MONTE CARLO BASED CONTROL ALGORITHM
FOR ECONOMIC FEASIBILITY OF V2G APPLICATIONS

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ABSTRACT

MONTE CARLO BASED CONTROL ALGORITHM FOR ECONOMIC FEASIBILITY OF V2G APPLICATIONS

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The use of electric vehicles (EVs) has been increasing in recent years due to economic and environmental factors. This rapid development makes it necessary to investigate the effects EVs on the power system planning and system participants. The aim of this study is to determine the optimal operating strategy for a microgrid operator which can function as a prosumer with the contribution of vehicle to grid (V2G) application. The connection time, plug-in time and state of charge (SoC) of EVs are stochastic variables and these variables are represented in the algorithm using a respective Gaussian distribution function. The Monte Carlo based algorithm aims to obtain a more accurate result despite these stochastic input values.

The developed algorithm controls the battery energy of EVs, updating the decision at every hour, according to the estimated daily load and electricity price curves to minimize the operational cost of a smart grid. The algorithm has been applied to three different cases, which are categorized according to the connection points of EVs (i.e., residential, commercial, both residential and commercial). Uncontrolled charging, controlled charging and discharging scenarios apply to all of these cases to determine and compare the economic contribution of V2G application. These cases are also analyzed in order to evaluate the output of the control algorithm to different tariffs, different load demands and different EV characteristics.

Keywords: Electric Vehicles, Vehicle to Grid Service, Energy Management, Monte Carlo Simulations

ÖZ

V2G UYGULAMASININ EKONOMİK FİZİBİLİTESİ İÇİN MONTE CARLO TABANLI KONTROL ALGORİTMASI

Şahinkaya, Kıvanç
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Ekonomik ve çevresel faktörler nedeniyle elektrikli araçların kullanımı son yıllarda artmaktadır. Bu hızlı gelişme, elektrikli araçların güç sistemi planlaması ve sistem katılımcıları üzerindeki etkilerini araştırmayı gerekli kılmaktadır. Bu çalışmanın amacı, V2G uygulamasının katkısıyla bir üreten tüketici olarak işlev görebilen akıllı şebeke operatörü için en uygun operasyon stratejisi belirlemektir. Elektrikli araçların bağlantı süresi, bağlantı zamanı ve şarj durumu olasılıksal değişkenlerdir ve bu değişkenler Gauss dağılım fonksiyonu kullanılarak algoritmaya yerleştirilmiştir. Monte Carlo tabanlı algoritma, olasılıksal girdi değerlerine rağmen daha doğru sonuçlar elde etmeyi amaçlanmıştır.

Geliştirilen algoritma, elektrikli araç kullanıcılarının para kaybına neden olmadan akıllı şebeke operatörünün işletme maliyetini en aza indirgemek için günlük yük ve para eğrisine göre her saat kararlarını güncelleyerek elektrikli araçların batarya enerjisini kontrol etmektedir. Algoritma, elektrikli araçların bağlantı noktalarına (konut, ticari ve hem konut hem de ticari) göre bölünmüş üç farklı durumu analiz etmektedir. Kontrolsüz şarj, kontrollü şarj ve deşarj senaryoları V2G uygulamasının ekonomik katkısını belirlemek için tüm bu durumlara uygulanmıştır. Bu durumlar farklı tarifelerde, farklı yük taleplerinde ve farklı elektrikli araç özelliklerinde kontrol algoritmasının sonuçlarını değerlendirmek için analiz edilmiştir.

Anahtar Kelimeler: Elektrikli Araçlar, Araçtan Şebekeye Enerji Servisi, Enerji Yönetimi, Monte Carlo Simülasyonları

To My Family and My Friends ...

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INTRODUCTION

1.1. Motivation

Electric vehicles (EV) have become more desirable in transportation due to both environmental and economic properties of EVs. Thus, many governments started to pay their attentions to EVs, and implement policies to give incentives to companies, which are willing to improve their technology on producing EV. The EV technology has been advanced with the help of many companies in this field. The development of EV technology and the governmental policies on encouraging the use of EVs made an impact on the penetration of EVs in the market. As a result, the number of EVs has started to increase significantly in recent years.

The programs which promote EVs are not only released by the developed countries, but also Turkey released similar support programs. Thus, the use of EVs has started to increase in Turkey as well. Particular study concerning the EV integration in Turkey does not exist, although numerous studies about the EV integration have been carried out by the developed countries' governments. Thus, it was also necessary to examine the effect of EV integration on the electric system and the system participant in Turkey.

The industrial development and urbanization in Turkey are causing a continuous load increase as similar to developing countries. The distribution companies need to plan their electrical infrastructure arrangements according to cover the anticipated load increases. Moreover, the fall in the cost of renewable resources and energy storage systems provide for many consumers to attend the electricity producing. These participations which produce and consume the electricity are called as prosumers. The integration of EV into the electric system will provide for prosumers to use the battery of EV as an energy storage system thanks to V2G operation. Prosumers can reduce the cost of their electricity usage, since EVs have long-term parking and their batteries have natural energy storage system. Therefore, this study carries out in order to investigate the feasibility of the business model which includes prosumers using EVs.

Prosumers can be classified commercial and residential by their connection point to the electric network. Residential, commercial and distributed (both commercial and residential) microgrids are formed to investigate their economic feasibility of the microgrid operator (MGO). The developed algorithm for the operator controls the energy transfer of EV batteries to minimize the operation cost of the microgrid operator. The microgrid operator, which behaves as a prosumer, decides to the charging and discharging operations of EVs in the microgrid. In this study, EV owners participate in this business model as members without cost transaction.

Different scenarios have been created as the uncontrolled or controlled grid-to-vehicle (G2V) and V2G operations to analyze the effect of V2G operation on the operation cost. Moreover, the different EV characteristics and microgrid variables, which are battery capacity, the number of charging stations, minimum SoC level, travel pattern, tariff and season, are applied to different microgrid types for investigating the economic feasibility of the operator.

The behavior of EV owners determines input variables of EVs which are the initial SoC, the arrival time and the departure time of EVs. This behavior has been developed with Gaussian distribution function to determine these stochastic variables. These functions are implemented in the algorithm at MATLAB. In addition, Monte Carlo based simulation trials are used in order to get acceptable and accurate results of Gaussian distribution functions.

1.2. Thesis Outline

The general background of EVs and Turkish Electricity Market are given in Chapter 2. The information about the historical background, EV types, the working principle of EVs and the technical aspects of EVs' components are explained in the first section of this chapter. In addition, the technical specifications and types of EV chargers is stated in the second section of this chapter. The global EV Market, the history and the structure of the Turkish Electricity Market, and the literature review on the integration of EVs are emphasized in the last section of Chapter 2.

The system model is described in Chapter 3 with assumptions. Three cases (commercial, residential and distributed microgrids) and five scenarios (without EV, uncontrolled charging, controlled charging, controlled charging and discharging, optimum controlled charging and discharging) are examined in details to investigate the impact of different EV integration types on the economic feasibility of the operator. The different EV characteristics and microgrid variables which can affect to this integration are also described in the second section of this chapter. The methodology of simulations is described with the flow chart of the algorithm in details in the last section. Moreover, Monte Carlo based simulation trials are also explained in this chapter.

The results of whole simulation for each cases and scenarios with the different variables are presented in Chapter 4. The discussion of the simulation results is examined in the last section of this chapter.

The conclusion of this study is expressed in Chapter 5 with the evaluation from the viewpoint belonging to the microgrid operator.

CHAPTER 2

GENERAL BACKGROUND OF ELECTRIC VEHICLES

2.1. Overview of Electric Vehicles

2.1.1. History of Electric Vehicles

The history of EVs dates back to the early 19th century. In the last quarter of the 19th century, a significant number of vehicles, which include an electric motor, began to come into sight on the roads. EVs especially have become widespread because the range of EV is sufficient for short length highway in the U.S.A. Although EVs lived their golden age between the years 1900 and 1912, the cost of EV usage became three times more expensive than the use of internal combustion engine vehicles (ICEVs) due to the construction of new roads. Thus, the number of ICEVs became more than the number of EVs in 1912 in the U.S.A after the manufacture of Ford Model-T. This development signaled the end for EVs availability and EVs were not preferred for road transport until the last quarter of the 20th century.

The main development for EVs has been provided with the new battery technologies after the 1990s. Toyota launched the Toyota Prius, which is a Hybrid Electric Vehicle (HEV), in 1997 in Japan. This vehicle has mostly responded to the expectations of costumers with its comfort and economic transformation; thus, it has become the first large-scale serial production of EVs. Renault, Peugeot, and Citroen also started manufacturing in Europe at the same time with Toyota. Especially in the last fifteen years, EVs entered the market again with the productions mentioned above. The Roadster, which is Battery Electric Vehicle (BEV) was produced in 2006 by Tesla

Motors. Tesla has been successful in sales over the estimated number despite its high price. It led to the serial production of EVs in other companies. At present, almost all vehicle brands have an electric vehicle model.

2.1.2. Types of Electric Vehicles

In general, all types of vehicles can be classified under six types according to primary and secondary energy sources which provide the movement of vehicles. These types of vehicles are given in Table 1 with their energy sources. The most basic version of these vehicles is called ICEV, which only contains an internal combustion engine. ICEV is still the most widely used type of vehicle in the world in contrast with high CO_2 emission. The operation of the internal combustion engine starts with the injected fuel which is under high pressure and temperature in the combustion chamber mixes with the air and they are ignited. The generated energy with this combustion is converted into motion energy.

Vehicles which contain an electric motor in addition to an internal combustion engine are called HEV. The HEV which contains the fuel tank, an electronic controller, the internal combustion engine, a power electronic controller, an electric motor, a main battery, an DC/DC converter and a secondary battery is one of the most widely used in types of EV. The main energy source is the fuel tank which is used by an internal combustion engine. The electric motor makes the acceleration of the vehicle to be energy efficient and it gets energy from the main battery. This battery is charged by the internal combustion engine during the braking of the vehicle without external charging. The DC/DC converter provides lower voltage level for the secondary battery. This battery supplies the energy of electronics of vehicles.

Plug-in Hybrid Electric Vehicle (PHEV) contains a larger battery than HEV and this battery can be charged externally. PHEV has also an AC/DC rectifier different from HEV to charge the main battery externally. On short trip, PHEVs can only use the energy of the battery that is different from HEVs. Therefore, PHEVs is more economic than HEVs in terms of the travel cost, HEVs and PHEVs save fuel consumption in comparison with ICEVs.

Range Extended Electric Vehicle (REEV) has an internal combustion engine and an electric motor as HEV and PHEV. However, electricity is the primary energy source in the movement of REEV unlike ICEV, HEV and PHEV. The internal combustion engine charges the battery by using a generator. This battery is also charged during the braking of the vehicle and externally.

Table 1. General Classification of Different Types of Vehicles

Type	**Primary Energy Source**	**Secondary Energy Source**	**Source**
Internal Combustion Engine Vehicles (ICEV)	Fossil Fuel	❌	Refuel
Hybrid Electric Vehicle (HEV)	Fossil Fuel	Battery	Refuel
Plug-in Hybrid Electric Vehicle (PHEV)	Fossil Fuel	Battery	Plug-in
Range Extended Electric Vehicle (REEV)	Battery	Fossil Fuel	Plug-in
Battery Electric Vehicle (BEV)	Battery	❌	Plug-in
Fuel Cell Electric Vehicle (FCEV)	Hydrogen	Battery	Refill

BEVs only use an electric motor that is different from other four types of vehicles. The required energy is taken from the battery which can be charged externally. In BEV, the electrical energy from the battery is converted into mechanical energy by the electric motor. This mechanical energy is transferred to the wheels and the movement of vehicle is provided. The power electronic controller controls the torque and speed of vehicles. The color in Figure 1 represents different electrical functions in a BEV. The red line represents the main energy of the movement and the yellow line presents the supplied energy to the second battery. In addition, the green line represents the supplied energy to main battery.

Important parameters for EVs are the battery capacity and the recharge duration. The range of BEVs is up to 500 kilometers nowadays and the battery capacity is up to 100 kWh. The battery charging time changes according to the battery type of BEVs, the battery capacity of BEVs and the output power of the charger.

Fuel Cell Electric Vehicles (FCEVs) only use the electric motor for the movement of wheels as in BEVs. FCEV contains hydrogen fuel cell instead of the classic battery. The hydrogen is stored in the fuel cell to obtain the required energy of the electric motor and this fuel cell can be refueled.

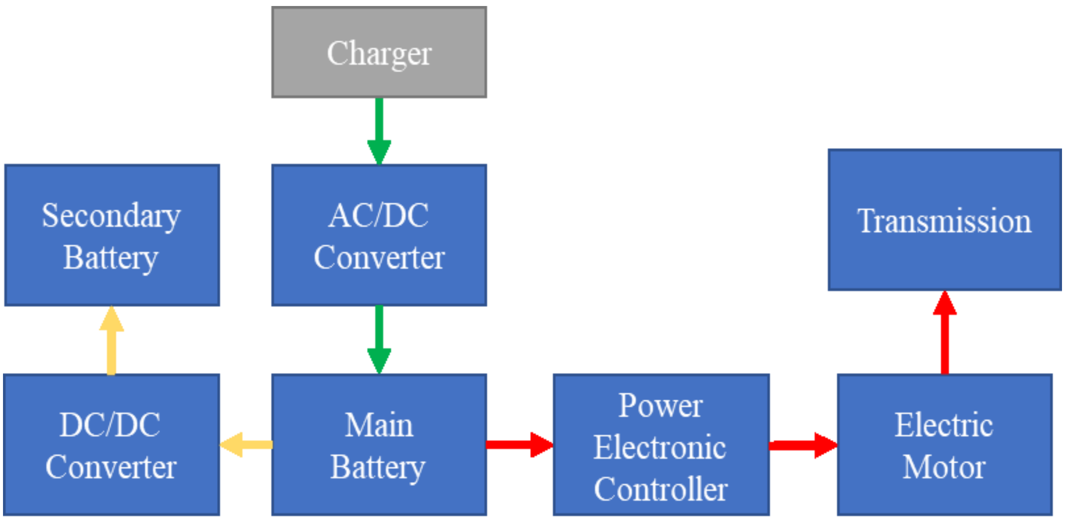

Figure 1. Working Principle Diagram of BEVs

2.1.3. Batteries of Electric Vehicles

The most important feature in the choice of an EV is the travel range. The travel range is highly dependent of the battery technology and battery capacity of EV. Therefore, the advancement of battery technology means the advancement of EV technology and the expansion of EV market.

2.1.3.1. Types of Batteries

There are different types of rechargeable batteries with different chemical structures and technologies. These types are Lead-Acid battery, Lithium-ion (Li-ion) battery, Nickel Cadmium (NiCd) battery, Nickel Metal Hydride (NiMH) battery. Unlike other types of batteries, Nickel Cadmium and Lead Acid batteries may produce toxic heavy metals with time. NiMH battery is less expensive, more tolerant to heat than Li-ion battery and displays the same performance in energy storage as a Li-ion battery. However, NiMH battery is nearly two times larger and heavier than a Li-ion battery. Li-ion batteries have higher energy density, higher power density and higher cycle life than other battery types. Thus, electric vehicle manufacturers mostly prefer the Li-on battery in the production of EV.

Li-ion batteries are also grouped among themselves in accordance with the ion structure. The major types of Li-ion batteries used in EVs are Lithium Nickel Cobalt Aluminum (NCA), Lithium Nickel Manganese Cobalt (NMC), Lithium Manganese Spinel (LMO), Lithium Titanate (LTO) and Lithium-iron phosphate (LFP). LTO and LMO batteries have low energy and power density than other Li-ion batteries. Additionally, the temperature of LTO and LFP is more stable during their usage. In spite of these features of LFP and LTO, NCA battery is more preferable by EV manufacturers because of its higher performance. The disadvantage of NCA is that it must be used with cooling and monitoring system for the safety of EV. The main properties of selection battery for EV are energy density, power density, performance,

Table 2. Properties of Battery Types Respect to Each Other [1]

	NCA	NMC	LMO	LTO	LFP
Specific Energy	High	High	Average	Low	Low
Specific Power	High	Average	Average	Average	Average
Safety	Low	Average	Average	High	High
Cost	Low	Average	Average	Very Low	Average
Performance	Average	Average	Low	High	Average
Life Span	High	Average	Low	High	High

life-span, cost and safety. The main properties of battery types are given in Table 2 compared to each other.

2.1.3.2. Technical Specification of Batteries

The most important technical aspects of batteries are capacity, specific energy, specific power, state of charge (SoC), state of health (SoH).

Capacity (Ah): Available charge stored at the battery.

Specific Energy (Wh/kg): The battery energy per unit mass.

$$\text{Specific Energy} = \frac{\text{Energy(Wh)}}{\text{Mass(kg)}} \quad \textbf{(1)}$$

Specific Power (W/kg): The battery power per unit mass.

$$\text{Specific Power} = \frac{\text{Power(W)}}{\text{Mass(kg)}} \quad \textbf{(2)}$$

SoC (%): The available battery capacity percentage of its rated capacity.

$$\text{SoC} = \frac{\text{Current Capacity(C)}\ x\ 100}{\text{Full Charged Capacity(C)}} \qquad \textbf{(3)}$$

SoH (%): The available storage ability of battery percentage of its rated storage ability.

$$\text{SoH} = \frac{\text{Full Charged Capacity(C)}\ x\ 100}{\text{Maximum Designed Capacity(C)}} \qquad \textbf{(4)}$$

2.2. Overview of Electric Vehicle Chargers

2.2.1. Types of Electric Vehicle Chargers

Electric vehicle chargers are examined in three different classes from an industrial perspective. These classes are slow (Level-1), fast (Level-2) and ultra-fast (Level-3) chargers. Level-1 and Level-2 chargers have the similar concept in terms of electrical circuits they contain. Charger at these levels are often used at residential and commercial places due to long period charging time. They do not contain an AC/DC rectifier to satisfy the connection between EV and electric grid because of the internal AC/DC rectifier in EV [2]. However, the other one is Level-3 charger that includes an AC/DC rectifier or an isolated DC/DC converter. Level-3 chargers are often used on intercity roads, in some shopping centers and petrol stations. The charging power of Level-3 is from 25 kW to 350 kW; however, the charging power of Level-1 and Level-2 is up to 22 kW.

Electric vehicle chargers can usually be examined in four modes according to IEC-61851-1 Standard, taking into account the charging energy. The first one is Mode 1 which is the slow charge in AC. In this mode, EVs are connected to power grid with using a standard power connection cable and EVs are charged with between 3.7 kW and 11 kW. Mode 2 is also called slow charge in AC and EVs are charged with up to 22 kW. In this mode, EVs are connected to the power grid with an intermediate electronic device. Mode 3 can be called slow or quick charge based on phase number of the input electricity and EVs must be connected with a specific electric device at three phase charging. In Mode 4, EVs are connected to the power grid with an electric device which includes an AC/DC converter. Level-1, Level-2 and wireless chargers' type can be examined under Mode-1 and Mode-2. These modes and level chargers are mostly used in electric vehicle charger among EV owners. Energy technology companies and electric vehicle manufactures have also invested in these electric vehicle chargers. As an example of these investment, OVO Energy which is an energy technology company in United Kingdom installed nearly 1,000 bi-directional Nissan-Leaf chargers in the UK. In addition, OVO did not want a payment from EV owners for this installation. Bi-directional chargers behave as vehicle-to-grid (V2G) and grid-to-charger (G2V). OVO chargers allow the 6 kWh discharge and charge rate of EV batteries [3]**.** More detailed information about these modes is given in Table 3 with respect to IEC-61851-1 Standard.

2.2.2. Charging and Discharging Pattern of Li-ion Batteries

The charging profile of Li-ion batteries is very essential for the battery life. Therefore, it is important to determine the charging pattern for the battery life optimization for IEC-61851-1 Standard.

Table 3. Charging Modes of EVs Respect to IEC-61851-1 Standard [4]

Charge Type	Phase	Maximum Charge Voltage (V)	Maximum Charge Current (A)
Mode 1	1	250	16
	3	480	16
Mode 2	1	250	32
	3	480	32
Mode 3	1	250	32
	3	690	250
Mode 4	DC	600	400

EV is charging under Mode-3 and Mode-4 for extended periods of operation, it damages the chemical structure of the Li-ion battery, and it decreases the battery life. For this reason, the charging of EV under Mode-1 and Mode-2 will be appropriate for the battery life. Level-1 and Level-2 chargers Level 1 and Level 2 charging stations charge EVs according to Mode-1 and Mode-2 coverage. As a result, it can be concluded that Level-1 and Level-2 charging stations are suitable for the battery life.

The Li-ion battery charging must be cut off when it is fully charged to minimize the stress on battery and to keep the battery safe. In addition, Li-ion battery should not be discharged under the 45% of SoC because of the battery degradation. The relation between the discharging behavior and the degradation of Li-ion batteries is given in Figure 2. The suitable discharging behavior is the use of the battery between 75% and 65% SoC for battery life-span. However, this behavior has a very small interval for EV usage. Hence, EV owner can prefer to use of their EVs between 75% and 45% SoC values.

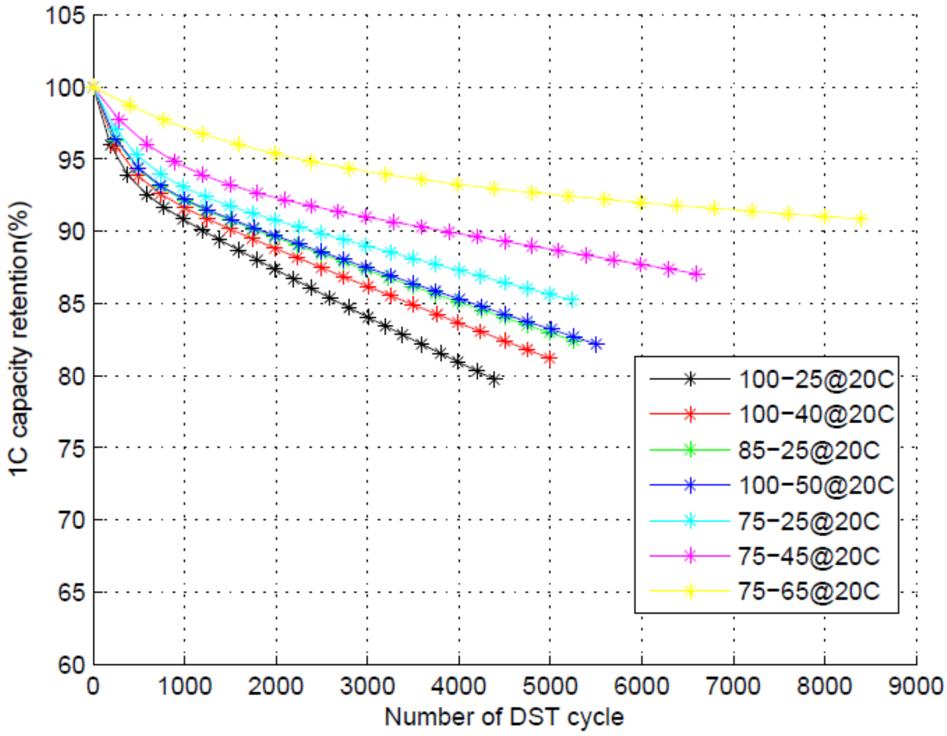

Figure 2. The Degradation of Li-ion Battery Respect to Charging Behavior [5]

2.3. Overview of Market of Electric Vehicles

2.3.1. Market of Electric Vehicles over the World

The second rise of electric vehicles began in 1997 with the production of the Toyota Prius in Japan. Another automotive company, Tesla Inc., was founded in 2006. The production of EVs has started to gain importance for other companies with the achievements of Tesla in the EV market. Another significant progress was the entrance of Chevrolet and Nissan entered into the U.S.A electric vehicle market in 2010. Thus, the number of plug-in vehicles worldwide has increased steadily since 2010. The number of EVs has increased almost 100% each year over the world. Although the increase rate of BEVs was slower than the increase rate of EVs until 2016, the gap between the number of BEVs and EVs has started to get closer in recent years. The change in the number of plug-in EVs at global EV market is given in Figure 3 according to countries.

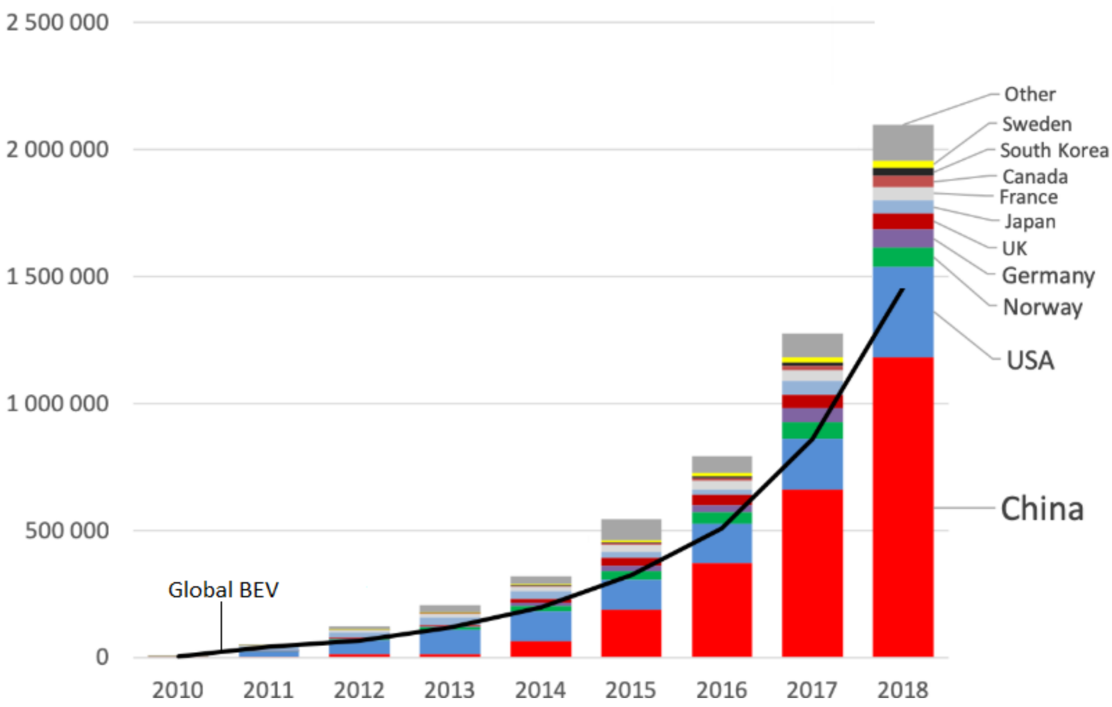

Figure 3. The Number of Plug-in EV in the Global Market [6]

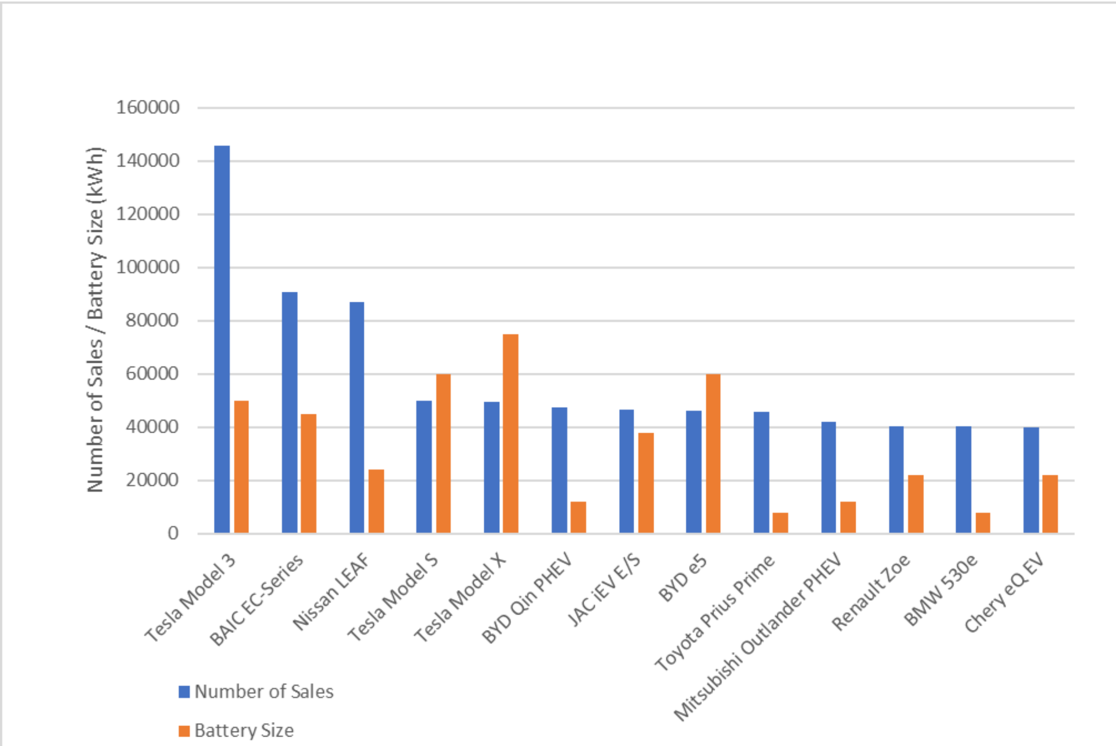

Figure 4. Best-selling Electric Vehicles in 2018 [7]

The majority of EV production was in the USA until 2014; however, since then China gotten ahead of the USA. Nowadays, more than half of EVs in the world are used in China. Currently, the number of vehicles and the rate of increase in European countries are comparatively low, while the increase rates of EVs in the U.S.A and China are considerably high.

The best-selling five BEVs in 2018 were Tesla Model-3, BAIC EC-Series, Nissan Leaf, Tesla Model S and Tesla Model X. According to Figure 4, which includes the number of sales and the battery size of the best-selling EVs in 2018, shows that BEVs dominated the global EV market in 2018. Besides, it can be concluded that Tesla Inc. has the great part of the EV market with its all models.

2.3.2. Market of Electric Vehicles in Turkey

Fluence ZE model developed by Renault was produced in Bursa Renault Factory in 2011. However, until recently, only about two hundred Fluence ZE’s have been sold in Turkey due to the lack of adequate EV chargers and high battery rent cost. After that, another EV model has been produced as a prototype by Koç Group with Ford brand. Similarly, Toyota company produced Toyota Yaris, but serial production of Toyota and Ford has not started due to infrastructure problems in Turkey. While 100,000 plug-in EVs were sold in China in January 2019 [8], this number was nearly 4,000 in Turkey, in 2018. This shows that the EV sale in Turkey is very low compared to the USA and China. On the contrary, the number of EVs sold in Turkey each year is becoming more than the previous years. The information about the number of sold EVs according to EV models in Turkey are given in Table 4 by Turkey Electric and Hybrid Vehicle Association (TEHVA).

Deloitte Company has published a study showing what customers care about when buying a vehicle in Turkey. Table 5 shows the expectations of customers of different generation in Turkey. It would not be wrong to say that the general preference of all generations is towards an economic transportation. The cost of fuel and taxes of EV are economic compared to ICEV. The price of Special Consumption Tax (SCT) varies between 30% and 160% rate of the price of vehicles [9]. Average SCT of one ICEV is nearly same with the price of a vehicle in Turkey. The advantage purchasing an EV is that SCT is not collected from EVs. Therefore, it is thought that Turkish car users' orientation towards electric vehicles will increase in the coming years.

According to the results of the survey, nearly 50% of people in Turkey consider getting a vehicle, which has an alternative motor. However, according to Figure 5, the general preference for the plug-in electric vehicles is slightly less than HEVs in Turkey. Despite this situation, people’s opinion about plug-in electric vehicles is returning to become positive day by day in Turkey. Thus, it can be concluded that the plug-in electric vehicles started to provide an available market in Turkey.

Table 4. Number of Sales of Electric Vehicles in Turkey [10]

MODEL	TYPE	YEARS				Total
		2015	**2016**	**2017**	**2018**	
BMW-i3	EV	83	24	35	37	179
Renault ZOE	EV	36	20	42	79	177
Jaguar I_PACE	EV	0	0	0	38	38
SMART EQ	EV	0	0	0	1	1
BMW-i8	PHEV	106	51	16	5	178
Volvo XC90 T8	PHEV	0	32	11	11	54
MercedesBenz-GLC350e	PHEV	0	0	0	13	13
BMW-740L	PHEV	0	0	0	10	10
Toyota C-HR	HEV	0	28	3381	2576	5985
Toyota YARIS	HEV	0	835	163	126	1124
Toyota AURIS Series	HEV	0	0	314	415	729
Toyota RAV4	HEV	0	0	248	254	502
Hyundai IONIQ	HEV	0	0	166	220	386
Kia NIRO	HEV	0	0	118	199	317
Lexus Series	HEV	0	3	29	40	72
Toyota PRIUS	HEV	0	0	4	2	6
Honda NSX	HEV	0	0	1	3	4
MercedesBenz C200	HEV	0	0	0	2	2
TOTAL		225	993	4528	4031	9777

Table 5. Tendency of Customers in Turkey [11]

Features	**Y Generation**	**Other Generation**
Low Cost	High Important	Most Important
Comfort	High Medium Important	High Important
Fun	Highest Important	High Medium Important
Functional	Low Medium Important	Medium Important
Technological	Medium Important	Low Medium Important
Luxury	Unimportant	Unimportant
Eco-friendly	Unimportant	Unimportant

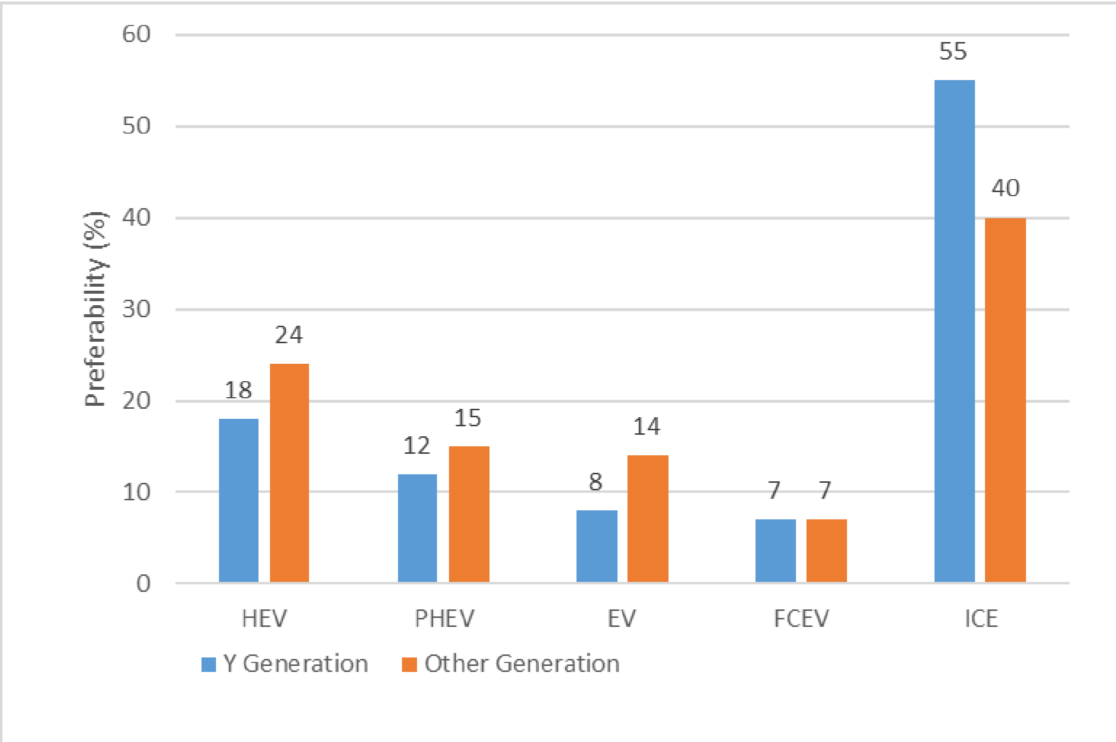

Figure 5. Customers' Preferences of Vehicles in Turkey [11]

2.4. History of Turkish Electricity Market

To begin with, there were no regular electricity management or market in Turkey until 1970s. Therefore, as a requirement, the government established Turkey Electricity Institution (TEK) in 1970. In this period, the private companies could not enter the electricity market; however, the private companies had the chance to enter the market with Law No. 3096 in 1984 [12].

State Electricity Generation and Transmission Corporation (TEAŞ) and Turkish Electric Distribution Corporation (TEDAS) were founded by TEK in 1993. In 2001, TEAŞ was divided into three parts which were Turkey Electricity Trade and Contracting Corporation (TETAS), Turkish Electricity Transmission Corporation (TEIAS) and Electric Generation Company (EUAS). Turkey was divided into regions and the responsibility of distribution of electricity for these regions was taken by different private companies during the years 2004-2013. In Figure 6, the general structure of electricity of Turkey, which changed during the years, is indicated.

In this process, institutions have been commissioned for the regulation and the operation of the electricity market. The one of these institutions is Energy Market Regulatory Authority (EMRA) which was commissioned in 2001. This authority provides the licenses for the companies that will work in the electricity area and establishes the standard formation for the market performance. It ensures that the participants are compliance with these standards and these regulations. The second institution is Energy Exchange Istanbul (EPIAS) which got the authorization for the management of Turkish Electricity Market to plan and operate in 2015.

The decision to determine the electricity price initially belonged to TEIAS until the establishment of EPIAS. The hourly offers given by electricity producers started in 2009 and the day ahead market was taken into the operation in 2011 [13]. EPIAS gets the bids from suppliers on hourly basis at the day ahead market to provide the scheduling and the balancing for the power system.

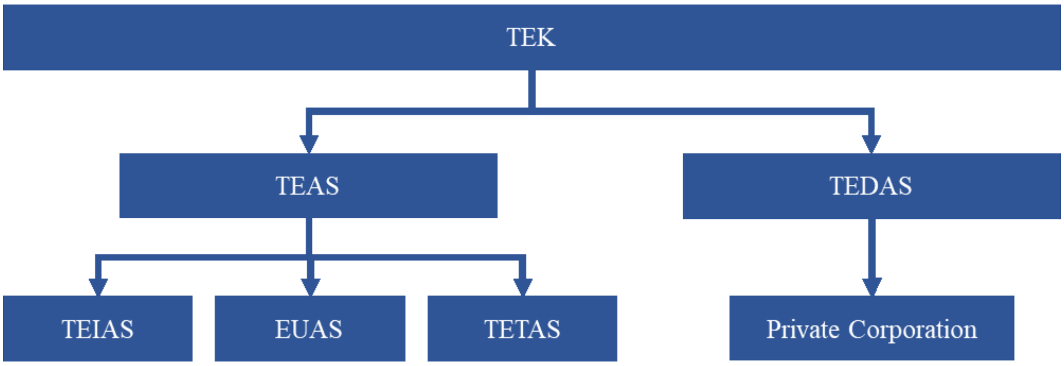

Figure 6. The Evolution Structure of Electricity Sector in Turkey

EPIAS plans the commitment schedule, the sequence and the duration of plants, the hourly and average price of electricity for a day. The other regulation is associated with intraday market, which is real time price fluctuation due to technical reasons and the price deficit in a day. The hourly price is different from the day ahead market and hourly prices vary in accordance with the planning of the consumption or the difference of the production in the day ahead market.

At the moment, the customers can make bilateral agreements when their consumption is higher than 2 MWh in a year in Turkey [14]. A bilateral agreement is a commercial agreement between consumers and suppliers, subject to the provisions of private law, on the purchase and sale of electrical energy. If the customer does not consume higher than 2 MWh in a year, they have to buy the electricity from the retail company. In Turkey, these retail companies offer a single rate tariff and a time-of-use tariff (TOUT) to the consumers.

2.5. Literature Review and Future Trends

Economical and the environmental factors led to the tendency of vehicle firms to new technologies. The developments in battery and electric motor technologies have led to the advancement of EVs in recent years. The effects of these developments for the EV markets in the world and Turkey are examined on Section 2.3. This section shows us that the number of EVs in use is increasing day by day. Therefore, it has become important to examine the effects of EVs on the power network and energy market. The impact of the increase in the use of EVs on the power systems and the effect on the energy market has started to become an interesting subject.

A great number of methods are used in the literature in studies for investigating the impact of EV on the power systems and energy market. The energy need of EVs causes challenges with the integration of EVs in the system. In [15], the effect of increase in demand on low level distribution network with increasing number of EVs in Turkey is studied by applying Monte Carlo based load flow. In addition, the SoC of an EV is obtained from daily traffic data of vehicles in Ankara and represented as using Weibull distribution. In another research, it is focused on optimizing the power system demand using EVs charge cycle with the stochastic initial SoC of EVs and the stochastic of travel pattern of EVs. In this regard, the probability distribution function of the daily travel distance of the vehicles was generated by using the vehicles' data in the UK in 2009. The SoC of EVs was estimated by using this probability distribution function of the daily travel distance of the vehicles [16]. The researcher studied on Nordic Power System to decrease the peak of power load under different scenarios via adjusting the charge scheduling with 100% EV penetration [17]. In the studies above, the EV integration to the distribution network is examined without V2G scenario. Developments in EV technology have led consumers in many countries to focus on the renewable energy resources (such roof top photovoltaics, small wind turbines). Thanks to regulations in the legislation, prosumers can sell their excess energy to the power system. These developments and regulations have made V2G operation preferable. In this thesis, V2G operation is studied to investigate the effect of this operation on the energy market in contradiction to references [15], [16] and [17].

EVs in parking stations are scheduled to maximize savings of EV owners and minimize the operation cost by using mixed integer linear programming [18]. This study shows that the supply demand curve can be made flatter by the charge of EVs. From a different viewpoint, it is considered that EVs will not only be integrated in the power system for charging but also electric vehicles will be used for discharging. It is fact that EVs can be used as an energy storage device due to their batteries, which can allow the power system to utilize these batteries when it is needed. However, stochastic variables of EVs are known by the operator. In [19], the study focused on the V2G concept in order to use EVs in ancillary services, as spinning reserves for the regulation to improve the reliability, and minimize the price of the electricity. The researcher studied on the direct load control on shifting grid to the vehicle (G2V), setting V2G, scheduling the vehicle according to the vehicle times to reduce the cost of energy when saving the battery life. However, the arrival and departure times are not used as stochastic inputs and the operator knows these variables [20]. The other study is the comparison of uncontrolled charging, the charge scheduling and V2G strategies to optimize the power system with different EV penetration [21]. Another research is about the optimization scheduling of charging and discharging pattern of EVs in microgrid day-by with the sequential quadratic programming [22]. The studies show that the supply demand curve can also be made flatter by the discharge of EVs. The EVs can provide the minimization of energy cost while behaving as distributed generator with V2G concept. In addition to this, it is useful for the regulation of power system with scheduling of charging and discharging of EVs. However, in this research, EVs cannot be interrupted when they are charging or discharging and whole EVs departures with 100% SoC from the microgrid.

There are several challenges in the integration of the EV to the power system. One of them is relating to the arrival time and departure time of the EVs that are depended on the behavior of EV owners. Another challenge is that initial SoC value of EVs is unknown when EVs connect to the power system. In this thesis, the inputs which are the arrival time, departure time and the initial SoC value of EVs are used as unknown variables by the algorithm unlike other studies [18], [20] and [22] because these values are stochastic variables and depend on the behavior of EV owners. The initial SoC value of an EV depends on travelled distance. Additionally, arrival and departure times of an EV depend on the travel pattern of it, as well. The probability density function and the Monte Carlo based simulation are used to obtain more realistic and reliable results since each simulation with stochastic inputs gives different results. It is possible to control demands by using information technology with the spread of smart grid and microgrid concept. In this way, a more reliable and economic power system can be obtained with this demand control. Renewable energy sources are installed in the distribution systems with governmental incentives policies. It is clear that batteries of EVs will also help prosumers control the demand and reduce operational electricity cost. In this study, a microgrid operator (such a citizen-led cooperatives, residential, commercial prosumers) controls the EV batteries to investigate the economic feasibility of EV integration with V2G operation.

In this study, it is introduced a realistic microgrid model that supports economic feasibility analysis of the microgrid operator. This microgrid model, supporting economic feasibility analysis with the developed algorithm, becomes the main part of this study. Also, the microgrid types are differentiated to perform the economic feasibility of the operator according to different types of prosumer. The algorithm is developed with different methodologies to understand the effect of controlled G2V operation and the effect of V2G operation on the operator about economic perspective. The Monte Carlo Methodology is adapted in this algorithm to handle with stochastic parameter of the EV owners' behavior. This behavior is developed with probabilistic model to determine plug-in times and plug-in SoC values of EVs. Moreover, different parameters of microgrid model and EV usage model are adapted in different microgrid types to evaluate the response of the economic feasibility of the microgrid operator.

CHAPTER 3

SYSTEM MODELLING AND CASE ANALYSIS

In this study, a model, including residential and commercial loads, is created with a solar power plant. Three different microgrids are formed of this model according to the connection point of EVs. In this way, the economic feasibility of the microgrid operator in the residential, commercial and distributed (both commercial and residential) microgrids are investigated in this study. The economic feasibility of EV owners participating in the microgrid must be ensured when the economic feasibility of microgrid operator is investigating. However, EVs participate in the microgrid as members, thus, the saving of an EV owner are not taken into consideration in this study. The savings of the microgrid operation are earned by the microgrid operator. Moreover, stochastic input variables of the developed algorithm affect the relation between the electric network and EVs. The behavior of EV owners determines the time and the amount of charging-discharging energy. These stochastic inputs also vary from social lives of EV owners. Generally, the travelled distance and time of EVs in the metropolitan areas are longer than in small settlements due to traffic density and human lifestyle. Therefore, the behavior of EV owners should be taken into consideration while creating a model.

3.1. System Modelling

The electricity price, energy consumption and production in a power system change during a day. The daily connection times for EVs are important to providing the amount of energy transfer between the system and EVs. These times also affect the cost transaction between the microgrid operator and the external power system operator because of electricity price changeability in a day. Hence, the electricity cost for EVs change with the arrival and departure times of EVs. The initial SoC, the arrival time, and the departure time of EVs have been taken into account representing these by the probabilistic function in this study. Monte Carlo based simulations are performed to minimize the effect of these stochastic variables on the results.

The assumptions for the base model in this study are given below:

- The battery capacity is selected as 40 kWh for EVs.

EVs have different battery capacities, which vary between 6 kWh and 84 kWh. In this study, PHEVs and the BEVs which are plug-in type vehicles can be integrated into the system to use G2V and V2G operations. The battery of whole EVs, which are integrated with this microgrid, is assumed as 40 kWh by considering the average battery capacities of PHEVs and BEVs.

- The MSoCL of EVs is selected as 50% SoC. The microgrid operator does not allow discharging EVs below MSoCL, and an EV is charged directly to reach up to MSoCL.

An EV owner needs the sufficient energy to travel sufficient distances when an EV depart from the grid location. The needed minimum SoC level (MSoCL) depends on the travel pattern of an EV owner. On a daily travel distance, 80% of people drive generally lower than 100 kilometers [15] and this range nearly equals to 20 kWh energy [23]. Thus, MSoCL in simulations is chosen as the 50% of battery capacity a for 40 kWh battery. Thus, the criterion assumed in the simulation is that an EV which is connected to the system cannot be discharged to drop down below 50% SoC. The connected EV with under 50% SoC will be charged directly until 50% SoC independently from the decision of the algorithm.

- The charging power is selected as 6.6 kW until 80% SoC and the charging power linearly decreases when an EV has more than 80% SoC. The constant discharging power is selected as 6.6 kW.

An EV owner generally uses Level-1 and Level-2 chargers at residential and commercial places. These chargers can be classified in Mode-1 and Mode-2, which are given in Table 3 defined in IEC-61851-1 [4]. In this standard, the charging power profile is defined as the constant power until 80% of SoC, and after 80% of SoC, the charging power decreases linearly [16], [24]. The charging power, according to time, is given in Figure 7 for a 40 kWh battery capacity. The battery discharges with constant power, which is equal to 6.6 kW. The charging power (P_{ch}) equation is given in Equation 5, and the discharging power (P_{disc}) is given in Equation 6 where t is the charging or discharging time, t_0 is the charging time after 80% SoC and n is the number of charging station.

$$P_{ch,n}(t) = \begin{cases} 6.6 * \Delta t_n \quad kW, & SoC < 80 \\ 6.6 * \Delta t_n - 2.727 * t_{0,n} * \Delta t - 1.364 * \Delta t_n^2 \; kW, & SoC \geq 80 \end{cases} \quad \textbf{(5)}$$

$$\text{when } 6.6 * t_{0,n} - 1.364 * t_{0,n}^2 = 40 * \frac{SoC_n - 80}{100}$$

$$P_{disc,n}(t) = \begin{cases} 0 \quad , & SoC < 50 \\ 6.6 * \Delta t_n \; kW, & SoC \geq 50 \end{cases} \quad \textbf{(6)}$$

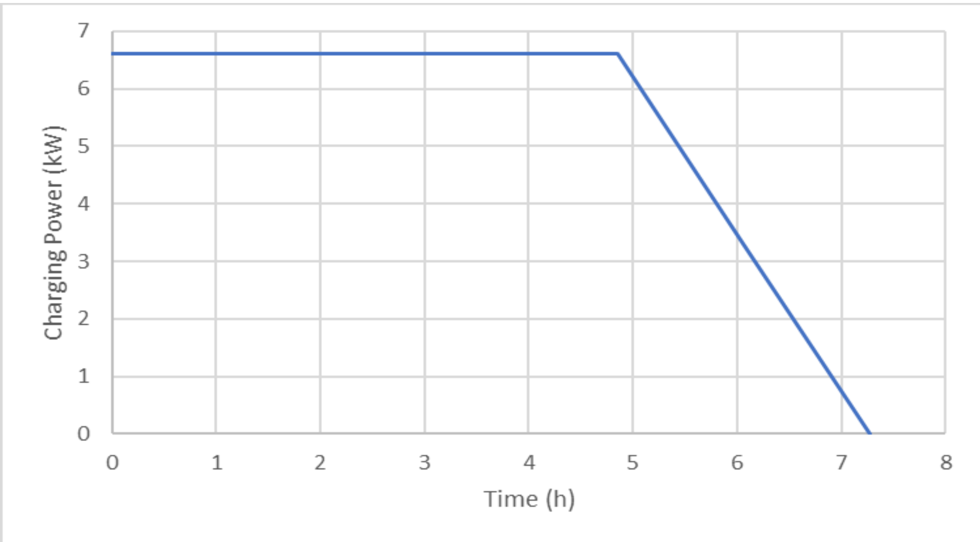

Figure 7. The Generic Charging Profile [16]

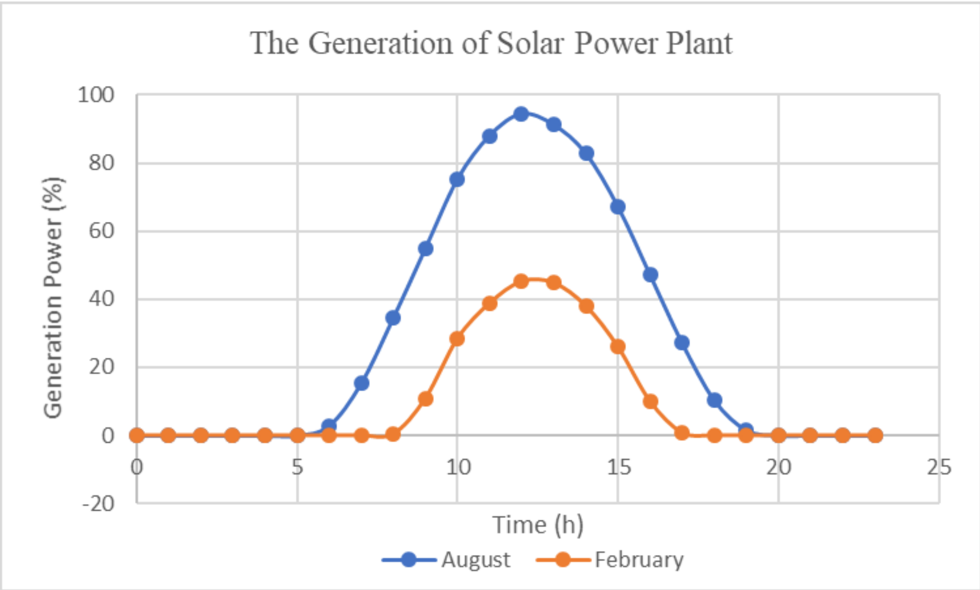

Figure 8 . The Electricity Generation of the Solar Power Plant

- The solar power plant connected generates electricity with a 250 kW maximum capacity.

In this study, a solar power plant with 250 kW capacity is assumed to be connected to the grid being considered. The daily energy generation curves of the solar power plant are given in Figure 8. These curves represent the daily average energy generation for February and August as seen. The energy generation in August is nearly as twice as the energy generation in February.

- The microgrid operator estimates daily load and cost curves from the previous days.

EPIAS publishes the electricity data of Turkey such as the amount of electricity generation and consumption, the cost of day ahead market and intraday market [25]. These data are provided on an hourly basis from EPIAS. The daily scheduling with bids of suppliers in the day-ahead market sometimes does not occur as planned due to failures. Besides, this data is not sometimes obtained from the field due to failure of the data collection system. Hence, some gaps occur in this data set due to these failures.

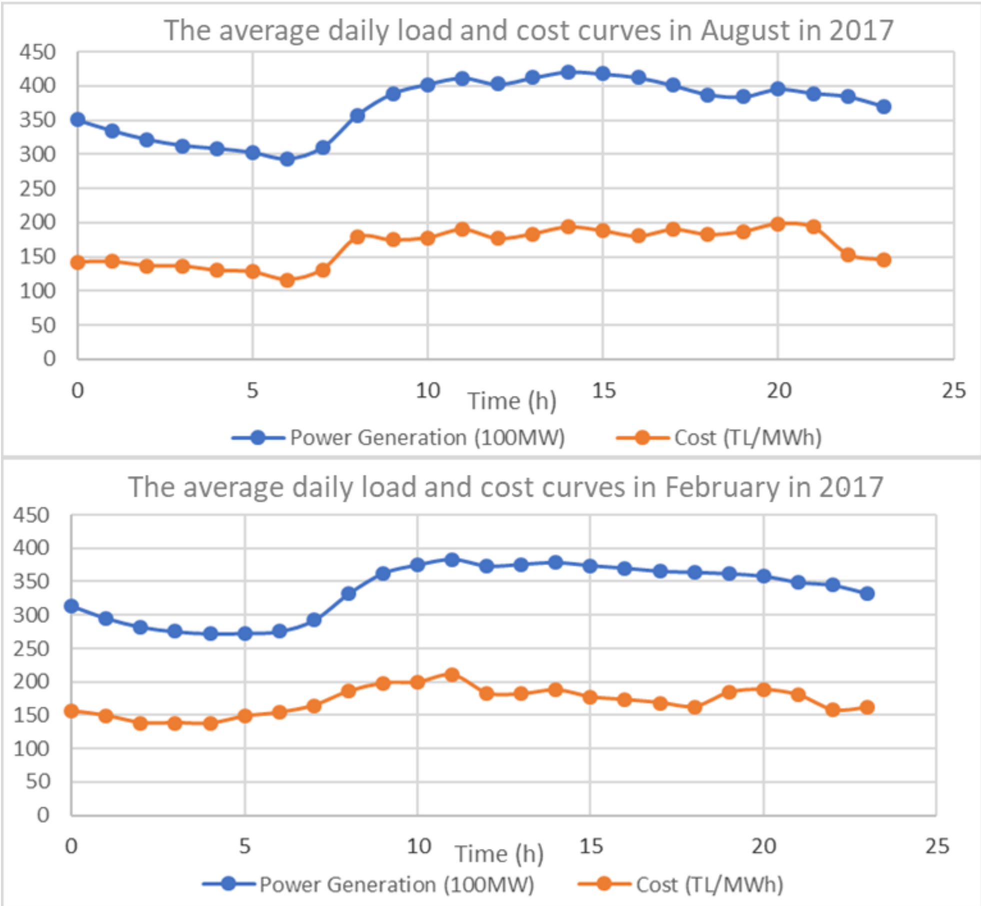

Figure 9. The Average Daily Load and Price Curves of EPIAS

The daily average data for months February and August given in Figure 9 are obtained from EPIAS by removing these gaps in data set to obtain more accurate data set.

- The daily average load and cost curves of electricity in Turkey are proportionated for this model, and the peak load of the microgrid is assumed to be 1 MW.

The data of electricity generation and electricity cost of EPIAS is proportioned with respect to 1 MW maximum load power for this model. In Figure 10, the daily average load and cost curves in the months of August and February are given. The microgrid operator uses this data set to decide EV charging and discharging operations. The electricity cost of a customer includes the clearing price of the intraday market, the bid of distribution belonging to the distribution companies and taxes. Thus, the data of

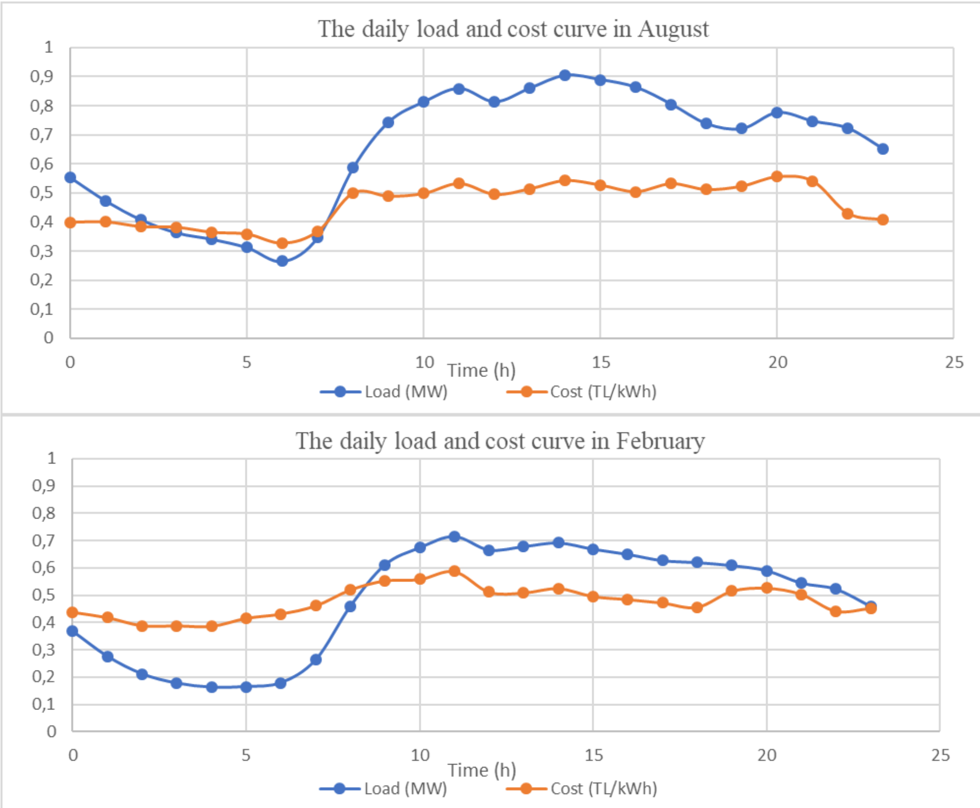

Figure 10. The Daily Load and Price Curves for Models

cost in Figure 9 is updating with these bids and taxes to obtain the last cost for customers in Figure 10.

- The efficiency is selected as 85% for energy transfer between microgrids and EVs in one direction.

The efficiency of charger stations is necessary to calculate the energy transfer between an EV and microgrids. This efficiency decreases with energy losses because of the cables, the converter and the inverter in EVs and chargers. This efficiency changes due to the type of chargers. In the reference [26], the Level-1 chargers have 83.8% efficiency, the Level-2 chargers have 89.4% efficiency. In this study, the efficiencies of charging and discharging are taken as 85%. Moreover, the efficiency of operation equals to 72.25% when EVs are charging with discharging energy which is obtained from EVs.

- The cost transaction ratio from microgrids to the external power system is selected as 0.9. (i.e., the utility purchases power from the microgrid based on 90% of the selling price)

There will be bidirectional energy transfer between EVs and microgrids. The microgrid operator buys the electricity from the external power system with the hourly electricity cost of this energy transfer. However, the external power system buys the electricity from the microgrid with the cost transaction ratio times of the hourly electricity cost.

- The number of charger stations is chosen as 50.

3.2. Definition of Cases and Scenarios

3.2.1. Case Determination

The travel pattern of EVs is very essential data to find the probability of arrival time and departure time of EVs for the simulation of this model. In [15], the traffic density data of Ankara is obtained and this data shows that the travel of vehicles from commercial to residential places is generally between 17:00 and 20:00 and the travel from residential to commercial places is between 07:00 and 10:00. Thus, the installation place of EV charging stations is a crucial factor to the trade of power because EVs are connected to the microgrid at different times in commercial and residential places. The electricity cost also is changing with time in a day; thus, the connection point of EVs change the cost transaction between the external power system operator and the microgrid operator. Moreover, people's average travel distance is defined as 15 kilometers between the residential and the commercial place, and it is valid for all microgrids [15]. Thus, the probability density function of the initial SoC of EVs is calculated as Equation 7 when the weighted average value (μ) equals to 92.5 and the deviation from the mean (σ) equals to 10.

$$F(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(x-\mu)^2}{2\sigma^2}} \quad \textbf{(7)}$$

Case I: Commercial Microgrid

Case I is that charging stations are integrated to a microgrid which includes workplaces (i.e., factory, commercial facilities, offices etc.). And thus, EVs considered are owned by drivers who use the charging station during hour of work. This case will be referred to as a commercial microgrid from now on this thesis. Commercial places behave like prosumers; however, residential places behave only consumers in the microgrid for this case. This microgrid is represented in Figure 13 when the connection point of the charging station is 2. As in real life, EVs are simulated as leaving the commercials in the evening and returning in the morning. This behavior of EV owners is modelled stochastically based on normal distribution. Thus, the departure time of mean and standard deviation equal to 19:10 and 1.25 and the arrival time of mean and standard deviation equal to 08:30 and 1.25 for the commercial microgrid. Curves of probability density function of these times are given in Figure 11.

Case II: Residential Microgrid

Case II is associated with a microgrid which includes residential places (as in a housing estate). Hence, EV users connect their EVs in the charging stations at residential places. Although commercial places behave only consumers, residential places behave like prosumers in the microgrid for this case. EVs are simulated as returning in the evening and leaving the residentials in the morning. This behavior of EV owners is modelled stochastically based on normal distribution. With respect to travel pattern of people, the mean and the standard deviation are chosen as 19:30 and 1.25 in this microgrid for arriving at the residential place. In addition, the mean and the standard deviation equal to 08:10 and 1.25 to calculate the probability distribution function of departure times from residential places. In Figure 12, the curves of probability density function for this microgrid are given to show the arrival and departure times of EVs.

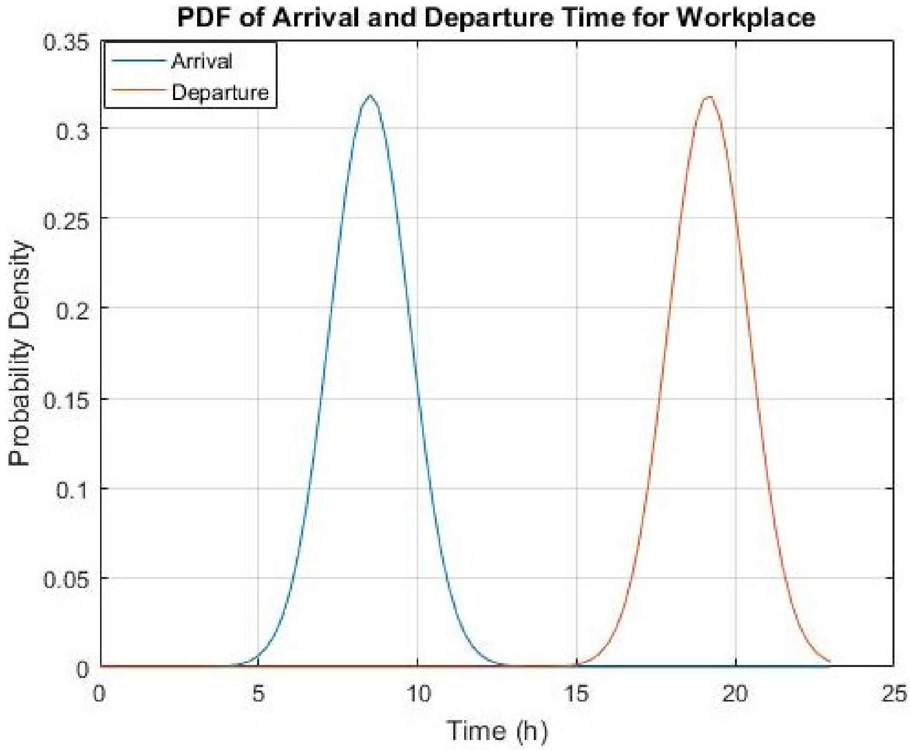

Figure 11. The PDF of Arrival Time and Departure Time for Case I

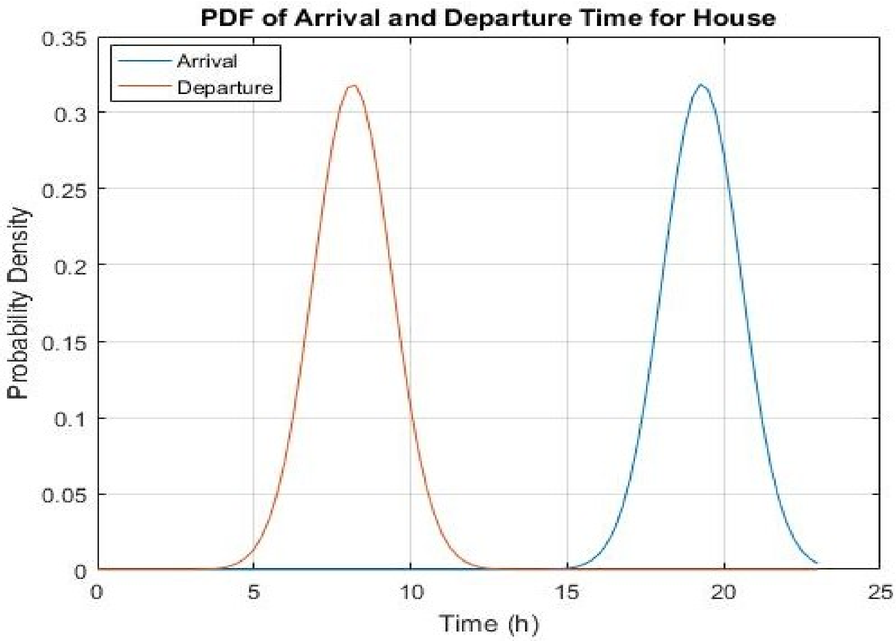

Figure 12. The PDF of Arrival Time and Departure Time for Case II

Case III: Distributed Microgrid

Case III is associated with a microgrid which involves both workplace and residential customers, and will be denoted as "distributed microgrid". In Figure 13, this distributed microgrid can be a hybrid microgrid with residences and workplaces physically in the same place as A or a distributed microgrid with physically apart as B. In this study, this case will be referred to as a distributed microgrid from now. EVs are assumed to be connected to the distributed microgrid, however, EVs are not connected to this microgrid at their travel times. Thus, the times of plug-in or plug-out of EVs are only related to the travel pattern, which is given in Case I and II. The plug-out time of mean and standard time equal to 08:20 and 1.25 for the travel from residential to commercial places in the morning. The plug-out time of mean and standard time equal to 19:20 and 1.25 for the travel from residential to commercial places in the evening.

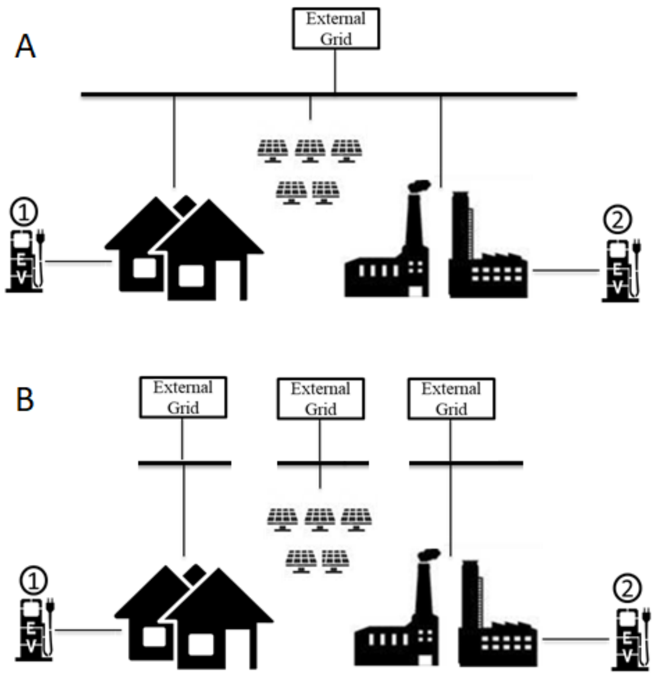

Figure 13. The Illustration of the Distributed Microgrid

3.2.2. Scenario Determination

The different scenarios applied to the model to compare to the results to investigate the effect of EVs on the savings of the microgrid operator. In this way, it can be determined the effects of charging, controlled charging, and controlled discharging and charging of the EVs.

i. Without EVs Scenario (WEVS)

The microgrid is simulated without EV integration in this scenario. The microgrid includes only the load and the solar power plant and this microgrid is simulated to determine the total cost of the microgrid without EVs.

ii. The Uncontrolled Charging Scenario (UCCS)

In this scenario, EVs are connected to the microgrid. An EV is charged directly until its SoC reaches 100%. Therefore, it is called as the uncontrolled charging. In this scenario, the integration of EVs is simulated to understand the effect of independent EVs charging without the control of the microgrid operator.

iii. The Controlled Charging Scenario (CCS)

The microgrid operator gives charging decision to maximize own savings with control the batteries of EVs. The charging decision of an EV can be given by the microgrid operator when this EV is connected to the charge station. The daily cost of the electricity is known by the microgrid operator. In this way, the microgrid operator can schedule the time of charging according to this daily curve. This schedule is updated every hour due to the arrival or departure of EV and electricity cost changing in an hour. The result of this scenario examines the effect of the charging decision on the saving of the microgrid operator.

iv. The Controlled Charging and Discharging Scenario (CCDS)

In this scenario, the microgrid operator, unlike other scenarios, can discharge the batteries of EVs. In this way, prosumers are included in the microgrid to investigate the effect of V2G on the saving of the microgrid operator. The charging and discharging decision of an EV is given by the microgrid operator with respect to comparing the hourly cost of energy with the daily cost of energy. The microgrid operator schedules the time of charging and discharging at each hour.

v. The Optimum Controlled Charging and Discharging Scenario (OCCDS)

This scenario is nearly the same with CCDS, however, the microgrid operator uses the SoC of EV battery as a parameter to give the charging and discharging decisions. This scenario shows the effect of the different decision mechanism on the saving of the microgrid operator. In addition, these scenarios are applied to all microgrid cases for comparing to the results to find the maximum saving for the microgrid operator.

3.2.3. Determination of Effects of Variables

Effect of MSoCL

MSoCL is a limit for the microgrid operator, and it provides the needed energy to travel for EV owners when they leave from the microgrid. MSoCL is selected 50% SoC for base cases to satisfy averagely 100 kilometers range for EVs. This range is long for most people as stated in Section 3.1. Thus, the range of EVs changes as 80 and 60 kilometers to determine the effect of MSoCL on the saving of the microgrid operator. MSoCL changes to 40% and 30% SoC with these ranges. The microgrid is simulated by using these MSoCLs for comparing to results at different MSoCL.

Effect of the Battery Capacity

EVs have different battery capacities between 6 kWh and 84 kWh. The average battery capacity of EVs in Turkey is used for base cases, and it is 40 kWh. However, this average battery capacity can change according to people's purchase tendency. Thus, the alternative sizes of battery capacity are selected as 30 kWh and 50 kWh. The different battery capacities are simulated to determine the effect of battery capacity on the savings on the microgrid operator.

Effect of the Number of Charging Stations

The number of EV and the charging stations are selected as 50 for base microgrids. The number of charging stations is changeable according to the people's purchase tendency. The number of people who prefer EVs instead of other vehicles has been increasing. Thus, the number of charging stations will increase to 100 to determine the effect of the number of charging stations on the savings of the microgrid operator. The number of EVs and the charging stations, which are integrated into the microgrid, are selected as 100.

Effect of Tariff Mechanism

The cost of electricity has a significant effect on the operational cost of the microgrid operator. The cost of electricity for consumers includes the bid of suppliers, the bid of the distribution companies, and the taxes. The retail companies generally use the different tariff, which is time-of-use tariff and single rate tariff for customers in Turkey [27]. A customer can select their tariff to decrease their electricity cost according to their electricity usage. The time-of-use tariff includes three different time slides in a day with different prices, which are peak, shoulder, and off-peak times. The single rate tariff cannot be used with V2G and G2V because the microgrid operator cannot obtain the same price at the EV charging and the EV discharging. Thus, the time-of-use tariff and the hourly rate tariff is simulated to determine the effect of the tariff on the saving of the microgrid operator. In Figure 14, the price curves of time-of-use tariff and hourly rate tariff in August and February are given together.

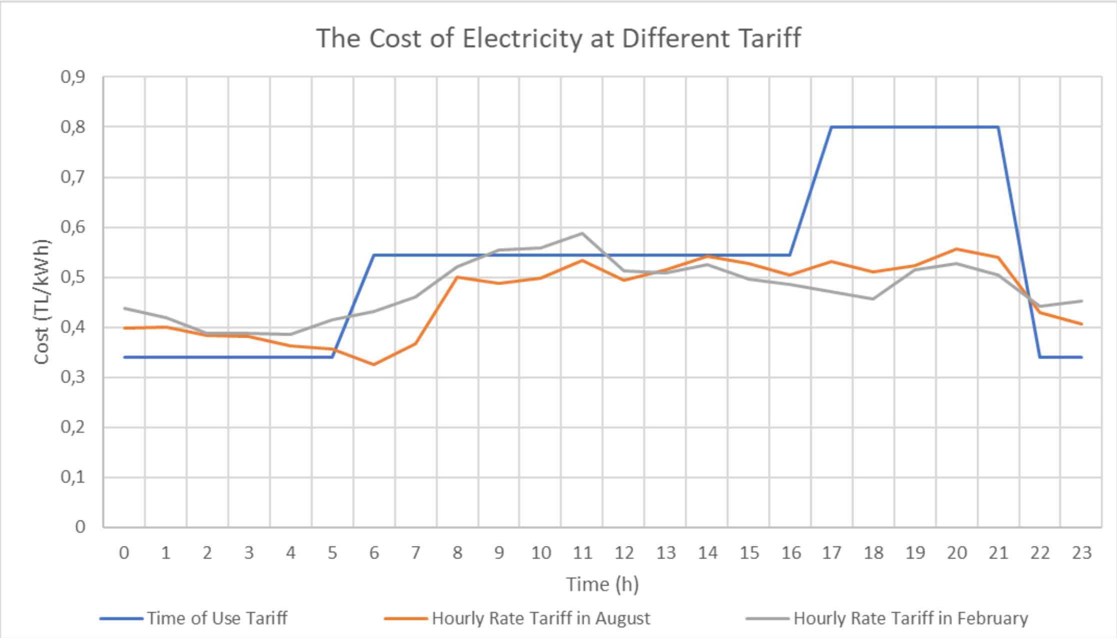

Figure 14. The Price Curves of Different Types Tariffs

Effect of Seasons

The electricity usage is changing with the needs of consumers. Thus, the energy consumption and the cost of electricity are different in different months. The electricity usage and the price of August are used for base cases. The data of February is used in the simulation to determine the effect of the months. In Figure 14, the price curve of hourly rate tariff in February is given with the price curves of the time-of-use tariff and the hourly rate tariff in August.

Effect of Travel Pattern

The travel pattern of vehicles is vital to determine the stochastic variables, which are the plug-in and plug-out times of EVs. The change of arrival time and departure time changes the connection time of EVs in the microgrid. These variables can affect the saving of the microgrid operator.

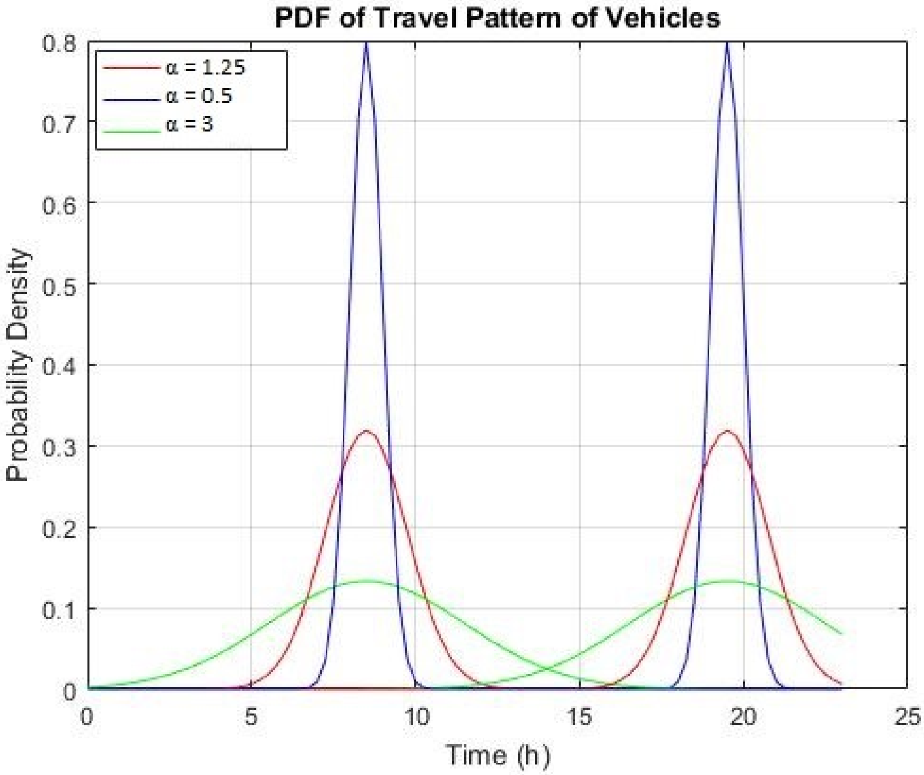

Figure 15. The PDF of Travel Pattern of Vehicles with the Standard Deviation

The probability density function gives different results with a different the standard deviation and the formula of this function is given at Equation 7. The standard deviation is selected as 1.25 for the base cases and it is changed from 1.25 to 0.5 and 3. The model with these values is simulated to investigate the travel pattern on the microgrid operator. In Figure 15, the probability density functions of plug-in and plug-out times are given for a different standard deviation.

3.3. Methodology of the Algorithm

The algorithm is written in MATLAB to decide the time of charging and discharging of EVs, which are connected to the microgrid. The main structure of the algorithm is given in Figure 16 as a flow chart. This main structure can be classified at four parts with respect to loops which are the initialization part, the Monte Carlo loop, the day loop and the decision loop. The initialization part gets data from input Excel file in two parts, which are the model inputs and EV inputs. The model inputs in Excel file include the hourly energy generation and consumption of the microgrid, the hourly price of the electricity between the microgrid and the external power system for the next day. The algorithm uses these data to calculate some variables such as the average price of a day, the total price of loads and the solar power plant.

The EV inputs in Excel file include several variables to research their effects on the saving of the microgrid operator. These variables are the battery capacity, the number of charging stations, the standard deviation of the arrival time and departure time of EVs, the minimum travel range.

The second loop of the flow chart, which is represented with gray color is the Monte Carlo loop. This loop is repeated fifty times to get more accurate results with the minimization of the effects of the stochastic variables by taking the averages of these trials. After the day loop, the daily output of Excel file is exported after daily calculations in Monte Carlo loop. This Excel file includes the daily energy and cost transactions between EVs and the microgrid and also between the microgrid and the external power system. The data between EVs and the microgrid consist of the total energy and cost transactions of charging and discharging EVs, the average price of charging and discharge EVs. In addition, the total energy and cost transactions between the microgrid and the external power system are given in this output of Excel file. The average data of the whole fifty trial is obtained from this Excel file to analyze the results more accurately.

The third loop, which is shown with the brown color in Figure 16 represents the day loop. The algorithm needs the information about EVs such as the connection information and the initial SoC of the EVs which are connected at this hour. The algorithm must obtain these stochastic variables at every loop based on the probability density function of the travel pattern of the EVs. Thus, the algorithm must generate input of EV Excel file to obtain these variables. The flow chart of this Excel file generation part is given in Figure 17. The probability density function of the arrival

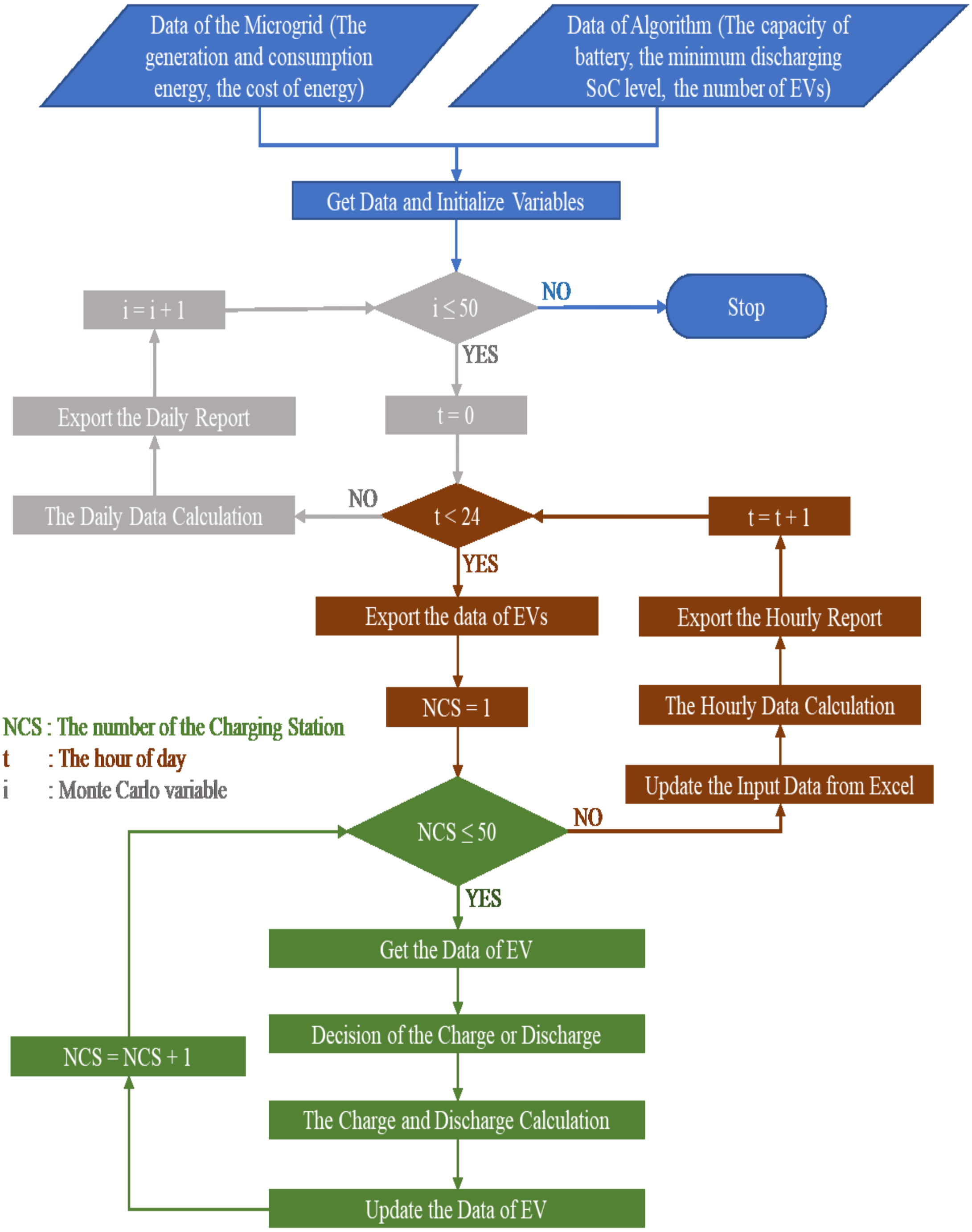

Figure 16. The Flow Chart of the Developed Algorithm

and departure times of EVs are calculated at each hour to use at Equation 8 or 9 with respect to connection status of EV. The connection status can be updated according to these equations at each hour until the number of charging station equals to fifty. If an EV is connected to the microgrid, the initial SoC of the EV can be calculated with the probability density function as described in Equation 10 when F is the probability density function which is given Equation 7.

The hourly data of the microgrid is calculated after the decision loop in the day loop. This hourly data includes the energy and cost transactions between each EV and the microgrid for charging and discharging at this hour. This data also includes the energy and cost transactions between the microgrid and the external power system at this hour. Also, the total energy and cost transactions of each EV and the SoC of each EV are updated at this hour. These data are exported to Excel file to analyze and compare to these results for each hour.

$$Random\ Variable < 100 * (1 - F_{departure}(NCS)) \quad \textbf{(8)}$$

$$Random\ Variable < 100 * (1 - F_{arrival}(NCS)) \quad \textbf{(9)}$$

$$Initial\ SoC = F_{SOC}(NCS) \quad \textbf{(10)}$$

The green color in Figure 16 represents the decision loop. The data of EVs are obtained from the input of EV Excel file. The decision of the charging or discharging for an EV is given according to the price of electricity at this hour and the SoC of EVs. The charging and discharging decisions change with the scenarios, which are UCCS, CCS, CCDS and OCCDS. The formulations of the decision according to these scenarios are given in Equations 12, 13, 14, 15 and 16. The hourly price (MP), the SoC of EVs, the average price of a day (ADP), and the cost transaction ratio (MTR) are used to give the decision by the algorithm. The decision change (DC) is a different decision, which is applied to an EV. This value cannot be bigger than 3 to protect to the battery life in all scenarios

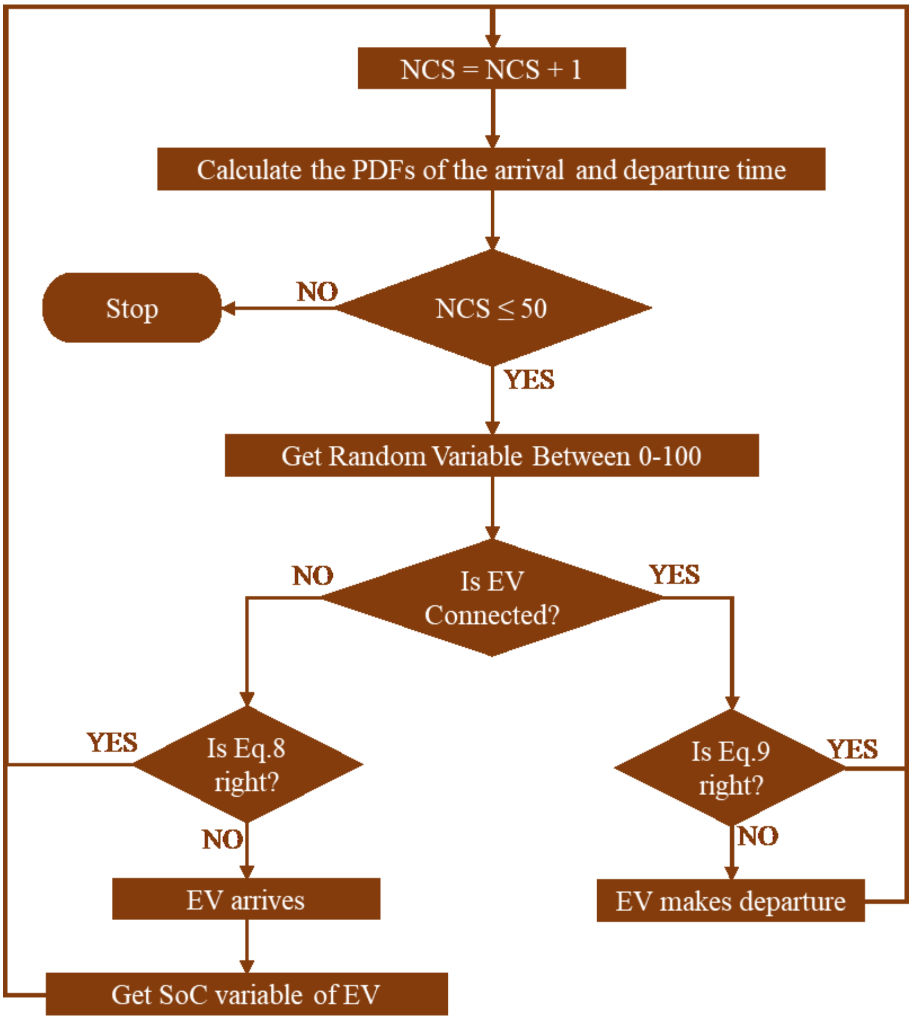

Figure 17. The Flow Chart of Generation of Probabilistic Variables About EVs

without giving harm to the chemistry structure of the battery. It means that EV cannot charge or discharge twice in one day. The cost of the charging energy is the same with the hourly price and the selling price calculation of the discharging energy (SPD) is given in Equation 11 when EV owners are selling the energy to the microgrid.

$$SPD_{NCS}(t) \; = MP(t) * MTR \qquad \textbf{(11)}$$

UCCS $$Decision_{NCS} = \begin{cases} 1, & SoC_{NCS} < 100 \\ 0, & SoC_{NCS} = 100 \end{cases} \quad \textbf{(12)}$$

CCS $$Decision_{NCS} = \begin{cases} 1, & SoC_{NCS} < MSoCL \ or \ p < ADP * MTR \\ 0, & otherwise \end{cases} \quad \textbf{(13)}$$

CCDS $$Decision_{NCS} = \begin{cases} 2, & SoC_{NCS} \geq MSoCL \ and \ p > \frac{ADP}{MTR} \ and \ DC < 3 \\ 1, & (SoC_{NCS} < MSoCL \ or \ p < ADP * MTR) \ and \ DC < 3 \\ 0, & otherwise \end{cases} \quad \textbf{(14)}$$

In addition to these scenarios, OCCDS is used to get more reliable solution for all-day calculation. In this scenario, all hours are sorting according to the hourly price in a day. The decision of charging and discharging EV is given according to the SoC of an EV and the price curve of a day. The low-priced times are selected chargeable times (CT) and the most expensive times are selected dischargeable times (DT) separately for each EV according to their SOC. The calculation of the chargeable time cycles (CTC) and dischargeable time cycles (DTC) are given in Equation 15 and 16. The low-priced times until CTC is called CTs and the more expensive times until DTC is called DTs. The flow chart of this process is given in Figure 18.

The calculations of charging and discharging power are calculated with respect to Equations 5 and 6 at Section 3.1. The SoC and the energy of EV are updated with calculated charging power or discharging power. The total and hourly cost transactions between an EV and the microgrid are also calculated in this cycle.

$$DTC_{NCS} = int(1 + \frac{SoC_{NCS} - MSoCL}{100} * \frac{Battery \ Capacity}{6.6}) \quad \textbf{(15)}$$

$$CTC_{NCS} = int(1 + \frac{100 - SoC_{NCS}}{100} * \frac{Battery \ Capacity}{6.6}) \quad \textbf{(16)}$$

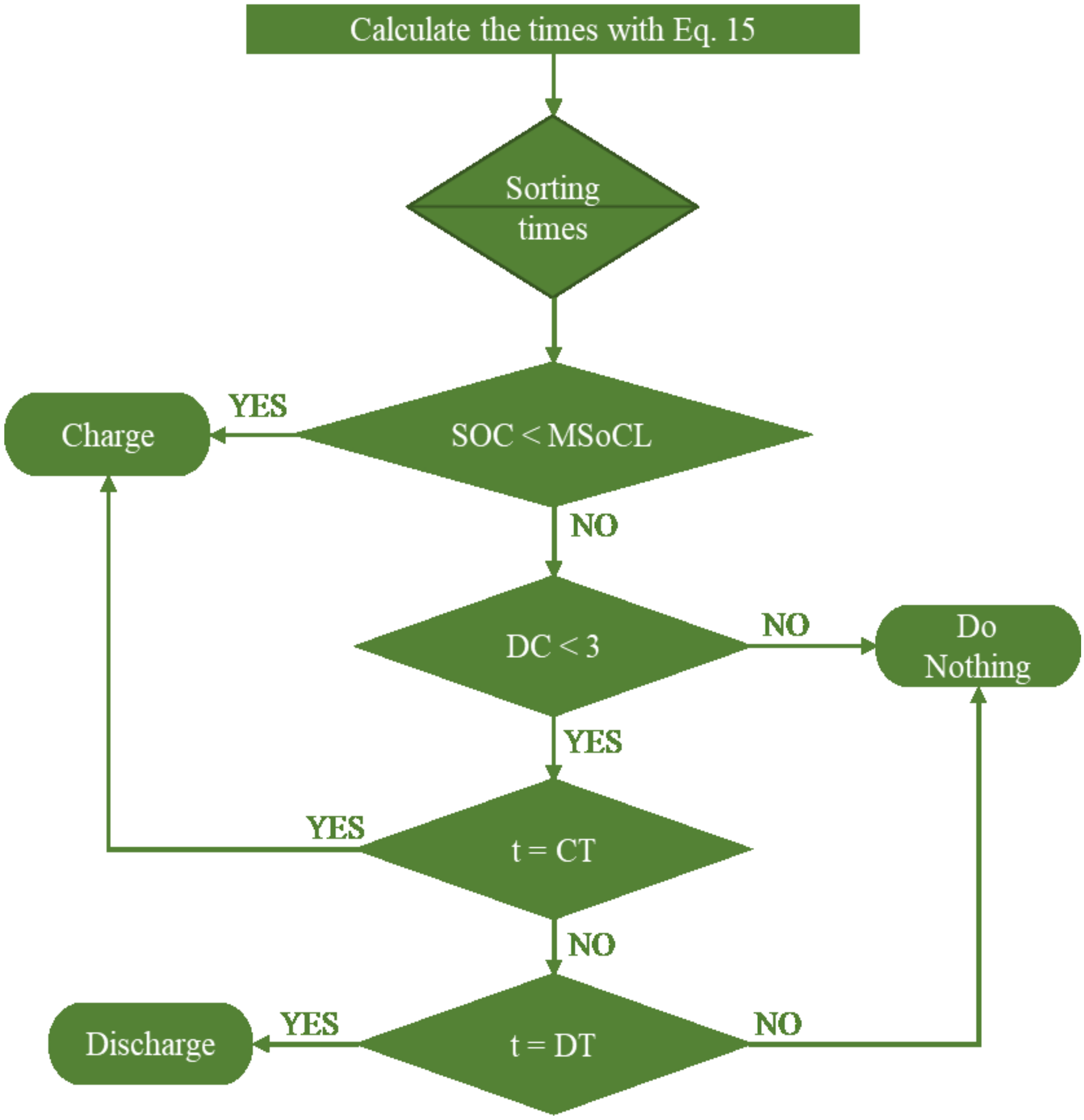

Figure 18. The Flow Chart of the Decision at OCCDS

The calculation of hourly charging and discharging powers of EVs is given in Equations 17 and 18 where MNCS is the total number of charging station in the microgrid. The calculations of the power transfer between the microgrid and EVs (P_{tr}) and the power consumption of the microgrid (P_{mg}) are given in Equations 19 and 20. The hourly energy calculation of all participations is given in Equation 21.

$$P_{ch}(t) = \sum_{NCS=1}^{MNCS} P_{ch}(NCS, t) \quad \textbf{(17)}$$

$$P_{disc}(t) = \sum_{NCS=1}^{MNCS} P_{disc}(NCS, t) \quad \textbf{(18)}$$

$$P_{tr}(t) = P_{ch}(t) - P_{disc}(t) \quad \textbf{(19)}$$

$$P_{mg}(t) = P_{load}(t) - P_{solar}(t) + \frac{P_{ch}(t)}{\eta} - P_{disc}(t) * \eta \quad \textbf{(20)}$$

$$E(t) = P(t) * t \quad \textbf{(21)}$$

In addition, hourly price equations of the microgrid operator (J_{op}), EV charging (J_{ch}) and EV discharging (J_{disc}) are given in Equations 22, 23 and 24. The average price function of participations is calculated with the same formulation and it is given in Equation 25.

$$J_{ch}(t) = E_{ch}(t) * MP(t) \quad \textbf{(22)}$$

$$J_{disc}(t) = E_{disc}(t) * SDP(t) \quad \textbf{(23)}$$

$$J_{op}(t) = E_{mg}(t) * MP(t) \quad \textbf{(24)}$$

$$C(t) = \frac{J(t)}{E(t)} \quad \textbf{(25)}$$

CHAPTER 4

SIMULATIONS AND RESULTS

The algorithm presented in the previous chapter is implemented in MATLAB to obtain the simulation results. Different microgrid types are simulated to understand the effect of types of prosumers in the microgrid on the saving of the microgrid operator. These cases investigated are: commercial microgrid, residential microgrid and distributed microgrid. In addition, different scenarios which are defined in section 3.2.2 as WEVS, UCCS, CCS, CCDS and OCCDS are simulated for all microgrid types to determine the effect of G2V and V2G operations on the saving of the microgrid operator. Moreover, the different variables which are defined in Chapter 3 are changed for Case I and Case II to analyze the effect of these variables on saving of the microgrid operator. In simulations, Monte Carlo approach has been utilized to get accurate results with eliminating the effect of stochastic variables. Simulation results are obtained for different microgrids, scenarios and variables with fifty Monte Carlo Trials. The algorithm generates output Excel files for each scenario to analyze and compare to the results of whole trials. This huge data is simplified with Excel file tool to get the average values of Monte Carlo Trials.

4.1. Simulation Results

Case I, Case II and Case III are simulated for three different tariff mechanism which are August and February hourly rate tariff, time-of-use tariff to understand the impact of the electricity cost on the saving of the microgrid operator. Different input variables and scenarios are applied on these tariff mechanisms. In this way, different microgrids which have different nature of prosumers, different EV connections concepts and different parameters concept are analyzed and compared to with simulation results.

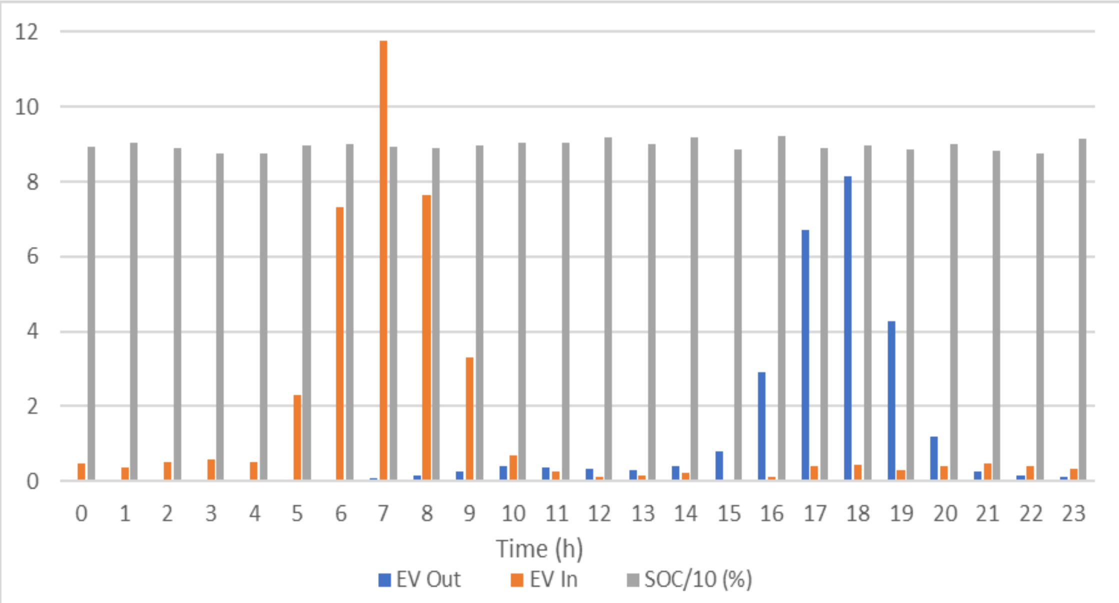

Figure 19. The Average Input Values for Case I

4.1.1. Simulation Results of Case I

The Case I is that the charging stations are integrated to commercial places in the microgrid. The probability density functions of arrival time and departure time of EVs for this type of microgrid are given in Section 3.2. The initial SOCs, the departure times and arrival times of EV are generated by the algorithm to obtain the input Excel file. The average number of EVs and the average SoC values of EV in fifty trials are given in Figure 19. The most probable departure times of EVs are between 17:00 and 19:00 in this microgrid and also most probable arrival times of EVs are between 06:00 and 8:00.

4.1.1.1. Results with Hourly Rate Tariff

The results for 24 hours of Case I for each scenario given in Figure 20. The vertical axis shows that energy transfer from microgrid to EVs at different scenarios. EVs are charged when they plug in the commercial microgrid at UCCS. They are mostly charged between 06:00 and 10:00 under this scenario. At CCS, EVs are charged with

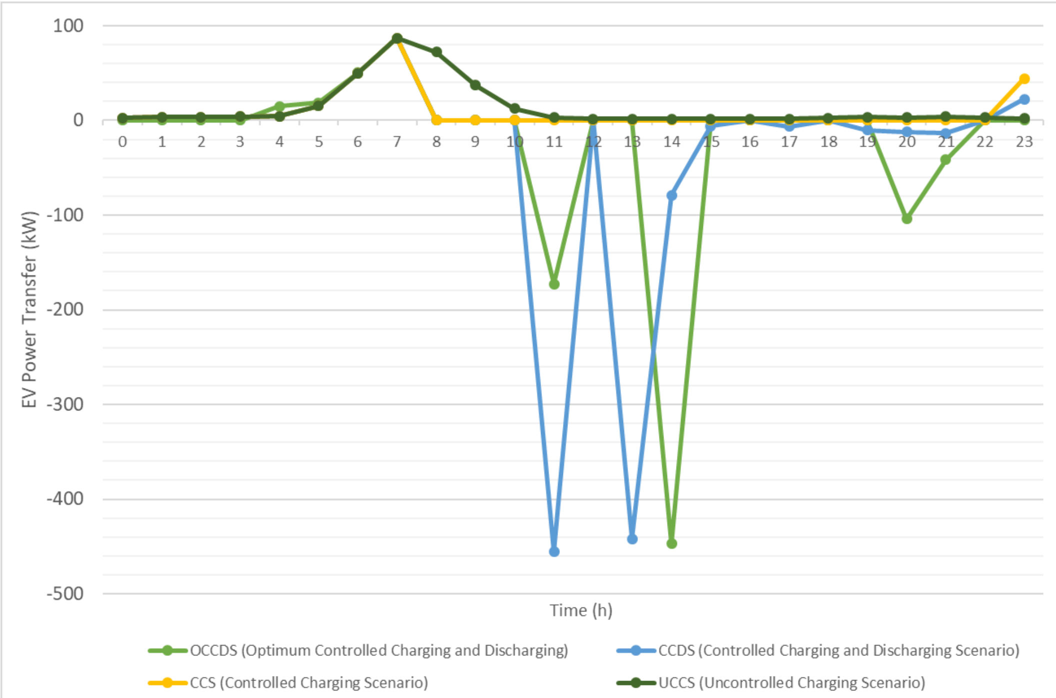

Figure 20. The Power Transfer Between the Microgrid and EVs for Case I

plugging as UCCS, however, EV charging continues until 08:00 with controlled charging. The microgrid operator gives the same decision for charging EVs at CCS, CCDS and OCCDS. The amount of charging energy of these scenarios is lower than UCCS with the increase in hourly cost of the electricity after 08:00. Thus, the longtime charging decision is not good option for this microgrid due to high operation cost. At CCDS, EVs are mostly discharging at 11:00 and 13:00 due to the suitable electricity cost in connection times of EVs. These times slips from 13:00 to 14:00 because of the sorting time of low-priced electricity at OCCDS to maximize the saving of the microgrid operator.

According to Figure 21, the time of most energy consumptions is between 11:00 and 15:00. The total energy consumption in these hours decreases with the energy generation of the solar plant. Hence, the peak of energy consumption of the microgrid occurs at 20:00. This peak cannot be also changed due to not sufficient connected EVs for sufficient discharging at OCCDS. The lowest energy consumptions for this type

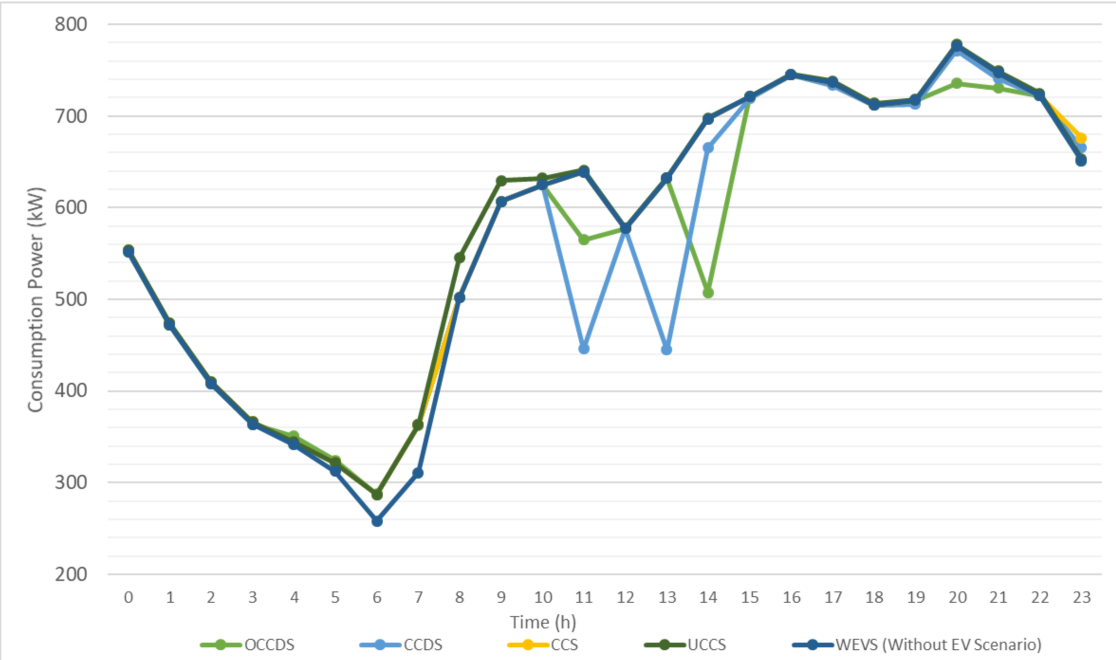

Figure 21. The Power Curve of the Microgrid for Case I

of microgrid are seen first hours of the connection times. At all scenarios, the lowest energy consumptions increase with EV charging due to low electricity cost at these hours. In the result of this, the curve of the external power system becomes more stable at CCDS and OCCDS.

Results for all scenarios for Case I are summarized in Table 6. The parameters are given in details at Section 3.3. The main parameter for the comparison between different scenarios is the net daily saving of the operator which is developed as J_{pop} with respect to uncontrolled charging scenarios. The total energy consumption of this microgrid increases with EV integration at UCCS and CCS due to only G2V operation. However, the energy consumption of this microgrid decreases because of V2G operation at CCDS and OCCDS. The average charging cost at OCCDS is nearly 15% economic than UCCS and the average discharging price is highest at OCCDS. This scenario is the optimal solution for EV owners but the operator gets a higher saving at CCDS when looking at the saving of the operator. The high amount of discharging energy provides high saving for the operator at CCDS in comparison with OCCDS.

Table 6. Overview of the Microgrid for Case I

	WEVS	UCCS	CCS	CCDS	OCCDS
E_{ch} (kWh)	0	164.1	107.8	98.4	86.8
J_{ch} (TL)	0	81.67	46.47	41.99	36.18
C_{ch} (TL/kWh)	0	0.4978	0.4311	0.4266	0.4167
E_{disc} (kWh)	0	0	0	508.3	377.2
J_{disc} (TL)	0	0	0	227.04	173.71
C_{disc} (TL/kWh)	0	0	0	0.4467	0.4605
E_{mg} (kWh)	13828	14020	13955	13512	13610
J_{op} (TL)	6622	6704	6669	6437	6485
C_{mg} (TL/kWh)	0.4789	0.4781	0.4778	0.4764	0.4764
J_{pop} (TL)	0	Reference	35	267	219
J_{pop} (%)	0	Reference	0.52	3.98	3.27

V2G operation provides 137 TL saving for the microgrid operator in a day at OCCDS when the difference between J_{ch} and J_{disc} are calculated. The cost of EV charging is nearly 82 TL in a day at UCCS. The total saving of the microgrid operator is nearly 6570 TL in a month at OCCDS.

Effect of Increase in Battery Capacity

The batteries of EVs are selected as 40 kWh for the base cases. The size of battery capacity is increased from 40 kWh to 50 kWh to investigate the effect of the battery capacity on the saving of the microgrid operator. Other variables in the input Excel file are kept same with base cases without the battery capacity. In order to observe the impact of the battery capacity on the result, the input variables for EVs in input Excel file are used in this simulation in Figure 19.

The charging and discharging times of EVs are nearly the same with the base microgrid. However, the amount of the energy transfer between the microgrid and EVs increases with the increase in the battery capacity of EVs due to available large energy

Table 7. Overview of the Microgrid with 50 kWh Battery for Case I

	WEVS	UCCS	CCS	CCDS	OCCDS
E_{ch} (kWh)	0	204.3	125.2	112.4	100.8
J_{ch} (TL)	0	102.95	54.01	47.89	42.01
C_{ch} (TL/kWh)	0	0.5040	0.4315	0.4261	0.4167
E_{disc} (kWh)	0	0	0	556.3	461.2
J_{disc} (TL)	0	0	0	248.91	211.38
C_{disc} (TL/kWh)	0	0	0	0.4474	0.4583
E_{mg} (kWh)	13828	14068	13975	13487	13555
J_{op} (TL)	6622	6725	6676	6421	6452
C_{mg} (TL/kWh)	0.4789	0.4780	0.4777	0.4761	0.4761
J_{pop} (TL)	0	Reference	49	304	273
J_{pop} (%)	0	Reference	0.73	4.52	4.06

for the microgrid operator. The lowest power consumptions of the external system increase and the peaks of power consumptions decrease more with respect to base microgrid. According to Figure 22, the external power system becomes more stable than base microgrid.

According to Table 7, the energy transfer between EVs and the microgrid increases at scenarios by applied from the microgrid operator. The average charging cost and discharging price at OCCDS are the same with base microgrid due to the same time of charging and discharging, but the average charging cost at UCCS increases with the increase in the time of charging. Thus, the saving of the microgrid operator increases for each kWh with respect to the base microgrid.

The amount of discharging energy increases at the second low-priced price time and it causes the decrease in the average discharging energy price at OCCDS. Although the saving of the microgrid operator for each kWh decreases, this saving increases with the increase in the discharging energy in this microgrid in comparison with the base

Table 8. Overview of the Microgrid with 30 kWh Battery for Case I

	WEVS	UCCS	CCS	CCDS	OCCDS
E_{ch} (kWh)	0	123.5	86.9	81.7	70.3
J_{ch} (TL)	0	60.64	37.42	34.94	29.30
C_{ch} (TL/kWh)	0	0.4911	0.4305	0.4274	0.4165
E_{disc} (kWh)	0	0	0	457.9	297.4
J_{disc} (TL)	0	0	0	204.15	137.91
C_{disc} (TL/kWh)	0	0	0	0.4459	0.4638
E_{mg} (kWh)	13828	13973	13930	13535	13658
J_{op} (TL)	6622	6683	6660	6453	6514
C_{mg} (TL/kWh)	0.4789	0.4783	0.4781	0.4768	0.4769
J_{pop} (TL)	0	Reference	23	230	169
J_{pop} (%)	0	Reference	0.34	3.44	2.53

microgrid. Hence, the microgrid operator earns 170 TL in a day at OCCDS with V2G operation. The cost of charging is nearly 3090 TL in a month at UCCS. The total saving of the microgrid operator is nearly 8170 TL in a month at OCCDS.

Effect of Decrease in Battery Capacity

The batteries of EVs are selected as 30 kWh for this microgrid in order to investigate the effect of the battery capacity on the saving of microgrid operator. The inputs of EVs and the microgrid without the battery capacity are used the same with the base microgrid. Thus, the charging and discharging times are nearly the same with the base microgrid.

The average charging cost at OCCDS decreases same as CCS and the average discharging price at OCCDS increases. Thus, the microgrid operator can obtain a higher saving for each kWh than the base microgrid and the microgrid with 50 kWh batteries. However, the saving of the microgrid operator decreases at OCCDS due to the small amount of the energy transfer between EVs and the microgrid. Hence, V2G

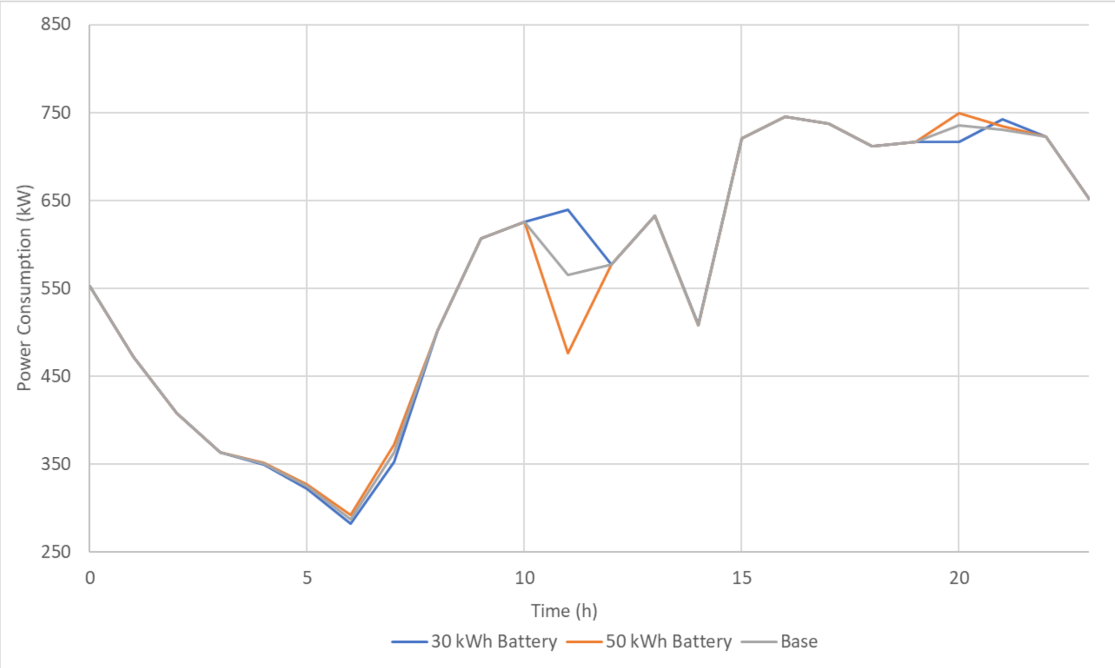

Figure 22. The Power Curve of the Microgrid with Different Battery Capacity for Case I

operation provides only 108 TL for the microgrid operator in a day. The charging cost decreases to 1820 TL in a month due to the small chargeable energy in the battery. Thus, the total saving of the microgrid operator is nearly 5090 TL in a month. According to Figure 22, the power consumption curve of the base microgrid is more stable than the microgrid with 30 kWh battery at OCCDS because of the small useable energy in batteries of EVs for the microgrid operator.

Effect of Decrease in MSoCL

The MSoCL is decreased from 50% to 40% which equals to 80 km range for EVs with same inputs EV and the microgrid. This microgrid is simulated to examine the effects of MSoCL on the cost and energy transaction between the microgrid and EVs or the external power system. The changing in MSoCL does not affect the amount and average cost of charging energy because the time of charging occurs the first hours of the commercial microgrid. Thus, the simulation results of this microgrid are totally similar with the base microgrid at UCCS and CCS.

Table 9. Overview of the Microgrid with 40% MSoCL for Case I

	WEVS	UCCS	CCS	CCDS	OCCDS
E_{ch} (kWh)	0	164.1	107.8	98.4	86.8
J_{ch} (TL)	0	81.67	46.47	41.99	36.18
C_{ch} (TL/kWh)	0	0.4978	0.4311	0.4266	0.4167
E_{disc} (kWh)	0	0	0	557.4	464.6
J_{disc} (TL)	0	0	0	249.40	212.90
C_{disc} (TL/kWh)	0	0	0	0.4475	0.4583
E_{mg} (kWh)	13828	14021	13955	13470	13535
J_{op} (TL)	6622	6704	6669	6415	6446
C_{mg} (TL/kWh)	0.4789	0.4781	0.4779	0.4762	0.4762
J_{pop} (TL)	0	Reference	35	289	258
J_{pop} (%)	0	Reference	0.52	4.31	3.85

The amount of discharging energy is increased due to suitable 24 kWh dischargeable energy instead of 20 kWh in batteries of EVs. However, only extra suitable 4 kWh dischargeable energy in each EV exists for the microgrid operator in this microgrid. According to Table 9, the amount and average cost of energy do not change significantly but the daily saving of the microgrid operator increases to 176 TL with V2G operation due to the increase in discharging energy at OCCDS. The charging cost is nearly 82 TL in a day as the base microgrid due to the time of charging. The total saving of the microgrid operator is nearly 7750 TL in a month at OCCDS.

Effect of Decrease in MSoCL

MSoCL is decreased to 30% which equals to 60 km range for EVs. 28 kWh dischargeable energy in each EV is suitable for the microgrid operator. This changing does not cause to change the amount and time of charging because this charging occurs at the first hours of EV connection.

Table 10. Overview of the Microgrid with 30% MSoCL for Case I

	WEVS	UCCS	CCS	CCDS	OCCDS
E_{ch} (kWh)	0	164.1	107.8	98.4	86.8
J_{ch} (TL)	0	81.67	46.47	41.99	36.33
C_{ch} (TL/kWh)	0	0.4978	0.4311	0.4266	0.4185
E_{disc} (kWh)	0	0	0	603.8	489.2
J_{disc} (TL)	0	0	0	270.36	223.93
C_{disc} (TL/kWh)	0	0	0	0.4477	0.4577
E_{mg} (kWh)	13828	14021	13955	13430	13514
J_{op} (TL)	6622	6704	6669	6393	6435
C_{mg} (TL/kWh)	0.4789	0.4781	0.4779	0.4761	0.4761
J_{pop} (TL)	0	Reference	66	311	269
J_{pop} (%)	0	Reference	0.98	4.63	4.01

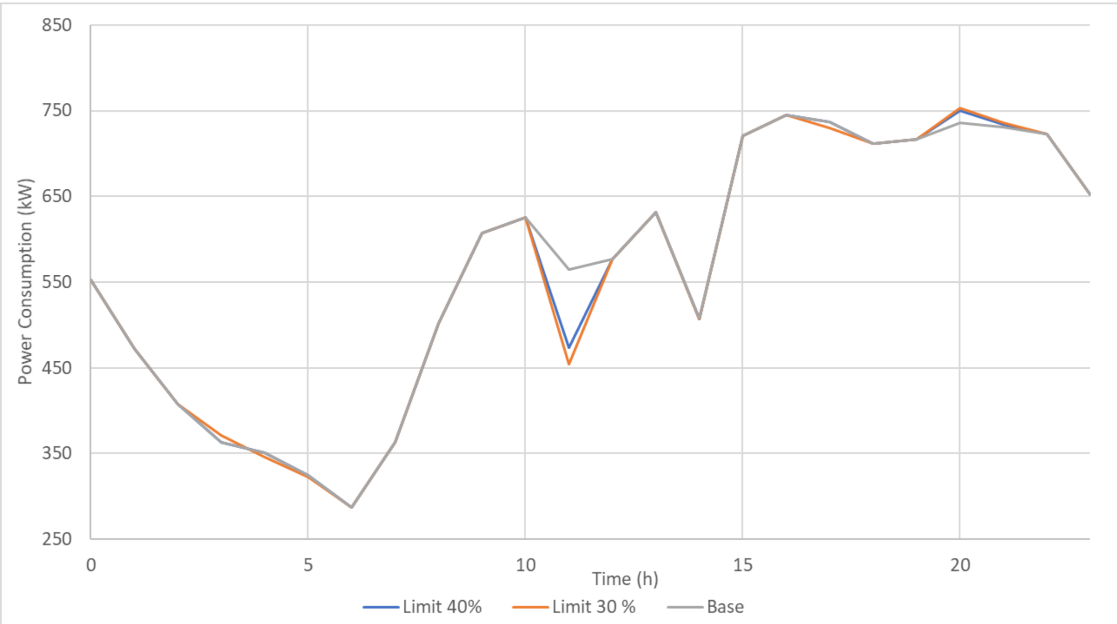

Figure 23. The Power Curve of the Microgrid with Different MSoCL for Case I

As it is seen from Table 10, the difference between the average charging cost and the average discharging price decreases with 30% MSoCL. The increase in the amount of discharging energy at the second and third suitable discharging hours decrease the average price of discharging at CCDS and OCCDS. The charging cost is the same at different MSoCL microgrids because the charging occurs before the discharging.

V2G operation provides 188 TL for the microgrid operator when the difference between J_{ch} and J_{disc} is calculated; thus, the total saving of the microgrid operator is 8080 TL in a month at OCCDS. According to Figure 23, the amount of discharging energy increases with decreasing MSoCL. However, the amount and time of charging in this microgrid are the same with base microgrid.

Effect of Travel Pattern with σ = 3

The standard deviation of the arrival times and departure times of EVs are changed from 1.25 to 3 to investigate the effect of the time interval of arrival times and departure times. Figure 24 shows that the connection time interval increases and the number of new connected EV in an hour is decreased with large standard deviation.

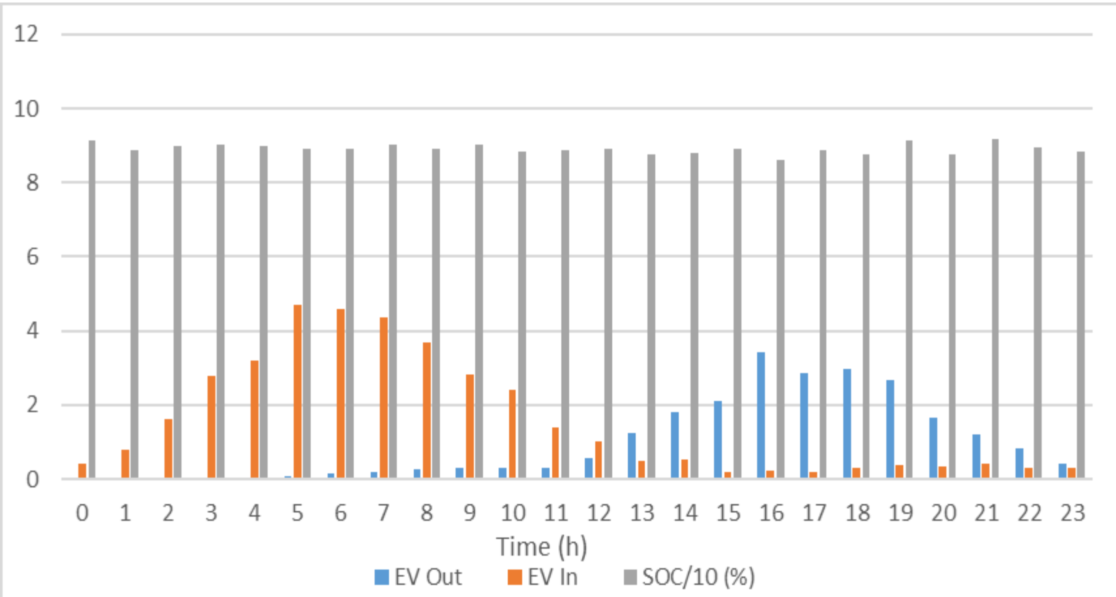

Figure 24. The Average Input Values for Case I with σ = 3

Table 11. Overview of the Microgrid with σ = 3 for Case I

	WEVS	UCCS	CCS	CCDS	OCCDS
E_{ch} (kWh)	0	156.8	109.4	99.6	88.0
J_{ch} (TL)	0	77.93	47.48	42.77	36.68
C_{ch} (TL/kWh)	0	0.4969	0.4338	0.4295	0.4167
E_{disc} (kWh)	0	0	0	472.9	381.5
J_{disc} (TL)	0	0	0	211.36	175.47
C_{disc} (TL/kWh)	0	0	0	0.4469	0.4599
E_{mg} (kWh)	13828	14012	13957	13543	13607
J_{op} (TL)	6622	6700	6670	6454	6483
C_{mg} (TL/kWh)	0.4789	0.4782	0.4779	0.4765	0.4765
J_{pop} (TL)	0	Reference	30	246	217
J_{pop} (%)	0	Reference	0.45	3.67	3.24

The microgrid operator earns nearly 139 TL with V2G operation. The saving is nearly the same with the base microgrid due to the same average charging cost. Moreover, the amount of discharging and charging energies in this microgrid are also nearly the same with the base microgrid. According to Table 11, the charging cost decreases to 78 TL due to the late arrival time of some EVs. Hence, the total saving of the microgrid operator is 6500 TL in a month at OCCDS.

Effect of Travel Pattern with σ = 0.5

The standard deviation of the arrival times and departure times of EVs are changed from 1.25 to 0.5 to investigate the time interval of arrival times and departure times. According to Figure 25, EVs are connected to or unconnected from the microgrid in the small-time interval. The plug-in and plug-out times of whole EVs are completed in nearly two hours.

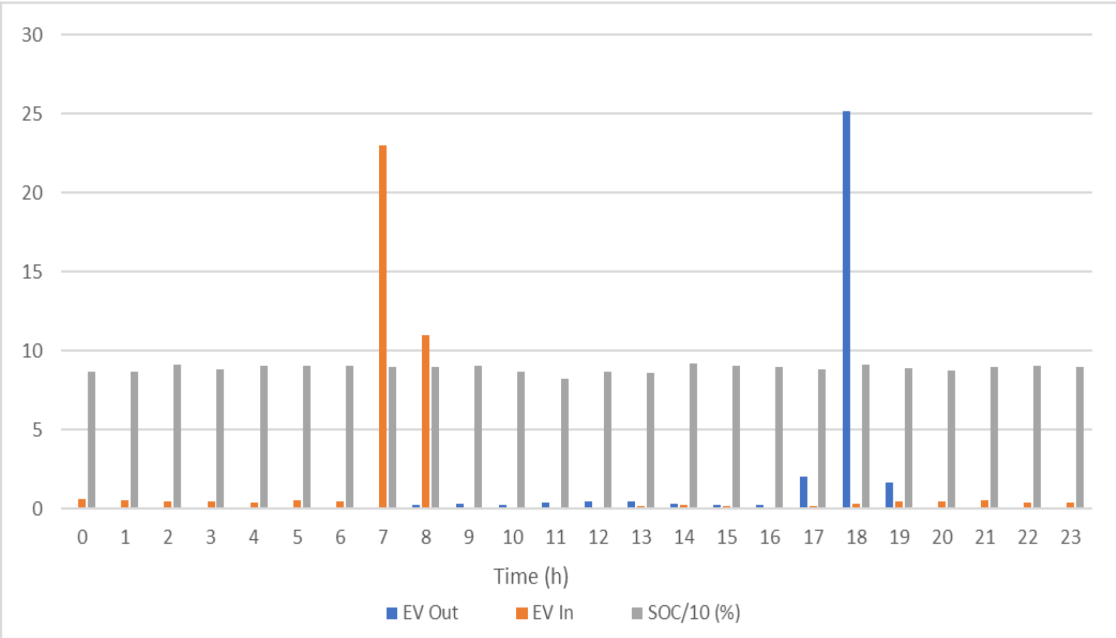

Figure 25. The Average Input Values for Case I with σ = 0.5

According to Table 12, the average charging cost increases with the increase in number of EVs which arrives the microgrid at late time. Thus, the microgrid operator earns only 120 TL in a day. The charging cost is 88 TL in a day at UCCS. The total saving of the microgrid operator decreases to 6270 TL.

The curve is changing with the standard deviation variety because times of charging and discharging are increasing with σ = 3. The charging energy is nearly the same because EVs are charged to 100% at first hours in a day. However, the discharging energy decrease with σ = 0.5 due to no discharging at late hour in a day. Figure 26 demonstrates differences between curves of different standard deviations which are 3, 0.5 and 1.25.

Table 12. Overview of the Microgrid with σ = 0.5 for Case I

	WEVS	UCCS	CCS	CCDS	OCCDS
E_{ch} (kWh)	0	173.5	105.4	100.9	87.8
J_{ch} (TL)	0	88.47	46.53	44.34	37.81
C_{ch} (TL/kWh)	0	0.5098	0.4413	0.4396	0.4303
E_{disc} (kWh)	0	0	0	532.2	343.3
J_{disc} (TL)	0	0	0	237.73	158.27
C_{disc} (TL/kWh)	0	0	0	0.4467	0.4611
E_{mg} (kWh)	13828	14032	13952	13494	13639
J_{op} (TL)	6622	6711	6669	6428	6501
C_{mg} (TL/kWh)	0.4789	0.4782	0.4779	0.4764	0.4767
J_{pop} (TL)	0	Reference	42	283	210
J_{pop} (%)	0	Reference	0.63	4.22	3.13

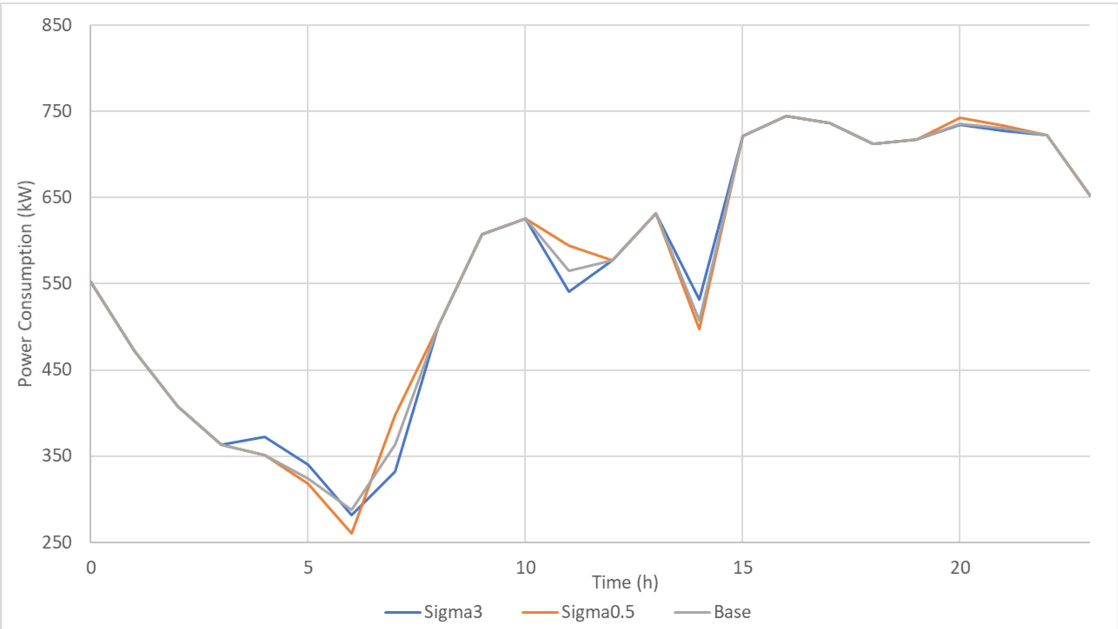

Figure 26. The Power Curve of the Microgrid with Different Travel Pattern for Case I

Effect of the Number of Charging Stations

The number of charging stations are increased from 10% to 20% to investigate the effect of the number of charging stations in the microgrid. In addition, the number of charging stations are also doubled to meet the maximum number of EVs. Figure 27 illustrates the arrival times and departure times of EVs for this microgrid. The plug-in or plug-out number of EVs in an hour are nearly doubled of the base microgrid. Hence, the microgrid operator has more sources to get more reliable and economic microgrid.

According to Table 13, charging and discharging energies are nearly doubled with increasing the number of charging stations in the microgrid. The average charge cost and discharge price are nearly the same because of the same time of charging and discharging. Therefore, the saving of the microgrid operator is the same for each kWh with the base microgrid. However, the increase in the amount of energy transfer between EV and the microgrid provides 281 TL in a day for the microgrid operator. The charging cost is also doubled with 100 charging stations. Hence, the saving of the microgrid operator is 10300 TL in a month with 100 charging stations.

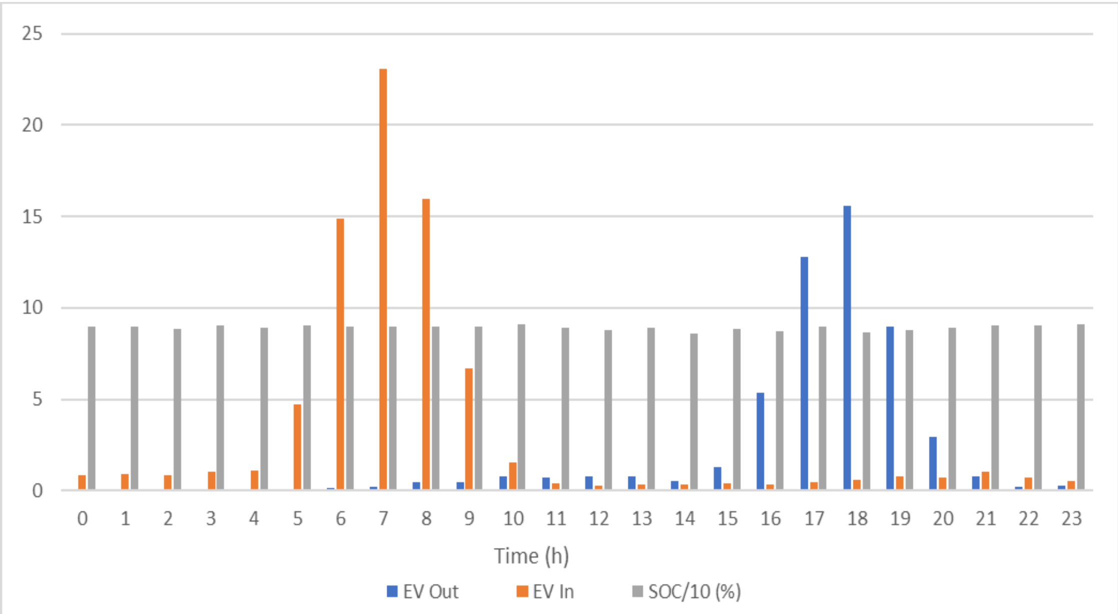

Figure 27. The Average Input Values for Case I with 100 Charging Stations

Table 13. Overview of the Microgrid with 100 Charging Stations for Case I

	WEVS	UCCS	CCS	CCDS	OCCDS
E_{ch} (kWh)	0	324.2	215.1	193.5	170.7
J_{ch} (TL)	0	161.65	92.77	82.42	71.05
C_{ch} (TL/kWh)	0	0.4986	0.4312	0.4260	0.4162
E_{disc} (kWh)	0	0	0	1024.4	765.4
J_{disc} (TL)	0	0	0	457.61	352.58
C_{disc} (TL/kWh)	0	0	0	0.4467	0.4611
E_{mg} (kWh)	13828	14209	14081	13184	13378
J_{op} (TL)	6622	6783	6715	6247	6340
C_{mg} (TL/kWh)	0.4789	0.4774	0.4769	0.4738	0.4739
J_{pop} (TL)	0	Reference	68	536	443
J_{pop} (%)	0	Reference	1.00	7.90	6.53

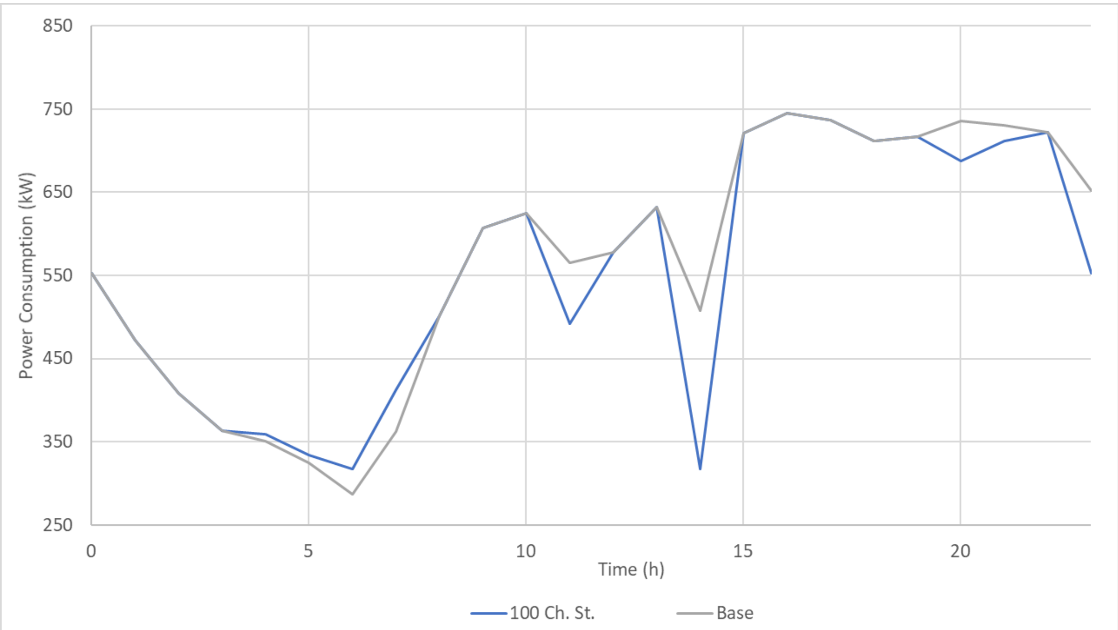

Figure 28. The Power Curve of the Microgrid with Different Number Charging Stations for Case I

The large number charging stations satisfies with the distributed energy source capacity in this microgrid. In this way, the microgrid operator has more controllable energy to obtain a higher saving and flatter curve for the external power system. At Figure 28, it can be seen that the lowest power consumptions of the microgrid increases with the charging and the highest power consumptions of the microgrid decreases with the discharging.

The charging cost in a day (J_{ch}), the saving thanks to V2G operation in a day (J_{popcd}) and the total saving of the microgrid operator in a month (J_{pop}) are given at OCCDS with the hourly rate tariff at Table 14. At small battery capacity, the electricity cost is lower at 07:00 and some EVs completed their charging before this hour due to lower needed charging time with the lower battery capacity. Thus, the decrease in the energy transfer decreases the saving of the microgrid operator.

The difference in MSoCL cannot change the charging cost due to the time of charging. The saving of the microgrid operator increases with the increase in the dischargeable energy on the batteries of EVs thanks to V2G operation. Hence, the total saving of the microgrid operator increases with the small MSoCL. The amount of energy transfer

Table 14. The Saving of the MGO at Different Microgrid for Case I

OCCDS	**J_{ch} (TL)**	**J_{popcd} (TL)**	**J_{pop}(TL)**
Base	81.67	137	6570
30 kWh Battery	60.64	108	5090
50 kWh Battery	102.95	170	8170
40% MSoCL	81.67	176	7750
30% MSoCL	81.67	188	8080
σ = 3	77.93	139	6500
σ = 0.5	88.47	120	6270
100 Charging Stations	161.65	281	10300

between EVs and the microgrid also increases with the increase in the number of charging stations. The saving of the microgrid operator is nearly doubled with 100 charging stations.

The arrival times and departure times variety of EVs are longer with the high standard deviation. These high time interval changes the time of G2V and V2G operations in this microgrid. The saving in this microgrid highly depends on the price variety of near hours of the mean value. Hence, the saving of the microgrid operator with high standard deviation microgrid is nearly the same with base microgrid. However, some EVs miss more suitable chargeable time at small standard deviation; thus, the saving of the microgrid operator decreases.

4.1.1.2. Results with Time-of-Use Tariff

A day is divided into three times which have different electricity prices. The off-peak time which is the low-priced time of a day is between 22:00 – 06:00. The peak time of a day is between 17:00 – 22:00 and this time is most expensive time in a day. At this microgrid, EVs are mostly connected to the microgrid between 08:00 – 19:00 and this time is named as the shoulder time of a day. The initial SoC, the arrival and departure times of EVs are the same with the hourly rate tariff.

According to Figure 29, the time of energy transfer between the microgrid and EVs is slipped with respect to the hourly rate tariff due to the electricity cost. The charging time is the same with hourly rate tariff due to the same low-priced time of the day. However, the amount of charging energy is very low due to the charging occurs until 06:00 at OCCDS and CCDS. EVs are discharging after 17:00 which is the peak time of a day. In Figure 30, the discharging occurs at most peaks of energy consumption of the external power system. It is more advantage situation to obtain flatter curve. However, the charging does not occur at the time of lowest energy consumptions.

The average electricity cost with the time-of-use tariff equals to 0.5296 TL/kWh instead of 0.4615 TL/kWh in the base microgrid without EV. Thus, the total cost of this microgrid is 7669 TL at WEVS instead of 6622 TL in the base microgrid. This 942 TL difference is caused from the average cost of tariff and 100 TL difference is caused from the different energy consumption in the different hours.

According to Table 15, the average charging cost and the average discharging price are very different from the hourly rate tariff. The time-of-use tariff provides a higher saving for the microgrid operator because of the high difference cost between time slides. The difference between the average charging and discharging price at time-of-use tariff is nearly 0.20 TL for each kWh with respect to the hourly rate tariff. In addition, the average charging costs at CCS, CCDS, OCCDS are nearly 36% economic than at UCCS. The total price of the microgrid is higher than hourly rate tariff. The daily saving of the microgrid operator is 147 TL with V2G operation. The charging cost is nearly 103 TL in a day at UCCS. The total saving of the microgrid operator approaching to 7500 TL in a month at OCCDS.

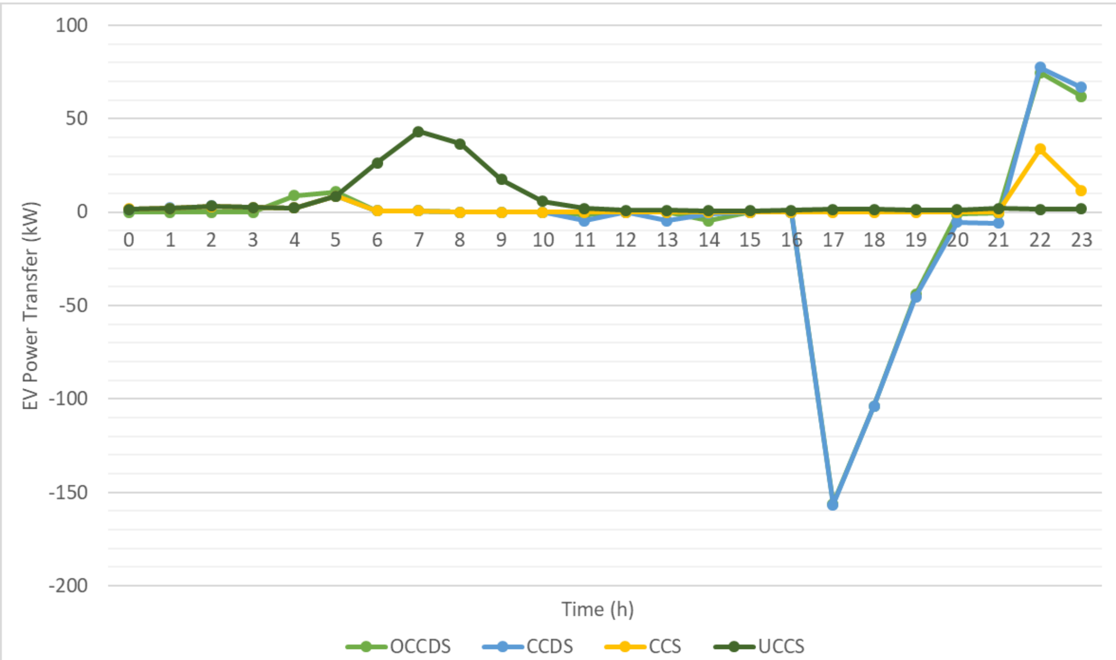

Figure 29. The Power Transfer Between the Microgrid and EVs for Case I with TOUT

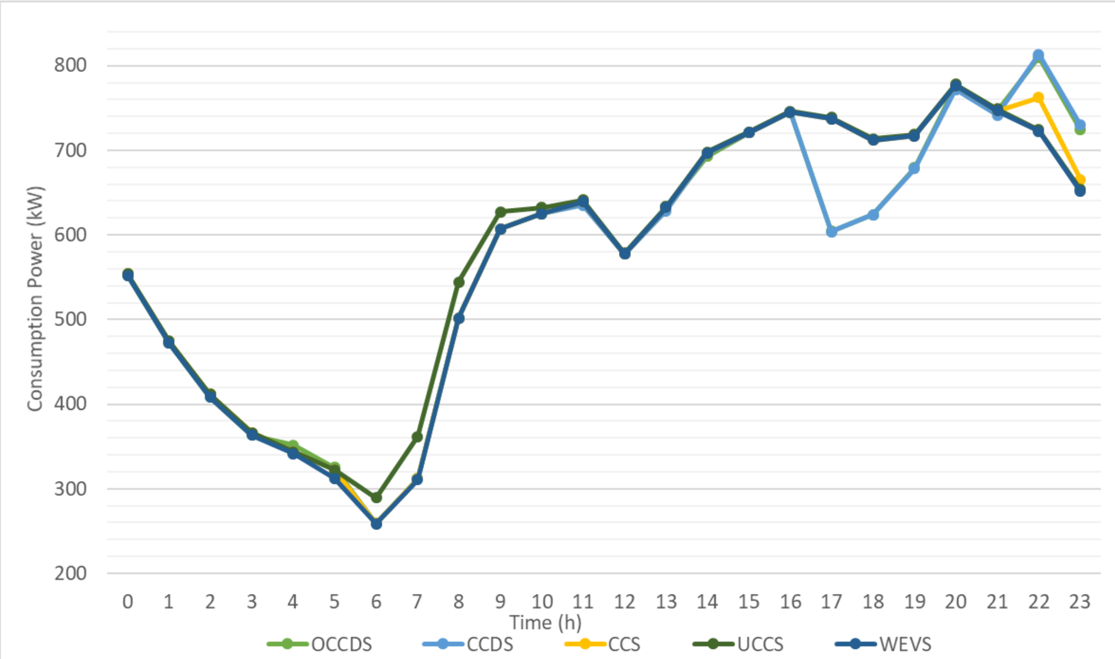

Figure 30. The Power Curve of the Microgrid for Case I with TOUT

Table 15. Overview of the Microgrid for Case I with TOUT

	WEVS	UCCS	CCS	CCDS	OCCDS
E_{ch} (kWh)	0	166.0	66.8	165.5	157.5
J_{ch} (TL)	0	102.47	26.77	66.32	63.08
C_{ch} (TL/kWh)	0	0.6173	0.4010	0.4007	0.4005
E_{disc} (kWh)	0	0	0	327.0	311.9
J_{disc} (TL)	0	0	0	219.69	210.33
C_{disc} (TL/kWh)	0	0	0	0.6718	0.6744
E_{mg} (kWh)	13828	14023	13907	13745	13748
J_{op} (TL)	7669	7772	7696	7516	7522
C_{mg} (TL/kWh)	0.5546	0.5542	0.5534	0.5468	0.5471
J_{pop} (TL)	0	Reference	76	256	250
J_{pop} (%)	0	Reference	0.98	3.29	3.21

Effects of Variables

The amount of charging and discharging energy have direct proportional relation with the battery capacities of EVs. The time of charging and discharging change with the alteration in the battery capacity at time-of-use tariff but these times are the same price slide. Hence, the average price of charging and discharging are nearly the same with different battery capacities. However, the saving of the microgrid operator increases with the increase in the amount of the energy transfer between an EV and the microgrid.

The curve of the power consumptions of the external power system becomes more stable with 50 kWh battery capacity with the increase in the energy transfer between

Table 16. Overview of the Microgrid with Different Battery Capacities for Case I with TOUT

		WEVS	UCCS	CCS	CCDS	OCCDS
30 kWh Battery	**E_{ch} (kWh)**	0	123.8	51.3	155.9	146.5
	C_{ch} (TL/kWh)	0	0.6185	0.4005	0.4005	0.4005
	E_{disc} (kWh)	0	0	0	264.7	253.1
	C_{disc} (TL/kWh)	0	0	0	0.6797	0.6797
	C_{mg} (TL/kWh)	0.5561	0.5558	0.5552	0.5493	0.5497
	J_{op} (TL)	7690	7767	7711	7573	7577
	J_{pop} (TL)	0	Reference	56	194	190
50 kWh Battery	**E_{ch} (kWh)**	0	206.2	79.4	172.3	166.6
	C_{ch} (TL/kWh)	0	0.6206	0.4005	0.4005	0.4005
	E_{disc} (kWh)	0	0	0	373.0	364.1
	C_{disc} (TL/kWh)	0	0	0	0.6797	0.6797
	C_{mg} (TL/kWh)	0.5561	0.5557	0.5547	0.5473	0.5476
	J_{op} (TL)	7690	7818	7722	7506	7510
	J_{pop} (TL)	0	Reference	96	312	309

Table 17. Overview of the Microgrid with Different MSoCL for Case I with TOUT

		WEVS	UCCS	CCS	CCDS	OCCDS
30% MSoCL	**E_{ch} (kWh)**	0	165.6	66.5	168.2	164.2
	C_{ch} (TL/kWh)	0	0.6196	0.4005	0.4005	0.4005
	E_{disc} (kWh)	0	0	0	419.4	411.8
	C_{disc} (TL/kWh)	0	0	0	0.6797	0.6797
	C_{mg} (TL/kWh)	0.5561	0.5557	0.5549	0.5467	0.5469
	J_{op} (TL)	7690	7793	7717	7473	7476
	J_{pop} (TL)	0	Reference	76	320	317
40% MSoCL	**E_{ch} (kWh)**	0	165.6	66.5	168.2	163
	C_{ch} (TL/kWh)	0	0.6196	0.4005	0.4005	0.4005
	E_{disc} (kWh)	0	0	0	373.5	364.8
	C_{disc} (TL/kWh)	0	0	0	0.6797	0.6797
	C_{mg} (TL/kWh)	0.5561	0.5557	0.5549	0.5474	0.5476
	J_{op} (TL)	7690	7793	7717	7504	7508
	J_{pop} (TL)	0	Reference	76	289	285

EVs and the microgrid. EV discharging occurs at the peak of the power consumption of the external system and the EV charging occurs at the off-peak time of the power consumption of the external system.

According to Table 17, the amount of charging energy is the same with different MSoCL values because the charging times are first hours of the EV connection at Case I. The microgrid operator can control the more dischargeable energy with low SOC limit. This extra dischargeable energy is using at the same time slide by the microgrid operator. Hence, the average discharging price is the same with the base microgrid. The average charging cost and discharging price of all scenarios are the same with different MSoCLs. However, the saving of the microgrid operator increases with the increase in the amount of the energy transfer between EVs and the microgrid. The

Table 18. Overview of the Microgrid with Different Variables for Case I with TOUT

		WEVS	UCCS	CCS	CCDS	OCCDS
σ = 0.5	**E_{ch} (kWh)**	0	177.2	47.1	114.0	103.8
	C_{ch} (TL/kWh)	0	0.6288	0.4023	0.4012	0.4010
	E_{disc} (kWh)	0	0	0	325.5	308.2
	C_{disc} (TL/kWh)	0	0	0	0.6725	0.6748
	C_{mg} (TL/kWh)	0.5561	0.5543	0.5538	0.5477	0.5481
	J_{op} (TL)	7690	7780	7688	7496	7503
	J_{pop} (TL)	0	Reference	92	284	277
σ =3	**E_{ch} (kWh)**	0	154.1	90.1	195.7	188.4
	C_{ch} (TL/kWh)	0	0.5687	0.4005	0.4005	0.4005
	E_{disc} (kWh)	0	0	0	349.4	338.9
	C_{disc} (TL/kWh)	0	0	0	0.6797	0.6797
	C_{mg} (TL/kWh)	0.5561	0.5552	0.5545	0.5473	0.5476
	J_{op} (TL)	7690	7778	7727	7531	7536
	J_{pop} (TL)	0	Reference	51	247	242
100 Charging Stations	**E_{ch} (kWh)**	0	342.4	138.7	337.9	324.8
	C_{ch} (TL/kWh)	0	0.6145	0.4013	0.4007	0.4006
	E_{disc} (kWh)	0	0	0	673.9	647.9
	C_{disc} (TL/kWh)	0	0	0	0.6727	0.6750
	C_{mg} (TL/kWh)	0.5561	0.5537	0.5521	0.5384	0.5389
	J_{op} (TL)	7690	7879	7725	7351	7362
	J_{pop} (TL)	0	Reference	154	528	517

power consumption curve of the external power system becomes more stable at microgrid at low MSoCL.

The amount of charging and discharging energy are increased with increasing in standard deviation due to electricity price. The charging energy increases at the same price slide because of the large number of EVs which connect in the microgrid before 07:00. Thus, the average charging cost is the same with the base microgrid. Moreover, the average charging cost becomes more expensive at small standard deviation with the large number of EVs which connect after 07:00. The average discharging price is economic with the large number of connecting EVs before 18:00. However, the saving of the microgrid operator increases with small standard deviation due to the lower amount of the EV charging.

The large number of charging stations provides the large controllable energy to optimize the microgrid and the external power system for the microgrid operator. In this way, the saving of the microgrid operator is nearly doubled with respect to the base microgrid because of the doubled amount of energy transfer between EVs and the microgrid. The average charging cost and the average discharging price are nearly the same with the base microgrid.

The saving of the microgrid operator presented at different microgrid and different scenarios with time-of-use tariff in Table 19. The saving of the microgrid operator dramatically decreases with 30 kWh battery capacity because of the decrease in the amount of energy transfer between EVs and the microgrid. The same simulation with 50 kWh battery is exactly opposite to the case of 30 kWh battery capacity. In addition, the EV charging cost increases with the increase in the chargeable energy in the battery. The effect of the batter capacity on the microgrid operator is the same with different tariffs.

Table 19. The Saving of the MGO at Different Microgrids for Case I with TOUT

OCCDS	J_{ch} (TL)	J_{popcd} (TL)	J_{pop}(TL)
Base	102.47	154	7500
30 kWh Battery	76.58	107	5500
50 kWh Battery	129.97	197	9760
40% MSoCL	102.60	202	9130
30% MSoCL	102.60	248	10510
σ = 3	87.65	150	7150
σ = 0.5	111.40	205	9480
100 Charging Stations	210.37	323	16010

The charging cost is the same at different MSoCLs because the charging occurs before the discharging and occurs at the first hours of EVs connection. The saving of the microgrid operator increases with the increase in the energy transfer. The high number of charging stations also increases the amount of the energy transfer. Thus, the saving of the microgrid operator is doubled with 100 charging stations as the hourly rate tariff.

The arrival times and departure times interval are longer with large standard deviation. More EVs depart from the microgrid early hours, thus, the microgrid operator cannot use these EVs to discharge in lowest-priced hours. The saving of the microgrid operator decreases with large standard deviation. However, the saving of the microgrid operator increases at this microgrid due to large energy transfer between EVs and the microgrid although there is no change in average charging cost and discharging price.

4.1.1.3. Result for February

The time-of-use tariff and the hourly rate tariff are used as input for simulations to analyze the effect of the price variety on the microgrid. The time-of-use tariff has the same electricity cost at different months. However, the hourly rate tariff is changing day by day due to variety on the bids of suppliers. The rate of electricity generation and loads are changing at different months because of natural reasons and behavior of people. The electricity generation of solar power plant decreases in winter due to lower solar insolation. In addition, people have different electricity usage with respect to season such as an air conditioner or heater. Thus, the curve of electricity price is changing with months. Also, the peak and the off-peak times are changing. The data of different months are simulated to analyze the behavior of the algorithm with different input data sets.

Firstly, the base commercial microgrid is simulated with data of February. According to Figure 31, the time of energy transfer between the microgrid and EVs is different from simulations in August. The time of charging occurs at the first hours of Case I and it is the same with other simulations. However, the microgrid operator maintains the charging only one hour at CCS, CCDS and OCCDS. According to Figure 31, the discharging occurs between 09:00 and 12:00 and this time period is the peak of the electricity cost in a day and the time of discharging is different from simulations in August.

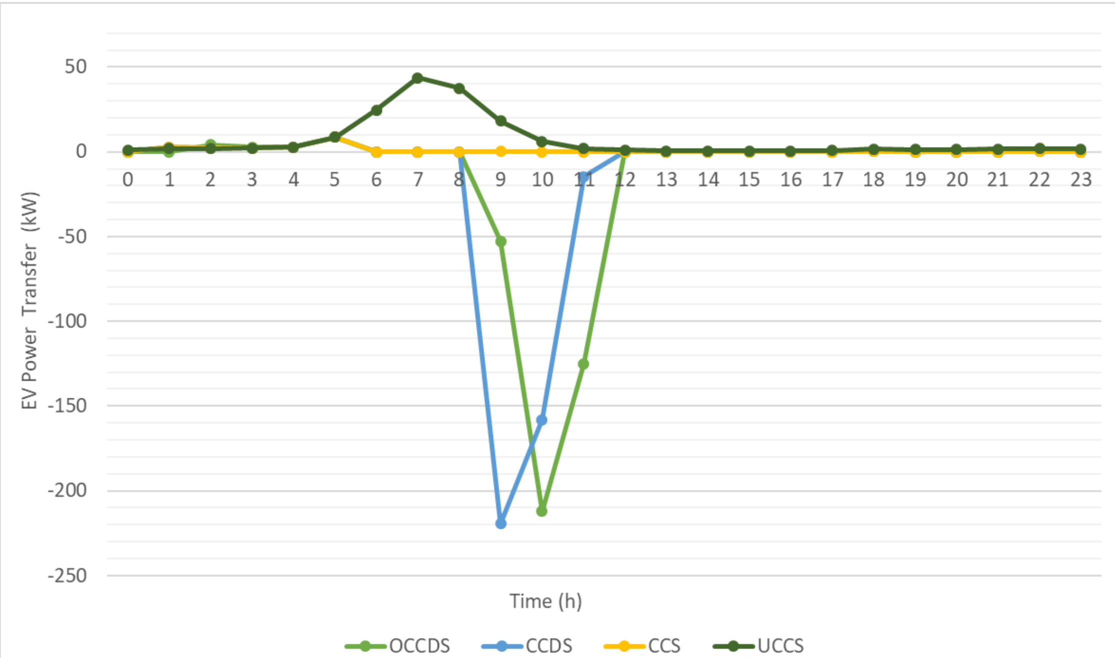

Figure 31. The Power Transfer Between the Microgrid and EVs for Case I in February

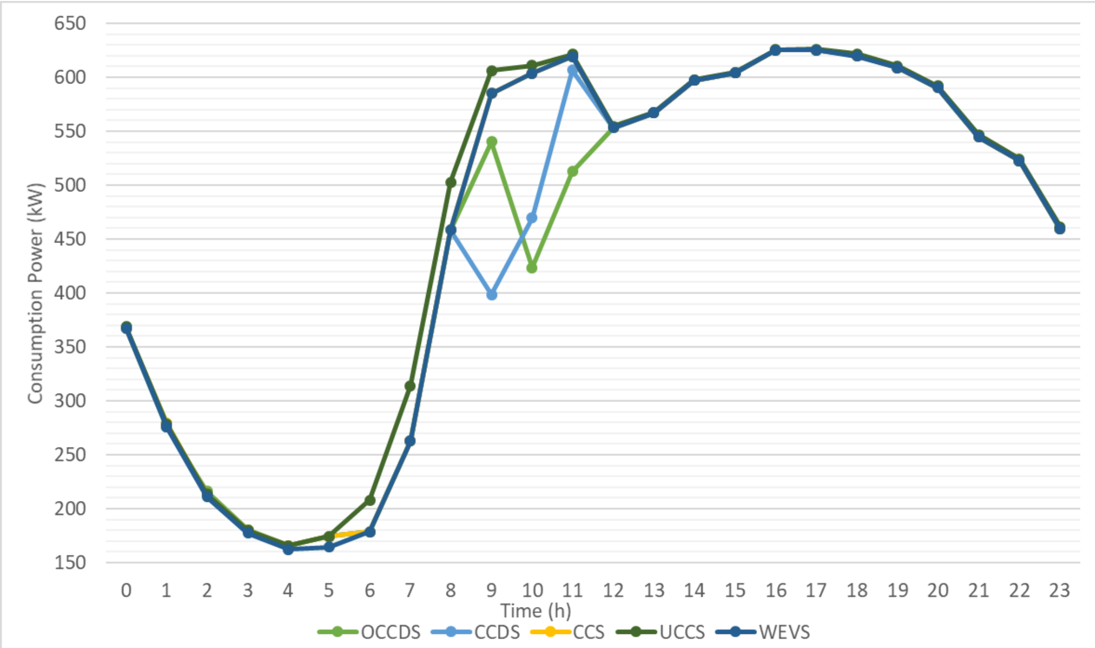

Figure 32. The Power Curve of the Microgrid for Case I in February

In Figure 32, the discharging occurs at most peaks of power consumption of the external power system. The time of discharge is more advantageous situation to obtain flatter curve. However, the charging energy of EVs is not sufficient for the increase in the lowest power consumptions.

The average electricity cost in February equals to 0.4766 TL/kWh instead of 0.4615 TL/kWh. The energy consumption in February is nearly 3000 MWh and it is lower than the energy consumption in August for one day.

According to Table 20, the average charging cost is very close to the average discharging price. This situation causes that the saving of the microgrid operator will be lower than August due to no price difference in February. However, the saving of the microgrid operator is higher with respect to August despite low energy transfer between EVs and the microgrid. The average charging cost of OCCDS is only 0.09

Table 20. Overview of the Microgrid for Case I in February

	WEVS	UCCS	CCS	CCDS	OCCDS
E_{ch} (kWh)	0	164.0	18.8	18.8	18.8
J_{ch} (TL)	0	92.84	8.99	8.99	8.90
C_{ch} (TL/kWh)	0	0.5662	0.4784	0.4784	0.4731
E_{disc} (kWh)	0	0	0	392.3	390.1
J_{disc} (TL)	0	0	0	185.69	185.05
C_{disc} (TL/kWh)	0	0	0	0.4734	0.4821
E_{mg} (kWh)	10984	11177	11006	10673	10675
J_{op} (TL)	5423	5515	5432	5246	5243
C_{mg} (TL/kWh)	0.4937	0.4935	0.4935	0.4915	0.4912
J_{pop} (TL)	0	Reference	83	269	272
J_{pop} (%)	0	Reference	1.50	4.88	4.93

TL more economic for each kWh than UCCS. In addition to this, the average discharging price is smaller than the average charging cost, thus, the microgrid operator makes a loss for each kWh at CCDS.

V2G operation provides 176 TL saving for the microgrid operator in a day at OCCDS. The charging cost is nearly 2790 TL in a month at UCCS. The total saving of the microgrid operator is nearly 8070 TL in a month at OCCDS.

Effects of Variables

The time of charging and discharging are the same with the base microgrid in February. The amount of the discharging energy increases with the increase in the battery capacity at same hours. However, the amount of the charging energy does not change with the battery capacity because the time of charging is first hours of the microgrid in February as the microgrid in August. The microgrid operator makes a loss at 30 kWh battery capacity for each kWh at CCDS. However, the microgrid operator get saving for each kWh with large battery capacities in the EVs. Large battery capacities provide the large amount of transfer energy for the microgrid operator. Thus, the saving of the microgrid operator increases with the increase in the amount of transfer energy between EVs and the microgrid.

Table 21. Overview of the Microgrid with Variables for Case I in February

		UCCS	CCS	CCDS	OCCDS
30 kWh Battery	C_{ch} **(TL/kWh)**	0.5610	0.4784	0.4784	0.4716
	C_{disc} **(TL/kWh)**	0	0	0.4736	0.4783
	J_{pop} **(TL)**	Reference	60	265	267
50 kWh Battery	C_{ch} **(TL/kWh)**	0.5699	0.4763	0.4763	0.4704
	C_{disc} **(TL/kWh)**	0	0	0.4808	0.4797
	J_{pop} **(TL)**	Reference	95	408	421
%40 MSoCL	C_{ch} **(TL/kWh)**	0.5658	0.4771	0.4771	0.4707
	C_{disc} **(TL/kWh)**	0	0	0.4809	0.4798
	J_{pop} **(TL)**	Reference	80	397	407
%30 MSoCL	C_{ch} **(TL/kWh)**	0.5646	0.4719	0.4719	0.4718
	C_{disc} **(TL/kWh)**	0	0	0.4810	0.4768
	J_{pop} **(TL)**	Reference	80	407	457
σ = 3	C_{ch} **(TL/kWh)**	0.5567	0.4691	0.4691	0.4663
	C_{disc} **(TL/kWh)**	0	0	0.4799	0.4808
	J_{pop} **(TL)**	Reference	67	315	316
σ = 0.5	C_{ch} **(TL/kWh)**	0.5737	0.4684	0.4688	0.4605
	C_{disc} **(TL/kWh)**	0	0	0.4779	0.4795
	J_{pop} **(TL)**	Reference	98	391	392
100 Charging Stations	C_{ch} **(TL/kWh)**	0.5680	0.4774	0.4774	0.4712
	C_{disc} **(TL/kWh)**	0	0	0.4783	0.4797
	J_{pop} **(TL)**	Reference	118	696	697

The different SoC limit cannot change the charging energy due to the time of charging at commercial microgrid. Hence, the simulation results at UCCS and CCS are the same at different MSoCL values. The discharging starts to occur at fourth expensive price with the increase in discharging energy. Therefore, the discharging energy increases with low MSoCL, although the average discharging price decreases. The saving of the microgrid operator increases with low MSoCL in spite of the same charging cost.

The standard deviation changes the travel pattern of EVs. The saving of an microgrid operator for each kWh increases with $\sigma = 3$ and $\sigma = 0.5$. The charging energy increases with $\sigma = 3$ due to the early connected EVs in the microgrid. In this way, the discharging occurs in the same time with the base microgrid in February but the amount of the discharging energy also increases. Thus, the saving of microgrid operator increases with the amount of the energy transfer. The high number of charging stations increases the amount of the energy transfer between EVs and the microgrid. This energy transfer provides large saving for the microgrid operator.

4.1.2. Simulation Results of Case II

The Case II is that charging stations are integrated to a residential microgrid, and the microgrid operator behaves as a residential prosumer. The probability density functions of arrival time and departure time are given in Section 3.2.1 with the mean and the standard deviation. The algorithm generates the initial SOC, the arrival and departure time of EVs as Case I. The average values of these in fifty trials are given in Figure 33 for Case II. The most arrival times of EVs are between 17:00 and 19:00 in this case and also the most departure times of EVs are between 06:00 and 8:00.

4.1.2.1. Results with Hourly Rate Tariff

According to Figure 34, an EV is charged when they arrive the charging station at UCCS. The highest energy transfer period is between 16:00 and 22:00. At CCS, EVs are not charged as they plug-in, they wait a suitable time for charging by the microgrid

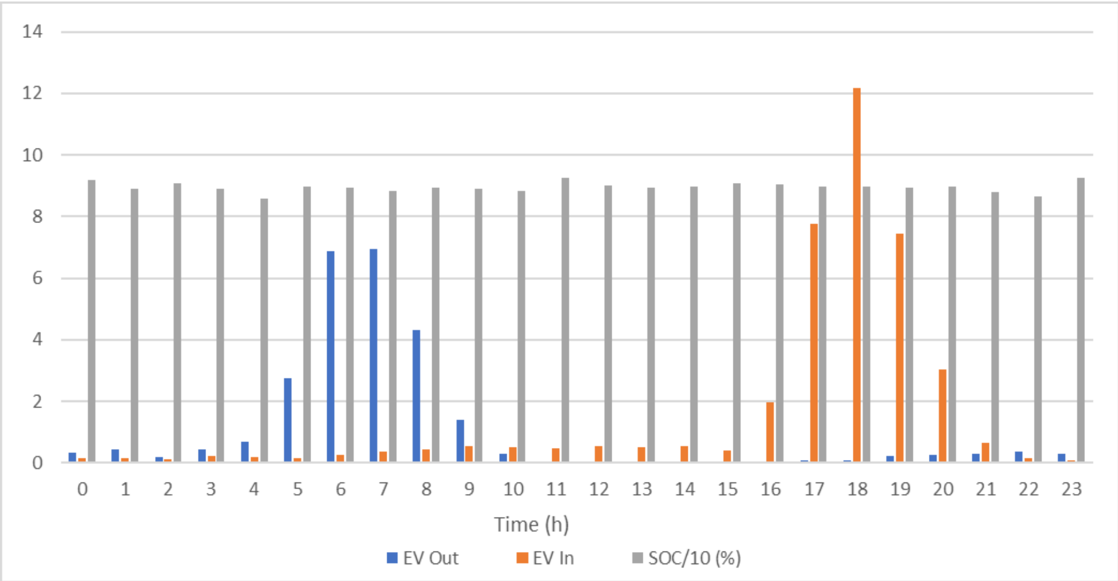

Figure 33. The Average Input Values of Case II

operator. This decision provides sliding charging time to more low-priced hours than UCCS. EVs are discharging with the connection to the microgrid at CCDS because the electricity cost of these hours is higher and these times are between 18:00 and 22:00. The charging starts after 22:00 due to lower price same as CCS. However, this time of charging is longer than CCS due to the discharging. At OCCDS, the highest and lowest electricity costs are selected for charging and discharging before a day. The time of discharging is slipping between 19:00 and 22:00 and the time of charging is slipping between 03:00 and 08:00.

Figure 35 shows that the most power consumptions are seen between 16:00 and 22:00. The lowest power consumptions of the microgrid are seen between 01:00 and 08:00. At UCCs, the peak of power consumption of the microgrid increases with the charging. EVs are charging after the peak times of power consumption at CCS. The charging and discharging decrease the peak power consumptions and increase the lowest power consumptions at controlled discharging scenarios. Thus, EVs provide flatter power consumption curve than only charging scenarios for the external power system.

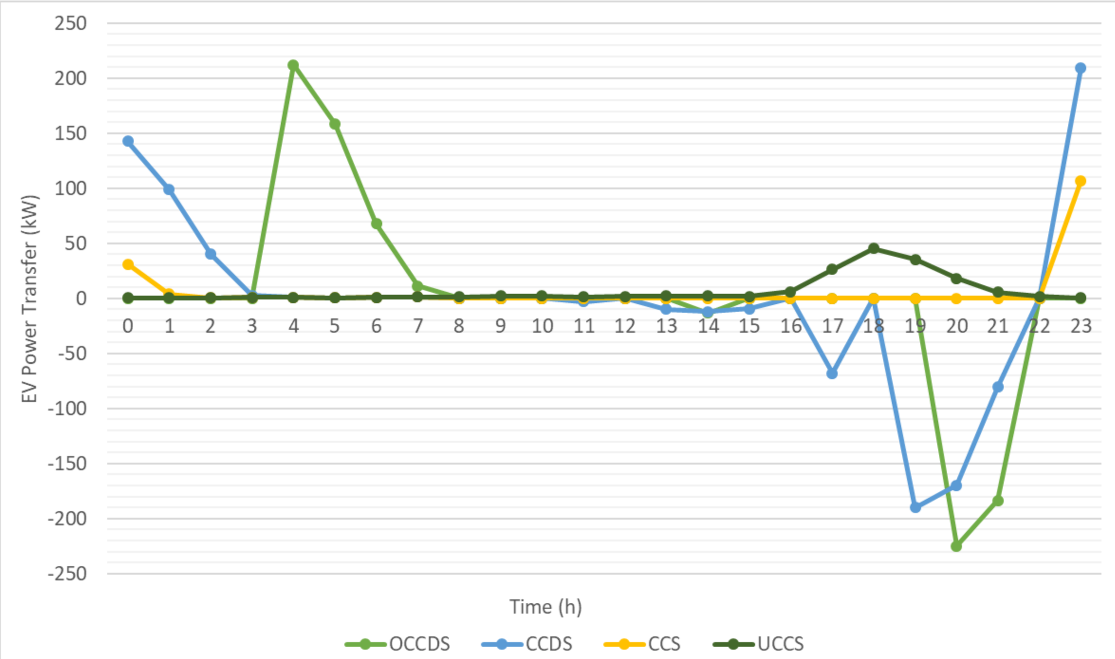

Figure 34. The Power Transfer Between the Microgrid and EVs for Case II

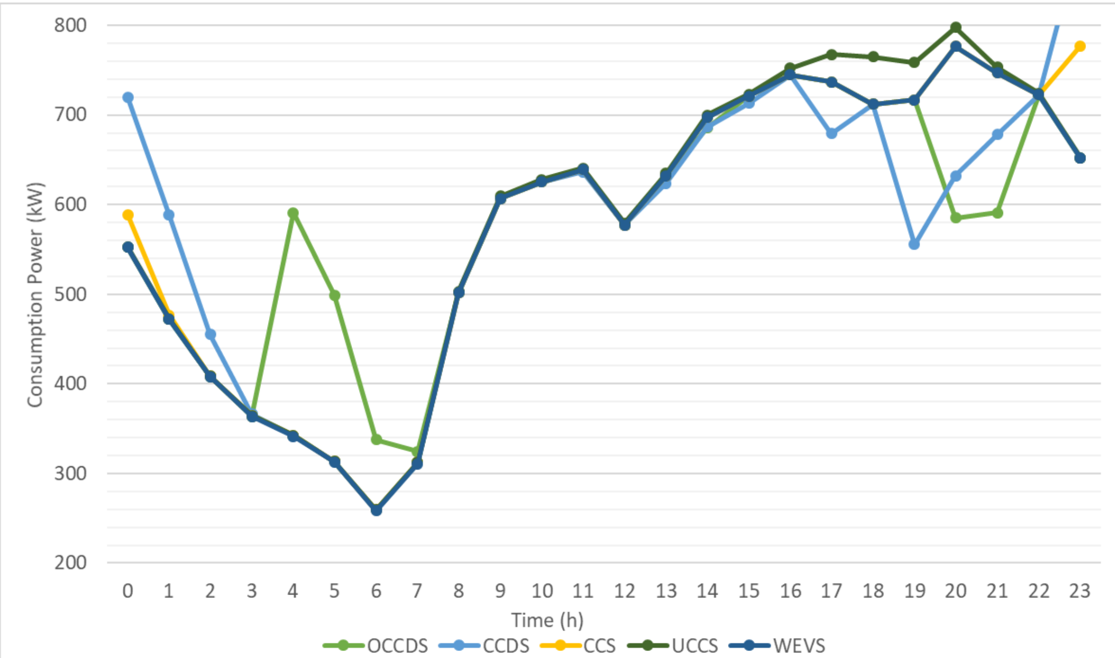

Figure 35. The Power Curve of the Microgrid for Case II

According to Table 22, the power consumption of the microgrid increases with the integration of EVs at UCCS and CCS. At OCCDS, the average charging cost is 10% economic than CCDS and 30% more economic than WEVS. The average discharging price is also more expensive than CCDS. In this case, the optimal solution for the microgrid operator is obtained with OCCDS due to low-priced average charging cost, and most expensive average discharging price. However, the optimal solution for the microgrid operator is obtained at CCDS when comparing with the saving of the microgrid operator. The high amount of discharging energy provides this high saving for the microgrid operator at CCDS. However, the average discharging price is more economic than the average charging cost at CCDS, thus, the microgrid operator makes a loss for each kWh. The saving of the microgrid operator is lower than Case I due to the high amount of the charging energy. EVs have nearly 100% SoC at Case II instead of 50% SoC at Case I when they depart from the microgrid. This situation more beneficial for EV owners. The microgrid operator earns only 9 TL in a day at OCCDS because of the different prices of charging and discharging. The charging cost is nearly 98 TL in a day at UCCS. The total saving of the microgrid operator is 3200 TL in a month at OCCDS.

Table 22. Overview of the Microgrid for Case II

	WEVS	UCCS	CCS	CCDS	OCCDS
E_{ch} (kWh)	0	160.6	147.5	497.6	449.5
J_{ch} (TL)	0	97.48	69.94	234.45	188.16
C_{ch} (TL/kWh)	0	0.6071	0.4742	0.4711	0.4186
E_{disc} (kWh)	0	0	0	542.8	421.9
J_{disc} (TL)	0	0	0	247.99	196.79
C_{disc} (TL/kWh)	0	0	0	0.4569	0.4664
E_{mg} (kWh)	13828	14016	14001	13952	13998
J_{op} (TL)	6622	6720	6692	6609	6613
C_{mg} (TL/kWh)	0.4789	0.4794	0.4779	0.4737	0.4725
J_{pop} (TL)	0	Reference	28	111	107
J_{pop} (%)	0	Reference	0.42	1.65	1.59

Effect of Increase in Battery Capacity

The battery capacities of EVs are selected as 40 kWh at the base microgrid. Battery capacities increase to 50 kWh to investigate the effect of battery capacity on the saving of the microgrid operator. The inputs in Excel file are used the same with the base microgrid without the battery capacities of EVs. The times of charging and discharging are nearly the same with the base microgrid. However, the energy transfer between EVs and the microgrid increases with the increase in the battery capacity. The effect of the battery capacity is also the same with Case I. The peaks of power consumption and the lowest power consumptions become near to average power consumption of a day to satisfy with flatter curve.

According to Table 23, the average charging cost at OCCDS is nearly the same, but the average charging cost at UCCS decreases because the low-priced hours come after the highest price hours at residential microgrid. The microgrid operator makes a loss for each kWh at CCDS as the base microgrid. However, the saving of the microgrid

Table 23. Overview of the Microgrid with 50 kWh Battery for Case II

	WEVS	UCCS	CCS	CCDS	OCCDS
E_{ch} (kWh)	0	199.70	183.74	570.51	466.03
J_{ch} (TL)	0	121.36	86.96	267.55	194.62
C_{ch} (TL/kWh)	0	0.6077	0.4733	0.4690	0.4177
E_{disc} (kWh)	0	0	0	640.70	453.39
J_{disc} (TL)	0	0	0	293.23	211.26
C_{disc} (TL/kWh)	0	0	0	0.4549	0.4660
E_{mg} (kWh)	13828	14063	14044	13955	13991
J_{op} (TL)	6622	6743	6709	6596	6606
C_{mg} (TL/kWh)	0.4789	0.4795	0.4777	0.4727	0.4721
J_{pop} (TL)	0	Reference	34	147	137
J_{pop} (%)	0	Reference	0.50	2.18	2.03

operator increases at all scenarios with the increase in the amount of the transfer energy. The microgrid operator earns nearly 500 TL in a month at OCCDS. This saving increases with respect to the base microgrid by mean of the increase in the battery capacity. The monthly charging cost is nearly 3630 TL for the microgrid operator at UCCS. The total saving of the microgrid operator is 4130 TL in a month at OCCDS with EVs including 50 kWh battery.

Effect of Decrease in Battery Capacity

The size of battery capacity is changed from 40 kWh to 30 kWh to investigate the effect of the battery capacity on the saving of the microgrid operator. The inputs are used as the same with the base microgrid without battery capacity. The times of the charging and discharging are the same with the base microgrid. However, the amount of energy transfer between the microgrid and EVs decreases for whole scenarios. The stability of curve decreases with respect to the base microgrid because of lower energy transfer in this microgrid.

Table 24. Overview of the Microgrid with 30 kWh Battery for Case II

	WEVS	**UCCS**	**CCS**	**CCDS**	**OCCDS**
E_{ch} (kWh)	0	120.90	110.33	391.66	326.53
J_{ch} (TL)	0	73.05	52.38	185.40	138.09
C_{ch} (TL/kWh)	0	0.6042	0.4747	0.4733	0.4229
E_{disc} (kWh)	0	0	0	418.17	286.30
J_{disc} (TL)	0	0	0	190.21	134.42
C_{disc} (TL/kWh)	0	0	0	0.4549	0.4695
E_{mg} (kWh)	13828	13970	13957	13933	13968
J_{op} (TL)	6622	6695	6675	6617	6626
C_{mg} (TL/kWh)	0.4789	0.4793	0.4782	0.4749	0.4743
J_{pop} (TL)	0	Reference	20	78	69
J_{pop} (%)	0	Reference	0.30	1.17	1.04

The average charging cost and discharging price increase at OCCDS. The difference between the average charging and discharging price is the same with the base microgrid. However, the discharging energy becomes nearly half of the base microgrid; thus, the microgrid operator loss nearly 4 TL in a day at OCCDS. The daily charging cost is 73 TL. Hence, the saving of the microgrid operator is 2080 TL for a month.

Table 23 and Table 24 demonstrates that the large battery capacity provides to decrease the average cost of the microgrid for all scenarios. According to Figure 36, the amount of energy transfer is increasing with the increase in the battery size and this changing provide flatter curve for the external power system. In addition to this, the large battery capacity increases the saving of the microgrid operator at CCS, CCDS and OCCDS in comparison with UCCS.

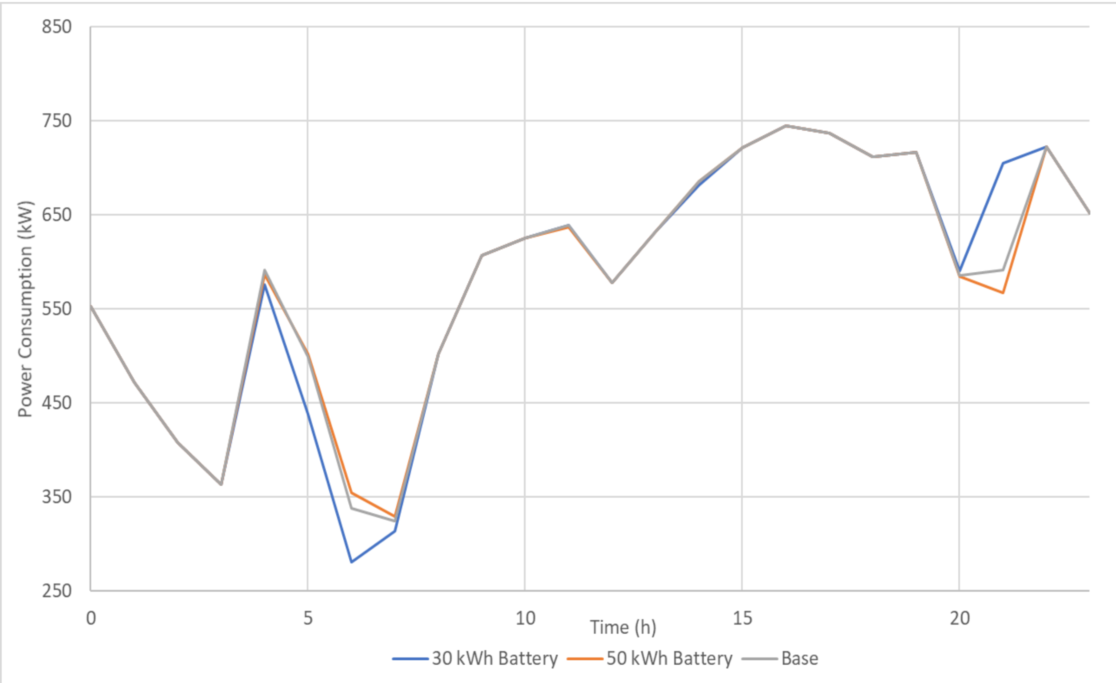

Figure 36. The Power Curve of the Microgrid with Different Battery Capacity for Case II

Effect of Decrease in MSoCL

The MSoCL is selected as 40% which equals to 80 km range for EVs instead of 50%. This microgrid is simulated to examine the effects of MSoCL on the saving of the microgrid operator. This MSoCL changing does not affect to the charging energy at UCCS and CCS because these scenarios do not include the discharging EV. Thus, the results of simulation are the same totally with the base microgrid. The amount of discharging energy increases due to being suitable for 24 kWh dischargeable energy. The amount of charging and discharging energy increases with the discharging before EV charging. The saving of microgrid operator increases with large amount of energy transfer. Hence, the microgrid operator earns nearly 22 TL in a day at OCCDS. As it is seen from Table 25, the daily charging cost is the same with base microgrid. The total saving of the microgrid operator is nearly 3590 TL in a month.

Table 25. Overview of the Microgrid with 40% MSoCL for Case II

	WEVS	UCCS	CCS	CCDS	OCCDS
E_{ch} (kWh)	0	160.56	147.49	551.85	460.66
J_{ch} (TL)	0	97.48	69.94	259.27	192.52
C_{ch} (TL/kWh)	0	0.6071	0.4742	0.4698	0.4179
E_{disc} (kWh)	0	0	0	646.73	460.64
J_{disc} (TL)	0	0	0	296.03	214.59
C_{disc} (TL/kWh)	0	0	0	0.4577	0.4659
E_{mg} (kWh)	13828	14017	14001	13928	13978
J_{op} (TL)	6622	6720	6692	6585	6600
C_{mg} (TL/kWh)	0.4789	0.4794	0.4780	0.4728	0.4722
J_{pop} (TL)	0	Reference	28	135	120
J_{pop} (%)	0	Reference	0.42	2.01	1.79

Effect of Decrease in MSoCL

The MSoCL is decreased from 50% to 30% which equals to 60 km range and 28 kWh dischargeable energy is suitable to discharge by the microgrid operator. The amount of energy and the cost transaction between all participations are the same with different MSoCL at UCCS and CCS. According to Table 26, the amount of energy transfer increases at CCDS. The difference between average discharging price and charging cost are not changing significantly with different MSoCL at CCDS. However, the energy transfer between the microgrid and EVs decreases OCCDS; thus, the microgrid operator earns only 17 TL in a day with V2G operation. The daily charging cost is the same with different MSoCL. The total saving of the microgrid operator is nearly 3440 TL in a month. As it is seen from Figure 37, the time of charging and discharging are nearly the same for microgrid with different MSoCL but the amount of power consumption is changing.

Table 26. Overview of the Microgrid with 30% MSoCL for Case II

	WEVS	UCCS	CCS	CCDS	OCCDS
E_{ch} (kWh)	0	160.56	147.49	567.74	406.37
J_{ch} (TL)	0	97.48	69.94	266.44	169.64
C_{ch} (TL/kWh)	0	0.6071	0.4742	0.4693	0.4175
E_{disc} (kWh)	0	0	0	709.00	401.24
J_{disc} (TL)	0	0	0	324.66	186.89
C_{disc} (TL/kWh)	0	0	0	0.4579	0.4658
E_{mg} (kWh)	13828	14017	14001	13893	13965
J_{op} (TL)	6622	6720	6692	6564	6605
C_{mg} (TL/kWh)	0.4789	0.4794	0.4780	0.4725	0.4730
J_{pop} (TL)	0	Reference	28	156	115
J_{pop} (%)	0	Reference	0.42	2.32	1.71

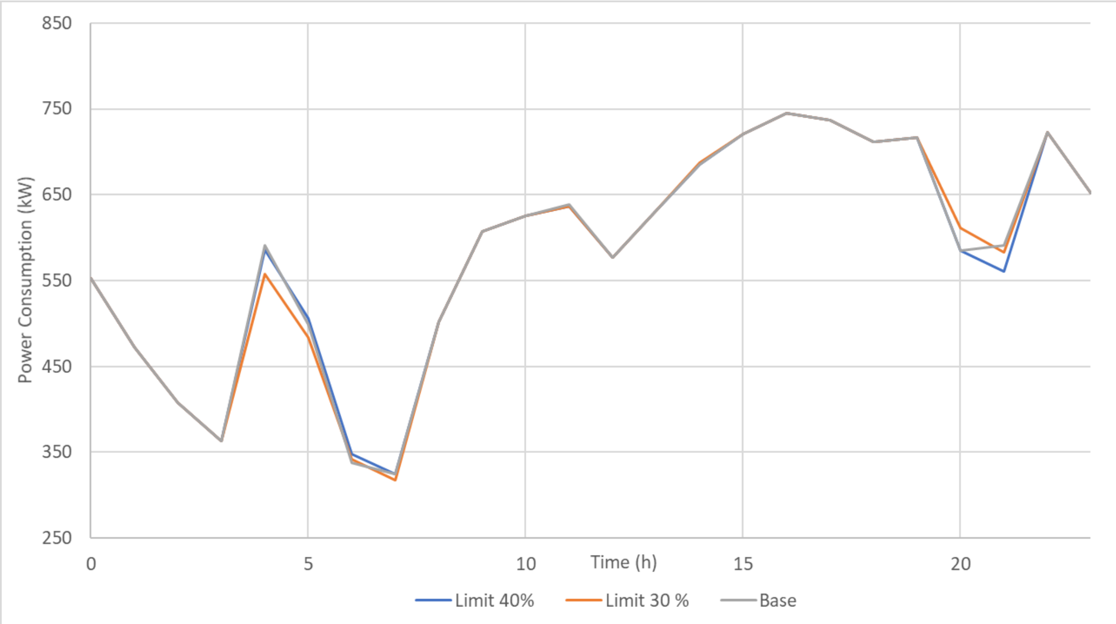

Figure 37. The Power Curve of the Microgrid with Different MSoCL for Case II

Effect of Travel Pattern with σ = 3

The travel pattern of EVs is important for the determination of the probability distribution of the arrival times and departure times. The standard deviation is changed from 1.25 to 3 hours to investigate the impact of the large time interval on the saving of the microgrid operator. According to Figure 38, the number of connected EV in an hour decreases but connection time interval increases with $\sigma = 3$.

The discharging energy decreases with the late arrival time of EVs because some EVs miss the hours of the most expensive prices. The charging energy also decreases because EVs also miss the low-priced hours with early departure of EVs. As a result of these, the average electricity cost of this microgrid increases significantly at CCDS and OCCDS with respect to the base microgrid. However, the microgrid operator earns nearly 34 TL in a day because of the low charging energy. The daily charging cost is nearly 92 TL. The total saving of the microgrid operator is 3770 TL in a month thanks to V2G operation and controlled charging operation.

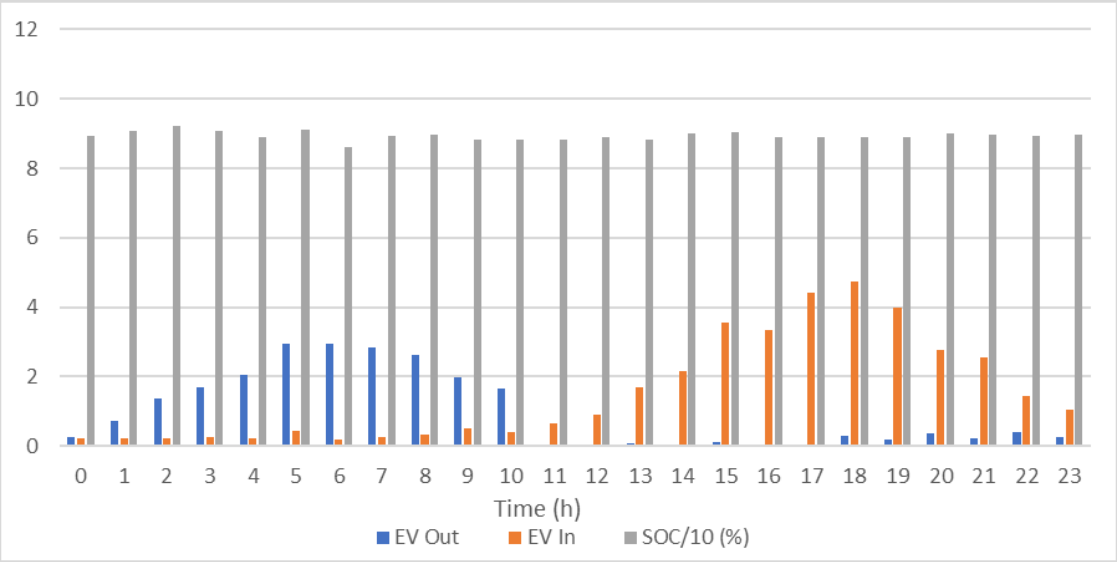

Figure 38. The Average Input Values of Case II with σ = 3

Table 27. Overview of the Microgrid with σ = 3 for Case II

	WEVS	UCCS	CCS	CCDS	OCCDS
E_{ch} (kWh)	0	153.20	138.45	301.71	314.56
J_{ch} (TL)	0	91.61	65.61	142.31	131.83
C_{ch} (TL/kWh)	0	0.5980	0.4739	0.4717	0.4190
E_{disc} (kWh)	0	0	0	443.69	355.96
J_{disc} (TL)	0	0	0	201.86	165.90
C_{disc} (TL/kWh)	0	0	0	0.4550	0.4660
E_{mg} (kWh)	13828	14008	13991	13806	13895
J_{op} (TL)	6622	6714	6688	6563	6588
C_{mg} (TL/kWh)	0.4789	0.4793	0.4780	0.4754	0.4741
J_{pop} (TL)	0	Reference	26	151	126
J_{pop} (%)	0	Reference	0.42	2.25	1.88

Effect of Travel Pattern with σ = 0.5

In order to investigate the impact of lower standard deviation related to arrive times and departure times, simulations are repeated for this case by using 0.5 hour. Figure 39 shows that the arrival and departure time intervals of EVs are shorter than the base case.

According to Table 28, the average charging cost decreases and the average discharging price increases at all scenarios. However, the saving of the microgrid operator spends nearly 5 TL in a day due to the large charging energy with σ = 0.5. The electricity cost is nearly 3180 TL in a month; thus, the total saving of the microgrid operator is 3450 TL in this microgrid.

As it is seen from Figure 40, EV charging and discharging are increasing with decreasing the connection time interval and these operations help to obtain flatter curve for the external power system.

Table 28. Overview of the Microgrid when σ = 0.5 for Case II

	WEVS	**UCCS**	**CCS**	**CCDS**	**OCCDS**
E_{ch} (kWh)	0	175.43	160.96	680.27	531.08
J_{ch} (TL)	0	106.17	76.38	319.89	221.42
C_{ch} (TL/kWh)	0	0.6052	0.4746	0.4702	0.4169
E_{disc} (kWh)	0	0	0	612.21	464.87
J_{disc} (TL)	0	0	0	280.24	216.90
C_{disc} (TL/kWh)	0	0	0	0.4578	0.4666
E_{mg} (kWh)	13828	14035	14017	14108	14058
J_{op} (TL)	6622	6728	6699	6661	6627
C_{mg} (TL/kWh)	0.4789	0.4794	0.4779	0.4722	0.4714
J_{pop} (TL)	0	Reference	29	67	101
J_{pop} (%)	0	Reference	0.43	1.00	1.50

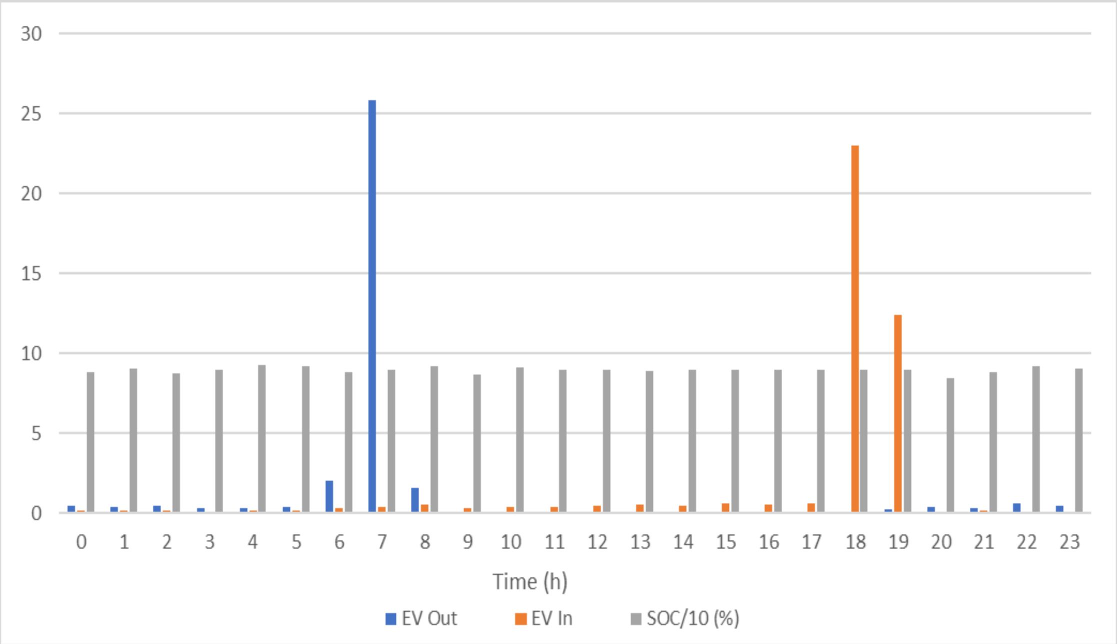

Figure 39. The Average Input Values of Case II with σ = 0.5

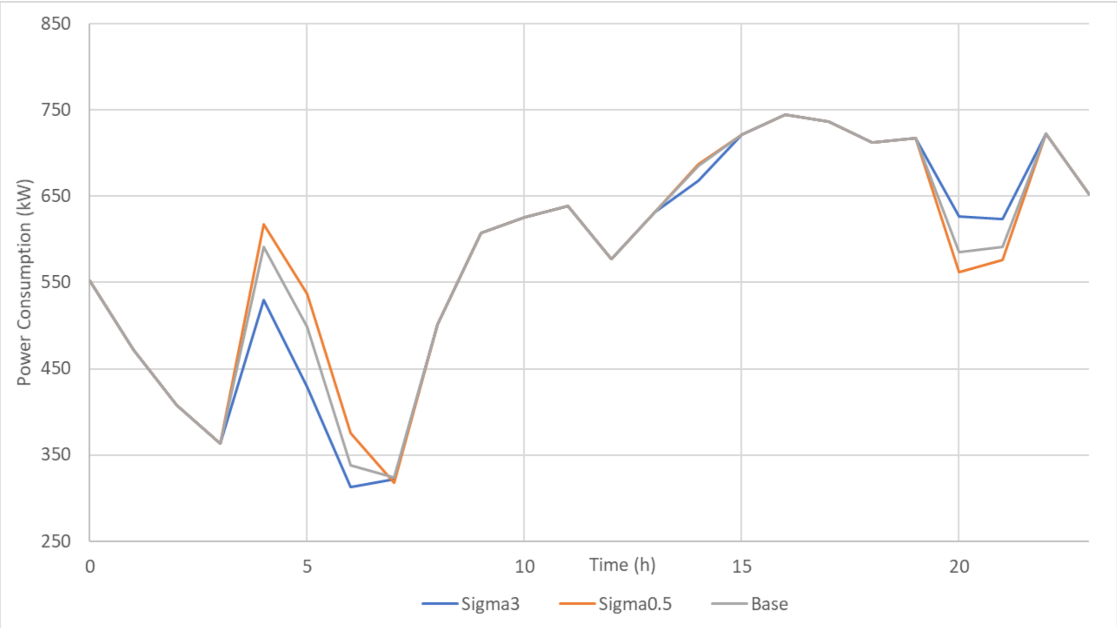

Figure 40. The Power Curve of the Microgrid with Different Travel Pattern for Case II

Effect of the Number of Charging Stations

In order to investigate the impact of the number of charging stations, this number increases to maximum EV numbers. According to Figure 41, the times of plug-in and plug-out are the same with the base microgrid, however, the number of EVs which is connected in an hour is doubled with respect to the base microgrid. Hence, the microgrid operator has more sources to get more reliable and economical microgrid. According to Table 29, the amount of energy transfer between the microgrid and EVs increases nearly two times of the base microgrid due to more controllable energy. The time of the charging and discharging are the same, thus, the average charging cost and discharging price are the same with the base microgrid. The saving of the microgrid operator earns nearly 21 TL in a day because of the large energy transfer. The electricity cost is nearly 194 TL in a day; thus, the total saving of the microgrid operator is 6440 TL in this microgrid because the large number of charging stations satisfies more capacity for the microgrid operator.

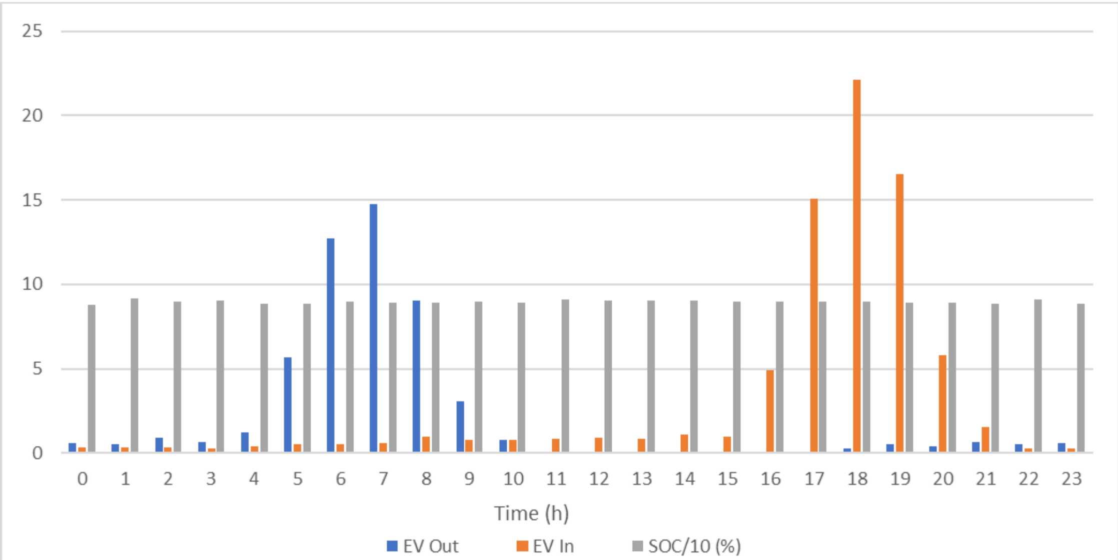

Figure 41. The Average Input Values of Case II with 100 Charging Stations

Table 29. Overview of the Microgrid with 100 Charging Stations for Case II

	WEVS	UCCS	CCS	CCDS	OCCDS
E_{ch} (kWh)	0	318.86	294.29	985.00	898.75
J_{ch} (TL)	0	193.60	139.53	464.07	376.14
C_{ch} (TL/kWh)	0	0.6071	0.4741	0.4711	0.4185
E_{disc} (kWh)	0	0	0	1073.49	830.95
J_{disc} (TL)	0	0	0	490.44	387.63
C_{disc} (TL/kWh)	0	0	0	0.4569	0.4665
E_{mg} (kWh)	13828	14203	14174	14074	14179
J_{mg} (TL)	6622	6816	6762	6596	6611
C_{mg} (TL/kWh)	0.4789	0.4799	0.4770	0.4686	0.4662
J_{pop} (TL)	0	Reference	54	120	105
J_{pop} (%)	0	Reference	0.79	1.76	1.54

At Figure 42, the peak of power consumption decreases with the discharging and the lowest power consumption increases with the charging. These changes provide curves for the external power system.

The charging cost in a day, the saving of V2G operation, and the total saving of the microgrid operator in a month are given at OCCDS with the hourly rate tariff at Table 30. The charging cost decreases with small battery because of needed small energy of EV. In addition, the saving of the microgrid operator of V2G operation decreases since the small energy can be controlled by the microgrid operator. Hence, the total saving of microgrid operator dramatically decreases with the small battery.

The charging cost is the same at different MSoCL values due to no discharging at UCCS. The saving of V2G operation increases with 40% MSoCL due to the large controllable energy on the battery and the total saving of the microgrid operator increases. However, this saving of the microgrid operator decreases with 30% MSoCL because of the small discharging energy.

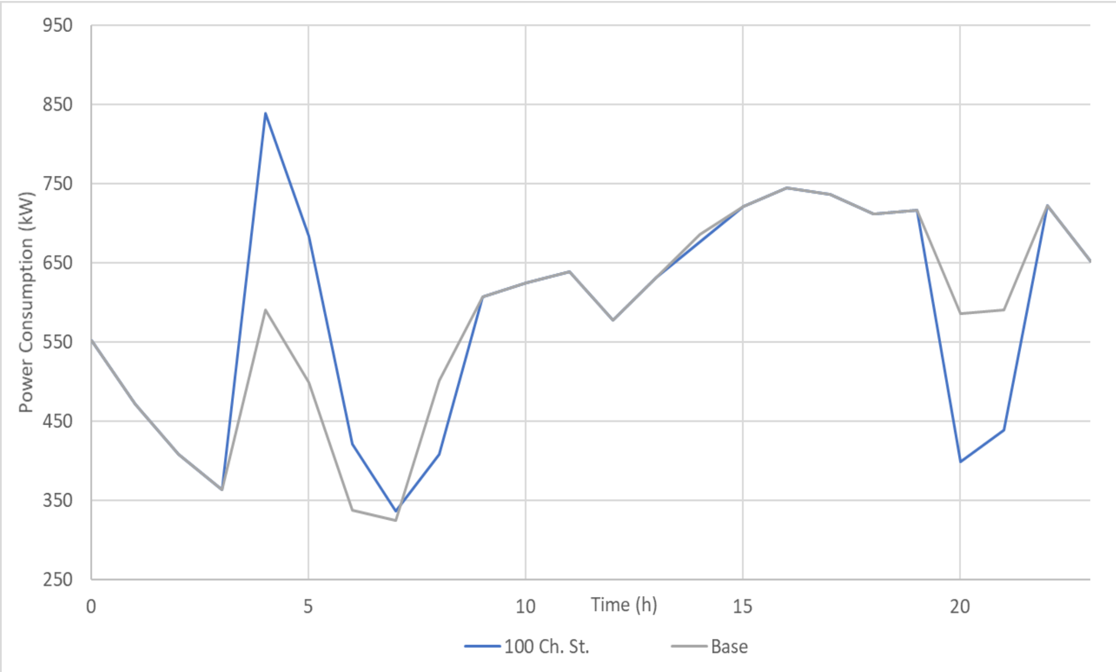

Figure 42. The Power Curve of the Microgrid with Different Number of Charging Stations for Case II

Table 30. The Saving of the MGO at Different Scenarios for Case II

OCCDS	J_{ch} (TL)	J_{popcd} (TL)	J_{pop}(TL)
Base	97.48	8.63	3200
30 kWh Battery	73.05	-3.67	2080
50 kWh Battery	121.36	16.64	4130
40% MSoCL	97.48	22.07	3590
30% MSoCL	97.48	17.25	3440
σ = 3	91.61	34.07	3770
σ = 0.5	106.17	-4.52	3450
100 Charging Stations	193.6	11.81	6440

The difference in travel pattern of EVs changes the saving of the microgrid operator. The effect of travel pattern highly depends on the electricity cost being near the mean time because some EVs can miss or catch chargeable or dischargeable times with large standard deviation. The saving of the microgrid operator with V2G increases with large standard deviation. However, the charging cost decreases with the increase in the standard deviation because some EVs connecting early time can catch chargeable times.

The large number of charging stations increases the amount of transfer energy. This energy provides more controllable energy for the microgrid operator. In this way, the saving of the microgrid operator is nearly doubled with 100 charging stations.

The electricity cost is low-priced between 04:00 and 07:00 in a day. Thus, EVs are charging at these hours. In this case, EVs are discharging when EVs are connected to the microgrid. The discharging occurs before EV charging; thus, the energy transfer between EVs and the microgrid is very high with respect to Case I. In addition to this, the saving of microgrid operator at Case II is lower than Case I because EVs depart from the microgrid with 100% SoC at Case II and 50% SoC at Case I.

4.1.2.2. Results with Time-of-Use Tariff

The connected time period for EVs occurs mostly between 19:00 and 08:00 in the residential microgrid. This period includes the low-priced and the most expensive price of a day. The first hour of this connection is the most expensive price of a day until 22:00. After these hours, the time has the low-priced of a day until 06:00.

According to Figure 43, the times of charging at CCS and CCDS are slipped from 23:00 to 22:00 with respect to the hourly rate tariff because of the electricity cost. The charging occurs between 04:00 and 07:00 at hourly rate tariff. However, this charging occurs between 22:00 and 00:00 at OCCDS in this microgrid. The time of discharging is the same with hourly rate tariff in the residential microgrid case because the time of low-priced is located at first hours of this microgrid. As it is seen from Figure 44, EVs

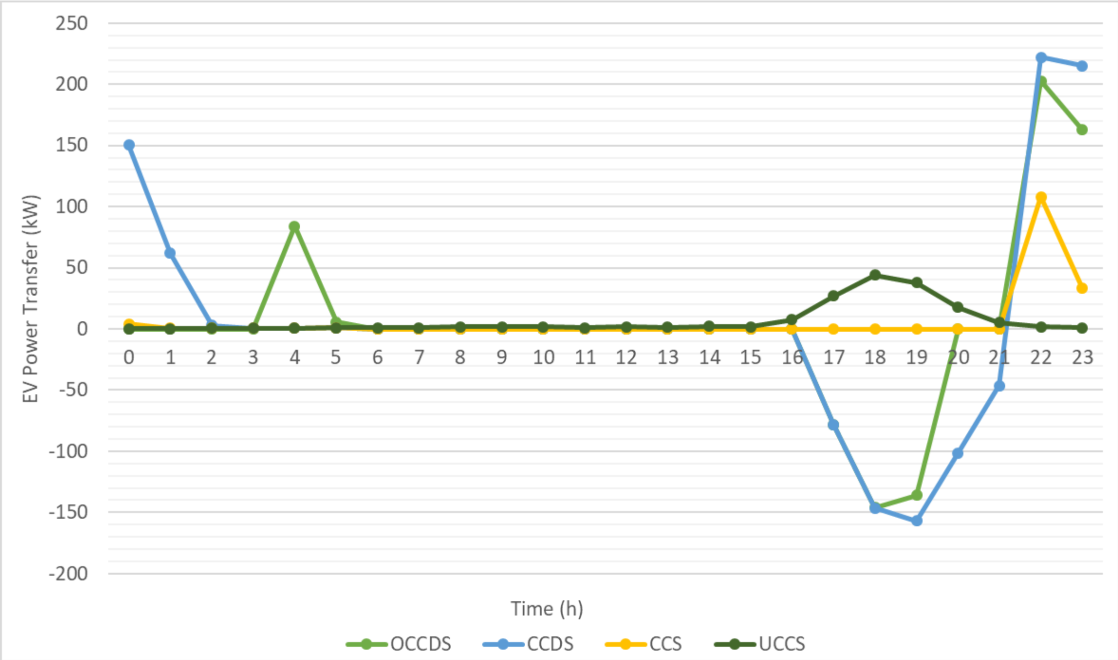

Figure 43. The Power Transfer Between the Microgrid and EVs for Case II with TOUT

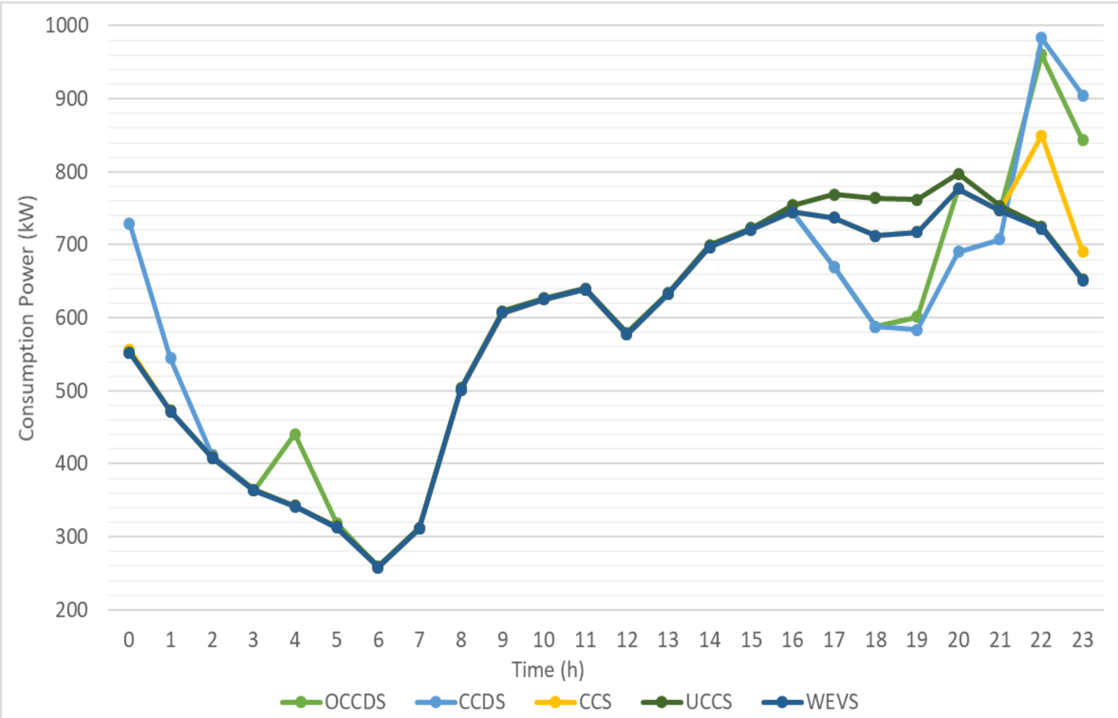

Figure 44. The Power Curve of the Microgrid Case II with TOUT

charging increases the peak of power consumption and the new peak occurs at OCCDS. This situation has a disadvantage to obtain flatter curve for the external power system. However, EVs discharging help to obtain flatter curve between 17:00 and 21:00 for the external power system. According Table 31, the average charging cost and discharging price are very different from the hourly rate tariff. In this case, the difference between the average discharging and charging price is nearly 0.28 TL for each kWh. This difference provides a higher saving for the microgrid operator for each kWh. In addition, the average charging cost at OCCDS and CCDS are nearly 54% economic than UCCS. The average electricity cost is higher at time-of-use tariff. In addition, the total cost of the microgrid is 7690 TL at WEVS instead of 6622 TL in the base microgrid. The saving of the microgrid operator also increases because of the difference between the electricity cost in different time slides. Thus, the microgrid operator has a higher saving with time-of-use tariff thanks to V2G operation. Moreover, the time-of-use tariff provides the total saving for the microgrid operator at Case I and Case II with respect to hourly rate tariff.

Table 31. Overview of the Microgrid for Case II with TOUT

	WEVS	**UCCS**	**CCS**	**CCDS**	**OCCDS**
E_{ch} (kWh)	0	161.7	148.5	654.9	455.2
J_{ch} (TL)	0	141.65	59.47	262.27	182.30
C_{ch} (TL/kWh)	0	0.8761	0.4005	0.4005	0.4005
E_{disc} (kWh)	0	0	0	529.9	360.4
J_{disc} (TL)	0	0	0	360.23	244.97
C_{disc} (TL/kWh)	0	0	0	0.6797	0.6797
E_{mg} (kWh)	13828	14018	14003	14148	14057
J_{op} (TL)	7690	7832	7750	7592	7628
C_{mg} (TL/kWh)	0.5561	0.5587	0.5535	0.5366	0.5426
J_{pop} (TL)	0	Reference	82	240	204
J_{pop} (%)	0	Reference	1.05	3.07	2.63

The microgrid operator saves nearly 63 TL in a day at OCCDS with V2G operation. The controlled charging provides 141 TL saving with respect to UCCS. Hence, the total saving of the microgrid operator is 204 TL in a day thanks to the controlled charging and V2G. The total saving of the microgrid operator is 6120 TL in a month and it is nearly two times of the saving at hourly rate tariff.

Effects of Variables

A larger battery capacity and a low MSOCL provide flexibility for the operator based on the higher controllable energy for charging and discharging. These changes increase the time of the charging and discharging but the average charging cost and discharging price are the same because these operations occur at the same price level. Hence, the average charging cost and discharging price are nearly the same with different battery capacity and MSoCL values. However, the charging cost increases with the increase in the battery capacity due to the large amount energy transfer. According to Table 32, the microgrid operator has the same amount of saving for each kWh as the base microgrid. The charging energy increases with discharging energy at low MSoCL because of the time of discharging. This situation is different from Case I.

Increasing the number of charging stations also provides larger controllable energy for the microgrid operator. As it is seen in Table 33, the increase in the amount of the energy transfer results in a higher saving for the microgrid operator. The charging cost and the amount of the energy transfer are nearly doubled with respect to the base residential microgrid. The increase in standard deviation value decreases the amount of charging and discharging energy exactly opposite to the hourly rate tariff because of the electricity cost of the near time of the mean. Thus, the saving of the microgrid operator is lower than the base microgrid due to the smaller amount of the energy transfer between EVs and the microgrid. According to Table 34, the charging cost also decreases with the increase in the standard deviation.

Table 32. Overview of the Microgrid with Different Variables for Case II with TOUT

		WEVS	UCCS	CCS	CCDS	OCCDS
30 kWh Battery	**E_{ch} (kWh)**	0	121.8	111.6	500.5	334.6
	C_{ch} (TL/kWh)	0	0.8753	0.4005	0.4005	0.4005
	E_{disc} (kWh)	0	0	0	406.1	238.0
	C_{disc} (TL/kWh)	0	0	0	0.6797	0.6797
	C_{mg} (TL/kWh)	0.5561	0.5581	0.5541	0.5411	0.5466
	J_{op} (TL)	7690	7797	7735	7615	7663
	J_{pop} (TL)	0	Reference	62	182	135
50 kWh Battery	**E_{ch} (kWh)**	0	201.3	185.2	795.2	549.6
	C_{ch} (TL/kWh)	0	0.8760	0.4005	0.4005	0.4005
	E_{disc} (kWh)	0	0	0	640.2	513.8
	C_{disc} (TL/kWh)	0	0	0	0.6797	06797
	C_{mg} (TL/kWh)	0.5561	0.5593	0.5528	0.5326	0.5386
	J_{op} (TL)	7690	7867	7765	7574	7561
	J_{pop} (TL)	0	Reference	102	293	306
30% MSoCL	**E_{ch} (kWh)**	0	161.7	148.5	855.0	591.8
	C_{ch} (TL/kWh)	0	0.8761	0.4005	0.4005	0.4005
	E_{disc} (kWh)	0	0	0	740.9	631.2
	C_{disc} (TL/kWh)	0	0	0	0.6797	0.6797
	C_{mg} (TL/kWh)	0.5561	0.5587	0.5535	0.5301	05361
	J_{op} (TL)	7690	7832	7750	7529	7498
	J_{pop} (TL)	0	Reference	82	303	334
40% MSoCL	**E_{ch} (kWh)**	0	161.7	148.2	756.9	542.3
	C_{ch} (TL/kWh)	0	0.8716	0.4018	0.4013	0.4007
	E_{disc} (kWh)	0	0	0	643.9	515.9
	C_{disc} (TL/kWh)	0	0	0	0.6755	0.6760
	C_{mg} (TL/kWh)	0.5561	0.5571	0.5520	0.5319	0.5373
	J_{op} (TL)	7690	7810	7729	7538	7538
	J_{pop} (TL)	0	Reference	81	272	273

Table 33. Overview of the Microgrid with Different Variables for Case II with TOUT

		WEVS	UCCS	CCS	CCDS	OCCDS
σ = 0.5	**E_{ch} (kWh)**	0	168.2	156.0	719.7	499.1
	C_{ch} (TL/kWh)	0	0.8967	0.4005	0.4005	0.4005
	E_{disc} (kWh)	0	0	0	591.0	385.9
	C_{disc} (TL/kWh)	0	0	0	0.6797	0.6797
	C_{mg} (TL/kWh)	0.5561	0.5591	0.5533	0.5346	0.5415
	J_{pop} (TL)	0	Reference	88	264	214
σ = 3	**E_{ch} (kWh)**	0	157.9	143.9	574.5	416.0
	C_{ch} (TL/kWh)	0	0.7725	0.4005	0.4005	0.4005
	E_{disc} (kWh)	0	0	0	451.9	343.9
	C_{disc} (TL/kWh)	0	0	0	0.6797	0.6797
	C_{mg} (TL/kWh)	0.5561	0.5575	0.5535	0.5392	0.5435
	J_{pop} (TL)	0	Reference	64	199	189
100 Charging Stations	**E_{ch} (kWh)**	0	326.8	297.7	1333.4	933.5
	C_{ch} (TL/kWh)	0	0.8746	0.4005	0.4005	0.4005
	E_{disc} (kWh)	0	0	0	1083.3	744.4
	C_{disc} (TL/kWh)	0	0	0	0.6797	0.6797
	C_{mg} (TL/kWh)	0.5561	0.5612	0.5508	0.5173	0.5289
	J_{pop} (TL)	0	Reference	117	488	418

Table 34. The Saving of the MGO at Different Scenarios for Case II with TOUT

OCCDS	**J_{ch} (TL)**	**J_{popcd} (TL)**	**J_{pop}(TL)**
Base	141.65	98	6130
30 kWh Battery	106.57	76	4030
50 kWh Battery	176.34	117	9160
40% MSoCL	140.95	131	8170
30% MSoCL	141.65	161	10010
σ = 3	121.96	77	5670
σ = 0.5	150.84	113	6400
100 Charging Stations	285.81	202	12540

The effect of variables on the saving of the microgrid operator is the same with hourly rate tariff without microgrids with 30% MSoCL and $\sigma = 3$. The saving of the microgrid operator increases with time-of-use tariff in the microgrid with 30% MSoCL, however, this saving decreases at $\sigma = 3$ microgrid. Moreover, the saving of the microgrid operator increases with the time-of-use tariff.

4.1.2.3. Results for February

The price of the electricity, the solar power plant generation and daily load differentiate in accordance with the months. The microgrid operator decides the charging and discharging basically based on the electricity cost. Thus, the decisions of the microgrid operator in February are very different from August.

According to Figure 45, the EV discharging occurs between 09:00 and 12:00 and this time period is the peak of the electricity price in a day and it is different from August simulations. Thus, the EV charging occurs before the discharging; thus, the energy transfer significantly decreases. Moreover, some EVs depart from the microgrid at 08:00, thus, very few EVs are connected to the microgrid at dischargeable times. This situation also causes low energy transfer between the microgrid and EVs. The decrease in the energy transfer decreases the saving of the microgrid operator. As it is seen from Figure 46, the overload of the microgrid between 21:00 and 23:00 in August is not seen in February for each scenario. Hence, the microgrid operator has a flatter demand curve for the external power system. This overload is seen only at UCCS due to the uncontrolled charging.

The average electricity cost in February equals to 0.4766 TL/kWh instead of 0.4615 TL/kWh in August without the energy consumption. The energy consumption in February is nearly 3000 MWh lower than in August for one day.

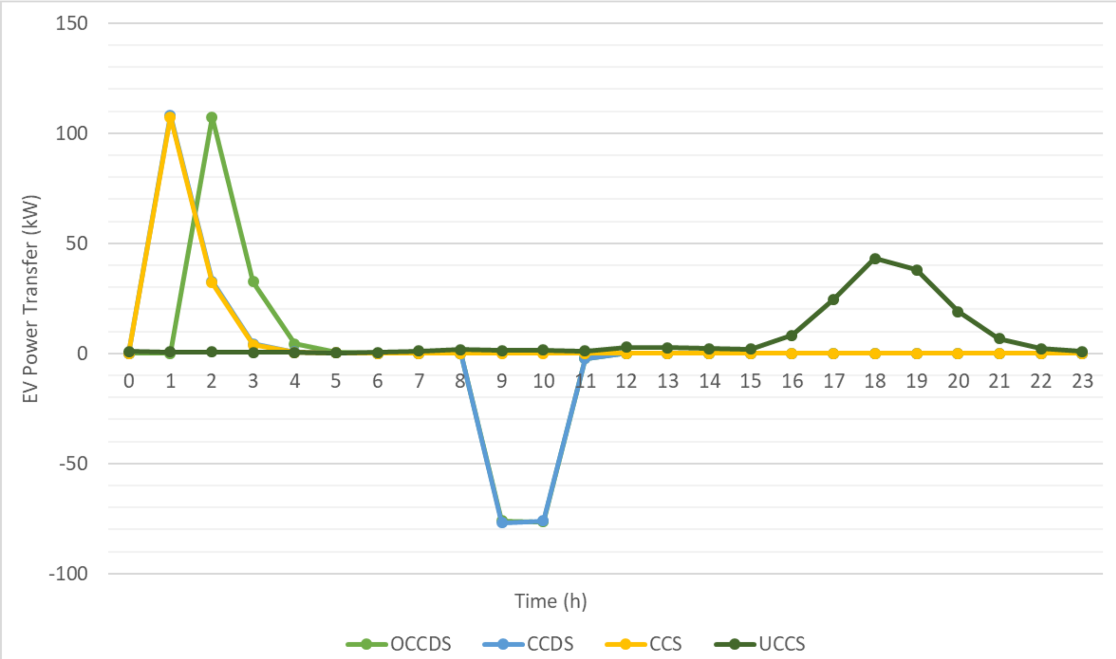

Figure 45. The Power Transfer Between the Microgrid and EVs for Case II in February

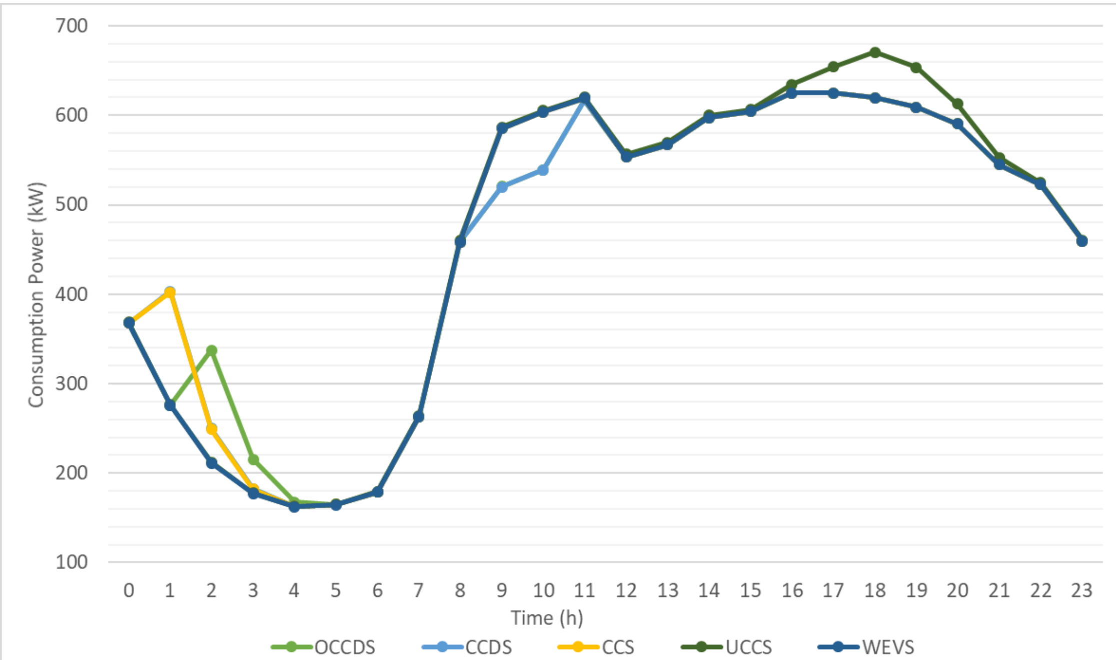

Figure 46. The Power Curve of the Microgrid for Case II in February

Table 35. Overview of the Microgrid for Case II in February

	WEVS	UCCS	CCS	CCDS	OCCDS
E_{ch} (kWh)	0	162.9	144.3	146.3	144.6
J_{ch} (TL)	0	93.7	69.7	70.6	66.0
C_{ch} (TL/kWh)	0	0.5754	0.4828	0.4826	0.4567
E_{disc} (kWh)	0	0	0	155.4	154.8
J_{disc} (TL)	0	0	0	73.5	73.2
C_{disc} (TL/kWh)	0	0	0	0.4731	0.4731
E_{mg} (kWh)	10984	11176	11154	11024	11023
J_{op} (TL)	5443	5516	5492	5420	5414
C_{mg} (TL/kWh)	0.4937	0.4936	0.4924	0.4916	0.4913
J_{pop} (TL)	0	Reference	24	96	102
J_{pop} (%)	0	Reference	0.44	1.74	1.85

According to Table 35, the average charging cost is very close to the value in February and August at CCS and CCDS, however, the average charging cost at UCCS decreases and the average charging cost at OCCDS increases in February with respect to August. In addition to this, the average discharging price is lower than the average charging cost at CCDS. Hence, the microgrid operator makes a loss for each kWh between the charging and discharging at CCDS. The average discharging price and charging cost in February are higher and the difference between the average charging cost and discharging prices is lower than August at OCCDS. Thus, the saving of the microgrid operator decreases for each kWh. Moreover, the saving of the microgrid operator decreases with these average prices and low energy transfer between EVs and the microgrid.

The microgrid operator earns nearly 7 TL in a day at OCCDS. The daily charging cost is nearly 94 TL at UCCS. The total saving of the microgrid is 3030 TL in a month because of controlled charging and V2G operation.

Table 36. Overview of the Microgrid with Variables for Case II in February

		UCCS	CCS	CCDS	OCCDS
30 kWh Battery	**C_{ch} (TL/kWh)**	0.5737	0.4868	0.4866	0.4568
	C_{disc} (TL/kWh)	0	0	0.4730	0.4732
	J_{pop} (TL)	Reference	17	90	92
50 kWh Battery	**C_{ch} (TL/kWh)**	0.5767	0.4793	0.4792	0.4559
	C_{disc} (TL/kWh)	0	0	0.4731	0.4592
	J_{pop} (TL)	Reference	31	104	105
%40 MSoCL	**C_{ch} (TL/kWh)**	0.5754	0.4828	0.4826	0.4559
	C_{disc} (TL/kWh)	0	0	0.4731	0.4591
	J_{pop} (TL)	Reference	24	96	92
%30 MSoCL	**C_{ch} (TL/kWh)**	0.5754	0.4828	0.4826	0.4586
	C_{disc} (TL/kWh)	0	0	0.4731	0.4553
	J_{pop} (TL)	Reference	24	97	80
σ = 3	**C_{ch} (TL/kWh)**	0.5758	0.4829	0.4827	0.4569
	C_{disc} (TL/kWh)	0	0	0.4729	0.4730
	J_{pop} (TL)	Reference	24	109	115
σ = 0.5	**C_{ch} (TL/kWh)**	0.5734	0.4827	0.4825	0.4568
	C_{disc} (TL/kWh)	0	0	0.4735	0.4735
	J_{pop} (TL)	Reference	25	72	76
100 Charging Stations	**C_{ch} (TL/kWh)**	0.5744	0.4827	0.4825	0.4568
	C_{disc} (TL/kWh)	0	0	0.4732	0.4732
	J_{pop} (TL)	Reference	45	199	202

Effects of Variables

The time of energy transfer between EVs and the microgrid with different variables are nearly the same with the base microgrid. However, the effect of variables on the saving of the microgrid operator is different from August simulations. The saving of V2G operation decreases due to the increase in the charging energy, however, the total saving of the microgrid operator increases with the increase in the battery capacity. The charging cost is the same for different values of MSoCL, but the total saving of the microgrid operator decreases with the decrease in MSoCL due to the large charging energy. In addition, the total saving of the microgrid operator does not change significantly when MSoCL decreases from 50% to 40%.

In addition to the mean arrival and departure times, the corresponding standard deviation value in a way specifies the travel pattern of EVs. The charging energy in an hour decreases with $\sigma = 3$ due to the late connected time of EVs. In this way, the peak energy consumption of the external power system decreases. Moreover, the saving of V2G operation also increases with the small amount of the charging energy. The saving of V2G operation and the EV charging cost are doubled with the increase in the energy transfer at 100 charging stations. Hence, the total saving of the microgrid operator is also doubled with these savings.

4.1.3. Simulation Results of Case III

The Case III is that charging stations are integrated to residential and commercial places in the microgrid. The microgrid includes residential and commercial prosumers for this Case III. The algorithm generates the arrival and departure time of EVs. In this microgrid, EVs are unconnected from the microgrid among two hours in a day, thus, EVs have long connection time for Case III. The most unconnected time of EVs is between 17:00 and 19:00 and between 06:00 and 8:00. At the Case III, the curve of the electricity cost is more important with respect to other cases because of the long connection time of EVs. An EV is connected to microgrid nearly twenty-two hours instead of ten hours. This simulation is run among thirty day to see continuity of the microgrid operation.

4.1.3.1. Results with Hourly Rate Tariff

The G2V operation occurs in every hour with nearly constant consumption at UCCS. This charging energy changes between 4 kWh and 15 kWh. This energy increases when EVs are connected to the microgrid after travels. At CCS, the charging does not occur between 08:00 and 23:00, the charging starts at 23:00 with suitable electricity costs. The charging scenario at CCDS is nearly the same with CCS, however, some EVs which are connected between 16:00 and 20:00 connect with under 50% SoC because of travels and V2G operation. These EVs are charged directly until 50% SoC by the microgrid operator. At the same time, some EVs which have above 50% SoC are discharged by the microgrid operator due to the electricity cost. EVs are charging between 23:00 and 07:00 until 100% SoC. The discharging occurs mostly at 11:00 and after 13:00, thus, EVs travels with 50% SoC at evening.

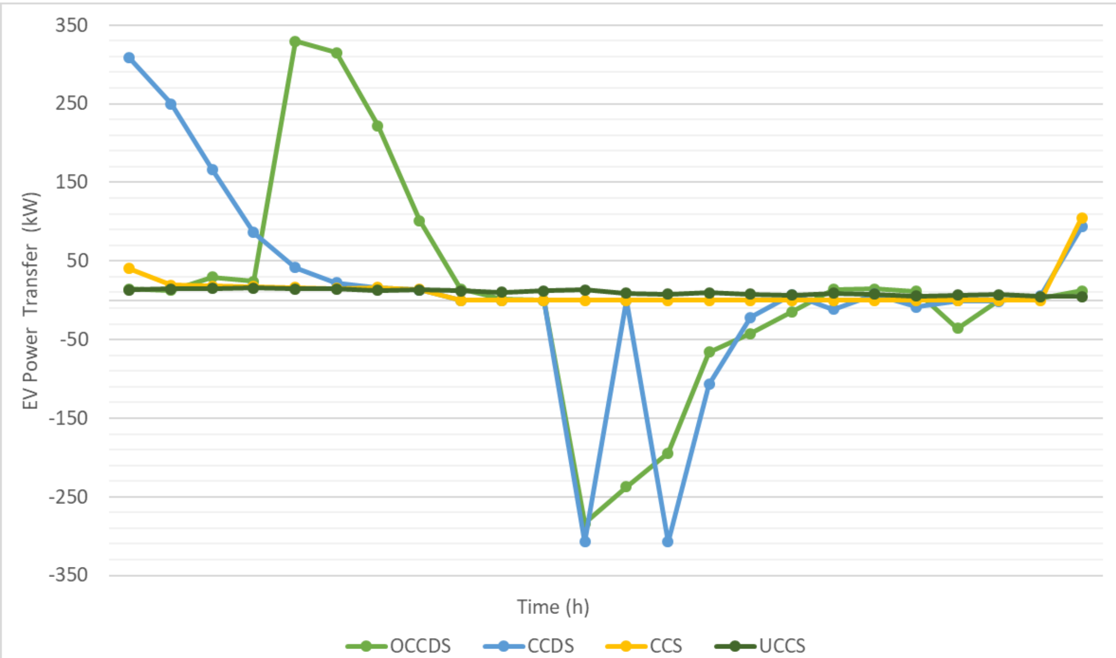

Figure 47. The Daily Power Transfer Between the Microgrid and EVs for Case III

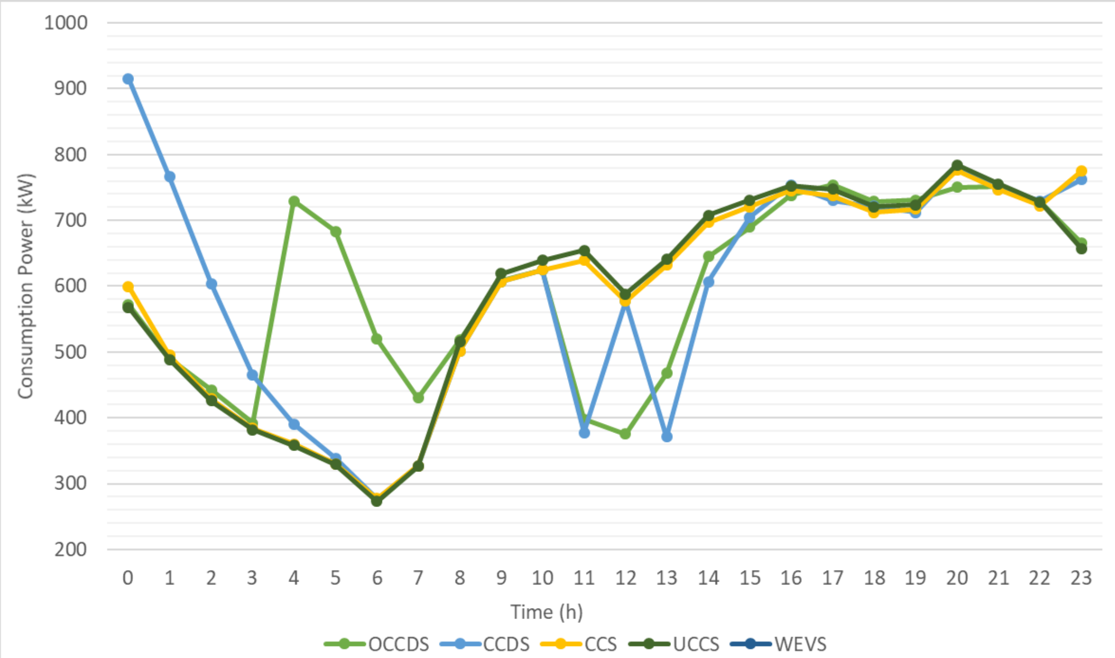

Figure 48. The Daily Power Curve of the Microgrid for Case III

The period of charging occurs between 04:00 and 08:00 at OCCDS. However, the charging starts at 19:00 for EVs which have under 50% SoC. The discharging occurs between 11:00 and 17:00 because of the electricity cost. The discharging also continues after 20:00, however, most EVs have under 50% SoC. Thus, V2G and G2V operations are applied to connected EVs at same time by the microgrid operator.

At Figure 47, the average daily energy transfer data between EVs and microgrid of thirty days are given to analyze the data accurately. According to Figure 48, the time of most power consumption of the loads is between 16:00 and 21:00. At Case II, this peak decreases with EV discharging, however, this peak does not change at Case III. due to not having sufficient discharging energy at batteries of EVs. The lowest power consumption of the microgrid is seen between 03:00 and 07:00. EVs are charging at these hours by the microgrid operator with OCCDS. This discharging helps to obtain flatter curve for the external power system. At CCDS, G2V operation starts at 23:00 which is before the lowest power consumption. The new peak is created by the microgrid operator at CCDS at 00:00 and 01:00. In addition to this, the power curve of the microgrid at thirty day is given in Figure 49 to see the power consumption of the microgrid with EVs among thirty days. The daily curve is changing day by day but this changing is not major.

According to Table 37, the total charging energies at UCCS and CCS are very low with respect to CCDS and OCCDS due to discharging. The saving of the microgrid operator at Case III is not thirty times at Case I and Case II with thirty days at all scenarios. The average charging cost at CCDS is higher than at CCS because of the increase in the amount of the charging energy with discharging. The charging operation takes more time and this situation occurs at the time of high electricity cost with respect to CCS. In addition, some EVs are charging at CCDS with high electricity cost when EVs are connected to the microgrid due to the SoC values of EVs. This situation also occurs at OCCDS and increases the price of the average charging cost. However, the average charging cost is lower than at CCDS because the microgrid operator schedules the charging and discharging operations before a day.

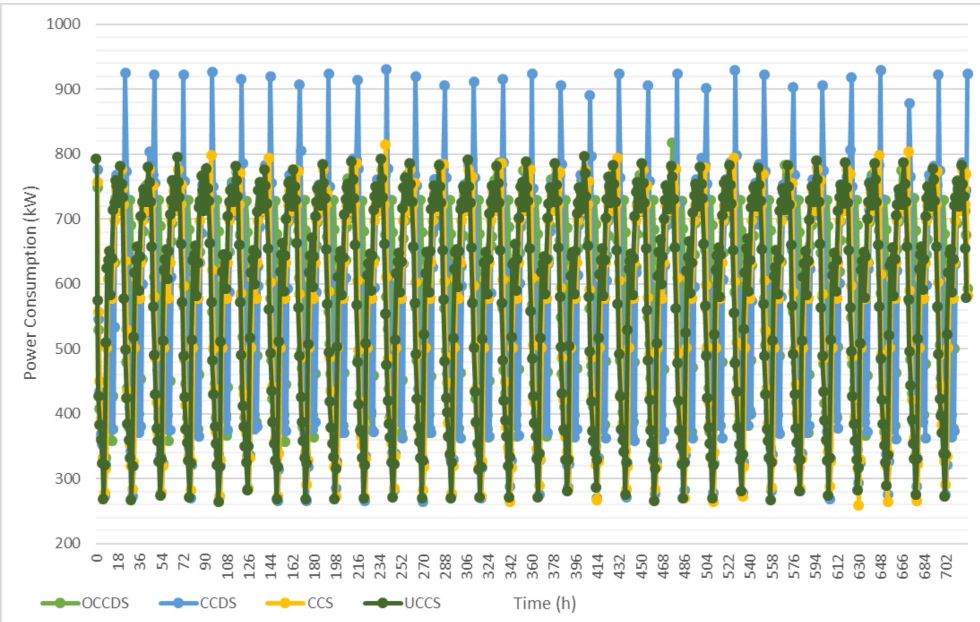

Figure 49. The Power Curve of the Microgrid for Case III

Table 37. Overview of the Microgrid for Case III

	WEVS	UCCS	CCS	CCDS	OCCDS
E_{ch} (kWh)	0	7646	7693	31485	35645
J_{ch} (TL)	0	4017	3533	14803	15709
C_{ch} (TL/kWh)	0	0.5254	0.4592	0.4702	0.4407
E_{disc} (kWh)	0	0	0	24312	28974
J_{disc} (TL)	0	0	0	10887	12764
C_{disc} (TL/kWh)	0	0	0	0.4478	0.4405
E_{mg} (kWh)	414740	423736	423891	431116	432048
J_{op} (TL)	198622	202639	202154	202538	201567
C_{op} (TL/kWh)	0.4789	0.4782	0.4770	0.4698	0.4665
J_{pop} (TL)	0	Reference	485	101	1072
J_{pop} (%)	0	Reference	0.24	0.05	0.53

The average charging cost at OCCDS becomes 0.085 TL more economic than UCCS. The average discharging price nearly equals to the average charging cost at OCCDS; thus, the microgrid operator cannot earn remarkable saving for each kWh. The microgrid operator spends 58 TL for each EV in a month at OCCDS. The monthly charging cost is nearly 80 TL at UCCS. Hence, the saving of the microgrid operator is 22 TL for each EV in a month thanks to controlled charging and V2G. The total saving of the microgrid operator is 1072 TL in a month.

4.1.3.2. Results with Time-of-Use Tariff

At UCCS, EVs are charging in every hour with almost constant consumption which is between 5 kWh and 16 kWh as in Case II. The EV charging occurs between 22:00 and 06:00 when are the peak-off time of time-of use tariff. Some EVs are connected to the microgrid after 18:00 and they are seen with under 50% SoC at CCDS and OCCDS.

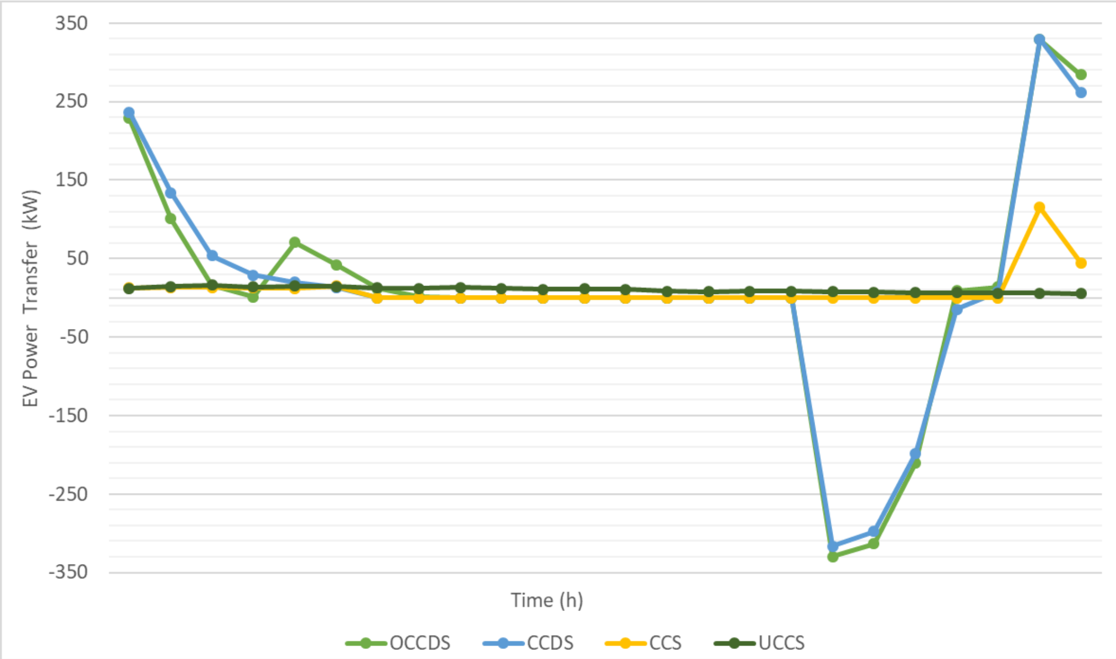

Figure 50. The Daily Power Transfer Between the Microgrid and EVs for Case III with TOUT

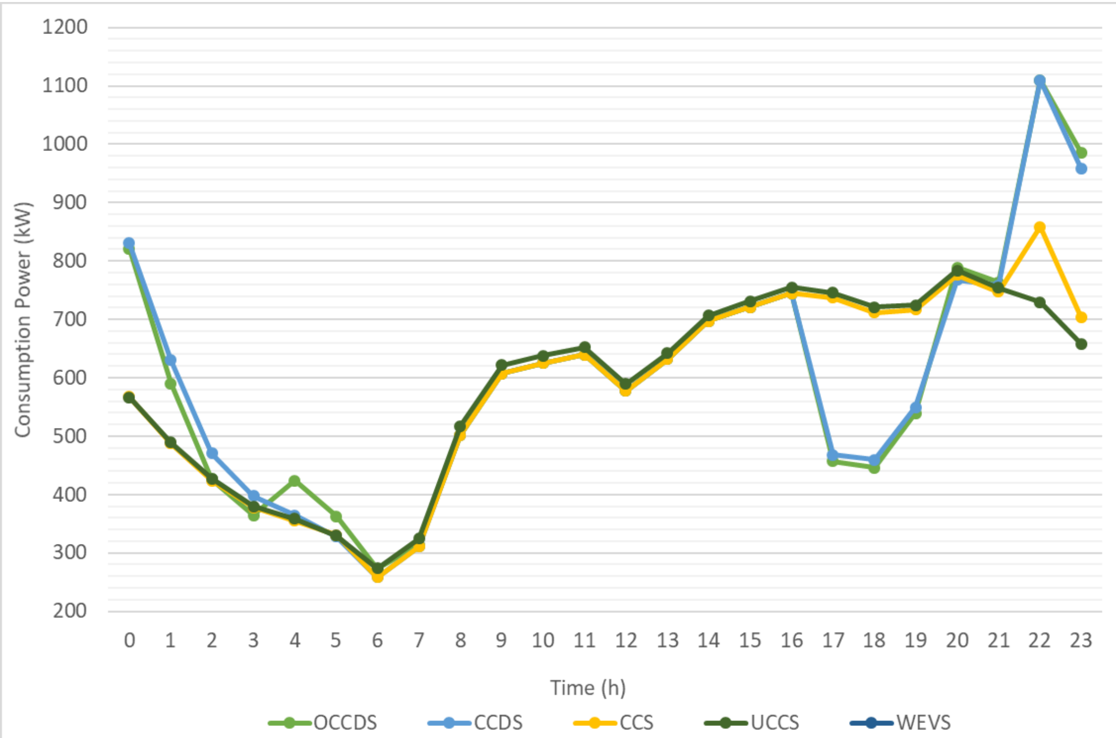

Figure 51. The Daily Power Curve of the Microgrid for Case III with TOUT

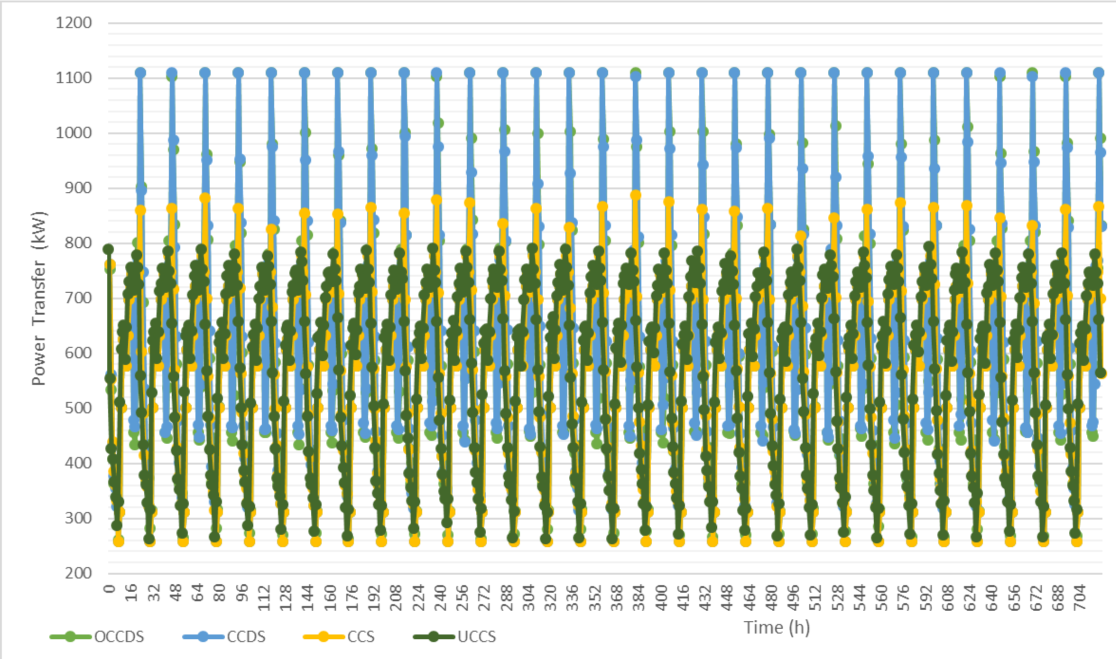

Figure 52. The Power Curve of the Microgrid for Case III with TOUT

These EVs are directly charging by the microgrid operator. Thus, the charging scenarios are similar with CCS without this directly charging. EVs are discharging at the time of peak of the electricity cost curve which are between 18:00 and 22:00. In addition, EVs are not discharging between their two travels. These situations provide 100% SoC for EVs to two travels in a day. The number of EVs which are under 50% SoC is lower than Case II. At Figure 50, the average daily energy transfer data between EVs and microgrid of thirty days are given to analyze the data accurately. The peak time of the power consumption curve of this microgrid is between 16:00 and 21:00.

As it is seen in Figure 51, V2G operation occurs at this time and it helps to decrease in the peak for the external power system. G2V operation also helps to obtain flatter power consumption curve, however, almost EVs reaches to 100% SoC before 05:00 Thus, the lowest power consumptions cannot increase sufficiently by the microgrid operator. Moreover, the new peak is created by the microgrid operator at CCS, CCDS and OCCDS between 22:00 and 01:00. The daily power consumption curve in Figure 51 is obtained with the average values of thirty day which is given in Figure 52.

According to Table 38, the total charging energy at UCCS and CCS is very low with respect to CCDS and OCCDS due to discharging energy. Minimum average charging cost is obtained with CCS due to short time of G2V operation. However, the average charging cost increases with the increase in the time of the charging at CCDS and OCCDS. The difference between the average charging cost and discharging price are nearly 0.26 TL for each kWh. Therefore, the time-of-use tariff provides higher saving for the microgrid operator for each kWh than the hourly rate tariff. However, the total payment of the microgrid operator is nearly 25500 TL and this payment higher than the hourly rate tariff due to the difference of the average electricity cost. At OCCDS, the microgrid operator earns nearly 73 TL from each EV in a month, including charging EV. The monthly G2V operation cost is nearly 90 TL at UCCS. Hence, the total saving of the microgrid operator is 163 TL in a month thanks to controlled charging and V2G. The total saving of the microgrid operator is 8162 TL in a month.

Table 38. Overview of the Microgrid for Case III with TOUT

	WEVS	**UCCS**	**CCS**	**CCDS**	**OCCDS**
E_{ch} (kWh)	0	7692	7682	33008	33432
J_{ch} (TL)	0	4501	3077	13669	13967
C_{ch} (TL/kWh)	0	0.5852	0.4005	0.4141	0.4178
E_{disc} (kWh)	0	0	0	25603	25933
J_{disc} (TL)	0	0	0	17404	17628
C_{disc} (TL/kWh)	0	0	0	0.6797	0.6797
E_{mg} (kWh)	414740	423789	423777	431810	432028
J_{op} (TL)	230679	235180	233756	226944	227018
C_{op} (TL/kWh)	0.5562	0.5549	0.5416	0.5256	0.5255
J_{pop} (TL)	0	Reference	1424	8263	8162
J_{pop} (%)	0	Reference	0.61	3.50	3.47

4.2. Discussion of Simulation Results

In the previous section, different microgrids with different conditions and different variables are simulated. These results give opinions about the operational cost and the saving of the microgrid operator.

The saving and cost of the microgrid operator change with different scenarios. The integration of EVs with uncontrolled charging scenario increases the average cost of the microgrid operator. On the other hand, the controlled scenarios result in a more economic operation than the uncontrolled scenario. This result shows that the control of the charging operation is important to obtain higher savings for the microgrid operator. In addition, the microgrid operator obtains a higher saving with the implementation of V2G operation. The microgrid operator has a higher saving for each kWh at OCCDS. On the other hand, the total saving of the microgrid operator is sometimes higher at CCDS because of the high amount of energy transfer between the microgrid and EVs.

Looking at results of Case I, the energy transfer between the microgrid and EVs occurs during the first hours of the connection time of EVs. After this, the EVs are discharged by the microgrid operator in the middle and end time of connection times of EVs with respect to the cost of the electricity. This situation results in a more total saving for the microgrid operator. However, SoC of EVs is nearly 50% when EVs depart from the microgrid and it provides a smaller travel range for EV owners. Hence, the commercial prosumers provide more total saving for microgrid operator although the small travel range for EV owners.

The times of lowest and highest hourly electricity costs do not include the EVs connection times of Case I for hourly rate tariff. Moreover, the connection times of EVs at Case I do not include the lowest price part at the time-of-use tariff. For time-of-use tariff, the shoulder part is nearly whole time of EVs connection time for Case I. This situation causes the small energy transfer with OCCDS. On the other hand, the saving of the microgrid operator for each kWh is higher at OCCDS due to the difference between the average prices of G2V and V2G operations. In addition, this saving at time-of-use tariff is nearly five times of the saving at hourly rate tariff. Hence, the saving of microgrid operator with time-of-use tariff is higher than the hourly rate tariff.

Although the total cost and daily load in February are lower than August, the average electricity cost in February is higher than August due to the high hourly electricity cost in February. These high costs cause the high G2V operation cost. As a result of this situation, the saving of microgrid operator decreases for each kWh in February due to small cost difference between G2V and V2G operations for Case I. However, the amount of the charging energy is smaller in February based on simulations in August. Hence, the total saving of the microgrid operator increases with the decrease in cost of the G2V operation, and these situations provide high saving of the microgrid operator in Case I based on simulations in August.

Looking at results of the Case II, the electricity cost is highest at first hours and lowest at last hours during the connection times of EVs. These situations cause more charging operation for EVs and it satisfies that the SoC of an EV is nearly 100% when an EV departs from the microgrid. Hence, the amount of charging energy is higher than the amount of discharging energy for Case II. This energy difference between G2V and V2G provides the maximum travel range for EV owners although the small saving for the microgrid operator.

The lowest and highest hourly electricity costs are during connection times of EVs at the hourly rate tariff for the residential microgrid. This situation has an advantage with respect to Case I due to the large cost difference between V2G and G2V operations. Hence, the saving of the microgrid operator for each kWh increases with this difference. On the other hand, the total saving of the microgrid operator is not higher due to large charging energy for the residential microgrid. EVs connection time also includes the time of highest and lowest costs of the electricity with time-of-use tariff. The average charging cost and discharging price at time-of-use tariff have large difference based on the hourly rate tariff. This situation provides large saving for the microgrid operator for each kWh energy transfer. The total saving of the microgrid operator at time-of-use tariff is nearly two times of the saving at hourly rate tariff. Moreover, the saving of the microgrid operator at Case II is smaller than Case I due to the high charging energy at Case II. For these reasons, the residential prosumer provides optimum solution for EV owners. Unlike residential prosumer, the commercial prosumer provides optimum solution for the microgrid operators.

The difference between the average charging cost and discharging cost in February is much lower than August in Case II, thus, the saving of the microgrid operator for each kWh is lower than August. Hence, the saving of the microgrid operator is very low in comparison with Case I. The total saving of the microgrid also decreases in February for Case II.

The data are obtained among thirty days at Case III. The cost of the electricity is in peak-off time part of time-of-use tariff at 22:00 and 00:00, thus, the new peak is created by G2V operation at this time. This situation causes a challenge for the external power system. However, the distributed microgrid with time-of-use tariff provides a higher saving for the microgrid operator which is nearly 0.27 TL for each kWh. This saving for each kWh is nearly half of the average electricity cost per kWh in a day and the saving of the microgrid operator is larger at OCCDS than whole cases and whole scenarios. Moreover, this saving is more than two times of the saving of the microgrid operator at Case I and Case II. Thus, distributed microgrid provides more economic operation for the microgrid operator. In addition, the distributed microgrid provides whole day operation for EV owners and this situation is more suitable for EV owners.

The energy transfer from EVs (E_{FEV}) and the saving of the microgrid operator are given for base cases at OCCDS in Table 39. EVs departing from the commercial microgrid have mostly 50% SoC at Case I, although the microgrid operator obtains a higher saving. However, EVs depart mostly with 100% SoC at Case II, thus, the residential microgrid provides more benefits for EV owners, although the microgrid operator obtains a lower saving compared to the commercial microgrid.

At OCCDS, larger battery capacity and low MSoCL provide the flexibility of larger amounts energy transfer between EVs and the microgrid. The high amount of energy transfer increases the time period of charging/discharging operation due to constant charging power. The average charging cost increases and the average discharging price decreases with the high time period due to sorting time at OCCDS.

The saving of microgrid operator changes according to the standard deviation of arrival and departure times of EVs. Higher dispersion of arrival and departure times changes the amount of the energy transfer between EVs and microgrid at the time of near mean time of the arrival and departure times of EVs. In other words, this higher dispersion can have negative or positive impact on the saving of the microgrid operator.

As expected, as the number of charging stations in the microgrid and the number of EV members increases the potential benefits and savings of the operation will increase. Thus, the saving of the microgrid operator is directly proportional with the number of charging stations.

Table 39. The Saving of MGO for Different Microgrids

OCCDS		E_{FEV} (kWh/mo)	J_{pop} (TL/mo)
Case I	**Hourly Rate Tariff**	8711	6750
	Time-of-use Tariff	4630	7500
Case II	**Hourly Rate Tariff**	-828	3200
	Time-of-use Tariff	-2850	6130
Case III	**Hourly Rate Tariff**	-6671	1072
	Time-of-use Tariff	-7500	8162

CHAPTER 5

CONCLUSION

The interest on EVs started at the last quarter of the 19^{th} century and EVs lost the interest shown because of the decrease in the economic benefit. After the development of EV technology and the governmental policies in 21^{th} century, the electrification of transportation has become more beneficial about environmental and economic benefits and concerns. Due to incentives given by governments and increased public awareness for environment, the number of EVs have been increasing significant in recent years.

The most important issues in the choice of an EV are the technology and efficiency of EVs. The EV technology not only increase the energy efficiency in the vehicle, but also reduces CO_2 emissions. These situations provide more economic transportation. In addition, the other important feature in the choice of an EV is the travel range of EVs and it is highly dependent on the battery capacity and technology. Li-on batteries are mostly selected for their high efficiency, high charge-discharge cycles, high energy density and long lifetime.

The battery ageing is an important factor for the efficiency of EVs. The battery ageing highly depends on the charging-discharging characteristic, age of the battery and the operation temperature. Li-ion batteries are charging with constant power until 80% SoC and the power decreases linearly after 80% SoC with using industrial charging stations. Low charging power is suitable for the battery life by minimizing the stress on the battery, although this charge type requires longer charging time.

In addition to the purchase of EVs, people also tend to produce the electricity due to the fall in the cost of renewable resources and energy storage technology. In this way, prosumers become important participants of the power system and obtain the possibility of reducing their electricity cost. Prosumers can use the batteries of EVs as an energy storage system to decide and control the duration of V2G and G2V operations.

A microgrid model and a methodology are developed to analyze the economic feasibility of the microgrid operator in this study. Different types of prosumer, including commercial, residential and distributed (both commercial and residential), are simulated with the microgrid model to observe the effect of types of prosumers on the economic feasibility of the microgrid operator. Moreover, different scenarios, including uncontrolled, controlled charging and controlled charging/discharging operations, are performed in order to investigate the economic benefits of V2G operations. In addition, the optimal controlled charging/discharging scenario is also performed with sorting time according to hourly electricity cost rather than using average electricity cost of a day at other scenarios. Simulations of microgrid models are performed with different parameters to investigate the effect of these variables on the economic operation of the microgrid operator. In addition, an EV usage model is also developed using probabilistic functions to determine stochastic variables related to EVs (i.e., arrival time, departure time and initial SoCs). All microgrid models are simulated with Monte Carlo Methodology in the algorithm to reduce the effect of stochastic variables on the results.

Simulation results show that the microgrid operator has different values of savings in energy cost for different microgrid types. One reason for this is that EVs have different SoC values when they disconnect and depart from the electric network. It has been observed from simulation results that the microgrid operator obtain a higher saving in the commercial microgrid compared to the residential microgrid, although EVs depart mostly with 50% SoC in the commercial microgrid. However, EVs departing from the residential microgrid have mostly 100% SoC, thus, the residential microgrid provides more benefits for EV owners. In this study, the saving of EV owners is not investigated privately for each EV. The behavior and habits of EV owners in EV usage should be investigated in detail to understand the required charging and discharging durations. Moreover, the generated energy of the solar power plant (or any other renewable source) connected to the microgrid should also be taken into account to obtain a more economic operation. Moreover, simulation results show that the best economic solution for the operator is obtained in the distributed microgrid structure with the time-of-use-tariff since this microgrid type provides a 24 hours service for EV owners and the operator.

It is observed that the electricity price volatility during a day has a positive effect on the saving of the microgrid operator. In this study, the operator has a higher saving at time-of-use tariff due to high price volatility in this tariff. It is also observed that the time periods for three term tariffs existing today in Turkey should be revaluated (and modified if necessary) in order to avoid new peak loads at certain hours with EV integration. However, price forecasting has not been taken into account in this study. In order to achieve better understanding for the effect of the electricity cost on the feasibility of microgrid operator, more research should be done on the short-term price forecasting.

As stated in this study, charging / discharging duration are reduced when charging power of charging stations increases without damaging vehicle batteries. In this case, the operator obtains a higher saving with the high charging power. Moreover, the high number of charging stations provides more resources to the microgrid operator; thus, these resources also provides a higher saving for the operator in despite of the high investment cost. Although simulation results in this study emphasizes the amount of the energy transfer (between EVs and microgrid) and the saving of the operator, the investment and operation costs of the microgrid operator are not taken into account in this study due to the uncertain electricity cost of this energy transfer.

Basically, the V2G operation and controlling the energy in the batteries of EVs provide the saving for the microgrid operator. The advancement in the technology (i.e., larger battery capacities, more efficient batteries, shorter charging times, increased penetration of EVs, etc.) is surely going to make V2G and G2V operations more attractive from the economic perspective. Moreover, the tariff system available is a very important parameter in the determination of the savings from the perspective of prosumers.

It is observed from simulation results that losses of charging stations should be reduced to increase the efficiency of energy transfer between EVs and electric grid during V2G and G2V operations. These losses during the energy transfer significantly reduce the saving of the operator as a result of the combination of V2G and G2V operations. Hence, the efficiency should be improved to obtain a more feasible microgrid operation.

As seen in this study, the savings of EV owners have not been considered. The driving behaviors and habits of EV owners should be further investigated in detail in order to implement an efficient control algorithm which decides on charging and discharging operations. Another important point to consider is the existence of renewable sources in the microgrid. Better forecasting the output of these resources is definitely going to have positive impact on the microgrid operator as well as the own load.

As a final suggestion for future work, the economic feasibility of the microgrid operator should also be investigated with purely residential load or purely commercial load in order to cover different microgrid structure. In such cases, an accurate determination and utilization of load profiles will be important to obtain more realistic results.

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