Analysis of Impact of Electric Vehicles on Distribution Grid Using Survey Data

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***Abstract*— Electric vehicles are more environmentally friendly and lower fuel costs than conventional vehicles. Thanks to these advantages, their numbers have increased rapidly in recent years and it is thought that they will be used more in the future so the power demanded from the electricity grid will increase. If electricity distribution companies and energy producing companies do not take the necessary precautions, they will not be able to provide quality service to users in the following years. Therefore, the effects of electric vehicles on the electricity distribution system should be examined. In this study, a survey was applied to a working group of 50 people. This survey was analyzed and daily travel information was modeled. Statistical home arrival time, work arrival time and daily trip distance curves were formed. Charging loads were calculated by converting the obtained model to daily charging model of electric vehicles.**

Keywords—electric vehicle, distribution grid, charging, on-board charging

I. Introduction

Research on electric vehicles (EV) began many years ago. However, fossil fuel vehicles have a higher utilization rate. In recent years, studies on electric vehicle and charging infrastructure have been increasing. Global warming, fossil fuel prices and the development of battery technologies can be listed as the main reasons [1], [2]. The use of EV is expected to increase rapidly in the coming years. In 2023, 6.4 million electric vehicles are expected to be sold worldwide [3]. Increasing sensitivity to global warming, economic reasons and increasing incentives of countries to EVs show that EV sales will increase rapidly. Today, 4 EV types are used in transportation. These; hybrid electric vehicle (HEV), Plug in hybrid electric vehicle (PHEV), battery electric vehicle (BEV) and fuel cell electric vehicle (FCEV) [4].

HEV is a type of EV that combines both conventional and electric motors. They cannot be charged externally. As the name suggests, the PHEV batteries are externally rechargeable and have tried to overcome the range problem by having a conventional motor. BEV, only electric motor is available. It has zero emissions. FCEVs generate electrical energy using fuel cells. Lithium ion batteries are generally used by the EVs mentioned above [4].

EVs are recharged according to their state of charge (SoC). It is very important for users to meet this requirement at the desired time. This is ensured by the reliable and flexible charging infrastructure. EVs can be charged with different charge levels. Choosing the charge level considering the electricity grid and the user will have positive results for both sides. EV charging levels are generally divided into 4 groups. Mode 1 is defined as slow charging. In this type of charging, vehicles can generally use household sockets. Mode 2 is specified as slow or semi-fast charging and the vehicles are charged with a special socket. Mode 3 is known as semi-fast or fast charging. It has a charging power of 20 kW and above. Mode 4 is DC (direct current) fast charging. It is extremely fast and has a charging power higher than 50 kW [5],[6], [7].

The effect of electric vehicle charging stations (EVCS) to be connected to the electricity distribution system is inevitable. EVs can cause voltage drops and frequency changes in the electricity distribution system. In particular, non-linear EV battery chargers can create harmful harmonic effects on the electrical distribution system. In their study, Gomez et al. analyzed the effect of the harmonics generated by the EV chargers on the distribution transformer. They also tried to extend the transformer life by determining the optimal charging time with a program which they proposed [8]. The effects of uncontrolled EV charging on the distribution grid can be examined using probabilistic approaches [9]. They have developed a model that predicts daily electricity demand. As a result of the analysis made with the proposed model, voltage drop and transformer overload conditions have observed. Minimizing the impacts of EV integration into the distribution grid is an important requirement [10]. Smart grid is thought to contribute in this direction. In order to examine the effect of EVs on the distribution grid, it is necessary to determine the habits of EV usage. In this study, an online survey was conducted to determine the driving habits of vehicle users. In accordance with the information obtained from the survey, the effect of EV on the distribution grid was analyzed.

II. EV Battery Charging

Electric vehicles must be charged at regular intervals depending on their use. Today, there are different types of chargers for charging electric vehicles. Electrical charging standards and requirements are set by some international organizations (IEC, SAE, JEVS, CHADEMO). Electric vehicle charging stations can be divided into four main groups as mentioned in the introduction [11].

Slow charging stations are located where electric vehicles can stay parked for a long time. Generally, homes and workplace are suitable for this type of charging station. In slow charging stations with an average charging power of 4 kW, the charging time is indicated as 6 hours or more. Due to the long charging time, there are no immediate loads on the distribution grid [12],[13].

Normal or semi-fast charging times vary between 3-6 hours. They are located in places where vehicles can stay in medium-term parking. Shopping centers, business centers and picnic areas are suitable locations for this type of

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charging station. They have an average 8-20 kW charging power. Fast charging stations are divided into DC and AC. The power of DC charging is higher. They are located in places where charging is required in a short time. Fast charging stations are located on highways for recreational facilities and city centers for emergency charging needs. Considering safety and battery life, EV batteries are charged at 80% at these charging stations. Since the safety requirements are high, there is an advanced communication system between the vehicle and the charger. They have an average 50-150 kW charging power [12].

In addition to the aforementioned charging station types, there are wireless charging stations, mobile charging stations and battery swapping centers. In wireless charging station, charging starts when the vehicle is parked on the charging cradle mounted on the floor. As there is no cable connection, there are ideas that it is practical. There is a high frequency transformer with primary and secondary. Power transmission has become more complex as it is carried out by electromagnetism. The efficiency is low compared to other methods [14],[15].

In mobile charging stations, batteries are charged when the electricity prices are low. The mobile charging station is activated when stationary charging stations are busy. In addition, an electric vehicle in urgent need of energy can charge the mobile charging station. In this system, the mobile charging station is likened to an ambulance [16], [17].

Some EV manufacturers are planning to install battery swapping centers to solve the energy needs of the vehicles in a shorter time. The batteries will not be charged quickly and their life will decrease in the normal course. Empty batteries in battery swapping centers provide load balance by charging in cases where energy demand is low and production is high [18].

III. ANALYSIS OF SURVEY DATA AND TRANSFORMER DATA

In order to analyze the effect of EV on the distribution grid, vehicle driving habits need to be modeled. It is also necessary to know the charging modes and EV penetration level. In this study, users were asked to complete an online survey in order to model their driving habits. A total of 50 people from public and private sectors participated in this survey. The questions in the survey are as follows;

- Arrival time to work
- Arrival time to home
- Daily trip distance

The survey results are used within the scope of the study provided that the identity information of the respondents are kept confidential. Instead of creating a random vehicle usage model, a probabilistic vehicle usage model was developed. The probabilistic distribution of the arrival time to home according to the survey results is shown in Fig. 1. According to the obtained information, the vehicle users arrive at their home at 18:40 on mean (mu) and standard deviation (sd) is 0,33. Normal distribution function in equation (1) was used to obtain this graph. The reason for this is the normal distribution of the histogram graph of the survey results. In this figure, the probability density function (pdf) is changing with time.

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

The arrival time to work graph is shown in Fig. 2.

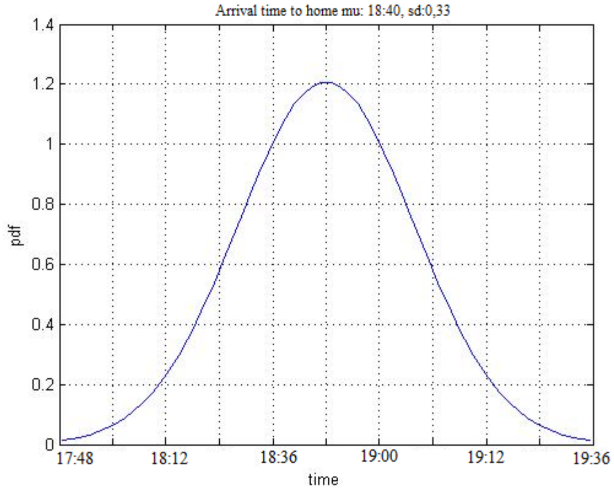

Fig. 1. Home arrival time

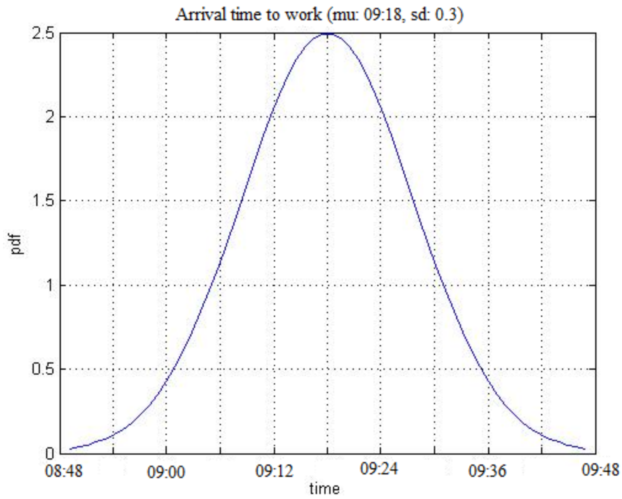

Fig. 2. Work arrival time

Daily trip distance graph and histogram graph of number of cars (noc) are shown in Fig. 3. In this figure, Weibull distribution function was used. Mean daily trip distance is 32 km. The Weibull distribution function is as follows.

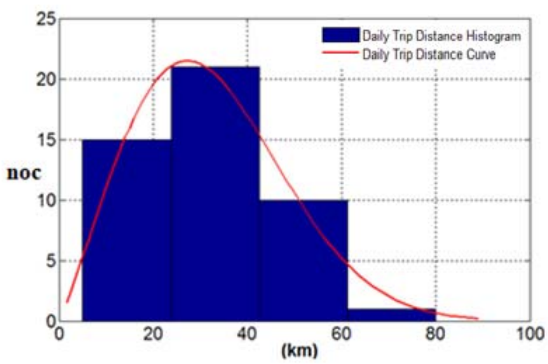

Fig. 3. Total daily trip distance

$$f(x;k,\lambda) = \frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{k-1} e^{-(x/\lambda)^k} \quad (2)$$

$\lambda > 0$ scale
$k > 0$ shape

On-board chargers charge the vehicle battery by converting the AC voltage to DC voltage. Each EV brand can have different specifications of battery and on-board charger. Therefore, battery charging times and battery capacities are different. The battery status of the EV or state of charge (SOC) is as follows.

$$SOC = \left(1 - \frac{D}{R_M}\right).100 \quad (3)$$

Where D is travelling distance(km), R_M is the maximum range of EV. It is assumed that when EVs are charged, the batteries are not removed before they are fully charged. Therefore, the charging time is calculated as follows.

$$C_t = \frac{B_{cap}(1-SOC)}{C_p.C_{eff}} \quad (4)$$

Where C_t is charging time (h), B_{cap} is EV battery capacity (kWh), C_p is charging power (kW), and C_{eff} is the charger efficiency.

In this study, a sample transformer feeding a certain region was selected. The average load curve of the transformer for April 2018 was calculated. Summer and winter months were not chosen on purpose because during these months there may be extra loads for heating and cooling. This may lead to errors in obtaining an average value. Transformer load curve is given in Fig. 4. The electric vehicle penetration level in the selected region is accepted as 10%, which corresponds to 100 electric vehicles. Different brands and models are considered. The selected EV models and their numbers are given in Table 1.

TABLE I. EV MODEL AND FEATURES [3]

EV Model	Number of EVs (noc)	B_{cap} (kWh)	R_M (km)	C_P (kW)
Opel Ampera	12	15	56	3.3
Mitsubishi MiEV	12	16	100	3.3
Toyota Prius PHEV	12	4.4	24	2
GM Chevrolet volt	12	15	56	3.3
Nissan leaf (EV)	13	24	117	3.3
Renault Zoe	13	22	100	43
Renault Twizy	13	7	80	2.2
Tesla Model S	13	42	250	20

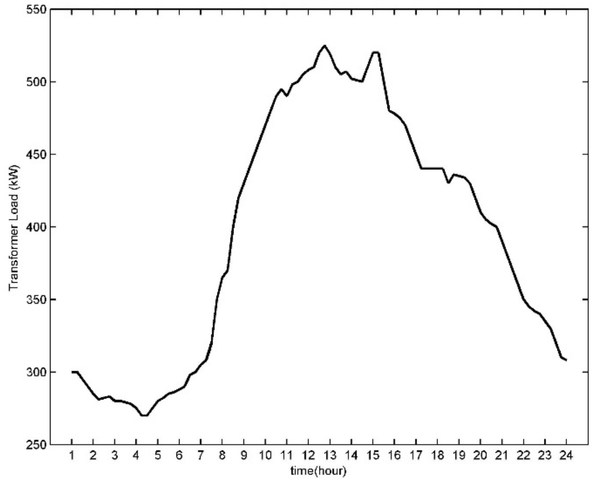

Fig. 4. Transformer loading for normal case

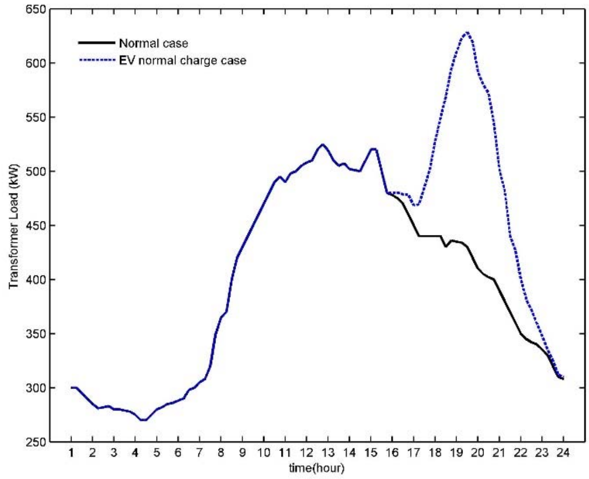

Fig. 5. Transformer loading for EV normal charge case

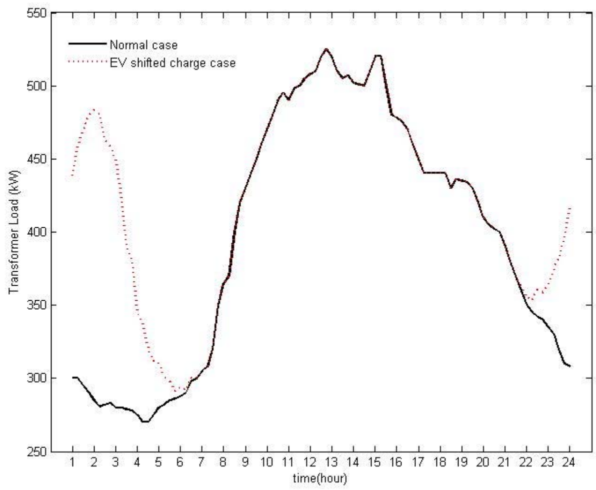

Fig. 6. Transformer loading for EV shifted charge case

In this section, the model obtained by using the driving habits has been turned into the electric vehicle charging model. Electric vehicle loads are added to transformer load curve. In the first case, a result was obtained assuming that the users immediately installed their vehicles when they came home. Fig. 5 shows the load curve of this case. In the second case, users started to charge their vehicles four hours after arriving home. In this case, electric vehicles were started charging at 23:40 which is mean value. The obtained load curve of this case is shown in Fig. 6. When the two cases are compared in Fig. 7, it is clear that the second case is more efficient. In the first case, the EV loads increase the peak value of the transformer load. In the second case, the load curve is more balanced.

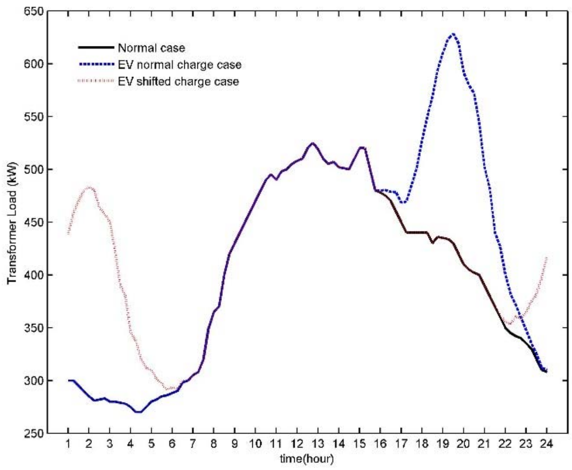

Fig. 7. Transformer loading for two cases

IV. CONCLUSION

The number of EVs is increasing day by day. Therefore, the potential impact of EV loads on the distribution grid is also increasing. In this study, the model which was created with the help of the survey was transformed into EV charging model and the power demanded by EVs was calculated for two cases. The calculations are based on the energy demand cycle on a daily basis. Electric vehicles are charged at the end of each day. In these two cases at %10 penetration level, no overloading of the transformers was observed. However, it is clear that in the second case a more stable transformer loading curve is obtained.

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