REPUBLIC OF TURKEY
ADANA ALPARSLAN TÜRKEŞ SCIENCE AND TECHNOLOGY UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

IMPACT OF EV CHARGING STATIONS ON THE POWER QUALITY OF DISTRIBUTION NETWORK AND OPTIMAL PLACEMENT OF CHARGING STATIONS ACCORDING TO NETWORK CONDITIONS

COŞKUN DENİZ TERAN
MASTER OF SCIENCE

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submitted by **Coşkun Deniz TERAN** in partial fulfillment of the requirements for the degree of **Master of Science in Department of Electrical&Electronics Engineering, Adana Alparslan Türkeş Science and Technology University** by,

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I hereby declare that all information in this thesis has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all information that is not original to this work.

[Signature]

Coşkun Deniz TERAN

ABSTRACT

IMPACT OF EV CHARGING STATIONS ON THE POWER QUALITY OF DISTRIBUTION NETWORK AND OPTIMAL PLACEMENT OF CHARGING STATIONS ACCORDING TO NETWORK CONDITIONS

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Nowadays, electric vehicles and their markets are growing gradually due to the development in battery and component technology. Many car companies announced that they will stop the production of diesel vehicles in the future and will work on electric vehicles. It is inevitable that some needs and problems will arise in the future due to this rapid increase in electric vehicles.

In this study, a method based on an analytical hierarchy process has been proposed to allocate the charging stations optimally considering specified criteria to eliminate possible problems that may occur as a result of the rapid penetration of electric vehicles to the grid. In addition, the prevalence of electric vehicles in the future and the load and power quality problems that may be brought to the electricity distribution network by electric vehicles as a result of these expansions have been examined. Increases in transformer loads and in distribution lines can cause power quality problems. Voltage drops and malfunctions that may occur due to new transformers are among these problems. In order to investigate the effects of locating charging stations considering the current status of the utility grid, a proof-of-concept model has been conducted by using MATLAB/Simulink environment. A ring network that is fed from two distribution centers has been determined as a reference area in the simulation model. With this allocation method, charging stations have been positioned on the sample network effectively. Following the layout of the charging stations according to the analytical hierarchy method, the power quality aspect has been examined.

Keywords: charging stations, electric vehicles, electric distribution systems

ÖZET

IMPACT OF EV CHARGING STATIONS ON THE POWER QUALITY OF DISTRIBUTION NETWORK AND OPTIMAL PLACEMENT OF CHARGING STATIONS ACCORDING TO NETWORK CONDITIONS

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Günümüzde, batarya ve bileşen teknolojisindeki gelişmelere bağlı olarak elektrikli araçlar ve pazarları giderek büyüyor. Birçok otomobil firması, gelecekte dizel araç üretimini durduracaklarını ve elektrikli araçlar üzerinde çalışacaklarını duyurdu. Elektrikli araçlardaki bu hızlı artış nedeniyle gelecekte bazı ihtiyaçların ve sorunların ortaya çıkması kaçınılmazdır.

Bu çalışmada, elektrikli araçların şebekeye hızlı bir şekilde girmesi sonucunda oluşabilecek olası sorunları ortadan kaldırmak için şarj istasyonlarının belirlenen kriterler göz önünde bulundurularak optimum şekilde tahsis edilmesi için analitik hiyerarşi sürecine dayalı bir yöntem önerilmiştir. Ayrıca gelecekte elektrikli araçların yaygınlığı ve bu açılımlar sonucunda elektrikli araçların elektrik dağıtım şebekesine getirebileceği yük ve güç kalitesi sorunları incelenmiştir. Trafo yüklerindeki ve dağıtım hatlarındaki artışlar güç kalitesi sorunlarına neden olabilir. Yeni trafolar nedeniyle oluşabilecek gerilim düşüşleri ve arızalar bu problemler arasındadır. Elektrik şebekesinin mevcut durumu dikkate alınarak şarj istasyonlarının konumlandırılmasının etkilerini araştırmak için MATLAB/Simulink ortamı kullanılarak bir kavram-kanıtı-modeli gerçekleştirilmiştir. Simülasyon modelinde referans alan olarak iki dağıtım merkezinden beslenen bir halka şebeke belirlenmiştir. Bu tahsis yöntemi ile şarj istasyonları örnek şebeke üzerinde etkin bir şekilde konumlandırılmıştır. Analitik hiyerarşi yöntemine göre şarj istasyonlarının yerleşiminin ardından güç kalitesi boyutu incelenmiştir.

Anahtar Kelimeler: şarj istasyonları, elektrikli araçlar, elektrik dağıtım şebekesi sistemi

To my wife

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I would like to thank to the precious thesis advisors Mustafa SAVRUN and Mustafa İNCİ for their feedbacks, cooperation and backups.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

As gasoline and diesel sources decrease, the importance of alternative sources increases for cars. Therefore, the importance given to electric vehicles is increasing day by day. In addition, the popularity of electric vehicles is increasing, as gasoline and diesel fuels cause environmental problems. Governments have recently announced that they will provide electric vehicle technologies with incentives and apply various tax cuts. While doing this study, google maps traffic data has been used. The number of electric vehicles in the next ten years will increase significantly, so it is crucial to position the charging stations. Positioning the charging stations is more strategically important than gas stations since electric vehicles will take longer to charge than petroleum-based fuels.

Ahmed (2018) presented Electric Vehicles (EVs) have become an upcoming alternative for petrol/diesel automobiles. Electric vehicles do not emit any pollutants and are therefore safe for the environment. A shift to solely manufacturing and using EVs drastically reduce CO2 emissions in the next 10-12 years. Electric vehicles are seriously environmentally friendly with 0 carbon emissions.

Catalbas and Yildirim (2017) investigated the positioning of electric charging stations is much more strategic than the positioning of gas stations. The recharging times of electric vehicles are longer than gasoline vehicles. For this reason, these times should also be taken into account when positioning the charging stations. In recently, the usage of EVs has increased rapidly. Due to this reason, finding an optimal location for EV charging stations has been an important topic.

However, the spread of electric vehicles will also bring some problems to the power grid. As the transformer loads in the existing power grid are limited, new power networks may need to be installed. The harmonics produced by the charging stations will affect the power quality of the network. It may also cause regional voltage drops and voltage collapse.

1.1. The Future of Electric Vehicles

The use of electric cars is increasing day by day. Car manufacturers no longer invest in diesel engine and gasoline engine development. Many leading companies in the world have stated that they will reduce or completely stop the production of gasoline and diesel engines in the future (Samuelsson, 2017).

While diesel and gasoline engines are losing their power, electric and hybrid vehicles, which are the new trends in the world, have become increasingly common. The Electric Vehicle World Sales Database (2021) published despite the covid 19 global pandemic in 2020; electric vehicle sales achieved good results. In 2020, vehicle sales across Europe fell by 20%, while electric vehicle sales increased by 137%.

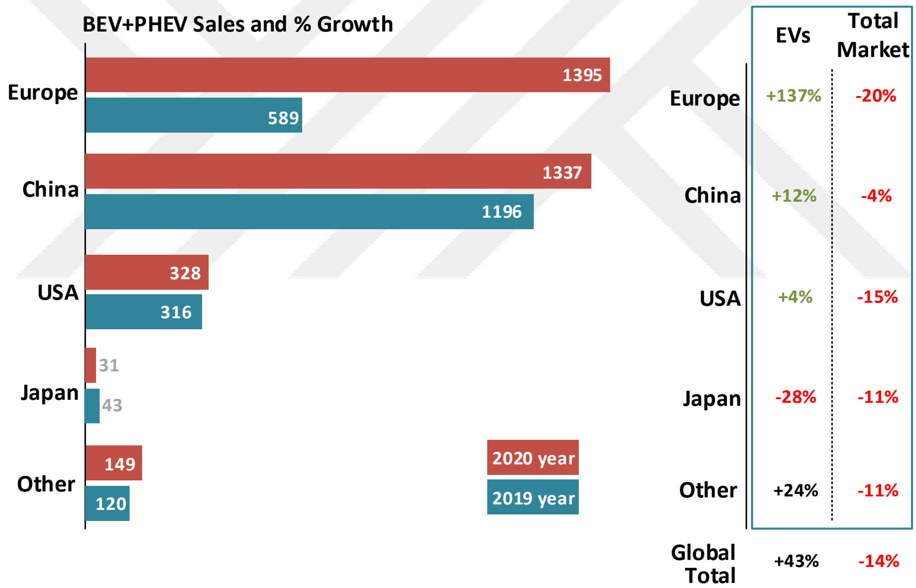

Figure 1.2. Comparison of electric vehicle sales in 2020 and 2019 by global market

Electric vehicle sales peaked in 2021 with increased environmental awareness globally and the increase in confidence in electric vehicle technology.

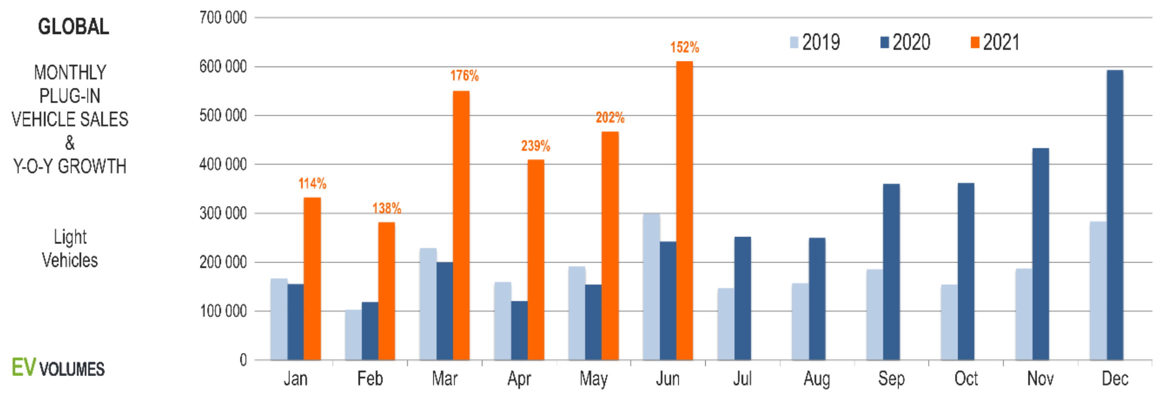

Figure 1.2. Global electric vehicle sales - https://www.ev-volumes.com

While the world is following this developing technology, the interest in electric vehicles in Turkey increases day by day. The Republic of Turkey has announced that it supports domestic electric vehicle production and will make new investments with the TOGG company in this regard (Republic of Turkey Ministry of Industry and Technology, 2021). There was a significant increase in electric vehicle sales in 2021 in Turkey. While 173 electric vehicles were sold in the first six months of 2020, 894 electric vehicles were sold in the first 6 months of 2021, increasing more than five times (Turkey Electric & Hybrid Vehicles Association, 2021). In line with the data coming from the world and Turkey, it is seen that electric vehicles are increasing rapidly.

How electric vehicles will take place in our world in the future has been examined in a study by the international energy agency. According to this study, it is foreseen that millions of electric vehicles will predominantly take over the market in 2030 (International Energy Agency, 2019).

Many countries have started to create production resources for this market, which is foreseen in the future. Turkey began to construct a large factory in Gemlik with TOGG company for the production of electric vehicles. With this factory, it is planned to create employment opportunities for 4300 people. It is planned to produce 175,000 electric vehicles annually.

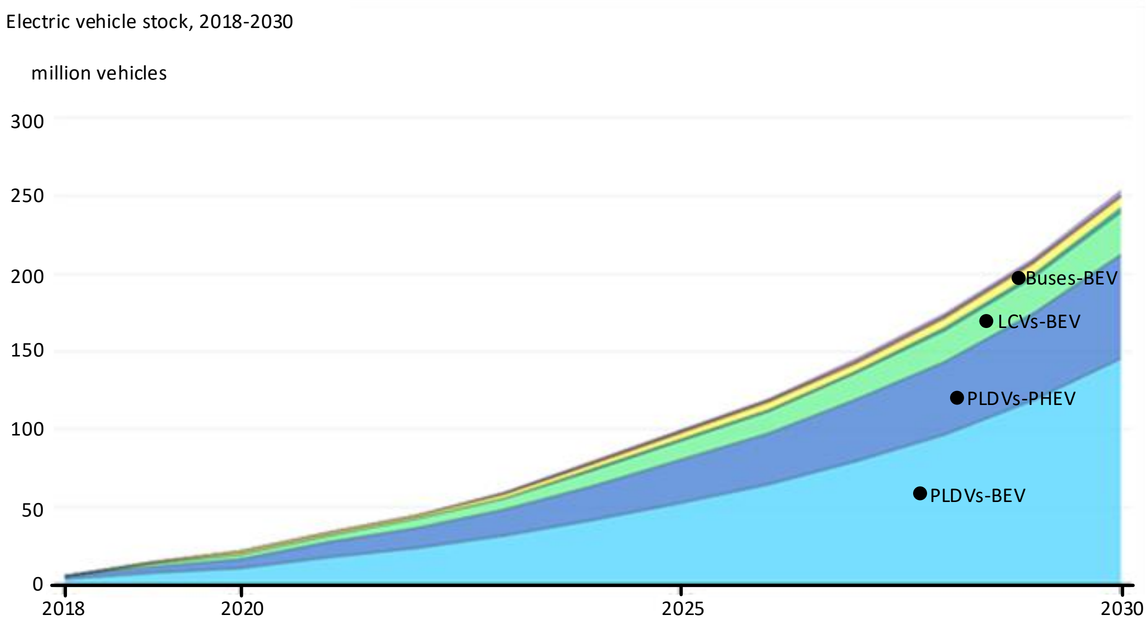

Figure 1.3 Electric vehicle stock in the EV30@30 scenario, 2018-2030 (International Energy Agency, 2019)

Countries like China, the United States, and Germany are also preparing for these future scenarios by investing in new factories and production facilities. Decisions are taken against the prevention of environmental pollution also encourage the use of electric vehicles. The following ten years are significant to create a livable world in the future.

The prevalence of electric vehicles is the most accurate proof that electric vehicle charging stations will gradually increase. Considering that approximately 300 million electric vehicles will be on the roads by 2030, it can be easily said that there will be a very high number of electric vehicle charging stations to meet the energy needs of these vehicles. With the development of electric vehicle battery technologies, longer range and shorter-term charging technologies are becoming widespread. With these developments, the confidence in electric vehicles will increase and many people will be acquainted with this technology in a very short time. Turkish people's interest in this technology will increase with the first domestic electric vehicles in Turkey.

1.2. Power Quality Parameters

It is essential to know the problems in power quality and the effects of these problems on the devices. The power that is not of good quality causes deterioration or high-performance losses in the devices. Today, with the development of technology, severe damage in power quality has occurred due to the increase in switching. These problems should be resolved quickly, and in place, otherwise, it won't be easy to find the source.

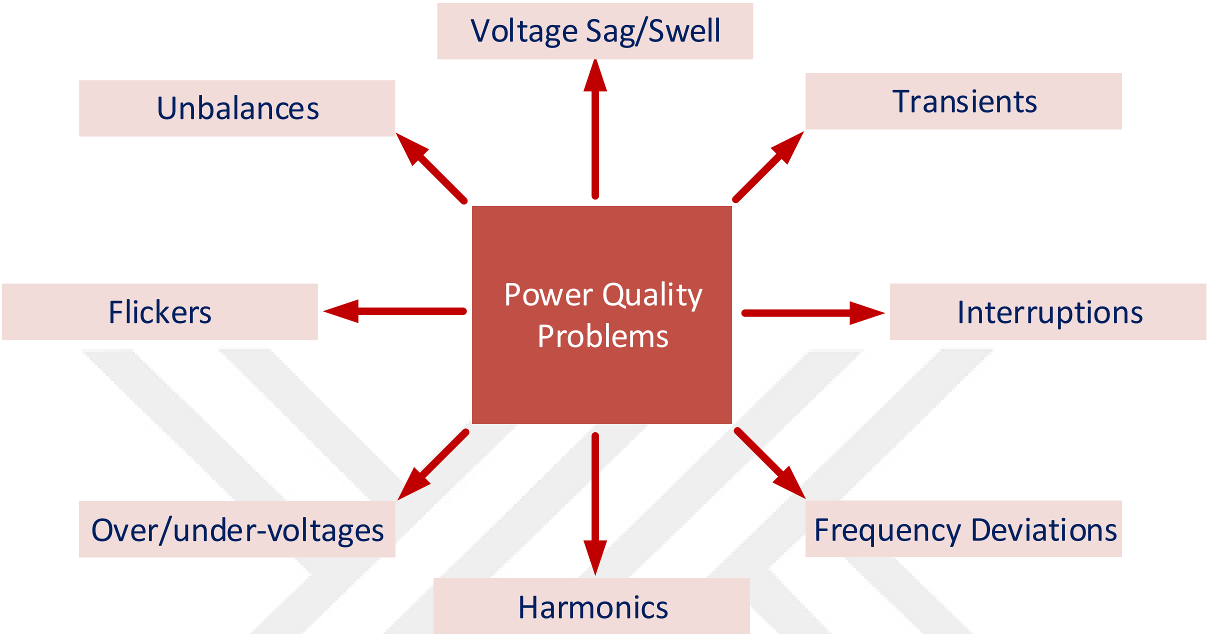

Figure 1.4. Common Power Quality Problems (Sinik et al., 2019)

Power quality is crucial for the electricity distribution network and electrical equipment. Some power quality problems are as follows:

Over-voltages: Overvoltages means the voltage on the equipment above the rated operating voltage limit for 1 minute.

Under-voltages: Undervoltage means the voltage on the equipment under the rated operating voltage limit for 1 minute.

Overvoltages are power quality problems that are undesirable in the electrical distribution network and can cause serious insulation failures on the devices. As a result of insulation problems, it can create difficult problems to repair, such as fire on the equipment (Zobaa et al., 2018).

Undervoltage can cause motor starting problems.

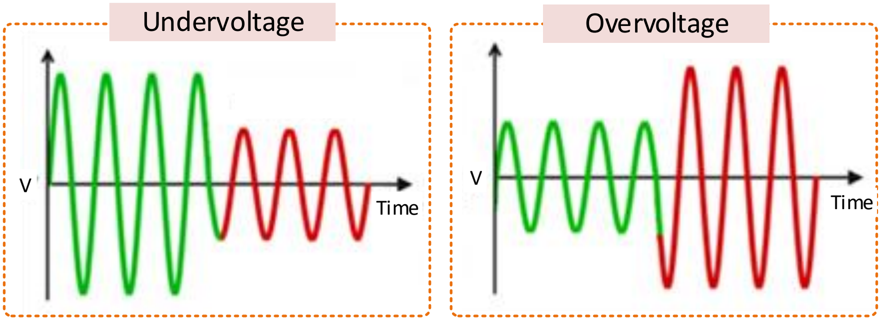

Figure 1.5. Over/Under Voltage Problems (Electrical Testing and Engineering Network, 2019)

Overload: Overload occurs when too much current passes through electric wires. Overload is very dangerous for electrical network equipment. Due to the overload, serious heating and cable burns may occur in the cables. In addition, it can cause power cuts by triggering thermal trips of protection equipment. As a result of overloading of transformers, it may cause heating in transformer inner windings and trigger transformer protection equipment.

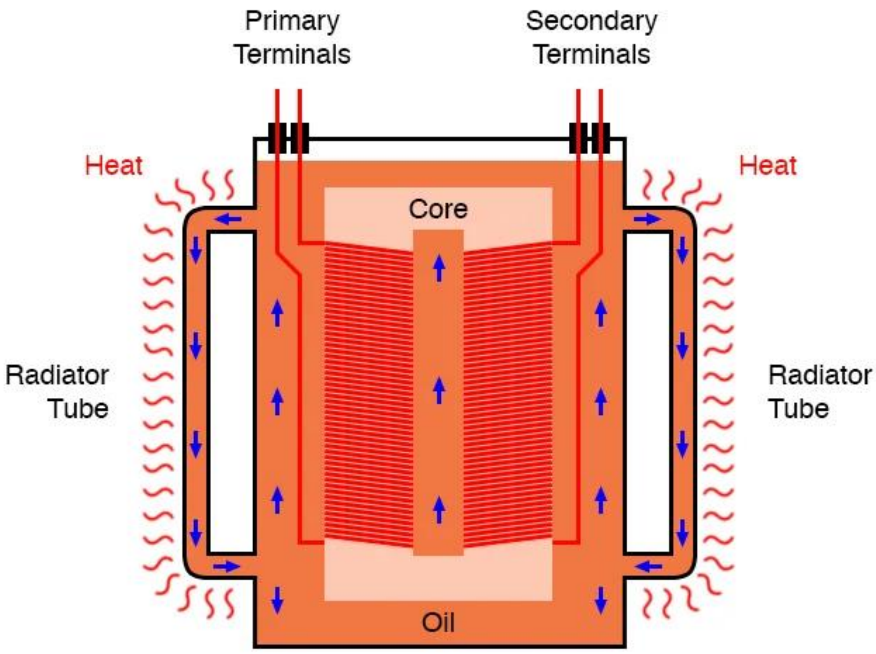

Figure 1.6. Transformer Cooling System (Kuphaldt and Haughery, 2020)

Disturbances in power quality can severely affect the equipment providing electricity distribution and the devices energized by these devices. Transformer heating, heating on the phase, and neutral cable are among the most critical effects on the distribution system. Customer satisfaction will also decrease significantly due to transformer failures and cable bursts after these warming effects. Costs such as cable and conductor costs, repair equipment costs (cable joints, etc.), excavation costs also create problems for the distribution company (Khan,et al., 2017).

Figure 1.7. XLPE Cable after Overload

The increase in electric vehicles means that new transformers and new energy transmission lines are included in the grid. Power quality problems may occur due to the inclusion of new charging stations and inverters in the electricity distribution network together with these transformers.

Figure 1.8. XLPE Cable Joint

Harmonics are sinusoidal voltages or currents having frequencies that are integer multiples of the fundamental frequency. Due to the increase in harmonics in the network, it causes results such as overheating in cables, efficiency losses in motors and generators, and faulty triggering of protection equipment. Harmonic filters are used to reduce undesirable harmonics on the electrical distribution system. They can be divided into two groups: passive filters and active filters (Almeida et al.,2003).

Customers receiving energy from the electricity distribution network face these consequences due to the increase in harmonics in the grid. In addition, distribution companies face the risk of penalties due to legal obligations. In order not to deal with such problems, power quality measurements are made from specific points. The factors that deteriorate the quality are determined, and sanctions are applied to them. Since the use of inverters will be common, especially in stations to be used as DC charging, it may cause such problems in the future. It may be necessary to take steps to solve these problems.

1.3. Analytical Hierarchy Process

Analytical Hierarchy Process (AHP) is a multi-criteria decision-making method developed by Thomas L. Saaty in 1971 (Wind and Saaty, 1980). The analytical hierarchy process is a widely used technique in decision-making problems. The analytical hierarchy process allows choosing the best option according to the needs in a multi-criteria and multi-alternative decision-making process. Determining the weights of the criteria allows us to see the best options and the worst options by making certain scoring among the alternative options. The method is used in a multi-criteria decision-making situation where there are many decision-makers, while choosing among many alternatives under certainty or uncertainty. AHP, complex problems of decision-makers; It allows them to model the problem in a hierarchical structure that shows the relationship between the main objective, criteria, sub-criteria, and alternatives.

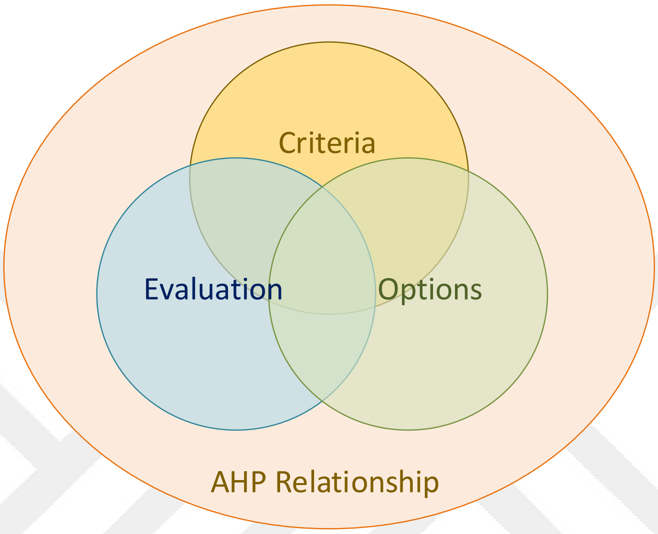

Figure 1.9. AHP Relationship

AHP is generally advanced by analyzing the matrices between the criteria and using the data obtained after checking the consistency. The alternative with the highest score is the best alternative for the comparator. There are seven main stages of AHP implementation (Forman and Selly, 2001).

In the analytical hierarchy process, there is a purpose and basic criteria determined to achieve this goal. The number of these criteria is chosen entirely according to our determination of the determinant. The low number of criteria facilitates the selection, while the high number of criteria ensures that the most suitable one is selected (Goel et al., 2021). There will of course be many alternatives when choosing these criteria. Choosing the best among the alternatives is essential for the operation of the process.

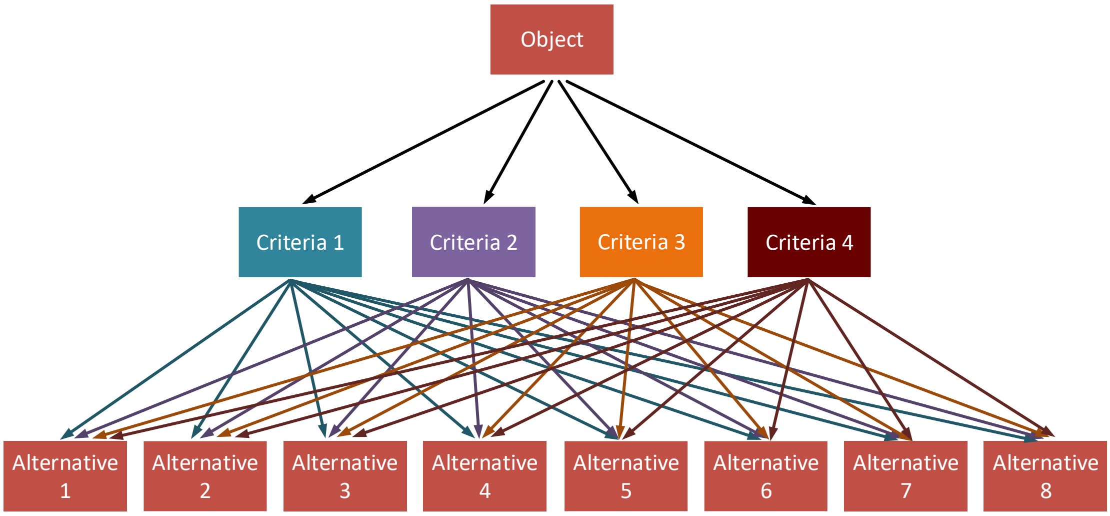

Figure 1.10. AHP working system

In this system, a hierarchical structure must first be created. At the top of the hierarchy is the purpose. At the bottom level, criteria must be found. At the bottom level, there are alternatives. Then pairwise comparisons are made between the other options. For these comparisons, the Saaty Scale given in Table 1.3.1 is used. According to this table, superiorities from 1 to 9 are determined, and the coefficients are located in the matrices. 9 indicates a significant advantage, 1 indicates equal importance. Then, the decision matrices are formed by forming the matrices with the coefficients. By solving the matrices, the best result is determined.

Table 1.1. Salty's Scale Of Comparison

Salty's Scale Of Comparison	
Importance level	**Definition**
1	Equally important
3	One criterion is considered slightly more important than the other
5	One criterion was deemed much more important than the other.
7	The criterion was definitely considered much more important than the other criterion.
9	One criterion is extremely important than another.
2,4,6,8	Intermediate values (compromise values)

Comparison matrices are a square matrix with diagonal elements 1. aij, which compares elements i and j.

$$A=\begin{bmatrix} 1 & a12.. & a1n \\ a21 = 1/a12 & 1 \ldots & a2n \\ an1 = 1/a1n & an2 = 1/a2n & 1 \end{bmatrix} \tag{1}$$

Comparison matrices are a square matrix with diagonal elements 1. aij, which compares elements i and j.

With AHP, people organize and manage their different feelings and understandings. Thanks to AHP, it is possible to develop the most appropriate objective result according to the conditions based on subjective judgments to solve significant problems (Basar, 2018). In this study, by applying AHP, alternative charging stations can be positioned in the best way according to the essential criteria that have determined. Arbitrary positioning of charging stations will both increase cost and reduce usefulness. For this reason, it is essential to position the charging stations according to the criteria. In this way, these stations connected to the distribution network will have less impact on power quality.

The analytical hierarchy process is used in many areas around the world. It is used in many areas such as recruitment processes of human resources, car, and mobile phone selection processes, and regional selection issues for the new construction of cities.

According to Anderluh, et al., (2019) work in the Viennese region, he worked on the need for new urbanization choices due to the increase in crowding and human density in the city center. In these studies, they determined some basic criteria while choosing their new regions and used the analytical hierarchy process to make the best selection among the alternatives. For this study, they determined three main criteria as cost, environmental & social aspects, and location - specific characteristics. As an alternative, they determined six alternative regions as A-B-C-D-E-F. They saw that the D region's most suitable region according to the criteria they determined by applying the AHP process.

In a study using the analytical hierarchy process for the proper selection of fans, which are of vital and critical importance in underground coal mines in Turkey, four main criteria were determined for the selection of fans. As a result of these four criteria, which were determined as operational, technical, environmental, and economical, three fan alternatives were evaluated, and the most suitable one among these three fans was tried to be selected. Fan 1 was found to be the most appropriate fan in this study, according to the solution (Kursunoglu and Onder, 2014).

In a study in which low-cost carriers use the analytical hierarchy process for airport selection, criteria were determined, and the most appropriate airport was selected. Five main criteria are focused on in this study for low-cost carriers. These are airport charges, airport performance, airport growth opportunities, catchment area, and airport infrastructure. It has been studied that the most appropriate airport selection can be made by using Fuzzy AHP (Loh et al., 2020).

In another study conducted to determine the most suitable region for a hospital to be built in Muğla province of Turkey, the districts of Muğla were determined as alternatives and the selection was made using six main criteria and 19 sub-criteria. Competitors, environmental conditions, demand factor, accessibility, related industry, and government were determined as the main criteria for this study. A certain number of sub-criteria were determined under each main criterion. Three scenarios were established, and the analytic hierarchy process was run. As a result of the three scenarios, Bodrum district became the most suitable district for establishing a hospital, and Marmaris district ranked second (Şahin et al., 2019).

According to another study conducted in the Philippines, the analytical hierarchy process was used to select clean technologies appropriately. Besides the economic and social aspects of technologies in this study, their environmental aspects are also examined (Promentilla and Isagani, 2017).

In another study, which uses the Fuzzy AHP process to protect from cyber attacks to increase security in high voltage transformer facilities, work has been done to improve reliability and customer satisfaction. This study tries to create the safest transformer center by spending more on which areas of the budgets. By determining route selection, shielding, software and hardware criteria, it was understood which alternatives should be invested more in transformer centers (Xiao et al., 2021).

Another study conducted with the analytic hierarchy process, which can also be used in the banking sector, aims to give loans to people looking for loans according to suitable alternatives by using the proper criteria in the loan granting process. In this study, Character, Capacity, Capital, Conditions of economy, Collateral were determined as five main criteria, and customers were taken as alternatives. Customer scores were also obtained in line with certain surveys, contributing to the decision-making process (Fernando and Siagia, 2021).

The forestry sector can also be another sector where the analytical hierarchy process can be applied. According to a study on forestry, the risks that people working in this sector may be exposed to while using chainsaws have been determined. 6 main risks and 29 sub-risks were determined by expert teams, and the consistency values of risk factors were calculated. The top priority sub-risk criteria were identified as inadequate safety precautions, field conditions, carelessness, morale, and allergic plants. Prioritization of risk criteria will support employers to take priority security measures (Unver and Ergenc, 2021).

1.4. Studies On Allocation

There are many methods used by countries and companies regarding the positioning of EV charging stations in the world. Some companies also prefer to position them randomly, such as a gas station, without using any method. Studies on this subject show that the positioning of EV charging stations is much more important than gas stations. Because while a gasoline vehicle can fill its entire tank in a short time, like 3-5 minutes, a severe time is required depending on the charging station and battery duration for an electric vehicle to charge its battery. This reveals the need for a location where electric vehicles will need to wait while charging. At the same time, the effects of charging stations on the distribution network increase the importance of positioning. Problems such as the effects of charging stations on power quality, their loading on cables and conductors, and their impact on transformer power will be limiting factors (Angeline and Rajkumar, 2020).

According to a study, traffic conditions were taken as the main criterion for the positioning of fast-charging stations. (Islam, 2018) They used Google Maps API to analyze traffic conditions in their studies. Here, they developed an algorithm by processing the results of the traffic density of the roads on Google Maps maps. They used an optimization technique for fast charging station positioning.

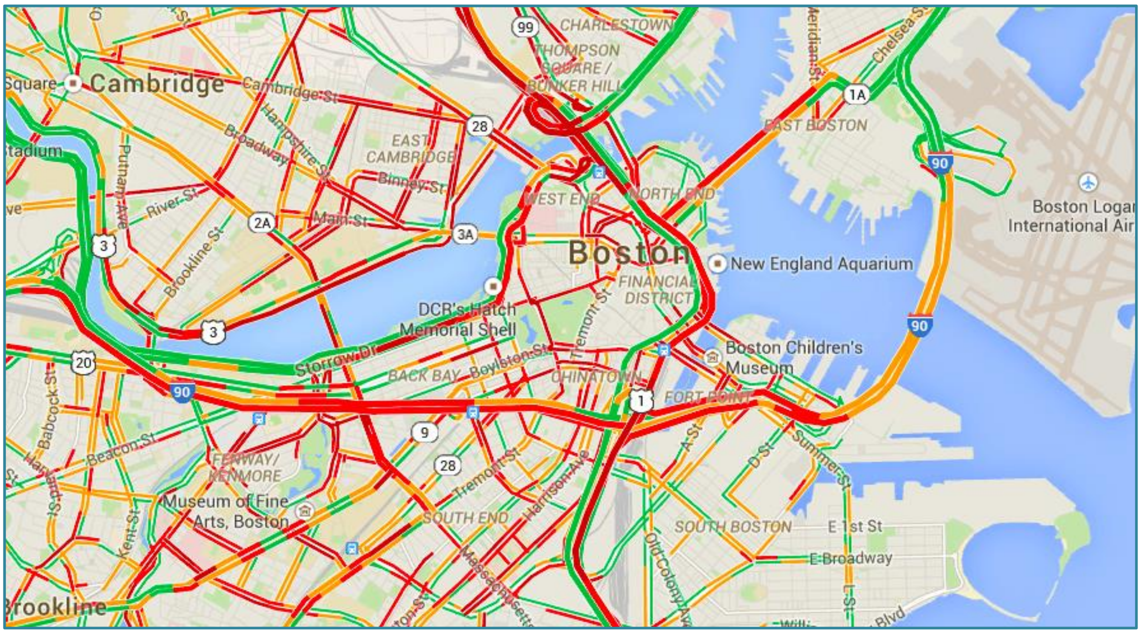

Figure 1.11. Google Maps traffic density display.

They tested the proposed method in an urban area and shared their results. Their results stated that costs such as EV Transportation Energy Loss Cost, Station Build-up Cost, Sub-station Energy Loss Cost should also be considered.

In another study, a study is carried out on the positioning of fast charging stations, taking into account elastic demands. In this study, it is considered to position the charging stations by establishing an equation between the charging times and the needs of the vehicles. A main charging station is determined, and the positioning of other charging stations is based on this main station. According to the simulation results, it has been calculated that this method brings 15% more profitability compared to the Greedy Method in places where the need for fast charging stations is high (Gan et al., 2020).

In studies on electric vehicles, many different perspectives have been conducted on the positioning of charging stations (Bilal and Rizwan, 2020). In a study using Mapbox software, certain clusters were created by calculating the traffic density of the roads in the Ankara region. Using the Gaussian Mixture Model (GMM), the charging station positioning was made by making predictions between these clusters (Catalbas and Yildirim, 2017).

In a study conducted as a test system on a highway in Hainan Island, China, fast-charging stations were planned to be located on highways. In this study, an algorithm was created to determine the location using the Shared Nearest Neighbor (SNN) Clustering algorithm. Queuing theory was applied to determine the capacity of each electric vehicle charging station (Dong et al., 2018).

In another study examining residential charging stations, smart charging algorithms were created using Time of Use logic, and it was aimed to eliminate voltage problems (Dubey and Santoso, 2015).

Using Genetic Algorithm logic to reduce EV energy losses in Corpus Christi, Texas, a population of 10,000 vehicles, the study examines each charging station's daily energy consumption and annual revenue (Hayajneh and Salim, 2019).

In this study to plan high rate EV chargers in the UK, charging stations are planned by considering battery capacity, street maps, and traffic flow. Total electric vehicle usage rate and traffic flow maps were drawn to determine which regions were dense at which times of the day (Hilton et al., 2018).

Another study, which runs the charging loads of electric vehicles on the traffic simulator, has been worked on integrating charging stations into smart grids. Utilizing the traffic simulator, dense areas have been determined, and charging stations have been positioned considering the ranges of electric vehicles (Ito and Iwafune, 2012).

Using the Unconstrained Traffic Assignment Model, the interdependence of the traffic network and the electricity distribution network was explained. A positioning study was carried out for the charging stations. With this study, a coordinated planning model was created, and experiments were carried out on traffic. A typical topology of traffic and grid network has been created (Wang and Shahidehpour, 2018).

In another paper prepared to reduce installation costs and losses, Particle Swarm Optimization was used to reduce distribution transformer loads. Simulations related to the study were prepared on Matlab and OpenDSS, and charging station placements were made to reduce charging stations' initial installation costs. According to the results of the study, it has been observed that there is a decrease in the installation costs of charging stations and transformer loadings (Zeb and Imran, 2020).

In another study comparing the structure of distributed generation and electric vehicle charging stations, they modeled travel demands according to real lifestyle by using the column and constraint algorithm by considering distributed generation planning (Zhao and Xu, 2018).

2. CHARGING STATION TYPES OF ELECTRIC VEHICLES

2.1. Overview of Charging Station Types

Different charging methods have been used to charge electric vehicles, such as conductive, wireless, and charging technology. Conductive charging methods are typically known as DC charging and AC charging. Wireless charging systems can be considered in two types: inductive and capacitive. According to the structural technology, three types (level 1, level 2, level 3) are used to charge electric vehicles (Rajendran et al., 2021).

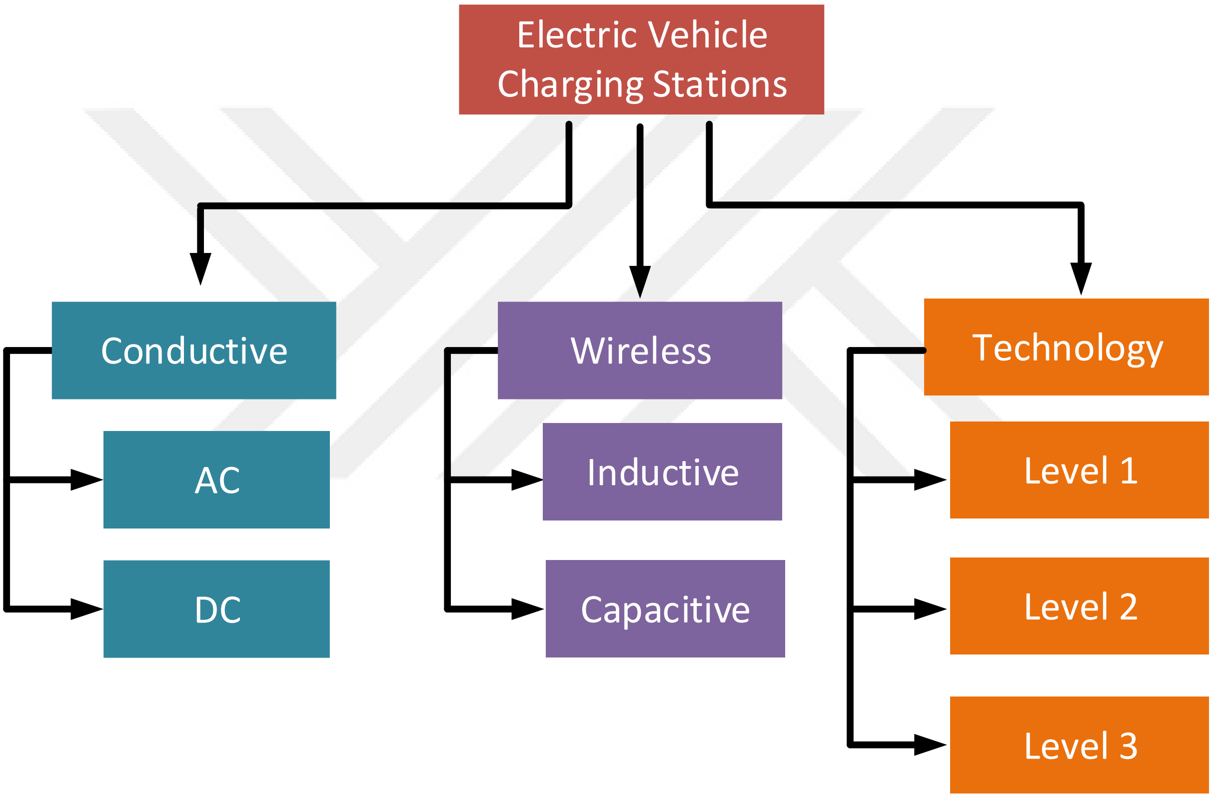

Figure 2.1. Charging Stations Types

2.2. Conductive Charging Systems

Figure 2.2 introduces conductive charging systems to charge electric vehicles. In the AC charging system, AC output is given from the charger, but the batteries are charged by converting to DC thanks to the converter in the vehicle. AC chargers generally charge slower than DC chargers (Funke et al., 2019).

The DC charging system is the fastest charging method used today, and it is the device that users will most prefer due to time constraints. According to the DC charging logic, the AC electrical current coming from the electricity distribution network is converted into DC current by the converter in the charging station, and the electric vehicle is energized. So the difference between AC and DC charging is where the electricity is converted. If electricity is converted in a rectifier in the vehicle, it is called AC charging, if it is converted at a charging station, it is called DC charging (Suarez and Martinez, 2019).

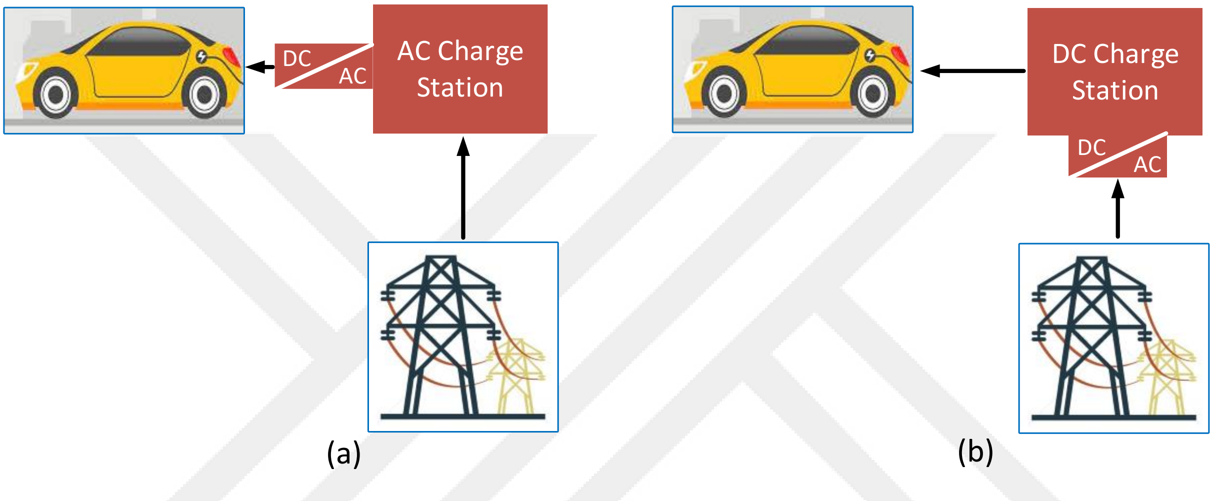

Figure 2.2. AC onboard charger and DC charger

The power capacity of the onboard chargers in the vehicle is essential for the charging of electric vehicles. While the onboard charger capacities of some brands are high, some of them are low. This prolongs the charging time.

2.3. Wireless Charging Systems

Although conductive charging systems are the most common chargers in the world today, wireless charging systems are shown as the future technology, can also be used for charging electric vehicles.

For the wireless charging system, there must be two electrically isolated structures. These are called receiver and transmitter. The transmitter part converts low-frequency mains electricity to high frequency and feeds the transmitter coil. From here, electromagnetic forces are created, and a current is induced in the receiver coil in the vehicle. Thanks to the coil, the receiver, the vehicle battery, is charged (Mohameda et al., 2020).

Another wireless electric vehicle charging method is capacitive charging. Capacitive power transfer is handled in two forms, unipolar and bipolar. In the unipolar system, there is 1 plate each on the transmitter and receiver side. In the bipolar system, there are 4 plates, 2 on the receiving and transmitting sides. The biggest advantage of capacitive power transfer compared to inductive system is that the need for electromagnetic field protection is less. This system, which provides electricity transmission at higher frequencies, makes it cheaper because ferrite is not used. (Mohammed et al., 2019)

2.4. Charging Technology Levels and Standards

While the number of electric vehicles is increasing day by day, the charging stations used to charge electric vehicles also increase day by day. With the increasing need for developing technology, many types of charging stations have been produced. Some of these charging stations are DC type and some are AC type. Countries worldwide have named "level" or "type" for these different types of stations according to the norms they accept. While the cost and charging speed are low in household chargers, commercial devices' cost and charging speed are high. Devices designated as Level 1 usually use 120V AC mains voltage, with slow and inexpensive charging time (U.S Department of Energy, 2012). In Level 1 chargers, one of the cable terminals has a Nema 5-15 connector, while the other end has a J1772 standard connector.

Figure 2.3. Level 1 J1772 Standart EVSE Connector

The supply power of household-level 1 appliances is usually limited to 3.7 kW. Level 1 chargers can be connected to household plugs and offer 12-24 hours charging time depending on the type of battery they will charge (Hydro Quebec, 2015).

Level 2 charging uses 240 V to enable faster regeneration of an EV's battery system. Providing this type of charging requires the installation of an EVSE unit and electrical wiring capable of handling higher voltage power. Level 2 chargers use J1772 as a connector port (Nelder and Rogers, 2020). Level 2 chargers are generally used in garages, but they can also be used in homes. Level 2 chargers are suitable for commercial use and can provide higher powers to charge more vehicles faster. (Drive Electric Vermont, 2021) Level 2 chargers have a higher installation cost than level 1 charging.

Table 2.1. Level 1 and Level 2 Charger Comparasion (Hydro Quebec,2015)

	Level 1 Chargers	Level 2 Chargers
Voltage	120V-220V	208V-480V
Current Type	AC	AC
Useful Power	1.4 KW	7.2 KW
Maximum Output	1.9 KW	19.2 KW
Charging Time	12h-24h	3h-6h
Connector	J1772	J1772

As can be seen from Table 2.1, level 1 chargers operate at low power and low voltage levels. Charging times can take up to 1 day, depending on the battery capacity. Level 2 chargers, on the other hand, can operate at higher voltage levels and meet higher demand forces. They can shorten charging times up to 3 hours.

Figure 2.4. Level 2 Charge Station

Level 3 chargers are known as quick charges.With the development of electric vehicle technologies, the growth of charging technologies is undoubtedly expected. Thanks to new battery technologies, batteries can be charged much faster. In North America and Pacifics, the SAE-J1772 standard for charge electric vehicles is used. But, in China, the GB/T 20234 standard is used, while, in Europe, the IEC-62196 standard using commonly (Sanguesa et al., 2021). DC chargers have also recently begun to be classified as fast and ultra-fast (Wolbertus and Hoed, 2020).

Table 2.2. Charge ratings of the SAE-J1772 (SAE International, 2009)

Charge Method	Volts	Maximum Current	Maximum Power
DC Level 1	200 to 500 VDC	80 A	40 kW
DC Level 2	200 to 500 VDC	200 A	100 kW

According to the SAE-J1772 standard, DC charges are divided into two levels. According to this standard, Level 1 DC devices can operate as a maximum of 80 Amperes and 40 kilowatts. Level 2 DC devices can be operated up to 200 amps and 100 kilowatts.

According to the IEC 62196 standard, AC chargers are classified in 3 different levels, while DC chargers are not classified in a different level. While using four different modes with this type of devices, 16 A maximum current can be provided for mode 1. In mode 1, 7.6 kW power can be supplied for 3 phases. For Mode 2, a maximum current of 32 amps can be given, while a maximum of 15.3 kilowatts can be provided for 3 phases. Mode 3, on the other hand, is one of the fastest charging types for AC charging types and means that a power of 60 (single-phase) to 120 kilowatts can be provided by giving current between 32 and 250 amperes. According to this standard, all AC type chargers can operate up to 480 volts for 3 phases. According to the IEC-62196 standard, DC chargers can provide much higher amperes. While the devices used here can provide high currents in the range of 250 - 400 amperes, they can provide powers up to 400 kilowatts. These devices operate between 600 and 1000 volt voltage levels. In order to use these modes, it is used with devices that provide communication and security between the vehicle and the charger.

Table 2.3. Charge ratings of the IEC-62196 (International Electrotechnical Commission,2014)

Modes	Charge Type	Max Current	Max Voltage	Max Power
Mode 1	AC Three Ph.	16A	480 V	7.6 kW
Mode 2	AC Three Ph.	32 A	480 V	15.3 kW
Mode 3	AC Three Ph.	32 – 250 A	480 V	120 kW
Mode 4	DC	250-400 A	600 – 1000 V	400 kW

China uses its own standard GB/T-20234 as well as other standards. They use GB/T-20234.3-2015 standard for DC charging. According to this standard, 440 v AC voltage and 16, 32 and 63 Ampere rated current are used. The maximum power is 27.7 kW. For DC charging, a voltage of 750 to 1000 volts is used, while a current of 80-250 Amperes is used. Maximum power of 250 kilowatts is generated.

Table 2.4. Charge ratings of the GB/T-20234 (Quebec CQC, 2021)

Charge Method	Volts	Maximum Current	Maximum Power
AC Charging	440 V	16- 63 A	27.7 kW
DC Charging	750 to 1000 VDC	80-250 A	250 kW

3. DISTRIBUTION NETWORK SIMULATION

The main objective of this thesis is to allocate the charging stations optimally according to the current status of the utility grid. For this reason, firstly, it is essential to analyze the status of the existing utility grid well. Under the title of the current status of the utility grid, subjects such as loading conditions, percentage loading of transformers, adequacy of distribution line cable infrastructures have critical importance. The aforementioned parameters should be analyzed to determine the adequacy of the cable and transformer infrastructure for the extra load caused by the charging stations. For this reason, the current situation analysis and optimal charging station allocation on a reference area that has a heavy population in Turkey has been studied.

3.1. Current Distribution Network Structure

To investigate the effects of locating charging stations considering the current status of the utility grid, a proof-of-concept model has been conducted by using MATLAB/Simulink environment. The area between the Distribution Center 1 (DC1) and the Distribution Center 2 (DC2) has been determined as a reference area. This area assumed as relatively crowded. Because of this reason, it is estimated that the number of electric vehicles to be connected to the grid will be considerably higher in this region.

The related location is a ring network and is fed from DC1 and DC2. Ring distribution systems are used in heavily populated areas. Power is delivered from one or more power sources into substations near the service area. When a power line is opened, no interruption to other loads occurs. The ring system provides continuous service to the loads. The related location has 17 transformers to feed the radial networks that are composed of homes, commercial buildings, and institutional buildings. The TR1 is located to feed a home settlement consisting of an apartment. The transformer power is determined as 1000 KVA considering the 800 KVA consumption rating of related load. The TR2 is located to feed homes. The transformer power is determined as 400 KVA considering the 400 KVA consumption rating of related load. The TR3 is located to feed houses on the street. The transformer power is determined as 1000 KVA considering the 800 KVA consumption rating of related load. The TR4 is located to feed a home settlement consisting of a site. The transformer power is determined as 400 KVA considering the 400 KVA consumption rating of related load. The TR5 is located to feed home settlement consisting of an apartment. The transformer power is determined as 1000 KVA considering the 800 KVA consumption rating of related load. The TR6 is located to feed home settlement consisting of an apartment. The transformer power is determined as 1000 KVA considering the 800 KVA consumption rating of related load. The TR7 is located to feed shopping mall on the street. The transformer power is determined as 2000 KVA considering the 1600 KVA consumption rating of related load. The TR8 is located to feed houses on the street. The transformer power is determined as 400 KVA considering the 400 KVA consumption rating of related load. The TR9 is located to shopping mall. The transformer power is determined as 1600 KVA considering the 1200 KVA consumption rating of related load. The TR10 is located to official institution. The transformer power is determined as 1000 KVA considering the 800 KVA consumption rating of related load. The TR11 is located to feed official institution. The transformer power is determined as 1600 KVA considering the 1200 KVA consumption rating of related load. The TR12 is located to feed an institutional buildings. The transformer power is determined as 630 KVA considering the 500 KVA consumption rating of related load. The TR13 is located to feed an institutional buildings. The transformer power is determined as 1600 KVA considering the 1200 KVA consumption rating of related load. The TR14 is located to feed an institutional buildings. The transformer power is determined as 250 KVA considering the 200 KVA consumption rating of related load. The TR15 is located to feed a shopping mall. The transformer power is determined as 630 KVA considering the 500 KVA consumption rating of related load.. The TR16 is located to feed an homes. The transformer power is determined as 630 KVA considering the 500 KVA consumption rating of related load. The TR17 is located to feed an apartment. The transformer power is determined as 1000 KVA considering the 800 KVA consumption rating of related load. The specifications of the transformers, load, and cables located on the related area listed in Table 3.1 and 3.2 respectively. The single line diagram of the sample ring network is illustrated in Figure 3.1.

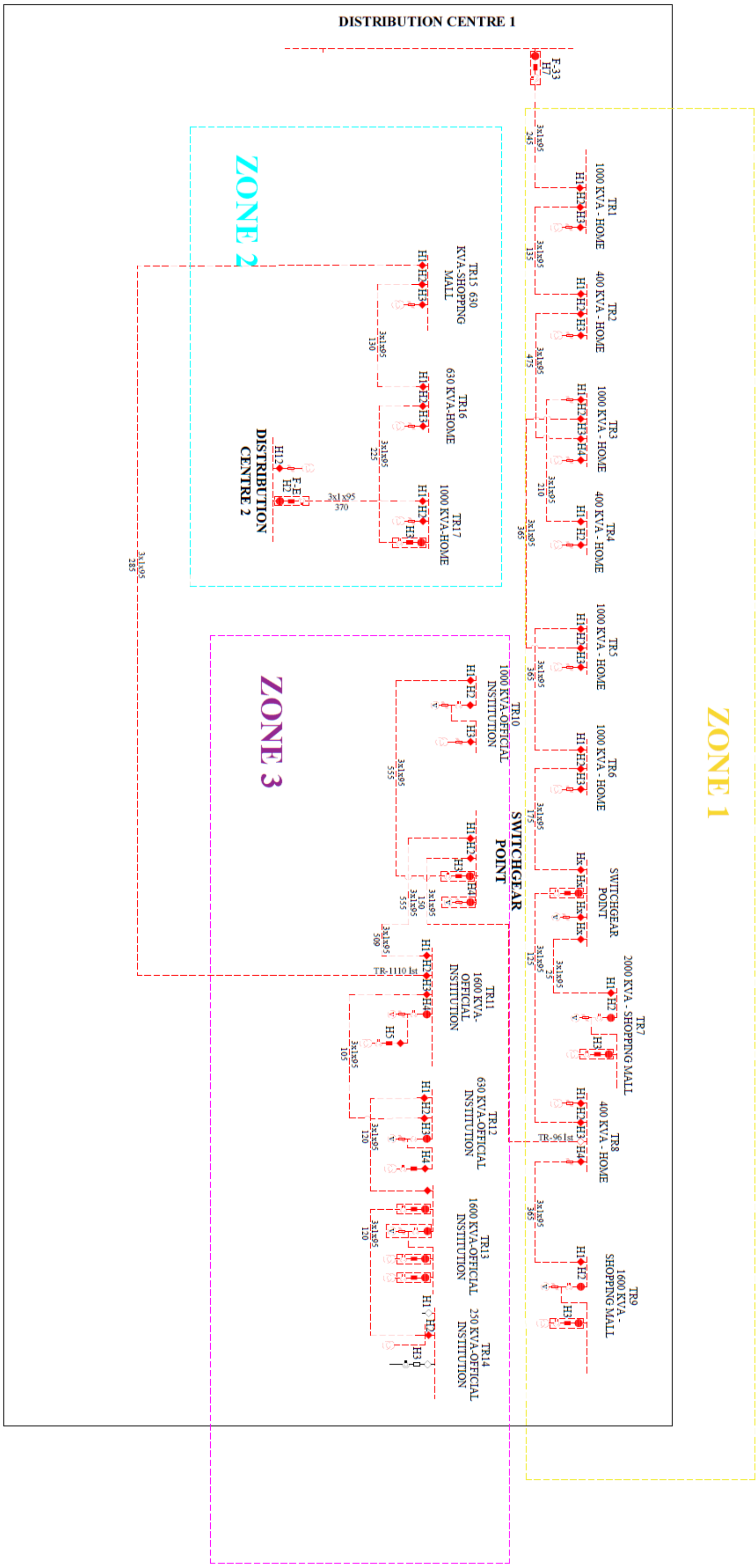

Figure 3.1. Single line diagram of sample network

Table 3.1. Specifications of sample network

Transformers		Distribution Line Cable XLPE 3×1×95 mm^2		Loads	
TR	Power	Line	Length / ohm	Load	Power
TR1	1000 kVA	Line1	245 m / 0.047 ohm	Load1-2	400+400 kVA
TR2	400 kVA	Line2	135 m / 0.03 ohm	Load3-4	200+200 kVA
TR3	1000 kVA	Line3	475 m / 0.077 ohm	Load5-6	400+400 kVA
TR4	400 kVA	Line4	210 m / 0.038 ohm	Load7-8	200+200 kVA
TR5	1000 kVA	Line5	365 m / 0.085 ohm	Load9-10	400+400 kVA
TR6	1000 kVA	Line6	365 m / 0.085 ohm	Load11-12	400+400 kVA
TR7	2000 kVA	Line7	175 m / 0.045 ohm	Load13-14	800+800 kVA
TR8	400 kVA	Line8	25 + 125 m / 0.01+0.03 ohm	Load15-16	200+200 kVA
TR9	1600 kVA	Line9	365 m / 0.085 ohm	Load17-18	600+600 kVA
TR10	1000 kVA	Line10	25 + 700 m / 0.001+0.15 ohm	Load19-20	400+400 kVA
TR11	1600 kVA	Line11	10+1000 m / 0.01+0.193 ohm	Load21-22	600+600 kVA
TR12	630 kVA	Line12	15+100 m / 0.01+0.001 ohm	Load23-24	250+250 kVA
TR13	1600 kVA	Line13	120 m / 0.02 ohm	Load25-26	600+600 kVA
TR14	250 kVA	Line14	20+120 m / 0.01+0.02 ohm	Load27-28	100+100 kVA
TR15	630 kVA	Line15	30+285 m / 0.01+0.05 ohm	Load29-30	250+250 kVA
TR16	630 kVA	Line16	22+130 m / 0.01+0.03 ohm	Load31-32	250+250 kVA
TR17	1000 kVA	Line17	225 m / 0.04 ohm	Load33-34	400+400 kVA

3.2. General Structure of Simulation

The sample network, which is a ring network and is fed from DC1 and DC2, has been modeled and simulated using MATLAB/Simulink blocksets. The transformers, distribution lines, and loads have been modeled according to their operating characteristics. The simulation model of the sample network is illustrated in Figure 3.2.

In the simulation model, parameters of transformers have been determined considering the sample network. The parameters have been arranged by using three phase transformer model of Simulink.

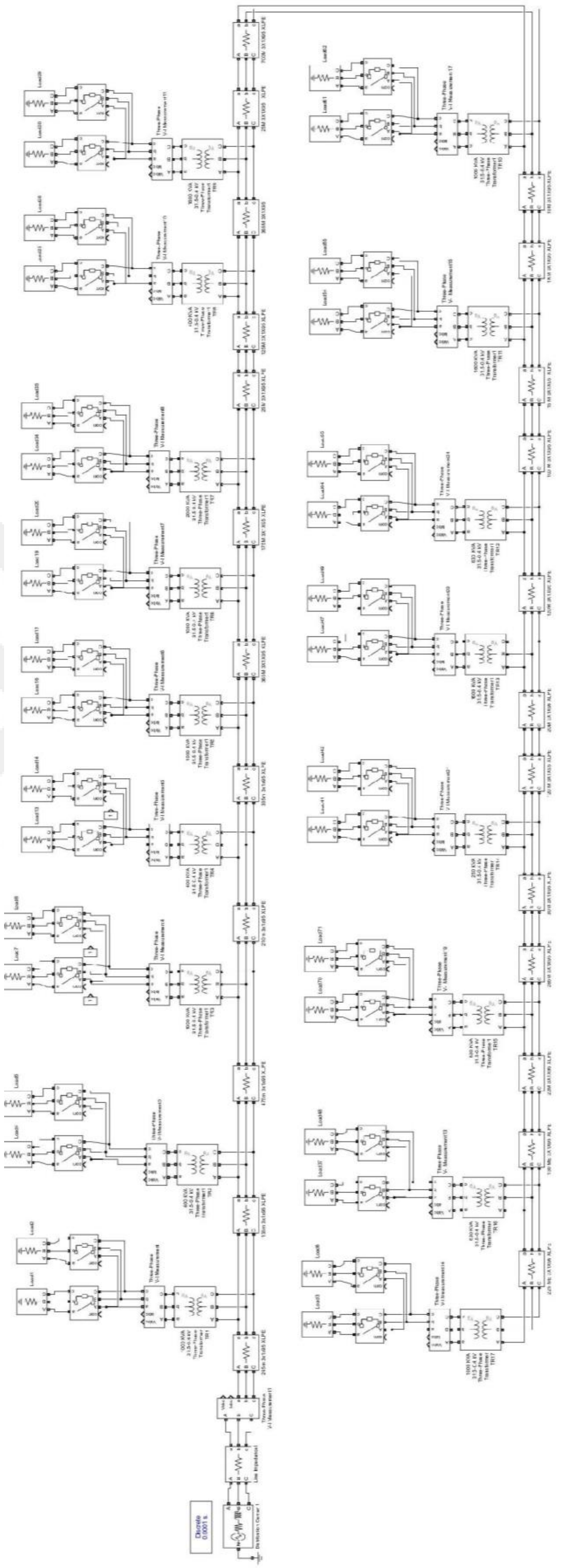

Figure 3.2. Simulation model of the sample network

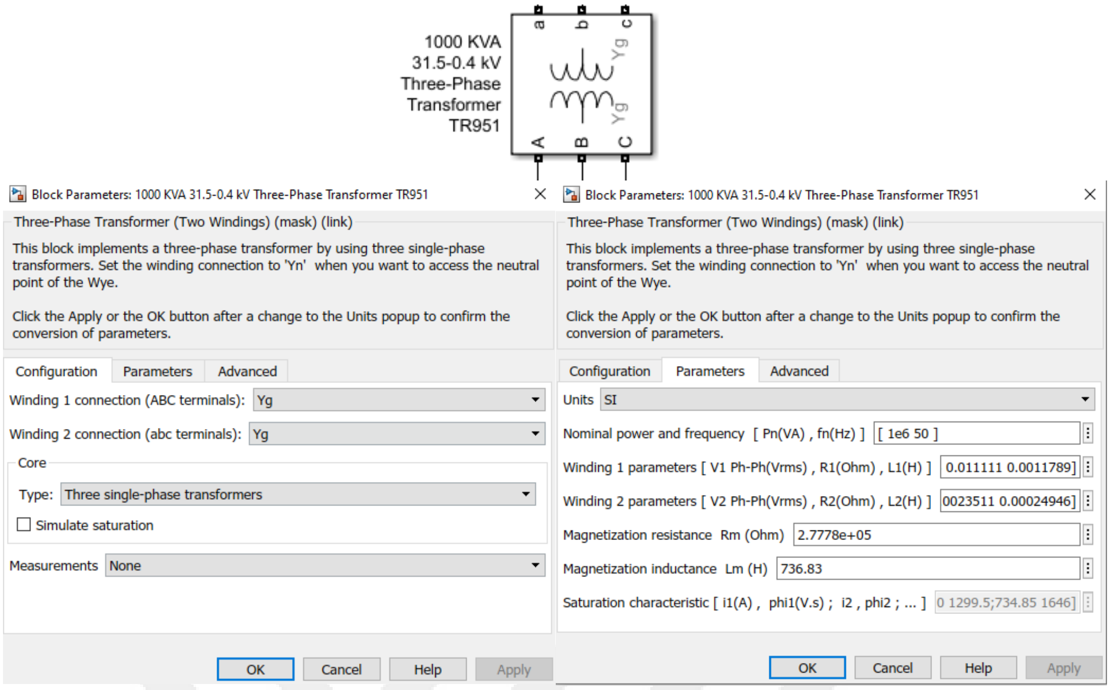

Figure 3.3. Three phase transformer model and parameter setting block

Different types of conductors are used in distribution lines. All conductors XLPE cable type but the length of the conductors differ from each other. The cable parameters in the simulation model are determined by considering the cable parameters of ohm/length given in the datasheet and the length of the related lines. The distribution line cables are modeled by using a three-phase RLC branch in Simulink. The cable model and parameter setting block are illustrated in Figure 3.4.

Loads are modeled considering the consumption values of the sample network. The load parameters are listed in Table 1. Three phase line breakers are used in the network to control the power flow of loads. The blocksets and parameter settings are illustrated in Figure 3.5.

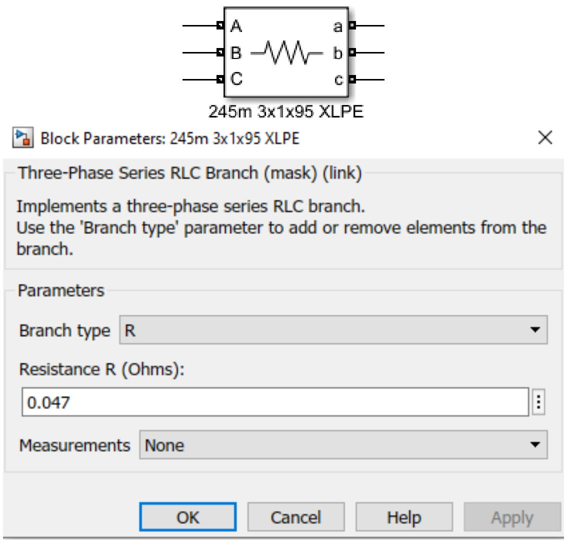

Figure 3.4. Cable model and parameter setting block

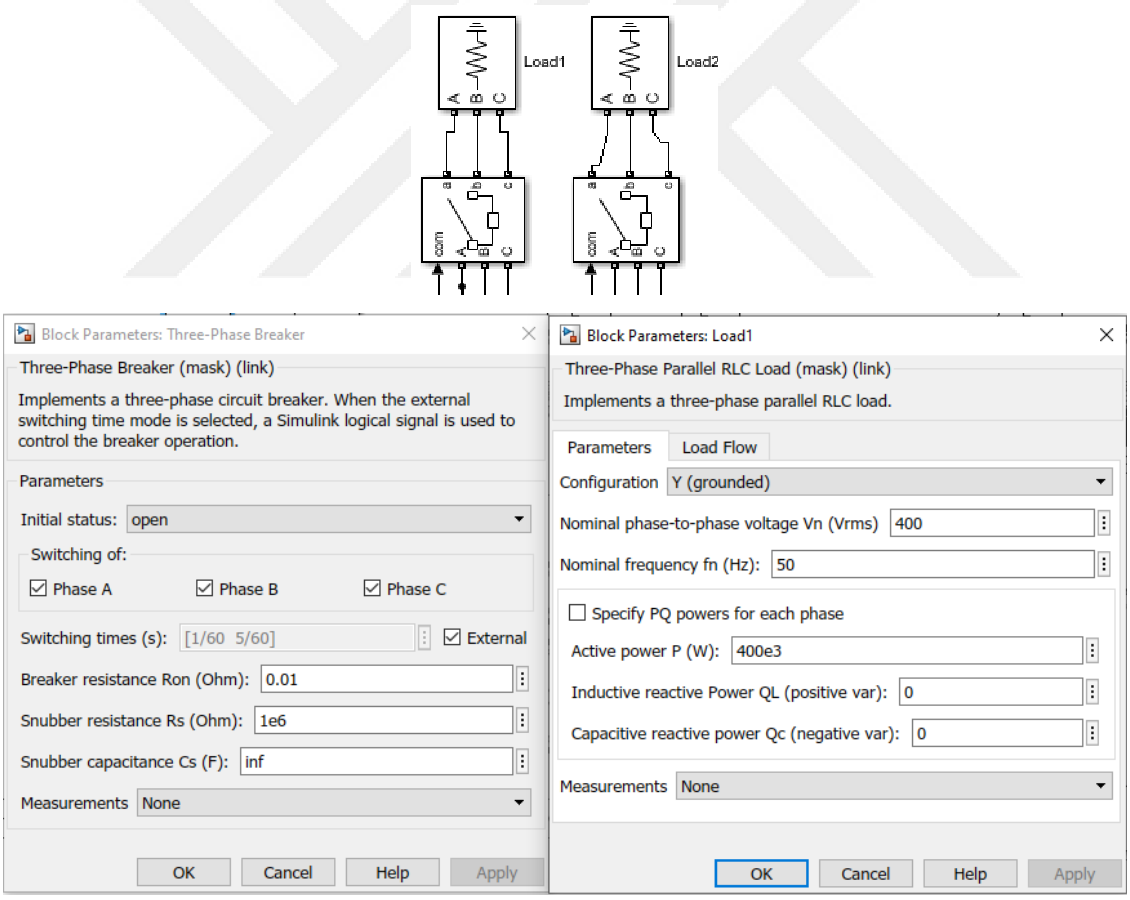

Figure 3.5. Line breakers, load models, and parameter setting blocks

The sample network area is fed from two different distribution centers as DC1 and DC2. However, the proof-of-concept network is modeled to be fed from a single-center, since the interruption situation or relay coordination will not be examined in the simulation model. In order to model the three-phase source, three-phase source block is shown in Figure 3.6 is used, and parameters are arranged considering the sample network. The phase-to-phase voltage of DC1 has been set as 31.5 kV.

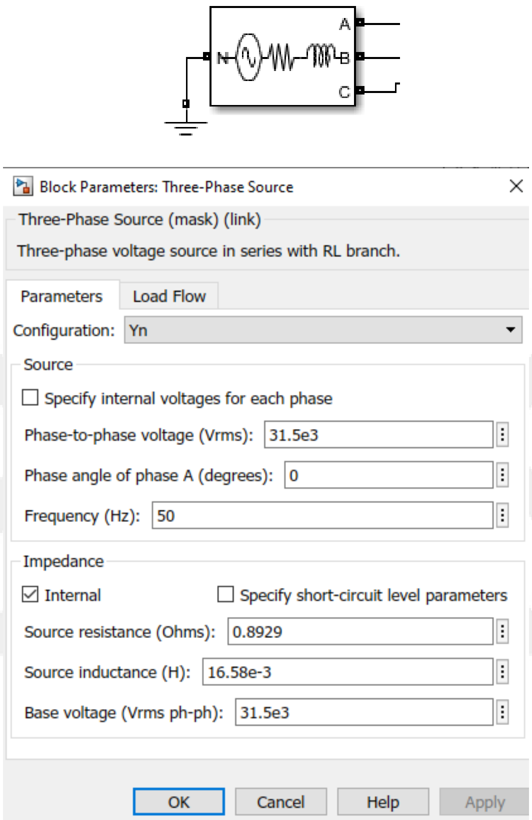

Figure 3.6. Three-phase source model and parameter setting blocks

3.3. Simulation Results of Sample Network

In this section, the performance investigation of the sample network has been performed in Simulink environment in terms of existing loading of transformers, power quality issues of the ring network, and voltage regulations. The performance investigation of the network has been conducted considering the dynamic load profiles. The dynamic load profiles are given as variations in the electrical power versus time for 24-h. The loading data has been captured from the electricity distribution company that is responsible for the related area. Figure 3.7 presents the load profile for hourly energy consumption per day. It shows that local loads consume more power during the day than night consumption. The instantaneous energy consumption values are 8300 MW and 8400 MW at 11:00-12:00 and 12:00-13:00, respectively. The energy consumption values during night hours decreases up to 4200 MW.

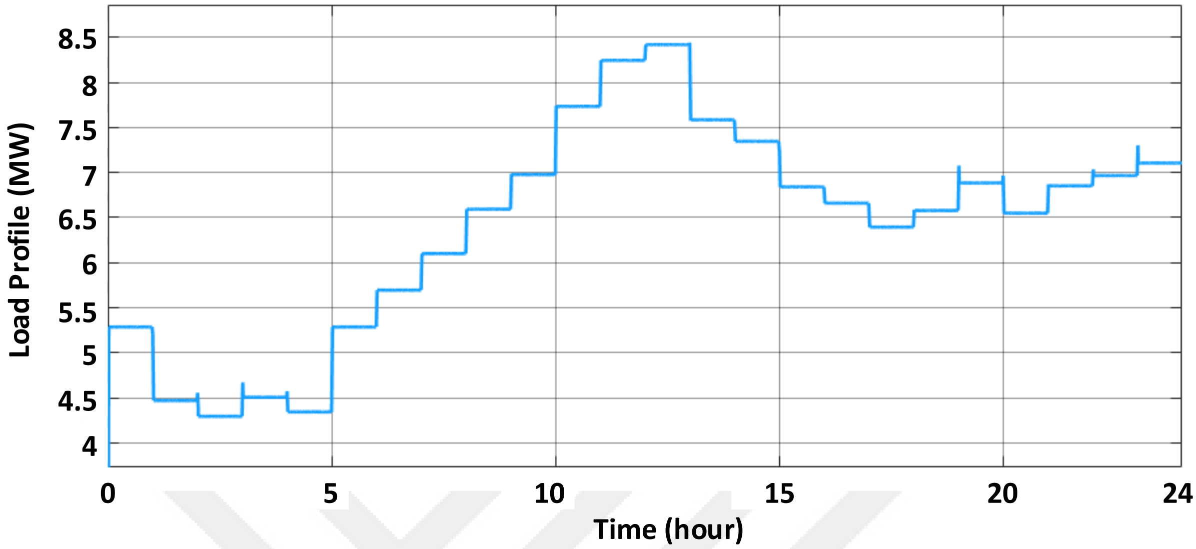

Figure 3.7. Load profile energy consumption values in hourly

The ring network consisting of a 6 km distance has been fed from DC1 with 31.5 kV. The sample network's simulation model illustrated in Figure 3.2 is composed of distribution line cables. The internal resistances of all cables are modeled according to the distance of the lines and datasheet values. The voltage values between the first load and the last load varies within 1-2 V because of the line losses. The distribution line voltage level is high with 31.5 kV. Because of this reason, the nominal currents of lines are relatively small and less than the low voltage distribution lines. Therefore, the line losses and voltage regulation values are relatively small in comparison with low voltage distribution lines. Figure 3.8 shows the RMS voltage trends of all loads during daily load conditions as can be seen from the figure that the voltage levels vary considering the loading conditions and distance from the central transformer.

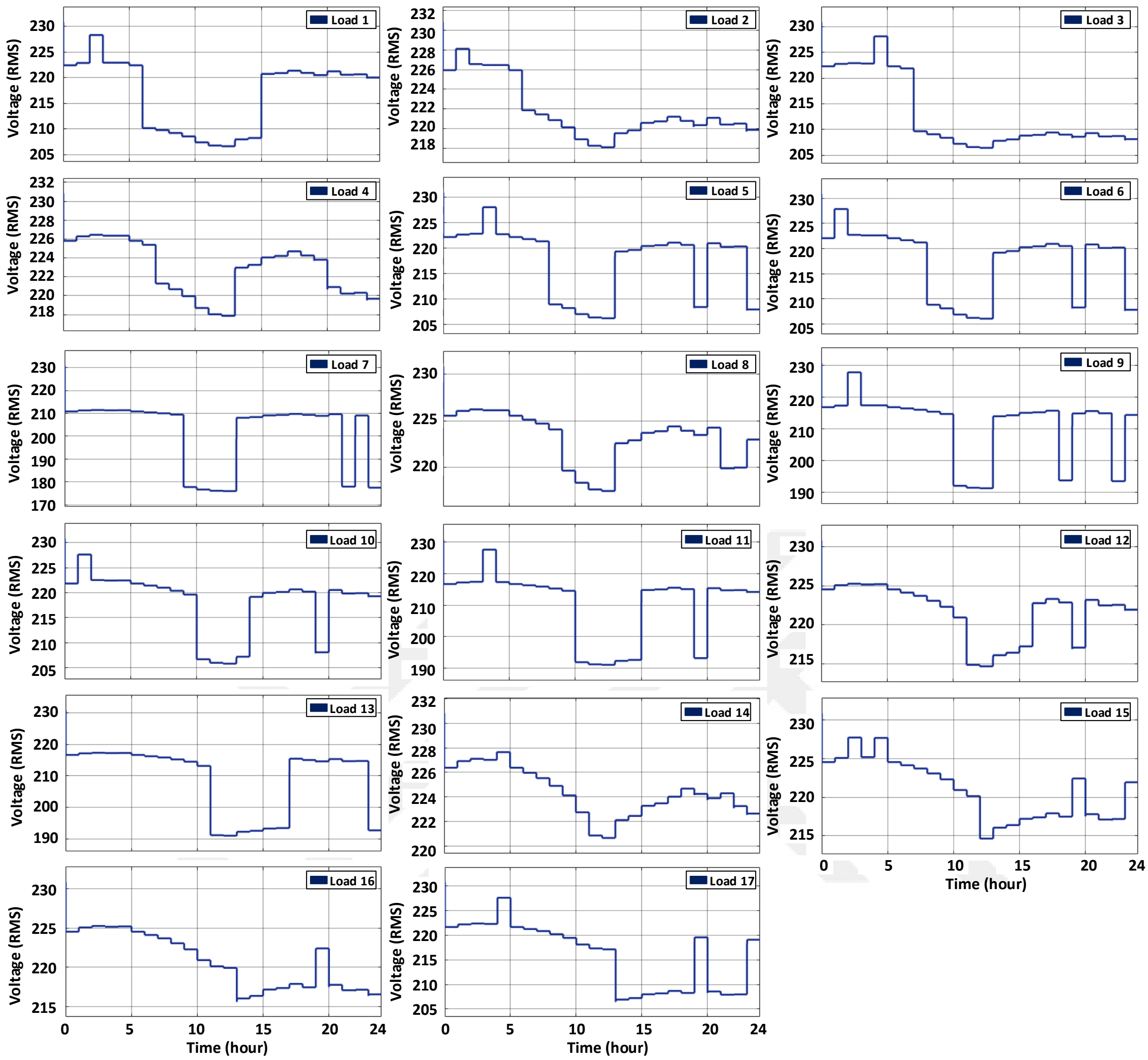

Figure 3.8. RMS voltage trends of loads

This thesis also investigates the effects of charging stations on the power quality issue of the grid. Therefore, the harmonics and total harmonic distortion of input current have been examined. During the operation with/without charging stations, it is assumed that the power consumption of all loads is resistive. The current waveform of DC1 is given in Figure 3.9. As can be seen from the figure, the current trend varies according to the demanded daily load profile of the ring network.

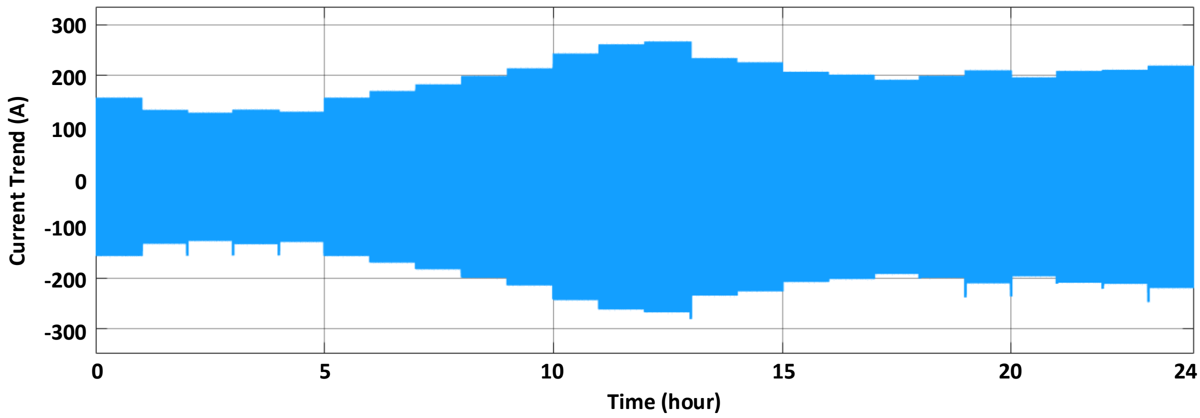

Figure 3.9. The current trend of DC1

Nonlinear loads are generating harmonic currents. The grid network is modeled without nonlinear loads. Therefore, as illustrated in Figure 3.10, the harmonic components and THD of the input current are low in the system without charging stations.

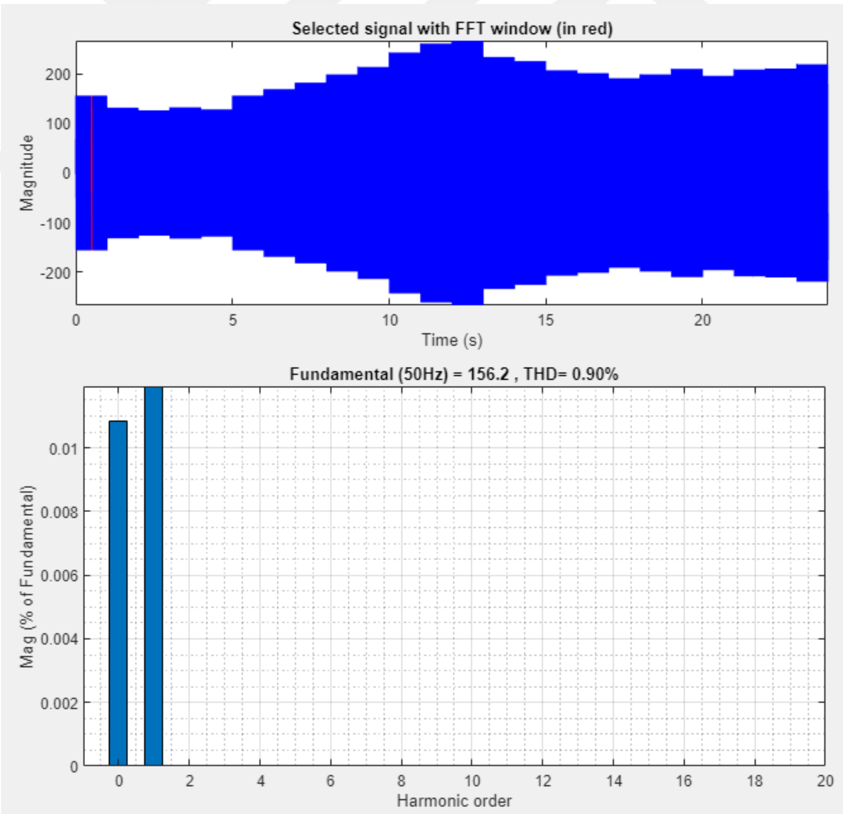

Figure 3.10. Current harmonic trend and THD of DC1

4. CHARGING STATION ALLOCATION

4.1. Allocation of Charging Stations On The Grid According to Proposed Method

In this study, the analytical hierarchy process was used while positioning the charging stations. The purpose of using the analytical hierarchy process is to give consistent results according to the specified criteria. The greatest convenience of the analytical hierarchy process is that it works on criteria determined over as many alternatives as desired. In this thesis, the study was carried out by determining four criteria and three alternative regions.

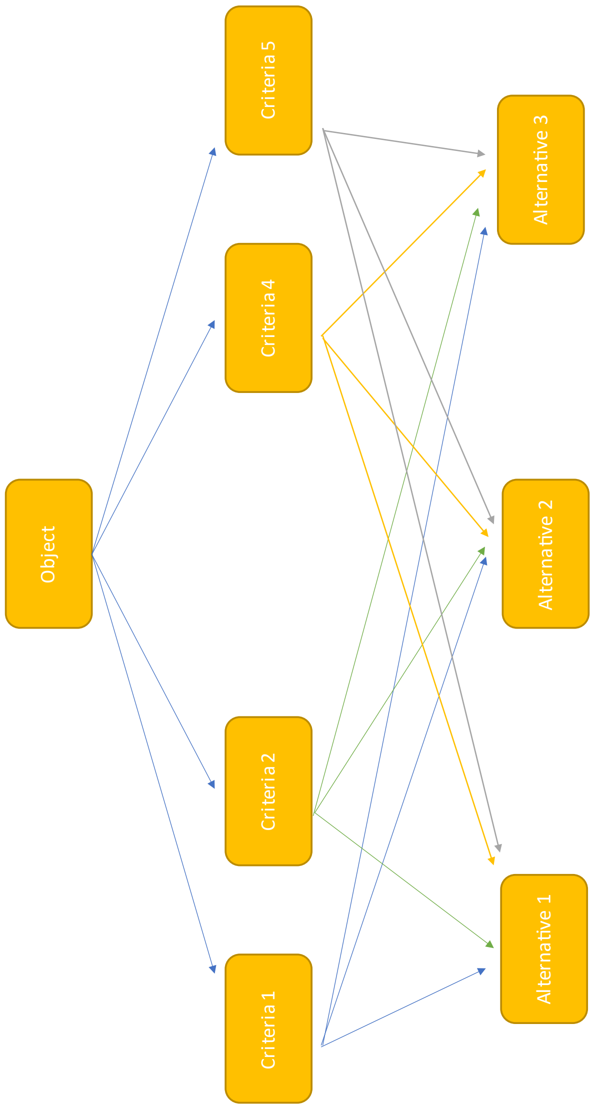

Figure 4.1. 4 Criteria 3 Alternatives AHP

While performing this study in the sample ring network, the region has been divided into 3 sub-regions, as illustrated in Figure 4.2. While determining these sub-regions, the proximity of the regions to each other has been considered.

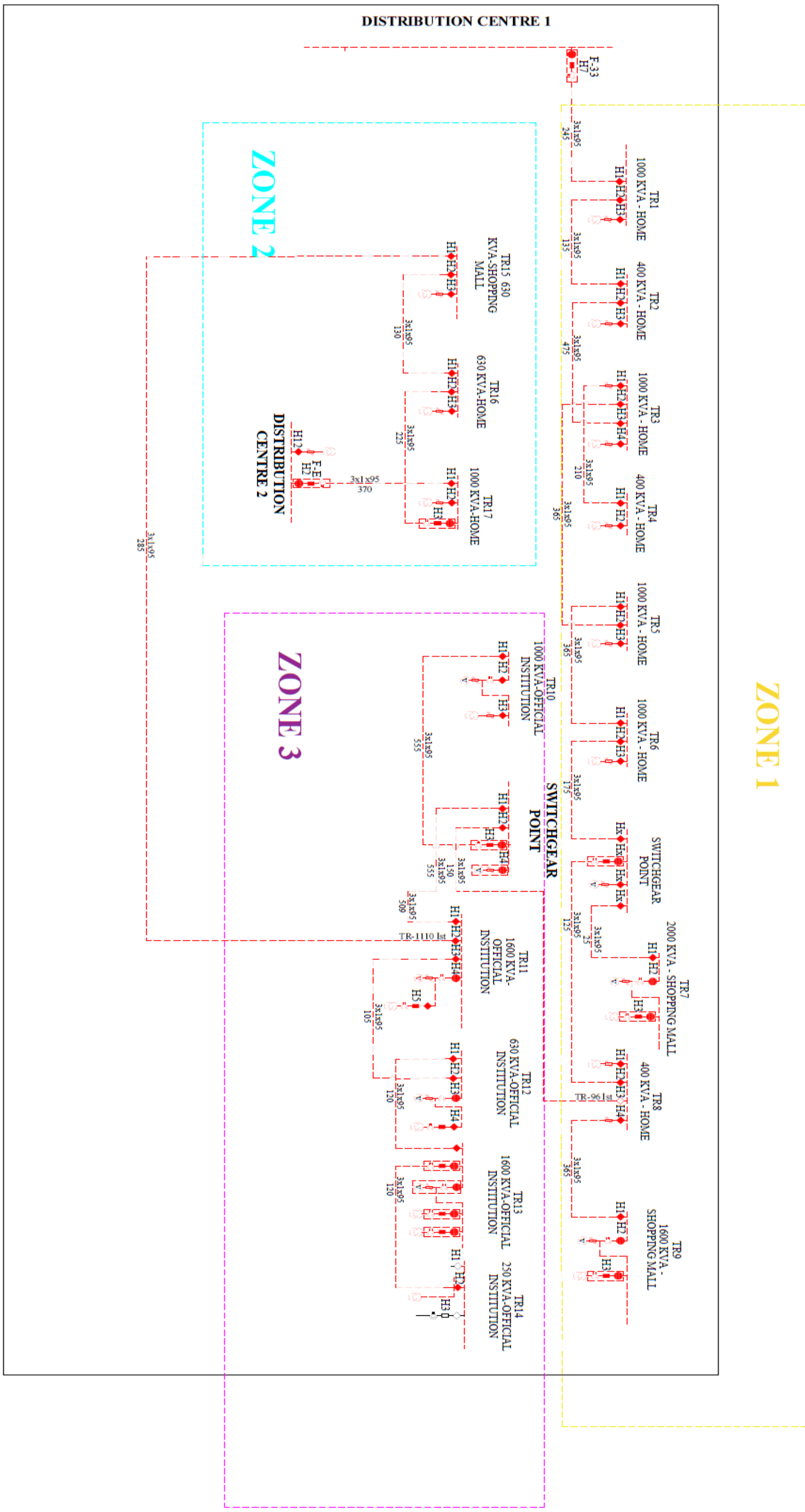

Figure 4.2. Case study region and subregions

While establishing the analytical hierarchy process, the hierarchical structure has been basically formed with seven application sequences:

1. Problem and purpose are determined
2. Setting criterias
3. Setting alternatives
4. Hierarchical structure is created
5. Pairwise comparison matrices are created
6. Priority vectors are calculated
7. Consistency analysis is done
8. Results are achieved

The main aim of the study is to determine the most suitable locations for charging stations in the sample ring network. In this regard, three sub-regions are available as an alternative, and four criteria have been determined. The first criterion is Land Cost & Area suitability. There must be a suitable area to build the charging stations of electric vehicles. For this, the land prices in the region are also important. The load density has been determined as the second criterion in this study. Especially in places where individual users are predominant, that is, where there is no industry and production, the amount of load and the number of users are directly proportional. As the third criterion, the devices' effects on the power quality have been taken. As the fourth and last criterion, the public institutions (governor's office, Social Insurance Institution, etc.) and the places where people come collectively (shopping mall, museum, etc.) has been determined as criteria.

While determining the criteria, it can increase or decrease the number of criteria. This is a situation that is completely determined by the needs and demands of the person who is the decision-maker. For the alternative, as mentioned before, the 3 sub-regions of Zone 1, Zone 2, and Zone 3 have been determined in the sample network.

1. Object: Best Place for Charging Stations
2. Criteria: Land Cost & Are Suitability, Power Density On Area, Power Quality Effect, Proximity To Official and Crowded Institutions
3. Alternatives: Zone 1, Zone 2, Zone 3
4. A hierarchical structure is created:

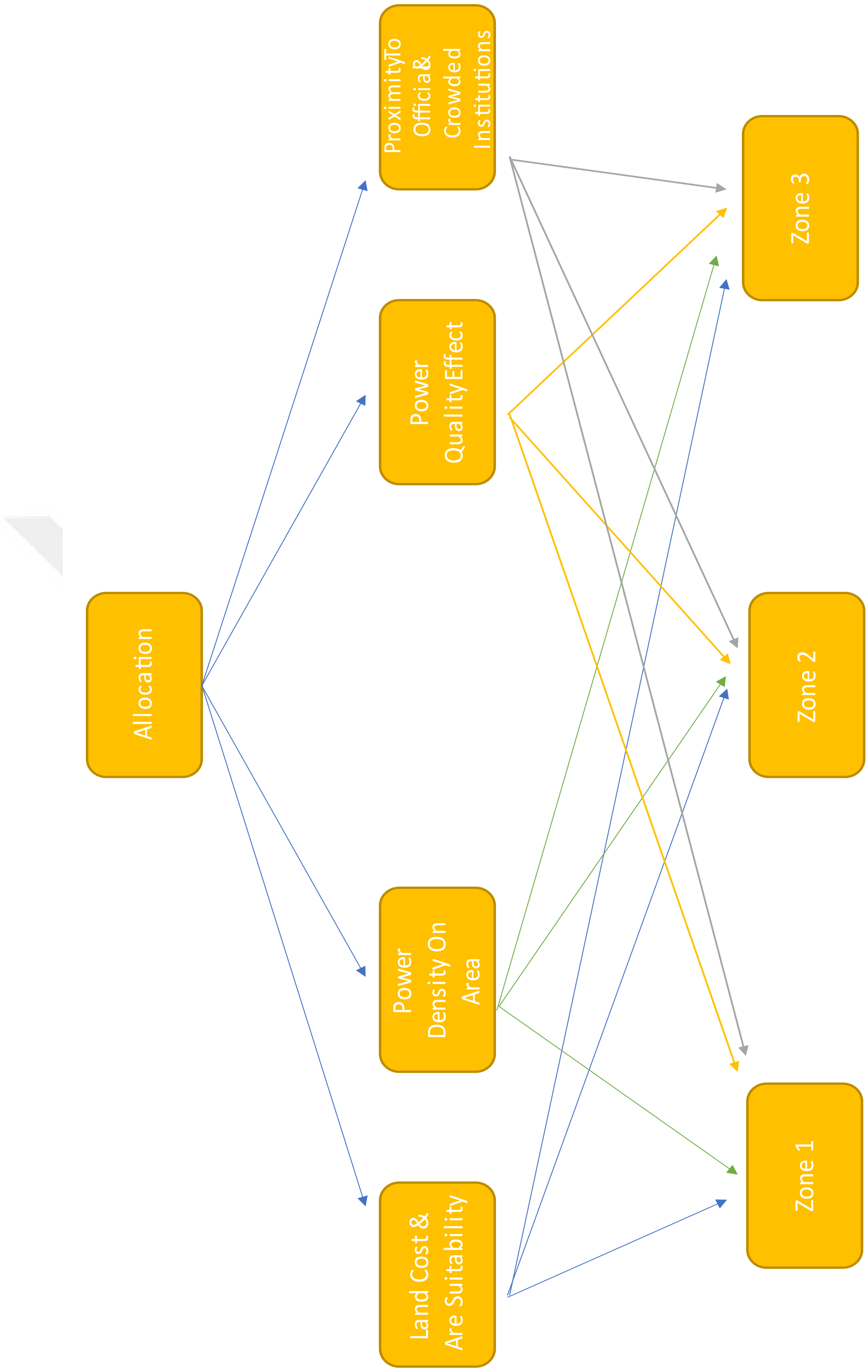

Figure 4.3. Created Hierarchical Structure, Object, Criteria, and Alternatives

Table 4.1. Salty's Scale Of Comparison

Salty's Scale Of Comparison	
Importance level	**Definition**
1	Equally important
3	One criterion is considered slightly more important than the other
5	One criterion was deemed much more important than the other.
7	The criterion was definitely considered much more important than the other criterion.
9	One criterion is extremely important than another.
2,4,6,8	Intermediate values (compromise values)

5. The tables for each criterion using the standard preference table for Proximity To Official& Crowded Institutions has been formed:

Table 4.2. Comparison Table for Proximity To Official& Crowded Institutions

	Proximity To Official& Crowded Institutions		
	Zone 1	Zone 2	Zone 3
Zone 1	1	3	1
Zone 2	1/3	1	1/5
Zone 3	1	5	1

Comparison matrices have been created according to the criteria of the decision maker. Following forming, the comparison matrices are normalized. Normalization is performed by dividing each element in the matrix by its column sum. In a normalized matrix, the sum of each column is equal to 1.

Table 4.3. Common Comparison Matrix for Proximity To Official & Crowded Institutions

	Proximity To Official& Crowded Institutions		
	Zone 1	Zone 2	Zone 3
Zone 1	1	3	1
Zone 2	0.33	1	0.2
Zone 3	1	5	1
Total:	2.33	9	2.2

Table 4.4. Normalized Comparison Table For Proximity To Official& Crowded Institutions

	Proximity To Official& Crowded Institutions		
	Zone 1	Zone 2	Zone 3
Zone 1	1 / 2.33= 0.43	3 / 9 = 0.33	1 / 2.2 = 0.45
Zone 2	0.33/2.33 = 0.14	1 / 9 = 0.11	0.2 / 2.2 = 0.09
Zone 3	1 / 2.33 = 0.43	5 / 9 = 0.56	1 / 2.2 = 0.45
Total:	1	1	1

The priority vector is formed by averaging each row of the normalized matrix.

Table 4.5. Normalized Comparison Table with Priorty Vector

	Proximity To Official& Crowded Institutions			
	Zone 1	Zone 2	Zone 3	Priority Vector (w)
Zone 1	0.43	0.33	0.45	(0.43+0.33+0.45) / 3 = 0.4055
Zone 2	0.14	0.11	0.09	(0.14+0.11+0.09) / 3 = 0.115
Zone 3	0.43	0.56	0.45	(0.43+0.56+0.45) / 3 = 0.4795
Total:	1	1	1	1

While performing AHP, it should be checked that the results are consistent. If the consistency value is greater than 0.10 after the consistency test, the decision-maker should be asked to change the pairwise comparison matrix.

$$\text{Consistency Rate} = CR = CI/RI \qquad (2)$$

where CI= Consistency Index, RI=Random Index

RI values (T. L. Saaty,1980)

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.53	1.56	1.57	1.59

The eigenvalue lambda is calculated by multiplying the comparison matrix with the priority vector.

$$A.w=\begin{bmatrix} a11 & a21 \ldots\ldots.\ldots. & a1n \\ a12 & a22 \ldots.\ldots\ldots & a2n \\ & \ldots\ldots \quad \ldots\ldots.\ldots\ldots\ldots & \\ a1m & a2m \ldots\ldots\ldots. & amn \end{bmatrix}\begin{bmatrix} w1 \\ w2 \\ w.. \\ wn \end{bmatrix} = \lambda \tag{3}$$

Consistency Index= $CI = \frac{\lambda\text{max}-\text{n}}{n-1}$

$$A.w=\begin{bmatrix} 1 & 3 & 1 \\ 1/3 & 1 & 1/5 \\ 1 & 5 & 1 \end{bmatrix}\begin{bmatrix} 0.4055 \\ 0.09 \\ 0.45 \end{bmatrix} = \begin{bmatrix} 1.1255 \\ 0.3138 \\ 1.305 \end{bmatrix} \tag{4}$$

$$\frac{A.w}{w}=\begin{bmatrix} 1.1255\ /0.4055 \\ 0.3138\ /0.09 \\ 1.305\ /0.45 \end{bmatrix} = \begin{bmatrix} 2.775 \\ 3.486 \\ 2.9 \end{bmatrix} \tag{5}$$

$$\lambda\text{max}= (2.775+3.486+2.9)\ /3 = 3.05 \tag{6}$$

$$= CI = \frac{\lambda\text{max}-\text{n}}{n-1} = CI = \frac{3.05-3}{3-1} = 0.025 \tag{7}$$

$$CR = \frac{CI}{RI} = \frac{0.025}{0.58} = 0.0431 < 0.10 \text{ so matrix is consistent.} \tag{8}$$

Tables are created for each criterion using the standard preference table for Power Density in the field:

Table 4.6. Comparison Table for Power Density on Area

Power Density on Area			
	Zone 1	Zone 2	Zone 3
Zone 1	1	6	1 / 3
Zone 2	1/6	1	1 / 9
Zone 3	3	9	1

Table 4.7. Common Comparison Matrix for Power Density on Area

Power Density on Area			
	Zone 1	Zone 2	Zone 3
Zone 1	1	6	0.33
Zone 2	0.16	1	0.11
Zone 3	3	9	1
Total:	4.16	16	1.44

Table 4.8. Normalized Comparison Matrix for Power Density on Area

Power Density on Area			
	Zone 1	Zone 2	Zone 3
Zone 1	1 / 4.16 = 0.24	6 / 16 = 0.37	0.33 / 1.44 = 0.23
Zone 2	0.16 / 4.16 = 0.038	1 / 16 = 0.0625	0.11 / 1.44 = 0.07
Zone 3	3 / 4.16 = 0.72	9 / 16 = 0.57	1 / 1.44 = 0.7
Total:	1	1	1

The priority vector is formed by averaging each row of the normalized matrix.

Table 4.9. Normalized Comparison Table with Priorty Vector

Power Density on Area				
	Zone 1	Zone 2	Zone 3	Priority Vector (w)
Zone 1	0.24	0.37	0.23	(0.24+0.37+0.23) / 3 = 0.28
Zone 2	0.038	0.0625	0.07	(0.038+0.0625+0.07) / 3 = 0.057
Zone 3	0.72	0.57	0.7	(0.72+0.57+0.7) / 3 = 0.66
Total:	1	1	1	1

$$A.w = \begin{bmatrix} 1 & 6 & 1/3 \\ 1/6 & 1 & 1/9 \\ 3 & 9 & 1 \end{bmatrix} \begin{bmatrix} 0.28 \\ 0.057 \\ 0.66 \end{bmatrix} = \begin{bmatrix} 0.839 \\ 0.222 \\ 2.01 \end{bmatrix} \quad (9)$$

$$\frac{A.w}{w} = \begin{bmatrix} 0.839/0.28 \\ 0.222/0.057 \\ 2.01/0.66 \end{bmatrix} = \begin{bmatrix} 2.99 \\ 3.80 \\ 3.045 \end{bmatrix} \quad (10)$$

$$\lambda max = (2.99+3.80+3.045)/3 = 3.25 \quad (11)$$

$$CI = \frac{\lambda max - n}{n-1} \; CI = \frac{3.25-3}{4-1} = 0.083 \quad (12)$$

$$CR = \frac{CI}{RI} = \frac{0.1}{0.9} = 0.092 < 0.1 \text{ so matrix is consistent} \quad (13)$$

Tables have been created for each criterion using the standard preference table for Power Quality Impact:

Table 4.10. Comparison Table For Power Quality Effect

	Power Quality Effect		
	Zone 1	Zone 2	Zone 3
Zone 1	1	1 / 3	1
Zone 2	3	1	5
Zone 3	1	0.2	1

Table 4.11. Common Comparison Matrix for Power Quality Effect

	Power Quality Effect		
	Zone 1	Zone 2	Zone 3
Zone 1	1	0.33	1
Zone 2	3	1	5
Zone 3	1	0.2	1

Total:	5	1.53	7

Table 4.12. Normalized Comparison Matrix for Power Quality Effect

	Power Quality Effect		
	Zone 1	Zone 2	Zone 3
Zone 1	1 / 5 = 0.2	0,33 / 1.53 = 0.215	1 / 7 = 0.142
Zone 2	3 / 5 = 0.6	1 / 1.53= 0.653	5 / 7 = 0.714
Zone 3	1/ 5 = 0.2	0.2 / 1.53 = 0.13	1 / 7 = 0.142
Total:	1	1	1

Table 4.13. Normalized Comparison Table with Priority Vector

	Power Quality Effect			
	Zone 1	Zone 2	Zone 3	Priority Vector (w)
Zone 1	0.2	0.215	0.142	(0.2+0.215+0.142) / 3 = 0.185
Zone 2	0.6	0.653	0.714	(0.6+0.653+0.714) / 3 = 0.655
Zone 3	0.2	0.13	0.142	(0.2+0.13+0.142) / 3 = 0.157
Total:	1	1	1	1

$$A.w= \begin{bmatrix} 1 & 1/3 & 1 \\ 3 & 1 & 5 \\ 1 & 1/5 & 1 \end{bmatrix} \begin{bmatrix} 0.185 \\ 0.655 \\ 0.157 \end{bmatrix} = \begin{bmatrix} 0.531 \\ 1.86 \\ 0.446 \end{bmatrix} \quad (14)$$

$$\frac{A.w}{w} = \begin{bmatrix} 0.531/0.185 \\ 1.86/0.655 \\ 0.446/0.157 \end{bmatrix} = \begin{bmatrix} 2.87 \\ 2.83 \\ 2.84 \end{bmatrix} \quad (15)$$

$$\lambda max= (2.87+2.83+2.84)/3=2.846 \quad (16)$$

$$CI = \frac{\lambda max - n}{n-1} \; CI = \frac{2.846-3}{4-1} = -0.05 \quad (17)$$

$$CR = \frac{CI}{RI} = \frac{-0.05}{0.9} = -0.055 < 0.1 \text{ so matrix is consistent} \qquad (18)$$

Tables have been created for each criterion using the standard preference table for Proximity Cost and Site Availability:

Table 4.14. Comparison Table Land Cost & Area Suitability

Land Cost & Area Suitability			
	Zone 1	Zone 2	Zone 3
Zone 1	1	1 / 3	1 / 2
Zone 2	3	1	3
Zone 3	2	1 / 3	1

Table 4.15. Typical comparison Table Land Cost & Area Suitability

Land Cost & Area Suitability			
	Zone 1	Zone 2	Zone 3
Zone 1	1	0.33	0.5
Zone 2	3	1	3
Zone 3	2	0.33	1
Total:	6	1.66	4.5

Table 4.16. Normalized comparison Table Land Cost & Area Suitability

Land Cost & Area Suitability			
	Zone 1	Zone 2	Zone 3
Zone 1	1 / 6 = 0.166	0.33 / 1.66 =0.198	0.5 / 4.5 = 0.11
Zone 2	3 / 6 = 0.5	1 / 1.66 = 0.602	3 / 4.5 = 0.66
Zone 3	2 / 6 = 0.33	0.33 /1.66 = 0.198	1 / 4.5 = 0.22
Total:	1	1	1

Table 4.17. Normalized Comparison Table with Priorty Vector

Land Cost & Area Suitability				
	Zone 1	Zone 2	Zone 3	Priority Vector (w)
Zone 1	0.166	0.198	0.11	(0.166+0.198+0.11) / 3 = 0.158
Zone 2	0.5	0.602	0.66	(0.5+0.602+0.66) / 3 = 0.587
Zone 3	0.33	0.198	0.22	(0.33+0.198+0.22) / 3 = 0.25
Total:	1	1	1	1

$$A.w= \begin{bmatrix} 1 & 1/3 & 1/2 \\ 3 & 1 & 3 \\ 2 & 1/3 & 1 \end{bmatrix} \begin{bmatrix} 0.158 \\ 0.587 \\ 0.25 \end{bmatrix} = \begin{bmatrix} 0.401 \\ 1.81 \\ 0.759 \end{bmatrix} \quad (19)$$

$$\frac{A.w}{w} = \begin{bmatrix} 0.401/0.158 \\ 1.81/0.587 \\ 0.759/0.25 \end{bmatrix} = \begin{bmatrix} 2.53 \\ 3.08 \\ 3.03 \end{bmatrix} \quad (20)$$

$$\lambda max= (2.53+3.08+3.03)/3=2.88 \quad (21)$$

$$CI = \frac{\lambda max - n}{n-1} = CI = \frac{2.88-3}{4-1} = -0.04 \quad (22)$$

$$CR = \frac{CI}{RI} = \frac{-0.04}{0.9} = -0.044 < 0.1 \text{ so matrix is consistent} \quad (23)$$

Comparison matrices have been applied between the alternatives to be selected until this stage. A comparison matrix now needs to be applied to determine the order of importance between the criteria.

Table 4.18. Comparison Table for Critera

Criteria	Land Cost & Area Suitability	Power Density on Area	Power Quality Effect	Proximity To Official& Crowded Institutions
Proximity To Official& Crowded Institutions	1	1/5	3	4
Power Density on Area	5	1	9	7
Power Quality Effect	1/3	1/9	1	1
Land Cost & Area Suitability	1/4	1/7	1	1

Table 4.19. Comparison Table for Criteria

Criteria	Land Cost & Area Suitability	Power Density on Area	Power Quality Effect	Proximity To Official& Crowded Institutions
Proximity To Official& Crowded Institutions	1	0.2	3	4
Power Density on Area	5	1	9	7
Power Quality Effect	0.33	0.11	1	1
Land Cost & Area Suitability	0.25	0.142	1	1
Total	6.58	1.45	14	13

Table 4.20. Normalized matrix for Criteria

Criteria	Land Cost & Area Suitability	Power Density on Area	Power Quality Effect	Proximity To Official& Crowded Institutions
Proximity To Official& Crowded Institutions	0.151	0.137	0.214	0.30
Power Density on Area	0.759	0.69	0.642	0.538
Power Quality Effect	0.05	0.075	0.071	0.076
Land Cost & Area Suitability	0.037	0.097	0.071	0.076
Total	1	1	1	1

Table 4.21. Normalized Comparison Table with Priorty Vector

Criteria	Land Cost & Area Suitability	Power Density on Area	Power Quality Effect	Proximity To Official& Crowded Institutions	Priority Vector (w)
Proximity To Official& Crowded Institutions	0.151	0.137	0.214	0.30	(0.151+0.137+0.214+0.3)/4= 0.20
Power Density on Area	0.759	0.69	0.642	0.538	(0.759+0.69+642+0.538) /4 =0.657
Power Quality Effect	0.05	0.075	0.071	0.076	(0.05+0.075+0.071+0.076)/4 =0.068
Land Cost & Area Suitability	0.037	0.097	0.071	0.076	(0.037+0,097+0.071+0.076) = 0.070
Total	1	1	1	1	1

Table 4.22. Normalized Comparison Table with Priority Vector for Zones

	Land Cost & Area Suitability	Power Density on Area	Power Quality Effect	Proximity To Official& Crowded Institutions
Zone 1	0.4055	0.28	0.185	0.158
Zone 2	0.115	0.057	0.655	0.587
Zone 3	0.4795	0.66	0.157	0.25

Table 4.23. Normalized Comparison Table with Priority Vector for Criteria

Proximity To Official& Crowded Institutions	0.20
Power Density on Area	0.657
Power Quality Effect	0.068
Land Cost & Area Suitability	0.07

Two matrices have been obtained as a result of the calculation. One of them shows the importance weights of the criteria among themselves, while the other matrix shows the importance weights of the regions among themselves. The final weights are obtained by multiplying these two matrices.

$$\begin{bmatrix} 0.4055 & 0.28 & 0.185 & 0.158 \\ 0.115 & 0.057 & 0.655 & 0.587 \\ 0.4795 & 0.66 & 0.157 & 0.25 \end{bmatrix} x \begin{bmatrix} 0.2 \\ 0.657 \\ 0.068 \\ 0.07 \end{bmatrix} = \begin{bmatrix} 0.2887 \\ 0.14 \\ 0.557 \end{bmatrix} \quad (24)$$

Finally,

Zone 1 weight is 0.2887, Zone 2 weight is 0.14 and zone 3 weight is 0.557 according to determined criteria. So;

Table 4.24. Zone results with weights

Zones	Weights
Zone 1	%28
Zone 2	%14
Zone 3	%56

4.2. Allocation of EV Chargers on Sample Grid

Arbitrary positioning of charging stations for electric vehicles may cause significant problems in the future. Therefore, the charging stations have been positioned according to a certain logic by using the analytical hierarchy process in this thesis. While creating the hierarchical structure, the sample ring network has been divided into 3 sub-regions. Here, 4 main criteria have been determined and pairwise comparison matrices have been created.

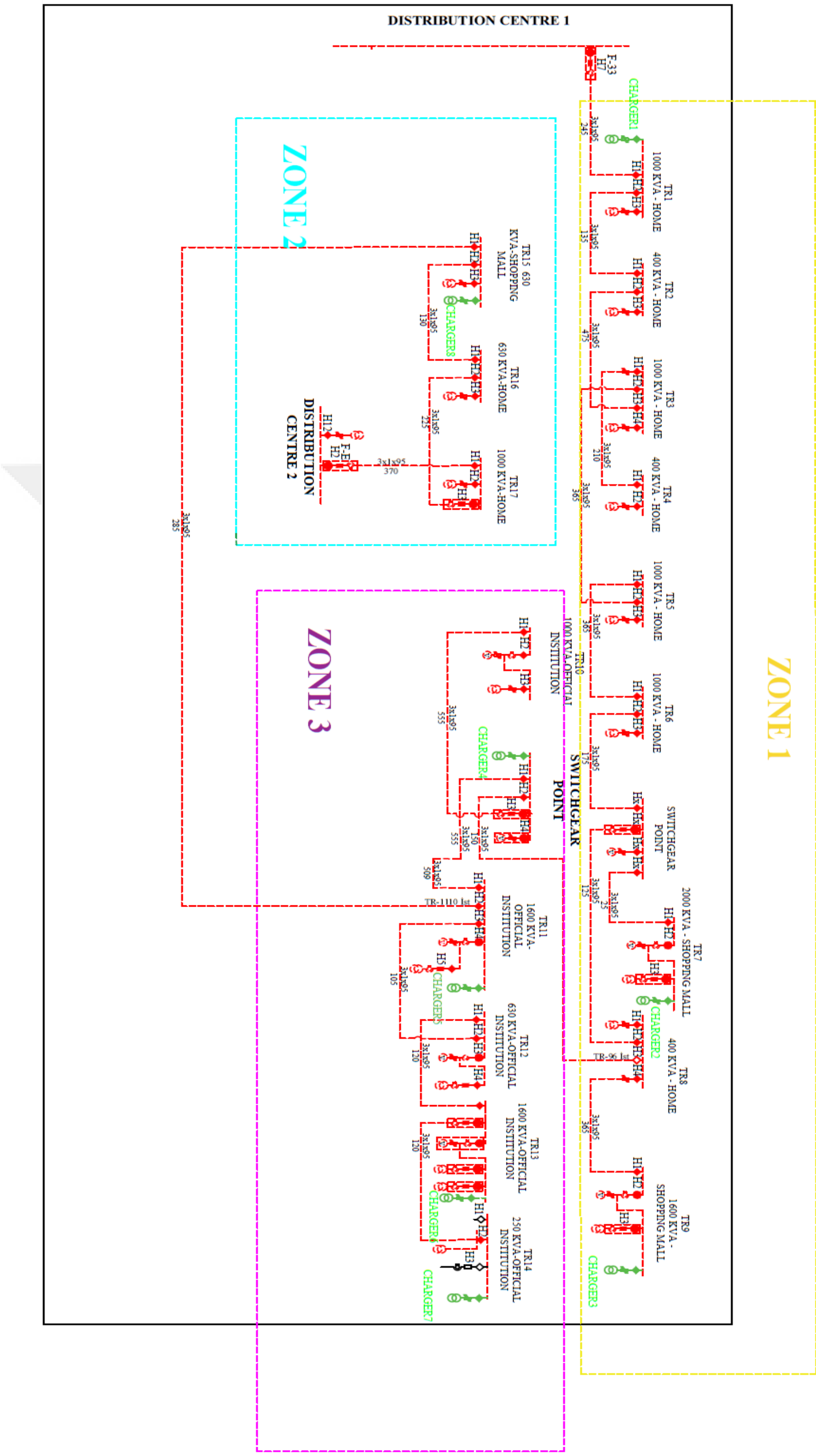

Figure 4.4. Sample Grid with EV Allocated Chargers

5. RESULTS AND DISCUSSIONS

Optimal allocation of EV charging stations is essential for widespread use of EVs, relieving the range anxiety of the users, easy access/use of users, and minimal impact on the existing grid from additional loads. To this end, the analytical hierarchy process has been used in order to allocate the charging stations. The proposed EV charging station allocation approach reveals the charging station pieces by zones. Following the layout of the charging stations according to the analytical hierarchy method, the power quality aspect has been examined. This chapter investigates the power quality effects of the charging stations on the utility grid. The results have been captured and compared with ring network modeled without charging stations.

5.1. Simulation Results With Charging Stations

The modeled network has been re-arranged, considering the results of the analytical hierarchy process. The weights of zones are computed as 0.2887, 0.14, and 0.557, respectively. Considering the weights, 3, 1, and 4 charging stations are allocated to the zones, respectively. As illustrated in Figure 5.1, the sample ring network has been re-modeled by adding the charging stations considering the results of the analytical hierarchy process. The charging stations are modeled by using 3-phase diode rectifier circuits in Simulink. There are different approaches for connecting charging stations to distribution lines. In this thesis, charging stations are connected to the high voltage distribution network. The reason is (1) to reduce power losses, (2) to mitigate power quality problems, and (3) to minimize the possibilities of existing infrastructure change. The charging stations are connected to the high voltage lines with their transformers. The model is illustrated in Figure 5.2.

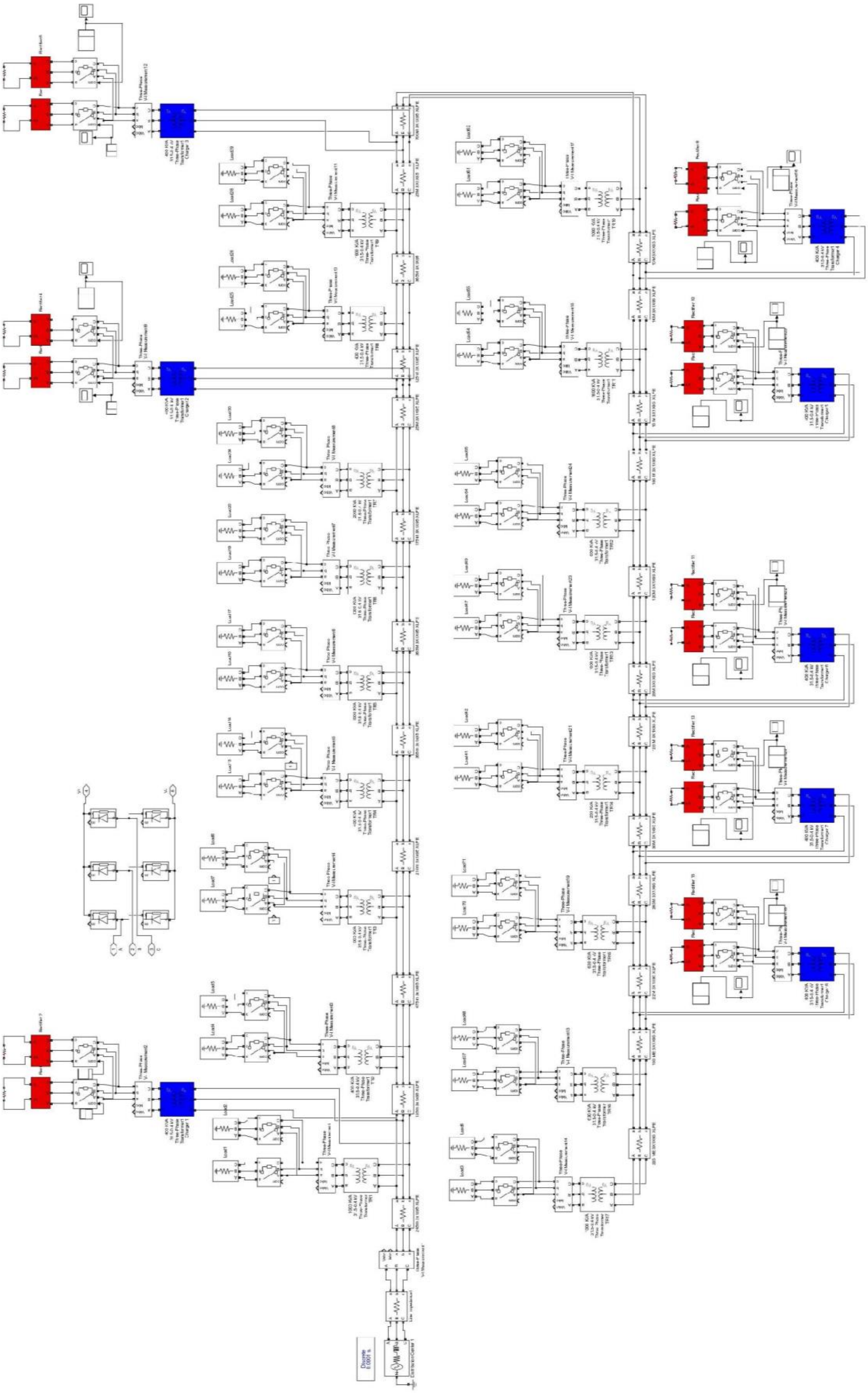

Figure 5.1. Simulation model of sample network with charging stations

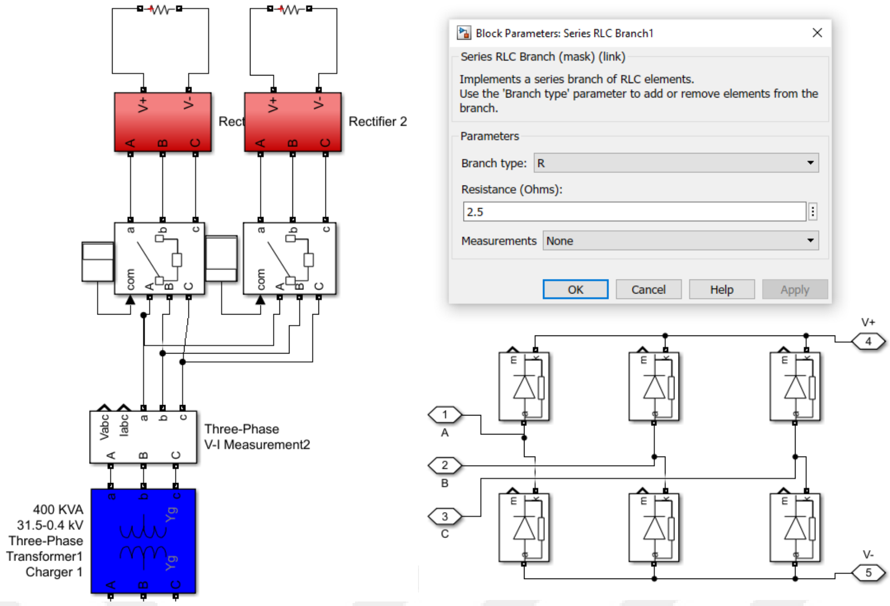

Figure 5.2. Charging station model

The performance validation of the optimal allocation has been performed using the dynamic load profile given in Chapter 3. The performance investigation has been performed under the same dynamic load profile for the ring network modeled with and without charging stations. Figure 5.4 presents the load profile, including the power consumption of charging stations for hourly energy consumption per day. It shows that local loads consumptions have been increased with charging stations in comparison with the network without charging stations. The energy consumption values are 5.31, 4.49, 4.32, 4.53, 4.37, 5.59, 6.18, 6.75, 7.66, 8.26, 9.08, 9.56, 9.66, 8.78, 7.98, 7.48, 7.04, 6.51, 6.60, 6.91, 9.75, 7.15, 8.02, and 8.38 MWh at 0:00-1:00, 1:00-2:00, 2:00-3:00, 3:00-4:00, 4:00-5:00, 5:00-6:00, 6:00-7:00, 7:00-8:00, 8:00-9:00, 9:00-10:00, 10:00-11:00, 11:00-12:00, 12:00-13:00, 13:00-14:00, 14:00-15:00, 15:00-16:00, 16:00-17:00, 17:00-18:00, 18:00-19:00, 19:00-20:00, 20:00-21:00, 21:00-22:00, 22:00-23:00, and 23:00-24:00, respectively. Figure 5.5 shows the RMS voltage trends of loads under dynamic load profiles and charging stations. As can be seen from the figure that the voltage sags because of the load ratings. The charging stations put an extra load on existing distribution line cables. For this reason, the I^2R losses increase, and thus the voltage drops on the user side are higher than the system without a charging station. However, due to the advantage of the existing infrastructure being oversized, the voltage drops encountered in the loads are considered acceptable.

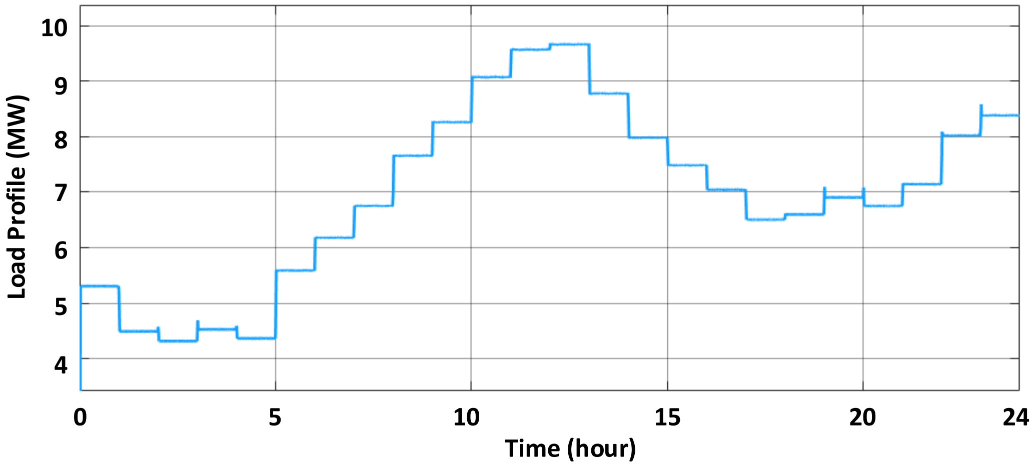

Figure 5.3. Load profile energy consumption values in hourly

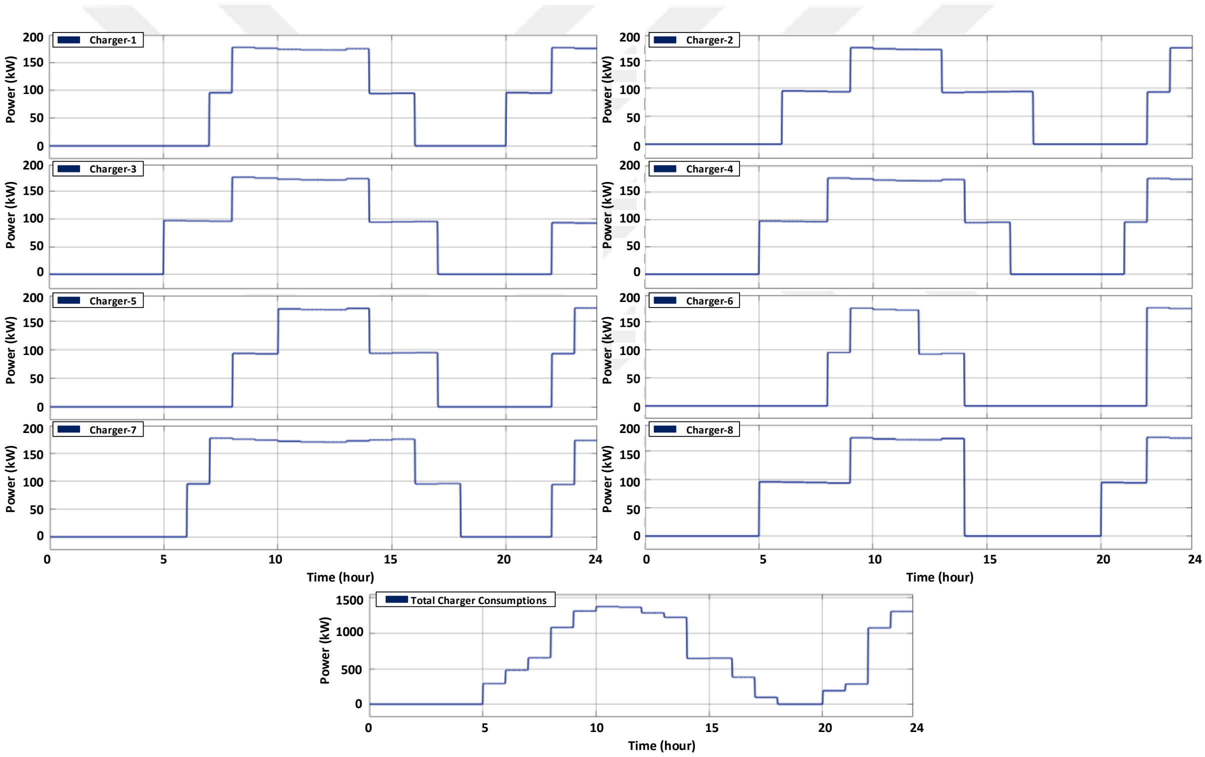

Figure 5.4. Charger’s consumption waveforms in hourly

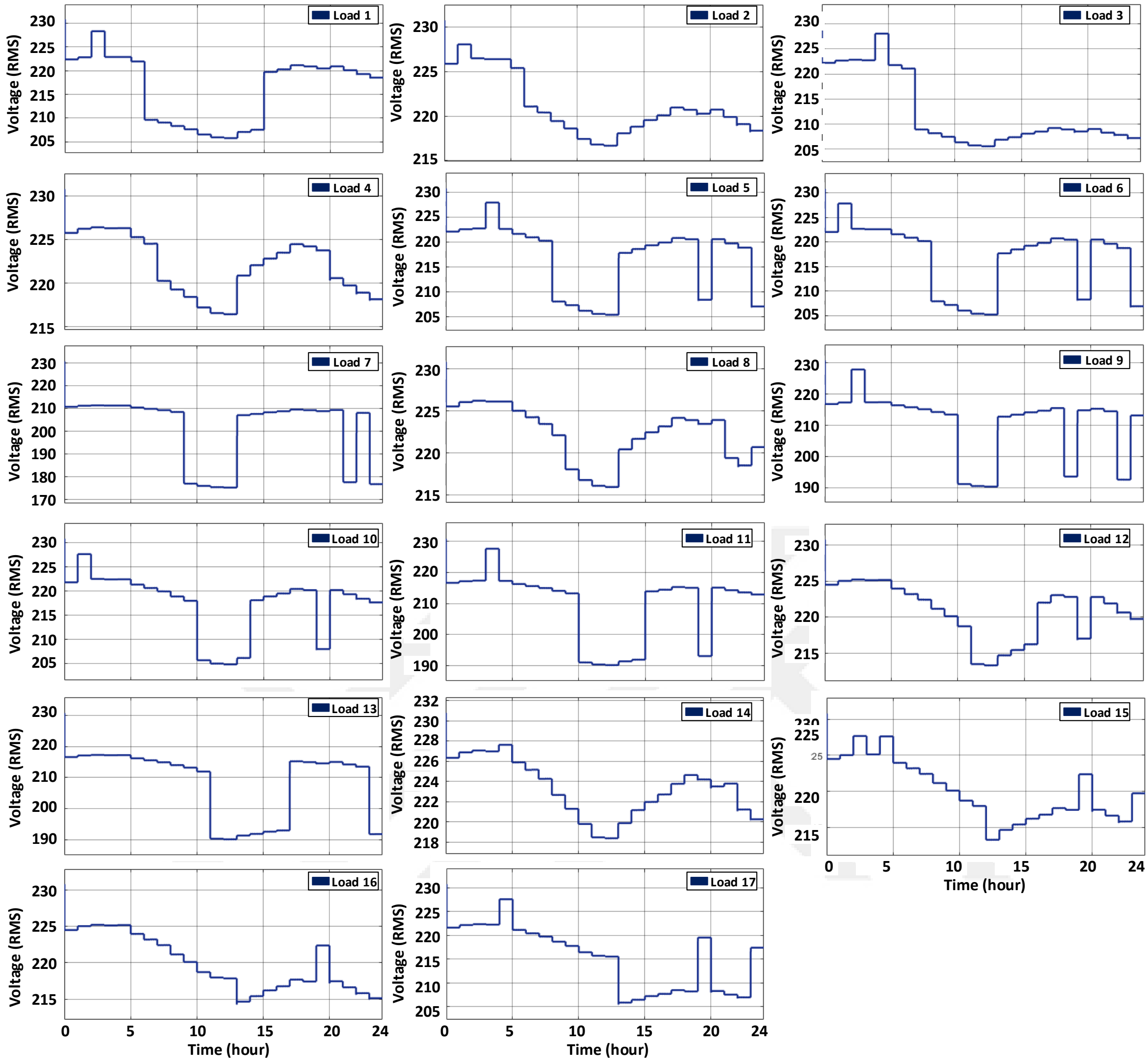

Figure 5.5. RMS voltage trends of loads of network with charging stations

As illustrated in Figure 5.2, the charging stations employed in this thesis composed of passive rectifiers, 400 kVA 31.5-0.4 kV transformers, and loads which corresponds to electric vehicles. The charging stations are modeled according to the IEC-62196 standard. There are 2 charging station units connected to each transformer and each unit has 4*50 kW sockets. With 2 units, 8 vehicles can be charged with DC fast charging at the same time. The charging stations which are equipped with active or passive rectifier circuits are nonlinear loads. Therefore, in addition to voltage drops, current harmonic trends and THD of main grid have been investigated as in model that is performed without charging stations. The current waveform of DC1 is given in Figure 5.6. The harmonic components and THD of the input current for 0-12 h load are illustrated in Figure 5.7, respectively. The harmonic components and THD of the input current for 12-24 h load are illustrated in Figure 5.8, respectively.

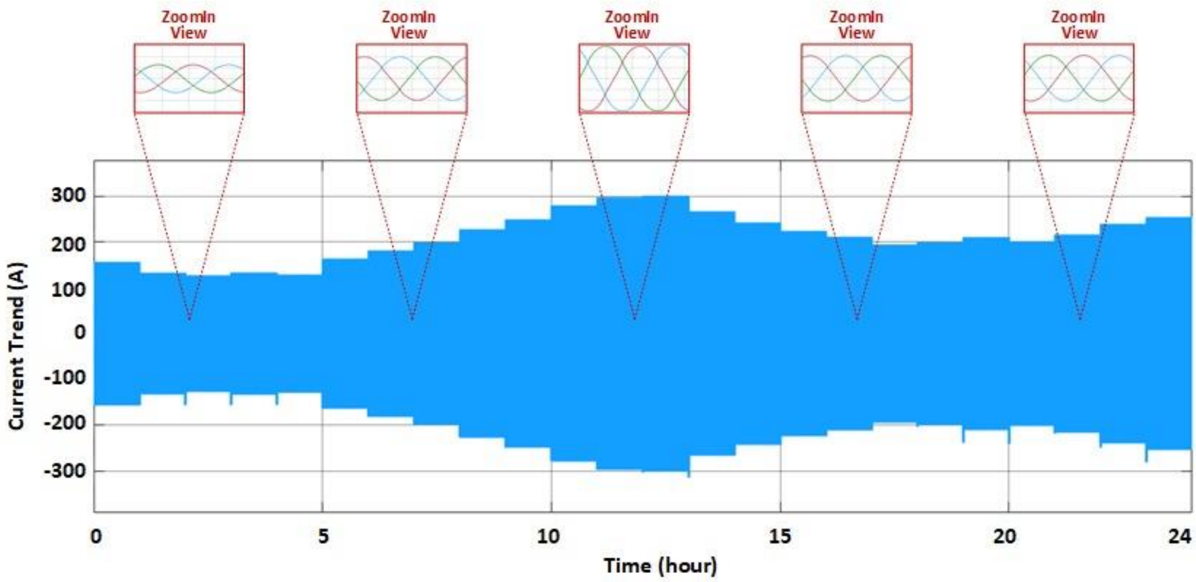

Figure 5.6. Current trend of DC1 of network with charging stations

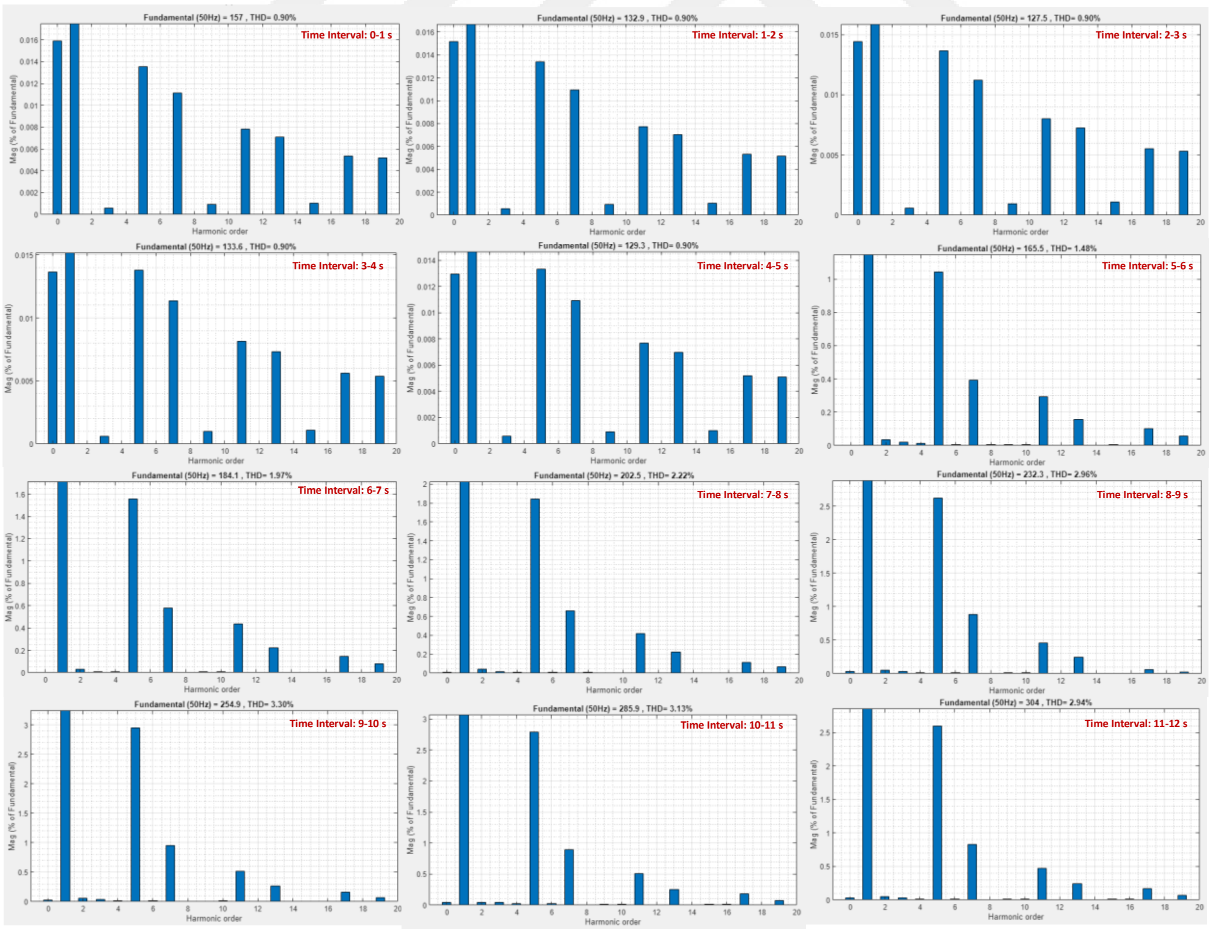

Figure 5.7. Current harmonic trends and THDs of network with charging stations (0-12 h)

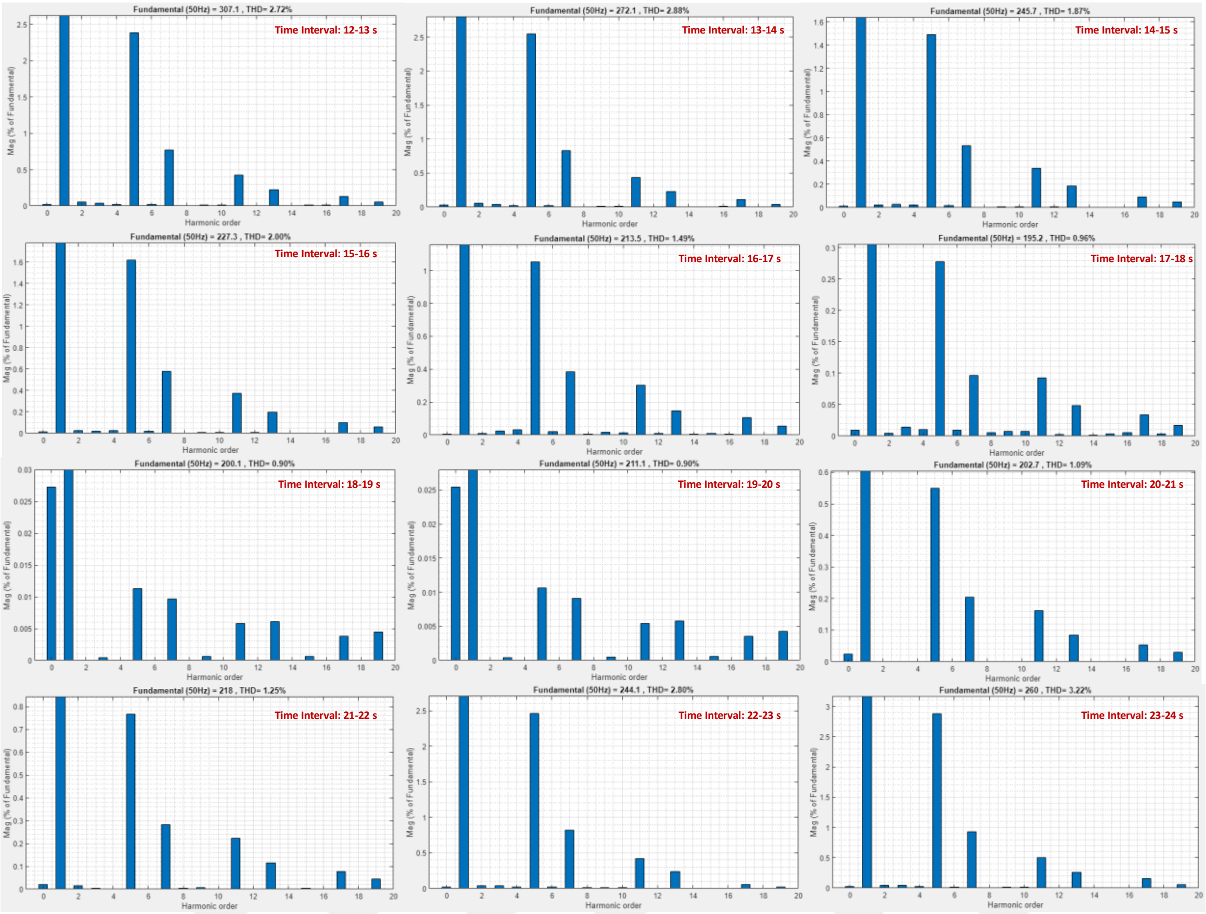

Figure 5.8. Current harmonic trends and THDs of network with charging stations (13-24 h)

5.2. Discussions

The fact that the number of electric vehicles is increasing day by day and the technology is developing means that the number of electric vehicle charging stations is also increasing. If this increase in the number of electric vehicle charging stations is not controlled and systematic, the problems it will create in the future may cause issues that are difficult to solve.

The study consists of two important subjects. These two subjects are linked to each other. One part of these topics is to analyze the power quality of a region. The other part is to ensure the placement of charging stations in these regions according to the criteria that have been determined using the Analytical Hierarchy Process.

First, the grid infrastructure and power quality issues of a region that receives energy from the DC1 was examined. There are many homes, official institutions and business centers/shopping malls in the region.

All the equipments (cables, transformers, distribution center) have been simulated by preparing the simulation of the selected region via Matlab / Simulink. The load profiles have been extracted from the region using SCADA. Load profiles have been adjusted according to the changes in the load profiles during the day. The load profile observed increased significantly during the hours that everyone used during the day and decreased significantly at night. This profile has been added to the simulation. The hourly current and RMS voltage trends of the DC1 were examined. It is observed that there was a certain decrease in voltage values during the hours when the load increased. At the same time, current harmonics have been analyzed without nonlinear loads.

The sample region has been divided into three sub-regions. Here aimed to distribute the charging stations using the analytical hierarchy process. These three sub-zones represent alternatives for charging stations. Then criteria were created to determine the positions of the charging stations. By selecting four main criteria, the criterion part of the analytical hierarchy process is created. Here, the number of criteria was determined as completely at own discretion and initiative. The number of criteria could have increased or decreased. However, four criteria have been considered sufficient for work in this region. These criteria are “Land Cost & Are Suitability”, “Power Density on Area”, “Power Quality Effect”, “Proximity To Official & Crowded Institutions”.

The first criteria, “Land Cost & Area Suitability”, is essential for the indispensable space requirement for an electric vehicle charging station. Land conditions are critical if an electric vehicle charging station is to be established in a region. Also, land prices are significant for the investor.

The second criterion is “Power Density on Area”. The higher the load density in a predominantly residential area, the higher the customer density. Because the consumption of the residences will not exceed 8-10 kWh, if the installed power in a transformer is high, it can be easily deduced that the number of customers in that region is high. It is not valid. Since there are no production centers or factories in our working area, this criterion is predominant.

The third criterion is “Power Quality Effect”. When power quality was simulated, it was observed that an increase in the number of charging stations in an area can cause some power quality issues. As the number of EV charging stations increases, so do power quality problems in the region.

The fourth criterion is “Proximity To Official & Crowded Institutions”. Crowded spots have always been attractive spots for electric vehicle charging stations. Shopping malls, hospitals, and places where there are various government institutions can be counted as overcrowded spots. Especially the Republic of Turkey's serious support for the domestic electric vehicle project and the statement that it supports the investments made in this regard shows that government institutions will also be attractive places for charging station points.

Table 5.1. Normalized Comparison Table with Priority Vector for Criteria

Proximity To Official& Crowded Institutions	0.20
Power Density on Area	0.657
Power Quality Effect	0.068
Land Cost & Area Suitability	0.07

In the case study, the Power Density criterion stands out as the most important criterion because it is directly proportional to an essential factor such as the number of customers, while the Proximity To Official & Crowded Institutions criterion shows itself in the second place due to the reasons that mentioned above. These two criteria are less important than the other two criteria since the land prices and area suitability are more or less the same in our case study area, and all lines are fed from the DC1.

Table 5.2. Zone results with weights

Zones	Weights
Zone 1	%28
Zone 2	%14
Zone 3	%56

As seen in Table 5.2, when all matrix operations are solved and the results of the analytical hierarchy process are considered, region 3, one of the three sub-regions, has the highest weight.

This was followed by zone 2 and zone 1, respectively. According to the results of the analytical hierarchy process, a planned distribution consisting of 8 charging stations was realized by installing 4 stations in zone 3 with a weight of 56%. 3 stations have been located in the 1st region with a weight of approximately 30%. A charging station has been positioned in the 2nd Region, which has a weight of 14%.

In the last part of the study, the parameters of the allocated electricity distribution network were examined. Although there were some deteriorations in power quality due to the installation of charging stations in these regions, it was not met with significant deterioration as the allocation was made through the analytical hierarchy process. Although charging stations had noticeable effects on power quality, other criteria were found to outweigh allocation. In particular, it is seen that the "Field Power Density" criterion is the most decisive criterion for this study area.

Table 5.3. Studies for EV Charging Station Allocation

Study	**The method on which it is based for Allocation**	**Scope**
Optimal Allocation Planning for Public EV Charging Station Considering AC and DC Integrated Chargers (Liu and Bie,2019)	Agent-Based Modeling and Simulation(ABMS) method	The simulation model is modeled on a system that includes AC and DC chargers together. An allocation optimization model has been formulated to minimize annual costs such as charging center investment cost, land price, and grid renewal cost.
Allocation Of Electric Vehicle Charging Station Considering Uncertainties (Pal et al., 2021)	2m Point Estimation method (2m PEM)	Electric charging stations are planned to be placed in the radial distribution network. The distribution of charging stations according to supermarkets and residences

		is based on minimizing energy loss and considering land costs.
Allocation of RESs and PEV Fast-Charging Station on Coupled Transportation and Distribution Networks (Sa'adati et al., 2021)	Capacitated Deviation Flow Refueling Location Model (CDFRLM)	In order to eliminate the voltage drops caused by the charging stations, renewable energy sources have been positioned, and the positioning of the charging stations on the bus lines has been worked on.
Allocation Optimisation Of Rapid Charging Stations In Large Urban Areas To Support Fully Electric Taxi Fleets (Cilio and Babacan, 2021)	Density-Based Spatial Clustering Of Applications With Noise (DBSCAN) algorithm	Based on the actively operating taxi data, charging stations are positioned according to the distribution of the taxi density of 18000 vehicles.
Coordinated Allocation Of Distributed Generation Resources And Electric Vehicle Charging Stations In Distribution Systems With Vehicle-To-Grid Interaction (Luo et al.,2020)	Distflow equations	In the study carried out on 3 cases, a line of 31 buses was considered according to the subjects of uncoordinated charging, unidirectional V2G and bidirectional V2G.

Many methods are used for the allocation of charging stations in the world. Using the analytical hierarchy process for the allocation of charging stations is a very smart solution in terms of solving the difficulties that may be encountered while positioning. Table 5.3 shows some studies for allocation. The biggest advantage of the analytical hierarchy process is that there is no number restriction in the criteria determined for the placement of charging stations, and as many criteria can be included in the algorithm as desired.

6. CONCLUSIONS

While the trend towards gasoline vehicles is decreasing day by day globally, the interest in electric vehicles is increasing. The fact that electric vehicles are environmentally friendly and the energy they use can also be produced from renewable sources increases the importance of these vehicles.

In this thesis, a single line diagram of a sample region drawn on Autocad was simulated with Matlab/Simulink software, and the power quality parameters in the region were examined. The load profiles in the simulation were adjusted according to the real-time values, and the results were obtained. The existing distribution network structure was examined by simulating the transformer model, cable dimensions, circuit breaker model, and load profile. Current, voltage, and total harmonic distortion parameters in the region were examined.

Charging station locations and needs were determined using the analytical hierarchy process for allocation. Using the criteria of Land Cost and Availability, Power Density on the Area, Power Quality Effect, Proximity to Governmental and Crowded Institutions, which are the four criteria, it was determined in which regions the charging stations should be established. In this study, where the working area is divided into three sub-regions, alternatives were determined while allocation was made. Solving these criteria with the determined pairwise comparison matrices makes it possible to choose between the alternative regions. After allocating using the analytical hierarchy process, the electricity distribution grid was re-examined. Although some deterioration in power quality was observed, it was not a significant problem for the grid.

Finally, by using the analytical hierarchy process, the settlements were made, with the least problem in power quality and taking into account all other determining criteria, with the best scores being weighted.

7. RECOMMENDATIONS

We will further develop this work in the future, create software that works synchronously with a geographic information system, and perform a study that can select the location of charging stations using an analytical hierarchy process.

Using this study will minimize the problems that electric vehicle charging stations, which are planned to become widespread in the future, will create for the electricity distribution network and for the devices that receive energy from the electricity distribution network. At the same time, we will allow the charging stations to be optimally positioned to meet the needs of both the consumer and the operator.

Thanks to this software, which will work together with the geographic information system, electricity distribution companies will be less exposed to power quality problems caused by electric vehicle charging stations, and work that will increase customer satisfaction will emerge.

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