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Simulation of Urban Electric Vehicle Transport and Charging Station Implementation at Çukurova University

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Abstract

Energy consumption is increasing gradually with worldwide industrialization. This increase creates a high demand for production which depends on mostly fossil fuels. The use of fossil fuels leads to environmental pollution. Additionally, remaining reserves are limited. Internal combustion engine (ICE) vehicles are the most widely used vehicles worldwide and there is an enormous amount of fossil fuel consumption by them. Furthermore emissions released to nature by these vehicles are pollutants and they are big chink in our nature's armor. Because of these reasons, nowadays the demand for electric vehicles (EV) is increasing as an alternative form of transportation. Thus, EVs put themselves forward. In this paper, a charging station infrastructure for commercial electric vehicles used in public and their integration to an existing system is studied that intended to be used in university in near future. Case studies are examined and their results are compared.

Keywords: University charging station, Urban electric vehicle, Battery charging, Grid integration

Çukurova Üniversitesinde Kentsel Elektrikli Araç Ulaşımı ve Şarj İstasyonu Uygulama Simülasyonu

Öz

Dünya çapındaki endüstriyelleşme enerji tüketiminin giderek artmasına sebep olmuştur. Artan bu tüketim fosil yakıtlar tarafından karşılanmaktadır. Fosil yakıt tüketimi ise çevre kirliliğine sebep olmaktadır. Buna ek olarak dünya fosil yakıt rezervleri ise giderek azalmaktadır. İçten yanmalı motorlu taşıtlar dünya genelinde en yaygın olarak kullanılan taşıtlardır ve büyük miktarlarda fosil yakıt tüketmektedirler. Dahası bu araçlardan çevreye yayılan emisyonlar doğaya büyük oranda zarar vermektedirler. Bu sebeplerden ötürü, günümüzde elektrikli araçlara olan ilgi artmış ve taşımacılık sektöründe alternatif bir çözüm olarak elektrikli araçlar öne çıkmışlardır. Bu makalede, yakın gelecekte üniversitede kullanılması öngörülen elektrikli araçlar için şarj istasyonu altyapısı ve bu altyapının var olan sisteme entegrasyonu çalışılmıştır.

Anahtar Kelimeler: Üniversite şarj istasyonu, Kentsel elektrikli araç, Batarya şarjı, Şebeke entegrasyonu

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1. INTRODUCTION

Demand for energy is increasing gradually with worldwide industrialization. As well as industrialization, there are plenty of reasons such as population growth, inefficient usage of resources, technological developments, etc. which increase consumption of energy significantly. The increase in consumption of energy creates a big amount of demand for production which is supplied almost exclusively by fossil fuels. Fossil fuels, which are known as petroleum, natural gas and coal, are hydrocarbon-containing fuel. According to the recent data published in mid-2014, there are petroleum reserves 892 billion tons of coal, 186 trillion cubic meters of natural gas, and 1688 billion barrels of crude oil. These numbers seems to be huge at a glance, but taking into account today's level of extraction proved reserves of coal will be exhausted in approximately 110 years, reserves of natural gas will be exhausted in approximately 55 years, reserves of crude oil will be exhausted in approximately 50 years [1].

In our daily lives, the urban transport is where we often encounter without being aware of these issues. Although urban transport is a daily routine, it has a big role in our lives. The main problems related to urban transport can be summarized as air pollution, noise, energy use, and lack of mobility for the poor. In today's conditions, most important problems are the energy consumption and environmental factors. Urban transport system is the major consumption of carbon-based fuels, and it is increasingly being highlighted as the sector which contributes least to CO_2 emission reduction targets [2]. Transport sector's fuel mix is dominated by liquid fossil fuels [3]. The urban transportation sector worldwide relies almost exclusively on petroleum fuels.

Since fossil fuel resources are running out and damage caused by fossil fuels to the nature are considered, alternative energy sources are of a great importance. Some of the studies in literature, point to renewable energy resources in order to reduce fossil fuel dependence substantially [4-7]. Apart from these studies, electric vehicle topic is another work field for reducing fossil fuel dependence. Considering the worldwide number of internal combustion vehicles, enormous amount of fossil fuel consumption is threatening. Given that electric vehicles will take internal combustion vehicles places, there will be a remarkable amount of reduction in the usage of fossil fuels. In addition to this, electric vehicles are clean, silent and simple to operate, electric motors has a constant relationship of torque to revolutions per minute (RPM), and features like regenerative breaking, etc. Thus, electric vehicles have more advantages when they are compared to internal combustion vehicles.

Today, the demand for electric vehicles is increasing. Manufacturers have focused their research and development activities on the electric vehicles. The number of electric vehicles on the market is increasing day by day. Therefore, the electric vehicle infrastructure technologies are also being developed. Some of the technology infrastructures are as follows: battery systems, communications, network integration, charging systems.

Electric vehicles have various options for recharging their batteries and charging stations are has been considered as the major source of energy. Since charging stations are prime source of energy, their whereabouts in a city are very crucial. So any EV can be able to simply access a charging station. Thus, charging stations must be pervasive and common. Additionally, location of a charging station is an important issue in this topic. In order to solve this issue deterministic and probabilistic algorithms are improved [8].

As a result, the purpose of this study is to examine electric vehicle infrastructure technology in the charging systems and network integration issues. Two of the most important electric vehicle simulation building blocks are battery charging systems and charging stations. Application of this simulation in a university campus is studied. Additionally, in this study, issues like "The current drawn by the system while electric vehicle is charging", "Whether the infrastructure is adequate or not", "In which places new infrastructure systems will be needed when installed infrastructure is not sufficient" , etc. are examined. The rest of the paper is organized as follows. First, in Section II the system model and its abstract simulation model are described. In Section III, case studies and related results are given. In Section IV the results of the system are discussed, and finally paper is concluded in Section V.

2. MODELING OF FAST DC CHARGER

In this chapter, design and parameters of the Çukurova University's grid, charging circuits, charging methods and battery parameters will be described. Design of the grid simulation is made on the Çukurova University's one line diagram (Figure 1) and includes actual values. Parameter values that used in simulation are also actual values too. Most basic aim of this simulation is to establish an electric vehicle infrastructure. Afterwards, by replacing the internal combustion engine vehicles that plying to Çukurova University with electric vehicles, it's aimed to reduce green-gas emissions (zero-emission by EVs, and less green-gas emissions by ICE), reduce the negative environmental effects and increased energy efficiency.

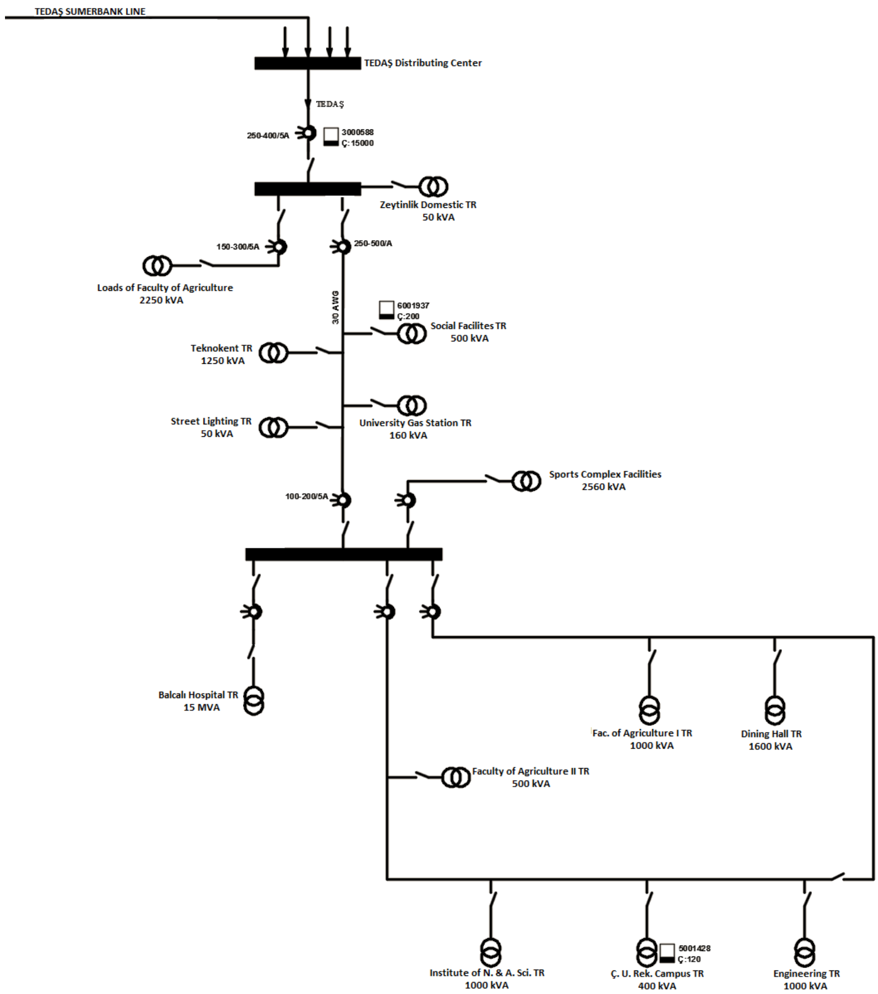

Figure 1. Main theme of HV-LV one line diagram of Çukurova University

Since, grid is simulated on a HV/LV single line diagram of the Çukurova University together with the loads, all transformers used in this simulation are simulated with their actual values. All transformers are 33.5 kV/400 V power transformers. All RL blocks seen before the every transformer block represents the voltage drop of the relevant transformer. These RL blocks' values are calculated according to the type of cables used and the distance between transformers and the main supply (Figure 2). Proper places for charging stations are envisaged to be on the road in front of the Food Engineering Department of the Faculty of Agriculture which is closer to Faculty of Agriculture 1 Transformer and will be supplied by Faculty of Agriculture 1 Transformer.

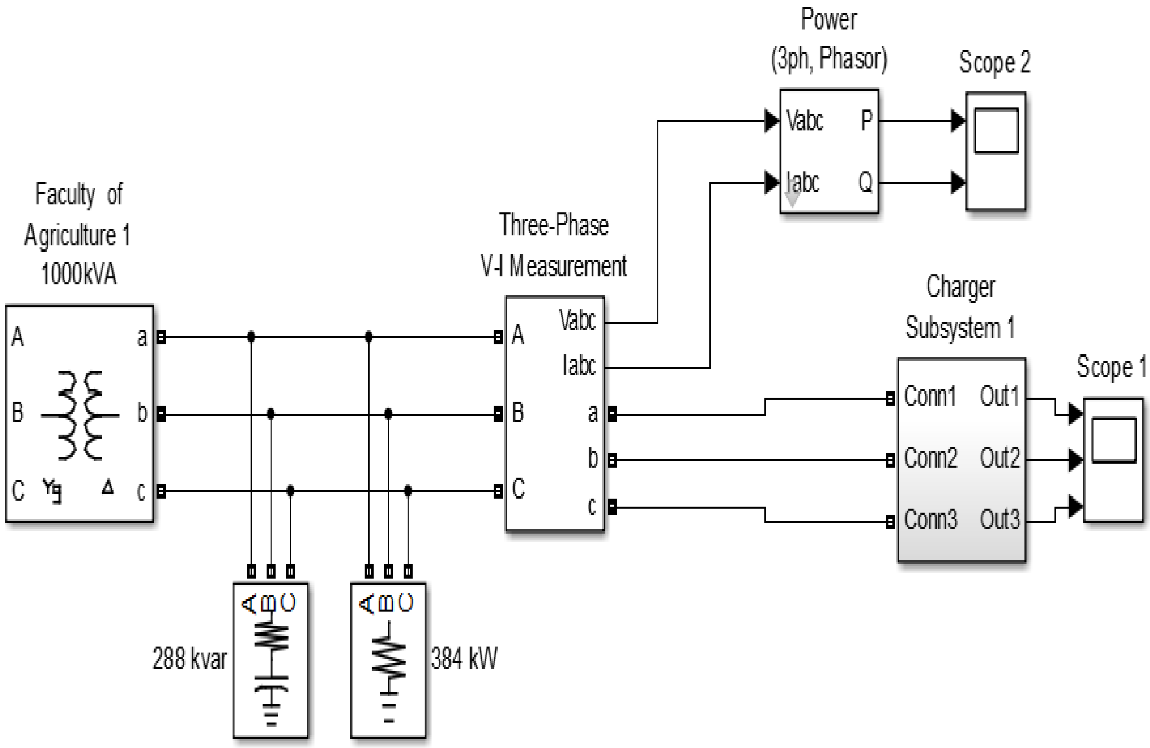

Figure 2. Grid integration and charger circuit diagram in MatLab/Simulink

3. CASE STUDIES

In this chapter, several case studies on different charging scenarios are introduced. These scenarios consist of inclusion of electric vehicles (EV) to the existing bus lines plying to Çukurova University.

Among 18 bus lines plying to Çukurova University, 10 lines are chosen and any chosen line is considered to have only one EV included. In any bus line, it is assumed to have X number of internal combustion engine (ICE) buses. Thus, any chosen bus line has X+1 number of vehicles. In the scenario, while EV is plying its route, one ICE vehicle removed from the fleet and added again while EV is charging its battery. Thus, in total there will always be X number of busses plying in order to serve to the public.

Selection of bus lines that are plying to the Çukurova University are performed by taking into account the criteria such as emphasis, intensity, and length of course (e.g. route of line 192 is about 125 km long which overcomes the battery's maximum capacity). EVs' plying hours, charging hours and daily total plying times are given in the Table 1.

Table 1. Bus lines, routes, plying hours, and charging times

Bus Line No	**113**	**116**	**121**	**122**	**133**
Route -SOC	30 km - 50% SOC	45 km - 75% SOC	40 km - 66% SOC	50 km - 80% SOC	45 km - 75% SOC
1. tour	06:15-08:15	06:23-08:30	07:30-09:30	06:00-08:00	07:10-09:10
Charge	08:15-09:05	08:30-09:45	09:30-10:40	08:00-09:20	09:10-10:25
2. tour	09:15-11:15	10:13-12:15	11:30-13:30	10:00-12:00	10:28-12:30
Charge	11:15-12:05	12:15-13:30	13:30-14:40	12:00-13:20	12:30-13:45
3. tour	12:15-14:15	14:03-16:00	15:30-17:30	14:00-16:00	13:46-15:45
Charge	14:30-15:20	16:00-17:15	17:30-18:40	16:00-17:20	15:45-17:00
4. tour	15:25-17-25	17:53-20:00	-	18:00-20:00	17:04-19:04
Charge	17:25-18:15	-	-	-	-
5. tour	18:15-20:15	-	-	-	-
Charge	-	-	-	-	-
Bus Line No	**135**	**154**	**155**	**156**	**160**
Route -SOC	25 km - 45% SOC	22 km - 36% SOC	35 km - 60% SOC	40 km - 66% SOC	45 km - 75% SOC
1. tour	10:00-12:00	06:00-08:00	08:00-10:00	08:05-10:05	06:54-09:00
Charge	12:00-12:45	08:00-08:40	10:15-11:15	10:05-11:15	9:00-10:15
2. tour	13:00-15:00	09:00-11:00	11:30-13:30	12:05-14:00	10:30-12:30
Charge	15:00-15:45	11:00-11:40	13:30-14:30	14:00-15:10	12:45-14:00
3. tour	16:00-18:00	12:00-14:00	15:00-17:00	16:05-18:00	14:06-16:10
Charge	18:00-18:45	14:00-14:40	17:00-18:00	18:00-19:05	16:10-17:25
4. tour	19:00-21:00	15:00-17:00	18:30-20:30	19:05-21:00	17:42-19:45
Charge	-	17:15-17:55	-	-	-
5. tour	-	18:00-20:00	-	-	-
Charge	-	-	-	-	-

In this paper, 5 cases are investigated in order to examine the existing system in detail and to see the effects of the proposed infrastructure on the actual system, gradually. These cases are:

- Case 1: 2 bus lines connected to grid,
- Case 2: 4 bus lines connected to grid,
- Case 3: 6 bus lines connected to grid,
- Case 4: 8 bus lines connected to grid,
- Case 5: 10 bus lines connected to grid.

3.1. Case 1: One Charging Station with Two Electric Vehicles

First bus line among the chosen bus lines is line 154. In line 154, every vehicle completes its tour in 60+60 minutes (from departure to arrival). First EV in the morning starts its route at 06:00, plying ends at 08:00 and connects to charging station. A battery's charging time takes up to 100 minutes (from 0% to 100%). In line 154, after completing a full route, 36% SOC will be used and in order to replenish the missing SOC approximately 35-40 minutes of charging will be required. This calculation can be basically described as; a full route's distance (in km) divided by maximum distance traveled (in km) with a fully charged battery. Based on this information, it will take up to forty minutes for an EV to join the fleet again after recharging its battery to the state of 100% SOC. Next plying will take place forty minutes ahead of beginning of the recharging process. So, EV will be active in fleet again at 09:00. When EV is in fleet, an ICE vehicle will be discarded again. If this loop continues in that way, EV in line 154 will be active in fleet at 12:00, 15:00 and 18:00. Since last plying takes place at 19:00, EV in line 154 makes 5 plyings during the day.

Second bus line among the chosen bus lines is line 135. In line 135, every vehicle completes its tour in 60+60 minutes (from departure to arrival). First EV in the morning starts its route at 07:00, plying ends at around 09:00 and connects to charging station. In line 135, after completing a full route, 45% SOC will be used and in order to replenish the missing SOC approximately 45 minutes of charging will be required. EV in line 135 will be active in fleet at 10:00, 13:00, 16:00 and 19:00. Since last plying takes place at 19:00, EV in line 135 will be made 5 plyings during the day. Time periods of charging for case 1 are shown in Figure 3.

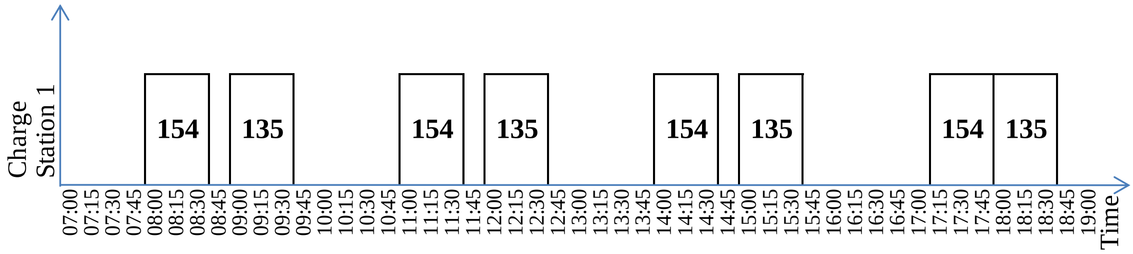

Figure 3. Charging periods of the proposed bus lines in case 1

3.2. Case 2: Two Charging Stations with Four Electric Vehicles

Additional 2 lines to Case 1 will be added to scenario. First added bus line is line 122. First EV in the morning starts its route at 06:00, plying ends at around 08:00 and connects to charging station. In line 122, after completing a full route, 80% SOC will be used and in order to replenish the missing SOC approximately 80 minutes of charging will be required. EV in line 122 will be active in fleet at 10:00, 14:00 and 18:00. Since last plying takes place at 18:00, EV in line 122 will be made 4 plyings during the day.

Second added bus line is line 121. In line 121, every vehicle completes its tour in 60+60 minutes (from departure to arrival). First EV in the morning starts its route at 07:30, plying ends at around 09:30 and connects to charging station. In line 121, after completing a full route, 66% SOC will be used and in order to replenish the missing SOC approximately 65-70 minutes of charging will be required. EV in line 121 will be active in fleet at 11:30 and 13:30. Since last plying takes place at 18:30, EV in line 121 will be made 3 plyings during the day. Time periods of charging for case 2 are shown in Figure 4.

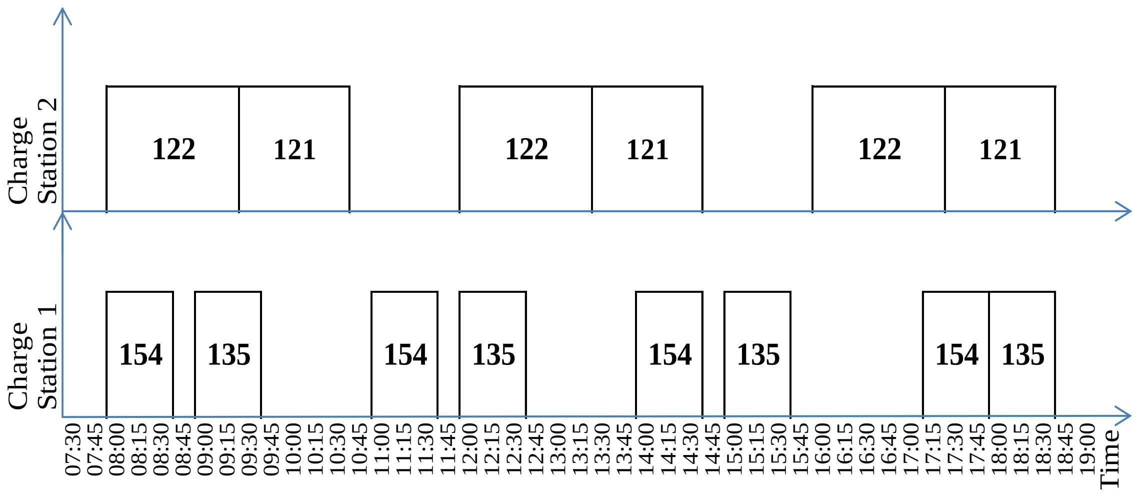

Figure 4. Charging periods of the proposed bus lines in case 2

3.3. Case 3: Three Charging Stations with Six Electric Vehicles

Additional 2 lines to Case 2 will be added to scenario. First added bus line is line 113. In line 113, every vehicle completes its tour in 60+60 minutes (from departure to arrival). First EV in the morning starts its route at 06:15, plying ends at 08:15 and then connects to charging station. In line 113, after completing a full route, 50% SOC will be used and in order to replenish the missing SOC approximately 50 minutes of charging will be required. EV in line 113 will be active in fleet at 09:15, 12:15, 15:25 and 18:15. Since last plying takes place at 19:00, EV in line 113 makes 5 plyings during the day.

Second added bus line is line 133. First EV in the morning starts its route at 07:10, plying ends at around 09:10 and connects to charging station. In line 133, after completing a full route, 75% SOC will be used and in order to replenish the missing SOC approximately 75 minutes of charging will be required. EV in line 133 will be active in fleet at 10:28, 13:46 and 17:04. Since last plying takes place at 17:04, EV in line 133 will be made 4 plyings during the day. Time periods of charging for case 3 are shown in Figure 5.

3.4. Case 4: Four Charging Stations with Eight Electric Vehicles

Additional 2 lines to Case 3 will be added to scenario. First added bus line is line 116. In line 116, every vehicle completes its tour in 60+60 minutes (from departure to arrival). First EV in the morning starts its route at 06:23, plying ends at around 08:30 and connects to charging station. In line 116, after completing a full route, 75% SOC will be used and in order to replenish the missing SOC approximately 75 minutes of charging will be required. EV in line 116 will be active in fleet at 10:13, 14:03 and 17:53. Since last plying takes place at 19:25, EV in line 116 will be made 4 plyings during the day.

Second added bus line is line 156. First EV in the morning starts its route at 08:05, plying ends at around 10:00 and connects to charging station. In line 156, after completing a full route, 66% SOC will be used and in order to replenish the missing SOC approximately 65-70 minutes of charging will be required. EV in line 156 will be active in fleet at 12:05, 16:05 and 19:05. Since last plying takes place at 19:05, EV in line 156 will be made 4 plyings during the day. Time periods of charging for case 4 are shown in Figure 6.

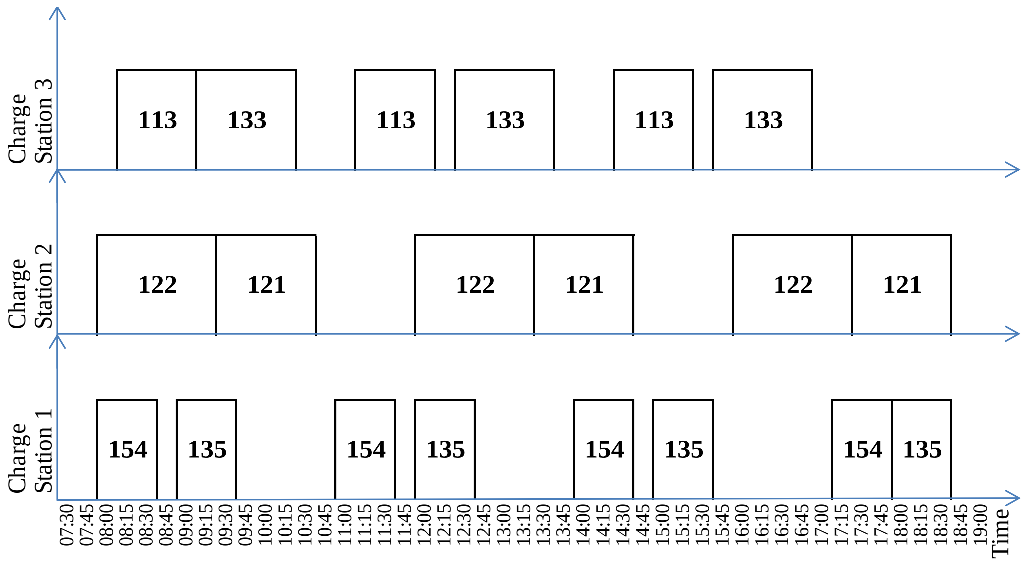

Figure 5. Charging periods of the proposed bus lines in case 3

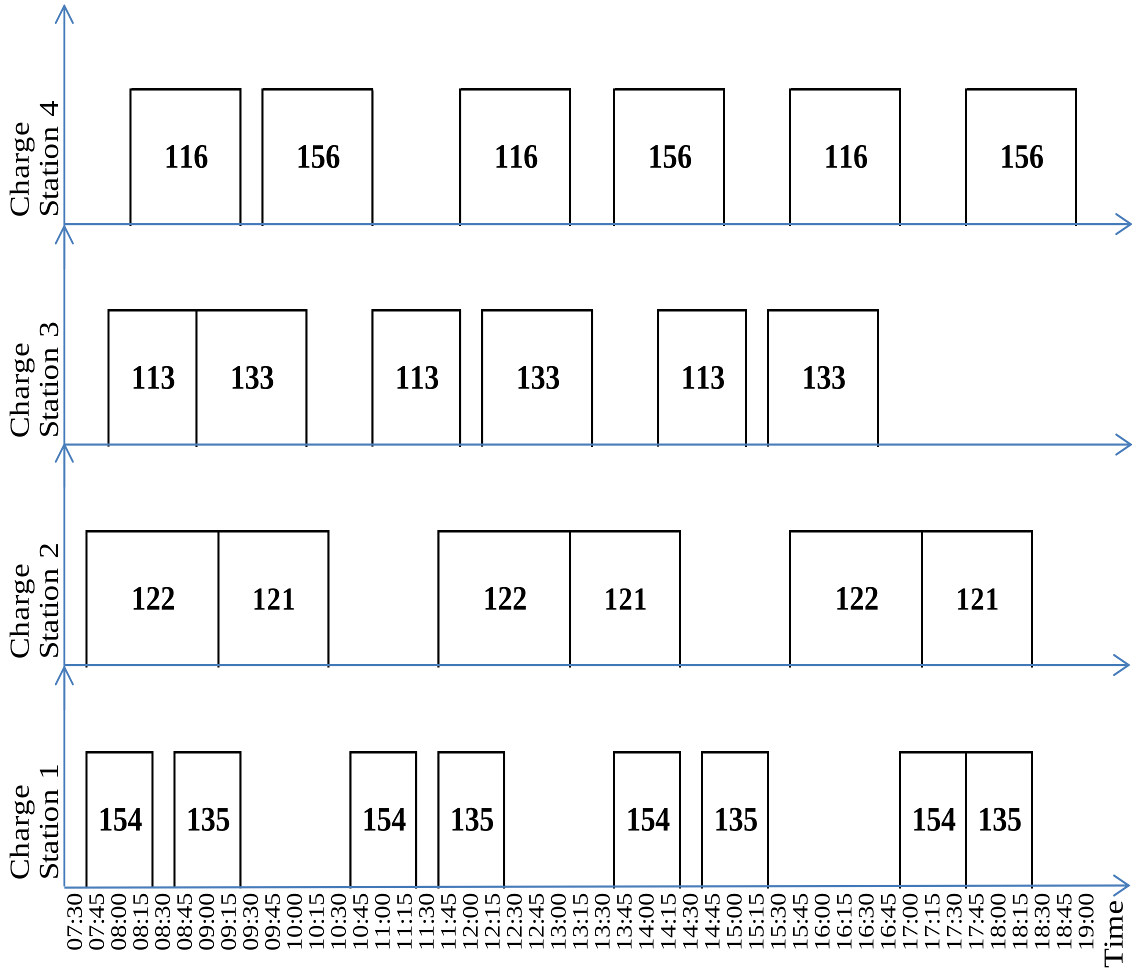

Figure 6. Charging periods of the proposed bus lines in case 4

3.5. Case 5: Four Charging Stations with Ten Electric Vehicles

Additional 2 lines to Case 4 will be added to scenario. First added bus line is line 155. First EV in the morning starts its route at 08:00, plying ends at around 10:00 and connects to charging station. In line 155, after completing a full route, 60% SOC will be used and in order to replenish the missing SOC approximately 60 minutes of charging will be required. EV in line 155 will be active in fleet at 11:30, 15:00 and 18:30. Since last plying takes place at 19:30, EV in line 155 will be made 4 plyings during the day.

Second and the last added bus line to the scenario is line 160. First EV in the morning starts its route at 06:54, plying ends at around 09:00 and connects to charging station. In line 160, after completing a full route, 75% SOC will be used and in order to replenish the missing SOC approximately 75 minutes of charging will be required. EV in line 160 will be active in fleet at 10:30, 14:06 and 17:42. Since last plying takes place at 19:30, EV in line 160 will be made 4 plyings during the day. Time periods of charging for case 5 are shown in Figure 7.

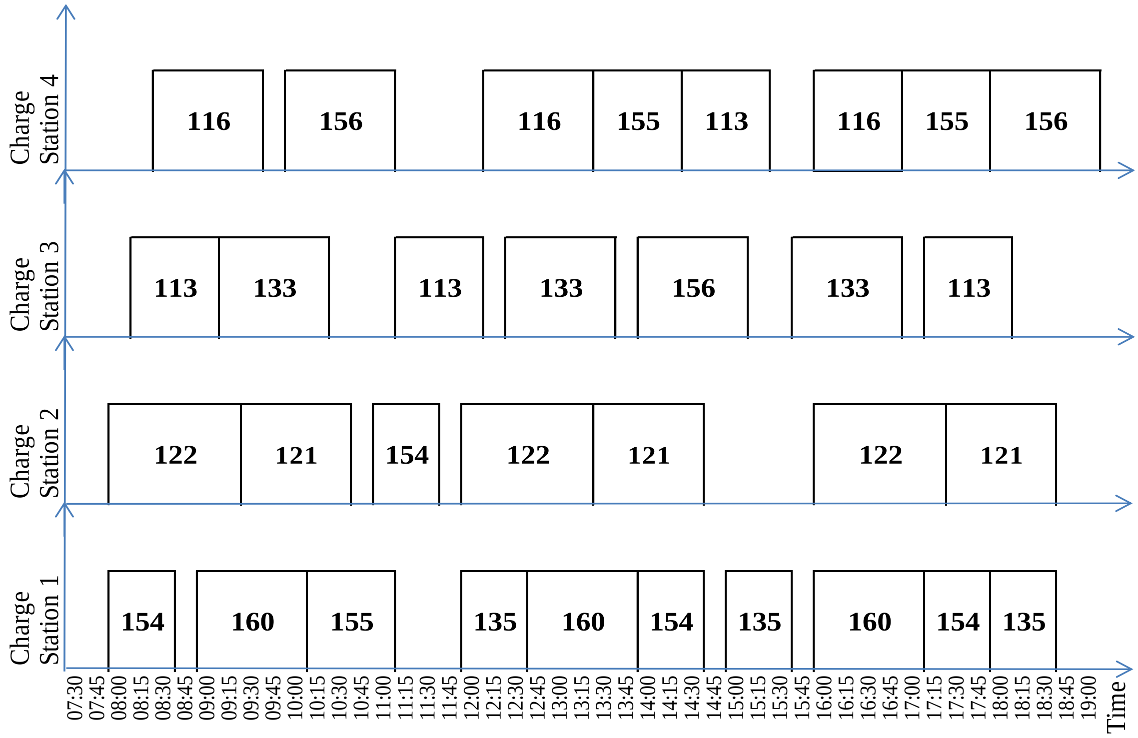

Figure 7. Charging periods of the proposed bus lines in case 5

4. RESULTS OF CASE STUDIES

The performance and effectiveness of the proposed system is tested with different case studies. In this study 5 different cases are examined. Since the last case (Case 5) is the busiest scenario, where the grid is affected mostly by EVs and charging stations, results of this case that are given in previous chapter are very important. When these results are examined it can be clearly seen that neither main supply nor balcalı hospital transformer is affected by our proposed charging circuit. Faculty of agriculture 1 transformer's voltage graphic is also stable. Only faculty of agriculture 1 transformer's current graphic has little fluctuations. Thus, this result led us to investigate its harmonic values.

4.1. Total Harmonic Distortion (THD) Analysis

The summation of all harmonics in a system is known as total harmonic distortion (THD). THD, in mathematical terms, can also be defined as the root mean square (RMS) value of the total harmonics of the signal, divided by the RMS value of its fundamental signal.

The THD has a null value for a pure sinusoidal voltage or current. In MatLab–Simulink simulation the THD block computes the total harmonic distortion of a periodic distorted signal. The signal can be measured as both voltage and current.

In the study, case 5 is the busiest scenario among all scenarios. Thus, THD results of the case 5 are predicted to have the worst distortion values. THD values for both current and voltage are very small at the Main Supply, which are between 0.1-0.3% THD. THD values for both current and voltage are very small at the Balcalı Hospital Transformer, which is between 0.1-0.6% THD. Voltage and THD values for voltage are very small at the Faculty of Agriculture 1 Transformer, which is 0.1% THD (Figures 8-9), and for current are also admissible, which is between 4.4-4.45% THD (Figures 10-11).

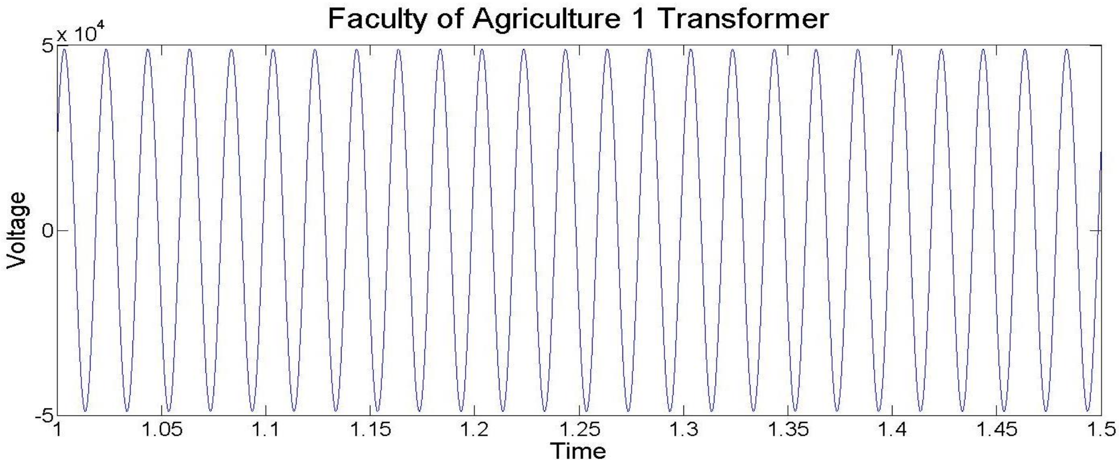

Figure 8. Faculty of agriculture 1 transformer voltage for busiest scenario (Case 5)

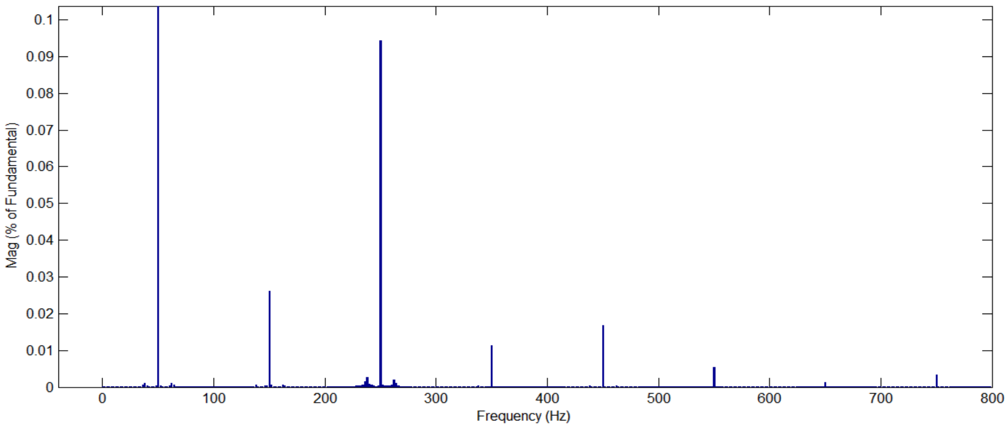

Figure 9. Voltage THD of faculty of agriculture 1 transformer for worst scenario (Case 5)

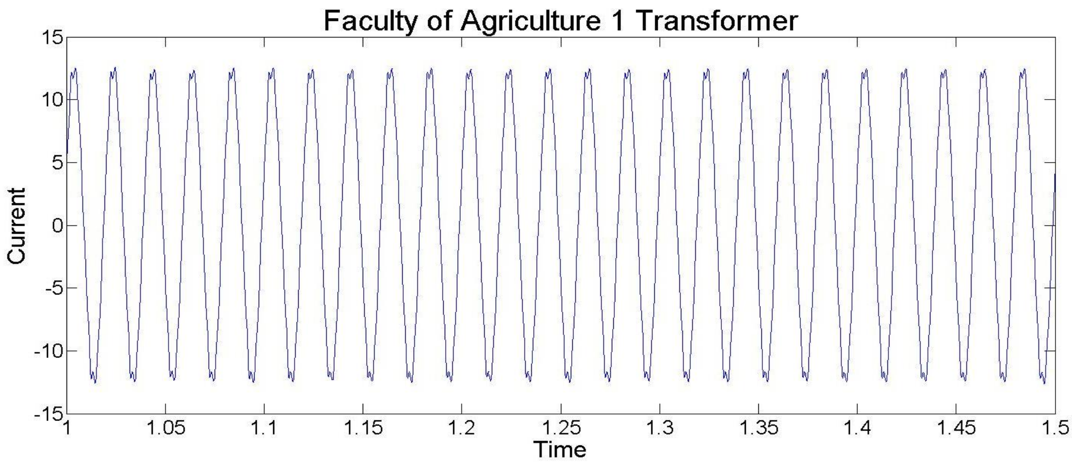

Figure 10. Faculty of agriculture 1 transformer current for busiest scenario (Case 5)

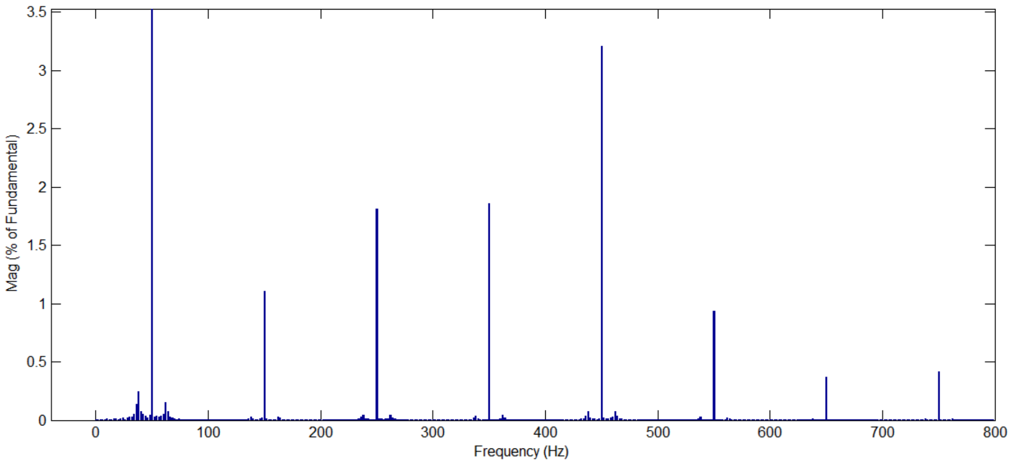

Figure 11. Current THD of faculty of agriculture 1 transformer for busiest scenario (Case 5)

5. CONCLUSION

Today, the demand for electric vehicles is increasing. Manufacturers have focused their research and development activities on the electric vehicles. The number of electric vehicles on the market is increasing day by the day. Therefore, the electric vehicle infrastructure technologies are also being developed. Some of the technology infrastructures are as follows: battery systems, communications, network integration, charging systems.

Therefore, in this study, electric vehicle infrastructure technology in the charging systems and network integration issues are examined. Related modeling and simulation studies were performed in MatLab/Simulink. Battery charging systems and integration of the charging stations to the grid are one of the most important building blocks of electric vehicles' simulation, which will be applied in the university, is studied.

Upon reviewing the results of the studied system's current, voltage and active-reactive power values they were found to be suitable values. Harmonic values of the studied system's transformers which are given in the previous chapter are below 5% that are also admissible. Thus, it can be easily said that the charger circuit was very successful during modeling simulations and additionally, results of the simulations have proved that Çukurova University's installed infrastructure has enough capacity to supply foreseen urban electric vehicle infrastructure. In the paper, detailed modeling of charging circuits are developed and presented. Up to four charging circuits per 1000 kVA transformer are simulated.

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