INSTITUTE OF SCIENCES AND ENGINEERING

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

THE MODEL OF THE DISTRIBUTION NETWORK OF ELECTRIC VEHICLE CHARGING STATIONS

A Thesis

submitted by

YIGIT RECEP SEN

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

June 2019

Program: Power Electronics and Clean Energy Systems

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June 2019

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ABSTRACT

THE MODEL OF THE DISTRIBUTION NETWORK OF ELECTRIC VEHICLE CHARGING STATIONS

With the latest advances in technology, vehicles that are used in the sustainability of daily life are constantly developing. Studies focusing especially on energy generation and consumption in vehicles led the focus to shift to alternative energy resources. With developing technology, efforts aim to decrease dependency on the main energy resource which is fossil fuels. The main reason for such efforts can be considered as decreasing two negative effects. First, one of these is increased costs due to decreased resources such as petroleum and natural gas that have limited reserves and related social and economic effects. Another one is the negative environmental effects of harmful greenhouses gas emission due to fossil fuel burning.

The transportation sector has the largest share of fossil fuel consumption and related negative consequences. Considering electric vehicles as an alternative resource in the transportation sector increased usage ratio as well. Expanding the usage of these vehicles that are both economic and environmentally friendly requires a suitable infrastructure to be ready. If a suitable infrastructure for electric vehicle charging operation is not facilitated, it is believed that there will be negative effects in power quality, overload and harmonic during vehicle charging.

To analyze such problems in the technical sense and to propose solutions, studies on various grids around the world have been conducted and future studies are planned. Since every country has a different infrastructure and user profile, it is clear that our country needs a study in this field.

Within this scope, the pilot region with different user groups was selected. Transportation based daily behavior of people in this pilot region was analyzed and different user profiles were created based on possible needs. After identifying user profiles and pilot region, distribution feeder in the region was selected with BEDAS infrastructure and real-time technical data such as map data, power data for this feeder were obtained.

Obtained and constructed data were defined as separate data to a program that is used for analyzing the effects of charging stations on the distribution grid and real-time simulations were conducted on the effects of electric vehicle charging stations on the grid.

Keywords: Electric vehicle, Electric distribution system, Electric vehicles charging station, Effect of charging station on the grid

KISA ÖZET

ELEKTRİKLİ ARAÇ ŞARJ İSTASYONLARININ DAĞITIM ŞEBEKESİ MODELLEMESİ

Günümüz teknolojisi ile birlikte günlük hayatın sürdürülebilirliği için kullanılan araçlar sürekli gelişmektedir. Özellikle enerji üretimi ve tüketiminde kullanılan araçlar üzerinde yapılan yoğun çalışmalar, alternatif enerji kaynaklarına yönelmeyi sağlamıştır. Gelişen teknoloji ile birlikte temel enerji kaynağı olan fosil yakıtlara olan bağımlılıkta giderek azaltılmaya çalışılmaktadır. Bunun başlıca nedenleri iki olumsuz etkiyi azaltmak olarak değerlendirilebilir. Bunlardan ilki, sınırlı rezerve sahip olan petrol ve doğal gaz gibi yakıtların azalmasına bağlı artan maliyet ve bu durumun oluşturduğu sosyal ve ekonomik etkiler. Diğeri ise fosil yakıtların yanması sonucu ortaya çıkan zararlı sera gazlarının çevre üzerine olumsuz etkileridir

Ulaşım sektörü fosil yakıt tüketimi ve beraberinde getirdiği olumsuzluklar ile en büyük paya sahiptir. Elektrikli araçların ulaşım sektöründe alternatif kaynak olarak değerlendirilmesi, kullanım oranındaki artışı beraberinde getirmiştir. Hem ekonomik hem de çevreci olan bu araçların kullanımının yaygınlaşması ile paralel olarak uygun altyapının da hazır olması gerekmektedir. Elektrikli araçların şarj işleminde uygun altyapı sağlanamaz ise araçların şarj işlemlerinde güç kalitesi, aşırı yüklenme ve harmonik gibi konularda olumsuz etkiler oluşturacağı düşünülmektedir.

Oluşabilecek bu problemlerin teknik olarak incelenmesi ve çözüm önerilerinin oluşturulabilmesi için dünyada birçok ülke şebekeleri hakkında çalışmalar yapılmıştır

ve bu çalışmalar devam etmektedir. Her ülkenin altyapısının ve kullanıcı profillerinin farklı olması sebebi ile ülkemiz için de çalışma yapılması gerekliliği ortadadır.

Bu kapsamda yapılan çalışmada önce farklı kullanıcı gruplarının olabileceği pilot bölge seçilmiştir. Pilot bölgede yaşayan insanların ulaşım amaçlı günlük davranışları incelenmiş ve doğabilecek ihtiyaçlar göz önüne alınarak farklı kullanıcı profilleri oluşturulmuştur. Kullanıcı profilleri ve pilot bölge belirlendikten sonra BEDAŞ altyapısı kullanılarak bölgede yer alan dağıtım fideri seçilmiş, bu fidere ait harita verileri, güç verileri gibi gerçek zamanlı teknik veriler elde edilmiştir.

Elde edilen ve oluşturulan veriler şarj istasyonlarının dağıtım şebekesine etkilerinin incelenmesi için kullanılan programa ayrı ayrı veriler olarak tanımlanmış ve tez kapsamında elektrikli araç şarj istasyonlarının şebeke etkileri hakkında gerçek zamanlı benzetim gerçekleştirilmiştir.

Anahtar Kelimeler: Elektrikli araç, Elektrik dağıtım sistemi, Elektrikli araç şarj istasyonu, Şarj istasyonunun şebekeye etkisi

To My Family

ACKNOWLEDGMENT

I would like to thank Prof. Dr. R. Nejat Tuncay for his help during my university education, support in work life and contributions to my thesis study.

I would like to thank Asst. Prof. Dr. Ö. Cihan Kıvanç, my workmates and my managers for all their support.

I would like to thank my mother and father who did not spare their support and knowledge in my education life and social life with respect.

And lastly, I would like to thank my wife for her love and support in every part of my life.

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ABBREVIATIONS

AC Alternative Current

AMR Automated Meter Reading

BEV Battery Electric Vehicle

BMS Battery Management System

CO_2 Carbon Dioxide

DC Direct Current

EMF Electromagnetic Field

FCEV Full Cell Electric Vehicle

GIS Geographic Information System

GPS Global Positioning System

HEV Hybrid Electric Vehicle

ICEV Internal Combustion Engine Vehicle

KM Kilometer

Li-Ion Lithium-Ion

Li-Po Lithium-Ion Polymer

LMF Least Mean Fourth

LV Low Voltage

MV Medium Voltage

V Volt

W Watt

Ni-MH Nickel Metal Hydride

Pb-Ac Lead-Acid

PHEV Plug-In Hybrid Electric Vehicles

TC Transformer Center

TEIAS Turkish Electricity Transmission Company

SOC State of Charge

SCADA Supervisory Control and Data Acquisition

I. INTRODUCTION

Today, increasing electric need is rapidly increasing with a high population, developments in the industry, larger digital markets and wasteful energy consumption. Decreasing natural sources with increasing electric demand caused alternative and clean energy resources to emerge. With the production of alternative clean energy resources, distribution network grids should significantly change and ensure constant and uninterrupted supply. As clean energy systems and current grids are adapted, it is possible to see a positive increase for both humans and nature. Accordingly, investments start to focus on smart grids rather than standard grips and there are significant investments in the smart grid field around the world. Main factors for smart network investments are stated below [1]:

- Increased electricity demand,
- Need for decreases loss,
- Management of excessive demand,
- Renewable energy integration,
- Global thermal solutions,
- Potential and new employment opportunities with technological advancement,
- Efficient vehicle usage (better customer satisfaction, overcoming meter reading problems, low efficiency of current production systems).

By combining smart grids and clean energy resources, it is possible to save rapidly extinguishing fossil fuels and decrease greenhouse gas emissions. The majority of energy resources required for sustainability on earth are obtained from fossil fuels. From the past until today, demand for fossil fuels increased constantly and important steps are taken to find alternative energy resources due to price uncertainties caused by increasing environmental pollution, fast consumption of fossil fuels and decreased amount of fossil fuels. Vehicles have a significant effect on the usage of fossil fuels and related toxic gas emissions. While 60% of fossil fuels are used in the transportation sector, 25.5% of related CO_2 emission is caused by the transportation sector [2]. According to the May 2018 data of the Turkish Statistic Institution, recorded vehicles in our country are 22,645,085 and transportation sector CO_2 emission is around 18% [2], [3].

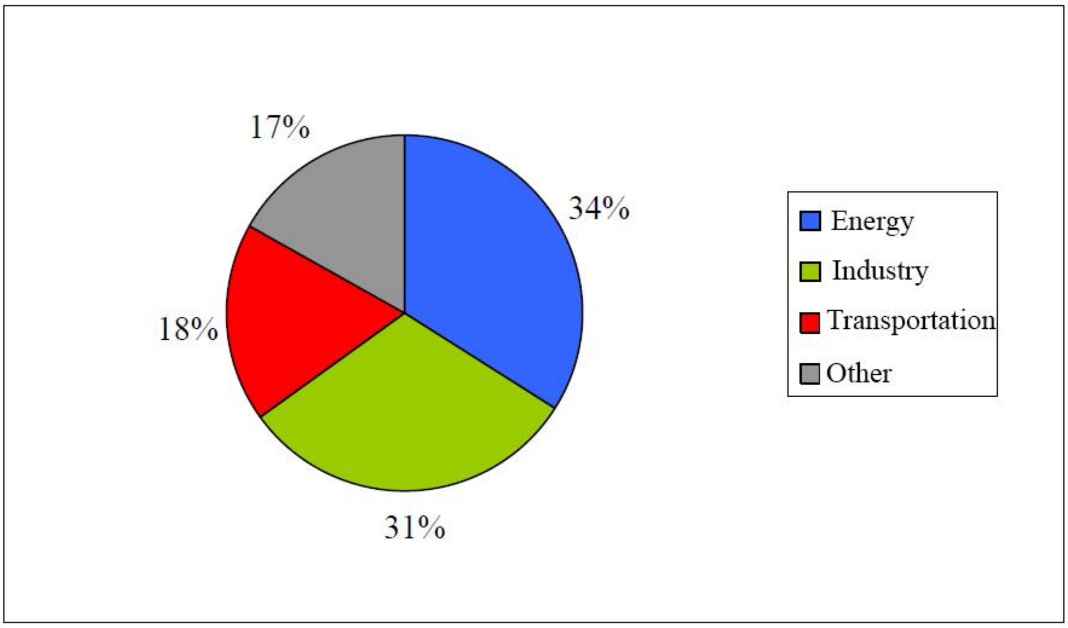

Figure I.1. CO_2 emission in Turkey by sectors [2].

Therefore, alternative solutions are created for fossil fueled vehicles in the transportation sector and research and development studies are conducted with different concept vehicles such as hybrid, hydrogen and electric vehicles [4], [6]. In recent years, studies on electric machines, batteries, and power electronics that form the basis of electrical vehicles led to significant development in EV technology and EV usage ratio has increased. It is possible that the increased usage of electrical vehicles will greatly contribute to the environment and economy. However, as electric vehicles are more common, demand for charging stations and energy demand in these stations will increase as well.

With these developments, while demand and usage ratio of electric vehicles increases, power demands will increase as well. If necessary preparations for power demands are incomplete, negative effects on grids such as lower power quality at distribution grids and overload can be observed. In addition to electric vehicles, there are research and development studies on the effects of these vehicles on grids. This study is designed by considering increased electric vehicle use and increased vehicle charging station demand in our country.

1.1. Generation, Transmission and Distribution of Electric Power

Electric energy as one of the greatest requirements of the modern age is an energy type that cannot be stored in bulk due to its nature and current technology. Therefore, lossless, uninterrupted and safe delivery by transmission and distribution systems are a priority in providing electric energy produced in power plants to millions of users such as housing, industry, hospitals, and schools.

All electric installation used for providing electric energy generated in power plants to consumers is called electric grid. Grids that transmit electric energy to the consumption region is called transmission grid and grids that distribute energy to these regions are called distribution grids.

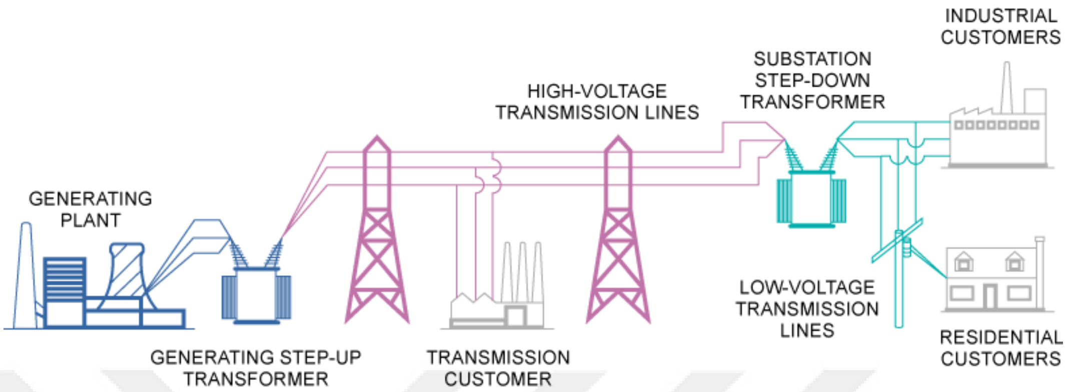

Figure I.2. Electric generation, transmission and distribution.

1.1.1. Electricity generation

History of commercial power plants and distribution grips date back to 04 September 1882 and to the implementation of electric generation stations that supply illumination systems with direct current. The first electric generation facility established by Thomas Edison was a Jumbo dynamo (generator) that converts mechanical energy to electric energy as given in Figure I.3 and this machine was the foundation of electric generation and distribution grid [7].

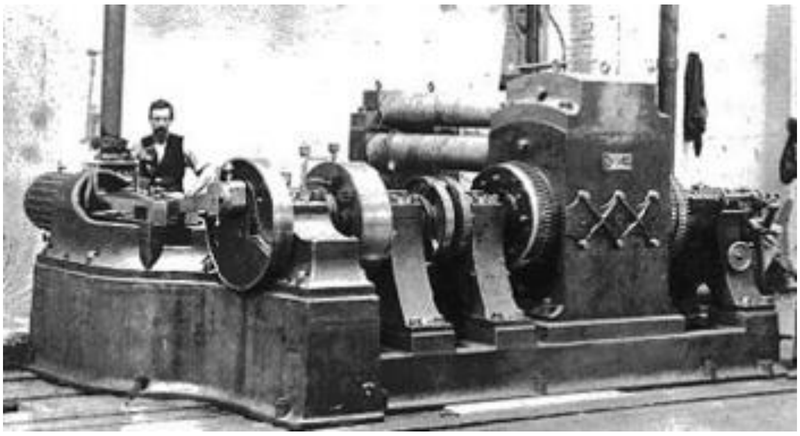

Figure I.3. Jumbo dynamo.

Direct current based grids were replaced by alternative current grids due to high cost, low efficiency, and problematic operations. The first alternating current electric grid was commissioned in 1889 in the US and this new alternative current grid with 4 kW power transmitted on a single phase and to 21 km.

Today, electric generation facilities that can generate thousands of MW are formed with different energy resources. Today, electric generation facilities are divided into two in terms of energy resources and environmental relationships as renewable energy resources (clean and environmentally friendly resources) and non-renewable energy resources. Power generation facilities based on resources are given in Figure I.4.

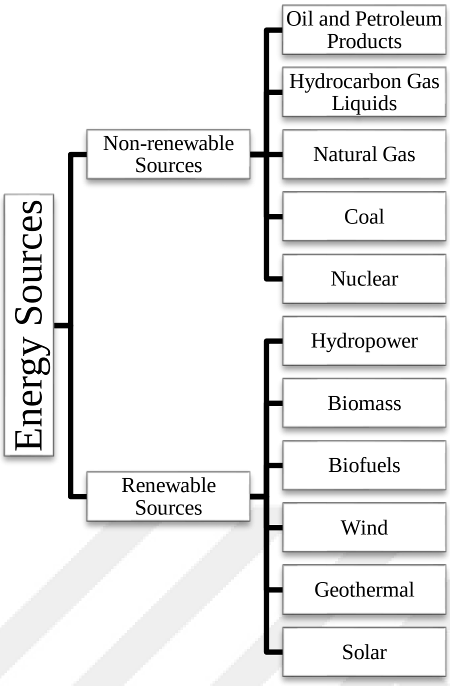

Figure I.4. Sources of energy.

1.1.2. Electric power transmission and distribution

In Turkey, generated electric energy is transmitted at 380 kV to 36 kV voltage level on transmission lines and at 36 kV or below voltage levels for distribution grids to provide electricity to end users.

It is possible to classify grids based on distribution types and voltages on these lines. The main rule for electric grids is supplying consumers in a technically economic and ergonomic way. Different grid systems are used for complying with this rule. Grid systems can be listed as:

- Radial distribution system

- Ring main distribution system
- Meshed distribution system

1.1.2.1. Radial distribution systems

Radial grids are called open system grids. These grids are supplied from one side. These grids are the simplest form of distribution systems that are supplied from one end and have a line to supply consumers from the other end or another point on the line. A single line schematic for the radial distribution system is given in Figure I.5.

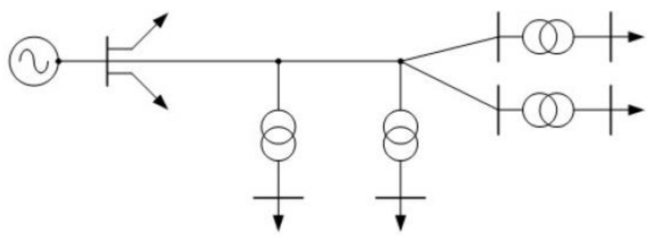

Figure I.5. Radial distribution system.

1.1.2.2. Ring main distribution systems

Since ring main distribution systems are supplied from multiple transformers in case of ring malfunction, only this part is decommissioned and energy loss for the high number of consumers is prevented. In the case of a problem, the system operated as two independent radial grid that is supplied from the same source. A single line schematic for the ring distribution system is given in Figure I.6.

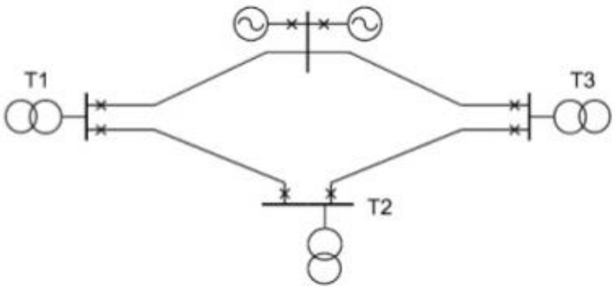

Figure I.6. Ring main distribution system.

1.1.2.3. Meshed distribution systems

Meshed distribution systems have other distributions systems. This way, if the transmission line or transmission component within the grid malfunctions, customers are supplied from an alternative source. Meshed distribution systems have various advantages such as uninterrupted energy flow, low voltage drop cases and connecting strong receivers to the system. A single line schematic for the meshed distribution system is given in Figure I.7.

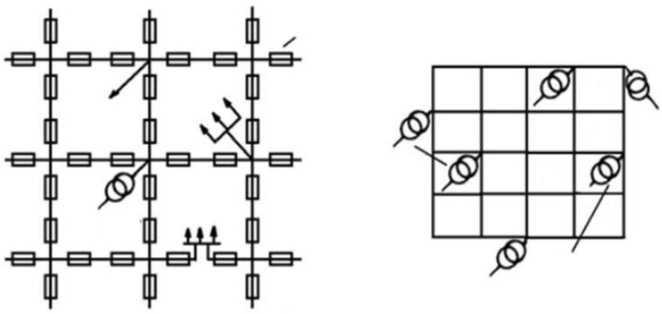

Figure I.7. Meshed distribution systems.

1.1.3. Interconnected grid

These are electrical systems that ensure the connection between two or more system or grid in different regions or at the international level to increase profitability and safety in transportation, transmission and transfer for significant energy exchange. When there is a malfunction in interconnected systems, only the energy of problematic line is cut. Energy continuity in other sections is not disrupted.

Each country has an interconnected grid to supply its own receivers. Additionally, some neighboring countries might connect their systems. There can be small power plants and users within a country. These do not affect the system. Interconnected systems in Turkey are connected to grids of Bulgaria, Russia, Iraq, Syria, and Georgia. Electric is exchanged over these connections.

II. LITERATURE REVIEW

2.1. Analysis of Electric Distribution Grids

The purpose of distribution grid design or expansion of the current grid is to provide quality energy to consumers with the lowest cost possible. Studies show that it is not possible to avoid losses in generation, transmission and distribution facilities on current grids. Studies show that losses mainly occur at distribution grids rather than generation step [8]. Research and investment on more efficient, economic and environmentally friendly smart grids have increased to minimize these losses [1].

2.1.1. Analysis of losses in distribution grids

There are studies on losses on distribution systems and the negative economic impacts of these losses to find new solutions. Additionally, methods adopted to design new distribution facilities try to prevent such losses. Losses on distribution grid can be divided as:

- Technical losses,
- Non-technical losses.

Technical losses are linked with electrical properties of a distribution line while non-technical losses are the difference between generated electricity and measured electricity consumption [9], [10], [11], [12].

2.1.1.1. Technical losses

Technique losses on distribution grids are caused by the physical properties of grid components. Technical losses on grids are caused naturally by a component structure such as transmission lines, power transformers, and measurement systems. These losses can be measures, effects on the grid can be controlled but it is not possible to entirely avoid these losses. Main reasons for technical losses on the grid can be listed as follows [9], [10], [12]:

- The Dielectric material thermal effect between conductors,
- Copper losses,
- Electromagnetic field effect on conductors,
- Harmonics,
- Overloading and low voltage,
- Using non-standard materials etc.

- **Transformer losses**

Transformer losses are the main portion of facility losses. Studies show that transmission and distribution losses caused by distribution transformers correspond to 26% and sub-transmission losses correspond to 41% of all losses [14]. Transformer losses are calculated in two groups as no-load and load losses.

No-load operation losses that are called iron or core losses are hysteresis and eddy current losses during the energized state of the transformer and these losses are independent of the transformer load.

Load operation losses are called copper or short circuity losses and these losses are caused by the transformer load. Therefore, studies on core and coils should minimize these losses and increase the transformer operation efficiency. In the electrical circuit model of transformers, the system model is formed over equivalent circuits. Cell models created with equivalent circuit models play an effective role to identify the calculation of losses that enable mathematical operations. Equivalent circuit models in the literature are given below [16].

- **Transformer equivalent circuit**

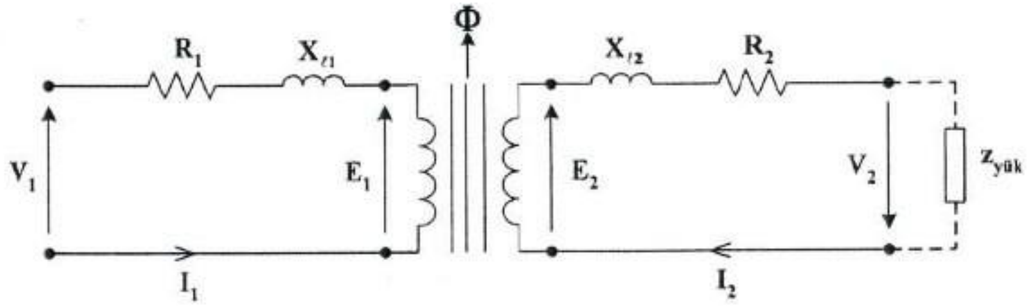

Figure II.1. Equivalent circuit models.

Induced EMF on transformers are calculated as follows;

$$E_1 = 4{,}44.f.N_1.\phi.10^{-8} \quad \text{(II.1)}$$

$$E_2 = 4{,}44.f.N_2.\phi.10^{-8} \quad \text{(II.2)}$$

There are no physical connections between primer and seconder circuits of the transformer. While conducting analysis on transformers, primer and seconder size are commonly used due to easier calculation and visualization. This is called a reduction of transformers and this transformation is applied by using “a” transformation ratio. Although it is possible to transform both sides, in practice, the seconder coil is reduced to primer coil and reduced values are indicated with a (‘) symbol. The following equivalent circuit is formed after reducing the seconder side to the primer side.

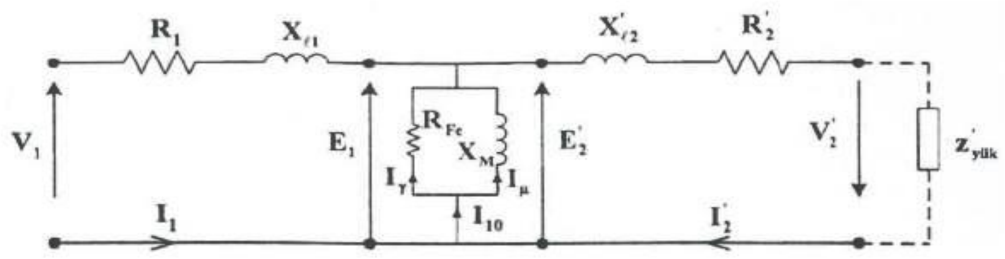

Figure II.2. Complete equivalent circuit where seconder is reduced to primer.

Here, I_1 is current from the grid, I_2 is current drawn by the load, I_{10} is no-load operation current, I_γ is no-load operation current iron loss, Iμ is no-load operation current magnetization component.

Iron losses are the main no-load operation losses. In $\varphi_0 = \delta + \psi_0$ statement, since δ angle between V_1 voltage and induced E_1 voltage is low if this angle is neglected, we have $\varphi_0 \cong \psi_0$ This means that no-load operation power factor angle can be equal to iron angle.

When $P_0 = P_{fe}$,

By using no-load operation measurements and following equations, R_f, X_M, I_μ *and* I_γ values are obtained.

$$R_{fe} = \frac{P_0}{I_\mu^2} \quad \text{(II.3a)}$$

$$I_\mu = I_{10} sin\varphi_0 \quad \text{(II.3b)}$$

$$I_\gamma = I_{10} cos\varphi_0 \quad \text{(II.3c)}$$

$$cos\varphi_0 = \frac{P_0}{V_1 I_{10}} \quad \text{(II.3d)}$$

$$sin\varphi_0 = \frac{Q_0}{V_1 I_{10}} \quad \text{(II.3e)}$$

$$X_M = \frac{Q_0}{I_\mu^2} \quad \text{(II.4f)}$$

$$X_M = \frac{Q_0}{I_\mu^2} \quad \text{(II.4g)}$$

When load impedance connected to seconder in the transformer equivalent circuit is zero, this means the transformer is short-circuited. If $Z_o = 0$, output voltage is $V_2' = 0$. The equivalent circuit of the short-circuited transformer is given in Figure II.3.

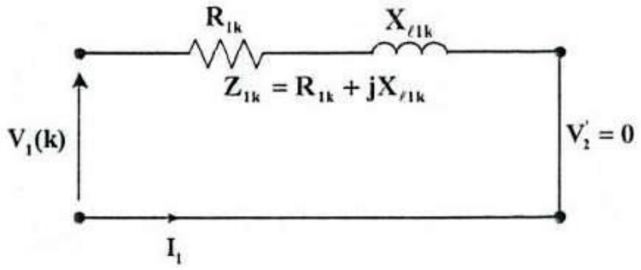

Figure II.3. Circuit of short circuited transformer.

After creating a short circuit equivalent circuit, short circuit current is calculated with the following formula.

$$I_k = \frac{V_k}{Z_{1k}} \quad \text{(II.5a)}$$

This current that is defined as short circuit current can damage transformer coils if the amplitude of this current is high. Therefore, the rated current is limited by applying the primer voltage adjustment method as the second phase of short circuit experiment. This adjusted voltage is represented as V_k , short circuit current is I_1.

$$V_k = I_1 . Z_{1k} \tag{II.5b}$$

By using this formula and operation current of transformer gives total copper loss. Z_{1k} is total seconder impedance, R_{1k} and X_{l1k} are short circuit resistance.

$$R_{1k} = \frac{P_{cu}}{I_\iota^2} \tag{II.6a}$$

$$Z_{1k} = R_{1k} + jX_{l1k} \tag{II.6b}$$

$$X_{l1k} = \sqrt{{Z_{1k}}^2} - {R_{1k}}^2 \tag{II.6c}$$

- **Conductor losses**

Electric energy is distributed and transmitted from power plants to end-user at different cross-sections and voltage levels. Line losses are inevitable during energy transmission. Distribution and transmission line losses are technical indicators of planning, design, production, and operation of the grid. Cross-section, types and electrical properties of these cables should be set based on properties of the environment and how they will be commissioned [17], [18], [19].

Cable types are selected by analyzing environment conditions and external factors in the facility. Cross-section of cable should be selected by correct analyses of required energy and possible energy addition in the future. The size of the conductor should be selected without pushing limits of polymer material that wraps the conducted and without exceeding maximum resistance values provided by international standards.

- **Current carrying capacity**

This is the maximum current value for a cable based on temperature values that ensures the integrity of components and safe cable use. The current carrying capacity directly affects cable cross-section selection. The current carrying capacity is calculated by using the formula below. Here, P is demanded power, U is voltage and cosφ is power factor.

$$P = \sqrt{3}.U.I.cos\varphi \quad \text{(II.7a)}$$

$$I = \frac{P}{\sqrt{3.U.cos\varphi}} \quad \text{(II.7b)}$$

- **Voltage drop**

Voltage drop is decreased voltage due to losses caused by the internal resistance of the conductor until the voltage reaches from source to load. If a current is carried on a conductor wire, energy loss in thermal format occurs that is proportional to the square of current on conductor wire and conductor resistance $I^2 = R$. As for carrying distance increases, these losses increase and cross-section of the conductor should be larger.

After finding current value, the voltage drop can be calculated from the formula below. Here, L is distance, e% is voltage drop, S is conductor cross-section and k is conductivity coefficient.

$$\%e = \frac{100.P.L}{k.S.U^2} \quad \text{(II.8)}$$

Other factors that affect current carrying capacity and the voltage drop is linked with cable mounting and this factor can be divided into two as underground cables and overhead line cables. When calculating voltage drop, The Ministry of Energy and

Natural Resource set standards based on operating current and voltage levels on conductor wire. Cables must comply with “Electric Distribution Grids Energy Cable Mounting Rules and Procedures”. Current carrying capacity and other properties of copper cable cross-section and mounting under different conditions under mounting rules and procedures (20.8/36 kV XLPE insulator) are given in Table II.1.

Table II.1. Current carrying capacity of the XLPE cables.

Nominal Cross Section	Insulation Thickness	Overall Diameter Approx.	Net Weight Approx.	Insulation Thickness	Conductor Resistance 20° Max	Current Carrying Capacity					
						Earth		Air		Duct	
mm²	mm	mm	kg/km	mm	Ω/km	○○○	⁂	○○○	⁂	○○○	⁂
1x50/25	8.8	36	1430	8.8	0.387	203	196	243	238	188	186
1x70/25	8.8	38	1680	8.8	0.268	246	239	303	296	229	227
1x95/25	8.8	40	1970	8.8	0.193	293	285	369	361	274	271
1x120/35	8.8	41	2330	8.8	.153	332	323	426	417	311	308
1x150/35	8.8	43	2650	8.8	0.124	366	361	481	473	347	343
1x185/35	8.8	45	3030	8.8	0.099	410	306	550	543	391	387
1x240/45	8.8	47	3600	8.8	0.075	470	469	647	641	453	447
1x300/35	8.8	49	4220	8.8	0.060	524	526	739	735	510	504
1x400/35	8.8	52	5220	8.8	0.048	572	590	837	845	571	564

2.1.1.2. Non-technical losses

Non-technical losses are caused by external factors outside power systems. The majority of non-technical losses are due to illegal electricity usage. Additionally, cabling, counter and invoicing errors are considered as non-technical losses. It is hard to measure these losses and these losses are generally excluded from calculations. Non-technical losses can be prevented by [9], [11], [12], [15]:

- Preventing external intervention on counters,
- Correctly calculating technical losses,
- Preventing illegal electric usage on distribution grids,
- Control of correct reading and measurement system operation.

2.1.2. Smart grid

Today, advanced technology and computer and network technology can be integrated to grids into ensure real-time bidirectional information transfer for reliable, sustainable and energy efficient energy transmission. Smart grid;

- Load demand control,
- Renewable energy resources,
- Remote reading and control,

Electric vehicles can be studied in the academic and industrial field. Studies on smart grids are given in the following sections.

2.2. Analysis of Electric Vehicles

Although electric vehicles are first building stones of the transportation sector, these vehicles were replaced by internal combustion engine (conventional) vehicles due to efficiency and ease of use. Due to economic incentives, increased efficiency due to advancements in technology, increased economic and environmental awareness of consumers increased demand for EV. These increased demands increased competition between automotive manufacturers and these firms invested in EV and conducted studies in this field.

From the past until today, humanity continues to search for alternative resources to meet all types of energy needs. An alternative energy resource search in the transportation field started with steam vehicles. However, negative aspects of steam vehicles caused people to find more efficient transportation vehicles with different resources. First one of these vehicles was internal combustion engine vehicles that worked with hydrogen and oxygen. However, the desired objectives were not met with these vehicles.

In 1834, Thomas Davenport manufactured a small, circular electric vehicle that can be used in an electrical track. Since this vehicle has no power resources that can be independently charged from electric energy, this vehicle was not adopted in the transportation field. With the invention of chargeable batteries, in 1881, Gustave Trouve manufactured electrical vehicles that meet the energy demand of 0.1 HP DC electric engine with a lead-acid battery. However, a small range and 15 km/h speed failed to attract the desired attention. At the beginning of the 20th century, interest to EV decreased due to negative results and these were replaced by ICEV. In the 1990s, interest to EVs increased again due to environmental pollution, instability in petroleum prices, increased price difference between electric - petroleum prices and statements of some countries to ban ICEV [20], [21].

In 2018, global EV sales exceeded 4 million. Figure.12 shows monthly and annual sales data [22]. Additionally, countries continue to report their EV projections and applications. According to J.P. Morgan study, it is predicted that by 2025, EVs will correspond to more than 38% of total vehicle sales.

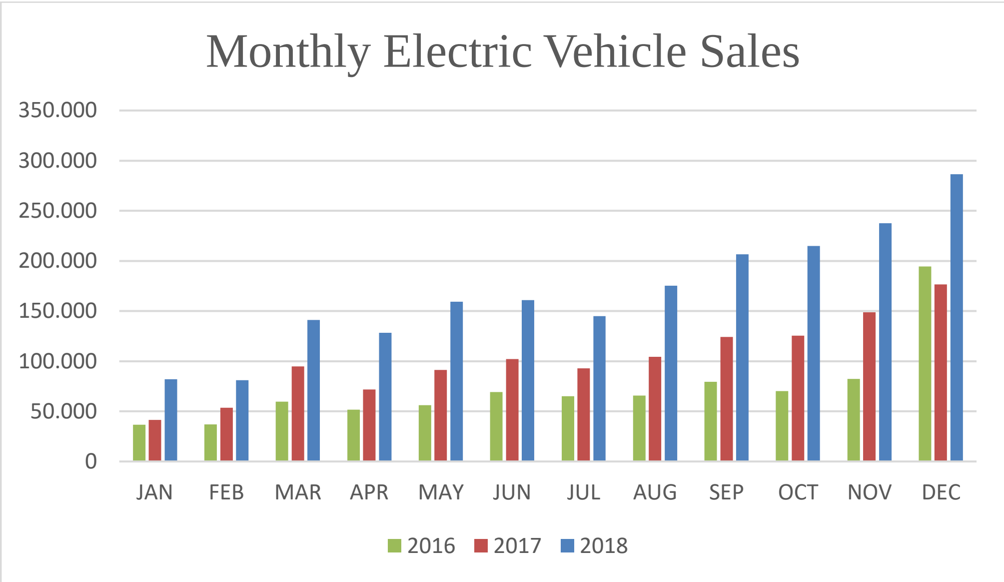

Figure II.4. Monthly EV sales.

Since the demand for electrical vehicles increases in our country, automotive firms offer different brands and models to users. Since 2019, there are 31 different EV models in Turkey. According to the TEHAD report, 119 BEV and 9383 HEV had been sold in Turkey as of December 2018. Other than these vehicles, there are vehicles that are converted from ICEV to EV and does not have an official distributor and these were excluded from the total number [23].

2.2.1. Classification of electric vehicles

Electric vehicles can be analyzed under three main titles as ‘’Full Cell Electric Vehicle’’, ‘’Battery Electric Vehicle’’, ‘’Hybrid Electric Vehicles’’ based on application. Electric vehicles are differentiated by electric machine type and operation principle, engine power and application method.

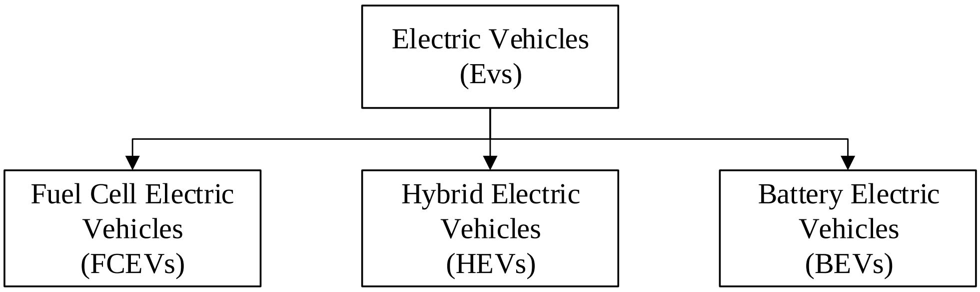

Figure II.5. Types of electric vehicles.

2.2.1.1. Fuel cell electric vehicles

Fuel cell electric vehicles use an electric motor like other EVs. But instead of storing electric energy at the battery, hydrogen gas in the tank is combusted to generate electrical energy. Fuel cell on FCEV combines hydrogen with oxygen in the air to generate electricity and this electricity is used for supplying electric motor.

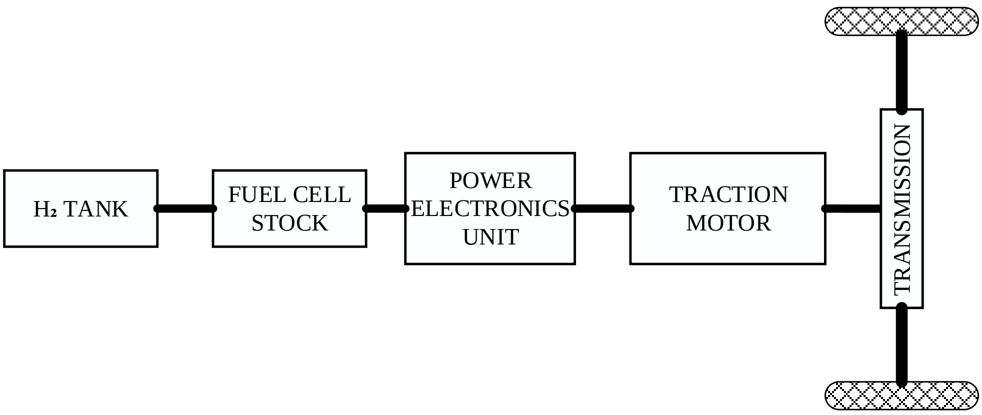

Figure II.6. Structure of FCEVs.

2.2.1.2. Hybrid electric vehicles

HEVs can be classified under two titles as “hybridization degree” and “design method".

HEV classification based on hybridization degree is related to electric motor power. This is classified with the effectiveness rate of driving an electric motor.

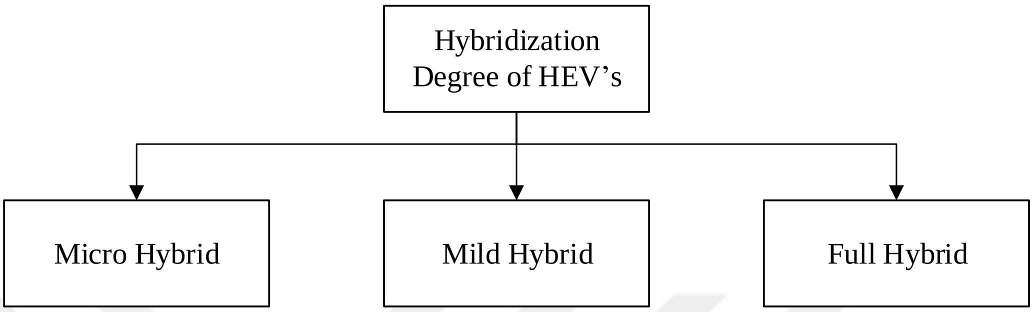

Figure II.7. Hybridization degree of HEVs.

- **Micro hybrid vehicles**

In micro-hybrid vehicles, there is no independent power source to supply electric motor. ICE on the vehicle will activate during idle operation and supports the system. This is the start-stop technology that is used in current vehicles.

- **Mild hybrid vehicles**

Mild hybrid vehicles have limited properties and these vehicles offer modest support to ICE during cruising in addition to start-stop. The most important property of these vehicles that differentiate from micro-hybrid vehicles is charging the battery that supplies electric motor.

- **Full hybrid vehicles**

Full hybrid vehicles can use both ICE and electric motor during cruising with a complex control algorithm. Energy is also recovered and saved into the battery and/or super-capacitor, during coasting and regenerative braking.

Table II.2. Comparison of hybrid levels.

Hybrids	Micro Hybrids		Mild Hybrids	Full Hybrids
	ISG, Start-Stop	ISG Hybrid		
Engine	Conventional	Conventional	Downsized	Downsized
Electric Motor	Belt Drive	Belt/Crankshaft	Belt/Crankshaft	Crankshaft
Electric Power	Crankshaft	3-10 kW	10-20 kW	15-100 kW
Operating Voltage	12V	12-42V	60-200V	200-600V
Fuel Economy Improvement	%3-5	%5-10	%15-20	%20-40

- **Plug-in hybrid**

Although PHEV has a similar structure, while PHEV batteries can be charged externally, engine power comes from ICE like HEV. In HEV, electric motor supports the internal combustion motor while this operation method is the opposite for PHEVs. Based on the design method, there are 3 different HEV technology as given in Figure.II.8.

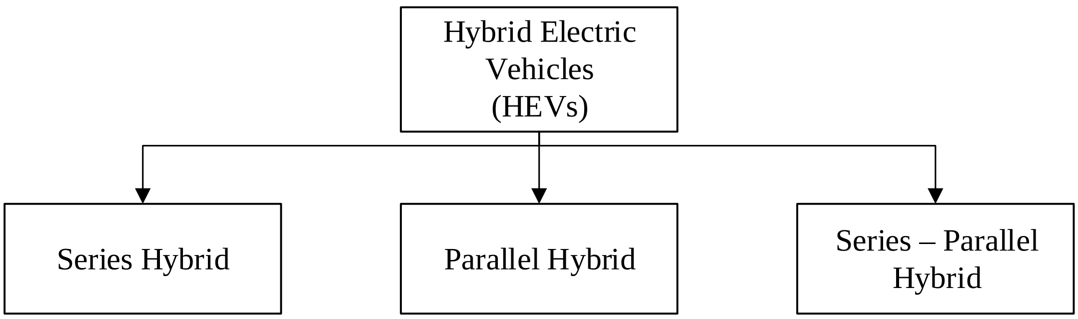

Figure II.8. Types of hybrid electric vehicles.

- **Series hybrid**

In the serial hybrid system, the internal combustion engine (ICE) operates as an electric generator to charge the battery and provide power to the electric motor that drives the vehicle. When the vehicle draws high power, the electric motor draws power from battery and generator.

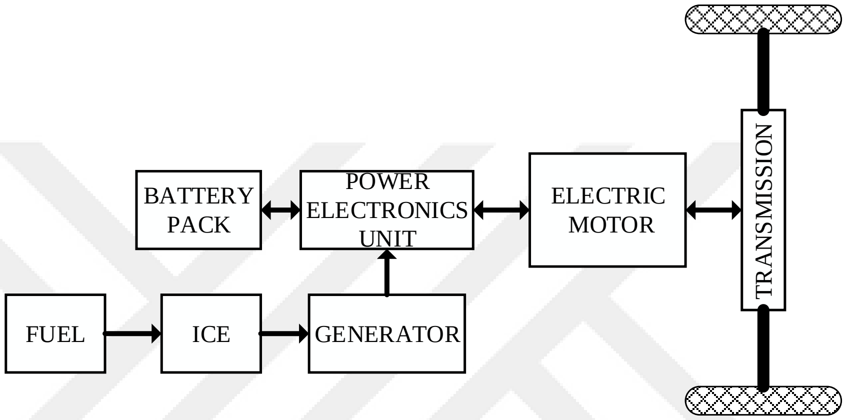

Figure II.9. Structure of serial hybrid system.

- **Parallel hybrid**

The parallel hybrid system has both the internal combustion engine (ICE) and an electric machine. Mechanical transmission in both engines has a parallel connection. The battery is charged during regenerative braking and during cruising if ICE is producing more power than needed.

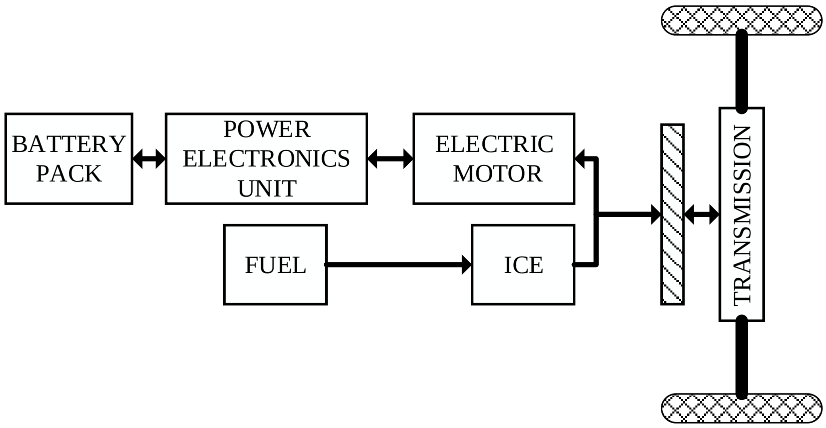

Figure II.10. Structure of parallel hybrid system.

- **Series-Parallel hybrid**

Series-Parallel hybrid vehicles have a complex structure and drive axle has two connections as mechanical and electrical. The main principle here is differentiating the operation of two engines. The system in these vehicles can independently control power resources for optimum energy efficiency during operation and cruising.

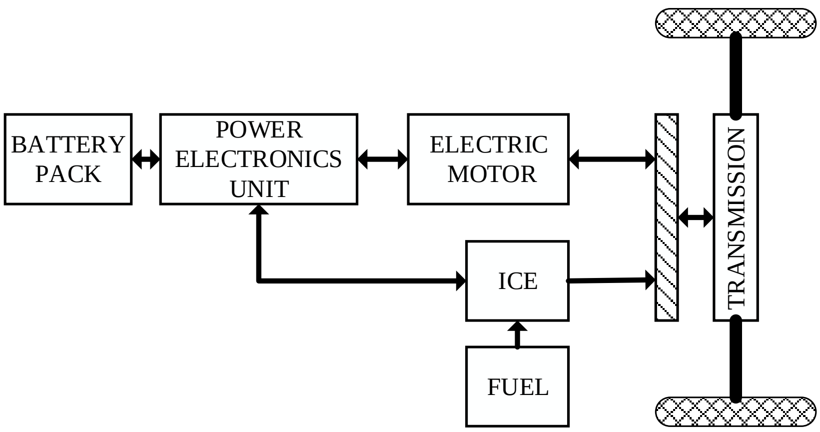

Figure II.11. Structure of series-parallel hybrid system.

2.2.1.3. Battery electric vehicle

Pure battery electric vehicles have one or more electric machines rather than ICE. Energy stored in the battery is directly transferred to the electric motor. Electric vehicles with batteries play an important role to supply the transportation sector with clean energy resources (wind and solar).

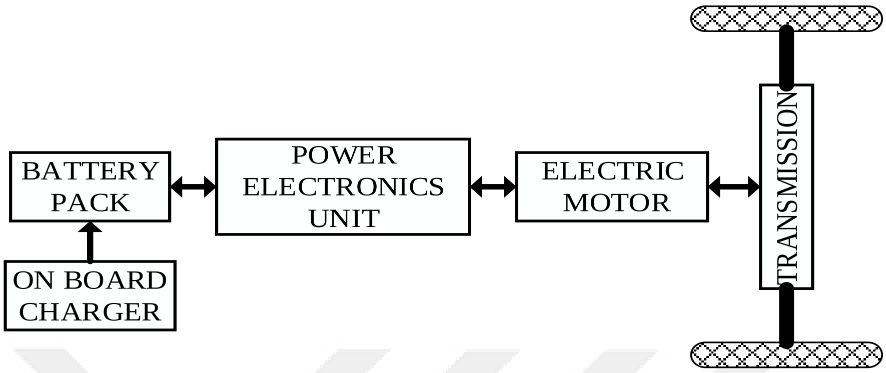

Figure II.12. Structure of battery electric vehicles.

2.2.2. Energy storage units of electric vehicles

EVs can supply required energy from different resources such as fuel cells, ultra-capacitor or batteries. As this study focused on battery, other parts are excluded from the analysis.

Today, most common battery systems have new generation batteries that contain nickel and lithium. Battery technologies in electric vehicles are nickel metal hybrid (Ni-MH), lithium-ion batteries (Li-on), lead acid (PB-Ac) and Li-polymer (Li-Po) and some properties of these batteries are given in Table II.3. [24].

Table II.3. Properties of some batteries.

	Ni-MH	Li-Ion	PB-Ac	Li-Po
Energy Density [wh/kg]	60-120	110-160	30-50	110-130
Power Density [W/kg]	1500-200	2000-650	300-80	>250
Cycle Life (80% DOD)	300-500	500-1000	200-300	300-500
Fast Charging Time	2-4h	2-4h	8-16h	2-4h
Overcharge Tolerance	Low	Very Low	High	Low
Self-Discharge / Month	%30	%10	%5	10%

2.2.2.1. Battery management system

Battery Management System (BMS) is based on monitoring, calculating and protecting charge and discharge of electric vehicle batteries. This way, batteries in these vehicles can be optimized for safety, efficiency and life cycle.

Voltage, current and temperature values of these batteries are constantly monitored and the system automatically intervenes when necessary. Some of the advantages of BMS are as follows:

- Instantaneous consumption, charge status and range of the vehicle can be observed by users.
- High current, high voltage, and high-temperature values during charge and discharge can be measured and the battery can be protected.
- By charging each cell group in the battery at an equal level, the life cycle and efficiency of the battery can be increased.

2.3. Electric Vehicle Charging Stations

EVs that can be charged as BEV and PHEV fail to charge batteries at full capacity although these can charge batteries with regenerative breaking [25]. Therefore, there is a need for electric energy from the external source to charge EV batteries. EV charging tool converts grid energy to the energy form needed by BEV or PHEV and ensures safe battery application.

Charging stations have three main functions. These are AC-DC rectification, voltage, and current level regulation based on predefined charging speed and physical connection between vehicle and charging station. In addition to these functions, these stations ensure communication with the vehicle during charging for protection and control.

To charge EVs in a safe and fast manner, institutions have set energy levels, safety, and connector group standards for charging units. These standards include the Society of Automotive Engineers (SAE) J1772 standard, International Electro technical Commission (IEC) 61851 standard and CHAdeMO standard formed by cooperation of Tokyo Electric Energy Company (TEPCO), Nissan, Mitsubishi, Subaru, and Toyota. In our country, IEC commission 61851 and 62196 standards are applied for charging stations and connectors, SAE J1772 standard and CHADEMO DC speed charging standards are applied.

Charging station levels are divided into three as slow, normal and fast. Slow charging stations are generally used in houses and places where parking duration is long. Normal charging stations are used in car parks, shopping malls and places with short parking duration. Fast charging stations are used where traffic is intense and when there is urgent energy need. Table II.4. shows charging levels for mode and power levels.

Table II.4. Charging levels for mode and power levels.

	Level	Phase	Voltage(V)	Current(A)	Power (max.)(W)
Mode 1	Low	1	120V-230V	12A-20A	1.4kW-3.5kW
				20A	3.4kW
Mode 2	Normal	1-3	240V -400V	32A	8kW
				80A	19.2kW
Mode 3	Fast	3	240V -480 V	32-250A	150 kW
Mode 4	Fast	3	600V DC	200A	

2.4. Factors That Effect Charging Infrastructure Planning

Battery charging in EV vehicles is similar to the fueling of ICEV. It is not possible to supply the electric energy necessary for EV in fast and on demand. Therefore, these vehicles should be charged in certain periods. However, correctly planned charging station location can ensure continuity to handle this issue. Some of the main factors to be considered when charging stations are planned location, driver profiles, closeness to distribution systems.

The location of these charging stations should be on easily accessed locations without preventing continuity in transportation. Car parks and fuel stations can be some of these locations.

Charging stations that are positioned based on drive profiles should consider the transportation habits of individuals. The time between home and school or shopping malls and time spend there should be considered. Additionally, profile density in these locations should be considered and infrastructure should be built accordingly.

One of the most important factors to position EV charging stations is closeness to distribution facilities (transformer centers). Charging stations with the correct infrastructure and close to distribution facilities will decrease investment costs as well as minimize grid losses. Additionally, closeness to TC can ensure simultaneous service to multiple EVs and minimizing overload of transformers and voltage drop that affect energy quality.

2.4.1. Methods for positioning charging stations

Needs that could arise for EV charging station infrastructure should be predicted and charging stations should be positioned and planned at an optimum level with long term plans. Therefore, there are various studies around the world on the positioning of electrical vehicle charging stations to predict needs that arise from intense EV usage.

Studies show that traffic intensity, driving profiles, social life, economic values, grid infrastructures, regional geographical structure data can be analyzed for ideal location selection. D. Guler and T. Yomralioglu identified charging station locations based on economic, environmental and social criteria with Geographic Information Systems (GIS) and by using Multi-Criteria Decision-Making Methods (MCDM), Analytical Hierarchy Process (AHP) [26]. H. Wang, Q. Huang, C. Zhang, and A. Xia applied a new approach method to position electric vehicle charging stations. Non-linear multi-objective planning model was created with the sustainability of electric vehicles, charging station characteristics, user profiles, and distribution of charging demand. With this planning model, the authors provided a study open for improvement and sustainability with electric infrastructure planning, urban planning and using current gas stations [27]. J. Zhu, Y. Li, J. Yang, X. Li, S. Zeng, and Y. Chen planned the positioning of charging stations with capacity optimization, decreasing investment cost and facilitating transportation with Queuing Theory (QT) [28]. The authors developed various alternative approaches with predetermined criteria to establish the charging station. New solution methods and plans can be developed by changing data in that study.

2.5. Effects of Electric Vehicle Charging Station On Grid

Today, as smart and environmentally friendly technologies are emphasized, advancements in EV technologies were achieved. With these advancements, it is believed that environmental threats will decrease in the near future. However, increased demand in line with technological developments in EV will create an additional need for energy that is supplied from grids. It is predicted that if electric vehicles are popular before the necessary infrastructure is built, there will be problems in charging and these problems will negatively affect electric grid power quality and overloading. However, to reduce these effects, load demand graphs of these electric grid systems should be obtained and EV expansion and future demand increase and capacity should be predicted with technical infrastructure.

Positive or negative impacts of electric vehicle charging stations of grip can be analyzed under voltage fluctuations, frequency, capacity, harmonic effect, transformer lifecycle, investment costs and maintenance costs.

When harmonic effects of charging stations are analyzed, controlling harmonics with different filtering, high harmonic in level/mode charging tools and financial losses and power quality losses of these harmonics on the grid should be analyzed. Studies analyzed different harmonic filtering methods and their effects, effects of active power filter, six pulse rectifier and LMS / LMF algorithms and observed that harmonics have significantly decreased and power factor significantly improved [29], [30], [31]. Additionally, other studies also emphasized that effects of distance between charging station and the vehicle should be analyzed for accessibility and planning of charging stations [32]. These studies aimed to collect preliminary information by observation to identify which filters should be used for charging level/mode and how close should charging stations be to load.

When it is considered that electric vehicle charging stations will be used at houses, sites and workplaces, negative effects of instant, uncontrolled or unplanned loading of the distribution grid, voltage fluctuations, imbalances between phases and overload of transformers are predicted for studies. In these studies, encouraging connection to grid after pricing policies and point of users are considered as alternative solutions to prevent negative effects on grid [33], [34], [35]. Correctly analyzing and applying load profiles and needs will prevent negative effects (thermal, aging, etc.) of transformers [36].

III. ANALYSIS OF EFFECTS OF ELECTRIC VEHICLE CHARGING STATION ON GRID

In this study, a pilot region under Bogazici Electric Distribution Co. (BEDAS) on the European side of İstanbul was selected. Real values of Transformer Centre location and center properties on distribution feeder, transformer feeder location and types collected with the GIS system and modeled. Additionally, data required to analyze hourly energy consumption in the last six-month on transformers on feeder were collected over AMR, these data were combined on the GIS system and real-time distribution feeder and feeder power profile were created on CYME for analysis. Two different studies are conducted on this model as analysis and experiment.

In the analysis stage, charging stations at different levels and additional power were defined to selected pilot region ad grid was observed. In the following study, analyzed results were considered to minimize possible negative effects on the distribution grid and the charging station model was designed. When the design was created, environmental factors such as housing, shopping mall, school, and business center around the region were considered and required electric vehicle charging station level and user profiles were identified as analysis data. It was observed that with different user profiles, there were different charging station levels (slow-medium fast-fast) and additional load on the grid at different times.

The purpose of this study was to minimize the effects of electric vehicle charging station requirements on the distribution grid and expand control of these systems.

3.1. Pilot Region Selection for Grid Model

Region for this model was selected by taking distribution feeder with transformer station as a reference that covered different user groups such as universities, shopping malls, site, and neighborhoods.

This distribution feeder had 12 transformers with different power capacity.

Table III.1. Feeder transformer information.

Kilovolt-Ampere (kVA)	Pieces
1000	4
1250	4
1600	3
2000	1

Four of these transformers were mid-voltage clients and measurements of related clients were taken from the primer side of the transformer. Data of the other 8 transformers were collected from the seconder side of the transformer.

The single line scheme of selected distribution feeder to create the model from the TEIAS step-down transformer center has been given in Figure III.1.

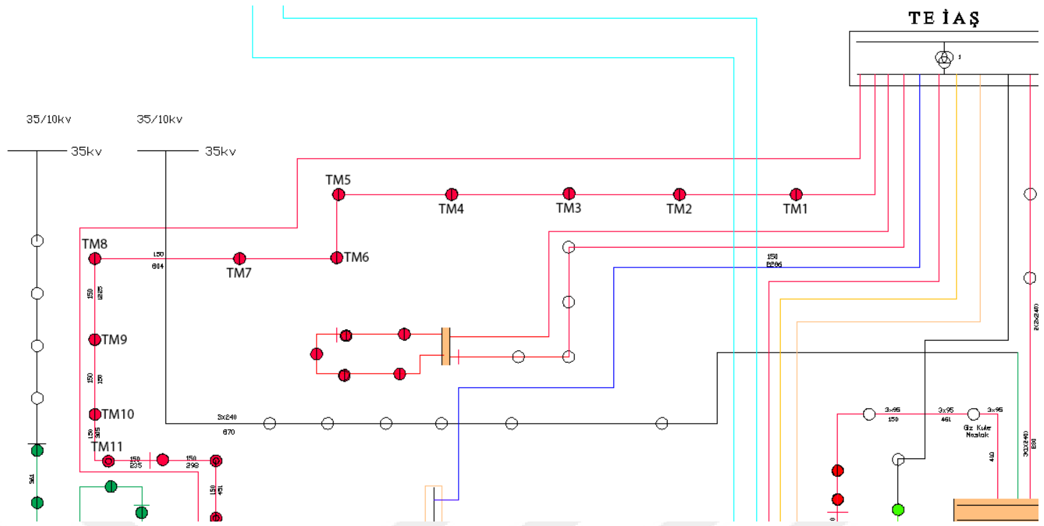

Figure III.1. Pilot region single line scheme.

3.2. Data collection from GIS

All mid-voltage (MV) and low voltage (LV) inventory information in the pilot region were collected from Geographic Information System (GIS). This model included all inventories such as MV main line, MV switching components, MV protection components, MV/LV transformers, LV panels. This way, a model that contains the LV grid will be connected to the grid from LV and the effects of EV can be analyzed under a different scenario. Data collected with the CYME program was been modeled and switching positions were organized for a single line on Figure III.1.

GIS system view of transformer centers under BEDAS are shown in Figure III.2.

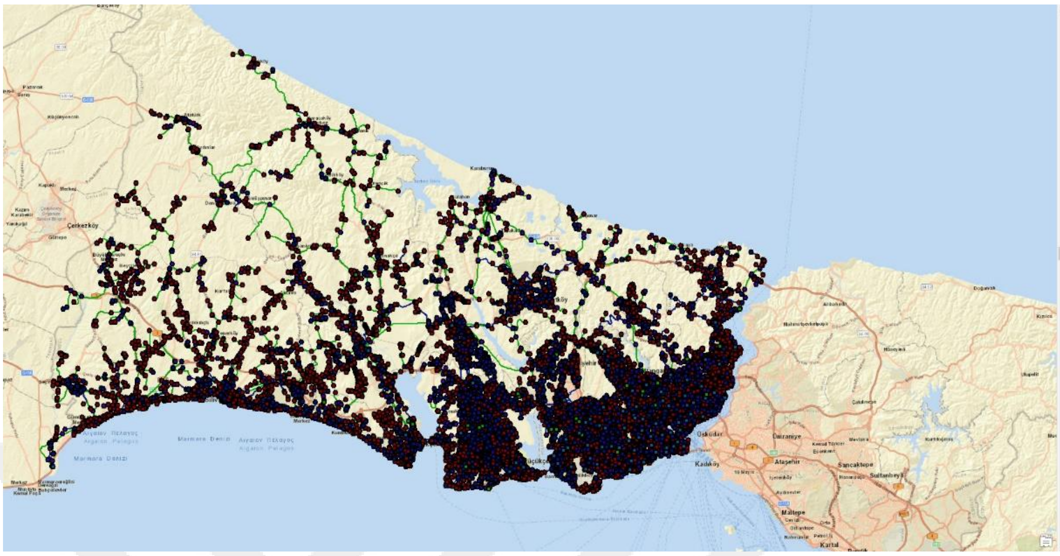

Figure III.2. Transformer map.

CYME program view of distribution feeder supplied on TEIAS step-down center obtained from GIS system is shown on Figure III.3.

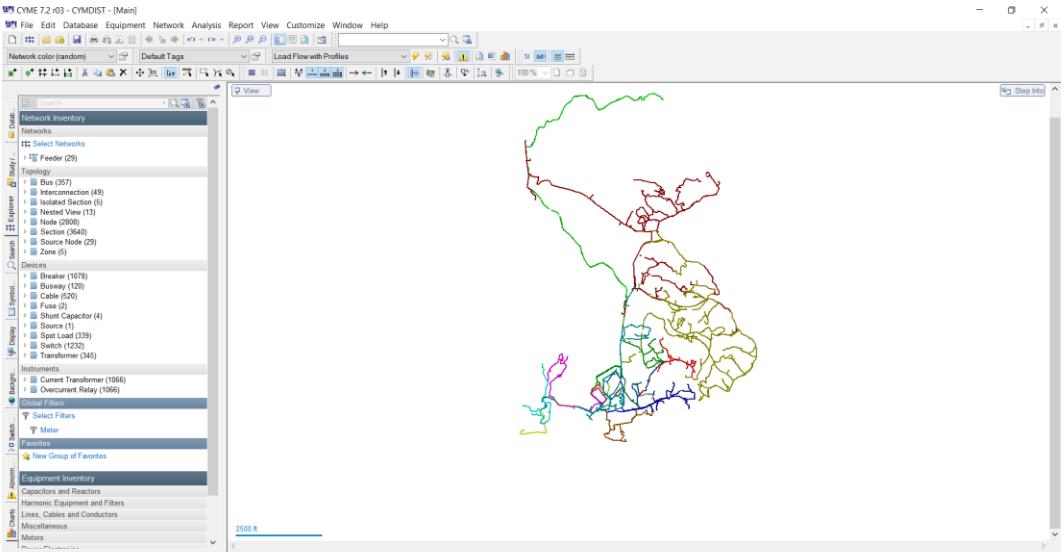

Figure III.3 Regional distribution feeder.

Feeder in the selected pilot region starts from TEIAS step-down center to TM-11 at the end of the line. TM-10 on the feeder is a center with two transformers and two bus bars. All MV underground cables on the distribution feeder are 3x1x150mm² XLPE CU cables. Cable distance between centers and loads on these centers is given in Table III.2.

Table III.2. Regional profile details.

	Transformer (kVA)	Lenght (m)	Load Type
TEİAS - TM1	2000	1.490	Building Estate
TM1 - TM2	1250	1614.8	Neighborhood
TM2 - TM3	1250	620.3	University – Shopping mall
TM3 - TM4	2 x 1600	104.2	Shopping mall - University- Office Buildings - Residence
TM4 - TM5	1000	111.8	Neighborhood
TM5 - TM6	1000	890	Neighborhood
TM6 - TM7	1600	596.2	Neighborhood
TM7 - TM8	1000	200	Neighborhood
TM8 - TM9	1000	332.7	Neighborhood
TM9 - TM10	1250	428	Neighborhood
TM10 - TM11	1250	366.4	Neighborhood

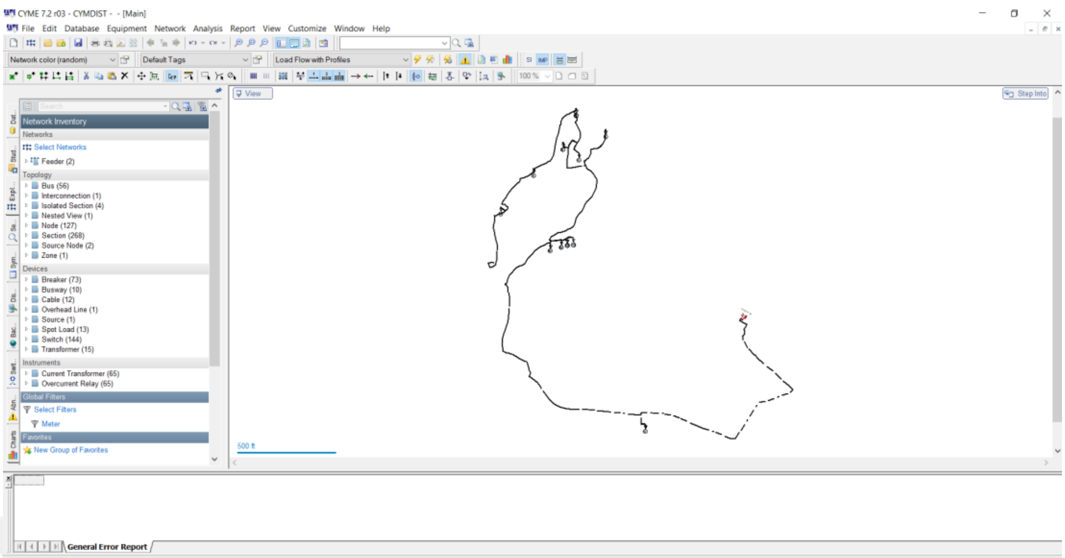

Figure III.4. CYME view of selected feeder.

3.3. Data collection from AMR

In terms of load management in distribution grids, (AMR, SCADA, etc.) systems are used for instantly monitoring grids and storing grid data. Data sources for related feeder were analyzed and recorded load profiles were obtained from the system. MV feeder of the selected distribution grid, TEIAS center, and operation regions was selected based on weighted subscriber profiles. Obtained AMR load profiles were measured on the primer side of the mid-voltage client and the seconder side of the BEDAS transformer. Load profiles were analyzed for annual, monthly, daily and seasonal changes. Based on these analyses, the identified parameter (Peak Ratio, Minimum load, Maximum load, Average load, Power Factor, etc.) were calculated as secondary data for load profiles.

Daily and hourly data samples of load profiles are given in Figure III.5.

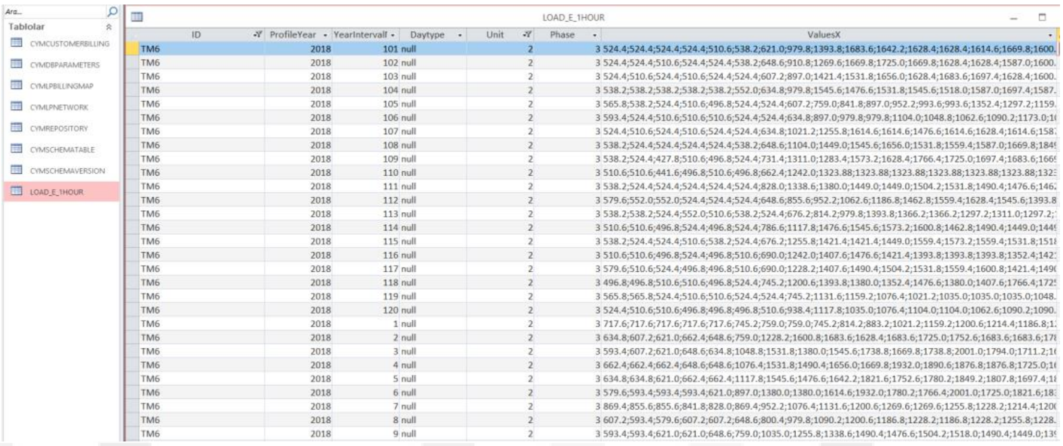

Figure III.5. Load profile data.

3.4. Creating User Profiles and Identifying Charging Station Types

3.4.1. Creating user profiles

This study analyzed the energy demand of EV from electric grid and field data were collected to predict this demand. Region-based load types in Table III.2. were analyzed and these data were organized to be applied to the model.

Data in housing and business centers were collected from GPS of company vehicles. Weekend use of company vehicles was adopted to the Shopping Mall scenario. University scenario was created based on Istanbul Okan University, Engineering Faculty curriculum.

After these studies:

- Home and work return hours of vehicles,
- Driving cars at the weekend (external places, time spent in these places),
- School arrival time of university students,

information was collected. ICEV usage adapted for creating scenario were considered as electric vehicle usage and the number of charging stations in transformer centers and additional loads was calculated.

Work and home arrival data were calculated as a one-week average of 20 vehicles. Figure III.6. shows arrival hours to work and Figure III.7. shows arrival hours at home.

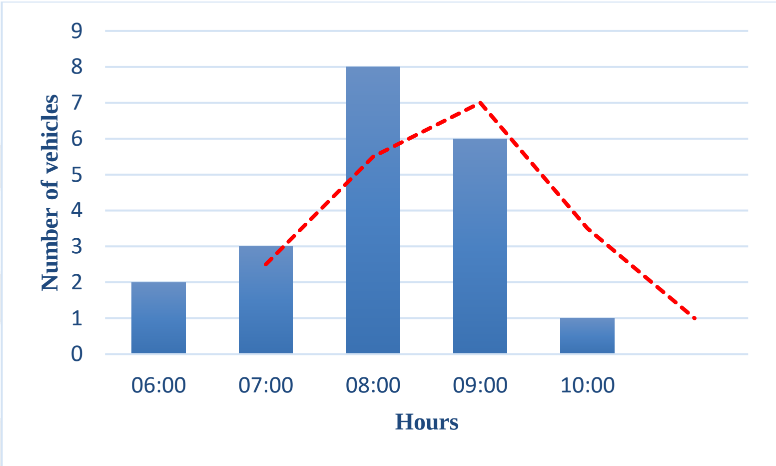

Figure III.6. Work arrival hour of vehicles.

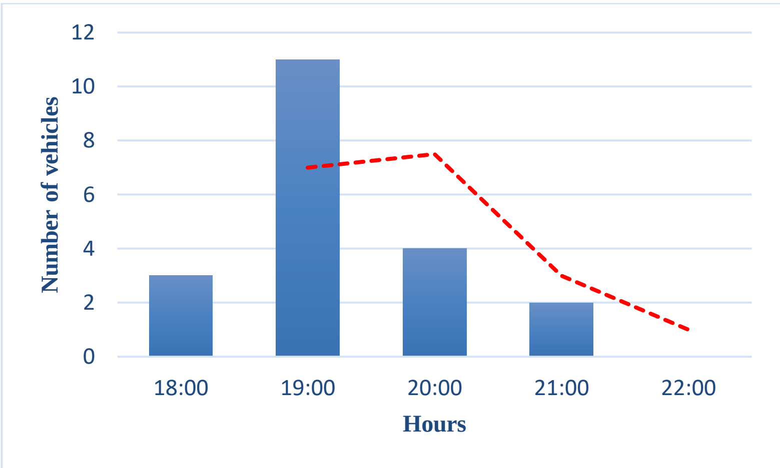

Figure III.7. Home arrival hour of vehicles.

Weekend arrival average of vehicles outside work are given in Figure III.8.

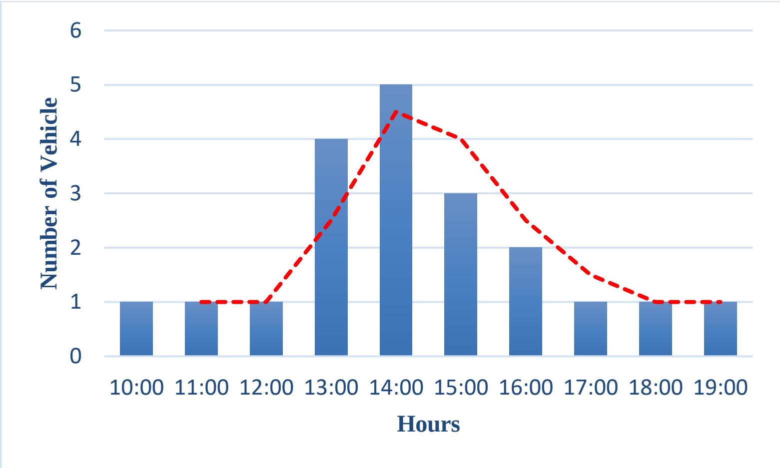

Figure III.8. Weekend vehicle usage.

When generating data for university, class hours between 09:00 and 17:00 were considered as arrival times to school. This study evaluated 60 vehicles and the number of vehicles was reduced to 20 by taking the average.

Vehicle transportation hours' average in university is given in Figure III.9.

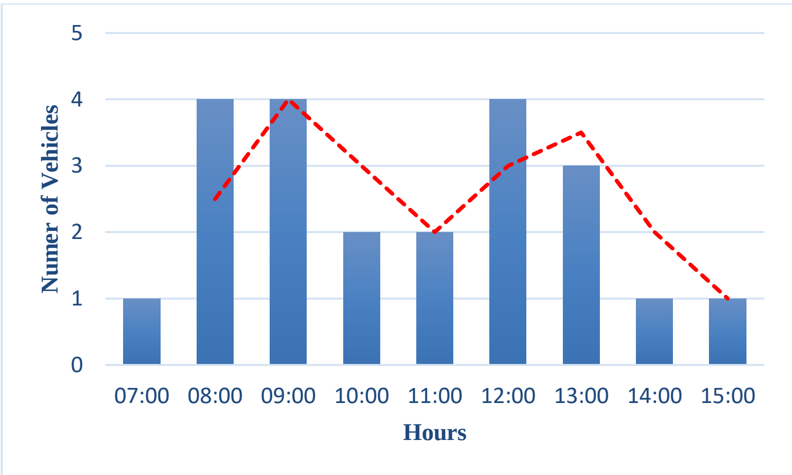

Figure III.9. Vehicles arrival hours at university.

3.4.2. Electric vehicle charging station test

There are previous studies on electric vehicle charging status, charging hours and data obtained from these studies are given below. In this model, this data was adopted for EV charging durations. The charging device used in this study is a 7.4 kW mode 3 / Type 2 station. The technical properties of this device are given in Table III.3. Charge test data of the vehicle are given in Figure III.10.

Table III.3. Technical properties of tested electric vehicle.

Battery Capacity (kWh)	Range (km)	Charger power (kW)	Charging Time (h)	Battery Voltage	E-Motor Power (kW)
22	160	7,4	5,5	360	125

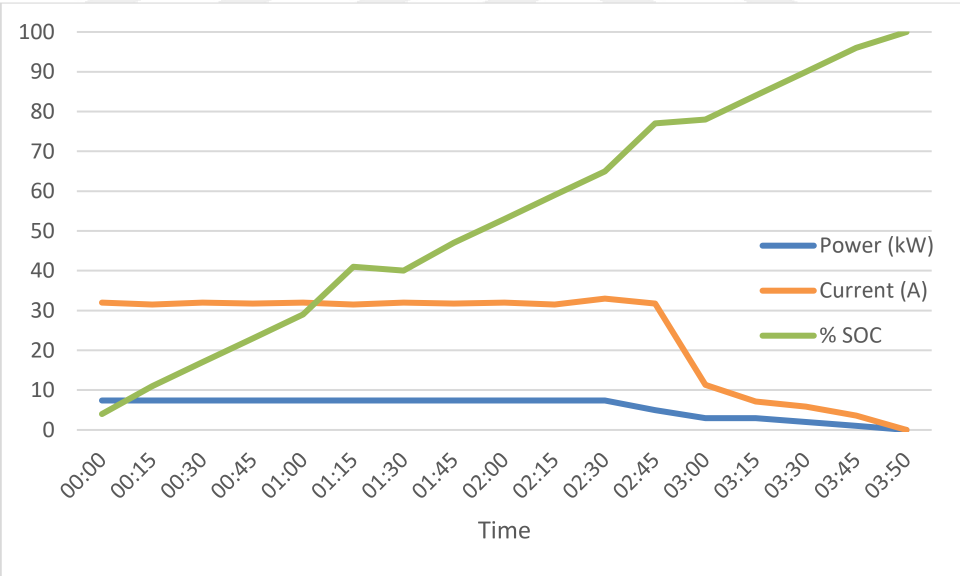

Figure III.10. EV charging test graphs.

3.5. Grid Analysis Based On Obtained Results

For this purpose, the current grid was analyzed. In these analyses, load demand and other data were not considered based on time. First, additional load profile analysis (without EV charging station) of distribution facility was conducted with the CYME model. Later, the effects of possible charging stations based on grid locations were observed.

Maximum transformer loading values of transformers on selected distribution feeder between 01/01/2018 01:00 - 11/07/2018 00:00 were collected, added to the model inside the CYME program and simulated for analysis. Sample load profiles on transformers on the model were given in Figure III.11.

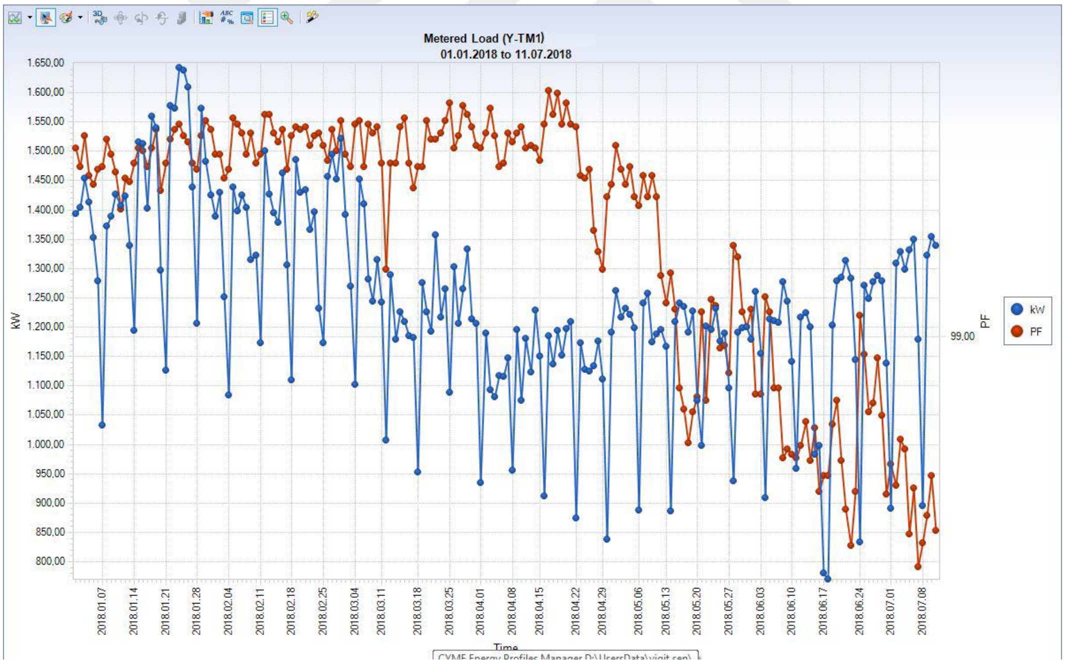

Figure III.11. 6 month maximum load graphic of transformer center.

Components on transformer center on CYME model are given in Figure III.12.

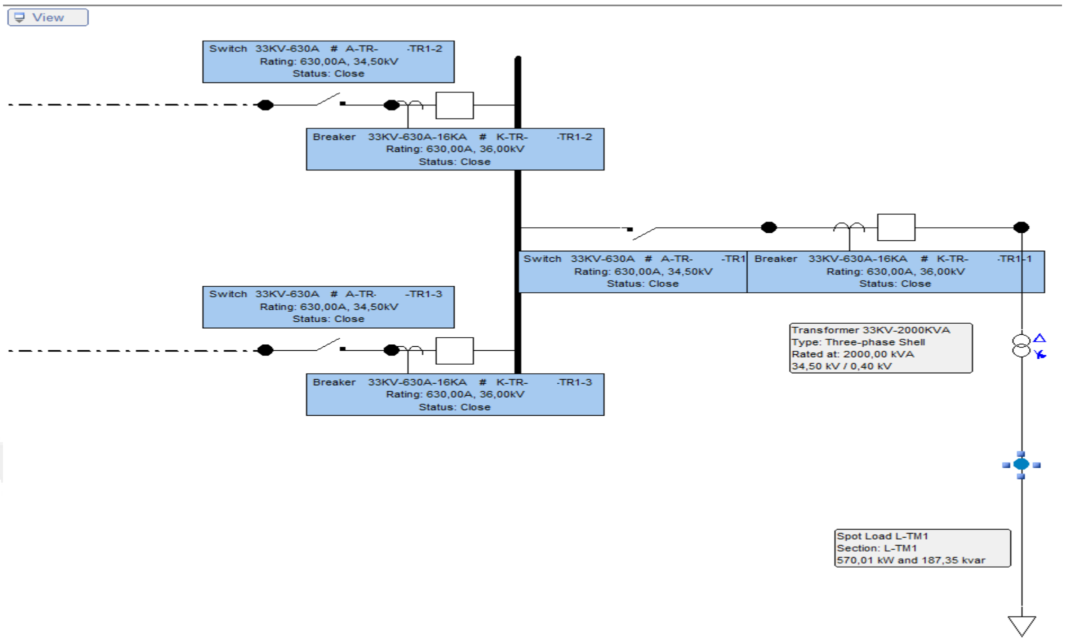

Figure III.12. CYME view of transformer center.

Measurement points of the transformer center that are analyzed are given in Table III.4.

Cable 3x120 NFGBY from the transformer center to charging station was selected on the Low Voltage bus bar. Different data were added for a cable length of each center.

Table III.4. Naming analysis points.

Center Name	Cable Name	TM Bus Bar Name	Nominal Load	TM connected charging station name	TM - EV cable name
TM1	C-S-TM1	B_A_TM1	L-TM1	EV_CHARGER_1	C-EV1
TM2	C-TM1-TM2	B_A_TM2	L-TM2	EV_CHARGER_2	C-EV2
TM3	C-TM2-TM3	B_A_TM3	L-TM3	EV_CHARGER_3	C-EV3
TM4-TR1	C-TM3-TM4	B_A_TM4	L-TM4-T1	EV_CHARGER_4.1	C-EVC4.1
TM4-TR2			L-TM4-T2	EV_CHARGER_4.2	C-EVC4.2
TM5	C-TM4-TM5	B_A_TM5	L-TM5	EV_CHARGER_5	C-EV5
TM6	C-TM5-TM6	B_A_TM6	L-TM6	EV_CHARGER_6	C-EV6
TM7	C-TM6-TM7	B_A_TM7	L-TM7	EV_CHARGER_7	C-EV7
TM8	C-TM7-TM8	B_A_TM8	L-TM8	EV_CHARGER_8	C-EV8
TM9	C-TM8-TM9	B_A_TM9	L-TM9	EC_CHARGER_9	C-EV9
TM10	C-TM9-TM10	B_A_TM10	L-TM10	EV_CHARGER_10	C-EV10
TM11	C-TM10-TM11	B_A_TM11	L-TM11	EV_CHARGER_11	C-EV11

The effects of connection of different electric vehicle charging stations on different grid points on active power loss were evaluated based on the model generated from obtained data.

Properties of different type of charging stations in the analysis are:

- 7.4 kW slow charging station.
- 22 kW medium speed charging station.

- 43 kW fast charging station.

Accordingly, grid analysis was conducted for the different charging stations and different numbers of vehicles for three different grid connection points (from farthest point to closest point). During analysis, (current) load profile except modeled charging station load profiles were excluded from the calculation. The CYME application of load profiles is shown in Figure III.13.

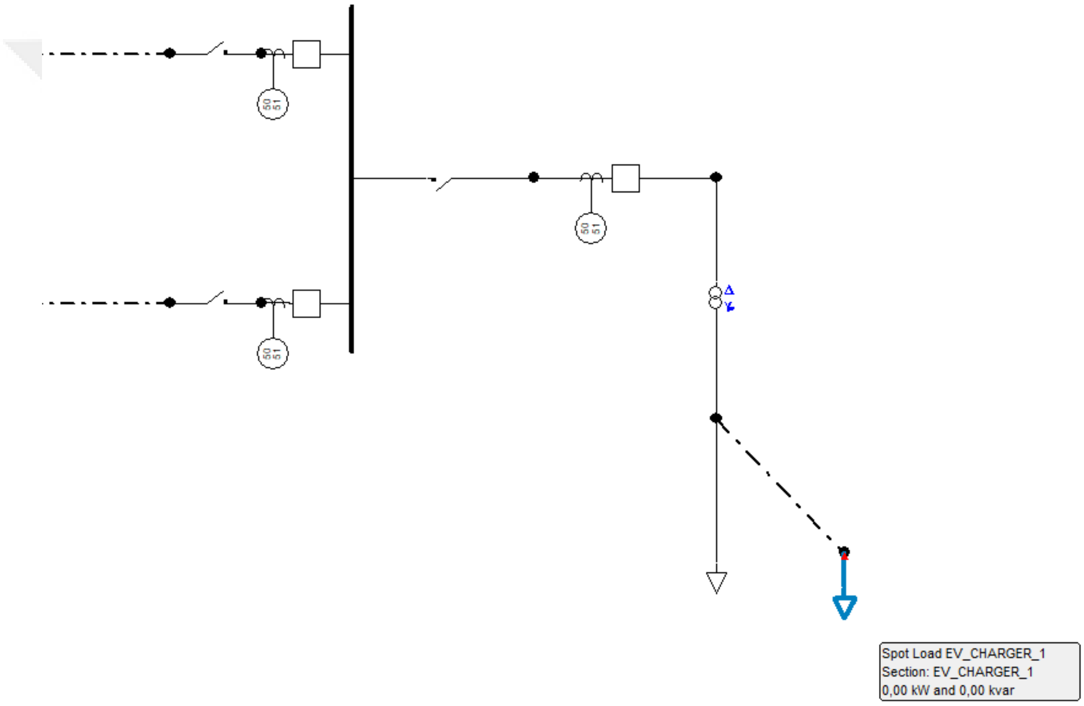

Figure III.13. CYME application of load profiles.

Analysis results for TM1 (first center on distribution feeder) that is the closest center to TEIAS output are presented in Table III.5.

Table III.5. TM1 load analysis.

TM1	20x7.4 kW	20x22kW	20x42 kW
Cable Losses	0.04 kW	0.08 kW	0.19 kW
Transformer Load Losses	0.12 kW	1.14 kW	4.22 kW
Transformer No-Load Losses	28.64 kW	28.64 kW	28.63 kW
Total Losses	28.81 kW	29.86 kW	33.01 kW

Load analysis results for TM6 are given in Table III.6.

Table III.6. TM6 load analysis.

TM6	20x7.4 kW	20x22kW	20x42 kW
Cable Losses	0.06 kW	0.18 kW	0.53 kW
Transformer Load Losses	0.21 kW	1.92 kW	7.09 kW
Transformer No-Load Losses	28.64 kW	28.63 kW	28.61 kW
Total Losses	28.91 kW	30.73 kW	36.24 kW

Load analysis results for TM11 are given in Table III.7.

Table III.7. TM11 load analysis.

TM11	20x7.4 kW	20x22kW	20x42 kW
Cable Losses	0.32 kW	2.65 kW	9.74 kW
Transformer Load Losses	0.16 kW	1.55 kW	5.78 kW
Transformer No-Load Losses	28.64 kW	28.63 kW	28.61 kW
Total Losses	29.12 kW	32.83 kW	44.13 kW

Regarding the data from the analysis results, the number of vehicles, charging station type and network connection point affect the results heavily. For example, connecting the same number of vehicles with the 42 kW fast charging station at the furthest bus TM11 point instead of at the closest bus TM1 point results in a loss of up to 33% regarding the active power. And this shows us the importance of the research about the positioning of charging stations.

3.6. Grid Modelling of EV Charging Station

The electric vehicle charging station grid model is created by using various analysis data as input. In addition to the current grid load, the main purpose of creating an EV charging station load model was to position the sufficient number of EV charging stations demanded each transformer center. When user profile data and regional scenarios were combined, the number of vehicles that will be simultaneously connected to transformer centers and demanded power will be calculated to meet the charging demands of all vehicles. In this model, capacities and inductive loads of charging stations were neglected.

The flow schematic of the ideal charging station for each transformer center is given below.

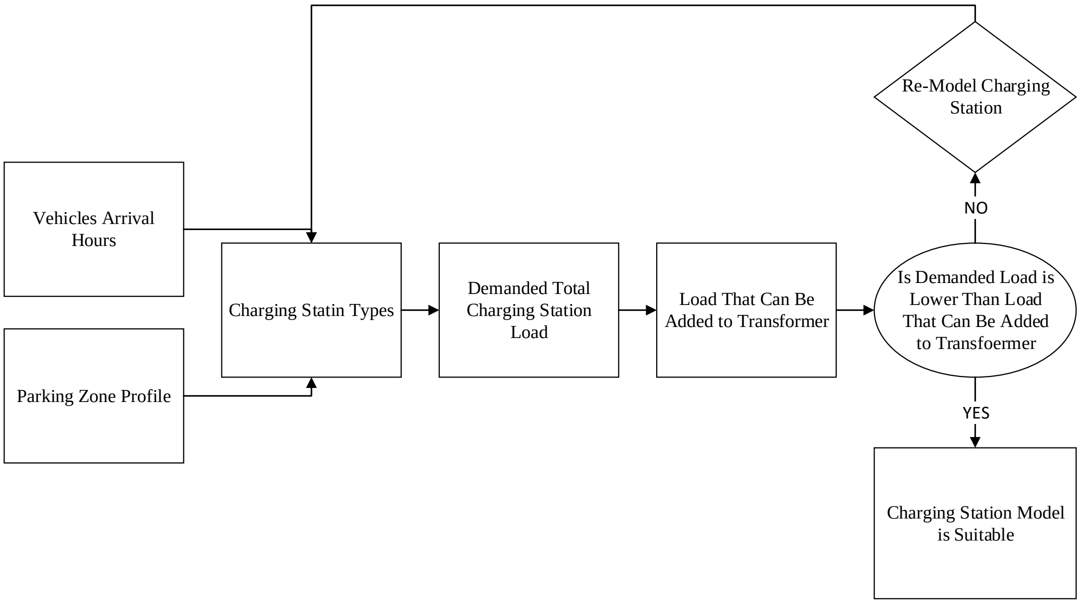

Figure III.14. Flow schematic of ideal charging station.

Formula 3.1 is used for load that will be added to grid in flow schematic.

$$\text{No} - \text{Load Transformer Load} = \text{Transformer Load} - \text{Current Max. Grid Load} \quad \text{III.1}$$

To determine number of charging stations:

$$\text{Numer of Charging Stations} = \frac{\text{Power Addition to Grid}}{\text{Charging Station Power}} \quad \text{III.2}$$

formula can be applied.

In this study, six-month load profiles of 11 transformer center on distribution feeder were analyzed and the ideal number of charging stations were positioned on each station.

When new additional load profiles were created, data were generated based on analysis on 3.4. Key factors that were applied for additional load profiles were as follows:

- For each transformer center region, separate load profiles were defined,
- The mixed scenario was applied to certain regions,
- Connection time of vehicles to charging station was identified as the time between 0% and 80% of SOC status,
- The power factor (cosφ) value of charging stations was selected by considering that this value will not be below 0.90,
- Random numbers were applied for every hour to calculated charging station loads,
- Real-time on a fast charging station was 30 minutes. However, since the analysis was conducted on an hourly basis, the charging time was selected for 1 hour,

Charging station types and properties for each scenario are given on Table III.8.

Table III.8. Charging station properties.

Mode	Type	Output Power	Charging Level
Mode 3	Type-2	7.4 kW	Slow EV charger
Mode 3	Type-2	22 kW	Medium Fast EV Charger
Mode 3	Type-2	43 kW	Fast EV charger

Mode3 has TYPE-2 7.4 kW (slow charge), TYPE-2 22 kW (medium-fast charge) and TYPE-2 43 kW nominal power. SC1, SC2, and SC3 scenarios were as follows:

- Slow Charging Station-SC1: This scenario is for the housing region. (Charging time was selected as 3 hours between 0%-80% SOC)
- Slow Charging Station-SC2: This scenario is for the workplace. (Charging time was selected as 3 hours between 0%-80% SOC)
- Medium-Fast Charging Station-SC3: This scenario is for public areas. Data will be used for the transformer center in the university region. (Charging time was selected as 2 hours between 0%-80% SOC)
- Supercharger Charging Station-SC4: This scenario is for the shopping mall. (Charging time was selected as 30 minutes between 0%-80% SOC)

- **Charging station modelling for TM1 region**

TM1 region consists of a site with housing and the selected charging station scenario was SC-1. Maximum load for six month and additional load for TM1 is calculated and these data are presented in Table III.9.

Table III.9. TM1 Load Analysis.

Installed Power (kVA)	Peak Power (kW)	Addable Power (kW)
2000	1642.2	357.80

For TM1, the maximum number of vehicles for simultaneous charging was set as 18 and 18 charging stations with 7.4 kW were added. A maximum load for vehicles that can simultaneously connect to the charging station was calculated as 128.51 kW. Weekly and hourly EV charging station load profiles for TM1 are given in Figure III.15.

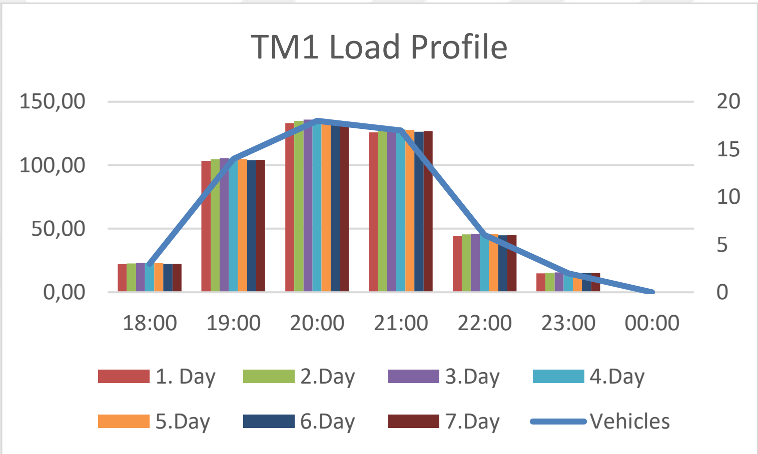

Figure III.15. TM1 charging station load profile.

- **Charging station modelling for TM2 region**

TM2 region consists of housing and business center. Therefore, SC-1 and SC-2 scenarios were applied together. Maximum load for six month and additional load for TM2 is calculated and these data are presented in Table III.10.

Table III.10. TM2 Load Analysis.

Installed Power (kVA)	Peak Power (kW)	Addable Power (kW)
1250	638.5	611.5

For TM2, the maximum number of vehicles for simultaneous charging was set as 18 and 18 charging stations with 7.4 kW were added. A maximum load for vehicles that can simultaneously connect to the charging station was calculated as 135.48 kW. Weekly and hourly EV charging station load profiles for TM2 are given in Figure III.16.

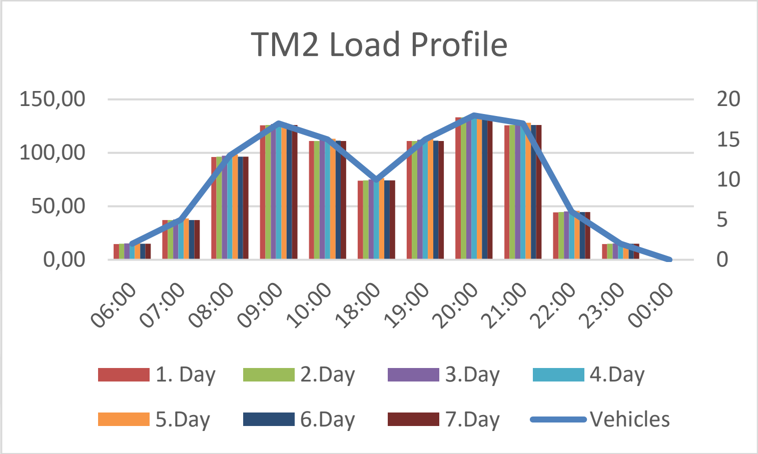

Figure III.16. TM2 charging station load profile.

- **Charging station modelling for TM3 region**

There are university buildings in the TM3 region. Therefore, the SC-3 scenario was applied. Maximum load for six month and additional load for TM3 is calculated and these data are presented in Table III.11.

Table III.11. TM3 Load Analysis.

Installed Power (kVA)	Peak Power (kW)	Addable Power (kW)
1250	1076.4	173.60

For TM3, the maximum number of vehicles for simultaneous charging was set as 7 and 7 charging station with 22 kW were added. A maximum load for vehicles that can simultaneously connect to the charging station was calculated as 155.42 kW. Weekly and hourly EV charging station load profiles for TM3 are given in Figure III.17.

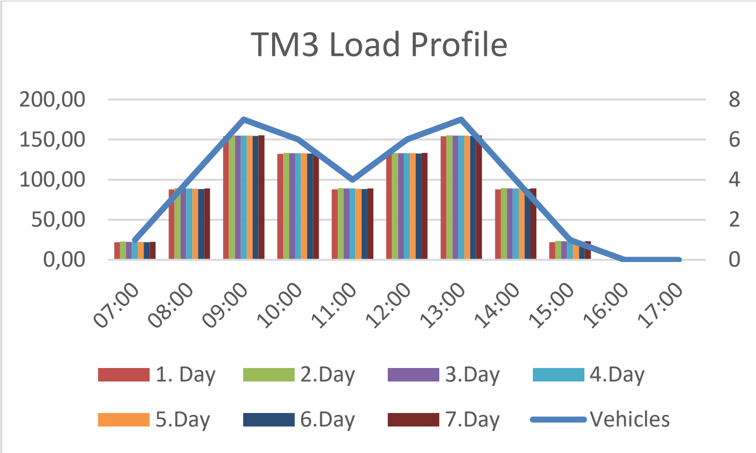

Figure III.17. TM3 charging station load profile.

- **TM4 - Charging station modelling for T1 region**

TM4 region has two different transformers. Transformers were defined as T1 and T2 and these transformers were analyzed separately. TM4-T1 consists of a university and shopping mall. Therefore, SC-3 and SC-4 scenarios were applied together. Maximum load for six month and additional load for TM4-T1 is calculated and these data are presented in Table III.12.

Table III.12. TM4-T1 Load Analysis.

Installed Power (kVA)	Peak Power (kW)	Addable Power (kW)
1600	343.2	1256.80

The maximum number of vehicles that can be charged simultaneously was set as 11 for TM4-T1. 4 of these vehicles will be connected to 43 kW fast charger and 7 of these vehicles will be connected to 7.4 kW charging station.

This caused a special condition in this region. Although a total of 11 vehicles with different power demand are connected to the grid, in the shopping mall profile, 5 different 43 kW charging station usage was identified at 14:00. Therefore, 43 kW charging stations were selected as 5.

A maximum load for vehicles that can simultaneously connect to the charging station was calculated as 328.07 kW. Weekly and hourly EV charging station load profiles for TM5-T1 are given in Figure III.18.

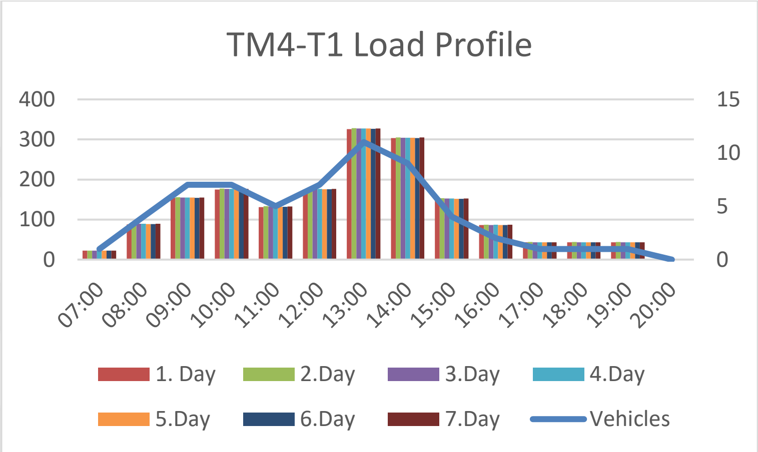

Figure III.18. TM4-T1 charging station load profile.

- **TM4 - Charging station modelling for T2 region**

TM4 region has two different transformers that were defined as T1 and T2 and these transformers were analyzed separately. TM4-T2 consists of housing and business center. Therefore, SC-1 and SC-2 scenarios were applied together. Maximum load for six month and additional load for TM4-T2 is calculated and these data are presented in Table III.13.

Table III.13. TM4-T2 Load Analysis.

Installed Power (kVA)	Peak Power (kW)	Addable Power (kW)
1600	587.4	1012.60

For TM4-T2, the maximum number of vehicles for simultaneous charging was set as 18 and 18 charging stations with 7.4 kW were added. A maximum load for vehicles that can simultaneously connect to the charging station was calculated as 135.06 kW. Weekly and hourly EV charging station load profiles for TM4-T2 are given in Figure III.19.

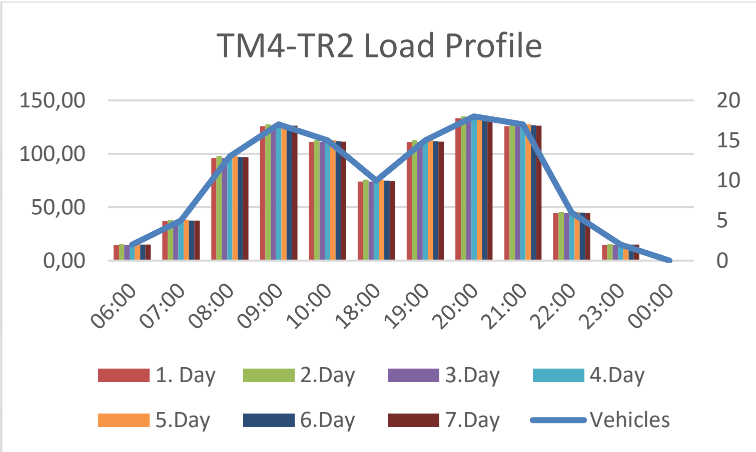

Figure III.19. TM4-T2 charging station load profile.

- **TM5 - TM11 charging station modelling**

Regions between TM5 and TM11 were the housing region. Therefore, SC-1 and SC-2 housing and business center scenarios were applied. Although scenarios were the same, since current load profiles in these regions are different, a six-month maximum load and additional load for transformers between TM5 and TM11 were calculated and presented in Table.III.14.

Table III.14. Between TM5 and T11 Load Analysis.

	Installed Power (kVA)	Peak Power (kW)	Addable Power (kW)
TM5	1000	539.6	460.4
TM6	1000	582.5	417.5
TM7	1600	132	1468.0
TM8	1000	671.5	328.5
TM9	1000	228	772.0
TM10	1250	504	746.0
TM11	1250	795	455

For TM5-TM11, the maximum number of vehicles for simultaneous charging was set as 18 and charging station with 7.4 kW were added. A maximum load for vehicles that can simultaneously connect to the charging station is given in Table.

Table III.15. Max. additional load power of the centers.

Center name	Additional power (kW)
TM5	135.85
TM6	135.91
TM7	136.16
TM8	136.13
TM9	135.96
TM10	135.84
TM11	135.93

Weekly and hourly EV charging station load profiles for TM4-TM11 are given in Figure III.20.

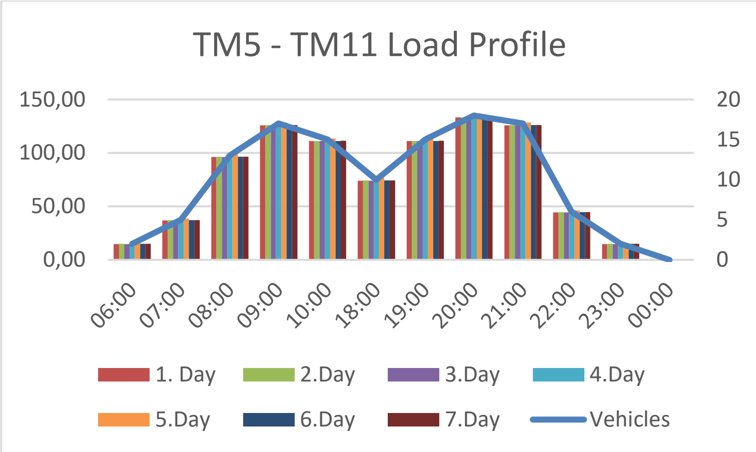

Figure III.20. Between TM5 and T11 charging station load profile.

The total of additional load of the charging station of the grid was analyzed on a daily basis. The maximum power that will be added to the grid in a day was calculated as 678.4 kW at 13:00. Figure III.21.

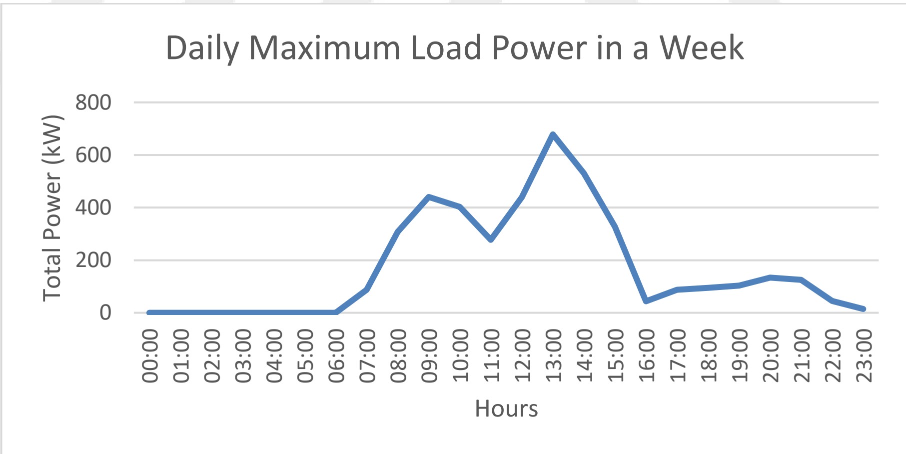

Figure III.21. Daily Maximum load power in a week.

After calculating additional load and identifying normal loads on the grid, each load profile data were added to the program for simulation and these loads were analyzed on the program. Analysis of EV charging station load profiles and current load profiles of transformers are given below;

- **TM1 and EV-CHARGER1 load profile**

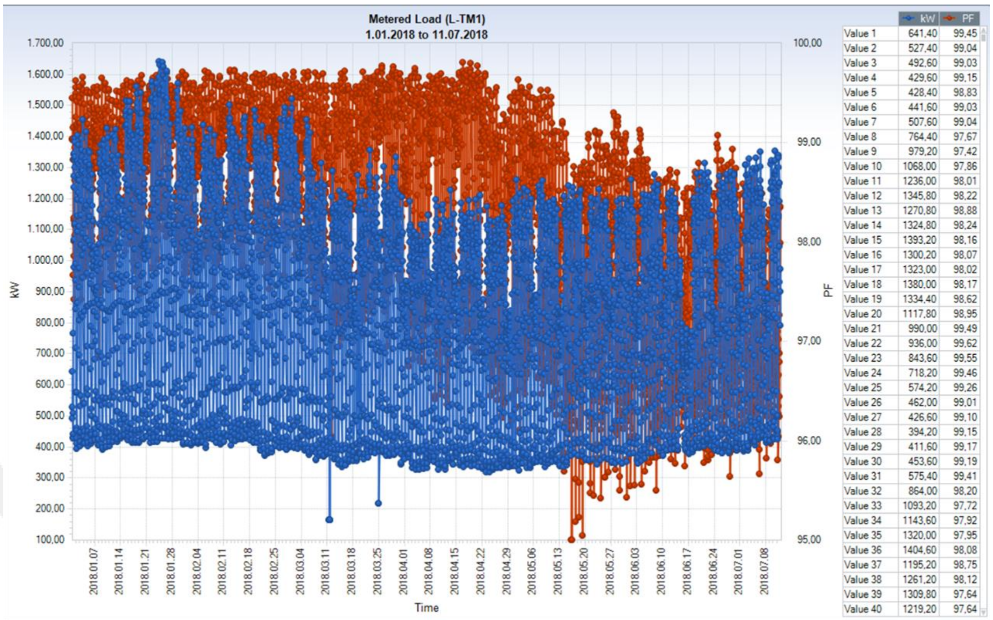

Figure III.22. Hourly analysis of loads without EV charger of the TM1 in six month.

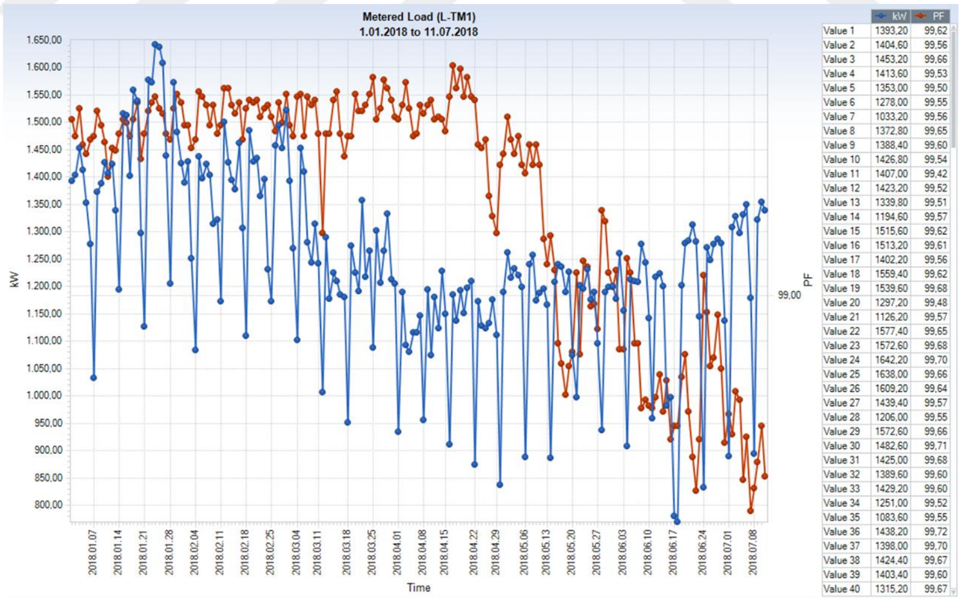

Figure III.23. Daily peak load without EV charger of the TM1 in six month.

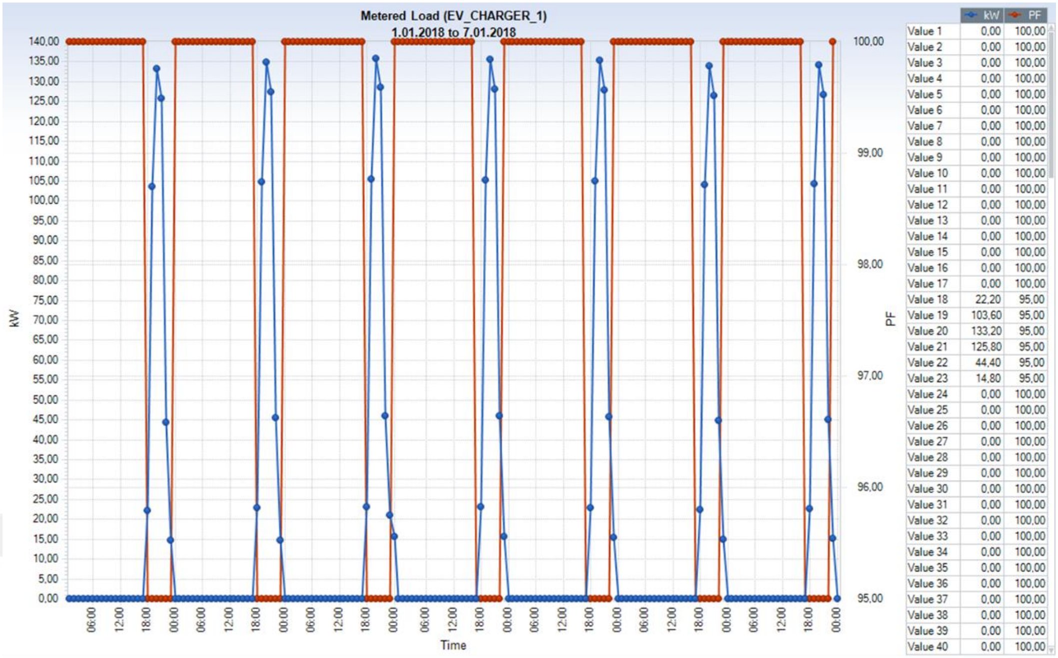

Figure III.24. Load profile of the EV-Charger1 in a week.

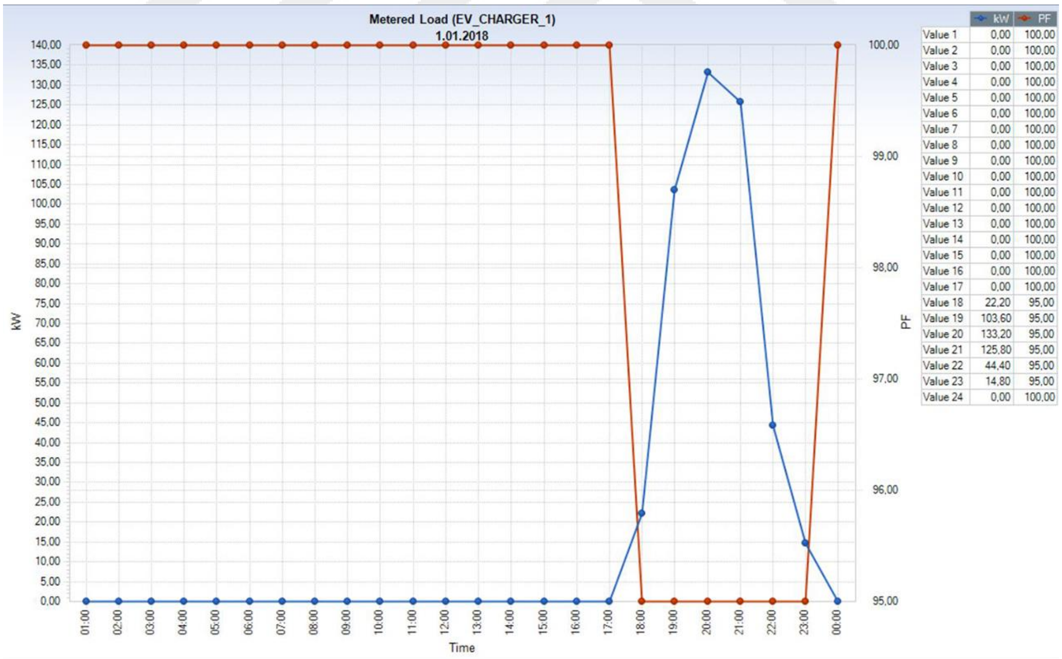

Figure III.25. Peak Load of the EV-Charger1 in a day.

- **TM2 and EV-CHARGER2 load profile**

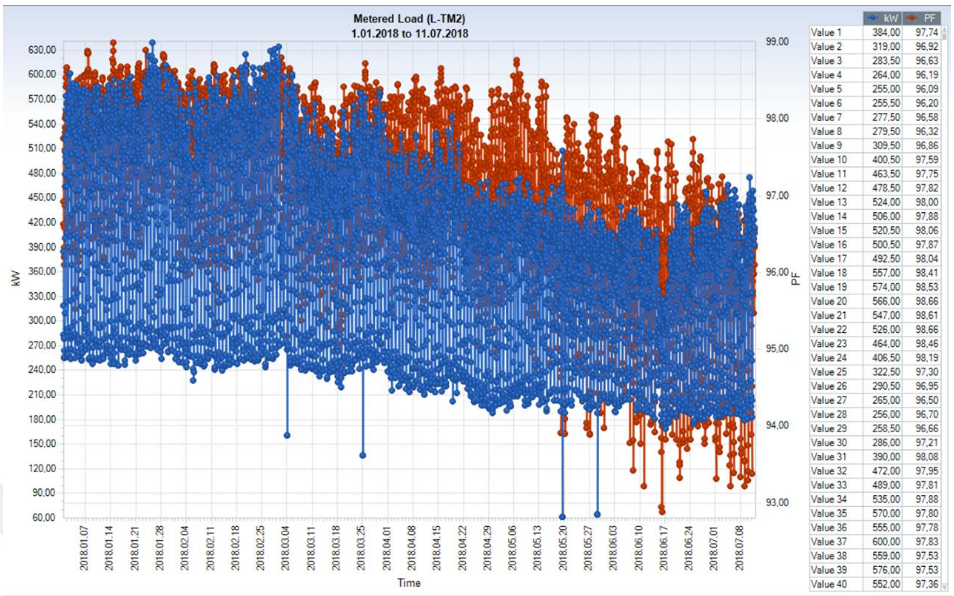

Figure III.26. Hourly analysis of loads without EV charger of the TM2 in six month.

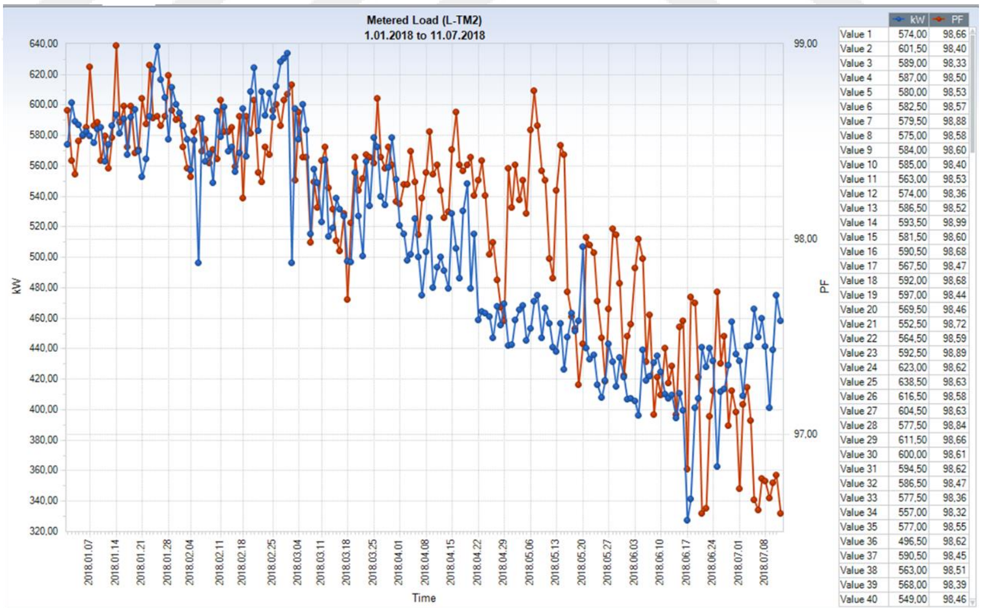

Figure III.27. Daily peak load without EV charger of the TM2 in six month.

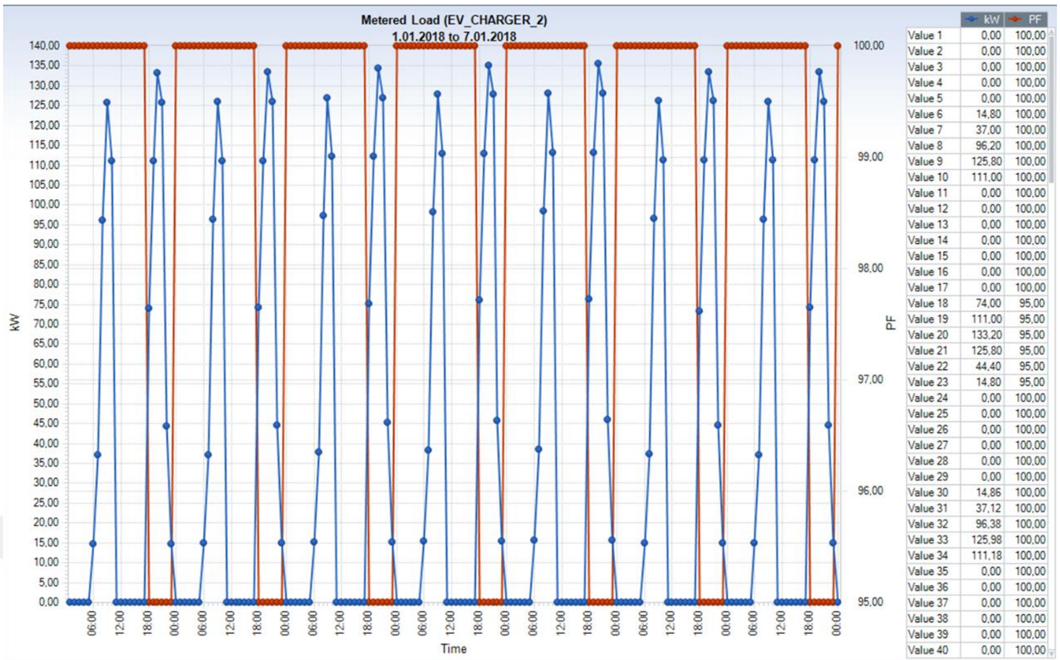

Figure III.28. Load profile of the EV-Charger2 in a week.

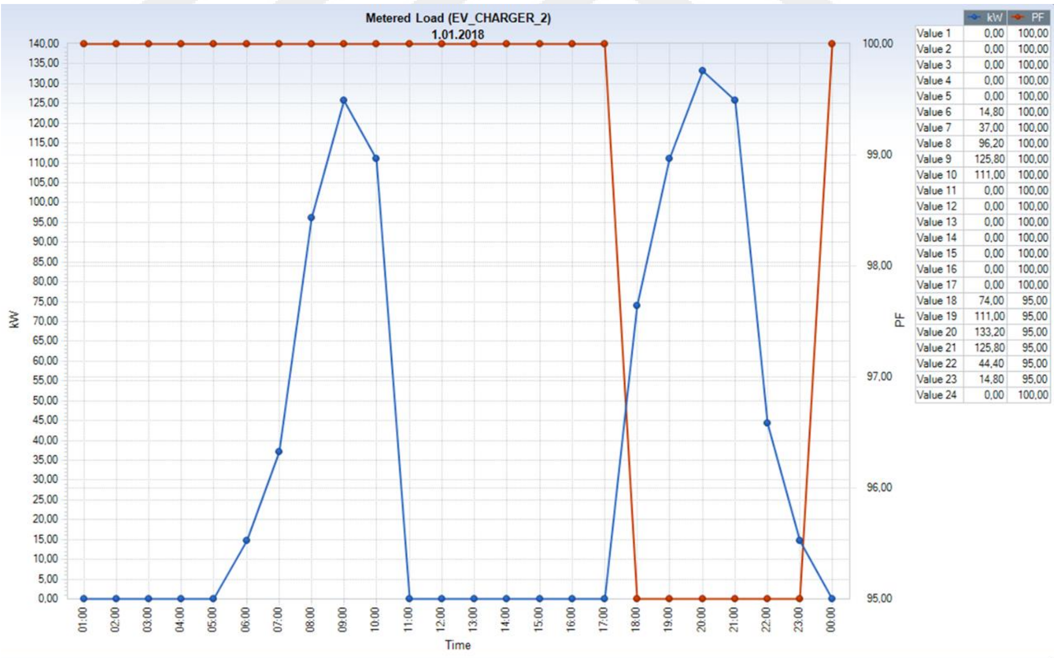

Figure III.29. Peak Load of the EV-Charger2 in a day.

- **TM3 and EV-CHARGER3 load profile**

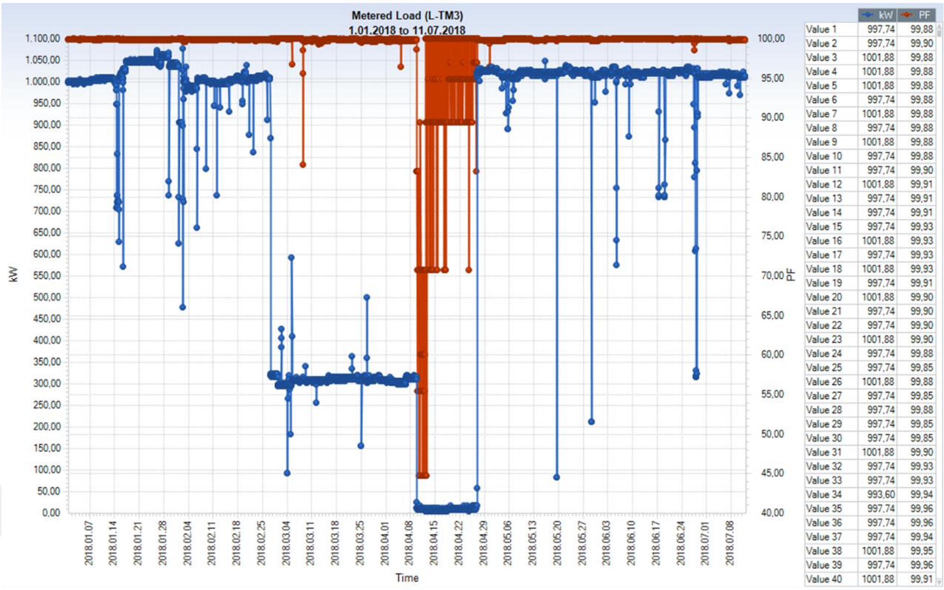

Figure III.30. Hourly analysis of loads without EV charger of the TM3 in six month.

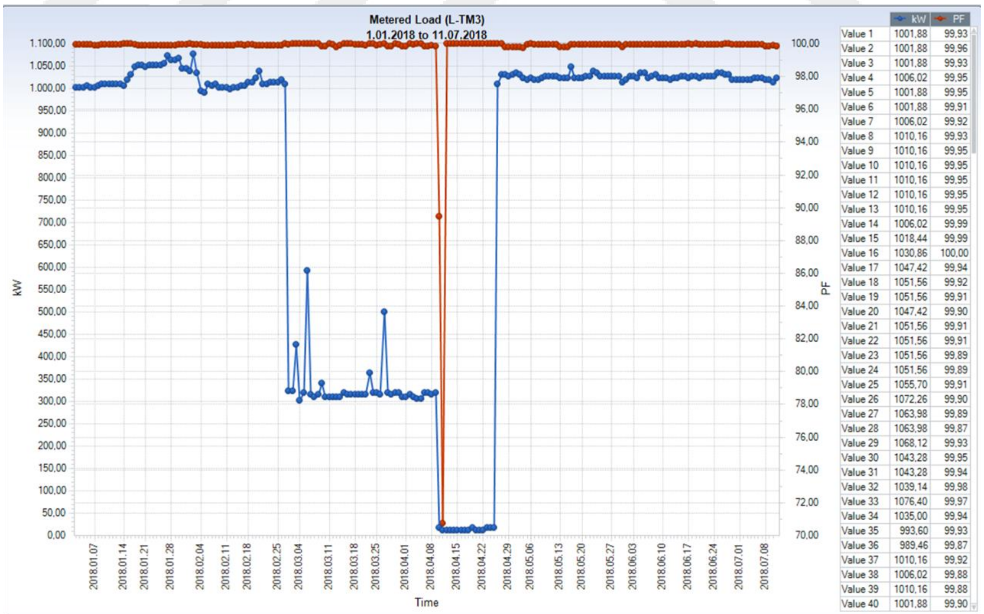

Figure III.31. Daily peak load without EV charger of the TM3 in six month.

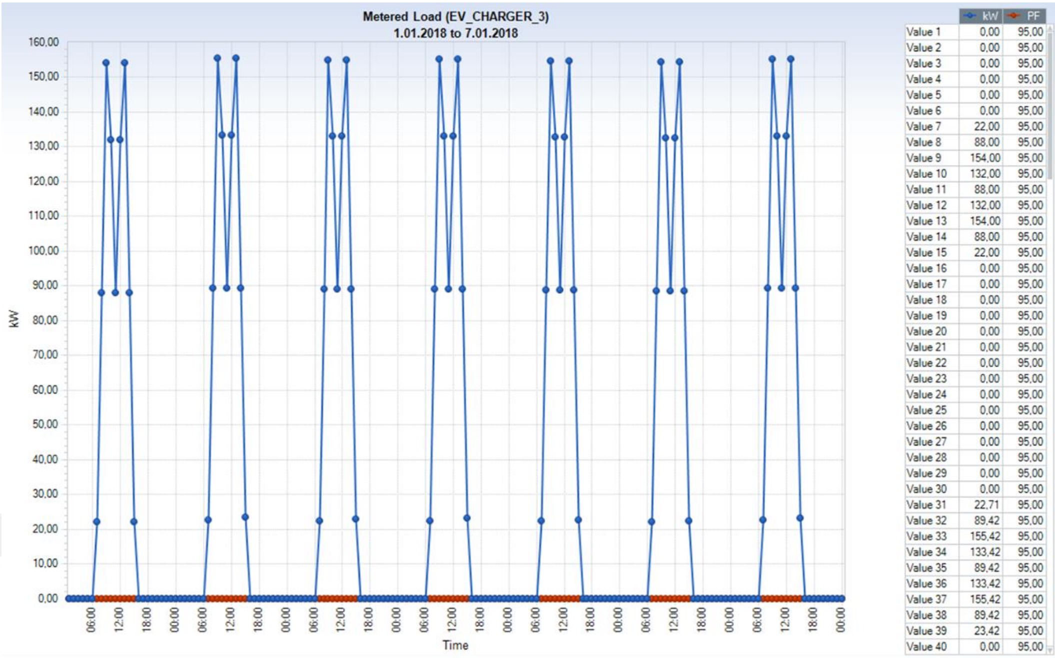

Figure III.32. Load profile of the EV-Charger3 in a week.

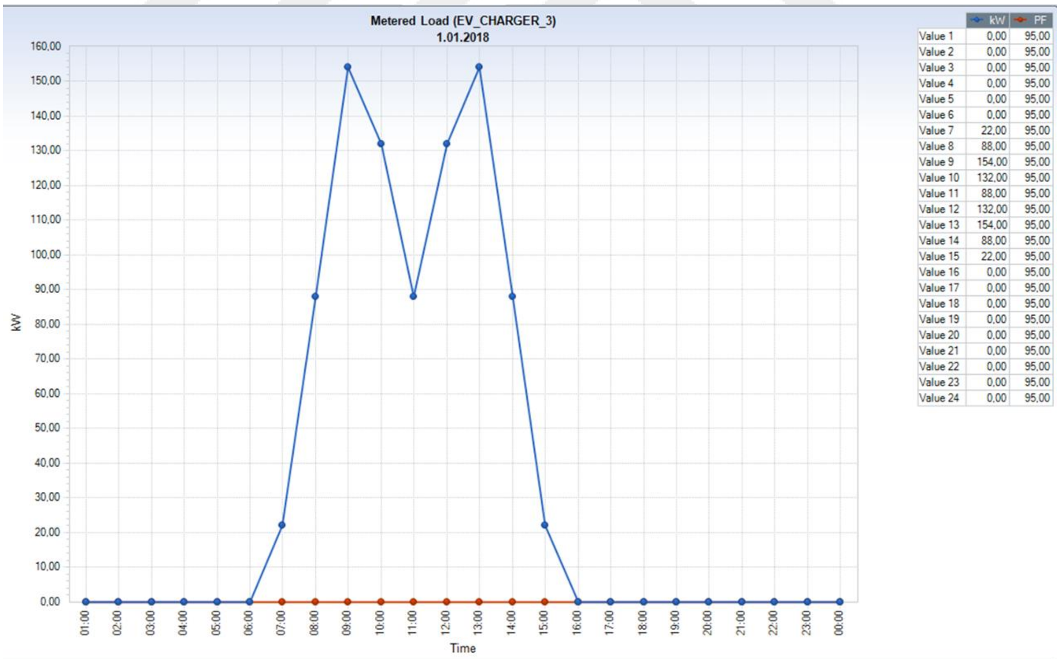

Figure III.33. Peak Load of the EV-Charger3 in a day.

- **TM4-T1 and EV-CHARGER4.1 load profile**

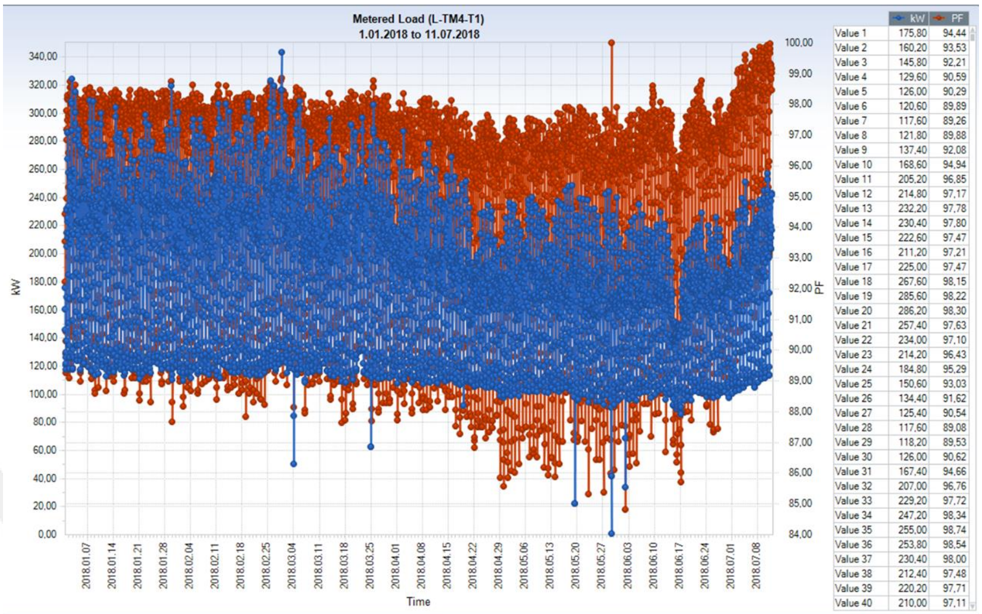

Figure III.34. Hourly analysis of loads without EV charger of the TM4-T1 in six month.

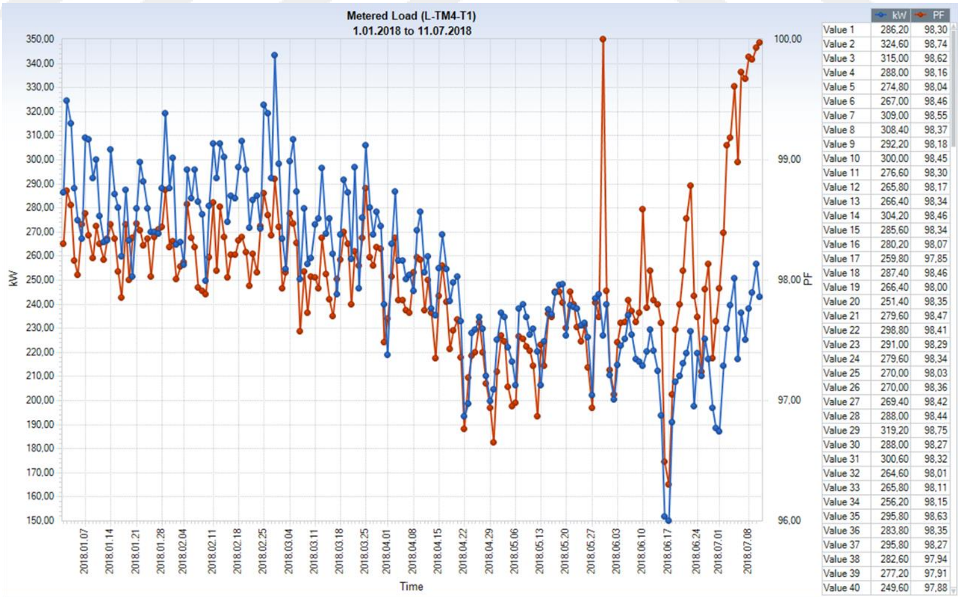

Figure III.35. Daily peak load without EV charger of the TM4-T1 in six month.

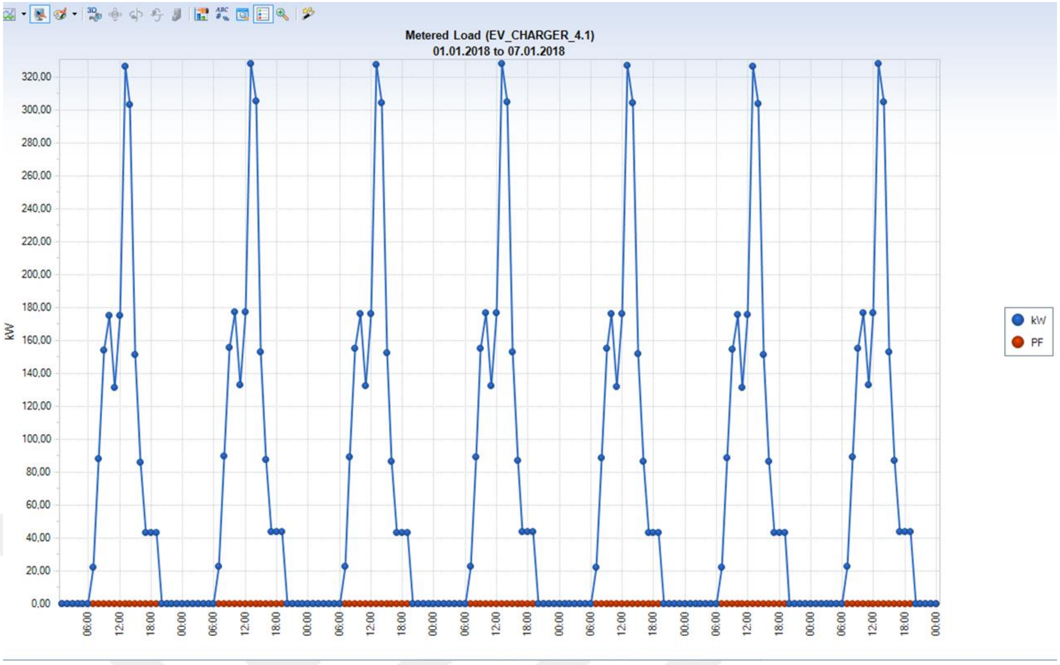

Figure III.36. Load profile of the EV-Charger4.1 in a week.

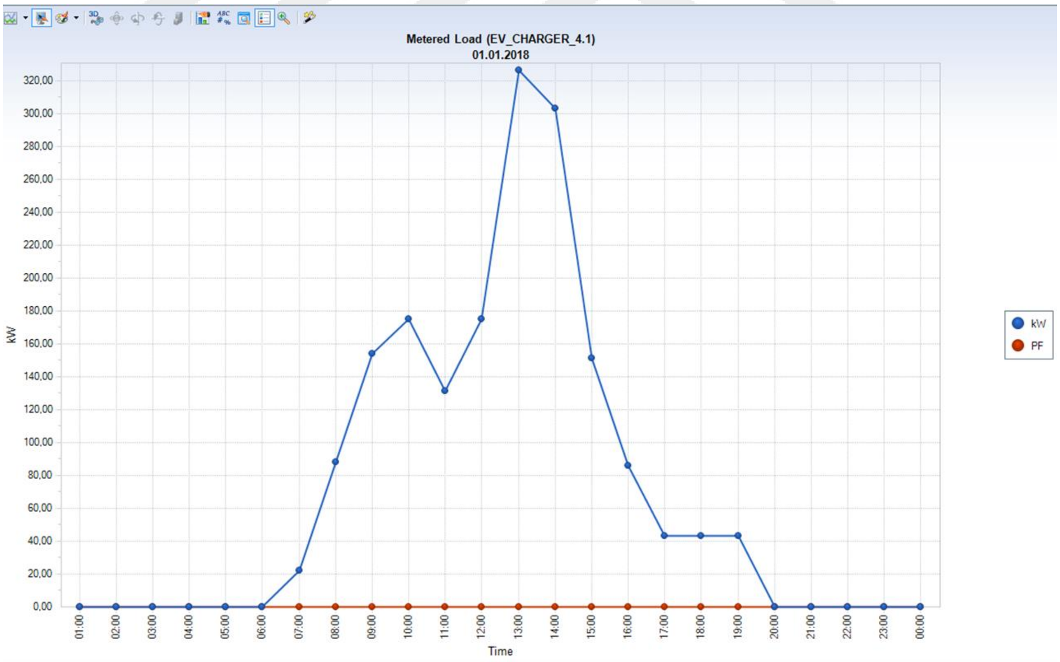

Figure III.37. Peak Load of the EV-Charger4.1 in a day.

- **TM4-T2 and EV-CHARGER4.2 load profile**

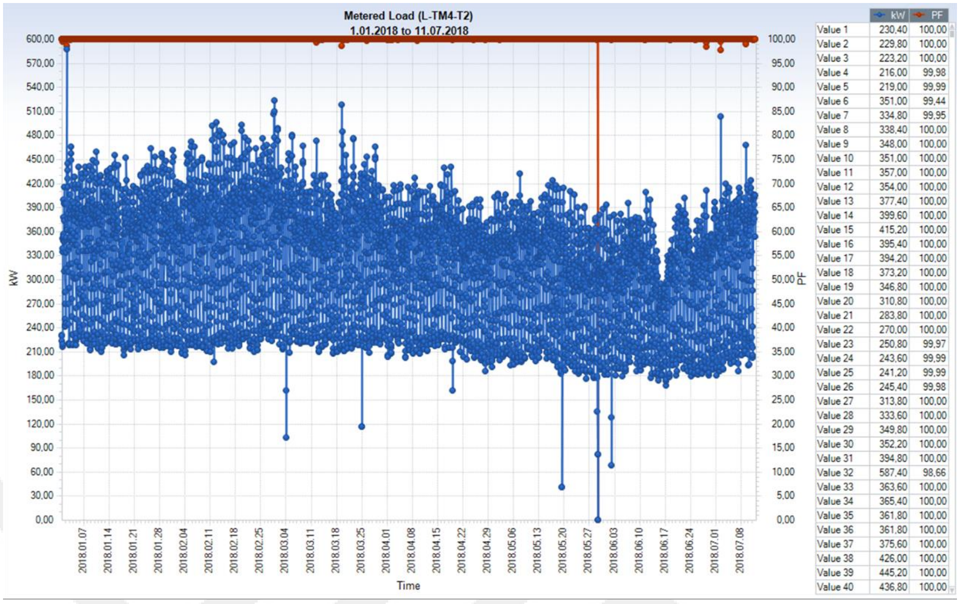

Figure III.38. Hourly analysis of loads without EV charger of the TM4-T2 in six month.

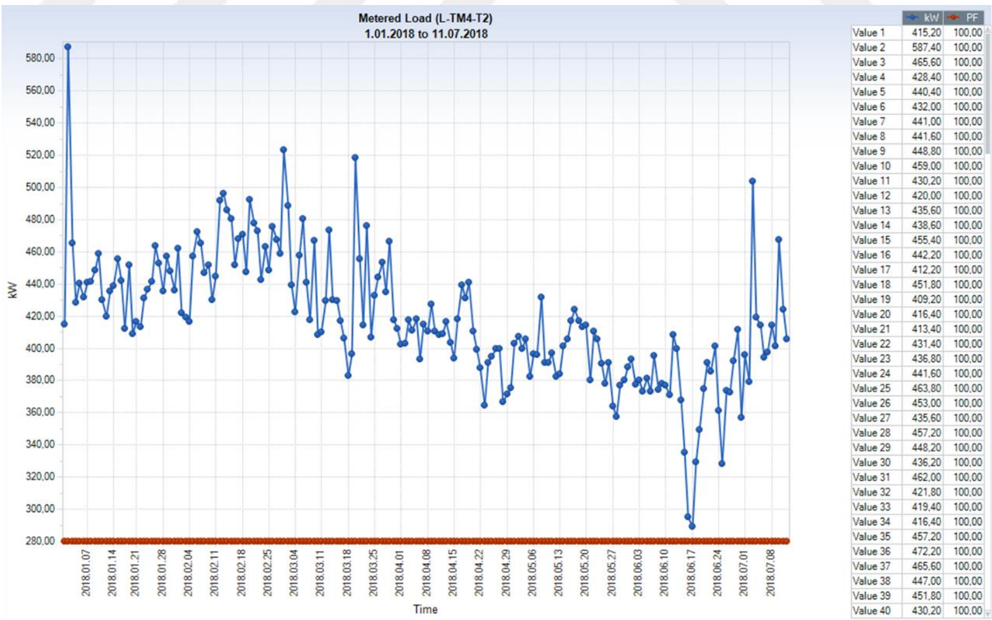

Figure III.39. Daily peak load without EV charger of the TM4-T2 in six month.

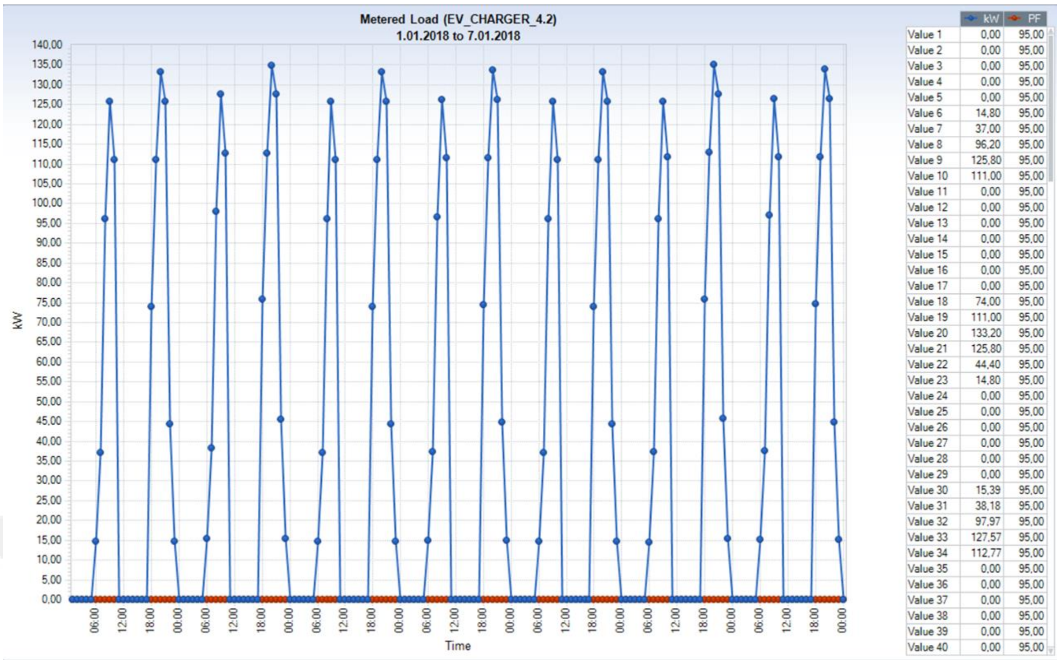

Figure III.40. Load profile of the EV-Charger4.2 in a week.

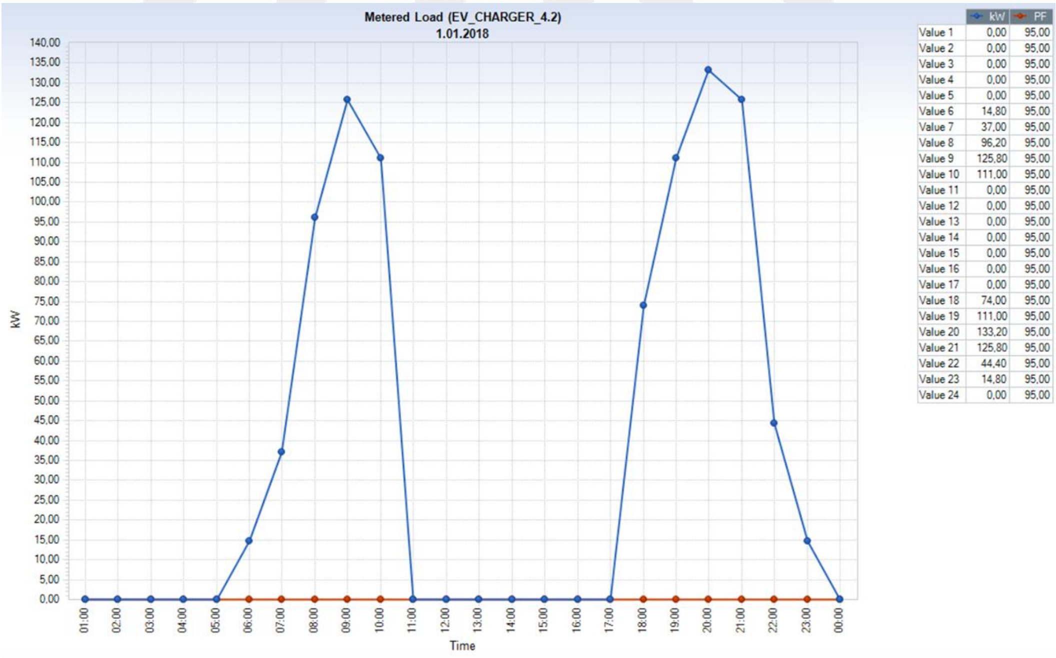

Figure III.41. Peak Load of the EV-Charger4.2 in a day.

- **TM5 and EV-CHARGER5 load profile**

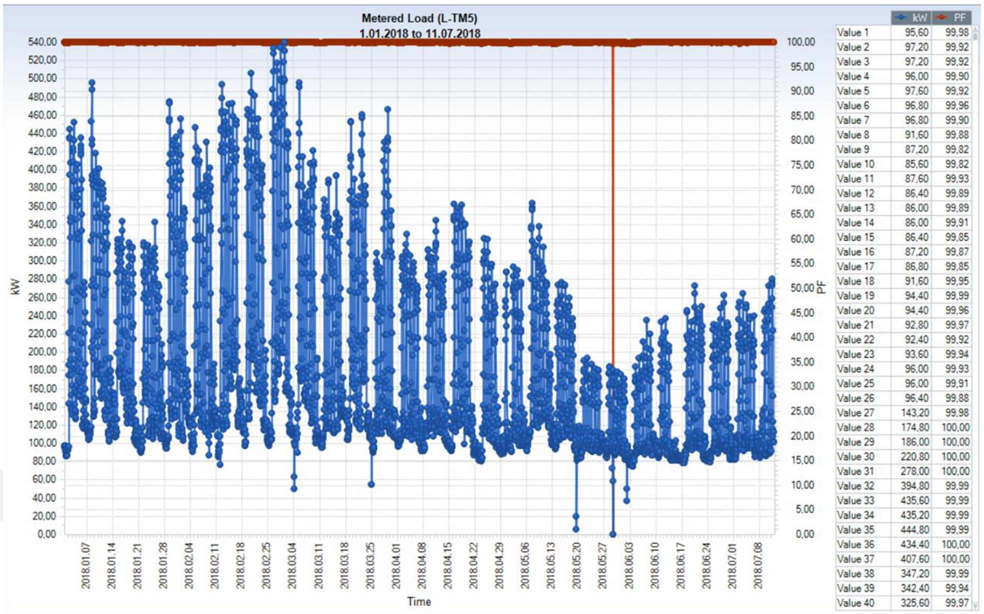

Figure III.42. Hourly analysis of loads without EV charger of the TM5 in six month.

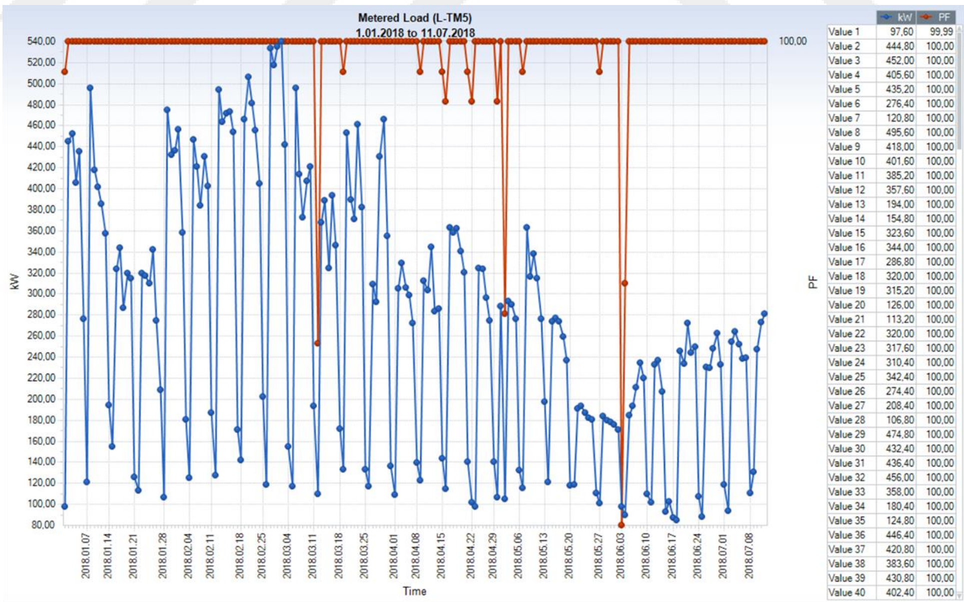

Figure III.43. Daily peak load without EV charger of the TM5 in six month.

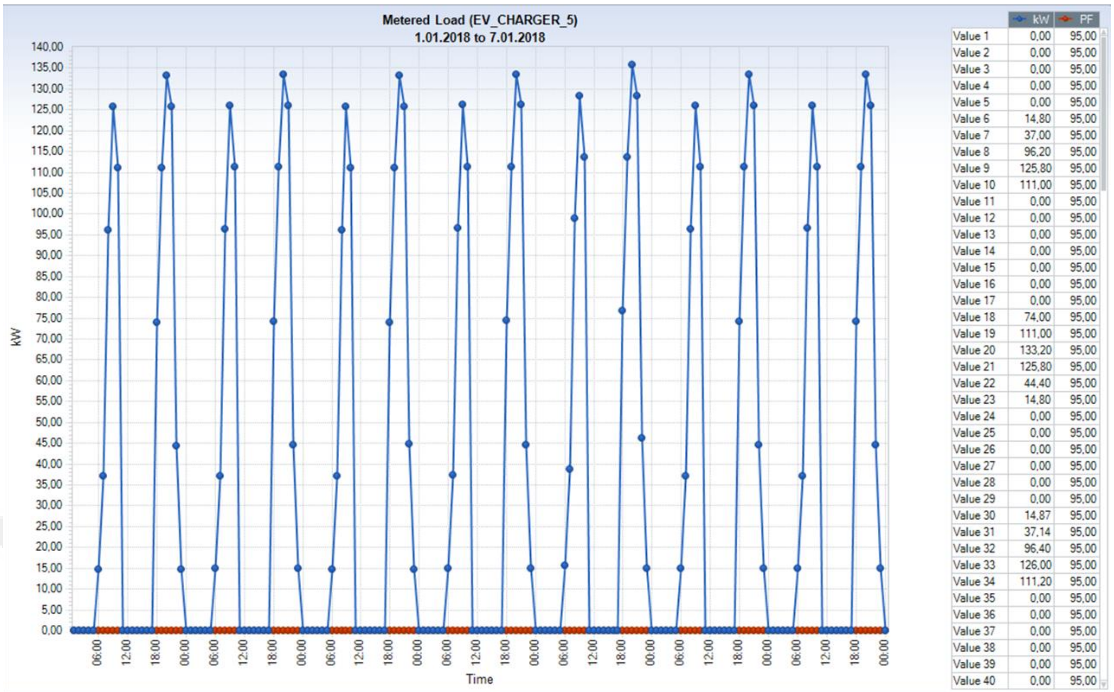

Figure III.44. Load profile of the EV-Charger5 in a week.

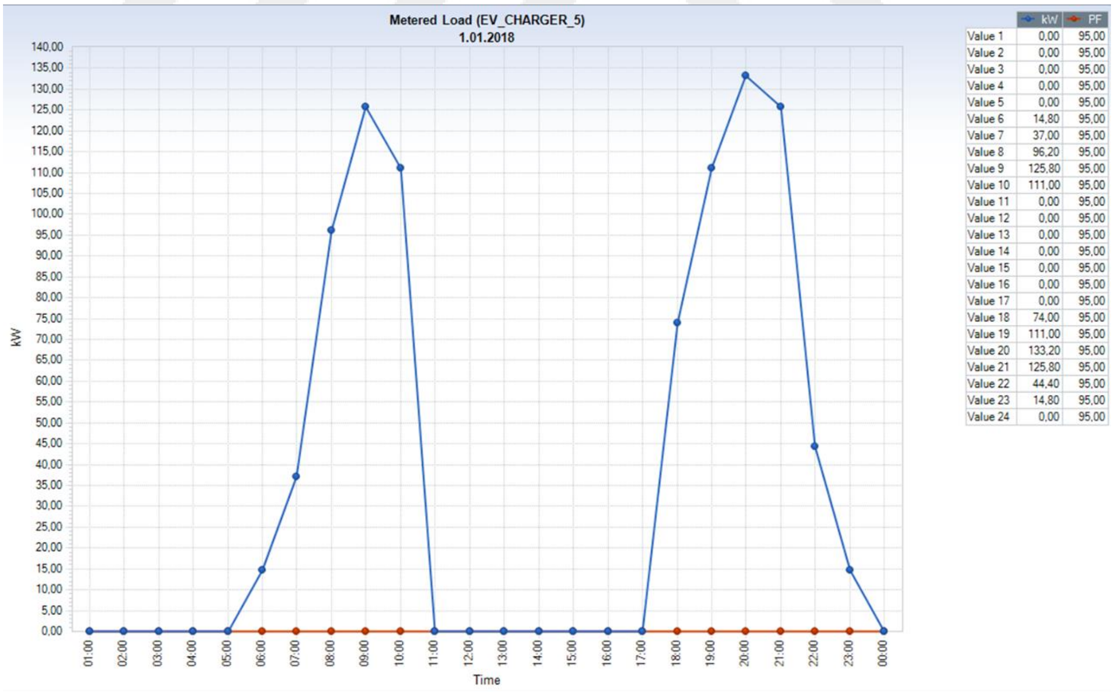

Figure III.45. Peak Load of the EV-Charger5 in a day.

- **TM6 and EV-CHARGER6 load profile**

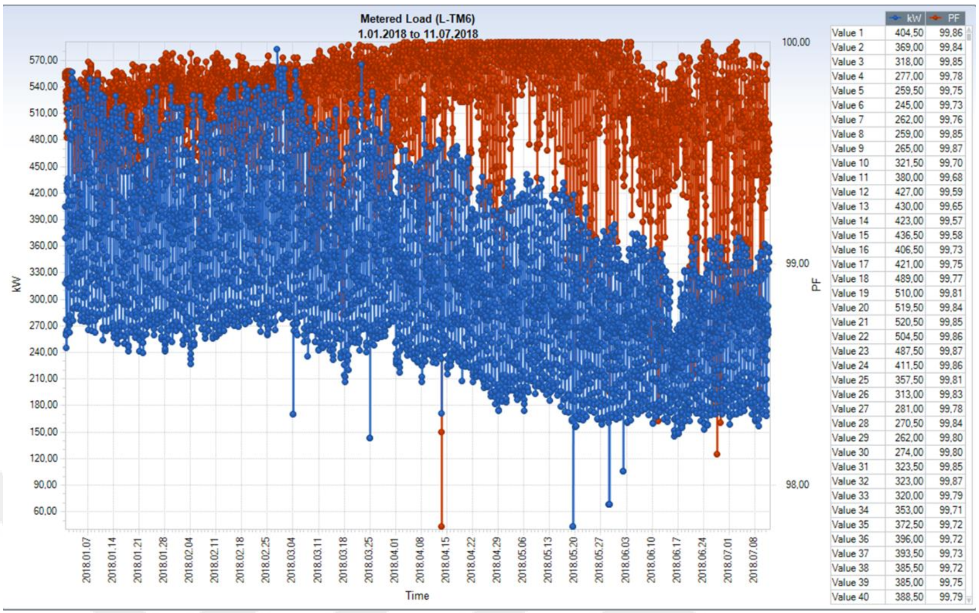

Figure III.46. Hourly analysis of loads without EV charger of the TM6 in six month.

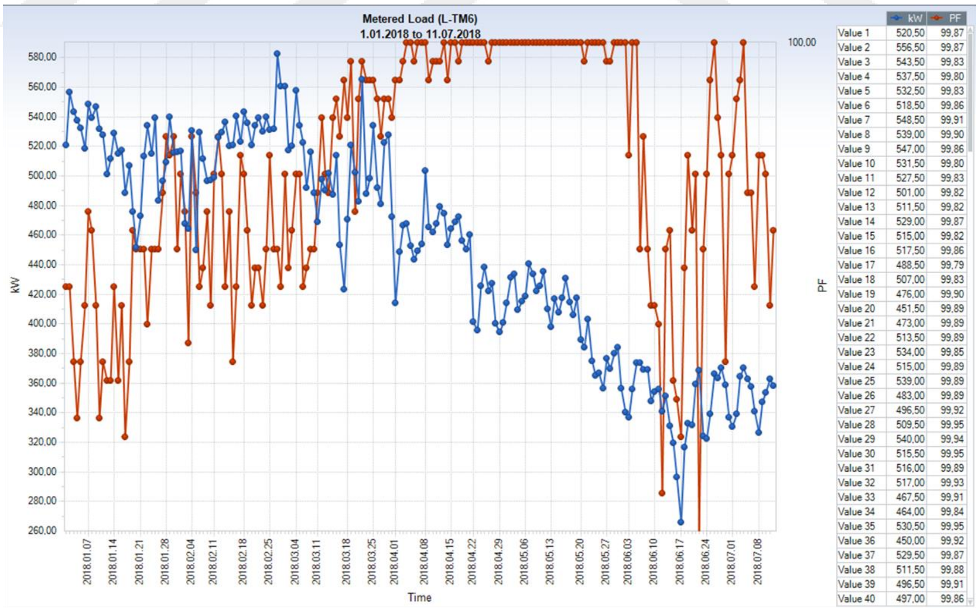

Figure III.47. Daily peak load without EV charger of the TM6 in six month.

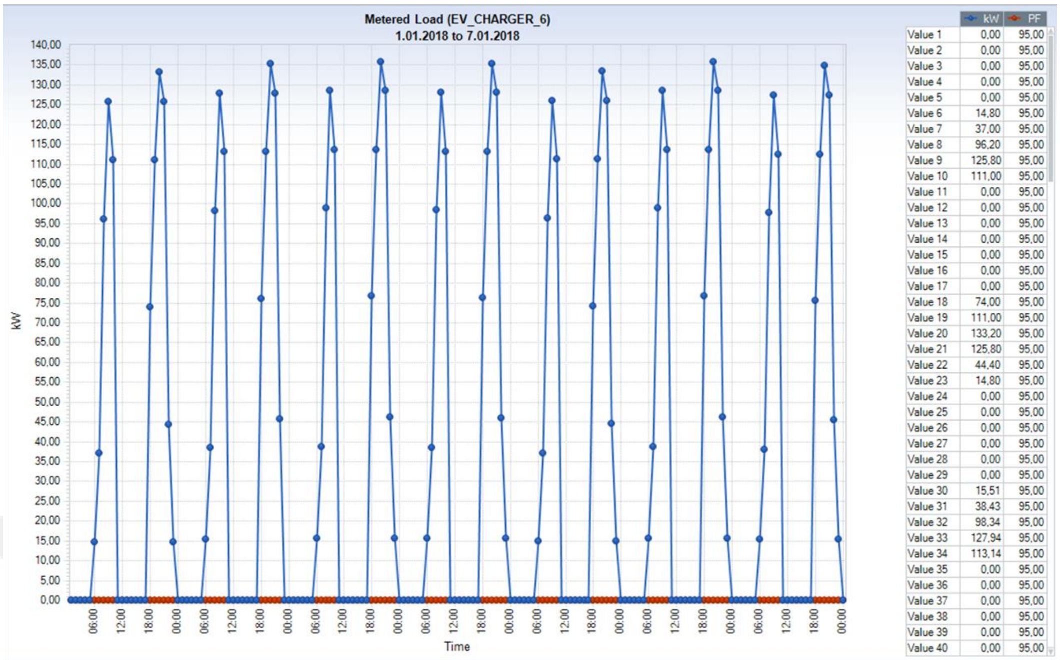

Figure III.48. Load profile of the EV-Charger6 in a week.

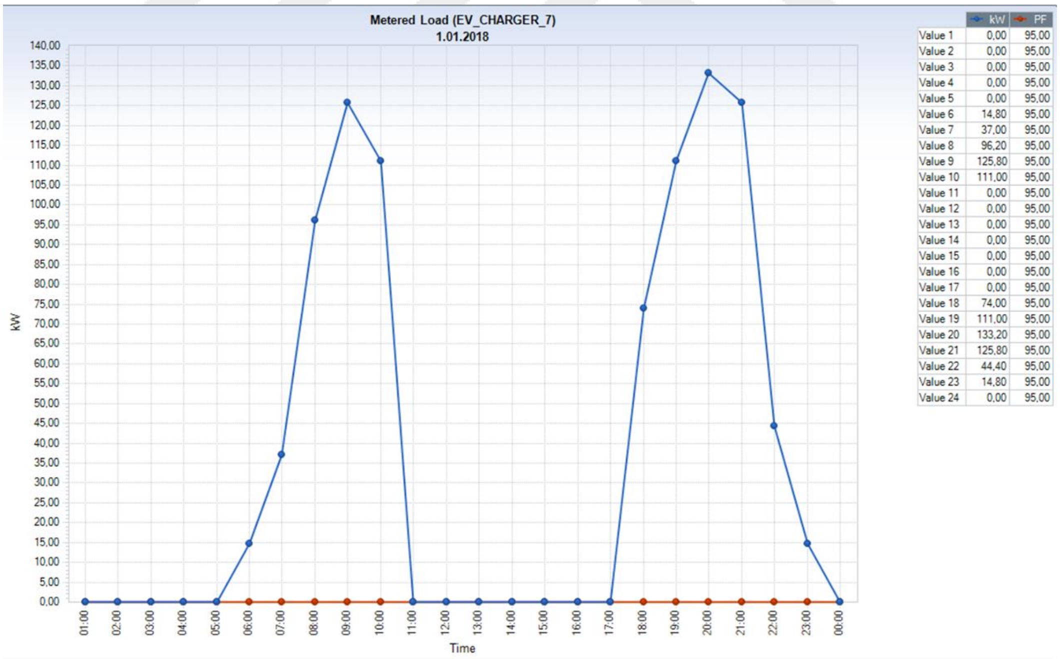

Figure III.49. Peak Load of the EV-Charger6 in a day.

- **TM7 and EV-CHARGER7 load profile**

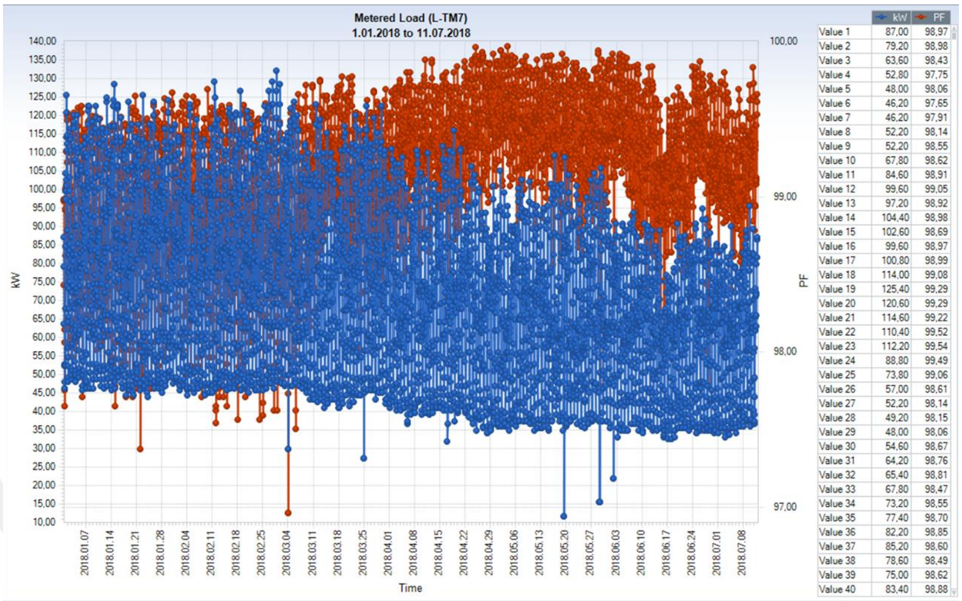

Figure III.50. Hourly analysis of loads without EV charger of the TM7 in six month.

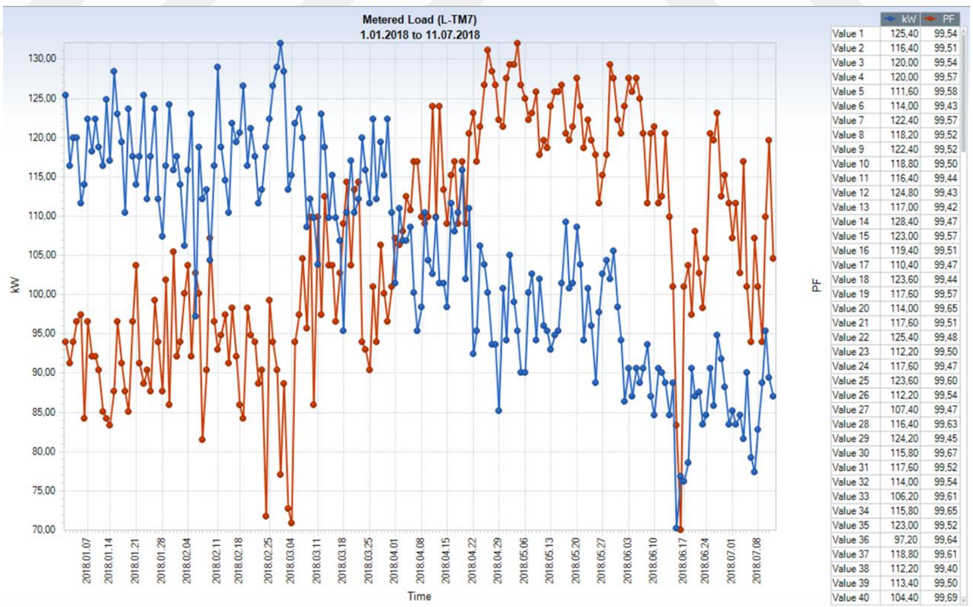

Figure III.51. Daily peak load without EV charger of the TM7 in six month.

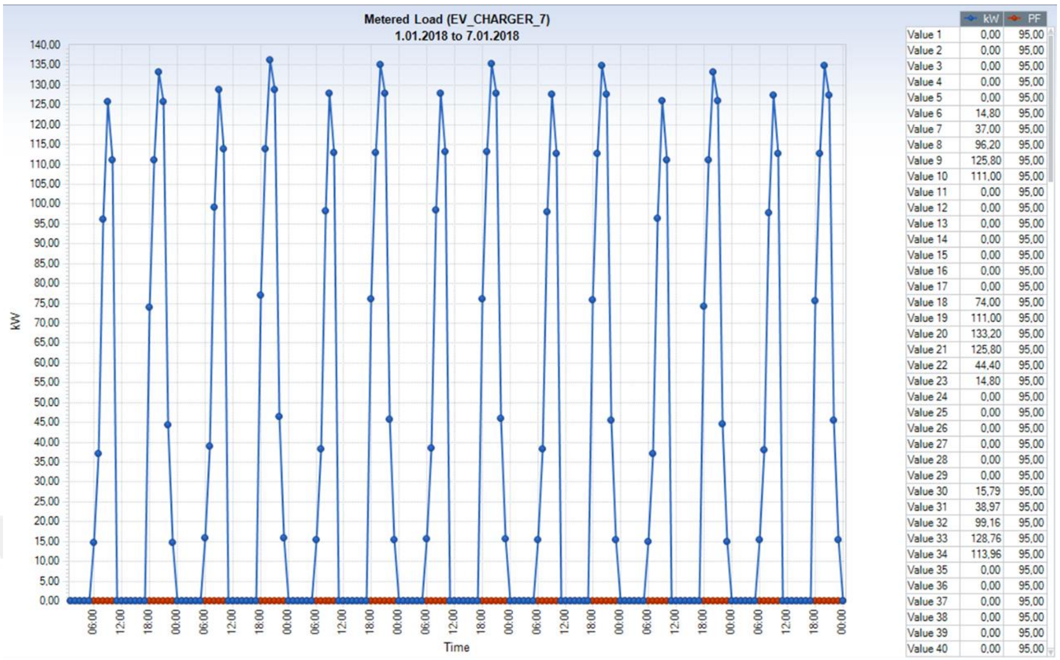

Figure III.52. Load profile of the EV-Charger7 in a week.

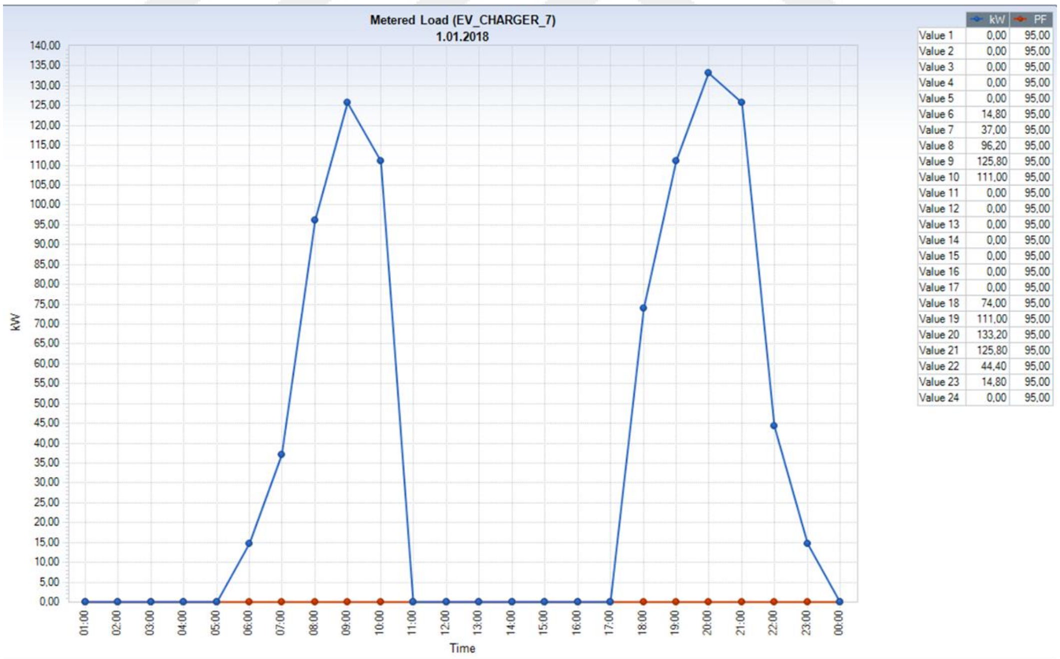

Figure III.53. Peak Load of the EV-Charger7 in a day.

- **TM8 and EV-CHARGER8 load profile**

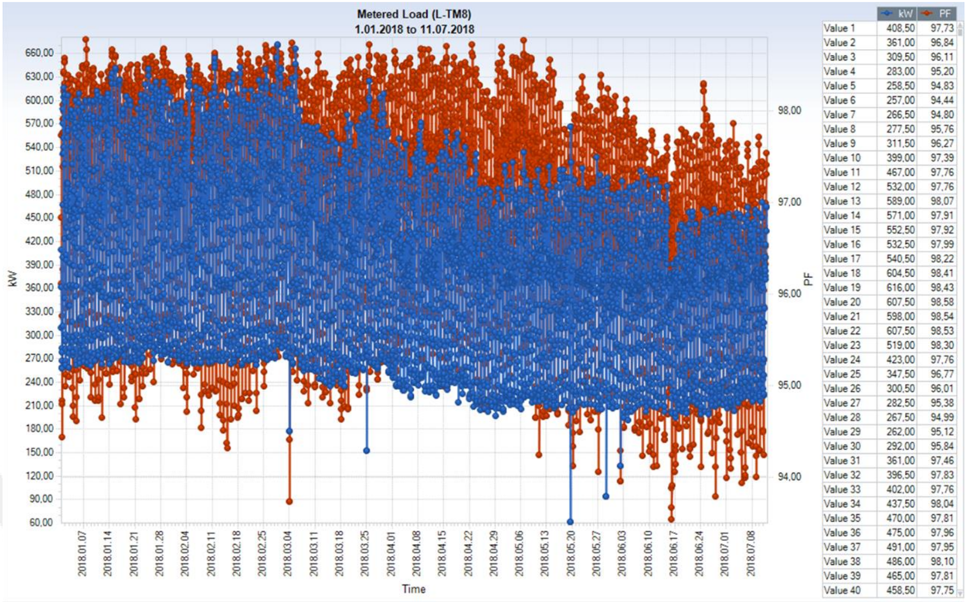

Figure III.54. Hourly analysis of loads without EV charger of the TM8 in six month.

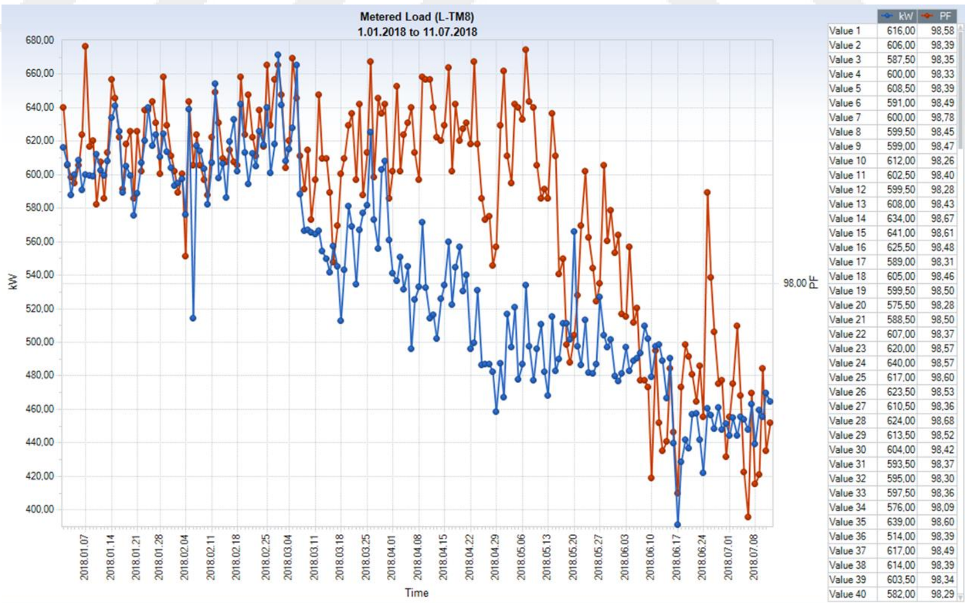

Figure III.55. Daily peak load without EV charger of the TM8 in six month.

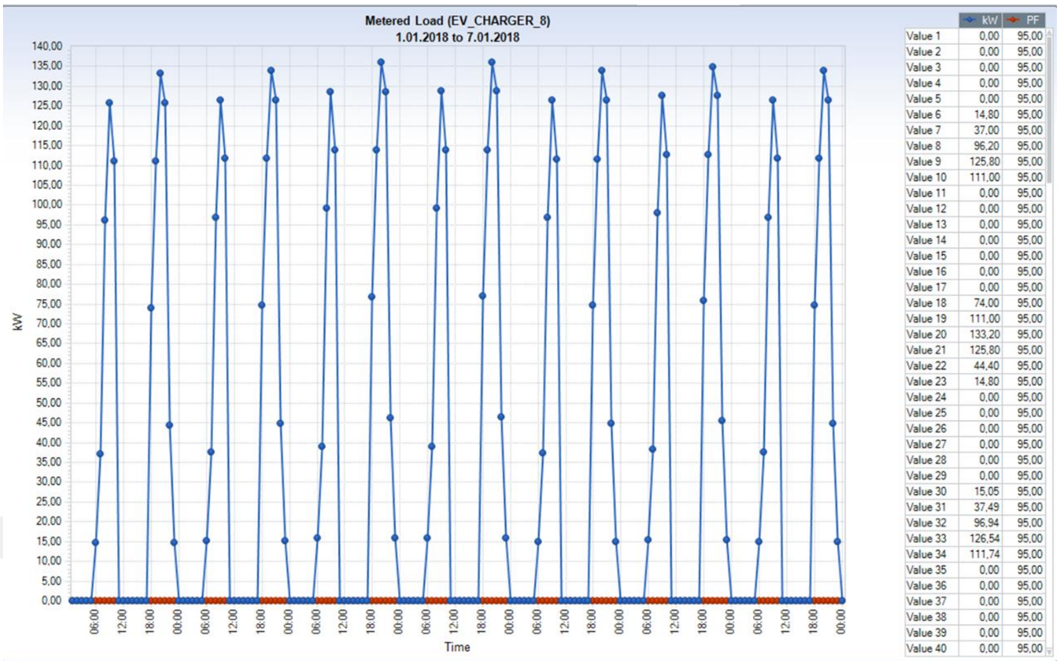

Figure III.56. Load profile of the EV-Charger8 in a week.

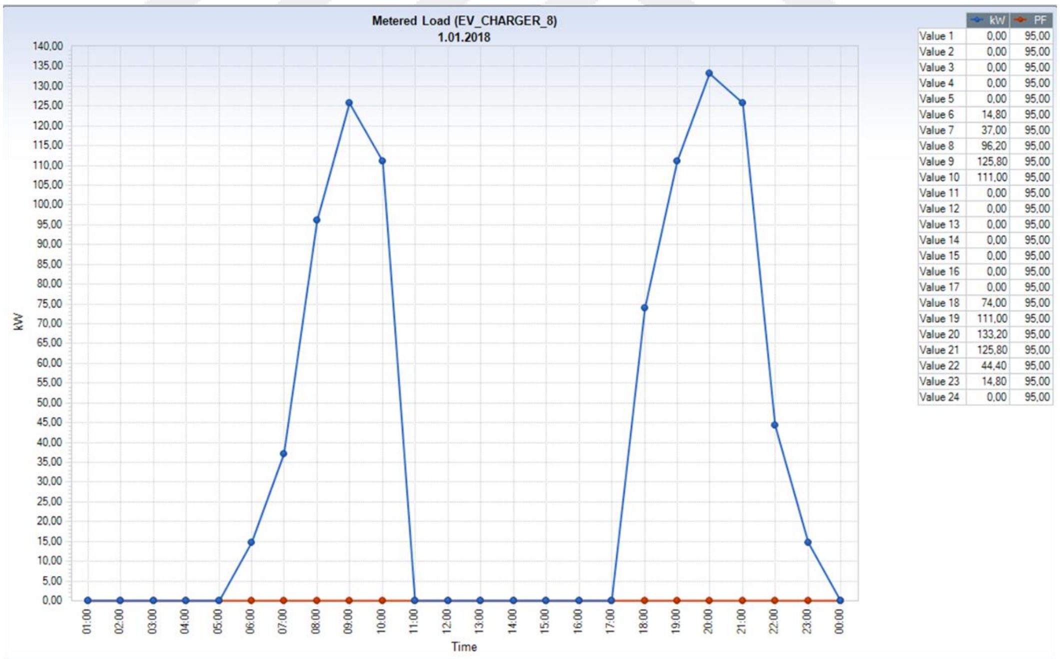

Figure III.57. Peak Load of the EV-Charger8 in a day.

- **TM9 and EV-CHARGER9 load profile**

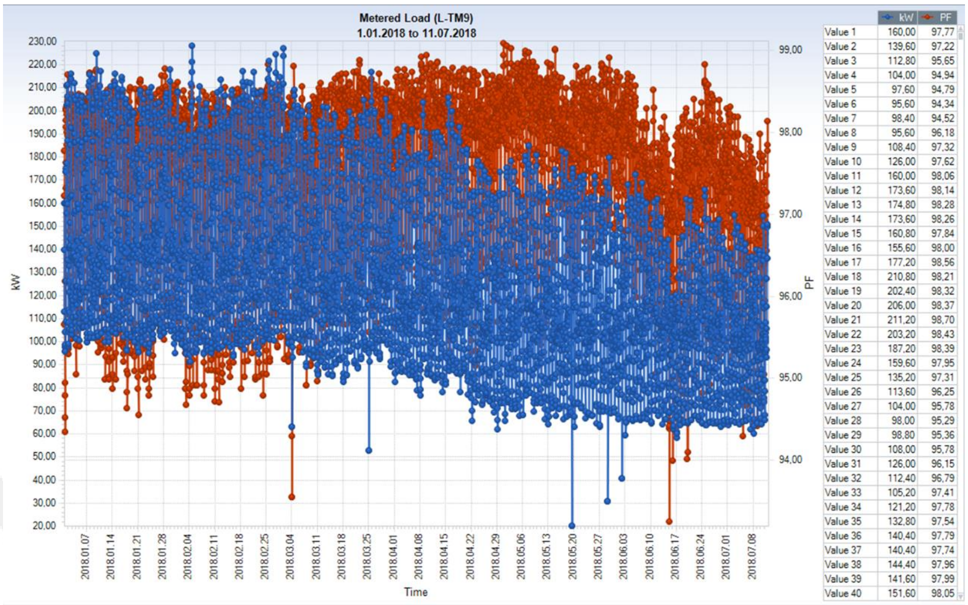

Figure III.58. Hourly analysis of loads without EV charger of the TM9 in six month.

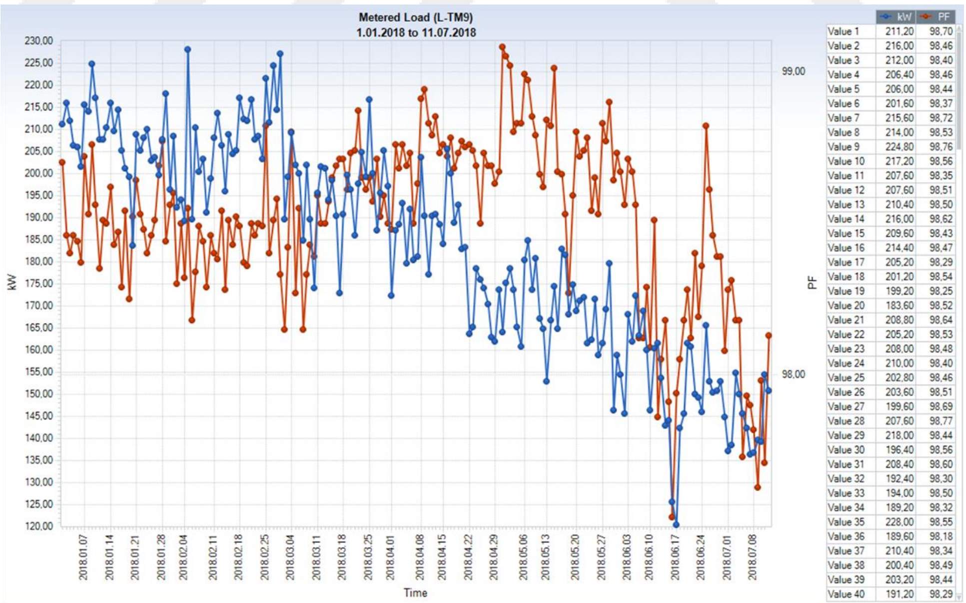

Figure III.59. Daily peak load without EV charger of the TM9 in six month.

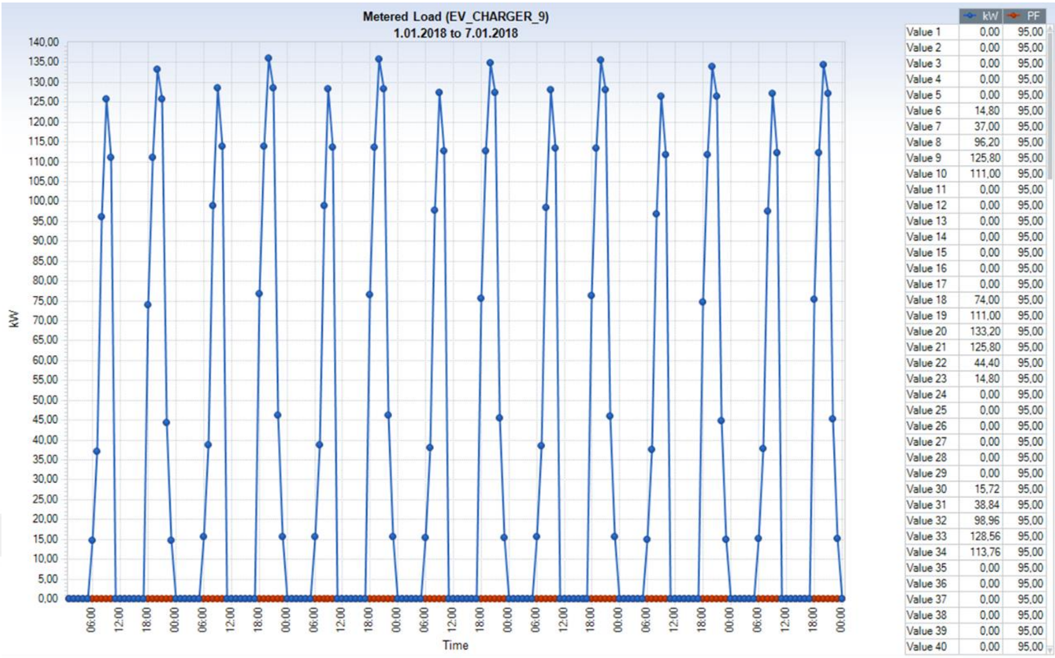

Figure III.60. Load profile of the EV-Charger9 in a week.

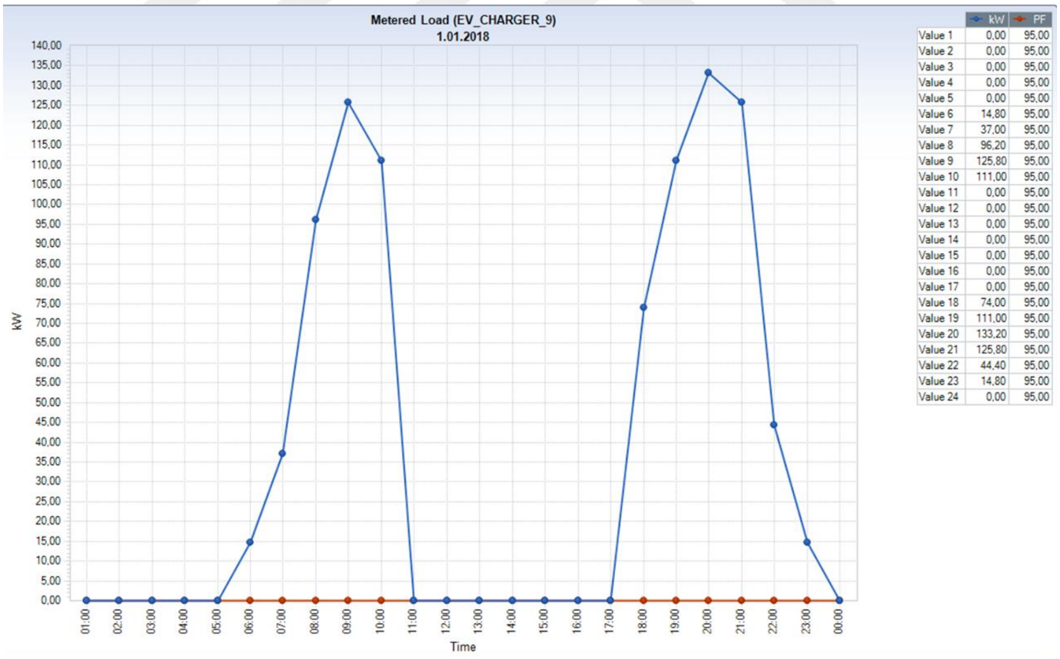

Figure III.61. Peak Load of the EV-Charger9 in a day.

- **TM10 and EV-CHARGER10 load profile**

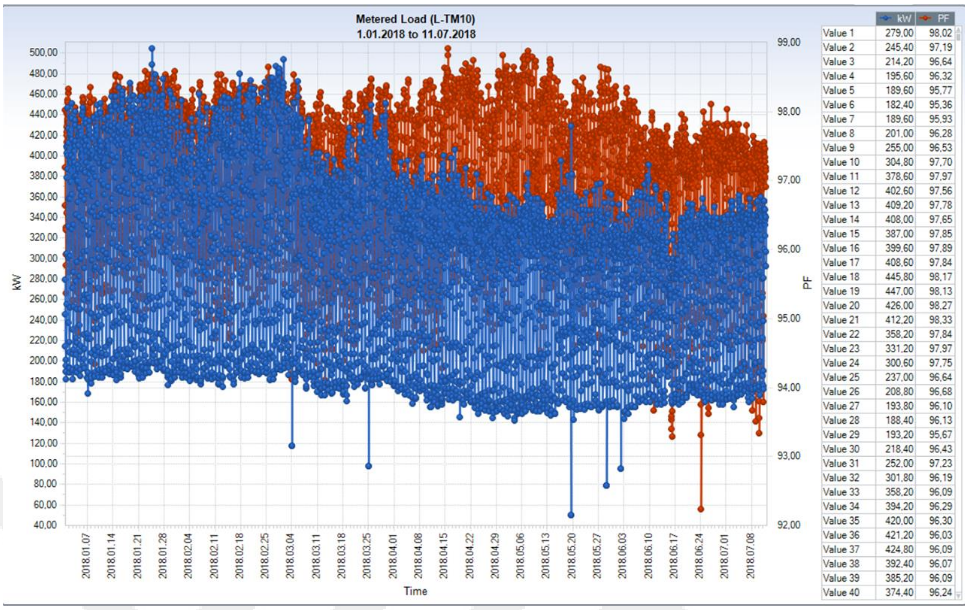

Figure III.62. Hourly analysis of loads without EV charger of the TM10 in six month.

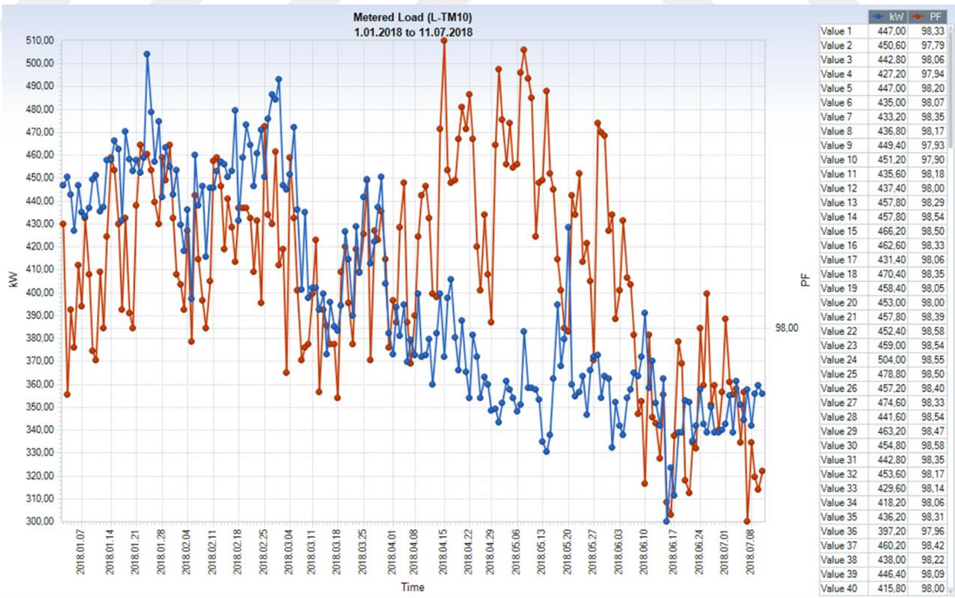

Figure III.63. Daily peak load without EV charger of the TM10 in six month.

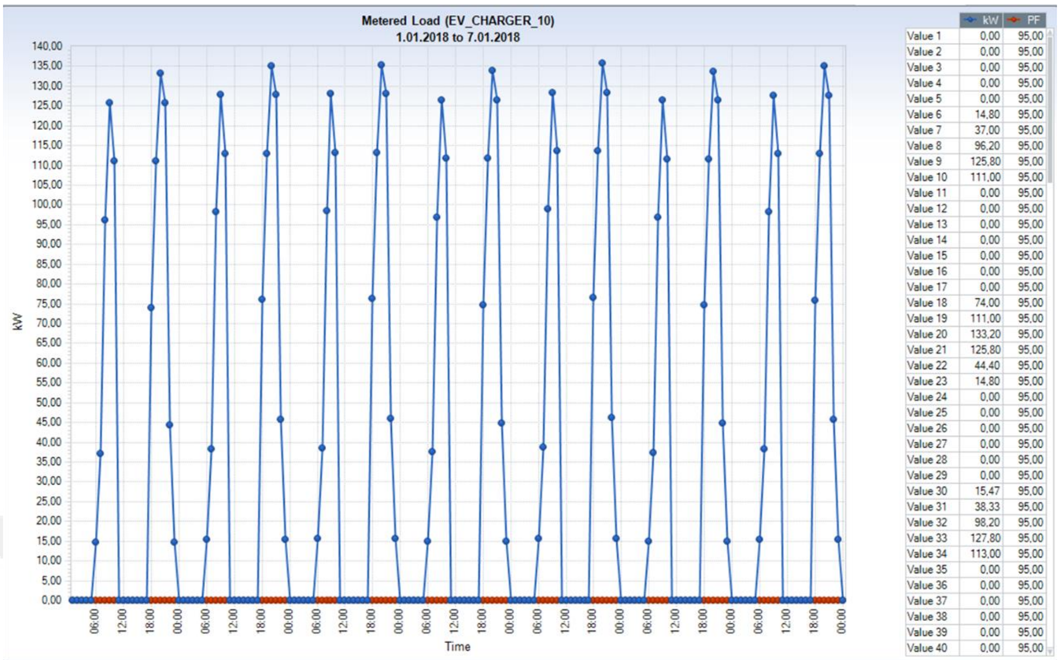

Figure III.64. Load profile of the EV-Charger10 in a week.

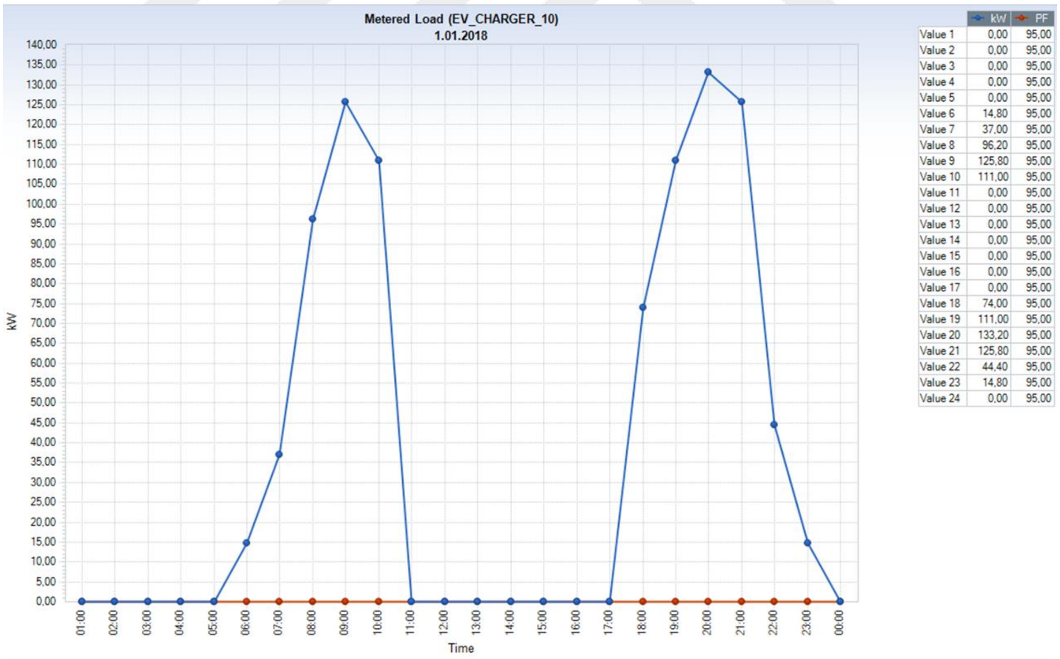

Figure III.65. Peak Load of the EV-Charger10 in a day.

- **TM11 and EV-CHARGER11 load profile**

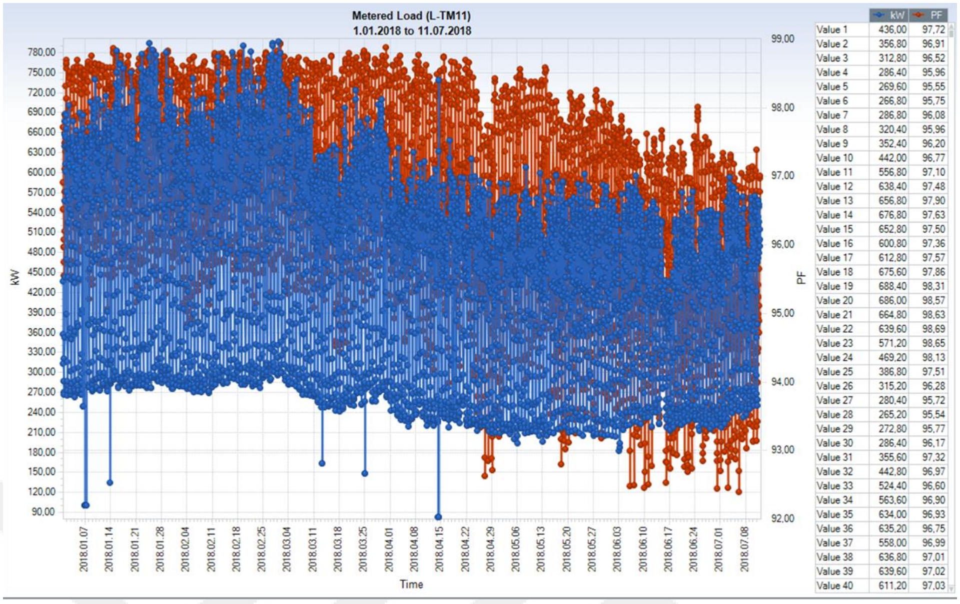

Figure III.66. Hourly analysis of loads without EV charger of the TM11 in six month.

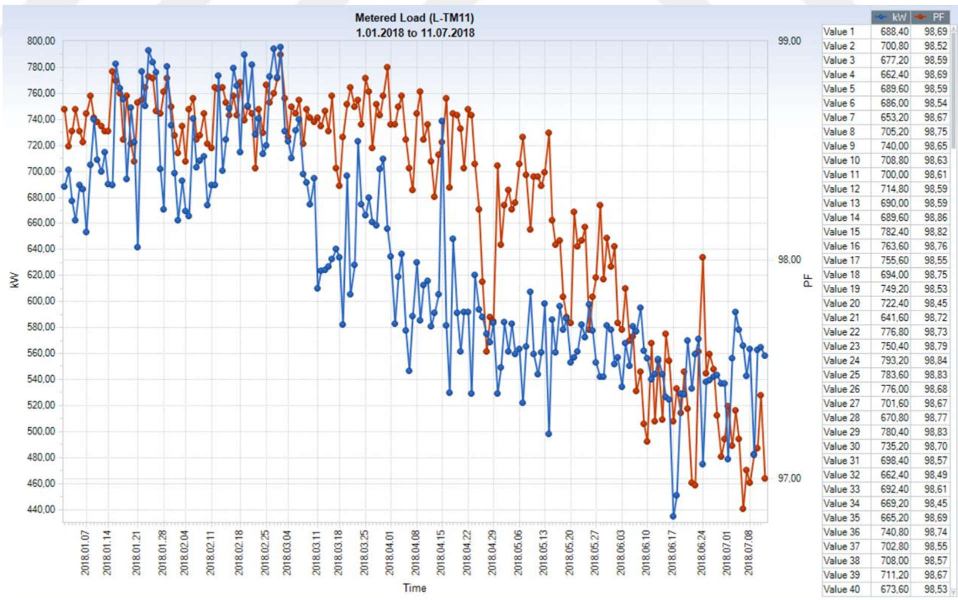

Figure III.67. Daily peak load without EV charger of the TM11 in six month.

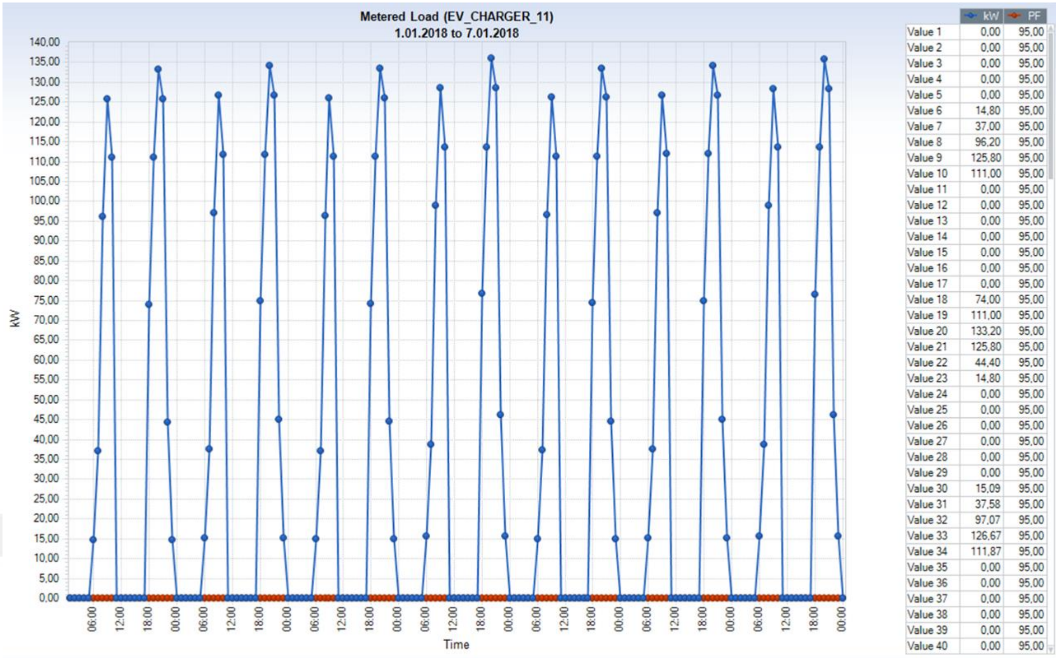

Figure III.68. Load profile of the EV-Charger11 in a week.

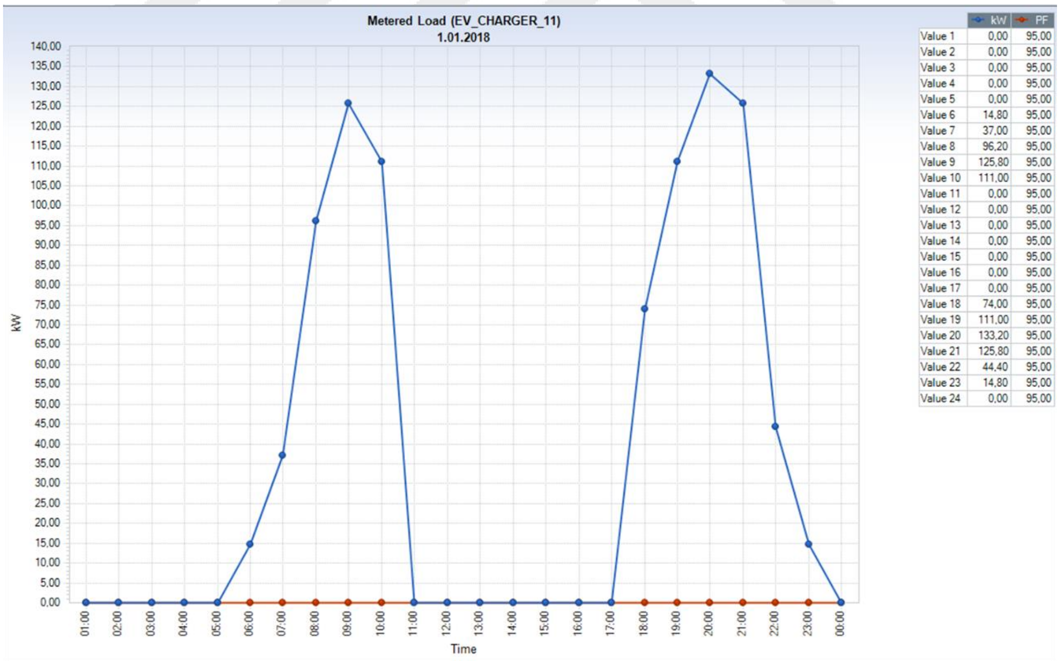

Figure III.69. Peak Load of the EV-Charger11 in a day.

3.7. Implementation and Results

After all parameters are defined as variable parameters, simulations were conducted. Analysis report for effects of data that are considered as variables in simulation on the grid were generated. Simulation results were analyzed and critical value overload was not observed for cables and transformers. Loss ratio was at ideal level. There was no voltage drop. Analysis results are presented below.

- **TM1**

Six months maximum load from TM1 was 1653.4 kW.

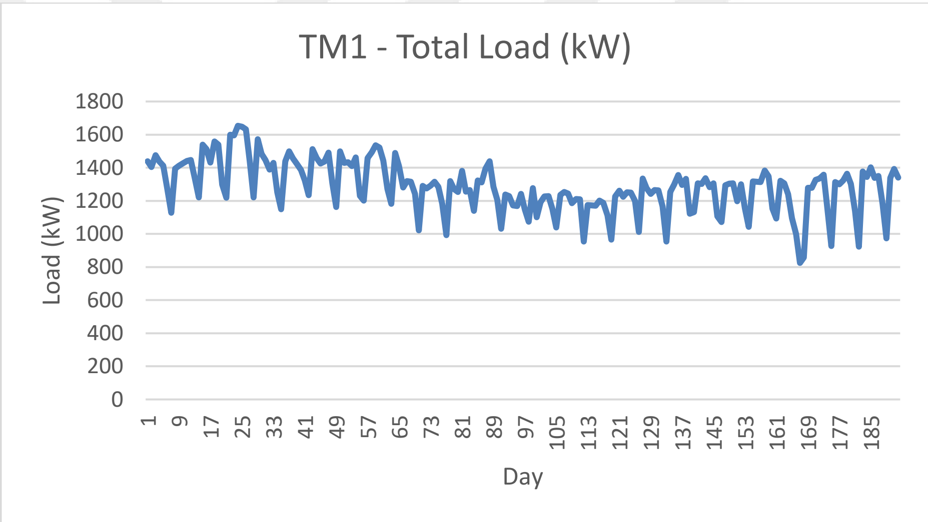

Figure III.70. Six months maximum loads from TM1.

- **TM2**

Six months maximum load from TM2 was 769.18 kW.

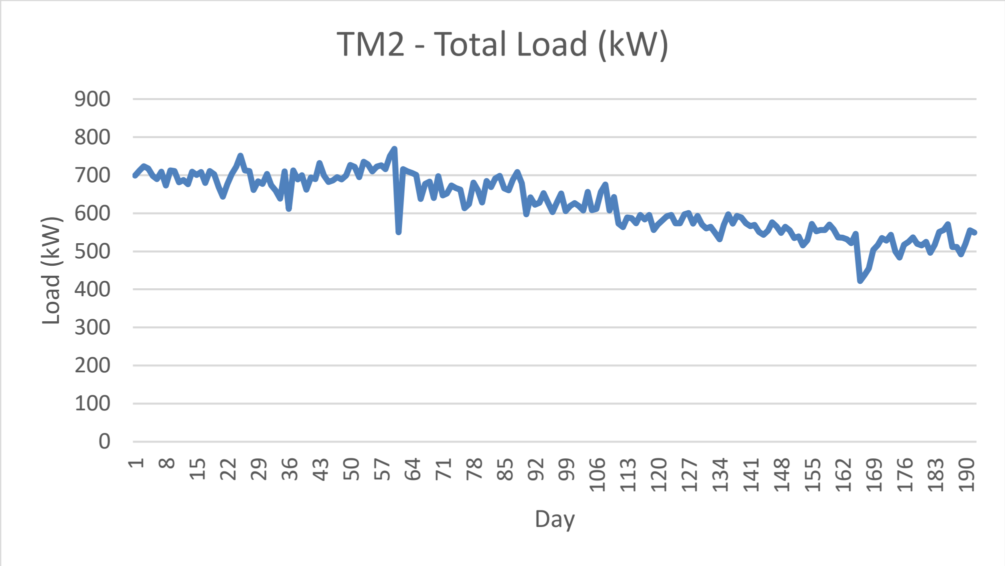

Figure III.71. Six months maximum loads from TM2.

- **TM3**

Six months maximum load from TM3 was 1215.04 kW.

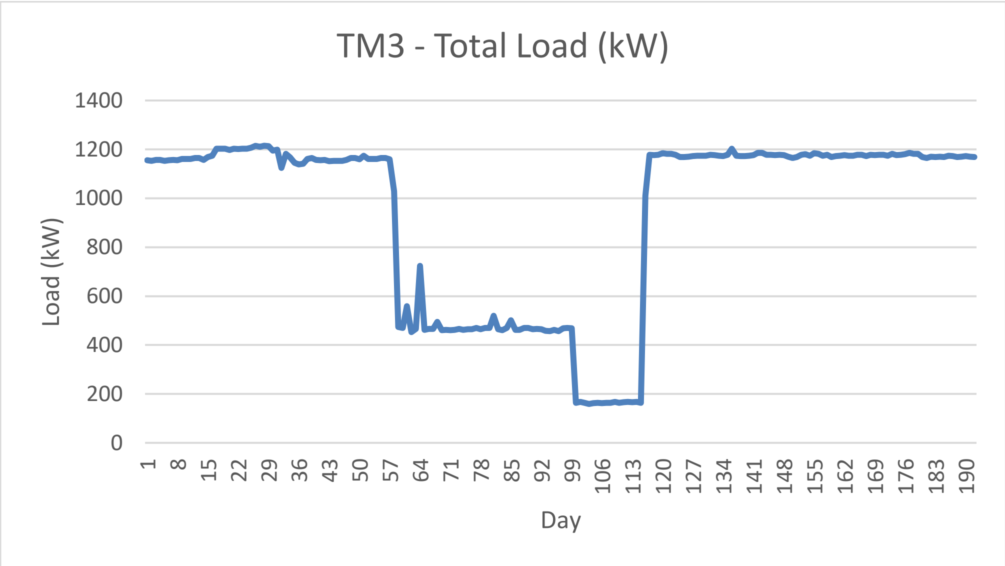

Figure III.72. Six months maximum loads from TM3.

- **TM4-T1**

Six months maximum load from TM4-T1 was 595.88 kW.

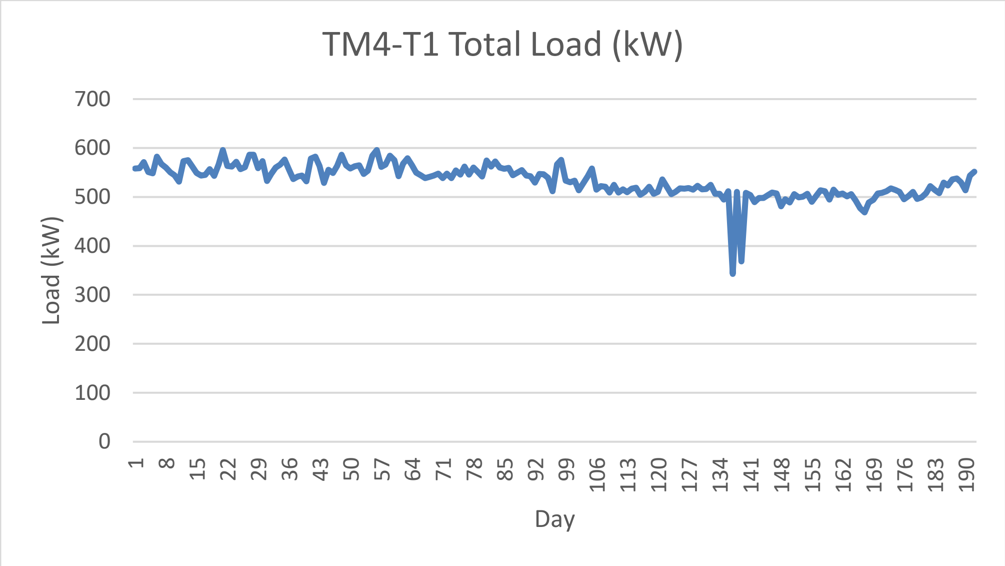

Figure III.73. Six months maximum loads from TM4-T1.

- **TM4-T2**

Six months maximum load from TM4-T2 was 626.54 kW.

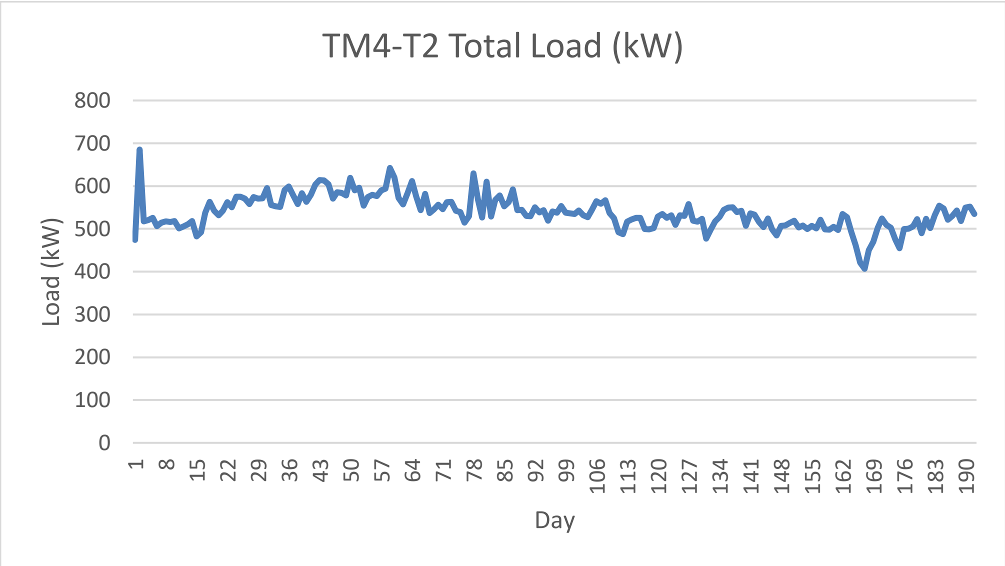

Figure III.74. Six months maximum loads from TM4-T2.

- **TM5**

Six months maximum load from TM5 was 626.54 kW.

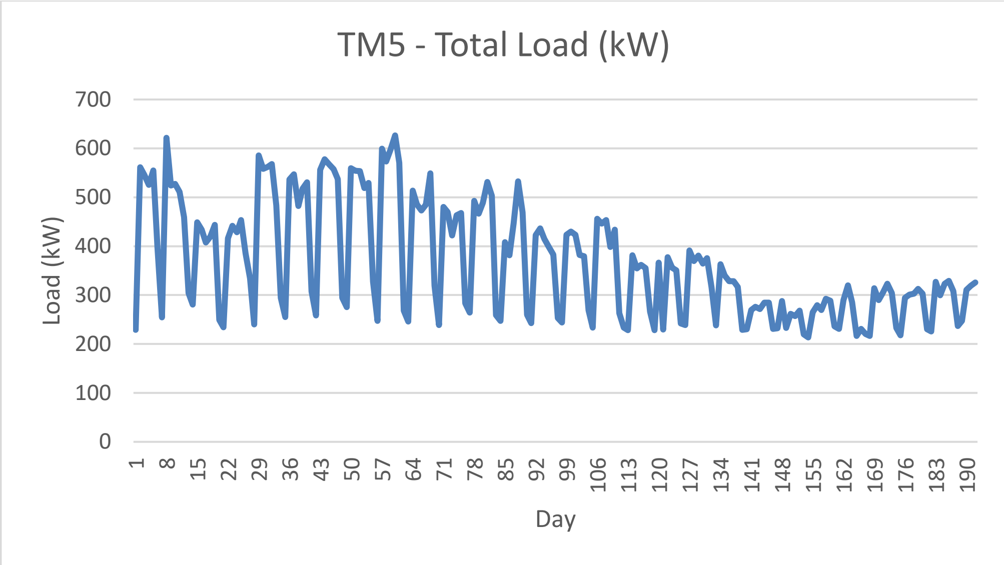

Figure III.75. Six month maximum loads from TM5.

- **TM6**

Six months maximum load from TM6 was 717.84 kW.

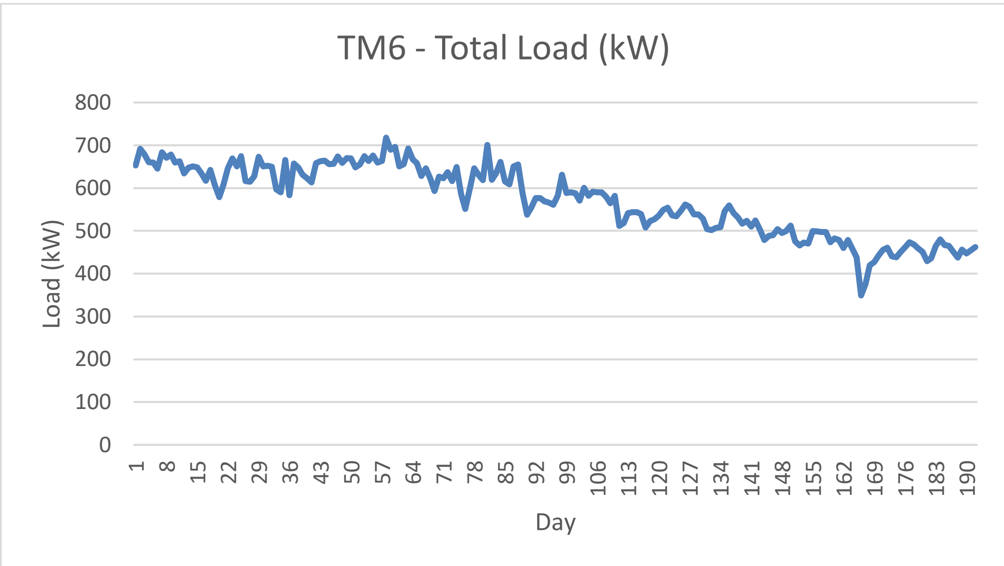

Figure III.76. Six months maximum loads from TM6.

- **TM7**

Six months maximum load from TM7 was 265.16 kW.

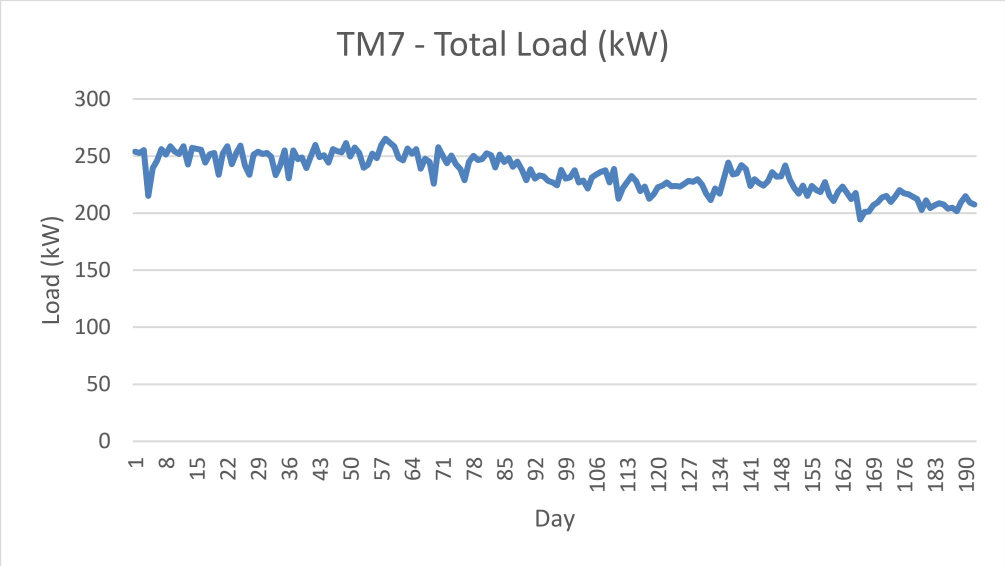

Figure III.77. Six months maximum loads from TM7.

- **TM8**

Six months maximum load from TM8 was 807.56 kW.

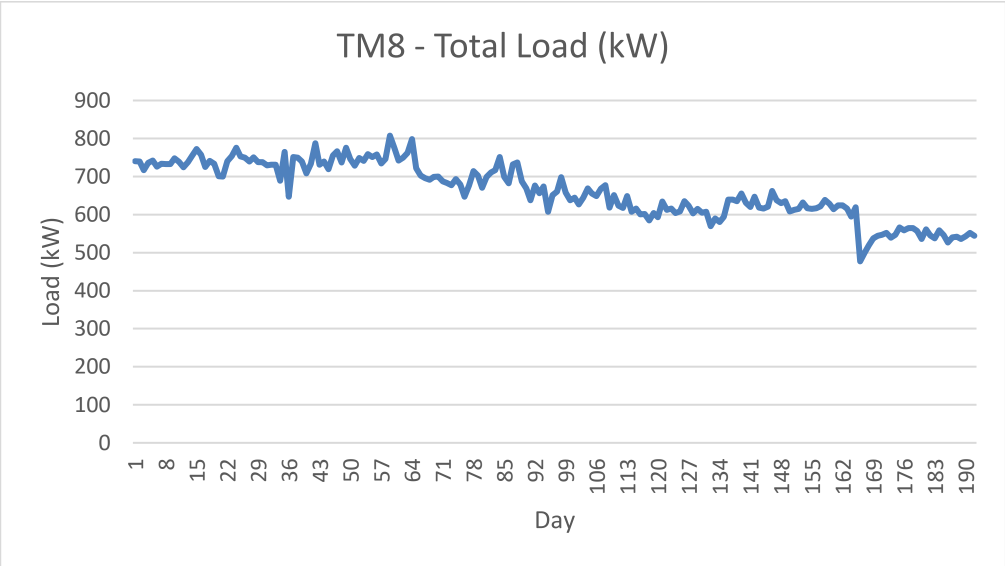

Figure III.78. Six months maximum loads from TM8.

- **TM9**

Six months maximum load from TM9 was 360.76 kW.

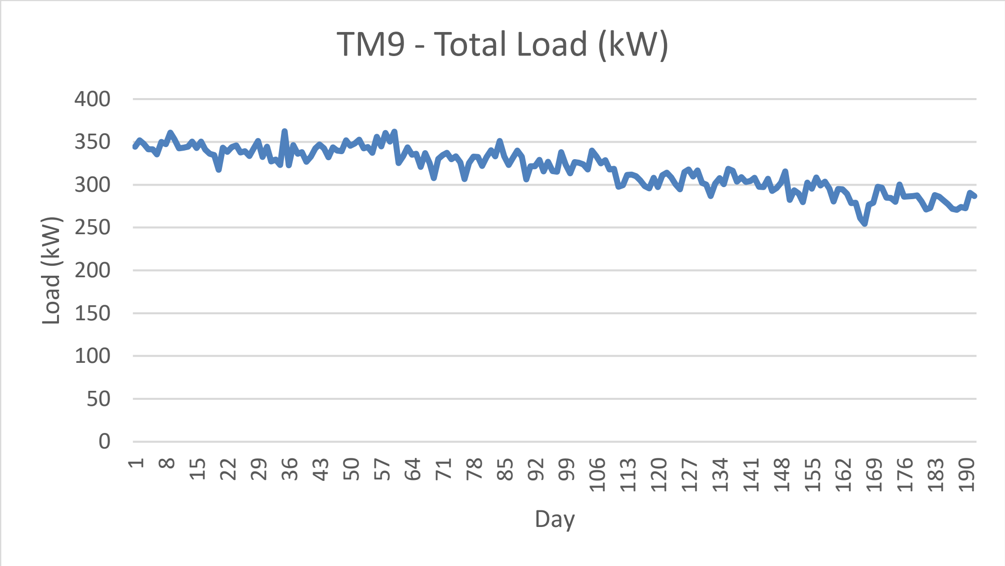

Figure III.79. Six months maximum loads from TM9.

- **TM10**

Six months maximum load from TM10 was 606.80 kW.

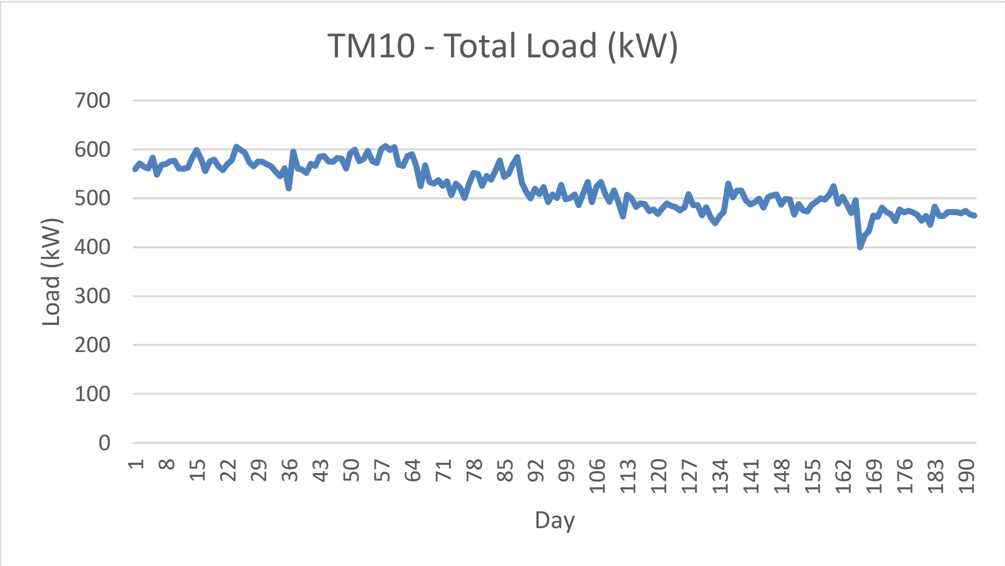

Figure III.80. Six months maximum loads from TM10.

- **TM11**

Six months maximum load from TM11 was 881.93 kW.

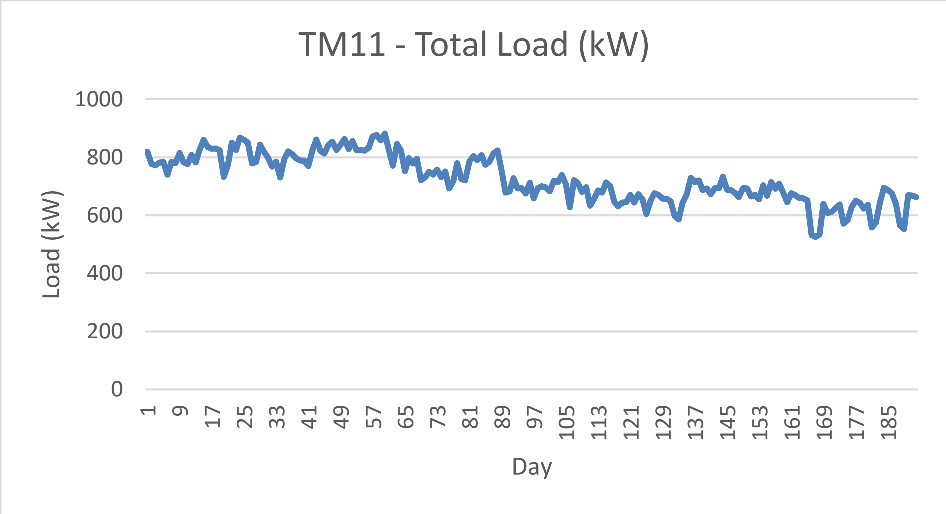

Figure III.81. Six months maximum loads from TM11.

According to analysis results, the maximum load of the grid was on 01/25/2018 at 19:00 as 7.885.36 kW. Analysis of data for the maximum load on the system is presented.

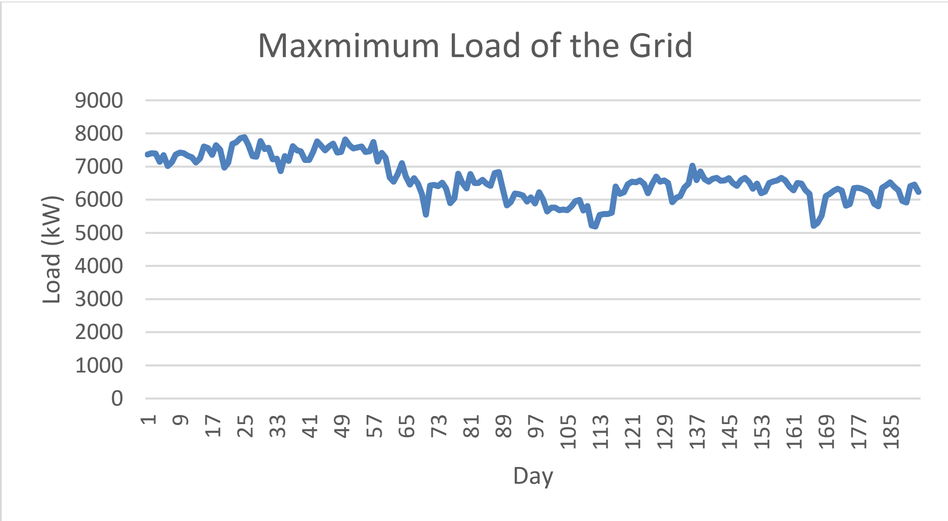

Figure III.82. Maximum load of the grid.

- **Load flow - busses (01/25/2018 19:00)**

Table III.16. Busses load flow report.

Node Id	Base Voltage (kVLL)	V (kVLL)	V (p.u.)	Angle V (Âº)	PLoad (MW)	QLoad (Mvar)
B-TM1	34,500	34,4	0,997	29,35	0,000000	0,000000
B_A_TM1	0,400	0,4	0,977	56,62	1,530533	0,257939
B-TM2	34,500	34,4	0,995	29,26	0,000000	0,000000
B_A_TM2	0,400	0,4	0,982	57,24	0,638388	0,111070
B-TM3	34,500	34,3	0,995	29,23	0,000000	0,000000
B_A_TM3	0,400	0,4	0,983	56,33	1,051477	0,053636
B-TM4	34,500	34,3	0,995	29,22	0,000000	0,000000
B_A_TM4_1	0,400	0,4	0,991	58,66	0,269986	0,054541
B_A_TM4_2	0,400	0,4	0,990	58,00	0,463749	-0,00004
B-TM5	34,500	34,3	0,995	29,22	0,000000	0,000000
B_A_TM5	0,400	0,4	0,990	58,37	0,142388	0,004504
B-TM6	34,500	34,3	0,994	29,20	0,000000	0,000000
B_A_TM6	0,400	0,4	0,983	57,05	0,516875	0,035120
B-TM7	34,500	34,3	0,994	29,20	0,000000	0,000000
B_A_TM7	0,400	0,4	0,991	58,72	0,116993	0,012545
B-TM8	34,500	34,3	0,994	29,20	0,000000	0,000000
B_A_TM8	0,400	0,4	0,977	56,74	0,613843	0,100830
B-TM9	34,500	34,3	0,994	29,19	0,000000	0,000000
B_A_TM9	0,400	0,4	0,986	58,16	0,197974	0,039178
B-TM10	34,500	34,3	0,994	29,19	0,000000	0,000000
B_A_TM10	0,400	0,4	0,983	57,61	0,478720	0,088089
B-TM11	34,500	34,3	0,994	29,19	0,000000	0,000000
B_A_TM11	0,400	0,4	0,978	56,99	0,700814	0,125564

- **Load flow - Cable and lines (01/25/2018 19:00)**

Table III.17. Low voltage cable report.

Equipment No	**Equipment Id**	**Base Voltage (kVLL)**	**Length (m)**	**Total Thru Power (kW)**	**Pf avg (%)**	**IBal (A)**	**Angle I (Âº)**	**Total Loss (kW)**	**Loading (%)**
C-EV1	3X120 NFGBY	0,400	0,0	105	95,00	163,6	38,42	0,000602	52,3
C-EV2	3X120 NFGBY	0,400	0,1	113	95,00	174,9	39,05	0,002250	55,9
C-EV3	3X120 NFGBY	0,400	0,1	0	0,00	0,0	146,34	0,00000	0,0
C-EVC4.1	3X120 NFGBY	0,400	0,1	0	0,00	0,0	148,66	0,000000	0,0
C-EVC4.2	3X120 NFGBY	0,400	0,1	111	95,00	171,1	39,80	0,002154	54,7
C-EV5	3X120 NFGBY	0,400	0,1	111	95,00	170,9	40,18	0,002150	54,6
C-EV6	3X120 NFGBY	0,400	0,1	113	95,00	175,0	38,85	0,002253	55,9
C-EV7	3X120 NFGBY	0,400	0,1	113	95,00	173,5	40,52	0,002135	55,4
C-EV8	3X120 NFGBY	0,400	0,1	114	95,00	177,1	38,55	0,002225	56,6
C-EV9	3X120 NFGBY	0,400	0,1	113	95,00	173,5	39,97	0,002136	55,4
C-EV10	3X120 NFGBY	0,400	0,1	112	95,00	172,7	39,41	0,002115	55,2
C-EV11	3X120 NFGBY	0,400	12,0	114	94,99	177,0	38,77	0,189870	56,5

- **Load flow - Cable and lines (01/25/2018 19:00)**

Table III.18. Medium voltage cable report.

Equipment No	**Equipment Id**	**Base Voltage (kVLL)**	**Length (m)**	**Total Thru Power (kW)**	**Pf avg (%)**	**IBal (A)**	**Angle I (Âº)**	**Total Loss (kW)**	**Loading (%)**
C-S-TM1	33kV_3x1x150 XLPE_CU	34,500	1490,8	7945	98,91	134,7	20,99	16,6	30,1
C-TM1-TM2	33kV_3x1x150 XLPE_CU	34,500	1614,8	6278	98,97	106,5	21,13	11,2	23,8
C-TM2-TM3	33kV_3x1x150 XLPE_CU	34,500	620,4	5513	98,84	93,8	20,53	3,3	20,9
C-TM3-TM4	33kV_3x1x150 XLPE_CU	34,500	104,2	4448	98,48	76,0	19,23	0,4	17,0
C-TM4-TM5	33kV_3x1x150 XLPE_CU	34,500	111,8	3595	98,23	61,6	18,42	0,3	13,7
C-TM5-TM6	33kV_3x1x150 XLPE_CU	34,500	890,0	3338	98,16	57,2	18,21	1,8	12,8
C-TM6-TM7	DEFAULT	34,500	0,0	2701	97,46	46,6	16,25	0,0	46,6
C-TM7-TM8	DEFAULT	34,500	0,0	2468	97,44	42,6	16,21	0,0	42,6
C-TM8-TM9	33kV_3x1x150 XLPE_CU	34,500	332,7	1732	97,59	29,9	16,59	0,2	3,0
C-TM9-TM10	33kV_3x1x150 XLPE_CU	34,500	428,0	1418	97,42	24,5	16,15	0,2	2,5
C-TM10-TM11	DEFAULT	34,500	0,0	823	96,85	14,3	14,76	0,0	14,3

- **Load Flow - Loads 01/25/2018 19:00**

Table III.19. Electric vehicle charging station voltages.

Section Id	**VA (V)**	**VB (V)**	**VC (V)**	**Spot Adj A (kVA)**	**Spot Adj B (kVA)**	**Spot Adj C (kVA)**	**Spot Adj (kVA)**	**Spot PF Adj A (%)**	**Spot PF Adj B (%)**	**Spot PF Adj C (%)**	**Spot PF Adj (%)**
EV_CHARGER_1	117,2	117,2	117,2	36,9	36,9	36,9	110,7	95	95	95	95
EV_CHARGER_2	117,8	117,8	117,8	39,6	39,6	39,6	118,9	95	95	95	95
EV_CHARGER_3	117,9	117,9	117,9	0,0	0,0	0,0	0,0	0	0	0	0
EV_CHARGER_4.1	118,9	118,9	118,9	0,0	0,0	0,0	0,0	0	0	0	0
EV_CHARGER_4.2	118,8	118,8	118,8	39,1	39,1	39,1	117,3	95	95	95	95
EV_CHARGER_5	118,8	118,8	118,8	39,1	39,1	39,1	117,2	95	95	95	95
EV_CHARGER_6	118,0	118,0	118,0	39,7	39,7	39,7	119,2	95	95	95	95
EV_CHARGER_7	118,9	118,9	118,9	39,7	39,7	39,7	119,1	95	95	95	95
EV_CHARGER_8	117,3	117,3	117,3	40,0	40,0	40,0	119,9	95	95	95	95
EV_CHARGER_9	118,3	118,3	118,3	39,5	39,5	39,5	118,6	95	95	95	95
EV_CHARGER_10	117,9	117,9	117,9	39,2	39,2	39,2	117,6	95	95	95	95
EV_CHARGER_11	117,2	117,2	117,2	39,9	39,9	39,9	119,7	95	95	95	95

- **Load Flow - Loads 01/25/2018 19:00**

Table III.20. The voltages of other electric loads in transformers.

Section Id	VA (V)	VB (V)	VC (V)	Spot Adj A (kVA)	Spot Adj B (kVA)	Spot Adj C (kVA)	Spot Adj (kVA)	Spot PF Adj A (%)	Spot PF Adj B (%)	Spot PF Adj C (%)	Spot PF Adj (%)
L-TM1	117,2	117,2	117,2	517,4	517,4	517,4	1552,1	98,61	98,61	98,61	98,61
L-TM2	117,8	117,8	117,8	216,0	216,0	216,0	648,0	98,52	98,52	98,52	98,52
L-TM3	117,9	117,9	117,9	350,9	350,9	350,9	1052,8	99,87	99,87	99,87	99,87
L-TM4-T1	118,9	118,9	118,9	91,8	91,8	91,8	275,4	98,02	98,02	98,02	98,02
L-TM4-T2	118,8	118,8	118,8	154,6	154,6	154,6	463,7	100,0	100,0	100,0	100,0
L-TM5	118,8	118,8	118,8	47,5	47,5	47,5	142,5	99,95	99,95	99,95	99,95
L-TM6	118,0	118,0	118,0	172,7	172,7	172,7	518,1	99,77	99,77	99,77	99,77
L-TM7	118,9	118,9	118,9	39,2	39,2	39,2	117,7	99,43	99,43	99,43	99,43
L-TM8	117,3	117,3	117,3	207,9	207,9	207,9	623,6	98,43	98,43	98,43	98,43
L-TM9	118,4	118,4	118,4	67,4	67,4	67,4	202,3	97,86	97,86	97,86	97,86
L-TM10	117,9	117,9	117,9	162,7	162,7	162,7	488,2	98,05	98,05	98,05	98,05
L-TM11	117,4	117,4	117,4	238,2	238,2	238,2	714,6	98,07	98,07	98,07	98,07

Load Flow - Transformers 01/25/2018 19:00

Table III.21. Transformer analysis.

Equipment No	Equipment Id	Prim Volt (kVLL)	Sec Volt (kVLL)	Total Thru Power (kW)	Total Thru Power (kvar)	Total Thru Power (kVA)	Pf avg (%)	IBal (A)	Angle I (Â°)	Total Loss (kW)	Total Loss (kvar)	Loading (%)
TM1	33KV-2000KVA	34.5	0.4	1656	378	1698	97.50	22.8	16.5	20.20	85.1	83.1
TM2	33KV-1250KVA	34.5	0.4	758	177	779	97.38	12.5	16.12	7.03	28.8	61.3
TM3	33KV-1250KVA	34.5	0.4	1063	108	1068	99.49	5.4	23.43	11.28	54.5	84.2
TM4-TR1	33KV-1600KVA	34.5	0.4	273	57	279	98.86	5.1	17.36	3.24	2.9	17.2
TM4-TR2	33KV-1600KVA	34.5	0.4	580	49	582	99.64	10.1	24.38	4.86	12.5	36.0
TM5	33KV-1000KVA	34.5	0.4	256	45	260	98.49	5.8	19.25	2.64	4.0	25.7
TM6	33KV-1000KVA	34.5	0.4	636	97	644	98.86	12.3	20.53	6.08	24.6	63.4
TM7	33KV-1600KVA	34.5	0.4	233	52	239	97.62	4.6	16.67	3.11	2.1	14.7
TM8	33KV-1000KVA	34.5	0.4	735	182	758	97.08	13	15.32	7.67	34.2	74.3
TM9	33KV-1000KVA	34.5	0.4	314	85	325	96.53	6.3	14.04	3.01	6.2	32.0
TM10	33KV-1250KVA	34.5	0.4	596	151	614	97.95	10.6	14.99	5.21	18.0	48.4
TM11	33KV-1250KVA	34.5	0.4	823	212	849	97.85	15.3	14.76	7.95	34.4	66.7

The map showing the charging stations positioned as a part of the study shown in figure III.83.

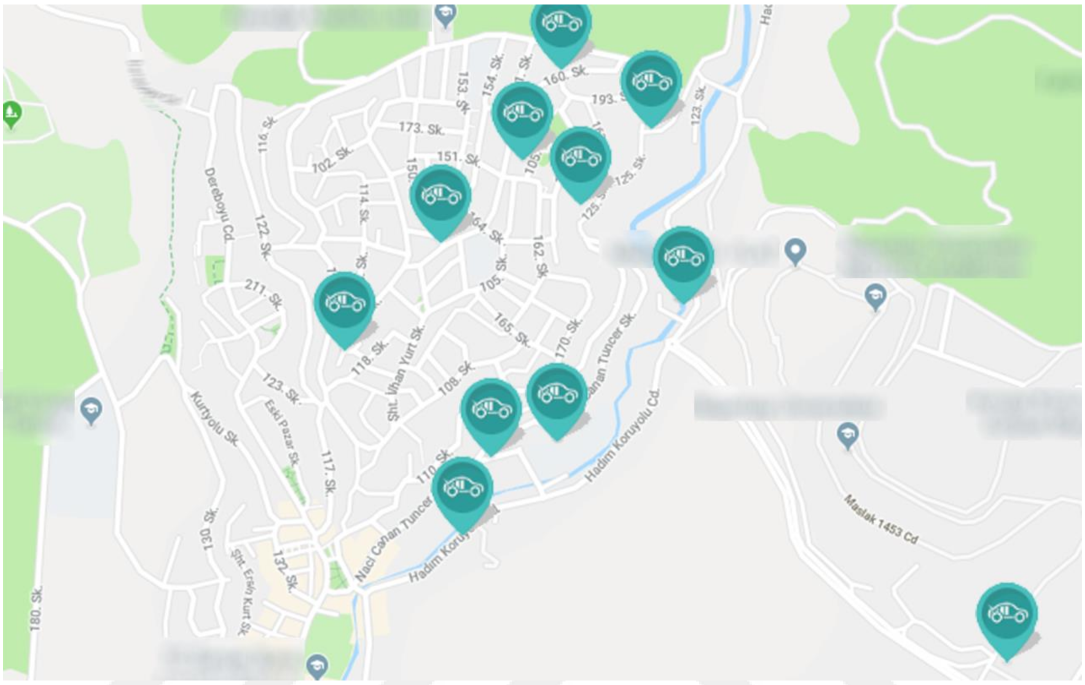

Figure III.83. Map showing the charging stations.

IV. SUMMARY AND CONCLUSIONS

4.1. Conclusions

In this study, the literature review on electrical vehicles, electric vehicle charging stations and electric vehicles connected to the grid were accomplished. Charging stations where electric vehicles are connected to the grid were analyzed. The power level of charging stations and connection standards were reviewed.

Possible load modeling on distribution grids and different grid load modeling methods were analyzed. Charging station positioning on the grid and negative effects of these stations on the grid were also analyzed.

By using consumer profile analysis, the charging station positioning that might be needed and sustained were analyzed. Based on analysis results, the main factors that need to be considered were studied and the requirements were defined.

In simulation studies, the regions that might have different station power requirements were identified and regional user profiles were created. Loads were analyzed for minimum grid effect; different simulations for different operating conditions have conducted the analysis about described.

The target grid and charging station map were created by considering and the analysis was conducted for various operational conditions. In these simulations, the number of vehicles that can be simultaneously connected to each transformer center and finally, simultaneous loading was analyzed and the optimum study model was planned to charge all the vehicles. The vehicle effects on the grid were analyzed by taking the losses, voltage drops, cable overloading, transformer overloading, and negative effects were not found.

In conclusion, It is observed that for selected optimum localization of charging stations will yield minimum adverse effect on the grid.

4.2. Future Work

This study was based on real-time past field data. With software development application on the distribution grid, the main objective is to instantly monitor live grid load on the CYME program, ensure simultaneous data entry and instantaneous analysis.

Another future study can share the momentary status of charging stations connected to the smart grid with users via the mobile system. This way, users can control and access to available charging stations near them. Additionally, the current-voltage level of charging stations can be instantly monitored with software. This way, charging levels can be adjusted to users can be directed to other charging stations after closing the charging station. Instant overload of the grid can be kept under control.

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