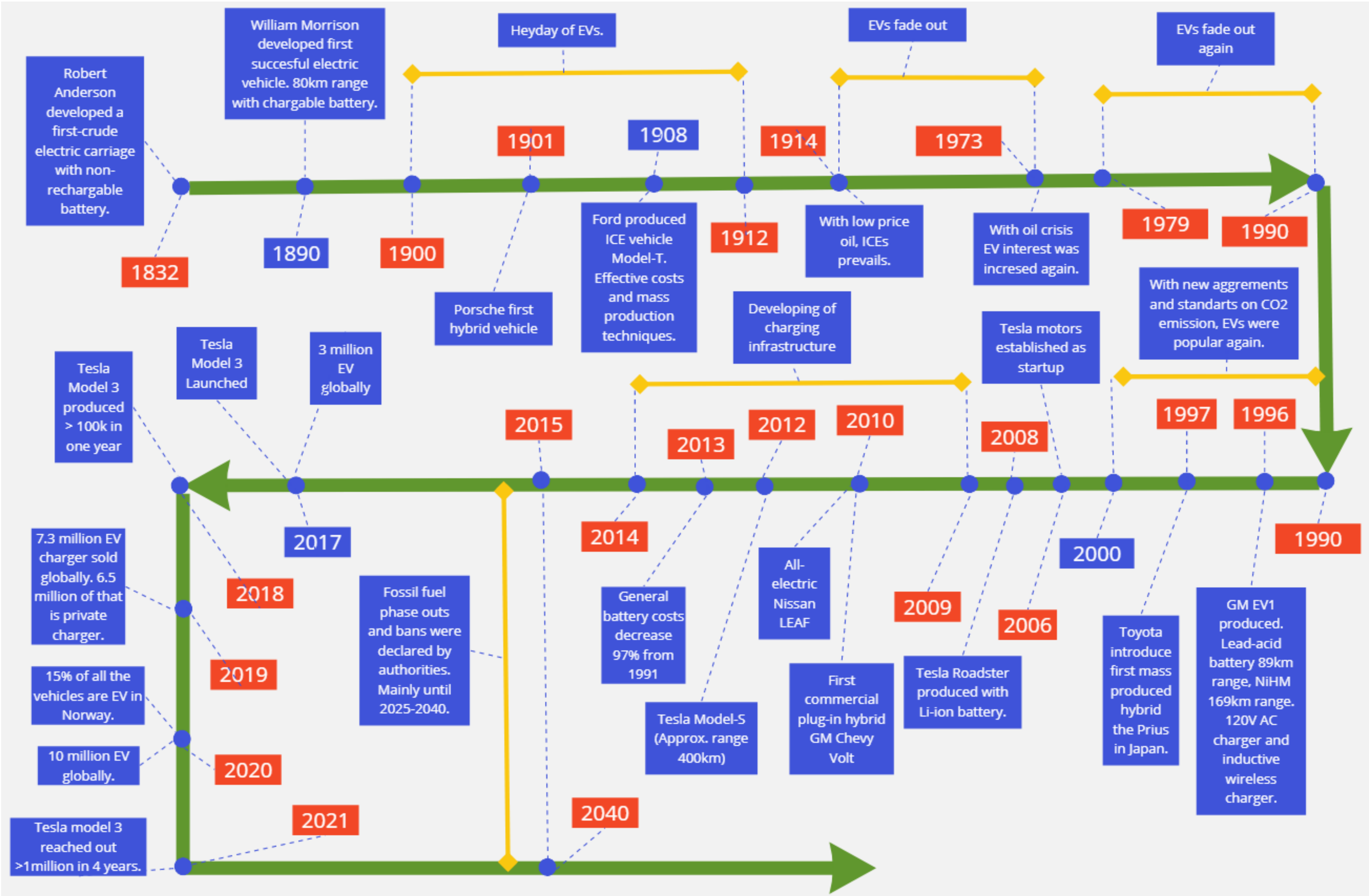

Figure 1: Timeline of Electric Vehicles

2.2 Widespread Use of EVs and Future Projection

Electric vehicles are not yet included as the mainstream transportation method in the world. However, very important data are obtained that this will change in the coming years [12]. Many examples such as the environmental effects, the policies implemented by governments, and the February 2022 Russia-Ukraine War, which has recently affected the organization of fossil fuels, will open the doors to a new energy world and therefore a new mobility method [13].

Many reasons stood in the way of the expansion of the number of EV vehicles around the world as a barrier in previous years. With the developing technologies and new approaches, these obstacles are starting to disappear for electric vehicles organizationally. Elimination of these factors will improve EV conversion much more rapidly. First of all, if it is necessary to talk about a few main obstacles, the first of these obstacles is range anxiety. Range anxiety is the product of the perception that EVs are not suitable vehicles for long distances and the approach towards not finding the charging stations that will be needed when traveling long distances. At this point, the first thing to examine is how long the drivers usually need to drive on a daily basis. According to the research, it has been seen that a distance of 160 km per charge will generally meet the driving distance needed by the drivers [14]. In Figure 2, the status of vehicles with different distance values according to daily driving distance is given. It is seen that a 200km range covers the daily driving distance of 96% of drivers [15]. It has been observed that studies based on daily driving distance in different regions give similar results [16]. The situation that can be considered as another pillar of the range problem can be described as the state of battery technologies. The development of battery technologies and the decrease in battery prices in recent years seem to have directly affected the development of EVs and driver interest in terms of distance. The negative view towards capacity loss in batteries is also seen as another problem, but the actual figures will create a more optimistic atmosphere. According to the information obtained in the ongoing studies, the losses in the battery capacity are only 8% in the event that the vehicle reaches 150 thousand km [17]. With the need for driving distance in the daily routine and the dynamically continuing development, the problem of range anxiety begins to disappear.

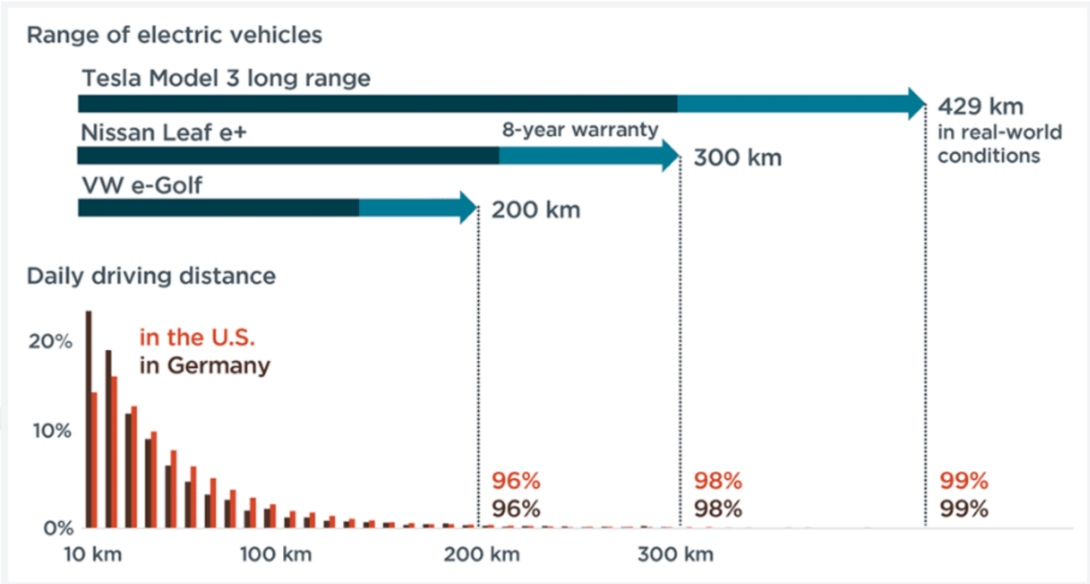

Figure 2: Daily Travel Lengths and Ranges of EV Samples [15]

Another main concern for the proliferation of EVs is the availability of infrastructure and charging stations. Generally, private chargers are common in homes that have their parking lot. Public chargers are more usable for drivers living in common areas such as apartments. According to the research, accessibility to stations is an important bottleneck for 62% of the participants [18]. However, recently, we see that many service providers are rapidly developing their EV charger infrastructure and increasing the number of stations. In addition, although the number of stations is increasing, it is a fact that charging times are very important for the fluidity of charging the vehicles. A situation where the charging time is at acceptable levels is extremely important for users. It is clear that long charging times are not a very good scenario for EV conversion. DC fast chargers are important in this respect among chargers with a wide range of power levels. In Figure 3, it is seen how far different types of chargers fill the capacity corresponding to a certain time [15]. Along with the ease of payment after the charge and making sure that it is completed, the pricing of the charges will also be an important detail for the drivers.

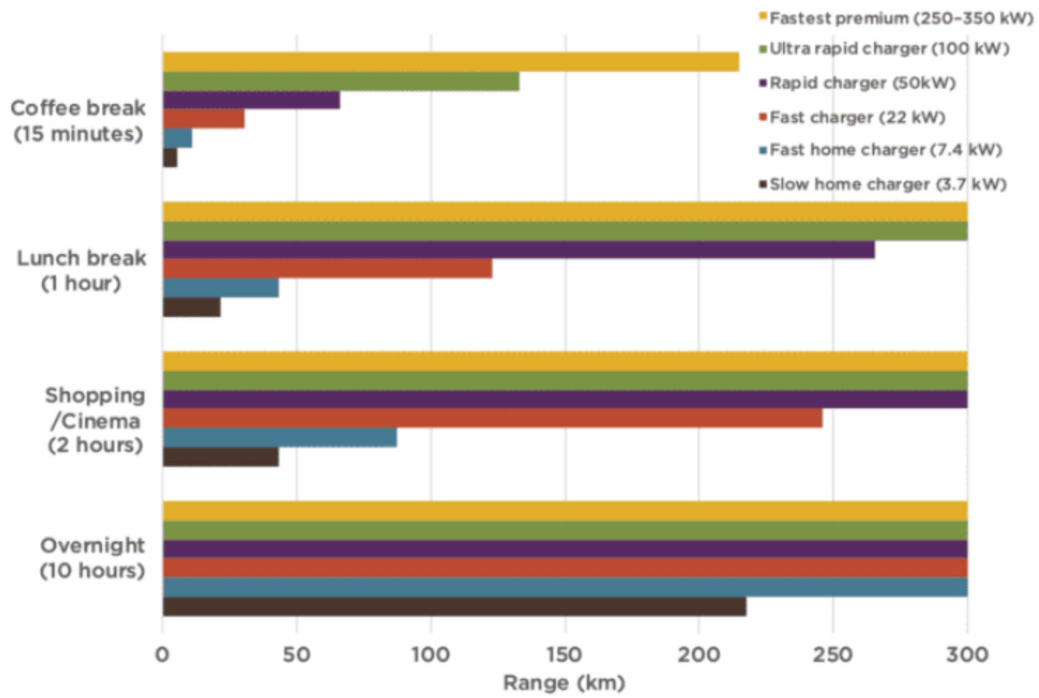

Figure 3: Capacity Filling States of Chargers in Certain Times [15]

The situation of electric vehicles in terms of pricing is also one of the most important main issues. According to studies, the initial purchase price of EVs stands out as a concern parameter for drivers with a rate of 60%. But it is obvious that the point of view here must be relative. Both the price advantage of electricity and charging prices over petroleum products and the general maintenance and lifespan costs of EVs are important for the electrification of vehicles. Another cost advantage is the advantages in taxation and similar practices applied/to be applied by governments for EVs. In Table 1, the maintenance costs are compared according to the powertrain [19].

Apart from these main topics, other factors also play an important role in the spread of EVs. The fact that EVs are more efficient in terms of performance is one

Table 1: Maintenance Cost Comparisons of Vehicle Types [19]

Powertrain Type	*LifetimeMaintenance and RepairCost*	*Lifetime Savings vs.ICE*
ICE	$9,200	$0
BEV	$4,600	$4,600
PHEV	$4,600	$4,600

of them [20]. EVs are more effective than ICE vehicles. Another point is socio-technical problems. Along with the development of technologies, social, cultural, and political changes and trends are also important in a new transformation, apart from finding solutions to technical issues [21]. At this point, various encouraging practices to be applied, social information about electric vehicles, and the correct flow of information will be very effective. For example, looking at the last 16 years in Turkey, an average of 737 thousand vehicles are sold annually [22]. With an appropriate approach, EVs being the dominant vehicle type in the mentioned annual sales will accelerate the transformation.

Finally, as the most important transformation parameter and perhaps one of the issues that will require extensive work, the distributions, loads, capacity problems, infrastructure requirements, and investments on the grid will come with EV-based electrification. EV transformation and expansion are progressing by producing solutions with developing technologies and approaches for the other main and side problems mentioned above. As the main subject of this thesis, it is aimed to produce a solution to the EV stress on the grid and the installation that the charging station adaptations will bring.

2.2.1 EV Market Dynamics

With the developing and transforming trend, the share of electric vehicles in the market is increasing. One pillar of this is environmental factors and related policies, which are based on reducing the carbon emissions of EVs. Another pillar is that EVs are more effective for energy efficiency and more affordable mobility. Due to these and similar reasons, it is predicted that EVs have reached an increased volume in the market, especially in recent years, and that this will increase even more in the future.

Considering the current and future projection data, important signs and developments stand out. First of all, when the economic data is examined, a very important share of mobility passes to EVs with the growing market volume. Looking at the current situation first, with approximately 6.8 million EVs sold in 2021, the EV market volume in 2021 at the global and Asia-Pacific (APAC) level is approximately 230 billion USD. It is predicted that the value, which will reach 1,725 billion USD by 2030, will reach 72,798 billion dollars by 2050 [23]. These increases are 750% (2021-2030) and 4220% (2030-2050) respectively. The compound annual growth rate (CAGR) has been calculated to understand the growth rate. Figure 4 shows the economic value of the future EV market. CAGR is a composite rate in which the initial and final value of the economic growth or investment account is recalculated at the end of each period. CAGR values are calculated in Equation 1.

$$CAGR = \frac{V_{final}}{V_{begin}}^{1/t} - 1 \tag{1}$$

Here, V_{begin} is the beginning value, V_{final} is the final value, and t is time in years.

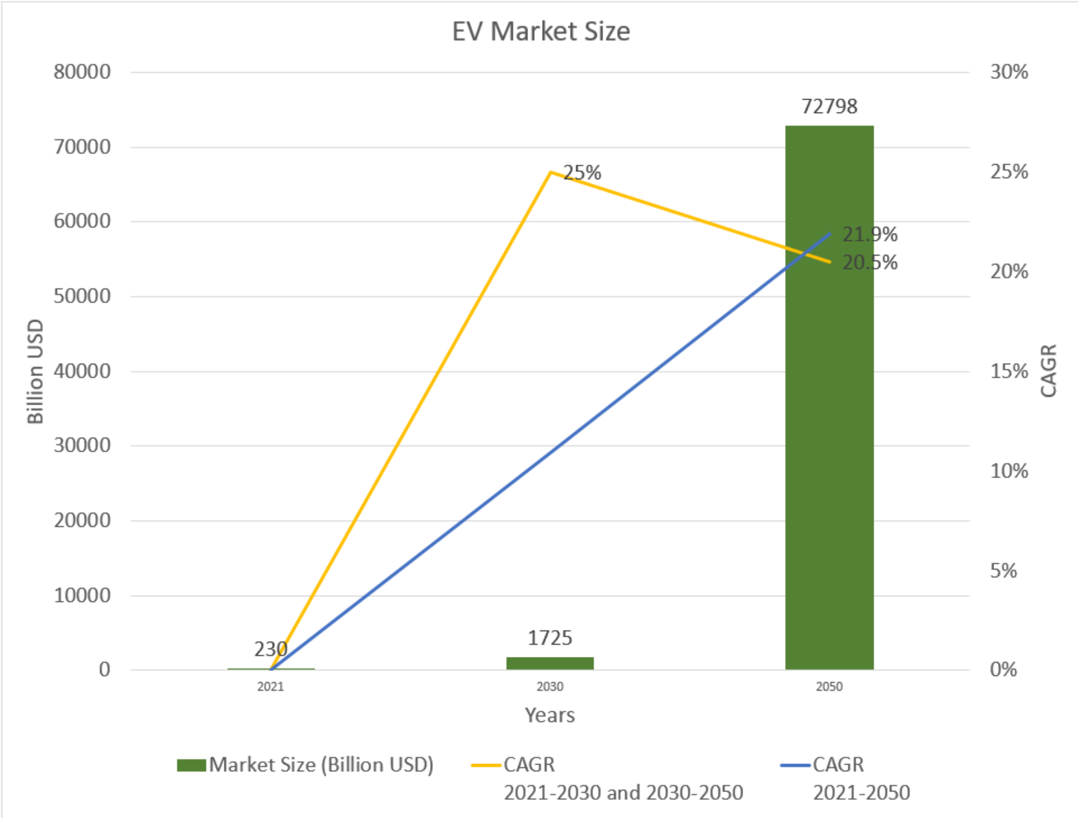

Figure 4: Economic Value of Future EV Market

When the general sales trends of electric vehicles are analyzed, it can be seen how high the increases have reached. While 130 thousand vehicles were sold worldwide in 2012, these 130 thousand EV sales can only be realized in a week. The increase, especially in the last 3 years, is impressively high. EV sales of 2.2 million in 2019 reached 2.5% of all vehicle sales in the world, reaching 4.1% in 2020 with sales of 3 million. In the following 2021, electric vehicles, which had a market share of 9% with sales of 6.7 million, tripled the number of sales in 2019 and reached more than double the market share of the previous one. It is estimated that over 17 million electric vehicles are currently in use worldwide.

Another parameter shows that the sales of electric vehicles in the world are generally concentrated in 3 main regions; China, the U.S., and Europe. In 2021, EV sales in China tripled to reach 3.4 million, 2.3 million in Europe, and 700 thousand in the US. In the rest of the world, this number remained at 300,000. Especially in Europe, there is an increase of over 60%. Another factor that may be critical for the transition from ICE vehicles to EVs is that EVs, which have a 21% share in vehicle sales in the last quarter of 2021 in Europe, outperform diesel products. If we go through some more specific examples for EVs, which have a 17% share in Europe, more serious inferences can be made going forward. For example, the market share is 72% in Norway, 45% in Sweden, and 30% in the Netherlands [24]. Details of the region-specific growth of EVs over years can be seen in Figure 5.

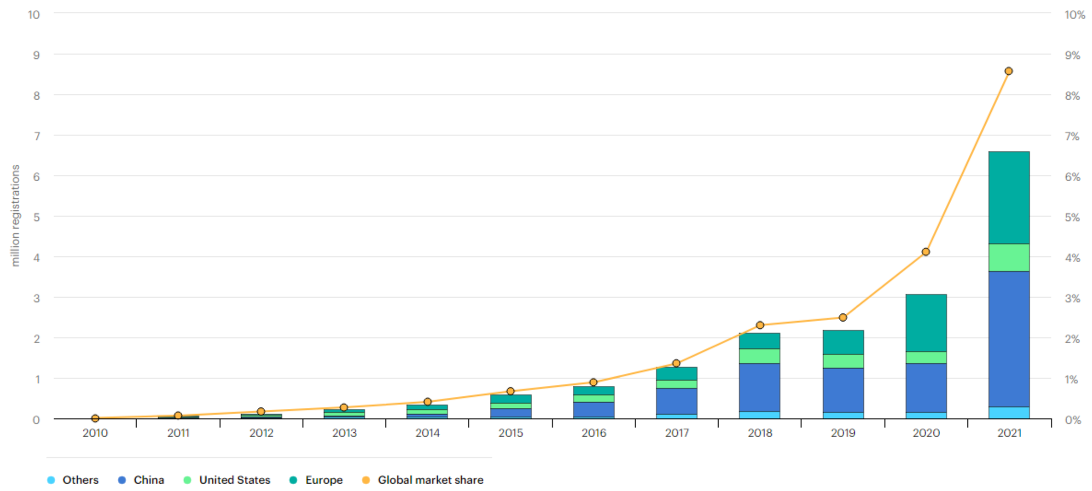

Figure 5: Region-Specific Growth of EVs by Years [23]

Turkey can be mentioned as a country that has the potential to become another actor in the field of electric vehicles. It has the motivation to take a leap forward to take its place in the market. However, when we look at the general situation for now, when we look at the other countries, Turkey's acceleration in EV is low. Nevertheless, following the general trend in 2021, electric vehicle sales increased by 135% compared to the previous year with the sales of around 3000 vehicles [25].

Of course, these increases had the potential to be even more and this needs to be mentioned. Because when we look at the last 3 years, this great effect has actually been negatively affected by the Covid-19 pandemic both directly and indirectly. Apart from this, it is expected that the fast-growing EVs and their affiliated sectors for the EV market will develop at the same rate. But often the natural limits and the acceleration potential of the sectors do not match one hundred percent. In short, if we consider the situation that there are no limitations that directly affect EV mass production, we could talk about a much more accelerated increase in the last 3 years. The semiconductor or chip crisis, which has directly affected EV mass production for the last two years, emerges as an example of this. The supply chain shortage and the chip crisis, which have been experienced for the last two years and still continue, have seriously affected EV mass production, as well as other global sectors. Considering that 2.3 times more semiconductors are used in EVs, which use the power electronics industry much more than ICE vehicles, it is obvious that the EV sector was more affected by this crisis [26]. However, it is clearly seen that the EV market continues to rise by facing these circumstances.

As a last, it is seen that the number of electric vehicles worldwide, which was limited to thousands in the last decade, starting from 2010, is over 10 million by 2020. In the future projection, it is predicted that in the period from 2020 to 2030, the number of EVs, which is around 10 million, will increase to 150 million in the case of current policies, and it will move to more than 220 million in the scenario where sustainability policies continue to increase [12]. Details of the future projection of electric vehicle units can be seen in Figure 6.

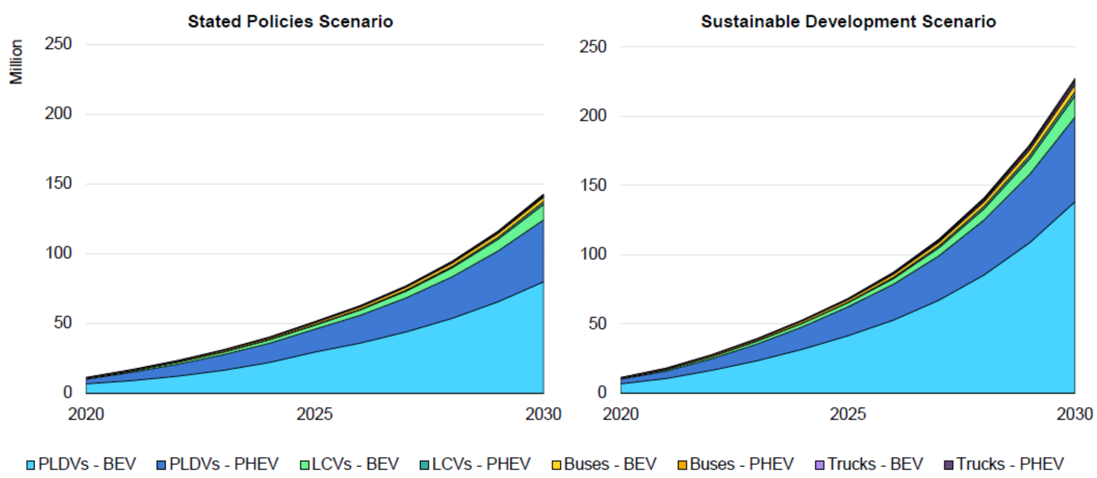

Figure 6: Policy Scenario Based Number of EV by Years [12]

2.2.2 EV Based Electrification

The most basic definition of electrification is that any device, technology, or system uses electricity as an energy source instead of other energy sources. Of course, the sources that we will talk about as other energy sources are primarily fossil fuels. From this point of view, another main definition of electrification is the use of electrical energy instead of other fossil fuels in industry, daily uses (household), and transportation as a more environmentally friendly and more efficient concept in which carbon emissions are reduced. It is known that electrification is increasing with the interest in cleaner energy with the transforming world trend. From this point of view, it is predicted that the demand for electricity will be 30% by 2030 and 60% by 2050 [27]. In EU and in all sectors; It is expected that there will be an increase of approximately 2700-3000TWh in 2030 and 3500-3800TWh in 2050 with the effect of electrification in industry, homes, and transportation.

Considering the benefits that the transformation of electrification will bring, there may be deeper benefits apart from the clean energy perspective. These benefits are;

- More reliable and affordable electricity supply with network structures that can be more flexible to changes
- Strong energy efficiency
- Resource efficiency and sustainability
- Positive environmental effects
- Digitization and user-friendliness

At this point, perhaps the most important example to be mentioned as a hot topic is electrification based on electric vehicles and the high demand for electricity. With the rapid rise in sales of electric vehicles, developing battery technologies, price optimizations, supportive policies, and of course, the increasing number of charging stations, EVs, and the electrification transformation in transportation will reach its peak.According to the studies, it is predicted that the share of transportation, namely EVs, in the total electricity demand will increase from 8% to 63% for the years 2030 and 2050, which are two important thresholds, respectively. The main reason for this is the annual sales rates of the number of electric vehicles that will naturally increase. Again, for the years 2030 and 2050, EV sales are estimated to reach 165 million with 80% from 65 million with 63% [28]. By 2050, when all road vehicles are electrified, there will be an increased demand for extra electricity between 5000TWh and 8500TWh. This corresponds to 25% of the worldwide electricity demand.

With the increase in electrification, resource problems may also arise. In addition, the increasing electricity demand should be taken into account. In a situation where fossil fuels are no longer a resource, new resources need to be created. Renewable energy is an important alternative for this, which has already become popular as well as being well established. For this, solar energy and wind energy have an important place. Nuclear energy is also an important alternative. Although nuclear energy has different disadvantages if reliable nuclear energy is a very large potential energy source. In addition, especially recently developed nuclear technologies and advanced nuclear experiments are extremely promising. In recent experiments at the Joint European Torus (JET), a fusion experiment has been performed that can generate an energy of 59 megajoules [29]. With this experiment, it may be possible to obtain clean nuclear energy in the future.

The spread of electric vehicles, that is, electrification in transportation, of course, also increases the number of charging stations, which means extra loads placed directly on the electricity grids. The number of charging stations worldwide in 2019 is 7.3 million [10], increasing by 40% from the previous year. This shows that both the load on the electrical network is increasing and even the need for electrical energy is increasing.

2.2.3 Effect on Electricty Grid and Distribution

The effects of the increase in the EV population in the world on the current electricity system need to be analyzed from another perspective. It is not difficult to predict that electricity demand will increase both on the user side and on the industry side with the aim of less emissions globally. On top of that, if we consider that EVs will host an even more effective change than recently, with the change in transportation, the impact on the electricity grids will be more. The important question here will be: Are the existing electricity grids adequate or do they need to be renewed and developed? A direct answer to this may not be very clear at first, but it is certain that electrical energy will need to be provided in a much more optimized and intelligent system. It is possible to encounter many different scenarios, for example, if all the vehicles are charged at the same time, if the number of charges is excessive in an area with heavy traffic, or if there is a balanced charging scenario. It may be useful to consider a few examples at this point. For example, in the UK, when the grid capacity in the whole country is taken into account, and when 7kW charging stations and all vehicles are charged at the same time, the electrical power needed is 3 times more than the grid capacity. When 50kW charging stations are used, the instantaneous power required is 21.5 times the capacity. There is a problem at this point. Of course, these values are instantaneous power needs and it is also necessary to examine the consumptions according to the time. At this point, the value required for annual charging of the current number of EVs in the UK is 69.1TWh, and the total annual electrical energy produced in the country is 323TWh [30]. From this point of view, it is seen that the capacity is sufficient in total. At this stage, the following details stand out as important questions. When to charge, how much to charge, and where to charge? From this point of view, there is no total capacity in the electricity grid. In regional electricity distribution, the capacity of each region is limited by the rated powers of distribution transformers. In other words, the EV charge density and the region to which this density depends should be analyzed specifically. Because overloads can also directly disable the system.

Based on individual scenarios, a neighborhood environment, a city environment, and a country environment should be analyzed with the increasing number of vehicles [31]. The place where a user with an EV will charge their vehicle is also important, along with the equipment to be purchased for vehicle charging. For example, considering that it is an apartment without a garage, if there is no fixed charging station or a public charging station, it will be possible to extend the charging cable to the street. In addition, although there is a chance to charge it from a socket in the house, it is an important limit whether the house or apartment is ready for this type of additional electricity demand. Considering that this is more than one, the result may be direr. In addition, electric vehicles can generally be concentrated in one region. This may be in socio-economic or socio-cultural regions that can receive EV under today's conditions. For example, EV populations may remain low in rural areas but are more concentrated in cities. This situation also calls for location-based problems. In fact, the studies are currently progressing on smarter algorithms and more controlled systems, so that the situation of charging each vehicle at the same time is eliminated. We can say that AI systems have also been developed for this. However, infrastructure problems can deepen the problem by resisting the optimizations made as to the number of vehicles increases. Although the increase in high-speed chargers provides an advantage in terms of time, it can also cause problems to the network in terms of capacity. Because charging stations with a wide range of power will become widespread and create a scenario according to the needs [32].

At this stage, it is necessary to talk about the problems that may occur by considering the electrical network and its components. The electrical network can be divided into three main parts. Electricity generation begins with the use of fossil fuels, nuclear energy, renewable energy, and various similar resources and the generation of electricity in generation plants. The electricity produced passes into the transmission medium and is stepped up to high voltages to reduce transmission losses and transmitted by power transformers along the transmission lines. The electricity from the transmission line is stepped-down to low voltage levels that can be used by the end-user by distribution transformers (DT) and is also distributed for use with DTs [33]. The source of EV charging stations, which is the end-user level, is the DTs that provide the distribution of electricity. Distribution transformers reduce the high voltage in transmission to the low voltage level that can be used by the end-user and deliver the electricity to the user with the cables in the distribution line. While the electricity is transferred to the end-user, it is transmitted as a single-phase or three-phase. DTs are at a certain power level and offer electrical energy to the users within the framework of this power level capacity. The general structure of an electrical network and the problems that may occur can be seen in Figure 7. With a possible capacity problem or imbalance in the network, the following difficult power quality problems may occur [34]:

- Overvoltage and Undervoltage
- Voltage Swells / Voltage Surges
- Voltage Spikes & Transients
- Voltage Sags
- Short and Long Interruptions
- Flicker Effect
- Harmonic Distortion
- Low Power Factor

It supports the optimization and reliability of the power system in the context of digitization of distribution grids, increasing electrification of energy uses, and penetration of renewable resources. The pace of decarbonization and electrification of the energy system presents three dominant challenges for power grids and systems:

- Managing volatility and uncertainty to ensure continuous stabilization of the system.
- Balancing supply and demand in times of production shortage or surplus.
- Distribution rated powers meet demand.

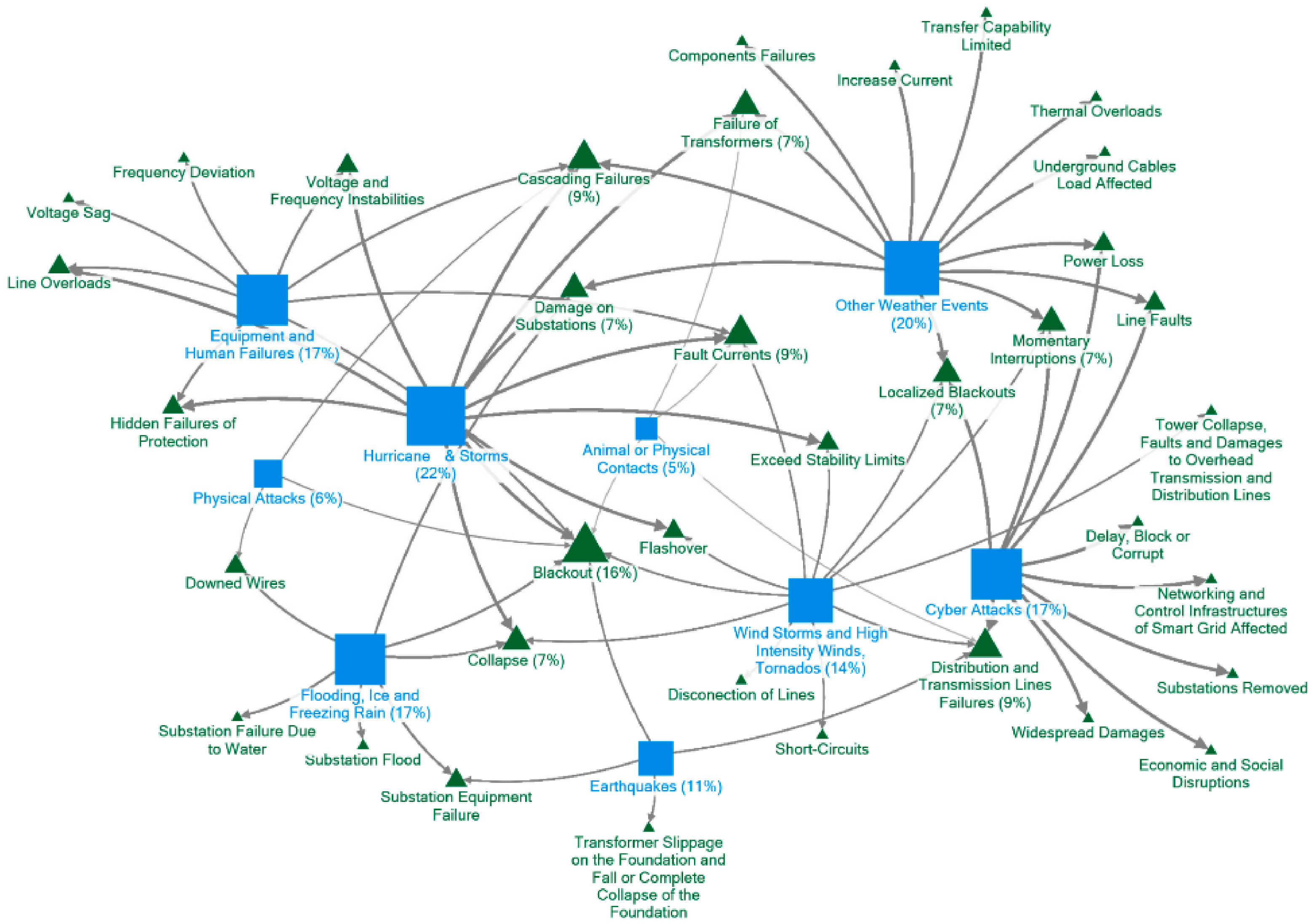

Figure 7: Relationship of Electricity Power Grid Faults and Causes [33]

CHAPTER III

TECHNICAL PERSPECTIVE: EV, EVSE, INFRASTRUCTURE

In this chapter, the working principle and important parts of EVs, how EV charging units charge vehicles, the details of EV charging infrastructure, and how charging stations are integrated into the grid are examined in detail.

3.1 EV Structure

Electric vehicles are named based on the energy source of the motion system, that is, the motors they use in their structures. Electric motors are used as the heart of the motion system, but due to their structure, electric vehicles are described as fully or partially electric. It can be mentioned that EVs, which can be of 4 main different types according to their structure, offer different options to users [35]. The tools and working principles of these 4 different structures are as follows. Details of the structures of the vehicle types can be seen in Figure 8.

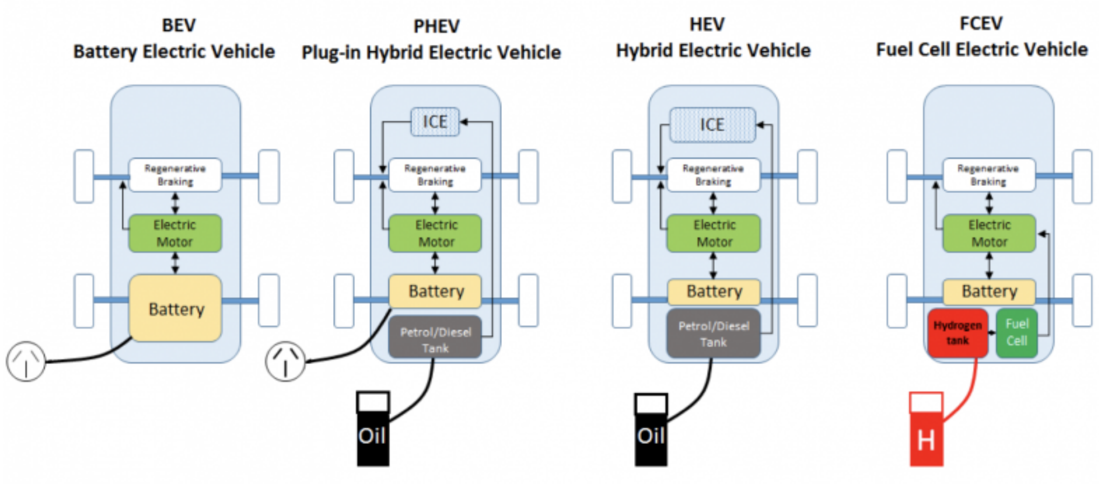

Figure 8: EV Structure Types [34]

- Battery EV (BEV): BEVs can also be called 'all-electric vehicles'. All movement and organization of the vehicle are done through batteries and an electric driving system. No ICE element is used. Motors fed with electrical energy held on rechargeable batteries provide movement. It does not use fossil fuels.

- Hybrid EV (HEV): Hybrid electric vehicles use an electric motor together with an ICE engine in their structure. Movement is provided by the combination of both motors of the system. In addition, the battery used is not externally rechargeable. The battery is charged by the generation of electricity provided by the ICE engine. Depending on the operating parameters of the vehicle, the electric motor or ICE or the ICE and the electric motor work together. It uses fossil fuels [36].

- Plug-in hybrid EV (PHEV): Unlike the hybrid vehicle, the batteries of PHEVs can be charged externally. Apart from that, PHEVs have a larger battery pack than HEVs. Two different operating modes can be mentioned; all-electric mode and hybrid mode. In addition, the batteries in PHEVs can be charged via ICE. Other than that, the working principle is the same as HEVs. It uses fossil fuels.

- Fuel Cell EV (FCEV): In fuel cells, electricity is produced by using hydrogen or different chemical materials as fuel and the battery on the vehicle is charged. The working principle of the vehicle after this stage is the same as BEVs. The electrical energy taken from the battery is used by the electric motor. They are vehicles in the zero-emission concept and the fuel waste is water vapor and hot air.

The vehicle types in the focus of this study are BEVs (all-electric vehicles), and vehicles defined as EVs are BEVs unless specifically stated. It focuses on the working principle and main components (powertrain, batteries, power electronics) of BEVs and mainly examines the charging details of these vehicles.

3.1.1 Working Principles

This section describes the general working principle of EVs. With the main parts, the basic working principle of the vehicle has been examined from the charging action to the moving action. EVs can be grouped under 3 main headings in their own structure. These are high voltage circuit/system, low voltage circuit/system, and multiple control area networks (CAN) networks. The high voltage system is the system that is carried by high power cables and transfers the energy from the main battery system to the motor. The low-voltage system, on the other hand, includes peripherals with lower power levels and uses a lower cable network. Multiple CAN networks provide general or general communication between electronic control units in the vehicle. Of course, there is a much more detailed working order in the vehicle [37]. The general working principle of EVs is given below in a certain flow with the relevant parts, and its details are shown in Figure 9.

- Electric Grid: Electric energy source of the EV charging station
- EV Charging Station: It is the equipment that transfers the electrical energy taken from the mains to the vehicle in AC or DC form and mostly within certain protocols and controls. ls.
- Charge Port: It is the place where the plug of the charging station is connected to the EV.
- Onboard Charger: It feeds the batteries by converting the AC power from the charging station to DC. If DC power is received from the station, the battery bypasses the onboard charger and feeds the battery directly.
- Battery Pack: It is the main power source of the vehicle and feeds the system.
- DC to DC Converter: It feeds the necessary unit by bringing the DC signal at the output of the battery pack, which may be required for the auxiliary battery, accessories, and other peripherals, to the required level.

- DC to AC Inverter: Creates DC link for inverter and also it is the unit that converts the DC signal from the battery pack output to the AC signal necessary for driving the electric motor. In addition, during the regenerative braking, it takes the DC signal from the rectifier and brings it to the battery charge level.

- AC to DC Rectifier: It is the unit that converts the signal generated by the motor to DC together with the regenerative brake. It takes part in charging the battery by creating input to the DC to DC converter.

- Electric Motor: It is the main source of motion of the vehicle. When the regenerative braking system is used, it works as a generator and charges the battery pack.

- Gear and Traction System: It is the mechanical movement system of the vehicle. It activates the wheels with the movement it receives from the motor.

- Brake and Accelerator: These are the units used by the car driver and give two inputs to the system. It provides acceleration and deceleration. Data from these two units are transferred to the power electronics control unit.

- Power Electronics Control Unit (PECU): It is the unit that provides control of the inverter according to the data it receives from the brake and accelerator, thus managing the acceleration and deceleration of the motor. This unit also manages the DC to DC converter, managing the power according to the needs of the peripherals. In addition, the charge (with brake) - discharge (with accelerator) state of the battery is managed according to acceleration and deceleration in coordination with the battery/energy management system (BMS). If there is another main controller in the vehicle, it can also communicate with it.

- Battery Management System (BMS): Totally controls the charge and discharge status of the battery pack. It is coordinated with the PECU. It manages the onboard charger and controls the supply of the battery from the charging station.

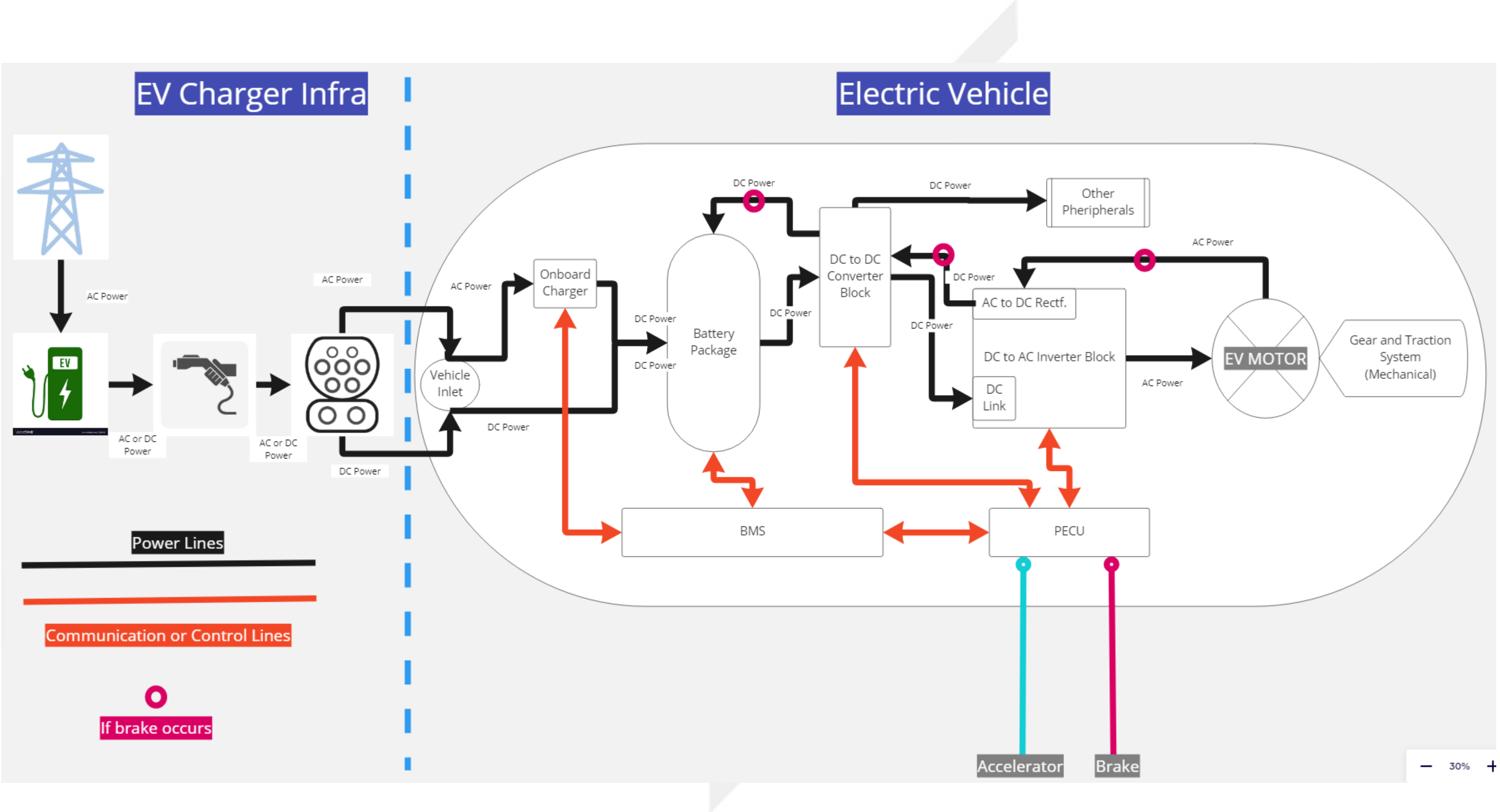

Figure 9: EV Main Parts and Working Principles

3.1.2 EV Electric Motors

The electric motor is at the center of the movement system of electric vehicles. In fact, the reason why we describe the vehicle we use as an electric vehicle is that the motor, which is the source of the main motion system, uses electrical energy. Electric motors are based on electromagnetic fundamentals. It converts electrical energy into motion energy by magnetism. On the contrary, when it uses motion energy as a source, it produces electrical energy. Basically, the working principle is to create a magnetic force with an electric current applied to electromagnetic magnet sets and changing polarity. A movement begins with the mechanical transfer of this magnetic force to a shaft. All electric motors consist of two main parts; stator and rotor. The stator is the fixed, static part of the motor, and it provides the formation of the magnetic field on the structure that will provide the rotation. The rotor is the moving part of the motor. With the relationship between the windings and the magnetic field, motion occurs on the rotor, and torque is created. With the rotation of the rotor, the shaft, which is another part of the motor, is activated and a rotational force is created according to the torque value created. However, by increasing the supplying values of the motor, acceleration is provided or, on the contrary, deceleration is provided. In short, in this way, torque and speed values are created on the motor and these create the movement of the vehicle together with the mechanical parts. The basic acceleration curve of the EV can be seen in Figure 10 [38].

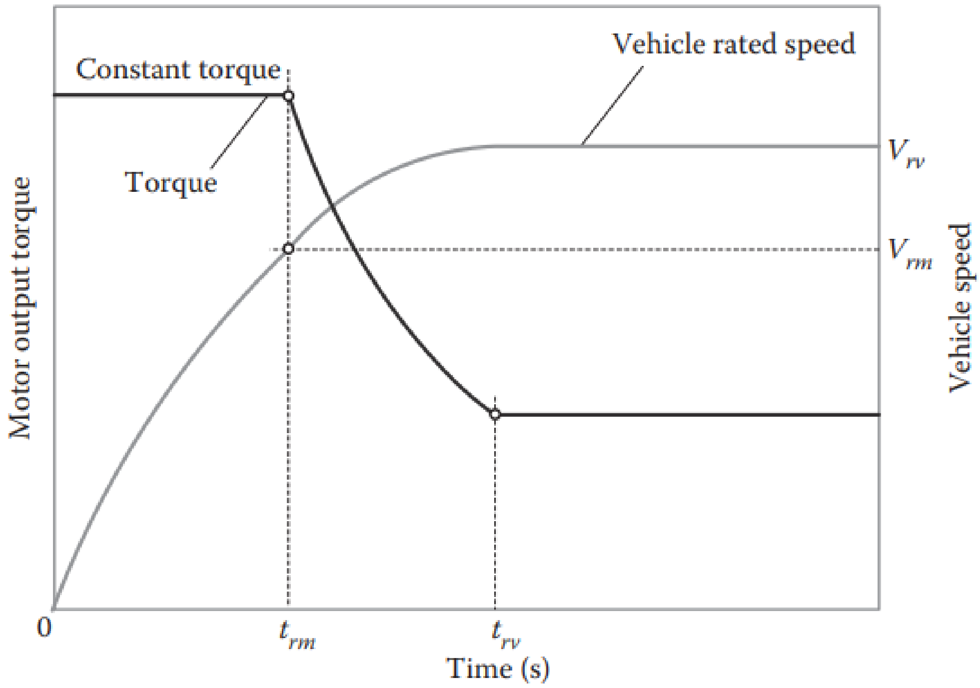

Figure 10: EV Acceleration Curves [37]

Various types of electric motors are used in EVs. These motors have different features in terms of technical details. Motor types with design differences that are customized according to many parameters have emerged according to certain needs [39]. At this point, 7 different types of motors that are widely used in EVs are examined. The basic working principles of these motors are given below [40]. The structural designs of these 7 different motors are shown in Figure 11.

- Brushed DC Motor: It is the simplest type of motors, in which the brushes carry the current to the motor windings by a mechanical commutation. The armature or rotor is electromagnetic and the field magnet is a permanent magnet. This type of motor does not need any controller to manage or change the speed.

- Brushedless DC Motor (BLDC): This type of motor is a permanent magnet DC motor with no brushes and commutation provided by electronic control. It is one of the most preferred engine types in EV applications due to its driving characteristics.

- Permanent Magnet Synchronous Motor (PMSM): This type of motor has permanent magnets on the rotor as in BLDC motors. It is an engine type preferred by many automotive manufacturers due to its high power capacity for driving.

- Induction Motor(IM): Due to their structure, this motor type does not have high starting torque like DC motors under constant voltage and constant frequency. However, it allows vector control and field-oriented control methods due to their structure. They are used on the performance vehicles generally.

- Switched Reluctance Motor (SRM): In SRM motors, the rotor is a single piece of laminated steel and does not contain windings or permanent magnets. This design reduces inertia on the rotor and improves accelerations. It is used in high-speed applications.

- Synchronous Reluctance Motor (SyRM): It is a type of motor that does not have any permanent magnet or winding on its rotor. The torque it creates is caused by magnetic inequalities due to the structure of the rotor. With its easy and powerful structure, its use in EVs is becoming widespread.

- Axial Flux Ironless Permanent Magnet Motor: It is the most advanced motor type used in EVs. It has a slotless outer rotor, where the use of iron is avoided. There is also no stator core to reduce the weight of the motor.

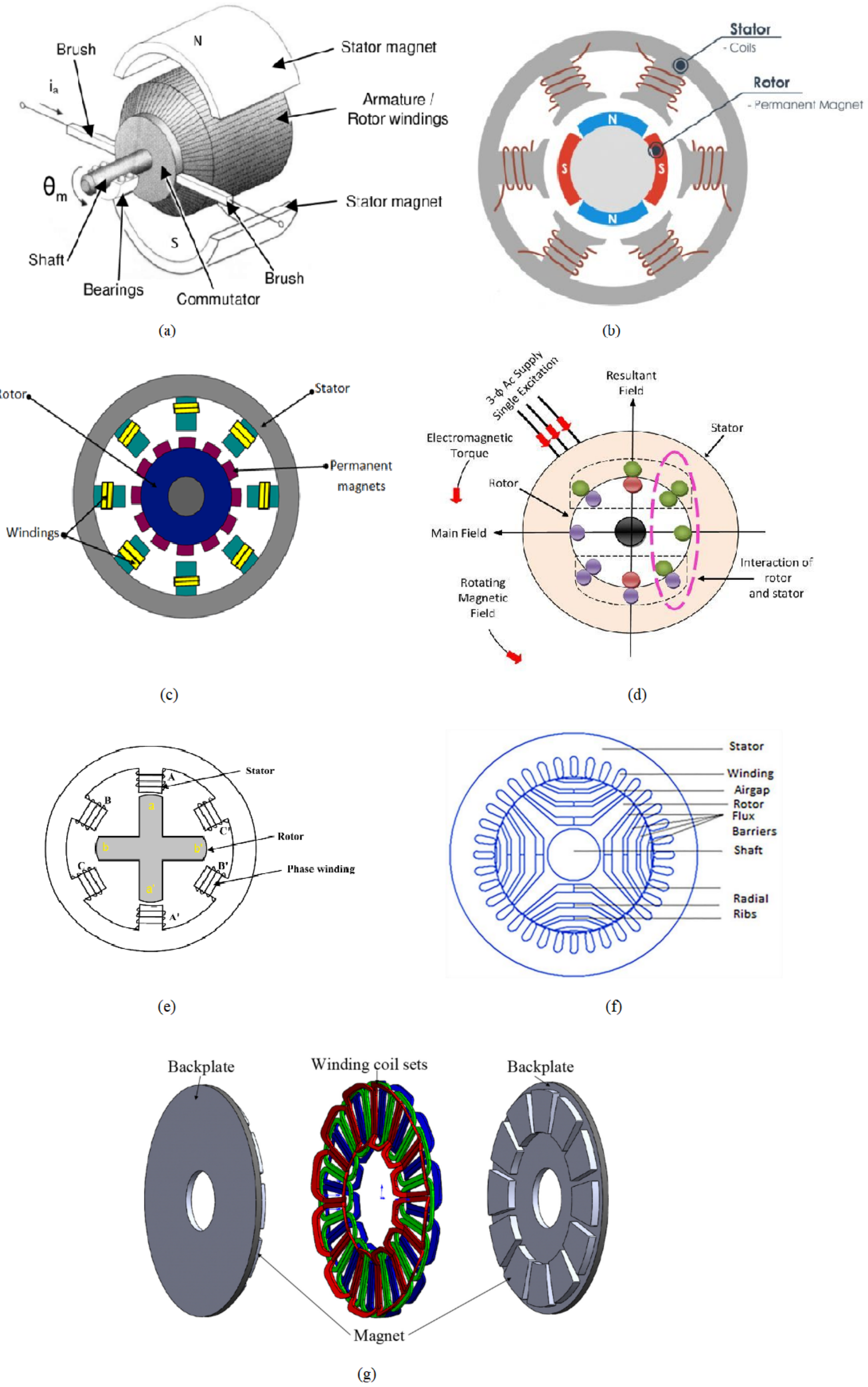

Figure 11: EV Motor Types: a)Brushed DC, b)BLDC, c)PMSM, d)IM, e)SRM, f)SyRM, g)Axial Flux Ironless PMM

Depending on the number of motors, the types of motor configurations in EVs also vary. This situation can be examined under two main headings according to the powertrain variety. The first is powertrains driven by a central single motor. The second is distributed multi-motor driven powertrains. Alongside the single-motor powertrain configuration common to many EVs, there are also multi-motor configurations available. The multi-motor configuration can also be divided into 3 subcategories; dual motor powertrain, triple motor powertrain, and 4-motor powertrain. The configurations indicated in Figure 12 are shown.

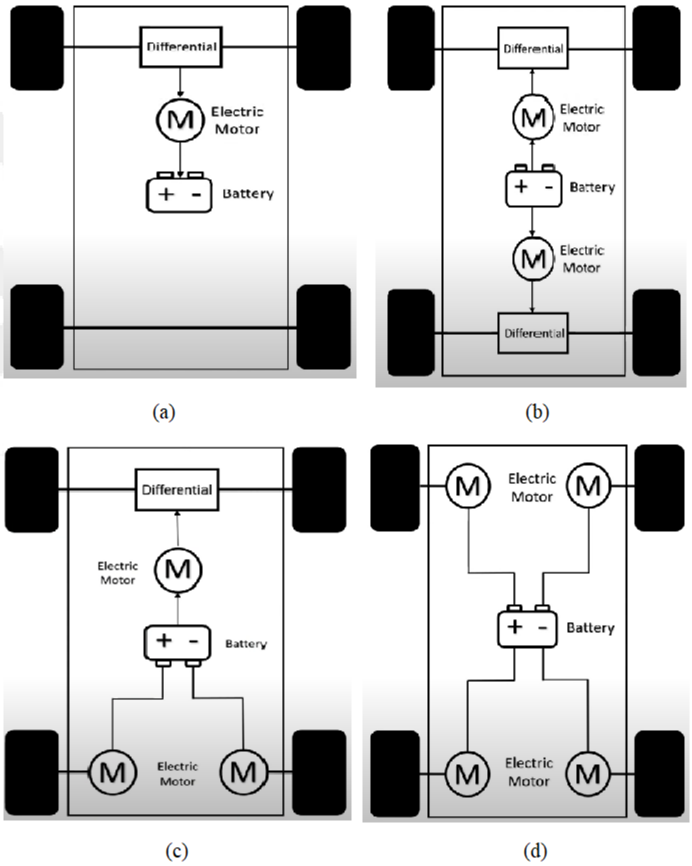

Figure 12: EV Motor Configurations: a)Single, b)Dual, c)Triple, d)Four

3.1.3 EV Batteries

Battery packs are one of the most important components of electric vehicles. Vehicles get the necessary energy from the energy stored in the batteries. The fuels used in ICE vehicles have been replaced by electrical energy here, and in fact, the source of the 'fuel' for EVs is batteries. EV batteries are of course rechargeable and designed for high electrical charging capacity. However, battery technology is developing day by day and battery prices are decreasing. With these developments, there has been an 89% decrease in battery costs in the last 11 years [41]. This is an important parameter in reducing the total prices of EVs and their spread. The capacity of the batteries used in EVs and, accordingly, the range values of the vehicles have developed significantly in recent years. When the vehicles in the EV market are examined, it is possible to talk about an average battery capacity of 61.7kWh. However, there are vehicles with various battery capacities from 16.7kWh to 118kWh [42]. When the range values are examined over these capacity values, there are vehicles with a maximum range of 695km, with an average of 322km [43]. Along with all this information, it is necessary to mention some important features in the use of batteries. These features are stated below.

- Life Cycle: Although it varies according to parameters such as climatic conditions and usage patterns, the life of EV Batteries is generally guaranteed as 8 years or 160000 km. With the latest studies, a lifetime of 10 years or 200000 km is also revealed [44]. Finally, it is stated that with the studies of some manufacturers, it will reach over 200000 km in the future.
- Safety: As with any technology, there may be concerns about safety at first, but with well-designed battery management systems, batteries can be used quite safely and for a long time.
- Performance: Batteries are more sensitive to climate conditions. While life

problems arise at high temperatures, their performance decreases temporarily at low temperatures. For this reason, a cooling system is used in battery packs to keep the climate at an ideal level.

- Energy and Efficiency: The energy that can be obtained from the same amount of fossil fuel is approximately 99% more than the battery will transmit. However, the point that should not be overlooked here is that fossil fuel is an energy source. Batteries are only storage units and the main energy is produced in the electricity grid. The most important thing is that EV engines operate approximately 4 times more efficiently than ICEs [45].

- Power: The motion system of electric vehicles produces higher torque with the power it receives from the battery system, which provides a much better acceleration performance

While the characteristics of the batteries are mentioned, the recycling status of the batteries should also be examined. In fact, it is out of the question to throw away the batteries that have a reduced capacity and come out when the EV needs to be replaced [46]. These batteries can be used in different storage applications. Details of the cycle can be seen in Figure 13.

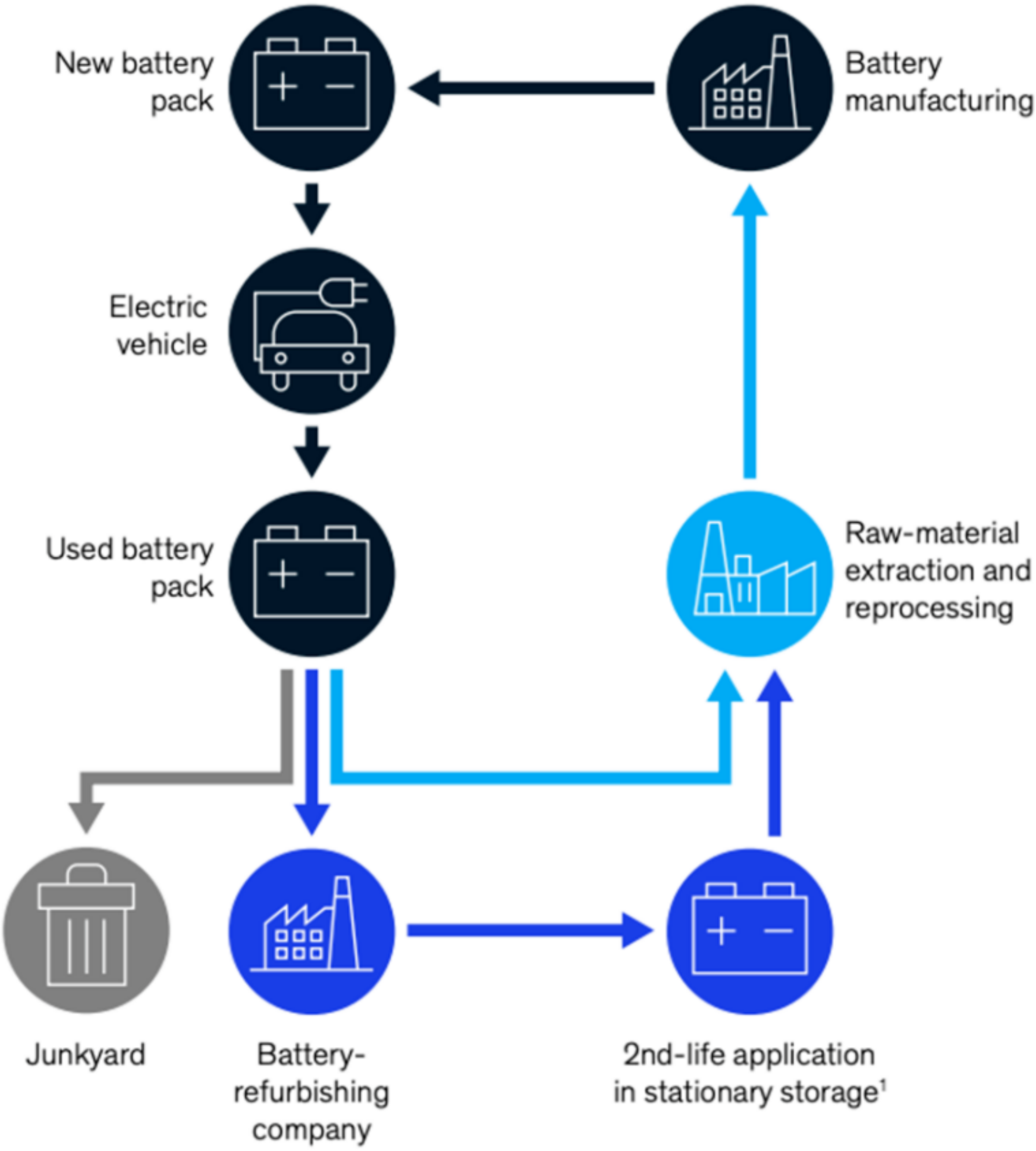

Figure 13: EV Batteries Recycling [45]

The structural design of EV batteries is done in the form of cell-module-package. While the designs are being carried out, the targets addressed are made specifically for the capacity and power of the battery pack. Designs with higher single cell capacity are brought to the targeted final values by connecting them in series with fewer numbers. In addition, in another technique, cells with lower single cell capacity are finalized by connecting them in parallel and in larger numbers. There are also structures in which the two topologies are used in common. While it is aimed to create structures with higher battery power with serial connections, designs are made according to capacity and current values in parallel connections [47]. The applied structural designs can be seen in Figure 14.

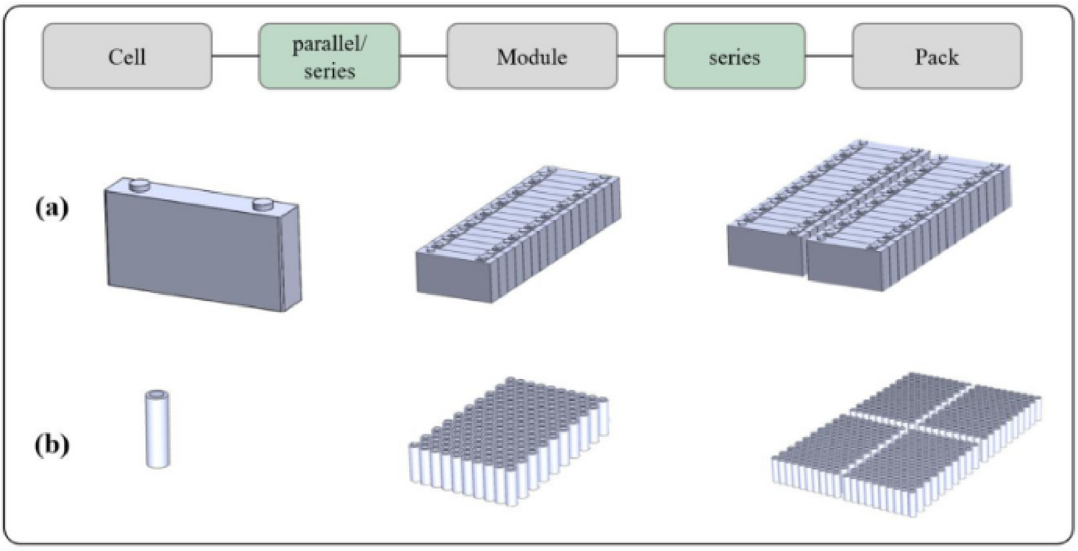

Figure 14: Structure of EV Battery Packs [46]

Since battery packs are multiple and complex structures, they are structures that need to be managed especially in terms of integration into the system within EVs, charging, discharging, and battery health. For this reason, battery management systems (BMS) have been developed. The task of BMS is the structures that manage the safe operation of the battery, communicate with the main control structures, and provide data flow. It performs the adaptation of the battery to environmental conditions, monitoring actions, calculations, and balancing tasks [48]. It monitors voltage, current, temperature, and cooling flow with monitoring operations. It controls overcurrent and overvoltage for safe operation. It manages the state of charge (SoC) action in charging states, the depth of discharge (DoD) action in discharge states, and the state of health (SoH) action according to ideal conditions.

- SoC: It is the percentage value that indicates the charge level of the battery relative to the capacity. To explain the actions of charging the batteries with an example, example, the charging stages of a Li-On battery have been looked at. Charging is carried out by a method based on the principle of constant current and constant voltage. The first stage of constant current charging is the method used to quickly charge 80% of the battery due to its structure. The current is high and constant until the charge reaches 80%. Usually, this current is increased relative to shortening the charging time. Since the current increases the battery voltage during charging, the internal resistance of the battery also increases, and therefore the current is kept constant. When the battery reaches 80%, the voltage is kept constant to prevent damage to the battery and to achieve a full charge. The remaining 20% charge is charged under constant voltage [49].

- DoD: It can be characterized as the inverse of the SoC parameter. It is the value that expresses the empty part of the battery according to the fully charged, 100% value. The DoD value can be expressed as in Equation 2.

$$DoD = 100\% - SoC \tag{2}$$

- SoH: It is the value that expresses the state of the battery in percent according to the specifications determined during production, that is, according to its ideal state.

An exemplary BMS structure is shown in Figure 15. In addition, an example SoC curve for the Li-On battery is shown in Figure 16.

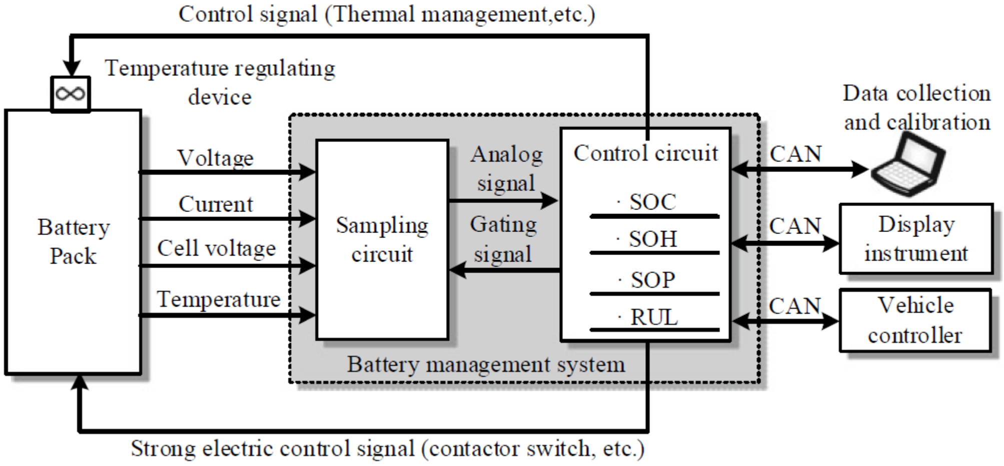

Figure 15: Typical BMS Block Diagram [47]

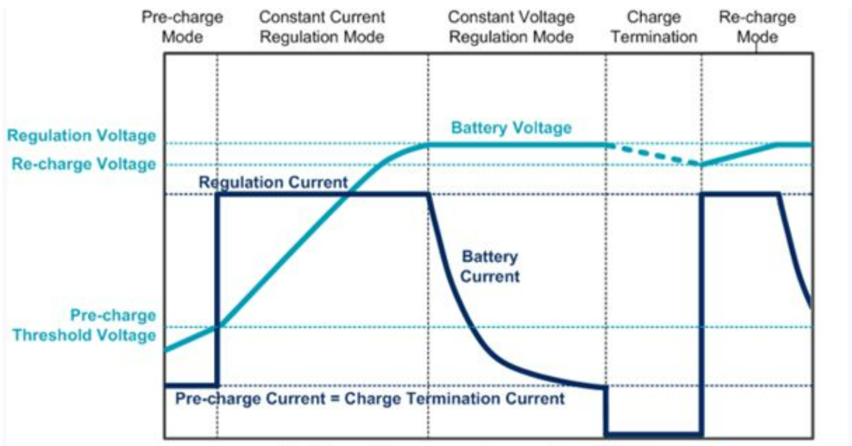

Figure 16: Li-On Battery SoC Curve with Constant Current and Constant Voltage [48]

3.1.4 EV Power Electronic Units

EV power electronic units are structures that provide the flow of electrical energy from the EV charging station on EVs. Of course, not every electrical or electronic component is driven with the same current, the same voltage, the same waveform, the same signal form, or the same frequency. In a system that consists of a wide network of electronic products such as EVs, all parts must be driven in a specialized way. For example, batteries can be charged with DC and produce a DC signal at their output. However, it can be said that the motor that needs to use the battery needs an AC signal. At this point, it is necessary to get the help of power electronics. In addition, there are control structures that enable all these units to work in a certain harmony. In this section, the main topologies used on the EV will be discussed in general terms.

Onboard Charger: EVs can usually be charged with DC or AC chargers. Due to the nature of the batteries, it is known that they are charged with DC. In this case, electrical energy from charging stations with AC output will not be able to charge the batteries. At this point, the onboard charger (OBC) integrated into the EV will be able to charge the battery by converting the AC power it receives to DC [50]. In addition, the charger can be single-phase or three-phase. If the structure is suitable (power switch sets), OBC will be able to convert the incoming AC to DC, both single-phase and three-phase, and transfer it to the battery. Considering that each battery has a specific charge specification if the DC output is not in the appropriate parameters for the battery during the AC-DC cycle, the necessary stepped up or down function is performed with the DC-DC cycle. OBC can be designed to make both AC-DC and DC-DC conversions [51]. Figure 17 shows example of topology for OBC. Also, Figure 18 shows placement of OBC on EV.

DC to DC Converter: The DC signal at the battery output can be used both by the peripherals and feeds the DC link of the inverter that will drive the motor. If the signal at the battery output is not suitable for other units by design, it is brought to the appropriate level with the DC-DC converter block. The same can

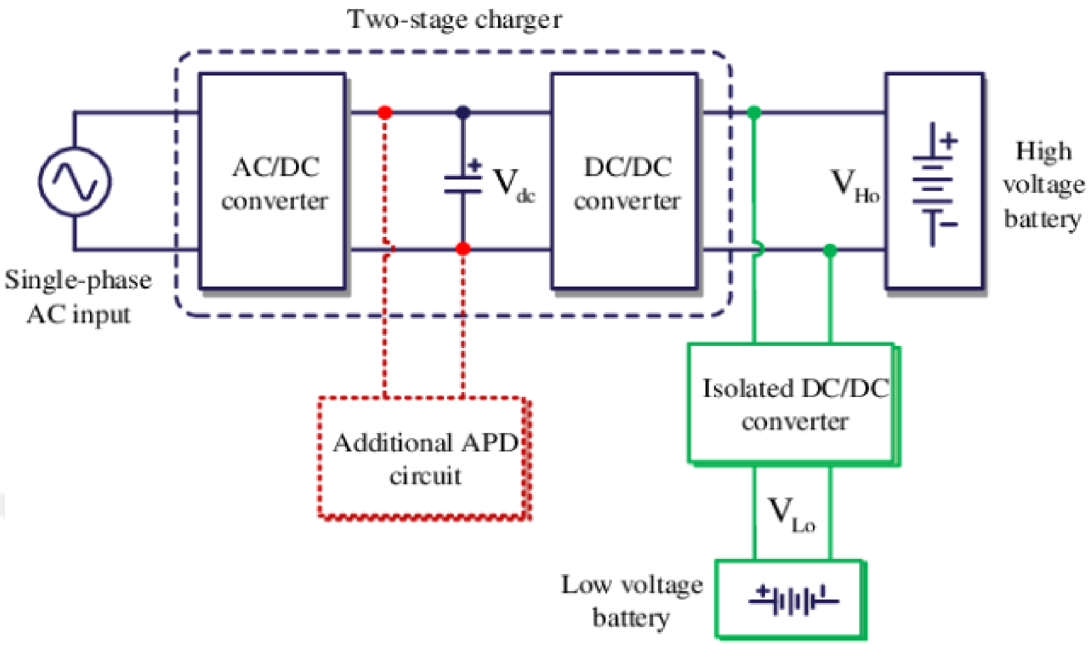

Figure 17: The Conventional Two-Stage Onboard Charger [50]

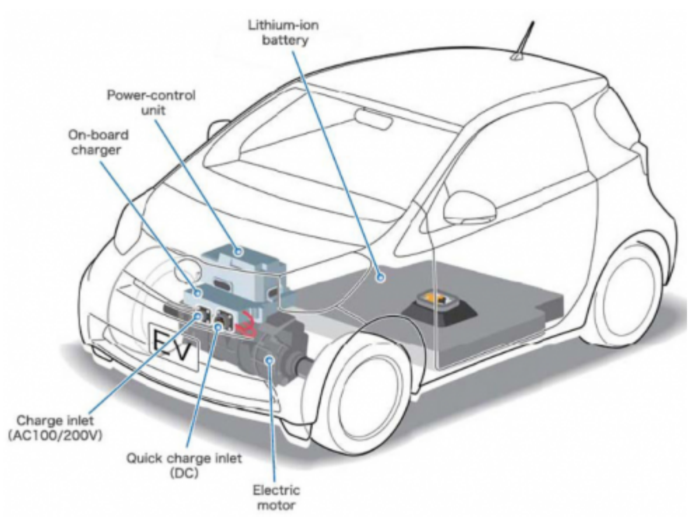

Figure 18: Placement of OBC on EV [49]

be true for the opposite. In the case of a situation such as regenerative braking, in which the motor works as a generator, the DC signal level required to feed the battery can be generated by this block [52]. An example of a bidirectional DC-DC converter topology can be seen in Figure 19.

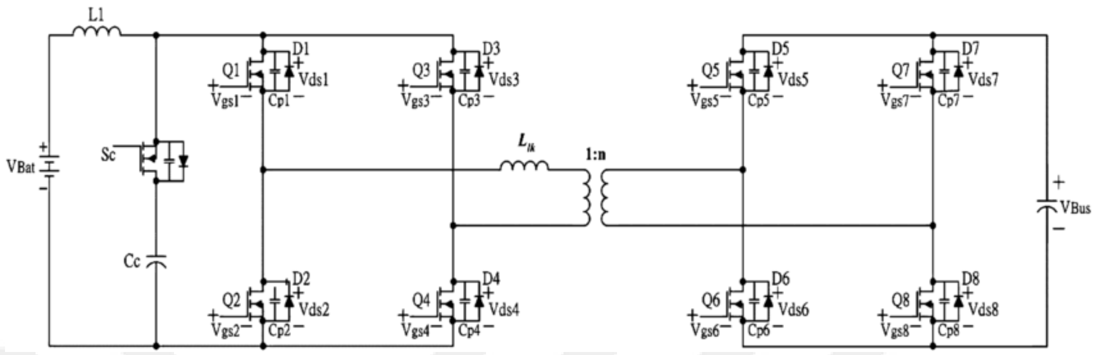

Figure 19: Convetional Bidirectional DC-DC Converter for EV [51]

DC to AC Inverter: Due to the magnetic structure of electric motors, variable polarity is needed and therefore electric motors are driven by AC signal. This is where inverters come into play. The inverter runs the motor by converting the DC power to AC by being fed with the appropriate signal generated by the DC-DC converter from the battery. Generally, inverters that generate AC signal levels adaptively with the pulse width modulation (PWM) technique can drive the motor in a smart way. Of course, the main system, which also controls other power electronic units, also controls the inverter according to the acceleration and deceleration actions of the motor. At the same time, the inverter works in reverse when the engine is running as a generator and forms the DC busbar with the power switches on it [53]. An example inverter topology is shown in Figure 20.

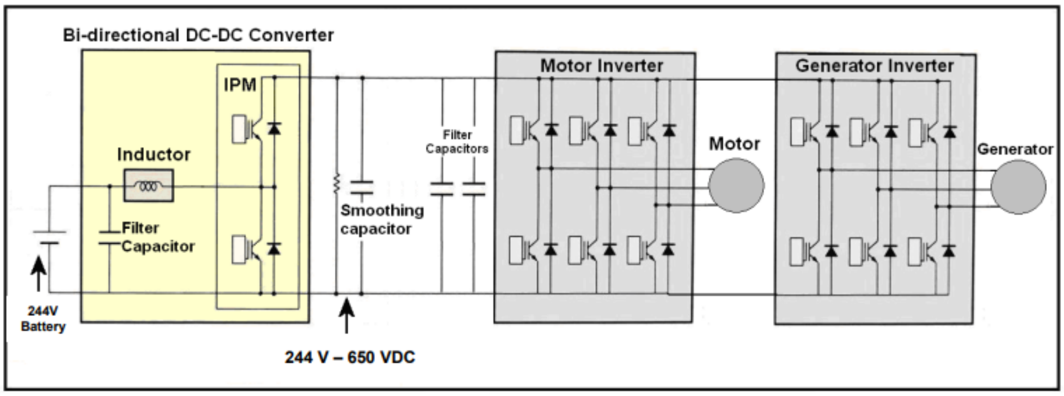

Figure 20: Motor Inverter of EV: Motor Mode and Generator Mode [52]

3.2 EVSE: EV Charging

Perhaps one of the factors that most affect the effectiveness of electric vehicles is the charge actions. EV users need to be able to easily meet their charging needs in order to use their vehicles comfortably. In short, the fact that drivers keep their vehicles' batteries full can be described as EV charging. Along with EV charging actions at different levels and modes, there is also access to public and private charging practices. At the same time, it is seen that the charging stations are diversified in terms of AC and DC electrical power type, topology, and power capacity [54].

In general, as stated in the IEC 61851-1 standard, it can be mentioned that EV charging has 4 different modes. The details of the socket types and standards will be stated in the following sections, but at this point, the details of the modes should be mentioned and they are as in Table 2. It is also visualized in Figure 21.

Table 2: Charging Modes According to 61851-1

Modes	*Features*
Mode-1	- Standart socket without any additional equipment - Simplest mode - Domestic Installation - On an AC Supply Network - 16 A and 250 V AC for single-phase (not exceed) - 16 A and 480 V AC for three-phase (not exceed) - Risk of fire or Electric schock - Limited power and long charging time
Mode-2	- Standart socket with AC EVSE - On an AC supply network - Domestic installation - Protection on cable - Control pilot function - 32 A and 250 V AC for single-phase (not exceed) - 32 A and 480 V AC for three-phase (not exceed) - Limited power
Mode-3	- AC EVSE permanently on an AC supply network - Specific equipment - Integrating protection and control functions - High power range than Mode-1 and Mode-2 - Shorter charging time than Mode-1 and Mode-2 - Comm. between EV and EVSE - Control functions; *continuity of protective connections,* *correctly connection of units,* *energization actions,* *information of permitted current*
Mode-4	- DC EVSE - Connected to the AC or DC network - By-pass onboard charger - High or massive power capacity - Faster than Mode-1, Mode-2, Mode-3 - Digital communication between EV and EVSE

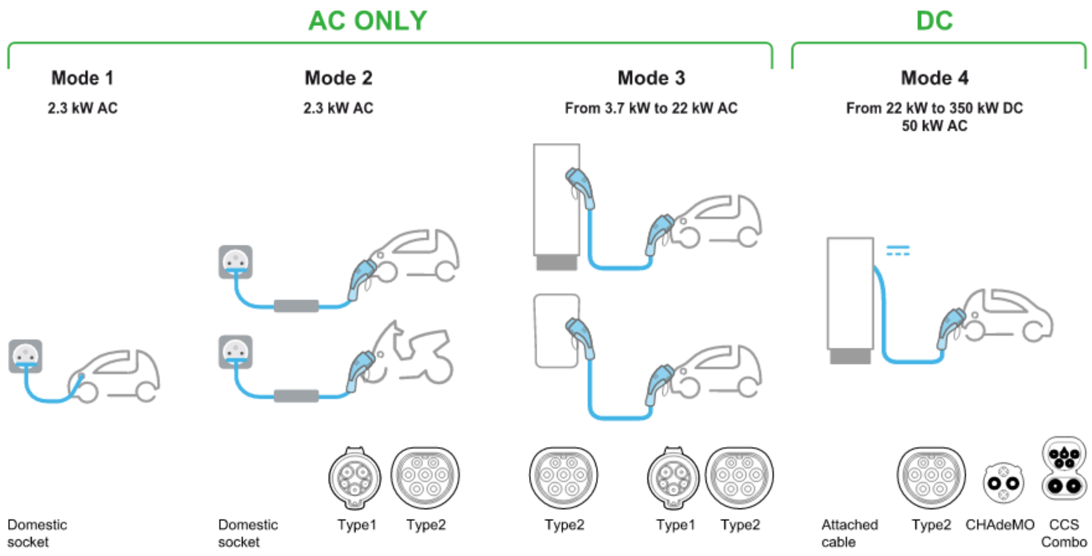

Figure 21: Charging Modes [53]

3.2.1 Charging Types

Charge types may vary according to the type of power used, the charging time, or the technology or topology used. It can talk about AC and DC charging types according to the power type. According to the duration, these types can be described as slow, fast, rapid, and ultra-rapid. When we look at the technology used, it can separate charging topologies as wired charging, wireless charging, and pantograph charging. Information on all charging types is described in detail below.

AC Charging: The type of power taken from the output of the charging station is AC power. When charging the vehicle, AC power is not transferred directly to the battery. First of all, AC power is converted to DC and this cycle is done with the onboard charger on the vehicle. AC charging is based on two different bases; single-phase and three-phase. Single-phase AC charging is slower than three-phase AC charging because it has less power capacity. AC charging can be characterized in terms of duration as slow and fast in proportion to the power capacity mentioned. The physical limitation of the onboard charger also limits the power transfer capacity of the AC charging.

DC (Fast) Charging: The power generated on the electric grid side is always in AC form. That is, the power at the output of charging stations or plugs is AC power. In fact, the main reason that separates AC and DC charging from each other is whether the AC-DC conversion that will charge the battery will be done inside or outside the vehicle. In AC charging, this cycle is done inside the vehicle, while in DC charging, this cycle is done on the station and the vehicle is directly supplied with DC power. By bypassing the onboard charger, the battery can be charged directly. The fact that the onboard charger is bypassed actually removes the obstacle in front of the charging power. Because in order to have high power transfer, the onboard charger must constantly grow, which makes it difficult to physically position it in the vehicle. Since the AC-DC conversion is outside the vehicle, the modules that make this conversion is located on the station and are less subject to limitations such as size and power than the onboard charger inside the vehicle. DC chargers are considered fast chargers because of the power capacity that can be transferred increases. It can be characterized as fast, rapid, and ultra-rapid in terms of duration.

AC and DC charger configurations can be seen in Figure 22 [55].

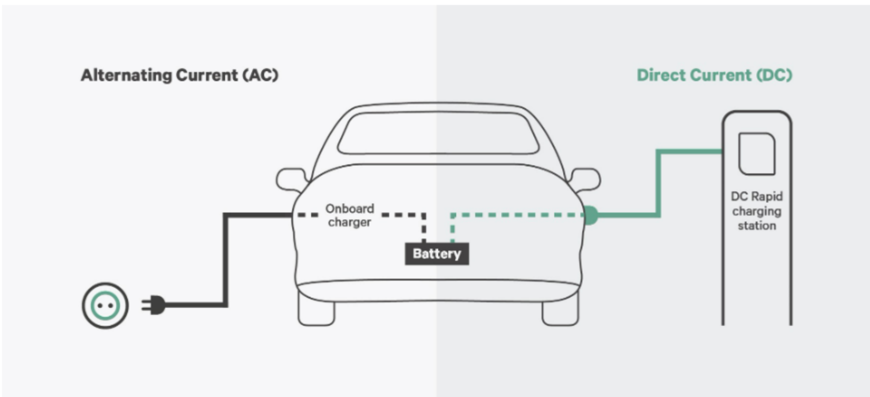

Figure 22: AC and DC Charger Configurations [54]

Wireless Charging: Wireless charging, which is also called inductive charging, provides charging of the EV vehicle's battery via electromagnetic induction without any direct connector. First, the moving electric charge passing over the inductive pad or the induction coil above the charging zone creates a magnetic field. With the change in the amplitude of the current, the magnetic field created also fluctuates. This fluctuating magnetic field creates an alternating current above the EV. This AC power is then converted to DC power that the battery can use and the battery is charged [56]. Apart from inductive wireless power transfer (WPT), capacitive WPT topology can also be used. In contrast to inductive charging, in capacitive charging, there is electric field activity instead of a magnetic field [57]. Wireless charging, which is a candidate to develop and become an important technology, has some challenges such as the need for high-frequency operations for high power transfer, compensation problems, and the long-distance between the vehicle and the charging pad. Figures 23 and 24 show examples of WPT.

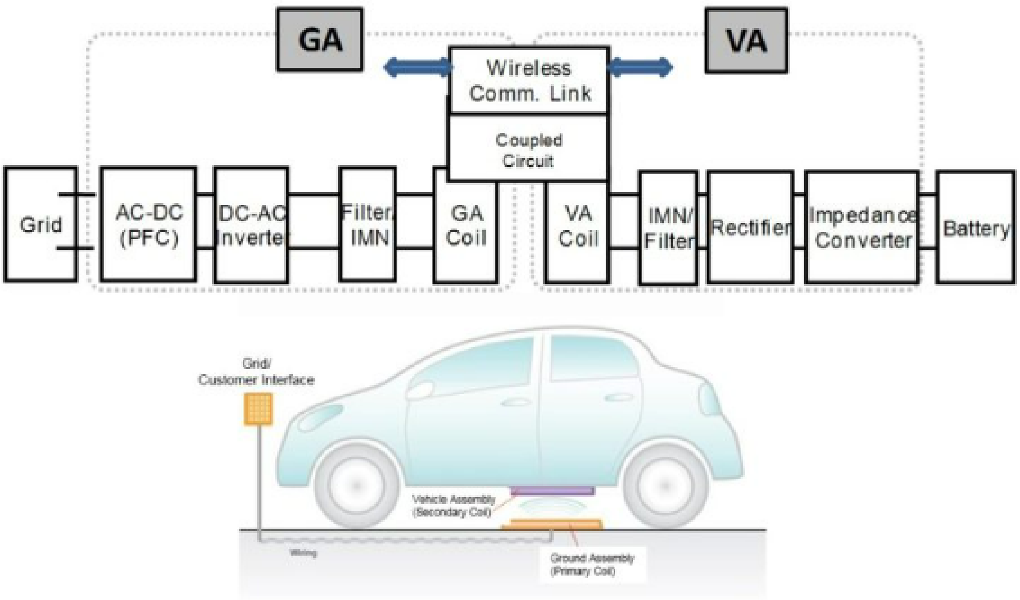

Figure 23: Inductive WPT [55]

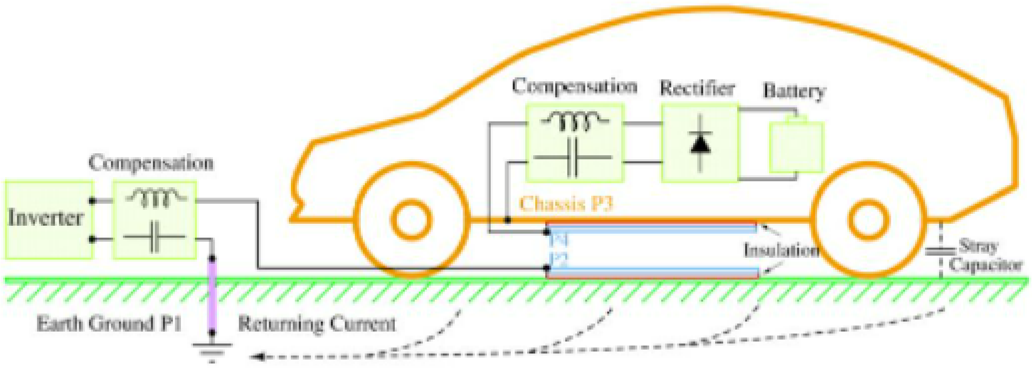

Figure 24: Capacitive WPT [56]

3.2.2 Main Standards and Protocols

EV charging is located in an integrated system that includes many different structures. In this system, the first leg of which is EVs themselves, there are charging concepts and infrastructures, the installation of stations, and the electricity grid infrastructure included in the system. In addition to all this general physical infrastructure, central systems that manage all charging actions from the superstructure are also integrated into the entire EV charging system. Many standards and protocols have been determined that govern the regular operation of these structures, which have many pillars, in a certain systematic. This section reviews the main EV charging standards and protocols in general [58]. In Figure 25, the standards and protocols that are generally included in the entire EV charging system are visualized.

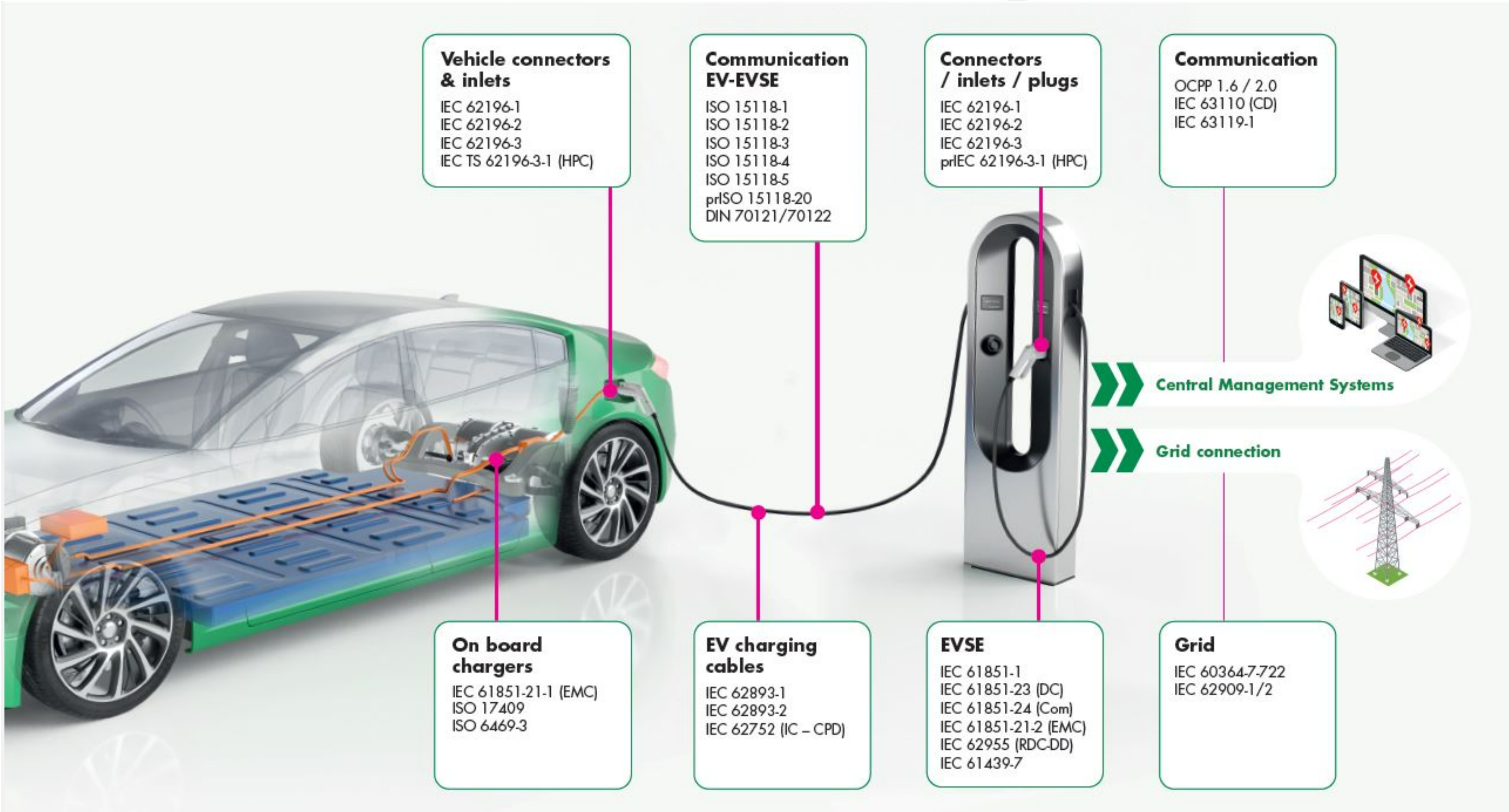

Figure 25: EV Charging Standards and Protocols [57]

IEC 61851: It is the standard determined by the International Electrotechnical Commission (IEC) standard organization for conductive EV charging. This standard is still under development and is a combination of a number of sub-standards. These sub-standards are set out below.

- IEC 61851-1: General requirements [59]
- IEC 61851-21-1: Electric vehicle on-board charger EMC requirements for conductive connection to AC/DC supply [60]
- IEC 61851-21-2: Electric vehicle requirements for conductive connection to an AC/DC supply - EMC requirements for off board electric vehicle charging systems [61]
- IEC 61851-23: DC electric vehicle charging station [62]
- IEC 61851-24: Digital communication between a DC EV charging station and an electric vehicle for control of DC charging[63]
- IEC 61851-25: DC EV supply equipment where protection relies on electrical separation [64]

The methods to be used for the modes given in Table.3 are determined in IEC 61851-1. The control pilot function, which provides control of the charging action, is also determined here. The Control pilot flow chart and state machine diagram are shown in Figure 26. Also, EV and EVSE equivalent circuit with control pilot connection is shown in Figure 27. However, the status of the control pilot and related parameter of the equivalent circuit for each state is shown in Table 3. The flow of starting the charge is as follows;

1. The CP is an open circuit when the control pilot is not connected. CP control is the pilot contact. In this case, it is in the 12V state, that is, the A1 state. V_a and V_b values are read as 0V. V_a on the EVSE side and V_b on the vehicle side are the points where the control pilot voltage is read. S_2 is an open circuit.

2. When the control pilot is connected, R_3 resistance comes in series with the 1k resistor R_1, and V_a and V_b values are read at the 9V level with the voltage divider. Equivalent resistance R_{Eq} is equal to R_3. Here we are in state B1. S_2 is an open circuit.

3. When it is at 9V when the authorization comes, EVSE PWM turns on, and the 9V PWM state, that is, the B2 state, is passed. S_2 is still an open circuit and the value of R_3 is the equivalent resistance.

4. Proper state formation by EV When switch S_2 is closed, the C2 state is entered. In this case, R_{Eq} is 882 Ω . In this case, the R_{Eq} value is as in Equation 3. In this case, charging is started.

$$R_{eq} = R_3||R_2 = \frac{R_3 * R_2}{R_3 + R_2} \tag{3}$$

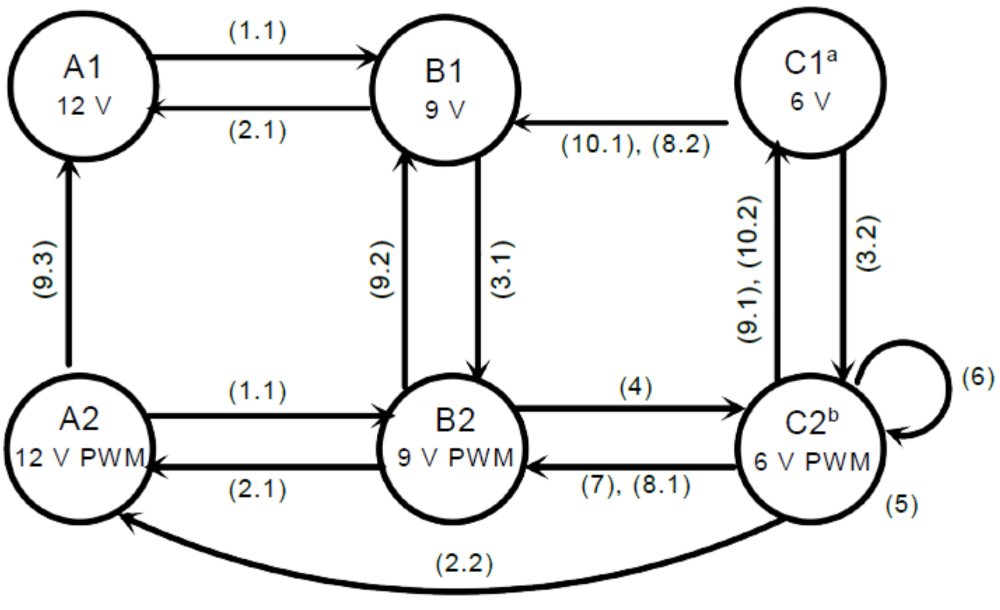

Figure 26: State Machine Diagram of Control Pilot [58]

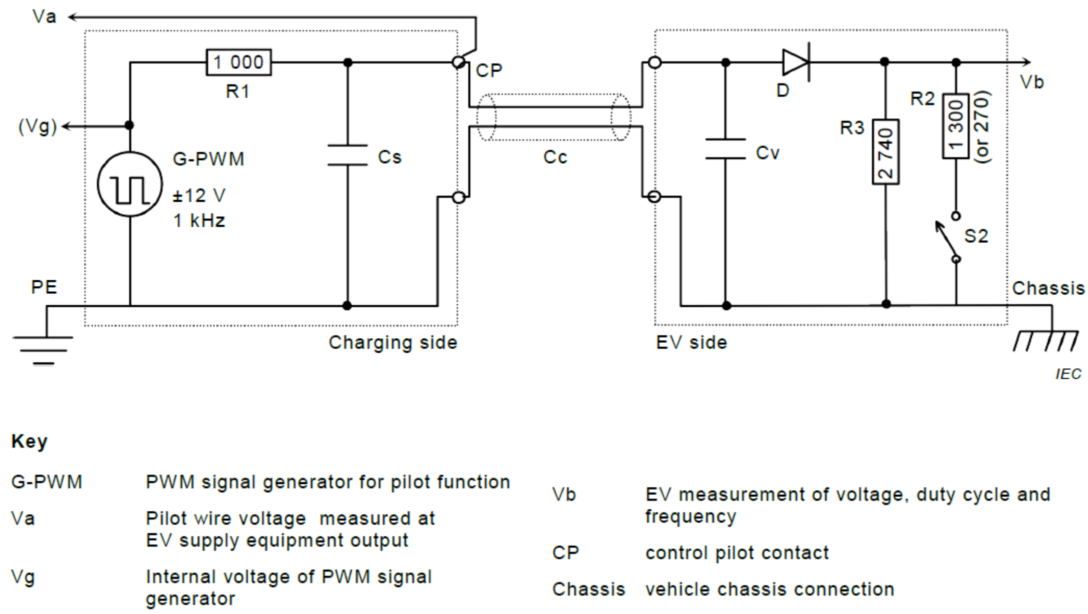

Figure 27: Typical Control Pilot Circuit [58]

Table 3: IEC 61851-1 Charging Sequence

Mode	*ChargeCable*	*State*	*CP*	*S2*	*Remarks*
Unplugged	No conn.	A1	12V	NA	Va=Vb=0
Unplugged	No conn.	A2	12V PWM	NA	Va=Vb=0
Plugged	Connected	B1	9V	OC	R_{Eq}=R_3
EVSE Ready	Connected	B2	9V PWM	OC	R_{Eq}=R_3
EV Ready	Connected	C1	6V	SC	R_{Eq}=882 Ω
Charging	Connected	C2	6V PWM	SC	R_{Eq}=882 Ω

OC: Open Circuit, SC: Short Circuit

ISO 15118: *Road vehicles- Vehicle to grid communication interface* is a standard published by the ISO standard organization that organizes V2G communication and the communication required for bi-directional (Vehicle-station) charging and discharging. However, it provides plug and charge capability for some EV networks. The ISO 15118 standard was formed by the combination of a group of sub-standards. The relations between the working organization of these standards given below and the OSI layers formed accordingly are shown in Figure 28 [65].

- ISO 15118-1: General information and use-case definition [66]
- ISO 15118-2: Network and application protocol requirements [67]

- ISO 15118-3: Physical and data link layer requirements [68]
- ISO 15118-4: Network and application protocol conformance test [69]
- ISO 15118-5: Physical and data link layer conformance test [70]
- ISO 15118-8: Physical layer and data link layer requirements for wireless communication [71]

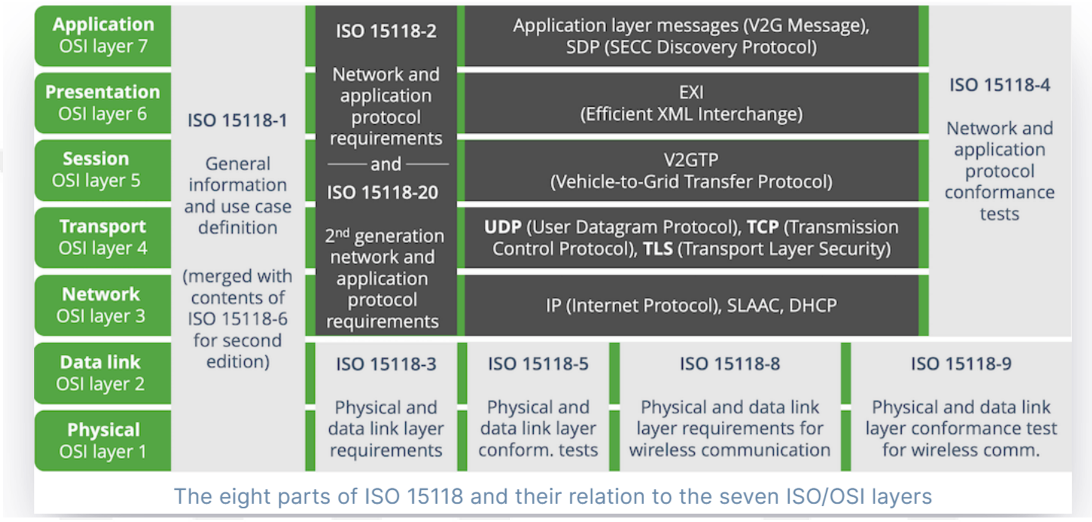

Figure 28: ISO 15118 Parts and OSI Layers [64]

The visual of the message sequence during DC charging of ISO 15118, which offers a communication standard, is shown in Figure 29. In this sequence, all the states and conditions during DC charging are seen, and the necessary actions such as contactor opening/closing are also visualized at which stage or condition to be performed. Voltage levels or similar parameters in all sessions are specified. ISO 15118 is a standard derived from the IEC 61851 standard and is a customized standard for digital communication during charging actions [72].

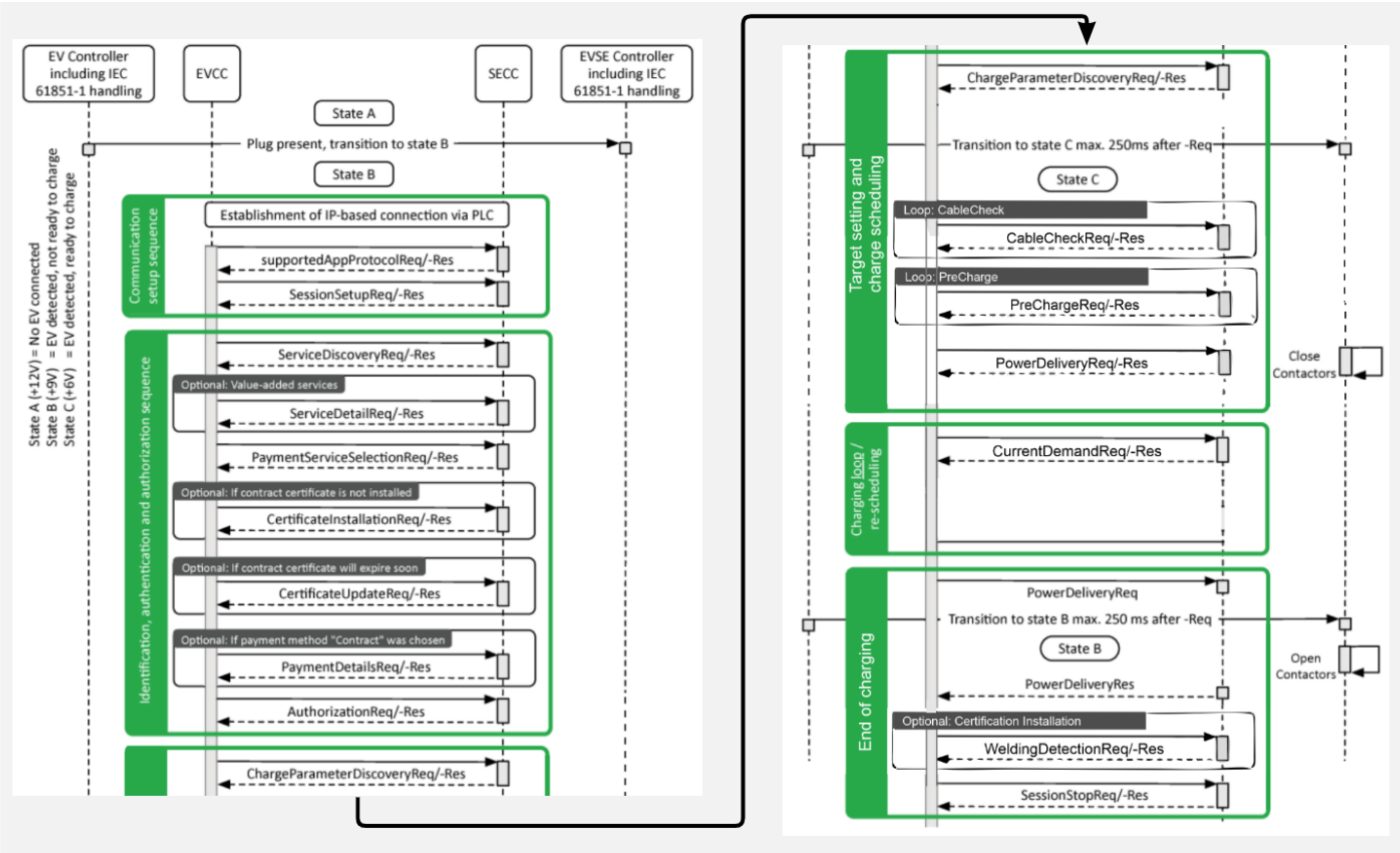

Figure 29: ISO 15118 DC Charging Message Sequance [71]

Open Protocols: Due to the multi-stakeholder structures in the EV industry, data flow and smooth communication between these structures are very important. Open protocols are being developed so that such data exchanges can be made in accordance with certain rules and standards [73]. All these protocols enable each stakeholder to easily integrate into the system to move the EV network forward and enable future infrastructure organizations to rise on better foundations. At the same time, it enables the user to benefit from the EV environment in a simple way [74].

- Open Charge Point Protocol (OCPP): Communication between digital systems and devices can often be quite complex. The joint operation of the communications between these different systems within a standard is described as a protocol. Considering that EV charging stations are also included in digital systems, it can be said that such a protocol is needed in order to perform many different operations (pricing, authorization, etc.) centrally. Because there can be chargers from different types and manufacturers in the field, each of them must be able to work under the same organization by the user. At this point, a structure like OCPP is needed. OCPP is an application protocol that provides communication within the network between EV charging stations in centralized management [75]. In short, OCPP is the protocol that enables charging stations to communicate within the network and with the central system, independent of vendors. Open Charge Alliance (OCA) is managing the OCPP. Figure 30 visualizes the place of OCPP in the EV charging organization.

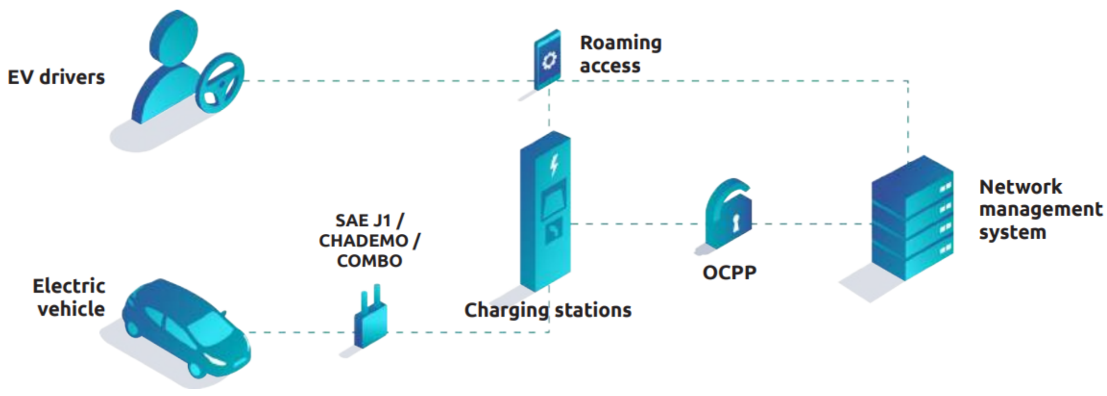

Figure 30: OCPP in EV Charging Enviroment [74]

- Open Smart Charge Protocol (OSCP): OSCP is the protocol that provides communication with the center that manages both the charging operations and the center that manages the energy systems. With this protocol, it manages the chargeability of EVs by forecasting available, accessible capacity on the electricity grid for 24 hours. OSCP is maintained by OCA.

- Open Charge Point Interface (OCPI): The OCPI protocol allows EV drivers to automatically roam between different EV charging networks. In its most basic terms, this protocol enables drivers to locate available and accessible EV charging stations, mobile access to stations, pricing, and billing in real-time. The OCPI protocol is managed and maintained by the EVRoaming Foundation.

- Open Automated Demand Response (OpenADR): The OpenADR protocol is a protocol created to balance the supply offered by the network and the demand made to the network side, and to eliminate cost disadvantages. It is an open and secure model that provides bilateral information exchange and facilitates automated demand response (DR) actions. This protocol enables the equal exchange of dynamic price and reliability signals between utilities, system operators, and energy management and control systems during DR events. Actually, this protocol may not be a protocol specific to EV charging directly, but it is important for the adaptation of EV charging to the smart grid concept with the increasing EV charging load. OpenADR is maintained by OpenADR Alliance.

3.2.3 EV Charging Stations

Charging stations differ in terms of both their capacities and places of use. Charging stations with various capacities are grouped under two headings in terms of the power they provide; AC charging stations and DC charging stations. AC charging stations are usually stations with lower power capacities. The capacities of AC charging stations vary according to single-phase and three-phase situations. Three-phase AC stations have higher charging capacities than single phases. The limitation of onboard chargers on the vehicle may cause the capacity of AC chargers to remain at lower levels than DCs. DC charging stations are also called fast charging because they have high power capacity. However, it should be noted that charging stations are also in a distinction as public or private. Public charging stations are stations that are open to everyone's use. Both AC and DC charging stations can be public, but private charging stations are mostly AC charging stations. Because while DC charging stations provide high capacity, they are much larger and dimensional structures due to the AC-DC conversion in their structure and it is not possible to use them as residential. AC stations usually have capacities of 3.7 kW, 7.4 kW, 11 kW, or 22 kW. In addition, DC stations can provide power from 24 kW to 900 kW. Figure 31 shows AC and DC station examples [76].

Another point in charging stations is the connector types used. The connector types used in each vehicle may be different. Some vehicles can use CCS, some vehicles Chademo, and some vehicles can use AC type inlet. AC stations generally provide one type of connector and one output, but DC stations can support multiple outputs and different connector types. In order to initiate charging actions, the connector must be connected to the vehicle and the charge must be started with authorization. Generally, authorization is done with RF cards, mobile applications, or protocols such as Bluetooth and NFC. However, there are also concepts that do not require authorization, such as the newly developed plug and charge.

Figure 31: AC and DC Charge Stations-Vestel Products: a)EVC02 AC Station, b)EVC04 AC Station, c)EVC05 AC Station, d)EVC03 DC Station, e) EVC06 DC Station [75]

3.3 Infrastructure

The increase in the number of EVs today brings with it an increase in charging stations. This means new loads need to be adapted to the electrical infrastructure and the user's demand on the grid will increase. Of course, the installation of EV charging stations into the electricity grid depends on certain criteria and standards. In this section, the installation of EVSE products on the grid and their connections with the infrastructure are explained.

3.3.1 Station Instatllation to the Grid

EV charging stations are structures used to charge electric vehicles. Where the charging stations will be installed and under what conditions is also very important in terms of the electricity grid. In fact, the installation of charging stations also has a certain design and there is a certain standard for how this design will be. This standard is *IEC 60364 Low-voltage electrical installations - Part 7-722: Requirements for special installations or locations – Supplies for electric vehicles.*This standard defines the specific requirements of the new EV charging station infrastructure to be installed or the low voltage (LV) electrical infrastructure already installed. In this standard, the use of devices such as overcurrent protective devices or RDCs, which are important for the system and mentioned in other IEC standards, has also been made compulsory. In fact, this standard is a standard that includes the protection of electrical infrastructure. When installing charging stations, they are installed based on their maximum values. In this case, the maximum demand to which the station will be loaded is actually determined. If the infrastructure of the station is adapted to a ready LV, revisions should be made for this max demand. If new infrastructure is being built, the design is completed according to this max demand. For ready-made LVs, this is an important parameter because it provides standard-based information for network structures that will be examined in later sections. It also lays the groundwork for the question of whether much larger infrastructure investment is required going forward.

Another important factor is the protection circuits of the infrastructure and the condition of the equipment suitable for them. These requirements are important when we consider all the dangerous situations that may occur. Electric shock, leakage current, grounding, etc. Such protections will not allow the negative effects that may occur in the EV or station to affect the user [77]. An example charging station connection diagram is visualized in Figure 32.

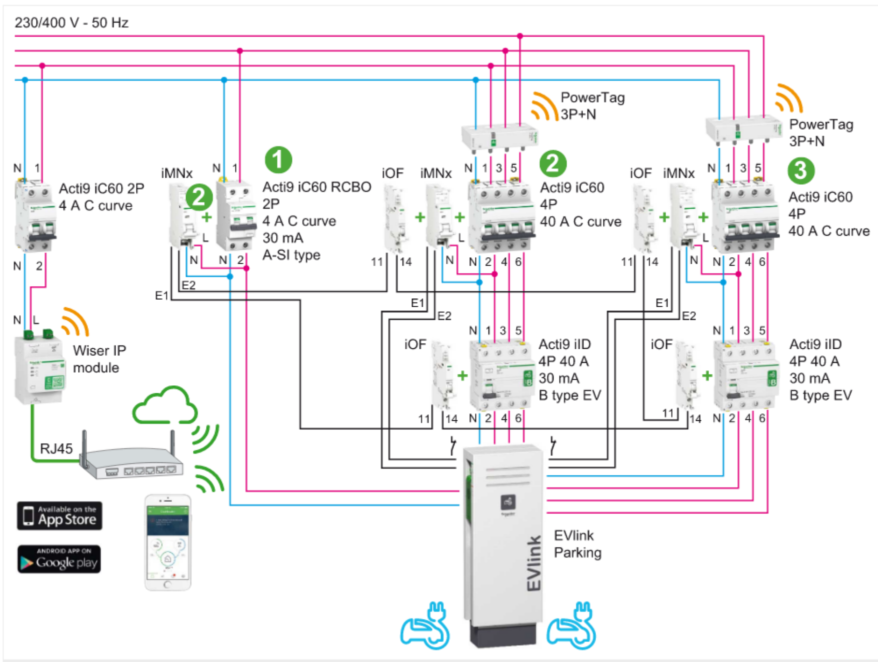

Figure 32: Charging Station Connection Diagram [76]

Two different scenarios can be mentioned for the charging station to be established. The first of these is when the capacity of the EV charging station is lower than the installed power. In this case, analysis can be started for the installation and if there is a suitable capacity gap, the installation can be done. The second scenario is that the station capacity is larger than the rated power. In this case, the LV switchboard must be replaced and brought to the appropriate capacity. Looking at this situation from a wider perspective, an update may also be required for distribution transformers. If the number/capacity of EV charging stations to be loaded is more than the locally installed power, the distribution transformer should also be updated. Another solution to this situation is to compensate the demand locally if there are opportunities at suitable power capacity values [78]. An example EV charging station deployment environment is given in Figure 33.

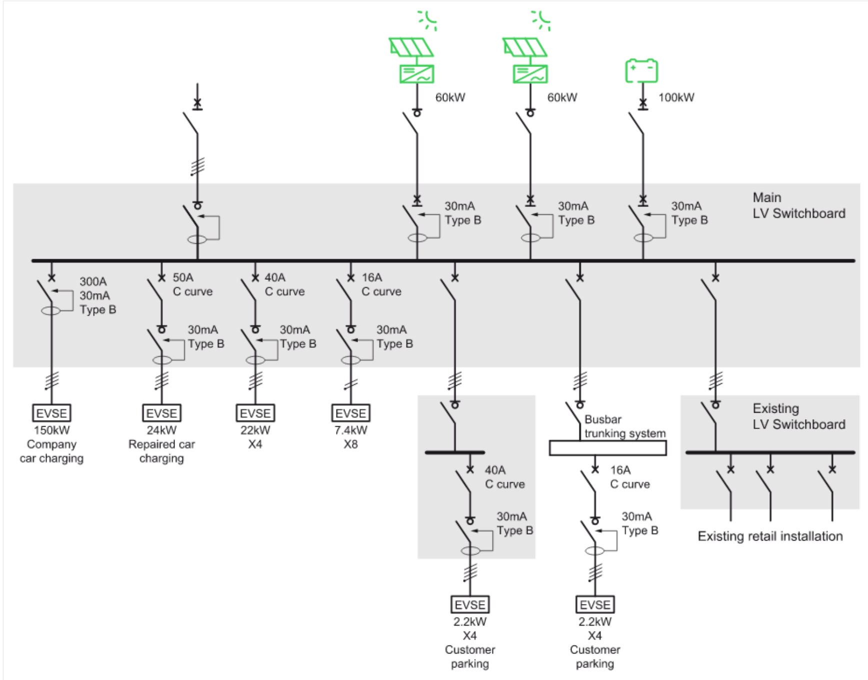

Figure 33: EV Charging Station Deployment Environment [77]

3.3.2 Charging Network

In terms of EV charging infrastructure, not only the electricity grid infrastructure but also the infrastructure in the digital environment is important. Many different parameters are known to be effective during EV charging [79]. Some of these factors are pricing, reservation, availability, accessibility, billing, scheduling, etc. In order to carry out all this organization, open protocols mentioned in the previous section are being developed. In addition, smart and artificial intelligence-based applications are also included in this organization. As the global interest in EVs grows, the EV charging network will grow. For this reason, risk-zero organizations both locally and on a wider scale are very important for the continuity of the systems.

CHAPTER IV

POWER RATINGS AND DEMAND ANALYSIS

In this chapter, load EV charging profiles based on user behaviors have been analyzed and it has been seen how users routinely charge their vehicles. In addition, power rating and demand analysis were performed on the distribution transformer data collected. However, it has been observed how the general capacity states of DTs are for EV charging.

4.1 User Routines and Load Profiles

With the spread of EVs, the demand for electricity has increased significantly and will increase further in the future. In fact, it is possible that EVs will replace ICEs, both when market data is examined and with the technologies developed. This situation will increase the electricity demand as stated and a supply will be needed to meet it. In the current electricity supply-demand, for example, there is already a power consumption for a home environment and it is demanded from the grid with a certain profile. As for EV charging, a brand new demand will be created. At this point, the characteristic of the demand profile or load profile to be formed plays an important role. In the formation of these load profiles, it is very important how the vehicle users routinely run their vehicles according to the following parameters and what kind of behavior they exhibit.

- How often EVs are used (daily or monthly distance traveled)
- How often EVs are charged
- Where the EVs' charging attachments are located (home, workplace, stations, etc.)
- What type of EV charging equipment do they use?

• At what time intervals do they have the habit of charging

At this stage, it would be more useful to look at user routines and habits before examining load profiles and new demand levels that may occur. At this stage, the point that should be mentioned first is the idea that the EV charging organization will be controllable and manageable with smart algorithms and management systems or in line with pricing, routing, and side applications. In today's conditions, this approach can be quite effective to a certain extent. Of course, these applications are extremely important and it is certain that they will be very useful in the future [80]. In Figure 34, it can be seen how the load profiles are directed with the management systems.

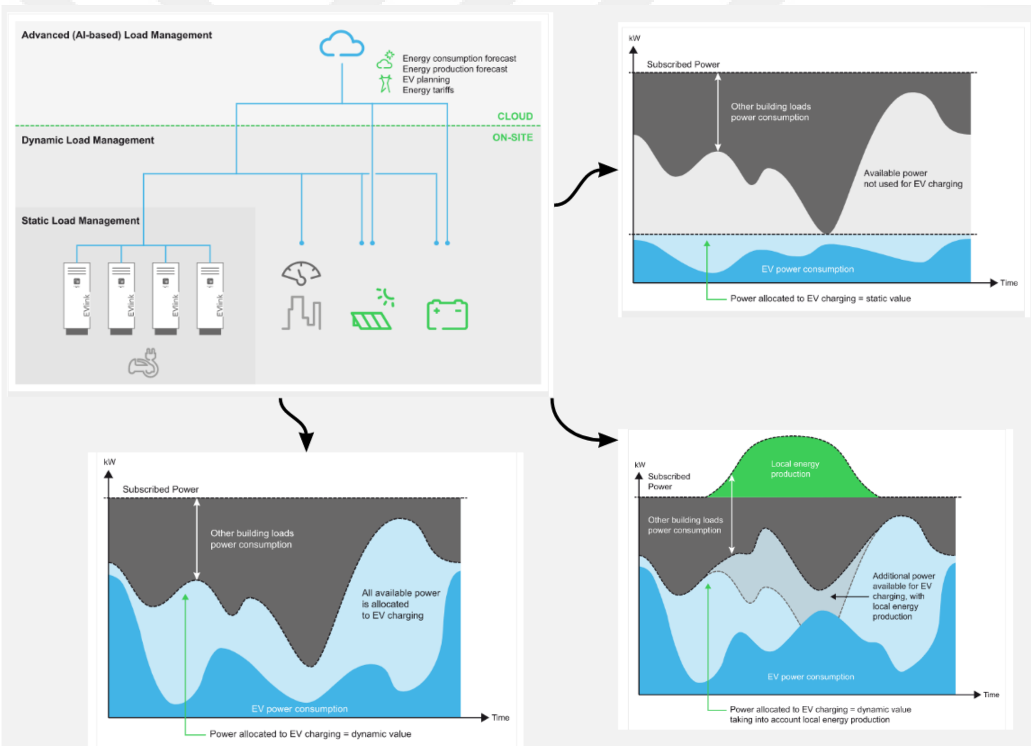

Figure 34: Load Management Topologies [79]

But here it is necessary to mention the existence of four main elements that should not be ignored. These elements are as follows. In line with these factors, it is possible to encounter very different and negative scenarios.

• Randomness and anomalies in EV charging actions

- The reality is that users are not completely controllable
- Real situations where all or most vehicles are EVs
- When viewed locally, it is seen that not every region has the same infrastructure opportunities.

It is important to mention a few critical survey results when looking at charging routines along with some studies on user behavior. The results of the survey included worldwide evaluations. First, it evaluates how often users use their EVs. 82% of users use their vehicles almost every day. 83% of the users have their own home type charger and 4% stated that they are considering buying one. This shows that users have a high tendency to charge their cars at home, and at least they want to keep the chance to charge at home. One of the important consequences is where is used as the primary charging station. 74% of users indicated their home as their primary charging location. In terms of charging frequency, the tendency to be charged every day is in the first place with 41%. The secondary trend is towards charging several times a week. The first of the questions asked to see the status of public charging stations is about how often public level 2 stations are used. The result is that it is less than once a week with 72%. The same question was asked for public level 3 charging stations, namely fast DC chargers. The result here is the same with 84% and again less than once a week. There are two results from here. The basic preference is that charging at home is more preferred. The second inference shows that users also benefit from public chargers even though they have chargers in their homes. So, although the trend is basically to use private charging, it is a combination of public-private charging. Another point that can be described as an interesting result is the battery charge level of its users, which is kept constant. Most drivers don't mind if the battery level drops below 50%. This means that range anxiety is not too much of a concern. The important detail here is that this result is only evaluations specific to Europe [81].

Finally, two important research results should be mentioned. The first is the result of how much time users can devote to EV charging action. The result is that users are more inclined to prefer charging at night. The second study explores where people are more likely to charge outside of the home. The result is mostly in the direction of shopping centers. The results of these two studies are shown in Table 4 and Table 5, as a percentage of user preferences [82].

Notes about Table 4 and Table 5. For Table 4; percentages represents the proportion of respondents rating option as "completely convenient" or "very convenient". For Table 5; respondents could select up to three responses.

Table 4: Convenience of Potential EV Charging Locations [81]

ChargingOptions	*Percentages*
Overnight at home 2 times per week	72
At nearby fast charging station for 10min twice a week	50
At nearby fast charging station for 30min once a week	36
At shopping center or restaurant for 2h twice a week	32
At shopping center or restaurant for 4h once a week	17

Table 5: Convenience of Potential EV Charging Locations [81]

ChargingLocations	*Percentages*
Grocery Stores	66
Restaurants	37
Shopping Malls	36
Recreational Areas	32
Major Warehouse Clubs	25
Entertainment Locations	24
Pharmacy Chains	17
Charging	17

Considering the load profiles, especially the daily load distribution is an important criterion. In a study, the density of charging was determined according to the vehicles arriving and leaving a particular charging facility. It has been observed that the density of vehicles in the public charging organization increases at noon, and in this case, the demand for charging also increases at noon [83]. The density graph is shown in Figure 35.

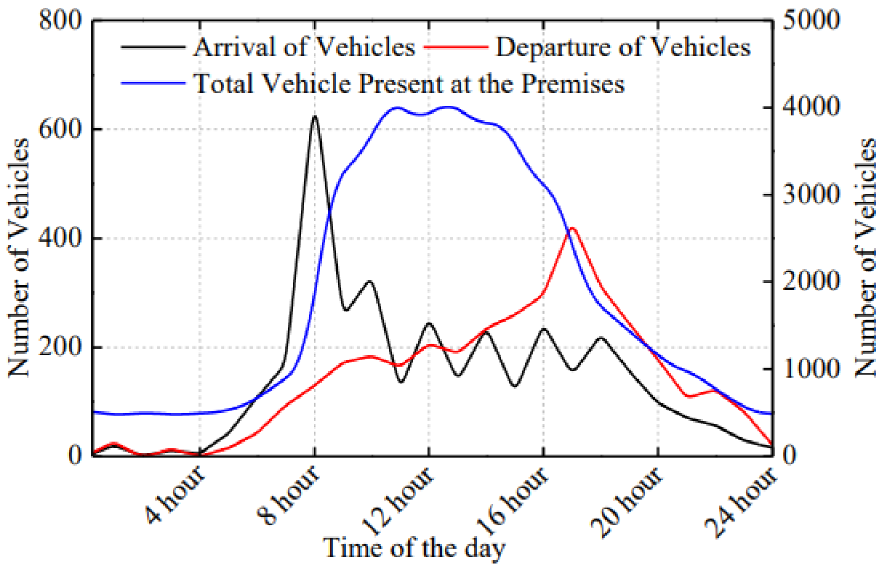

Figure 35: Present EV Number at Premises According to Arrival and Departed EV Numbers [82]

In addition, with the EVI-Pro tool [84], the charge density and demand in a sample region were obtained according to certain parameters. In the analysis made with Boston, Massachusetts as a sample, it is seen that public charging is concentrated at noon, while private charging is concentrated in the evening and night hours. At the same time, worst-case and best-case scenarios have been examined, and there is a possibility of a very serious impact in the result of the worst case. Figure 36 shows the graphs analyzed in two cases, weekdays and weekends. The conditions chosen for the average case are as follows. A circulation-improved scenario was applied by choosing the fastest charging scenario possible.

- EV Fleet Size: 100k

- Average Daily Miles Traveled per Vehicle: 25 miles
- Average Ambient Temperature: (10°C)
- Plug-in Vehicles that are All-Electric: 75%
- Plug-in Vehicles that are Sedans: 25%
- Mix of Workplace Charging: 50% Level 1 and 50% Level 2
- Access to Home Charging: 100% with the following mix: 50% Level 1 and 50% Level 2
- Preference for Home Charging: 80%
- Home Charging Strategy: Immediate – as fast as possible
- Workplace Charging Strategy: Immediate – as fast as possible

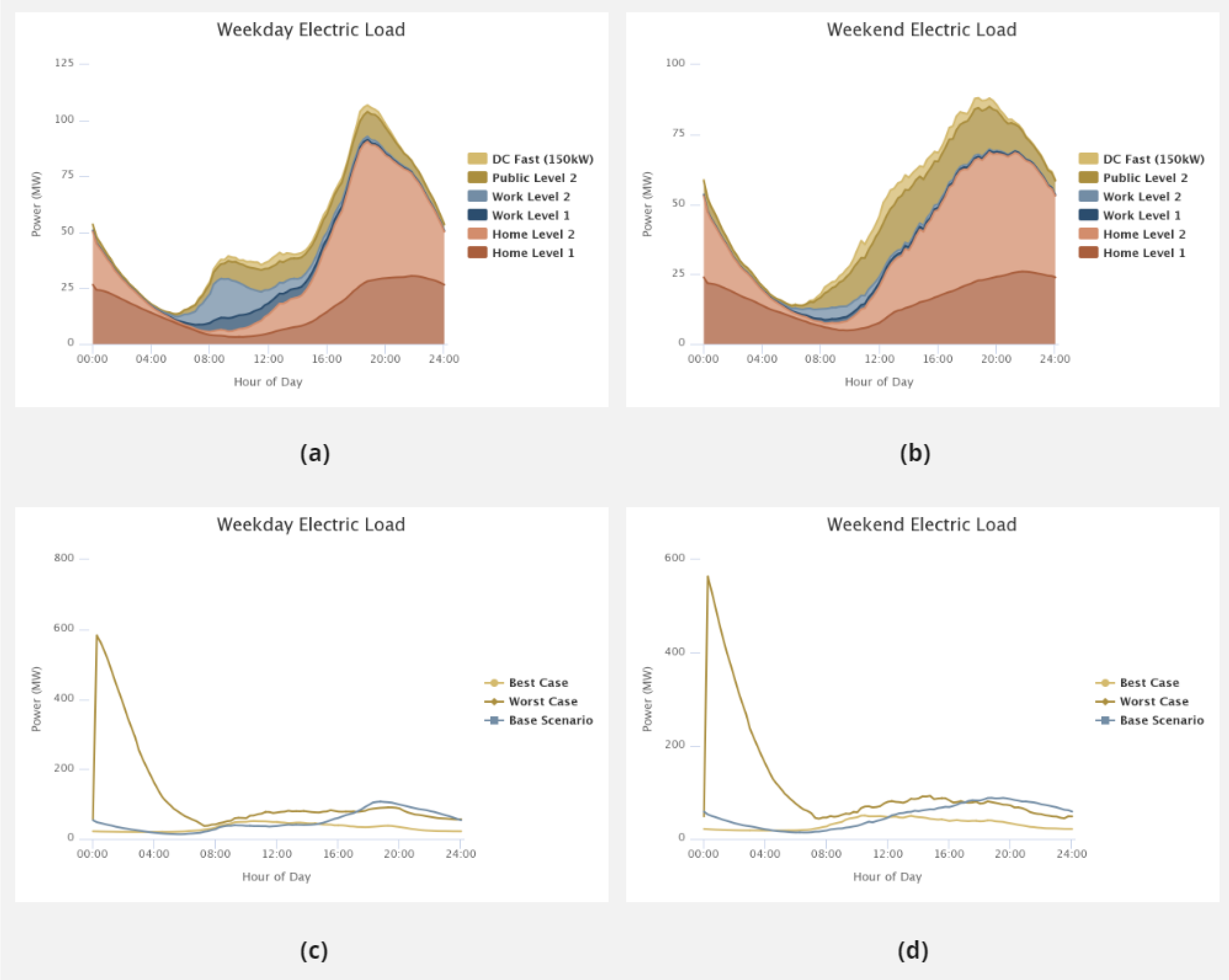

Figure 36: Load Profiles of Boston, Massachusetts: a) Weekday Basic Load, b) Weekend Basic Load, c) Weekday Worst-Basic-Best Load Comparision, d) Weekend Worst-Basic-Best Load Comparision

4.2 Electricity Grid Analysis: Central Anatolian Region

In this section of the thesis, it is analyzed how suitable the electricity grid infrastructure of the Central Anatolia Region is for EV charging installations and whether the infrastructure is sufficient for the need for charging stations that will arise from the increase in the EV population. Actual distribution transformers (DT) rated powers and these DT rated powers, as well as annual maximum demand data, determined how much free space is available for charging station installation. In Figure 37, where the status of the existing charging stations in this region of Turkey is monitored with the PlugShare application, the number and density of charging stations in the region are also determined [85]. It is seen that the number of charging stations in the region is around 50 and the majority of these stations are AC charging stations. Almost all of the stations are located in the city centers as public. From these perspectives, it is seen that the density of charging stations in wide geography (Aksaray, Konya, Karaman, Nevşehir, Kırşehir, Niğde) is very low. In this case, it can be said that it does not impose an excessive load on the electrical network for the time being. Based on the data of the distribution transformers (DT) in the region, the current situation for new station installations is analyzed in the following sections.

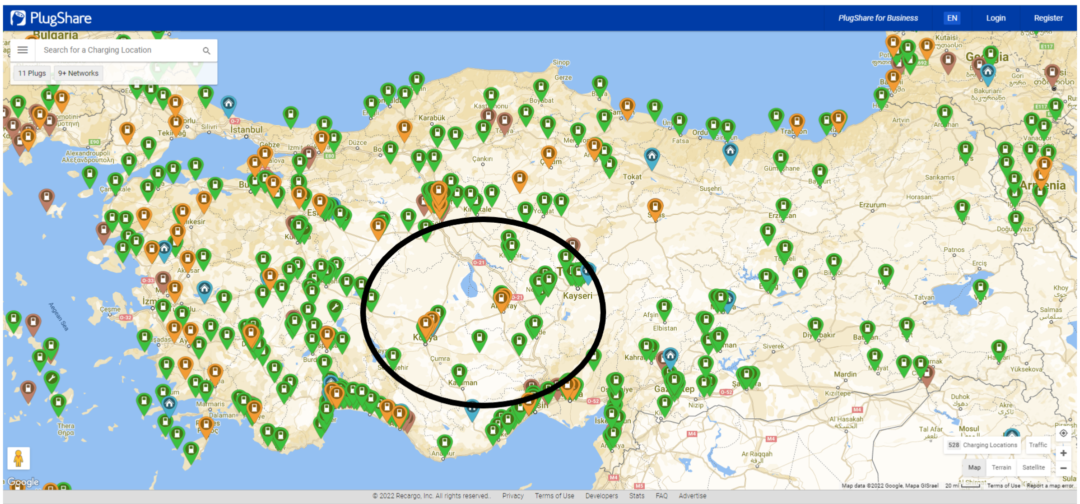

Figure 37: PlugShare - Central Anatolia Region's Current EV Charge Station Status [84]

4.2.1 Data: Collection and Cleansing Methods

Rated power and density information of DTs is needed for the analysis of EV charging station installation to be made over DTs in the Central Anatolian Region (CAR). The data to be analyzed quantitatively must primarily be collected reliably and accurately. At this point, the data of the DTs in the Central Anatolian Region were obtained through the automatic meter reading system or *Otomatik Sayaç Okuma Sistemi* (OSOS) [86]. OSOS is a special system that can monitor data remotely through meters with M-Bus data communication. Unlike conventional meter reading systems, inefficient situations such as the risk of human error, operation cost, and time loss in data collection are eliminated. Digital data outputs can be obtained from different platforms. The working principle is briefly as follows; The whole map of the system is drawn and comprehensive checks of all meters (M-bus) in the project and M - Bus data connection communication tests are performed, then the data flow begins. The DT data necessary for the study with the help of OSOS were collected in this way. Firstly, data collection made over all of the DTs of Turkey. In next section that will be mentioned, data cleansing methods will be applied and CAR's DT data will be filtered.

The data sets collected with OSOS contain quite a lot of recording data. In this case, some data may be corrupted due to various errors or corrupted readings. This reduces the data quality and may cause erroneous results. For this reason, data cleansing methods have been used to ensure data quality and to obtain more efficient results. Data Cleansing is a methodology that detects problematic, erroneous, corrupt, incomplete, and incorrect data in the registry or in a database, along with its correction or deletion. With this methodology, corrupted and unreliable data from the raw data received in .csv format were cleaned with the Excel program. The methods used are described below. Data cleansing visualized in Figure 38.

- Parsing: The data captured from the data loggers but not suitable for the format to be used for analysis were made meaningful and readable.

- Deduplication: Among the collected DT data, deduplication of data that may disrupt the analysis and repeat incorrectly has been made.

- Removal: Empty and non-data segments are deleted among the data collected from DTs.

- Standardization: The data has been arranged to give the analyzes to be made for all DTs in the same standard.

All data has been systematized with the data cleansing methodology. As stated in the previous paragraph, the data set has all DT data in Turkey. In order to make a regional analysis, the data of the Central Anatolia Region, which is the target region, were filtered.

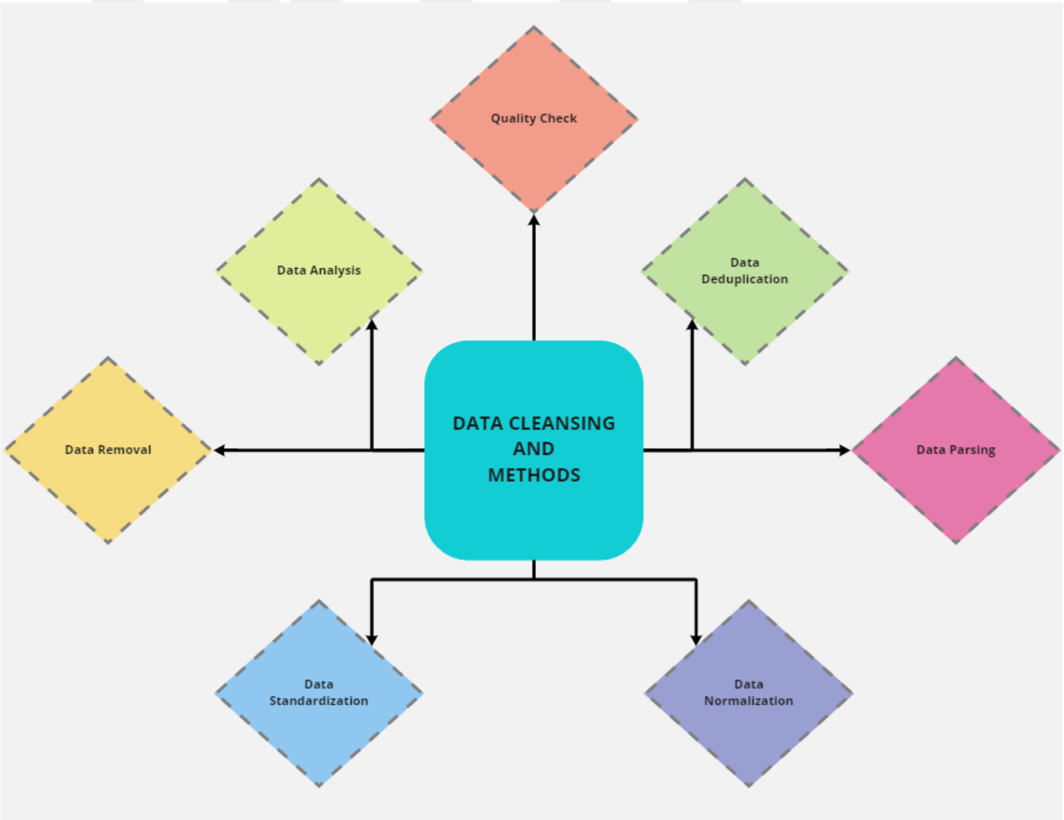

Figure 38: Data Cleansing Methodology

4.2.2 General DT Analysis

First of all, it is necessary to talk about parameters such as distribution transformer (DT), rated power, and demand with an overview [87]. The rated power (RP) of the DTs is the maximum output power that the transformer can provide to the end-users in the region to which it is connected. Peak demand (PD) is the maximum load drawn from the transformer depending on the electricity needs of all end-users connected to the DT. In order for the DT to work properly without collapsing, the PD level must stay within the RP level. In addition, the parameter that determines the status and power usage of the DT is the occupancy rate (OR). OR expresses the percentage of peak demand versus RP in terms of electrical power. The OR is given in Equation 4.

$$\%OR = \frac{PD}{RP} * 100 \tag{4}$$

The parameter used to load electric vehicle supply equipment (EVSE) products into the system is the Charger Installation Gap (CIG). According to the occupancy rate, the CIG is shown in Equation 5 as the difference between the installed power and the peak demand.

$$CIG = RP - PD \tag{5}$$

Gathering field data on DTs and performing status analysis allows EVSE products to be installed with the CIG.

There are DTs in different installed power values from 50kVA to 2000kVA in the Central Anatolia Region. DTs with these values are spread over the city centers and rural areas of the region. When the distribution of DTs with different installed power is analyzed according to the collected data, the ratio of 50kVA DTs with the lowest installed power among the total transformers is seen as 12.89%. At the same time, the 2000kVA DTs, which have the highest installed power, are the least with 0.05%. The place of the first four transformer types with the lowest installed power in the general distribution is in a large place in the general total with 70.99%. The installed power distribution is shown in Table 6.

Table 6: Rated Power (RP) Distribution of DTs of Central Anatolia Region

$RatedPower(kVA)$	$Number$	$PercentageinTotal$
50	1078	12.89%
100	1818	21.74%
160	1569	18.77%
250	1471	17.59%
400	820	9.81%
630	946	11.31%
800	47	0.56%
1000	361	4.32%
1250	159	1.90%
1600	89	1.06%
2000	3	0.05%
Total	**8361**	**100%**

In order for EV Chargers to be installed, the necessary power gap must be available on the DTs [88]. DTs, on the other hand, give the end-user an installation gap for the EV Chargers, depending on the demand situation, relative to the occupancy rate level above it. DTs with more than 100% occupancy rates are classified as overloaded, between 100%-80% as heavily loaded, between 80%-40% as considered loaded, and less than 40% as low-loaded. According to DT analysis data, 87% of transformers seem to be considered low-loaded. This allows EV Chargers to be installed, but at this point, the transformer installed power should be sufficient [89]. Overloaded transformers are 6 percent and seem low. However, overloaded DTs cannot be used to install EV Chargers and it will be still overloaded if the demands on DTs are not reduced. For heavily loaded DTs, a certain amount of EV Charger can be installed, but again, its installed power is important. The distribution of DTs according to the occupancy rate is shown in Table 7 and Figure 39.

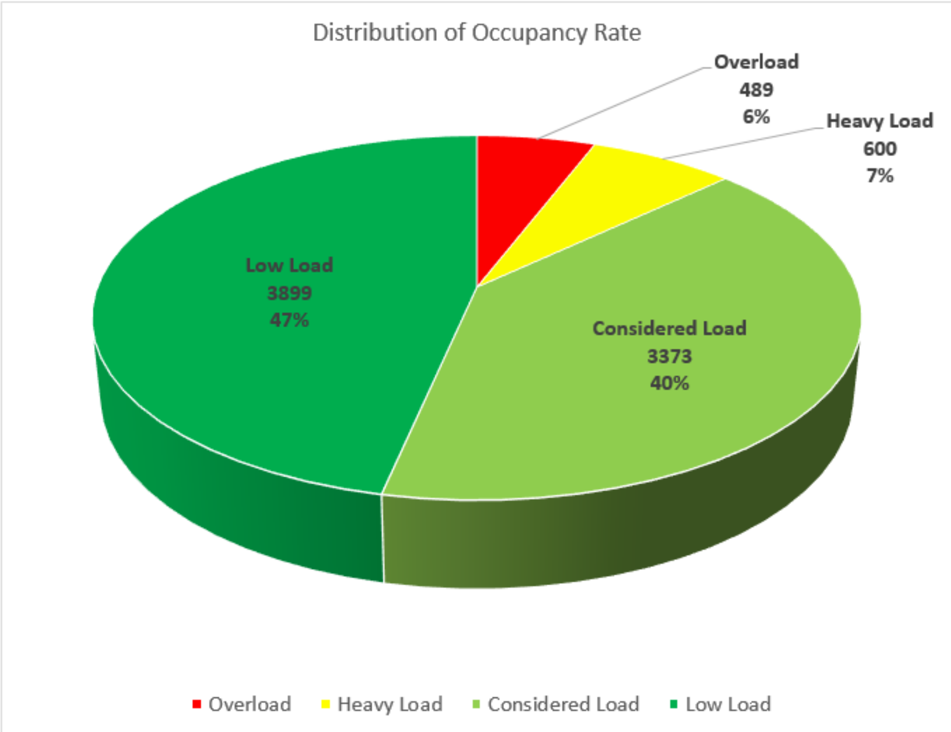

Figure 39: Distribution of Occupancy Rate

Table 7: Distribution of Occupancy Rate of DTs

OccupancyRate	*Condition*	*Number*
More than 100%	Overload	489
100% - 80%	Heavy Load	600
80% - 40%	Considered Load	3373
Lower than 40%	Low Load	3899

4.2.3 Charger Test Installations to DTs

The electrical energy demand in the battery system of EVs is provided by EV chargers. EV Chargers, on the other hand, transfer the energy they receive from the electric grid to the vehicles with their special equipment and cable systems . The development in battery technology also requires the development of EV Chargers. In this case, various types and different power capacity chargers offer solutions to different needs [90]. There are EV chargers that differ in AC or DC type according to their output power. AC type EV Chargers provide alternating current as output. At this point, it should be mentioned that batteries can only be charged with direct current. For this reason, there are onboard chargers that support AC charging on EVs. The output from the AC charger is converted to DC on the vehicle and the batteries are fed. When AC charging is done, the transmitted power is limited due to the onboard converter and a hardware size limitation in this cycle. AC chargers are also divided into two separate subtypes; single-phase and three-phase. Three-phase AC chargers have a higher power capacity. DC chargers, on the other hand, are suitable for higher power transfer than AC chargers. DC chargers directly feed the EV battery system by converting the AC electrical energy taken from the grid into DC itself. Thanks to their high power generation capacity, DC chargers can reduce charging times to very low levels.

Although there are products at various power levels in the market, some power levels have been determined for analysis. With the EV Charging Time Calculator application, a time analysis was made between different types of products with different power levels [91]. The highest battery capacity in the market was 107.8kWh, the lowest value was 16.7kWh. In the analysis, the average battery capacity of all EVs in the market, 60.3kWh, was chosen [42]. The initial battery charge level is 20% and the target level is 80%. These values are the most optimum charge level range of the batteries [92]. As a result of the analysis, charging with a 3.7kVA AC charger took 48min for 10h. On the other hand, it is completed in 20min with a 120kW DC charger. Table 8 shows the features of all chargers.

Table 8: Charging Times According to EV Charger Types

Charger Type	*Phase*	*Charger Voltage*	*Charger Current*	*Charging Power*	*Estimated ChargeTime*
AC	1	230V	16A	3.7kVA	648 min
AC	3	400V	32A	7.4kVA	324 min
AC	1	230V	16A	11kVA	218 min
AC	3	400V	32A	22kVA	109 min
DC	NA	400V	60A	24kW	99 min
DC	NA	400V	125A	50kW	48 min
DC	NA	400V	300A	120kW	20 min

As can be seen from the charging times, DC chargers charge EVs much faster. However, since DC chargers have high power capacity, they impose a significant load on DTs. In addition, since it is large, it can only be placed in suitable places. However, if there are suitable grid and DT infrastructures, DC fast chargers will make the charging network more efficient. At this point, AC and DC chargers should be used by diversifying. However, a certain number of DC fast chargers may need to be loaded into DTs to avoid congestion in charging traffic in each region. At the point of installing the chargers to the DTs, the number of 50kW DC chargers that can be installed has been tested by using the DT distribution data. 50kW DC chargers mid level DC charger and suitable for charger installation test to DTs. First, DTs that do not have a CIG value of 50kW are eliminated. 32% of DTs are not suitable for 50kW DC fast charger installation. In addition, there are 5725 DTs suitable for the installation of 50kW DC chargers. Only one DC charger can be installed into 1710 DTs. When viewed from all DTs, the number of DTs that can be loaded with 1, 2, and 3 DC chargers has a serious ratio of 59% among all DTs. The percentage of DT that can be installed with 20 or more DC chargers is only 1.89%. The distribution of DTs suitable for 50kW DC charger installation and the distribution of the number of DC chargers that can be installed on DTs are shown in Figure 40 and Table 9.

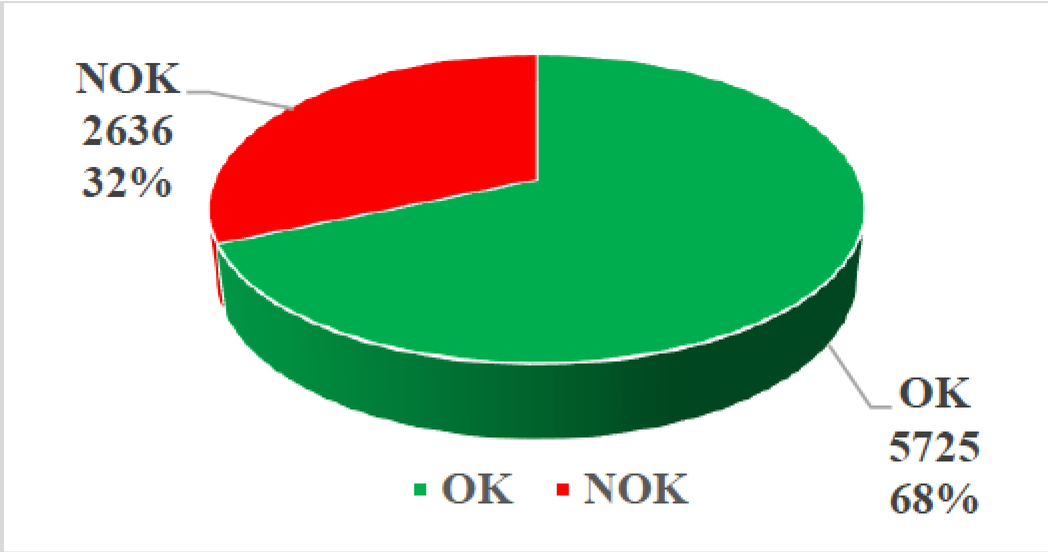

Figure 40: Suitability of 50kW DC Fast Charger Installation to DTs

Table 9: Installable 50kW DC Charger Distribution

$Number of Installable$ $50kW DC Charger$	$Number of DTs with$ $Appropriate CIG$	$Percetange of Number$ $of DT in Total$
1 Station	1710	29.87%
2 Station	1026	17.92%
3 Station	642	11.21%
4 Station	424	7.41%
5 Station	293	5.12%
6 Station	303	5.29%
7 Station	198	3.46%
8 Station	183	3.20%
9 Station	167	2.92%
10 Station	165	2.88%
11 Station	109	1.90%
12 Station	61	1.07%
13 Station	40	0.70%
14 Station	57	1.00%
15 Station	42	0.73%
16 Station	49	0.86%
17 Station	51	0.89%
18 Station	42	0.73%
19 Station	32	0.56%
20 Station	23	0.40%
20+ Station	108	1.89%

When the 50kW DC chargers that can be installed into all of 8361 DT are examined in terms of frequency, it is seen that the distribution is concentrated in the region of 1 station, 2 stations, and 3 stations, as indicated numerically. The frequency of installation at the high number of stations is at a low level. The frequency distribution is shown in Figure 41.

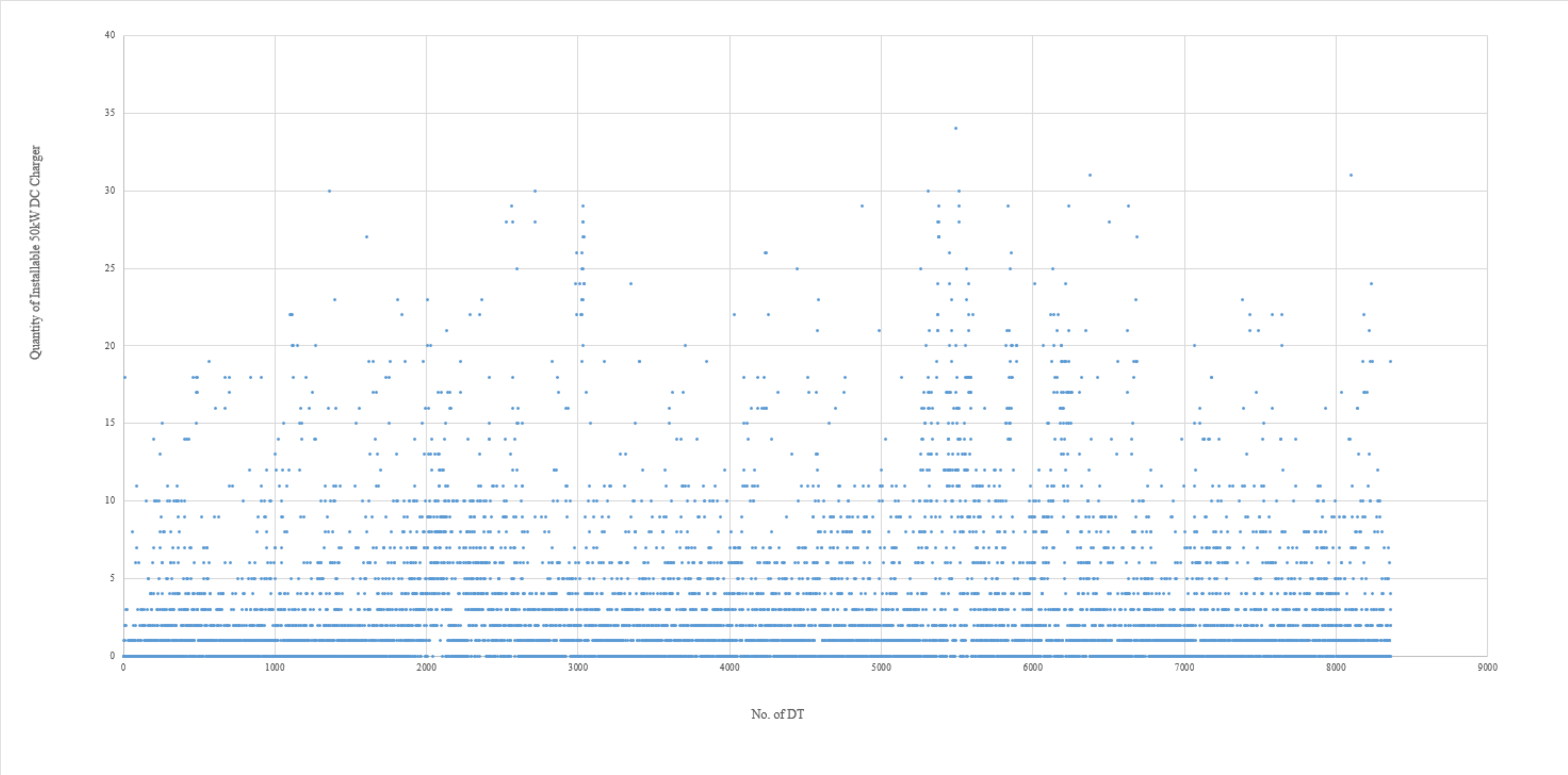

Figure 41: Frequency Distribution of Installable 50kW DC Charger

CHAPTER V

QUANTATIVE EV CHARGER DEPLOYMENT MODELLING TO DT NETWORKS

With the 50kW DC Charger load test, the state of the DT network was examined. This analysis is also meaningful for charging stations with less than 50kW power because CIGs can be installed more with low-power chargers. However, modeling is required in order to install charging stations to DTs in a variety and most optimized way. Starting from the peak demand on DTs, there are different levels of risk analysis around exceeding DT rated power for charging stations to be installed. At this point, it should be taken into account that the peak demand situation does not exist continuously on DT. Occupancy in DT will change over time and will not always be at peak demand occupancy as stated.

5.1 Quantitative Risk Models

For the installation of electric vehicle charging stations, the loading of existing transformers should be considered. Potential electric vehicle charging station capacities can be calculated at points where the installed power of the transformer is known, with the demand curve collected with the help of OSOS. In general, the peak demand point of the transformer should be considered in the charger planning. Because, at points where careful socket planning is not made, if electric vehicles are charged together with the current demand, serious problems may occur that may cause power cuts due to transformer overpower.

When considering the peak demand level, it should also be taken into account that the transformer does not always operate at that fullness. It has been observed that there can be a big difference between the peak demand and the average occupancy in the consumption curves of the transformers monitored by TRAFORM.

For this reason, a 3-level risk system has been created for the model to be applied. When the prior transformer data were analyzed for quantitative risk modeling, the risk levels were determined as follows.

- Power gap between 80% of the RP and peak demand
- Power gap between 80% of the RP and 80% of peak demand
- Power gap between 80% of the RP and 60% of peak demand

Taking 80% of the RPs (rated power) as the limit value allows the chargers to be installed on the DTs to apply the model without adversely affecting the DTs. In a sense, this is the acceptance of a DT occupancy rate of at least 80%. For this quantitative risk model, 3 different modules were created at 3 risk levels. The charging station capacities to be used in the modules are determined as follows.

- AC Stations/Sockets: 11kVA and 22kVA
- DC Stations/Sockets: 24kW and 50kW

Figure 42 shows an example transformer with an annual demand curve and this curve is used to visualize the modules.

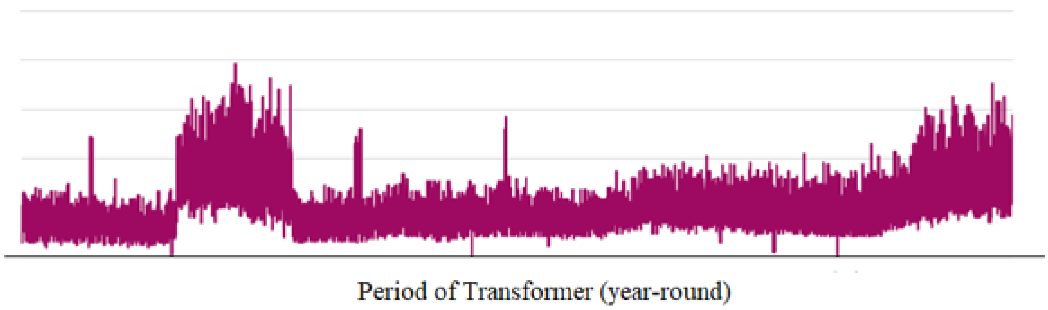

Figure 42: Sample Demand Curve of DTs

An important feature of charging stations is that they can have more than one output socket. In other words, a station can have multiple sockets and outputs of different capacities. It should be stated that the above power values are the power that can be taken from the sockets in the charging station. The power values can be specified after this point are considered as socket type and value.

5.1.1 Zero Risk Analysis Module

The zero risk analysis module is based on the peak demand points on DTs. In this module, the number of charging stations and sockets that can be installed is calculated by using the power rating between peak demand and the 80% occupancy rate of the transformers. Within the scope of the zero risk analysis module for a transformer, a total of 4 installation scenarios are created depending on the type of charging socket. With zero risk analysis, it is guaranteed that 80% of the transformer power is not exceeded in any period, even if electric vehicles are charged at the same time in all sockets according to the current load curve. The working principle of this analysis module is visualized in Figure 43. Installed socket numbers are sample numbers in Figure 43.

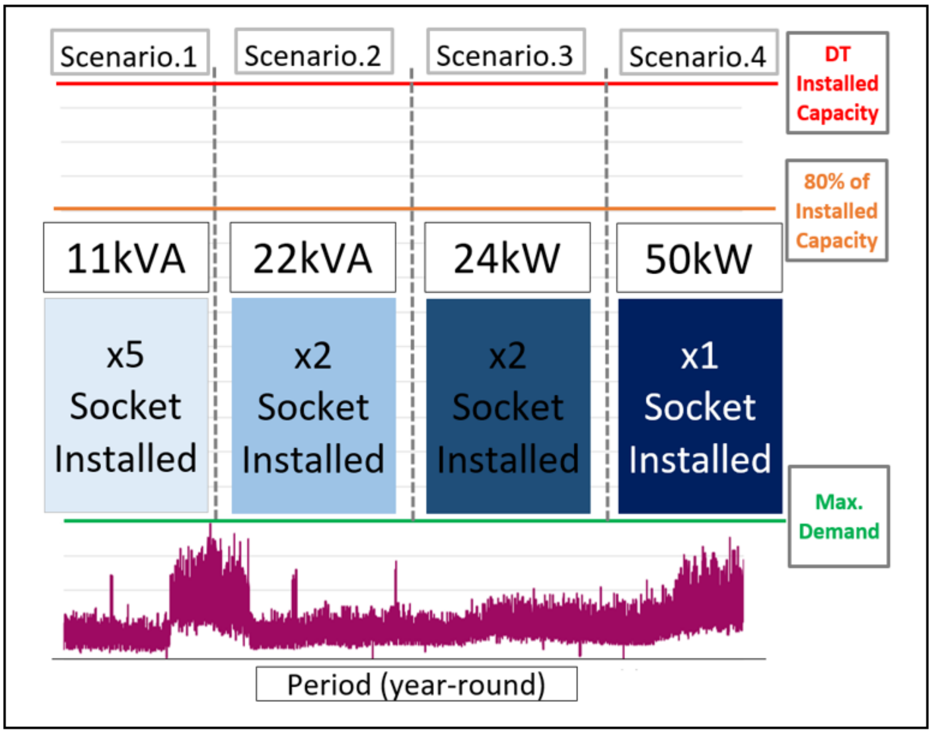

Figure 43: Zero-Risk Analysis Module Working Principle

5.1.2 First Level Risk Analysis Module

This module has been developed to slightly stretch the possibility of simultaneous peak demand and vehicle charging demand. The first level risk analysis module is based on 80% of the peak demand point. In this module, the number of charging sockets that can be installed is calculated by using the power rating between 80% of the peak demand and 80% of the transformer's occupancy point. Within the scope of the 1st Level risk analysis module for a transformer, a total of 4 installation scenarios are created depending on the type of charging socket. With the first level risk analysis, if electric vehicles are charged at the same time in all sockets according to the current load curve, it is guaranteed that 80% of the transformer power is not exceeded in any period. In addition, the probability of this situation is calculated by calculating the number of periods during which the transformer can be loaded at 80% and above in case of charging in all sockets. The working principle of first-level risk analysis module is visualized in Figure 44. Installed socket numbers are sample numbers in Figure 44.

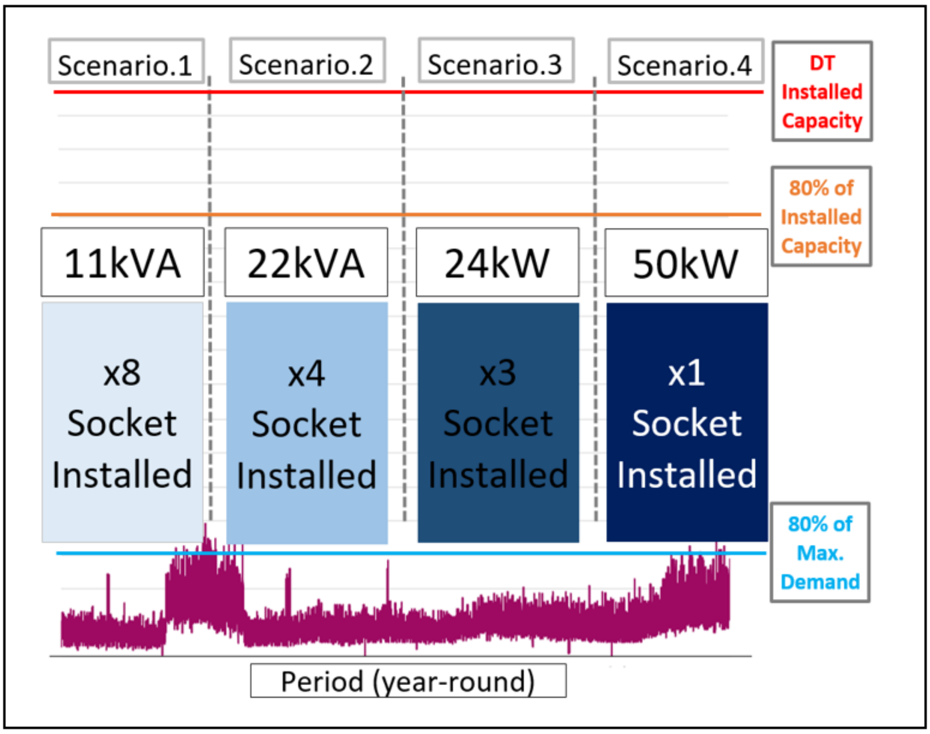

Figure 44: First-Level Risk Analysis Module Working Principle

5.1.3 Second Level Risk Analysis Module

This module has been developed to offer a more risky but viable analysis with less acceptance of the possibility of concurrency. The second level risk analysis module is based on 60% of the peak demand point. In this module, the number of charging sockets that can be installed is decided by using the power rating between 60% of peak demand and 80% of the transformer's occupancy point. Within the scope of the second-level risk analysis module for a transformer, a total of 4 installation scenarios are created depending on the type of charging socket. With the second level risk analysis, if electric vehicles are charged at the same time in all sockets according to the current load curve, it is guaranteed that 80% of the transformer power is not exceeded in any period. In addition, in the case of simultaneous charging in all sockets, the number of periods that can reach 80% and higher loading dimensions of the transformer is calculated, and the probability of this situation is calculated. The working principle of this analysis module is visualized in Figure 45. Installed socket numbers are sample numbers in Figure 45.

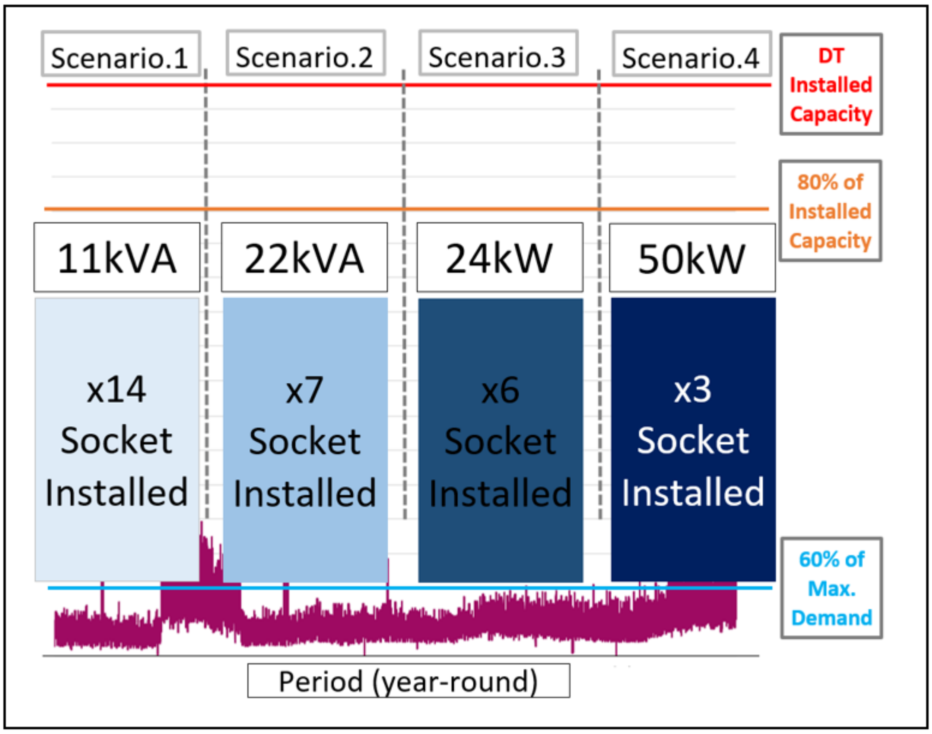

Figure 45: Second-Level Risk Analysis Module Working Principle

5.1.4 Tests of Modules

Considering the RP distributions of DTs in Table 6, 630kVA transformers will be used for sampling both in terms of average rated value and because of their share in the distribution of 11.31%.

Figure 46 shows the test of zero-risk modulation analysis with the sample taken from one of the city center which is among general DT data collecting from field and its transformer No.21 (630kVA) in DT data analysis. The values of that transformer are as follows. As can be seen in this example, when the zero-risk module is applied, only Scenario.1 is applicable and only one 11kVA socket can be installed into the system. For other scenarios no socket installation is possible. The values of that transformer are as follows.

- Occupancy Rate (OR): 77.97%
- Rated Power (RP): 630kVA
- Zero-Risk Module Power Gap: 12.79kVA

The test of first-level risk modulation analysis with the sample taken from sample city center No.21 transformer is shown in Figure 47. Here, Firs-Risk Module power gap is 110kVA. When this module is applied, 10 sockets of 11kVA EV chargers can be installed in Scenario.1. In addition, other scenarios that cannot be applied in the zero-risk module can also be applied. 5 sockets of 22kVA for Scenario.2, 4 sockets of 24kW for Scenario.3, and 2 sockets of 50kW for Scenario.4 can be installed.

- Occupancy Rate (OR): 77.97%
- Rated Power (RP): 630kVA
- First-Level Risk Module Power Gap: 110kVA

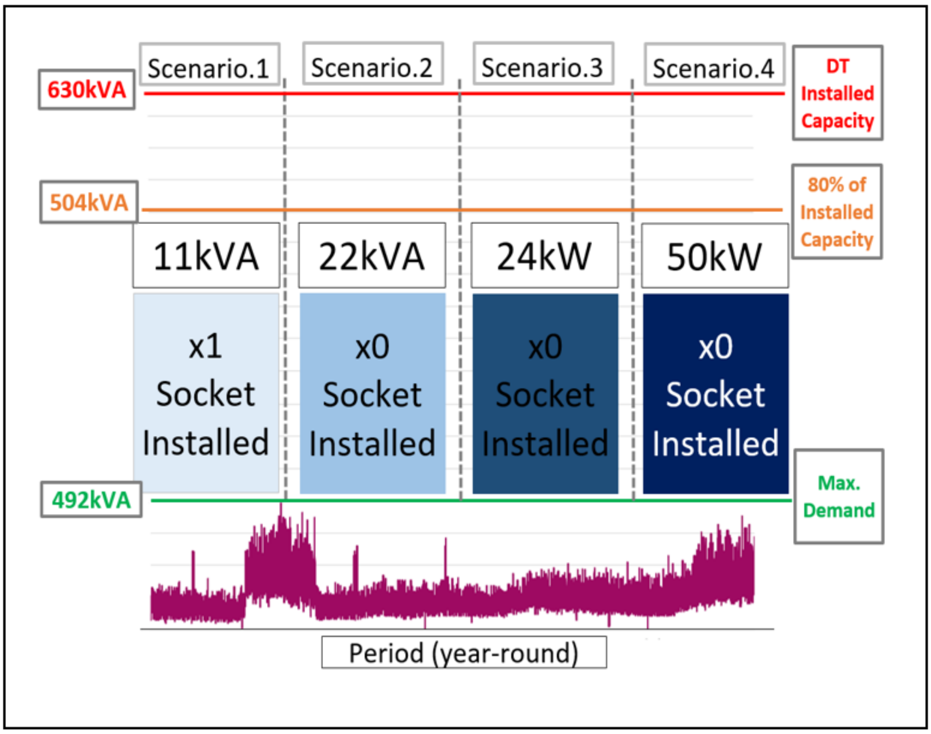

Figure 46: Zero-Risk Analysis Module Application to DT No.21 of Sample City Center

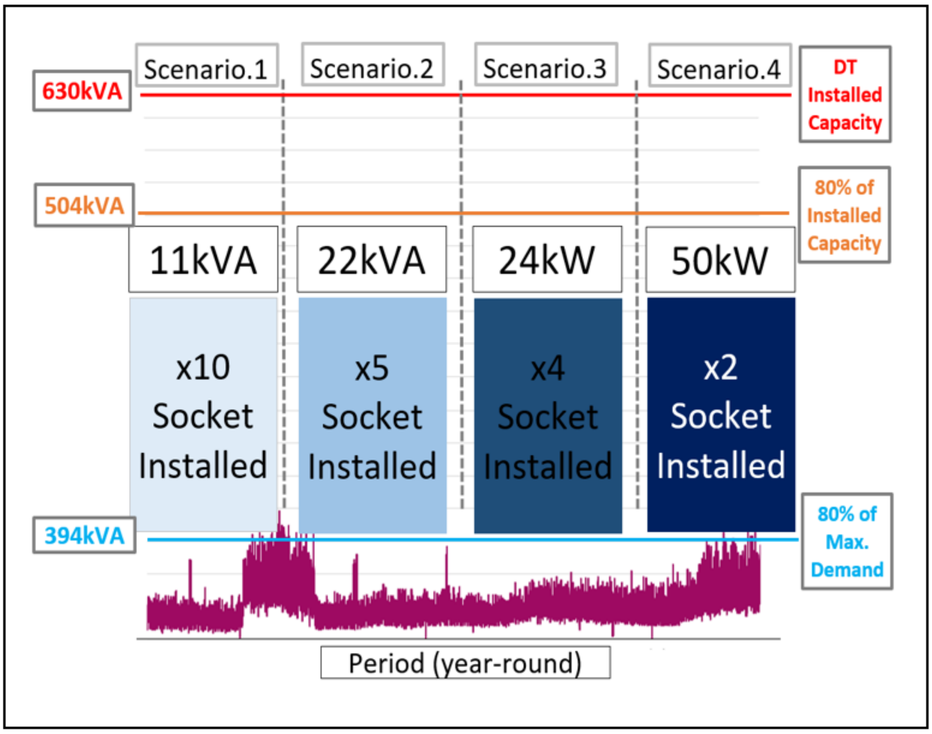

Figure 47: First-Level Risk Analysis Module Application to DT No.21 of Sample City Center

The test of second-level risk modulation analysis with the sample taken from sample city center No.21 transformer as like first-level risk module is shown in Figure 48. Here, Second-Risk Module power gap is 209kVA. When this module is applied, the number of installable sockets doubles in almost all scenarios. 19 sockets of 11kVA EV chargers can be installed in Scenario.1. 9 sockets of 22kVA for Scenario.2, 8 sockets of 24kW for Scenario.3, and 4 sockets of 50kW for Scenario.4 can be installed.

- Occupancy Rate (OR): 77.97%
- Rated Power (RP): 630kVA
- Second-Level Risk Module Power Gap: 209kVA

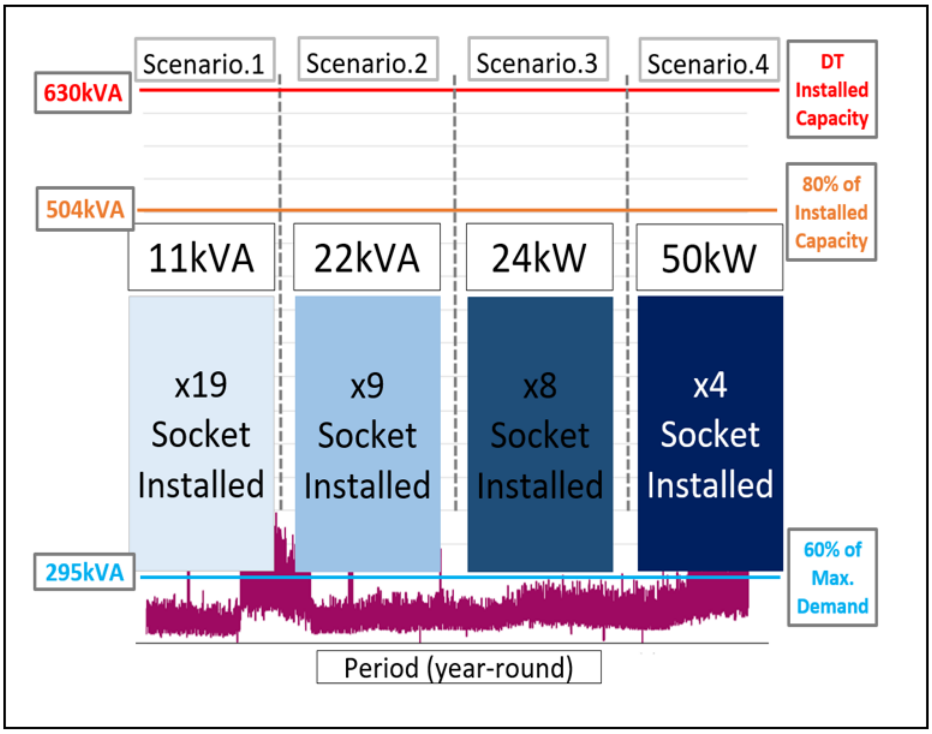

Figure 48: Second-Level Risk Analysis Module Application to DT No.21 of Sample City Center

5.2 *Deployment Mechanism*

The deployment mechanism is the quantitative decision mechanism that determines the capacity of the EVSE products to be installed on the DT network and how many of them will be installed. While basic deployment makes a more basic and direct decision, advanced deployment decides with a more optimized and more efficient but more detailed algorithm in terms of product variety.

5.2.1 Basic Deployment Mechanism and Testing

Basic Deployment is the mechanism that works with the implementation of one of the 4 scenarios directly selected by the risk modules without an additional algorithm. It is the loading of charging stations into the power gap according to the scenario to be selected, together with the selection of one of the risk modules according to the frequency and weighted probability of DT reaching peak demand. For example, when scenario 1 is selected (11kVA charging stations), the zero-risk module is selected according to the frequency of reaching peak demand, and the power gap between 80% of the RP and peak demand is divided by 11kVA. The result is the number of installable stations to be reached. Table 10, Table 11 and Figure 49 shows an application of Basic Deployment over all of the 630kVA DTs which are located in Sample City Center. In Table 10 SC is the scenario, ZRG is zero-risk gap, 1stLRG is the first-level risk gap and 2ndLRG is the second-level risk gap. Also SC1 is the 11kVA, SC2 is the 22kVA, SC3 is the 24kW, SC4 is the 50kW.

Table 10: Basic Deployment for 630kVA DTs According to Scenario 1-2 and Risk Modules

$SC1$ to ZRG	$SC1$ to $1stLRG$	$SC1$ to $2ndLRG$	$SC2$ to ZRG	$SC2$ to $1stLRG$	$SC2$ to $2ndLRG$
584	696	804	285	343	394

Table 11: Basic Deployment for 630kVA DTs According to Scenario 3-4 and Risk Modules

$SC3$ to ZRG	$SC3$ to $1stLRG$	$SC3$ to $2ndLRG$	$SC4$ to ZRG	$SC4$ to $1stLRG$	$SC4$ to $2ndLRG$
262	311	363	118	144	165

With the implementation of risk modules, an increase between modules has also been observed. The percentage increases in the number of charging stations in transitions from the zero-risk module to the first-level risk module and from the first-level risk module to the second-level risk module are as follows.

- SC1 - 50kW: 22.03% increase in conversion from ZR to 1stLR. 16.67% increase in conversion from 1stLR to 2ndLR
- SC2 - 24kW: 18.70% increase in conversion from ZR to 1stLR. 18.65% increase in conversion from 1stLR to 2ndLR
- SC3 - 22kVA: 20.35% increase in transition from ZR to 1stLR. 16.62% increase in transition from 1stLR to 2ndLR
- SC4 - 11kVA: 19.18% increase in transition from ZR to 1stLR. 17.53% increase in transition from 1stLR to 2ndLR

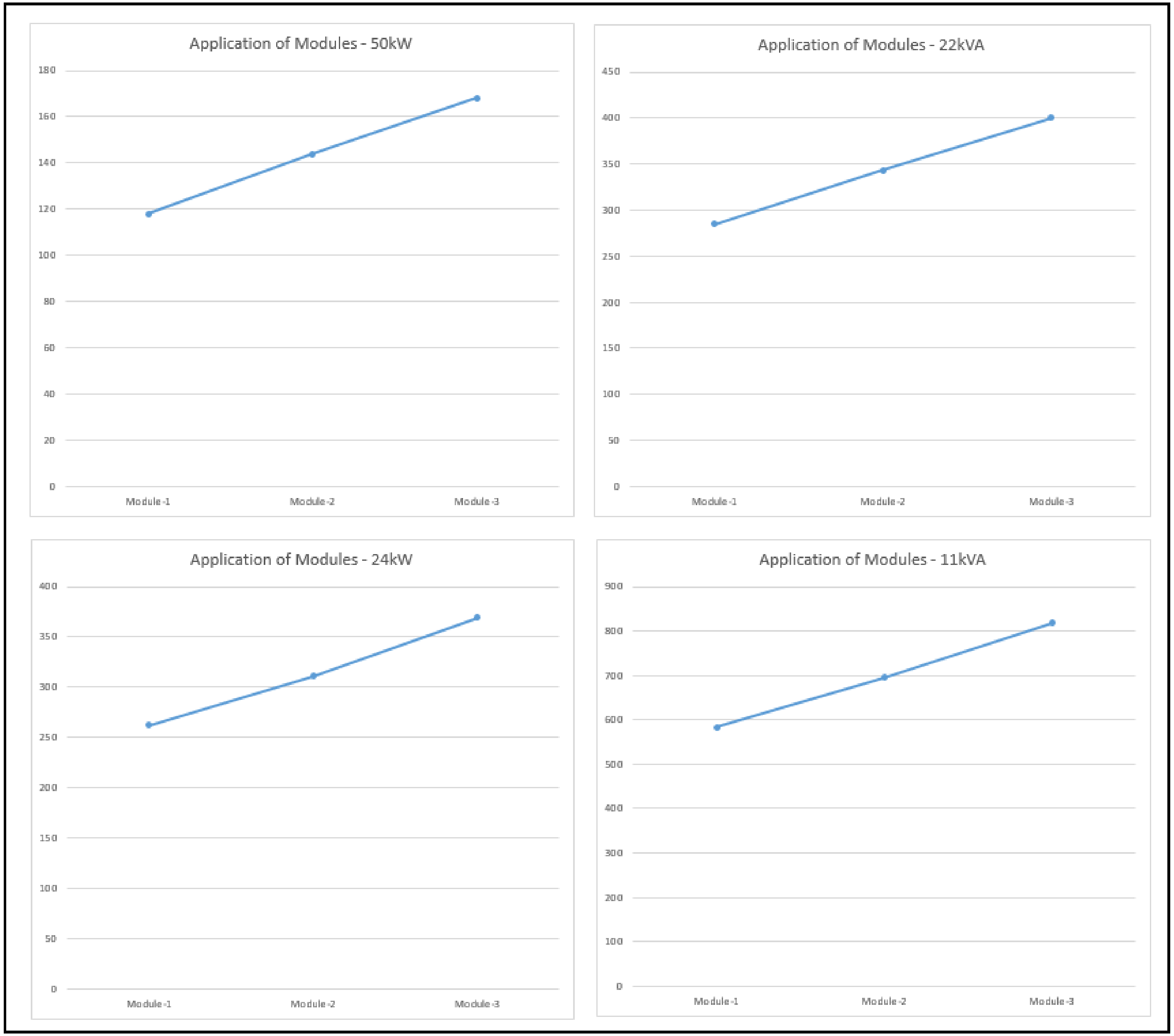

Figure 49: Application of Basic Deployment Graphs

Quantitative risk modeling for installing EV charging stations to DTs with risk modules has been applied to 630kVA transformers in the Sample City Center. These applications show the number of sockets that can be installed at all risk levels according to the occupancy rate and maximum demand. All scenarios involving each module were applied to all DTs studied. Of the 27 DTs in total, there are 2 DTs (DT No.23 and DT No.25) with an OR value of more than 100%. Since these DTs are above the rated power, the modules are already inapplicable. As can be seen in Figure 50, the bottoms on the graph are visible in DT.23 and DT.25, and the number of sockets that can be installed here is zero. In addition to this situation, the OR values of the other 25 DTs in the sample set are below 80%. In addition, with the application of modules and scenarios, if there is no suitable gap in the DT, the number of sockets that can be installed is zero.

Considering the general outputs of the modules and the scenarios belonging to the modules, a total of 1249 sockets from all socket types can be installed into DTs in the zero-risk module. In the first-level risk module, a total of 1494 sockets in all socket types can be installed onto DTs. When the second-level risk module is applied, 1726 sockets can be installed on all transformers, covering all socket types. Although not all scenarios can be implemented at the same time (which means that the socket type decreases to one and the total number decreases), the number of chargers that can be installed increases as the risk level of the modules increases. When the first-level risk module is applied, 19.6% more sockets can be installed into the grid compared to the zero risk module. When the second-level risk module is applied, 15.5% more sockets can be installed into the grid compared to the first-level risk module. The increase in the number of sockets that can be installed according to the modules can be seen in Figure 51. ZRG is the Zero-Risk Gap, 1stLRG is the First-Level Risk Gap and 2ndLRG is the Second-Level Risk Gap.

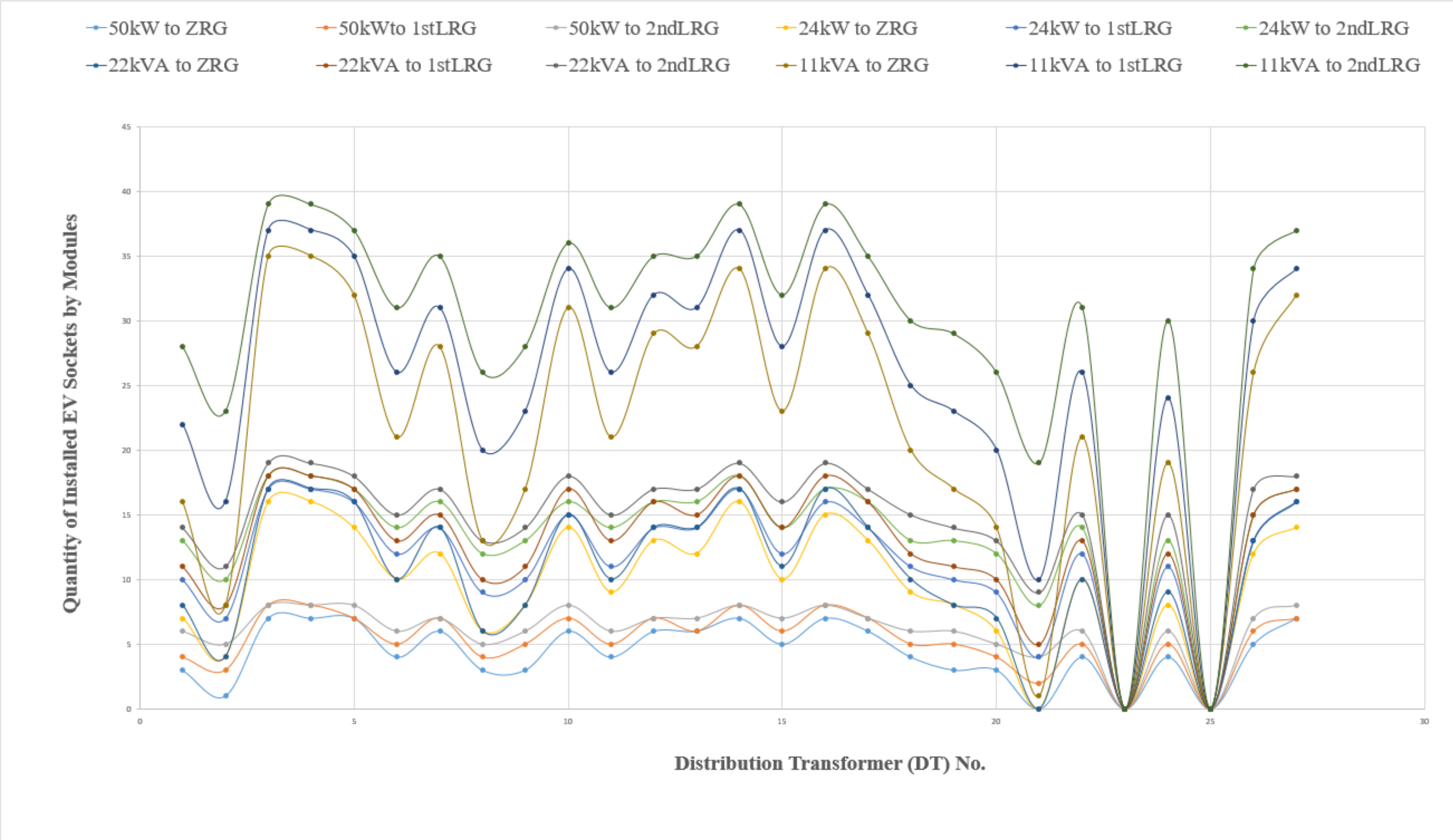

Figure 50: Application of Modules and Details of Sample City Center 630kVA DTs

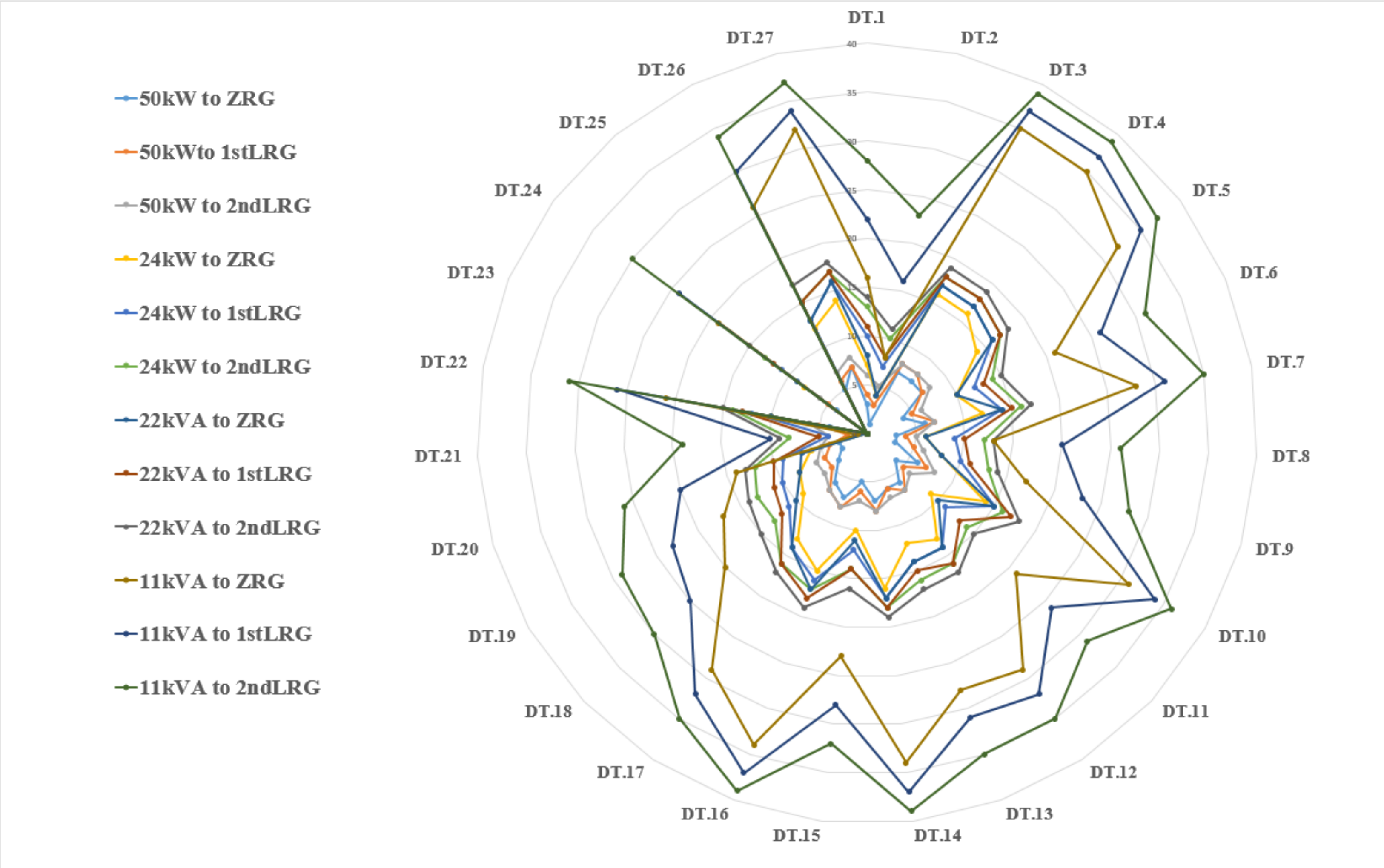

Figure 51: Variations According to Applications of Modules and Sockets

5.2.2 Advanced Deployment and Testing

Advance deployment was developed to create a more optimized, product-diversified system of quantitative EVSE deployment. There are two main decision mechanisms in this algorithm. The first is the RP value of the target DT and the second is the OR value. The rated power values of the transformers whose data we know are given in Table 6. According to the RP values in Table 6, 3 groups were formed. These groups are named DTRPGR-1, DTRPGR-2, and DTRPGR-3. 50, 100, 160, and 250 kVA transformers are in the first group, 400, 630, 800, and 100 kVA transformers are in the second group, and 1250, 1600, and 2000 kVA transformers are in the third group. These three groups are paired with each risk module and when any transformer is selected from these groups, the paired risk module will be used. Zero-risk module with the first group, first-level risk module with the second group, and second-level risk module with the third group. On the basis of these pairings, the low-rating first group is more fragile in case of a possible overload. The second group was determined as medium fragile, and the third group was determined as the least fragile group.

The second main decision mechanism is a structure that is decided according to the OR value. Two groups have been created here. These two groups, which are described as deployment groups, are DEPGR-1 and DEPGR-2. In the first group, there are 50kW DC chargers and 22kVA AC chargers, in the second group there is a 24kW DC charger and an 11kVA AC charger. The groups are divided into low and high segments and diversified as AC/DC. From this point of view, DEPGR-2s will be loaded on DTs with OR values between 80%-40%. This is because it is closer to the limit value of the RP, which is the 80% protection limit. DEPGR-1, on the other hand, is applied to DTs with an OR of 40%-0%. There are two advantages here; the first is to raise the low OR and inefficient DTs in a way that will make them efficient, and the second is to be able to upload high-capacity EVSEs to the DT network.

After these two main decision mechanisms, EVSEs will be installed on DTs starting from the high capacity EVSE of the selected DEPGR. After the high-capacity ones are installed, low-capacity ones will be loaded into the remaining spaces. The flow chart of the Advance deployment algorithm is shown in Figure 52.

A comparative test was conducted with basic deployment (BDM) to see the effectiveness of the advanced deployment mechanism (ADM). Tests were carried out with No. 27 and 630kVA DT in the pilot area. The specific features of DT are as follows.

- Rated Power (RP): 630kVA
- Occupancy Rate (OR): 23.75%
- Peak Demand (PD): 149.6kVA
- RP-PD: 480.4kVA
- Zero-Risk Gap (ZRG): 354.4kVA
- First-Level Risk Gap (1stLRG): 384.3kVA
- Second-Level Risk Gap (2ndLRG): 414.4kVA

According to the working principle of the ADM decision mechanism, the first step is to choose DTRPGR-2 according to DT rated power (630kVA). The model to be applied according to this choice is the First-Level Risk Gap (1stLRG). In the second selection stage, it chooses DEPGR-1 according to OR (40%-0%). After these selections, the total EV charger socket installation result decided by ADM is 7 x 50kW DC fast charger and 1 x 22kVA AC charger. According to UN's decision mechanism, 1stLRG, and according to scenario 4, EV charger socket loading result is 7 pieces of 50kW DC fast charger. According to these results, one 22kVA AC charger socket was loaded more with ADM.

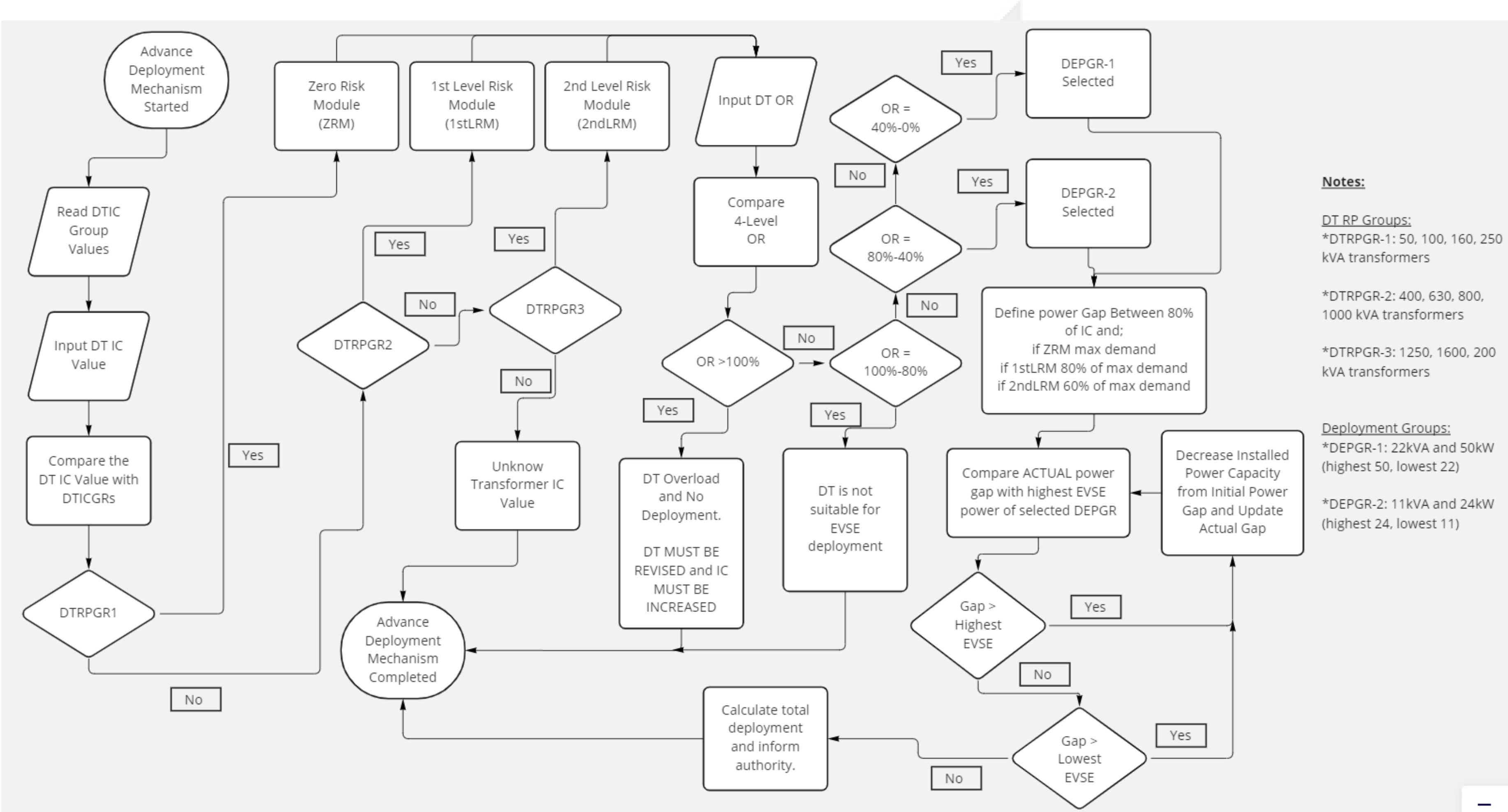

Figure 52: Advanced Deployment Mechanism Working Principle

5.3 *Extended DM with ABC*

In this section, a secondary system and algorithm are presented in order to get higher efficiency from deployment mechanisms (DMs). The system is called Extended Deployment Mechanism with Auxiliary Battery Charging. This system and algorithm will expand the effective quantitative organization as it is installed in the DT network of charging stations. The most important feature of this system and algorithm is that while theoretically only 1 station is loaded into the DT network, this station offers more than 1 station charging option at the same time without adding extra load to the DT. The working principle of the system is explained item by item below.

- It is an auxiliary system for conventional DC fast-charging stations.
- This system is first integrated into the DC station and a complete system is created.
- The system includes two or more additional battery systems.
- This additional battery system is charged by the algorithm determined by the DC charging station at idle times when there is no vehicle charge.
- The working principle of the algorithm is as follows; according to the 4-level local charging traffic congestion data received from the central system, the batteries are charged with 4-level charging power. The purpose of using 4 different charging power levels is not to impose an additional load on the DT network.

The flow diagram of the working principle of the system is shown in Figure 53.

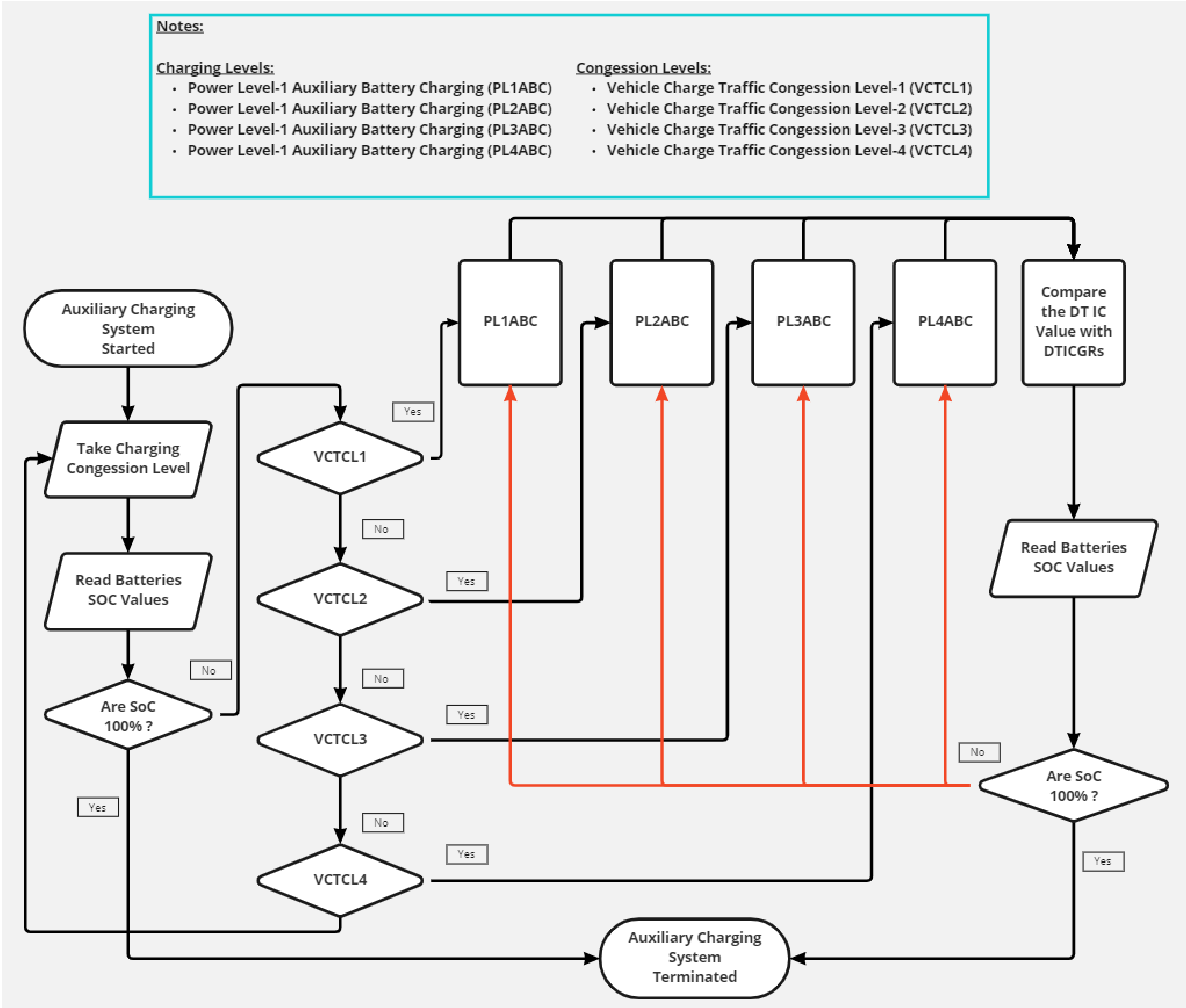

Figure 53: EDMwABC Working Principles

To talk about the advantages of the system, first of all, the advantage of the battery recycling system can be used. In these auxiliary systems, batteries that have been used in EVs and have lost a certain amount of power, but are suitable for use in secondary systems can be used. The most important advantage is; that while normally a single vehicle can be charged with a single station at a time of heavy charging traffic, for example, 3 vehicles can be charged with the main station with two auxiliary battery systems. Additional batteries will not be charged when vehicles arrive at the charging station and are to be charged, but when the station is empty before. In this case, since 3 vehicles will be charged at the same time, normally a charge of 3 vehicles will be loaded on the DT. However, with this presented system, a load of 1 vehicle will be loaded to the DT instead of 3 vehicles. The most important advantage of this situation is that instead of simultaneous charging, it actually offers a charging topology divided into time slots.

By using this offered system together with risk modules and deployment mechanisms, the following situations are provided.

- The healthy operation of the DT network despite the EV charging station installations around the risk modules or general increased EV charging demands.

- DTs remain robust against the installation of multiple EV charging stations (high demand increasing), in their current form or with minor improvements, with extended charging capability.

CHAPTER VI

INSIGHTS AND DISCUSSIONS

Apart from the 630kVA application, the results of the transformers with lower RP, that is, the transformers with lower than 630kVA, according to the application of the modules were examined. The total number of transformers is 282 and transformers of 50,100,160,250 and 400kVA are available. When we look at the reactions of the transformers with lower power after the modules are applied, 4319 chargers can be loaded in the zero-risk module, 5320 chargers in the first-level risk module, and 6303 chargers in the first-level risk module. A remarkable point here is that while the percentage of transformers that are not suitable for loading 50kW fast DC chargers in the zero-risk module in 630kVA transformers is 2.54%, this rate is 35.75% in transformers with a rated power less than 630kVA. This situation increases the number of regions where fast chargers cannot be applied.

Another point of analysis was made to maximize the number of vehicles that can be charged simultaneously. In this analysis, the second-level risk module, which reaches the highest number of vehicle charges, was used. According to the data in Table 8, the 11kVA charging socket has a charging time of 218 min, and the 50kW charging socket has a charging time of 48 min. In other words, the 50kW charging socket is 4.54 times faster. From this point of view, the correlation between the 50kW charger and the 11kVA charger was established by using the rate of charging time (ROCT) value. With this value, a certain number of 11kVA chargers are reduced to 50kW chargers number, but at the same time, the time is equalized with 50kW chargers. In short, with the correlation of charging time and socket number, 11kVA AC charger and 50kW DC charger were brought to the same domain for comparison. As a result of this comparison, it is 20.3% more advantageous to use 11kVA AC sockets instead of 50kW DC sockets for DTs with lower RPs than 630kVA DTs. This means that 20.3% more vehicles can be charged in a specified time. On the other hand, it is 7.2% more advantageous to use 11kVA AC sockets instead of 50kW DC sockets in 630kVA DTs. This means that 7.2% more vehicles can be charged in a specified time. However, the most important conclusion that can be drawn from this is that the use of 50kW DC sockets becomes more advantageous as the RP values of DTs increase (advantage significantly decreasing from 20.3% to 7.2%). This is important data for optimum use of modules and socket types in a certain order. The details of that analysis can be seen in Figures of 54 and 55.

Socket Type	Charging Time (min)	Rate of Charging Time (ROCT) Between 11kVA and 50kW	Socket Quantity of <630kVA DTs	Socket Quantities After ROCT Applied	Advantages of 11kVA Charger Installation over 50kW DC Socket Quantities
AC 11kVA	218	4.54	3013	663	20.3%
DC 50kW	48		551	551	
			Difference:	112	

Figure 54: ROCT Analysis of Less Than 630kVA DTs

Socket Type	Charging Time (min)	Rate of Charging Time (ROCT) Between 11kVA and 50kW	Socket Quantity of 630kVA DTs	Socket Quantities After ROCT Applied	Advantages of 11kVA Charger Installation over 50kW DC Socket Quantities
AC 11kVA	218	4.54	804	177	7.2%
DC 50KW	48		165	165	
			Difference:	12	

Figure 55: ROCT Analysis of 630kVA DTs

It is very important for the electricity grid that the occupancy rates of DTs carry out EV charging operations at the level of risk-free or acceptable risks. In general, the installation of high-capacity DC fast chargers in most of the distribution transformers of the Central Anatolia Region analyzed is far from the point that will support the levels that may be needed. The need for fast chargers is important for public uses and for reducing charging congestion. In addition, the low capacities of AC chargers seem to be relatively loadable to DTs, but even when an 11kVA charger is loaded onto a 50kVA transformer, 22% of the DT is filled. Moreover, in the region where only one 11kVA AC charger is installed, the vehicle circulation that can be charged will remain at very low levels. As mentioned, investments must be made in an optimized manner by EV transformation.

Up to this part of this section, analysis according to basic deployment is mentioned. In addition to this, an analysis to be made on ADM and BDM should also be mentioned. According to the result of test comparisons of the two mechanisms, ADM is basically 14.2 percent higher than BDM in quantitative terms. Considering the transformers in the entire Central Anatolia Region (8361 transformers), a significant difference can emerge. For example, assuming that 1 EV charger socket is loaded more on each transformer, a total of 1187 EV chargers can be connected to the DT network more. With 100% performance of this ADM, under ideal conditions and somewhat unrealistic, it would be considered a situation. But even if we think that it works with 50% performance (which is more logical), an average of 600 EV charger sockets can be loaded into the DT network. This is a situation that is currently 12 times more than the number of chargers in the Central Anatolian Region. Of course, having many charging stations to be loaded with this modeling is very important for future EV transformation. However, the first thing to focus on is that the electrical network infrastructure and DT network can handle these deployments.

It is especially important to control home charge equipment or private chargers. Because public chargers are already registered on smart systems, the load they will bring to the grid can be estimated. In other words, before the public charging stations are installed in the system, registration can be applied for the grid side, so that if the rated power of the DTs in the region is not suitable according to the risk modules, the installation can be canceled or revised beforehand. But as stated, home / private chargers are private and not subject to registration. At this point, it may be important to follow the basic home chargers. In fact, home chargers with low power capacity may not seem like a problem, but considering their cumulative situation, they can cause problems on the network.

One of the main benefits of the developed modeling, especially the advanced deployment model, is to increase the operating efficiency by installing charging stations on DTs that have low efficiency due to low load/demand levels. However, an advantage can be provided for the stabilization of the distribution frequency as well.

Another important point is to maintain the balance of the chargers installed in the three-phase system between the phases. Although the DT rated power is not exceeded, phase imbalance can damage the grid. The balance in the three-phase system should be maintained with an algorithm that assists the risk modules. Risk modules can work very effectively when supported by different approaches. They will be able to reach a more effective level with a detailed analysis of user profiles. Here, the effect of the classification of users and their habits on the distribution of the peak demand level within the periods should be analyzed in quite detail. Modules, which can be supported by pricing and smart charging algorithms, can channel charge intensity periods by the structure of the electricity grid. Here, applications such as taxation and low-priced hours, and automated systems are important. In addition, these approaches should be considered not only for passenger cars but also for general, such as light-duty vehicles, mid and heavy-duty vehicles, and buses with the developing EV transformation. This requires developing the entire regional EV charging infrastructure, whether urban or rural.

CHAPTER VII

CONCLUSION

This study aims to load the maximum number of chargers that can be installed, while minimizing the possible risks to the electrical grid, namely distribution transformers, of EV chargers. At the same time, together with the analysis made on DTs, it shows to what extent the grid is ready for this transformation compared to the increasing number of EVs in general. Although the regional distribution of transformers varies in rural and urban centers, the general distribution in the Central Anatolia Region is concentrated in rated powers of 100kVA, 160kVA, and 250kVA. Loading 50kW DC fast chargers or higher capacity chargers at these levels will install most of the transformer ratings. When the OR level rises, the RP values will be exceeded, which will cause the transformers to overload and the electrical service to be interrupted. In order to prevent this situation, regional transformer analysis can be done with EV charger quantitative risk modules, both the maximum demand levels can be checked, the number of chargers that can be installed without problems can be maximized, and the problems that may arise from the EV charging sequences of the transformers can be avoided. More optimized and more automated solutions focused on EV charging will be able to be used in electricity distribution, thanks to the in-depth and rich datasets, future studies, and the advantages offered by the risk modules.

REFERENCES

[1] M. Bellis, "The history of electric vehicles began in 1830." https://www.thoughtco.com/history-of-electric-vehicles-1991603, Thoughtco.com. (accessed Feb. 18, 2022).

[2] K. A. Wilson, "Worth the watt: A brief history of the electric car, 1830 to present." https://www.caranddriver.com/features/g15378765/worth-the-watt-a-brief-history-of-the-electric-car-1830-to-present/, Caranddriver.com. (accessed Feb. 18, 2022).

[3] T. Longden, "William Morrison / Inventor 1850-1927." https://www.newspapers.com/clip/42923029/the-des-moines-register/, The Des Moines Register. (accessed Feb. 18, 2022).

[4] G. Mom, *The Electric Vehicle: Technology and Expectations in the Automobile Age*. Charles Village, Baltimore: Johns Hopkins University Press, 2 ed., 2004.

[5] Wikipedia, "Tesla Roadster (first generation)." https://en.wikipedia.org/wiki/Tesla_Roadster_(first_generation), Wikipedia.org. (accessed Feb. 19, 2022).

[6] R. Matulka, "The History of the Electric Car." https://www.energy.gov/articles/history-electric-car, Energy.gov. (accessed Feb. 19, 2022).

[7] IEA, "Evolution of Li-ion battery price, 1995-2019." https://www.iea.org/data-and-statistics/charts/evolution-of-li-ion-battery-price-1995-2019, iea.org. (accessed Feb. 21, 2022).

[8] "Regulation of the European Parliment and of the Council amending Regulation (EU) 2019/631 as regards strengthening the CO2 emission performance standards for new passenger cars and new light commercial vehicles in line with the Union's increased climate ambition," standard, European Commission, Brussels, Belgium, July 2021.

[9] A. Vaughan, "Electric and plug-in hybrid cars whiz past 3m mark worldwide." https://www.theguardian.com/environment/2017/dec/25/electric-and-plug-in-hybrid-cars-3m-worldwide, theguardian.com. (accessed Feb. 21, 2022).

[10] IEA, "Global EV Outlook 2020," tech. rep., International Energy Agency, June 2020.

[11] R. Irle, "Global Plug-in Vehicle Sales Reached over 3,2 Million in 2020." https://www.ev-volumes.com/news/86364/, EV-volumes.com. (accessed Feb. 22, 2022).

[12] IEA, "Global EV Outlook 2021," tech. rep., International Energy Agency, April 2021.

[13] M. Kolaczkowski, "How does the war in Ukraine affect oil prices?." https://www.weforum.org/agenda/2022/03/how-does-the-war-in-ukraine-affect-oil-prices/, Weforum.org. (accessed Feb. 25, 2022).

[14] R. L. G. V. V. E. Nathaniel S. Pearre, Willett Kempton, "Electric vehicles: How much range is required for a day's driving?," *Transportation Research Part C: Emerging Technologies*, vol. 19, no. 6, pp. 1171–1184, 2011.

[15] ICCT, "Five Things You Know About Electric Vehicles That Aren't Exactly True." https://theicct.org/stack/explaining-evs/, theicct.org. (accessed Feb. 25, 2022).

[16] H. L. Marc A. Melliger, Oscar P.R. van Vliet, "Anxiety vs reality – sufficiency of battery electric vehicle range in switzerland and finland," *Transportation Research Part D: Transport and Environment*, vol. 65, pp. 101–115, 2018.

[17] S. Loveday, "11 Reasons People Don't Buy Electric Cars (and Why They're Wrong)." https://cars.usnews.com/cars-trucks/why-people-dont-buy-electric-cars, USNews.com. (accessed Feb. 28, 2022).

[18] J. Toth, "For Widespread Adoption of Electric Vehicles, Many Roadblocks Ahead." https://morningconsult.com/2019/05/22/for-widespread-adoption-of-electric-vehicles-many-roadblocks-ahead/, Morningconsult.com. (accessed March 1, 2022).

[19] C. Harto, "Electric Vehicle Ownership Costs: Today's Electric Vehicles Offer Big Savings for Consumers," tech. rep., Consumer Reports, October 2020.

[20] H. C. Righolt and F. G. Rieck, "Energy chain and efficiency in urban traffic for ice and ev," in *2013 World Electric Vehicle Symposium and Exhibition (EVS27)*, pp. 1–7, 2013.

[21] B. K. Sovacool, "Rejecting renewables: The socio-technical impediments to renewable electricity in the United States," *Energy Policy*, vol. 37, no. 11, pp. 4500–4513, 2009.

[22] B. Demandt, "Turkey Car Sales Data." https://carsalesbase.com/turkey-car-sales-data/, Carsalesbase.com. (accessed March 2, 2022).

[23] ResearchAndMarkets.co, "Global & APAC $1,725 Bn Electric Vehicle Market Analysis & Forecasts, 2017-2021 & 2022-2027." https://www.businesswire.com/news/home/20220426005659/en/Global-APAC-1725-Bn-Electric-Vehicle-Market-Analysis-Forecasts-2017-2021-2022-2027, Businesswire.com. (accessed April 26, 2022).

[24] IEA, "Electric cars fend off supply challenges to more than double global sales." https://www.iea.org/commentaries/electric-cars-fend-off-supply-challenges-to-more-than-double-global-sales, iea.org. (accessed March 9, 2022).

[25] K. Karamanoglu, "Electric Vehicle Sales Review Full Year 2021." https://www.strategyand.pwc.com/tr/en/medya/2021-yili-elektrikli-arac-satislari-incelemesi.html, Strategyand.pwc.com. (accessed March 12, 2022).

[26] L. Gear, "EV Power Electronics: Driving Semiconductor Demand in a Chip Shortage." https://www.idtechex.com/en/research-article/ev-power-electronics-driving-semiconductor-demand-in-a-chip-shortage/24820, Idtechex.com. (accessed March 13, 2022).

[27] "Communication From the Commission to the European Parliment, the Council, the European Economic and Social Committee and the Committee of the Regions Stepping up Europe's 2030 climate ambition," standard, European Commission, Brussels, Belgium, Sept. 2020.

[28] Enel, "Electricity's strategic role in leading Europe's decarbonization." https://www.enel.com/company/our-commitment/electricity-role-europe-decarbonization/electrification, Enel.com. (accessed March 14, 2022).

[29] E. Gibney, "Nuclear-fusion reactor smashes energy record." https://www.nature.com/articles/d41586-022-00391-1, Nature.com. (accessed Feb. 16, 2022).

[30] J. Morris, "Electricity Grids Can Handle Electric Vehicles Easily – They Just Need Proper Management." https://www.forbes.com/sites/jamesmorris/2021/11/13/electricity-grids-can-handle-electric-vehicles-easily–they-just-need-proper-management/?sh=760e6de97862, Forbes.com. (accessed March 15, 2022).

[31] A. Z. P. Z. P. D. C. T. Dimitrios Gkatzoflias, Yannis Drossinos, "Optimal allocation of electric vehicle charging infrastructure in cities and regions," tech. rep., European Commission JRC, October 2016.

[32] J. McBride, "No charging spots and a strained electrical grid. Welcome to the electric vehicle boom.." https://www.macleans.ca/society/technology/no-charging-spots-and-a-strained-electrical-grid-welcome-to-the-electric-vehicle-boom/, Macleans.ca. (accessed March 24, 2022).

[33] J. M. Tony Flick, *Securing the Smart Grid.* Boston: Syngress, 2011.

[34] J. F. M. Adriana Mar, Pedro Pereira, "A survey on power grid faults and their origins: A contribution to improving power grid resilience," *Energies*, vol. 12, no. 24, p. 4667, 2019.

[35] G. Omazaki, "Types of Electric Cars and Working Principles." https://www.omazaki.co.id/en/types-of-electric-cars-and-working-principles/, Omazaki.co.id. (accessed March 18, 2022).

[36] A. T. Kamil Çağatay Bayindir, Mehmet Ali Gözüküçük, "A comprehensive overview of hybrid electric vehicle: Powertrain configurations, powertrain control techniques and electronic control units," *Energy Conversion and Management*, vol. 52, no. 2, pp. 1305–1313, 2011.

[37] L. M.-P. M. N. M. E. H. Fuad Un-Noor, Sanjeevikumar Padmanaban, "A comprehensive study of key electric vehicle (EV) components, technologies, challenges, impacts, and future direction of development," *Energies*, vol. 10, no. 8, 2017.

[38] A. Emadi, *Advanced Electric Drive Vehicles.* Boca Raton: CRC Press, 2015.

[39] M. N. Hashemnia and B. Asaei, "Comparative study of using different electric motors in the electric vehicles," pp. 1 – 5, 10 2008.

[40] R. L. Frank Markus, "Electric Cars 101: How EV Motors Work, Tech Differences, and More." https://www.motortrend.com/features/how-electric-cars-work-ev-differences-definitions/, Motortrend.com. (accessed March 21, 2022).

[41] J. Frith, "Battery Price Declines Slow Down in Latest Pricing Survey," tech. rep., Bloomberg Hypedrive, November 2021.

[42] EV-database, "Useable battery capacity of full electric vehicles." https://ev-database.org/cheatsheet/useable-battery-capacity-electric-car, EV-database.org. (accessed April 3, 2022).

[43] EV-database, "Range of full electric vehicles." https://ev-database.org/cheatsheet/range-electric-car, EV-database.org. (accessed April 3, 2022).

[44] C. Argue, "What can 6,000 electric vehicles tell us about EV battery health?." https://www.geotab.com/blog/ev-battery-health/, Geotab.com. (accessed April 4, 2022).

[45] Fueleconomy, "What can 6,000 electric vehicles tell us about EV battery health?." https://www.fueleconomy.gov/feg/evtech.shtml, Fueleconomy.gov. (accessed April 4, 2022).

[46] G. S. Hauke Engel, Patrick Hertzke, "Second-life ev batteries: The newest value pool in energy storage," *McKinsey & Company*, 2019.

[47] W. Z. C. N. M.F.R. Zwicker, M. Moghadam, "Automotive battery pack manufacturing – a review of battery to tab joining," *Journal of Advanced Joining Processes*, vol. 1, p. 100017, 2020.

[48] R. Xiong, *Battery Management Algorithm for Electric Vehicles.* Singapore: Springer Singapore, 2020.

[49] Grepow, "What are the 3 stages of lithium battery charging?." https://www.grepow.com/blog/what-are-the-3-stages-of-lithium-battery-charging/, Grepow.com. (accessed April 12, 2022).

[50] EVexpert, "On-Board Charger." https://www.evexpert.eu/eshop1/knowledge-center/on-board-charger, Evexpert.eu. (accessed April 8, 2022).

[51] V. Nguyen, D.-D. To, and D.-C. Lee, "Onboard battery chargers for plug-in electric vehicles with dual functional circuit for low-voltage battery charging and active power decoupling," *IEEE Access*, vol. 6, pp. 70212 – 70222, 10 2018.

[52] H.-J. Chiu and L.-W. Lin, "A bidirectional dc/dc converter for fuel cell electric vehicle driving system," *IEEE Transactions on Power Electronics*, vol. 21, pp. 950 – 958, 08 2006.

[53] S. Arar, "Learning From the Past: EV High Power Density Trends." https://www.allaboutcircuits.com/news/learning-from-the-past-ev-high-power-density-trends/, Allaboutcircuits.com. (accessed April 12, 2022).

[54] electrical installation.org, "Electric Vehicle and EV charging fundamental." https://www.electrical-installation.org/enwiki/Electric_Vehicle_and_EV_charging_fundamentals, Electrical-installation.org. (accessed April 15, 2022).

[55] Wallbox, "EV Charging Current: What's the Difference Between AC and DC?." https://wallbox.com/en_au/faqs-difference-ac-dc, Wallbox.com. (accessed April 16, 2022).

[56] C. M. Fei Lu, "Recent Developments in Capacitive Wireless Power Transfer." https://tec.ieee.org/newsletter/march-2018/recent-developments-in-capacitive-wireless-power-transfer, Tec.ieee.org. (accessed April 20, 2022).

[57] D. L. Jesse Schneider, "SAE Publishes TIR J2954, Wireless Power Transfer EV/PHEV." https://www.standardsuniversity.org/e-magazine/june-2016/sae-publishes-tir-j2954-wireless-power-transfer-evphev/, Standardsuniversity.org. (accessed April 17, 2022).

[58] Dekra, "E-mobility: Testing and certification for electric vehicles and charging infrastructure technology." https://www.dekra-product-safety.com/en/diensten/testen-inspecteren/e-mobility-hoofdpagina, Dekra-product-safety.com. (accessed April 25, 2022).

[59] "IEC 61851-1:2017 Electric vehicle conductive charging system - Part 1: General requirements," standard, Geneva, Switzerland, February 2017.

[60] "IEC 61851-21-1:2017 Electric vehicle conductive charging system - Part 21-1 Electric vehicle on-board charger EMC requirements for conductive connection to AC/DC supply," standard, Geneva, Switzerland, June 2017.

[61] "IEC 61851-21-2:2018 Electric vehicle conductive charging system - Part 21-2: Electric vehicle requirements for conductive connection to an AC/DC supply - EMC requirements for off board electric vehicle charging systems," standard, Geneva, Switzerland, April 2018.

[62] "IEC 61851-23:2014 Electric vehicle conductive charging system - Part 23: DC electric vehicle charging station," standard, Geneva, Switzerland, March 2014.

[63] "IEC 61851-24:2014 Electric vehicle conductive charging system - Part 24: Digital communication between a d.c. EV charging station and an electric vehicle for control of d.c. charging," standard, Geneva, Switzerland, March 2014.

[64] "IEC 61851-25:2020 Electric vehicle conductive charging system - Part 25: DC EV supply equipment where protection relies on electrical separation," standard, Geneva, Switzerland, December 2020.

[65] M. Mültin, "What is ISO 15118?." https://www.switch-ev.com/knowledgebase/what-is-iso-15118, Switch-ev.com. (accessed April 26, 2022).

[66] "ISO 15118-1:2019 Road vehicles — Vehicle to grid communication interface — Part 1: General information and use-case definition," standard, Geneva, Switzerland, April 2019.

[67] "ISO 15118-2:2014 Road vehicles — Vehicle-to-Grid Communication Interface — Part 2: Network and application protocol requirements," standard, Geneva, Switzerland, April 2014.

[68] "ISO 15118-3:2015 Road vehicles — Vehicle to grid communication interface — Part 3: Physical and data link layer requirements," standard, Geneva, Switzerland, May 2015.

[69] "ISO 15118-4:2018 Road vehicles — Vehicle to grid communication interface — Part 4: Network and application protocol conformance test," standard, Geneva, Switzerland, February 2018.

[70] "ISO 15118-5:2018 Road vehicles — Vehicle to grid communication interface — Part 5: Physical layer and data link layer conformance test," standard, Geneva, Switzerland, February 2018.

[71] "ISO 15118-8:2020 Road vehicles — Vehicle to grid communication interface — Part 8: Physical layer and data link layer requirements for wireless communication," standard, Geneva, Switzerland, September 2020.

[72] TyphoonHILDocumentation, "Description of the ISO 15118 protocol implementation in the Typhoon HIL toolchain." https://www.typhoon-hil.com/documentation/typhoon-hil-software-manual/References/iso15118_protocol.html, Typhoon-hil.com. (accessed April 30, 2022).

[73] D. L. Klapwijk Paul, "EV related protocol study," *ElaadNL*, 05 2017.

[74] P. B. A. Myriam Neaimeh, "Mind the gap- open communication protocols for vehicle grid integration," *Energy Informatics*, vol. 3, p. 1, 02 2020.

[75] OCA, "Open vs. Closed Charging Stations: Advantages and Disadvantages." https://www.openchargealliance.org/uploads/files/OCA-Open-Standards-White-Paper-compressed.pdf, Openchargealliance.org. (accessed May 3, 2022).

[76] VestelInternational, "EV Charging Solutions." https://vestelinternational.com/en/ev-charger, VestelInternational.com. (accessed May 5, 2022).

[77] Electrical-installation.org, "EV charging - electrical installation design." https://www.electrical-installation.org/enwiki/EV_charging_-_electrical_installation_design, Electrical-installation.org. (accessed May 5, 2022).

[78] Electrical-installation.org, "EV charging - electrical architectures." https://www.electrical-installation.org/enwiki/EV_charging_-_electrical_architectures, Electrical-installation.org. (accessed May 5, 2022).

[79] O. Alatise, A. Karlsson, A. Deb, R. Wu, and J. Ortiz-Gonzalez, "Expanding ev charging capacity in distribution networks: A case study for charging evs at work," in *CIRED 2021 - The 26th International Conference and Exhibition on Electricity Distribution*, vol. 2021, pp. 2945–2949, 2021.

[80] Electrical-installation.org, "EV charging - energy and asset management." https://www.electrical-installation.org/enwiki/EV_charging_-_energy_and_asset_management, Electrical-installation.org. (accessed May 5, 2022).

[81] CleanTechnica, "EV Charging Habits & Patterns In USA & Europe." https://cleantechnica.com/2020/11/27/ev-charging-habits-patterns-in-usa-europe-cleantechnica-report, Cleantechnica.com. (accessed May 8, 2022).

[82] CR, "Electric Vehicle Survey Findings and Methodology," tech. rep., Consumer Report, July 2019.

[83] M. S. Islam and N. Mithulananthan, "Daily EV load profile of an EV charging station at business premises," in *2016 IEEE Innovative Smart Grid Technologies - Asia (ISGT-Asia)*, pp. 787–792, 2016.

[84] U.S.Dept.ofEnergy, "Electric Vehicle Infrastructure Projection Tool (EVI-Pro) Lite." https://afdc.energy.gov/evi-pro-lite, Afdc.energy.gov, Tool. (accessed May 10, 2022).

[85] PlugShare, "EV Charger Stations Mapping." https://www.plugshare.com/, Plugshare.com, Tool. (accessed May 11, 2022).

[86] OSOS, "OSOS Otomatik Sayaç Okuma Sistemi Nedir?." https://www.osos.com.tr/Intro/WhatOsos, Osos.com.tr, Tool. (accessed March 25, 2022).

[87] J. Coltman, "The transformer: Historical overview," *IEEE Industry Applications Magazine*, vol. 8, no. 1, pp. 8–15, 2002.

[88] S. Satarworn and N. Hoonchareon, "Impact of ev home charger on distribution transformer overloading in an urban area," in *14th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON)*, pp. 469–472, 2017.

[89] M. Li and Q. Zhou, "Distribution transformer mid-term heavy load and overload pre-warning based on logistic regression," in *IEEE Eindhoven PowerTech*, pp. 1–5, 2015.

[90] J. Dixon and K. Bell, "Electric vehicles: Battery capacity, charger power, access to charging and the impacts on distribution networks," *eTransportation*, vol. 4, p. 100059, 2020.

[91] HomeChargingStations, "Electric vehicle charging time calculator." https://www.homechargingstations.com/ev-charging-time-calculator, Homechargingstations.com, Tool. (accessed April 18, 2022).

[92] C. B. W. V. Barlingen, "How long do electric car batteries last?." https://blog.evbox.com/uk-en/ev-battery-longevity, EVbox.com. (accessed April 27, 2022).

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