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Effects of Electric Vehicles and Charging Stations on Microgrid Power Quality

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Keywords

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Abstract

In this study, integration of renewable energy sources and Electric Vehicles (EVs) into a micro-grid was modeled and analyzed. The microgrid is divided into four important parts; a diesel generator, acting as the base power generator; a photovoltaic (PV) farm combined with a wind farm, to produce electrical energy; a vehicle to grid (V2G) system installed next to the last part of the microgrid which is the load of the microgrid. The size of the microgrid represents approximately a community of a thousand households during a low consumption day in spring or fall. There are 100 electric vehicles in the base model which means that there is a 1:10 ratio between the cars and the households. This is a possible scenario in a foreseeable future. The continuous increase in their rate in energy production makes micro-grids important. Micrograds can be designed to meet the energy needs of hospitals, universities or charging stations of electric cars, as well as to meet the energy needs of a district, village or industrial site. Charging stations are needed to charge the electric vehicle battery. In this study, the effects of electric vehicles on the microgrid network are analyzed. Electric vehicles have non-linear circuit elements in their structures. Therefore, they are a source of harmonic current in the microgrid. They negatively affect the power quality of the microgrid. The battery in electric vehicles is charged with direct current. The alternating current from the microgrid needs to be converted to direct current.

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1. INTRODUCTION

It is thought that electric cars will have a significant impact on the automotive industry in the future. This type of car not only saves fuel, but also reduces city pollution and carbon emissions. The degree of reduction in carbon dioxide emissions depends on electricity generation, and a 30% reduction is expected in the future. Electric cars use one or more electric motors (Erhan et al., 2013; Özçelik et al., 2019). The energy needs of these vehicles are supplied from the energy stored in their batteries. Electric motors provide strong and stable acceleration with instant torque (Liu et al., 2015; Lee et al., 2017). Electric cars have some advantages over internal combustion engine vehicles; they reduce local air pollution, reduce dependency on oil importing countries. It will be very important to provide bidirectional charging in the future. Electric vehicles can feed the grid and serve the system when needed. Electric vehicles can act as “mobile stations” in a way that can store unused electricity and transmit it back to the grid (Izgi et al., 2012; Yong et al., 2018). With the EV market growing fast, the emerging wireless EV charging technology has attracted more and more attention in recent years. The basic components of the electric car are given in Figure 1.

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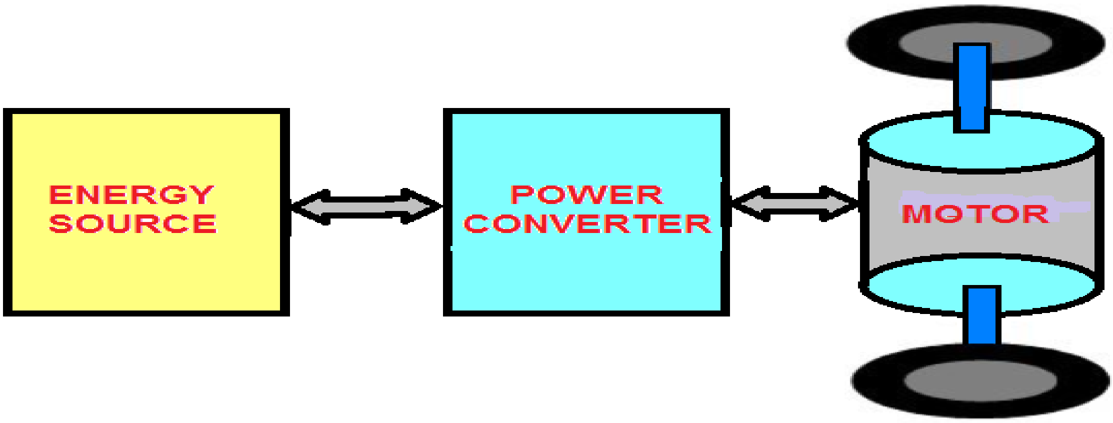

Figure 1. *Basic Structure of Electric Vehicle*

The second method is to overcome PV variation to use a local storage in the PV powered EV charging station. Electric motors give instant torque, providing powerful and balanced acceleration (Ashique et al., 2017). Priorities that may be important for the automotive industry, charging technology developers, urban planners and researchers:

- Acceleration of the electric vehicle market with the development of charging infrastructure
- Development and implementation of smart charging mechanisms for load management
- Taking region-specific measures to avoid overloads and voltage drops in the network
- Evaluation, development and implementation of new business models for charging electric vehicles
- Continuing planned investments in distribution networks in parallel with the increase in electricity demand
- Renewable energy integration in the charging of electric vehicles
- Evaluation and planning should be done in order to benefit from the advantages provided by electric vehicles.

The electric vehicle have an electric motor, batteries and an AC-DC converter to control the engine. The batteries of the electric vehicle can be charged wherever electricity is available, such as at home and in the workplace (Fathabadi, 2015). In principle, stored electricity is used for transportation. However, the stored electricity can be transferred back to the microgrid. There are different charging stations, such as AC charging station, DC charging station and inductive charging station. DC charging stations are the fastest growing type (Chandra Mouli et al., 2016). The EV market is still far from completing its development in our country, and many of the studies focus on battery technology, the use of the electric motor and technical details about the internal equipment.

2. HARMONIC COMPONENTS PRODUCED BY ELECTRIC VEHICLES

Modern electric vehicles inject harmonic components into the microgrid during charging. The harmonic components of the current wave forms are higher than the harmonic components of the voltage wave form. THD level can affect the microgrid power system. In addition microgrid power quality will be affected by the THD value. The analysis THD level is important in the charging station. Non-linear loads that increasing use of with in electric vehicles caused disorders in the sinusoidal form of current and voltage signals. Non-linear waveform contain harmonic components (Kong et al., 2019). AC/DC and DC/AC converters charging systems are used in at electric car. They are the most important of harmonic sources. Electric car and electrical components are given as follows. Electric vehicles consist of an electric motor powered by a battery pack. The main advantage of electric vehicles is that they emit zero emissions and are environmentally friendly. They also do not consume any fossil fuels, so they use a sustainable form of energy to power the vehicle. The main components of electric vehicles are as given in Figure 2.

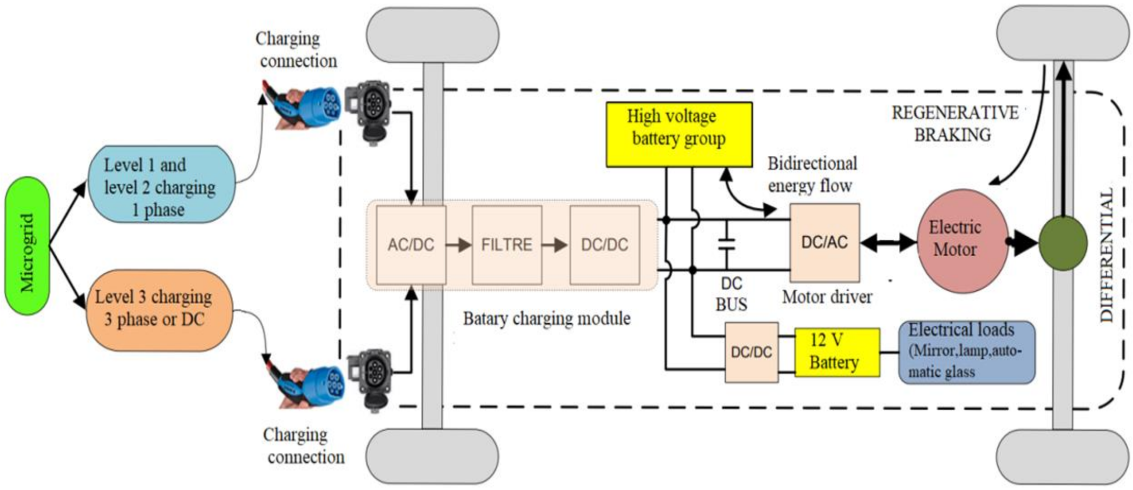

Figure 2. *Structure of Electric Vehicle*

Aforementioned harmonics create integer multiples of the main harmonics (50 Hz), i.e. 150Hz, 250Hz, 350Hz and 750Hz are the 3rd 5th, 7th, …, and 15th harmonics (Rüstemli et al., 2015). Total harmonic distortion (THD) is generally caused by a non-linear waveform in smart microgrid. Harmonics in the power system occurs the following hazards at smart microgrid: Overheating in power transmission lines.

- Overheating in power distribution lines.
- Harmonics occur resonance in the smart microgrid
- Life span of life transformers and electronics devices.
- Distruction of the reactive capacitors.
- Protective switches in microgrid enables to open timeless.
- Noises causes in communication facilities.

Nowadays, renewable energies have substantially importance in smart microgrid. Such these systems do not harm to the environment. In contrast, they are environment friendly (Erhan et al., 2013; Yapıcı et al., 2016). THD is a common measurement of the level of harmonic distortion present in smart microgrids. THDv can be defined as follows:

$$THD_V = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \cdots + V_n^2}}{V_1} \tag{1}$$

If the harmonics are equal to the “0”, THD_V will be equal to the “0”. Where, Vn, is the RMS voltage of nth harmonic and n=1 is the voltage of fundamental frequency. THD_I can be defined as follows:

$$THD_I = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + \cdots + I_n^2}}{I_1} \tag{2}$$

Where, In is the effective current of nth harmonic, and n = 1 is the fundamental of current. When the harmonics components are equal to zero, THD_I will be “0”. THDı value is bigger than THDv value in microgrids that charging station is located. A controversial situation for PV inverter is the harmonics level. The IEEE 929 standard permits a limit of 5% for the current total harmonic distortion.

The mathematical solutions and Matlab applications have been observed that 5th & 7th harmonics occur in the microgrids, any or both of these sources of non-sinusoidal non-linear elements in general. The existence of harmonics for both current and voltage of the microgrids mean that the distortion of sinusoidal waves. Electric vehicles are a source of harmonics in the microgrid. The harmonic components injected into the microgrid while charging the 16 kW battery used in the electric vehicle are given in Table 1.

Table 1. *The Harmonics Current Drawn from the Microgrid during the Charging of EVs*

The Harmonic Components	Amplitude
1	100
5	22
7	19
11	8.5
13	6.5
THD_I	31.90 (%)

Harmonic distortion in the control with PWM is considerably reduced. Thyristor-based rectification creates 28.16 (%) total harmonic distortion, while PWM-based rectification creates 0.18 (%) distortion. Researching and understanding the harmonic distortion caused by EVs is of great importance to ensure the continuous and reliable operation of the microgrid. The changing of harmonic components is given in Figure 3.

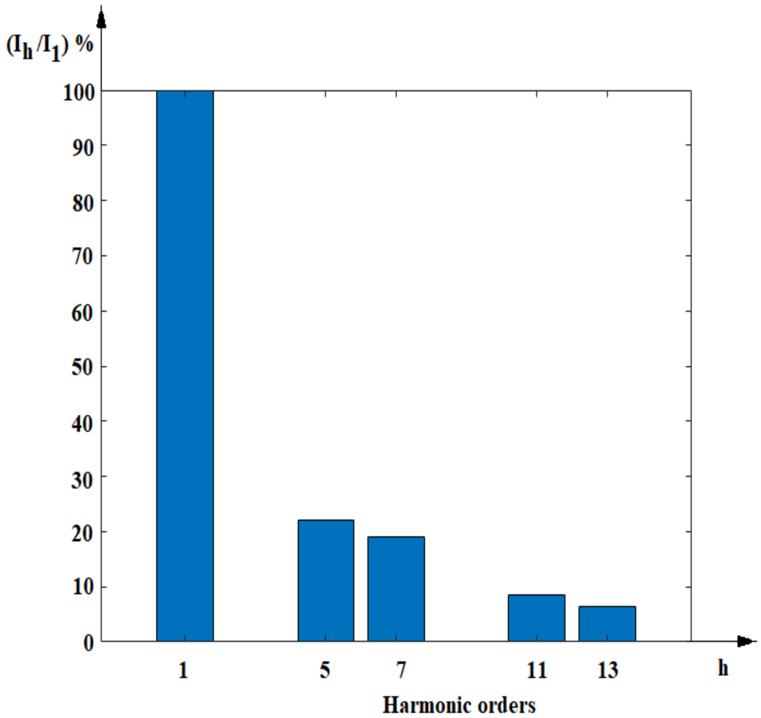

Figure 3. *The Harmonic Components of the Current during the Charging of EVs*

In the case of low level EVs with normal charge, harmonic levels and voltage drops are low and losses are minimal. Accordingly, when the charge is low, normal charge state and EV penetration level is 20 (%), THD (%) is 3.12 (%) between 08.00-17.00. THD (%) was calculated as 44.92 between 17:00 and 23:00 of the time when the EV penetration level was 80 (%) in overload and fast charge condition. As a result, an increase in transformer loading values will increase heating and decrease transformer life. The widespread use of EVs will create a huge load problem for the low voltage distribution network. Today, electric vehicles need low range and continuous charging. Positioning of charging stations is very important.

3. ANALYSIS OF THE MICROGRID WHERE ELECTRIC VEHICLES ARE CHARGED

Electric vehicles are made up of two parts. Electric vehicles provide the energy needs of their batteries, and the movement of the vehicle is provided by the electric motor. Batteries in electric vehicles need to be charged from an external energy source. In this case, vehicles need to be charged. Electric vehicles have different types of charging. There are different types of charging stations according to charging speed and voltage. The development of electric vehicles continues in parallel with the developments in battery technology (Khooban et al., 2017; Diaz et al., 2018). Obstacles to electric vehicle development are increasing the range and shortening the charging time. Today, intensive studies are carried out to solve these problems.

The quick method to charge an electric vehicle is to charge the vehicle in DC. In order to shorten the charging times of electric vehicles, the power of the charging stations is increased. For this reason, the number of charging stations with a power over 350 kW is increasing day by day. There are multiple charging sockets at the charging stations to charge more vehicles at the same time. Charging dozens of vehicles at the same time can cause serious problems on the microgrid. One of the problems is the increase in load demand on the grid. Only eight of these vehicles could be one at a time. Charging at the station will create an instantaneous energy need of 1 MW. The integration of renewable energy sources and Electric Vehicles into a microgrid is modeled in Figure 4.

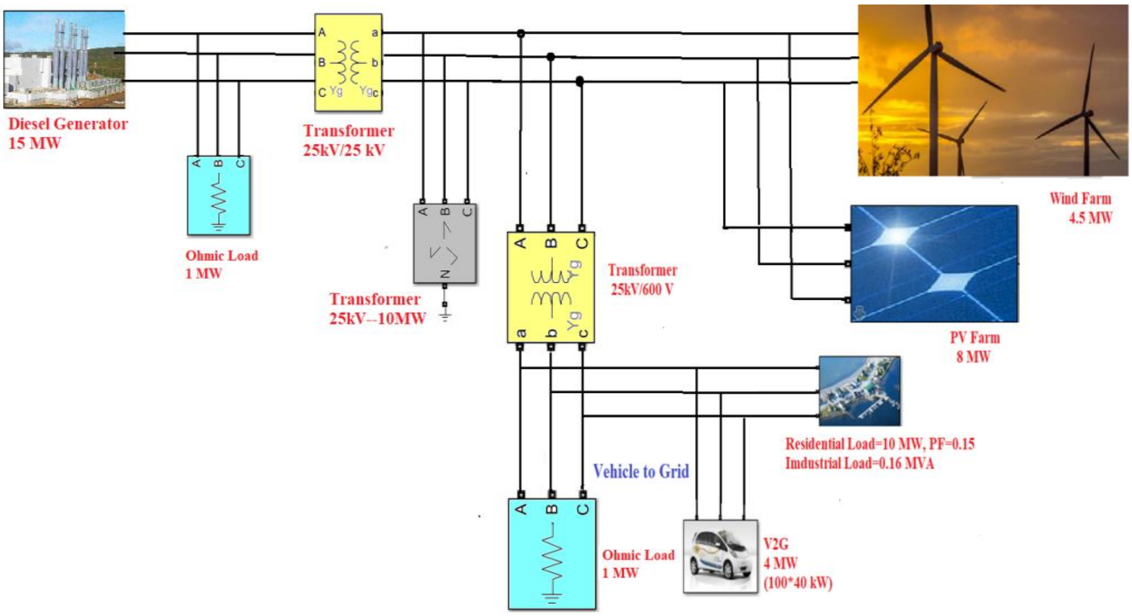

Figure 4. *Microgrid and Electrical Vehicles*

The analyzed microgrid consists of four parts. Diesel generators are acting as the primary power generator; PV plant with a wind turbines to produce green energy; the V2G system as a load on the network. It consists of a community of one thousand households with low consumption as microgrid load and 100 electric vehicles. There is a 1:10 ratio between electric vehicles and households. Increasing renewable energy production helps save the environment. Nevertheless, the energy production of renewable energy sources are strictly depending on environmental factors.

Microgrid systems to work perfectly and secure depend on the fundamental of quantities such as current and voltage which are sinusoidal waveform and 50 Hz frequency. But, such these fundamental quantities lose their sinusoidal characteristics because of many reasons, and unwanted harmonic component occur in the microgrid system. When the studies in the literature are scanned, many studies focus on the effect of charging of electric vehicles on the microgrid and the determination of the locations of charging stations within certain criteria.

The rapid increase of EVs increases the power demand and this causes an extra load on the microgrid. As a result, fluctuations in the microgrid increase. The diesel generator in the micro-grid ensures that the power consumed and the power produced are balanced. We can find the deviation in the grid frequency from the rotor speed of the synchronous machine. In Figure 5, the amount of energy produced by the diesel generator throughout the day is given.

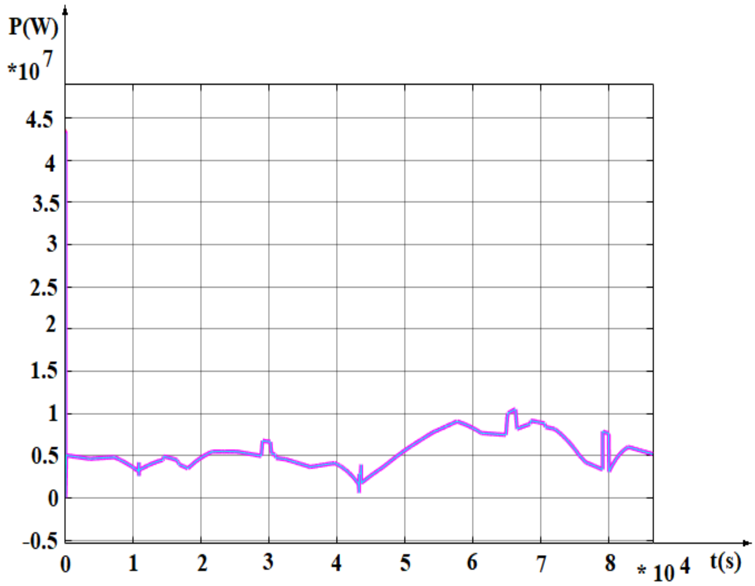

Figure 5. *Active Power Generated by the Diesel Generator throughout the Day*

High cost of diesel generator and polluting the environment are its disadvantages. However, in cases where the energy demand is not met with renewable energy sources, the energy to be produced by the diesel generator is needed.

The DC coupling capacitor, which provides electric vehicle charging, also provides reactive power compensation. Compensation control is provided by two-way electric vehicle fast charging stations. There are two renewable energy sources in the microgrid. Firstly, the PV plant produces energy proportional to the amount of irradiation in the environment. In Figure 6, the amount of energy produced in solar panels during the day is given.

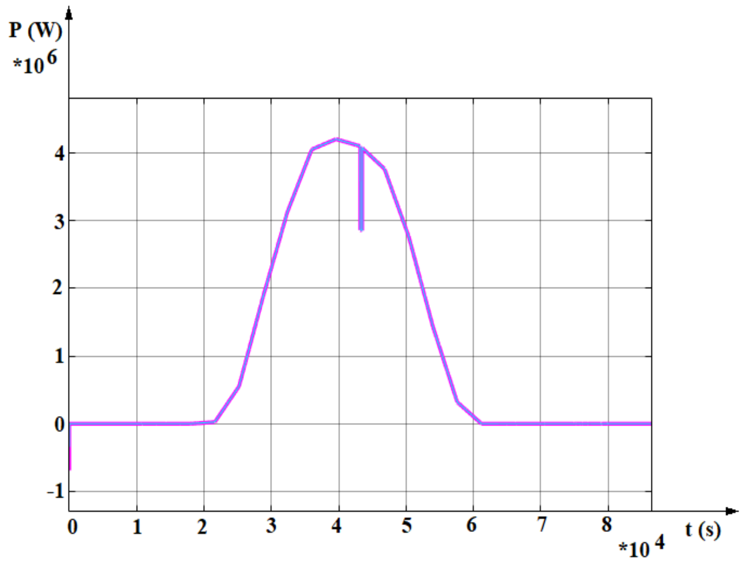

Figure 6. *Active Power Generated by the Solar Power Plant throughout the Day*

In the solar farm used in the micro-grid, direct current is produced by absorbing the solar irradiation. The amount of energy produced depends on the type of material used in the panel and the amount of solar irradiance that the panels absorb.

The wind farm generates electrical power linearly proportional to the wind. It generates the rated power when the wind speed reaches its rated value. When the wind speed exceeds its maximum value, the wind is disabled from the microgrid until it reaches its nominal value. In Figure 7, the amount of energy produced by the wind farm throughout the day in the microgrid is given.

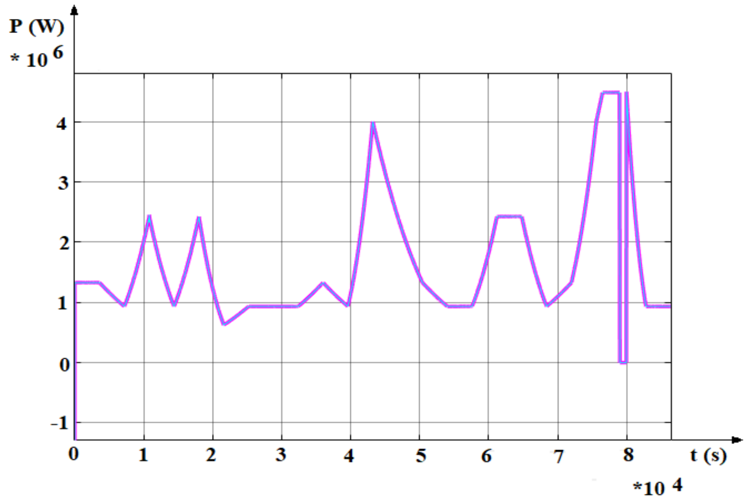

Figure 7. *Active Power Generated by the Wind Power Plant throughout the Day*

The use of wind power plants in the micro-grid is constantly increasing due to the fact that they are a renewable energy source, their simple structure and high efficiency. However, wind farms are different from other conventional power plants. Due to its structure, some problems occur during their connection to the microgrid.

The biggest advantage of EVs is the V2G application. This application is only applied to electric vehicles. Basically, it provides direct power flow from the vehicle to the distribution microgrid. The participation of electric vehicles in V2G technology requires higher charge and discharge rates of the battery and this causes the batteries to deteriorate faster. Charging stations are classified as level 1, level 2 and level 3. Level 1 slow charge, level 2 normal charge, level 3 indicates 3-phase or DC fast charging. In Figure 8, the current value charged from the EV to the microgrid during the day is given.

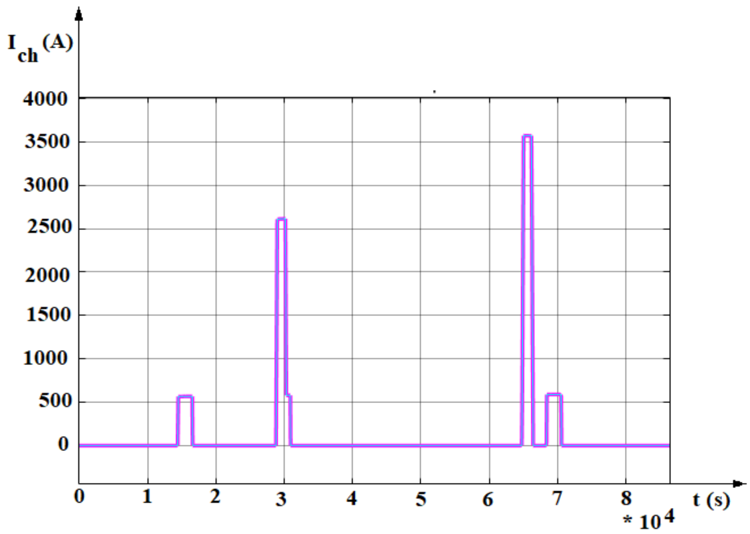

Figure 8. *Current Injected Into the Microgrid from Electric Vehicles throughout the Day*

V2G is basically the transmission of electricity from the batteries of electric vehicles to the microgrid. In the electrical system, the batteries of electric vehicles act as storage. With vehicle-to-grid technology, a vehicle battery is charged and discharged according to different signals such as energy production or consumption.

EV charging causes an increase in the load per transformer when energy consumption in the microgrid is intense. This creates major problems in balancing the energy supply. If many electric vehicles are charged from the same phase, a phase imbalance occurs in the microgrid. Unplanned charging of electric vehicles causes serious problems in the microgrid. Simultaneous charging of a large number of EVs can cause a voltage drop at the connectors of the chargers. During charging, electric vehicles consume high active power from the network, caused power losses in the microgrid. Positioning the charging stations in suitable places and choosing the right power capacity can minimize the power loss in the microgrid. Emission-free public transport, such as electric buses, improves local air quality and reduces noise pollution. Figure 9 shows the charging of an electric bus.

Figure 9. *Charging the Electric Bus*

Electric buses need EV charging stations equipped with smart systems to meet the charging needs. Batteries in electric vehicles are charged with Direct Current (DC) due to their nature. Since charging limitations for DC power support much higher speeds than AC power, electric vehicles can be charged with DC power at very high speeds, in very short times.

V2G have 2 functions. It controls the charge of the batteries and uses the existing power to regulate the grid when transients occur. V2G ensures that existing distributed energy storage devices are instantly available. Various applications of battery types enter the market.

The energy stored in the electric vehicle is transmitted back to the micro grid with bidirectional charging. In this way, electric vehicles will turn into a demand-side source and electric vehicle users will be able to earn additional income.

Electric vehicles and residential load drawn active power from the mıcrogrid durıng the day The charging time required for charging an electric vehicle with a 64 kWh battery at different speeds from 0% to 80% is given in Table 2.

Table 2. *Charging Speed and Times in Electric Vehicles (Speirs, 2020)*

Charge Type	Charge Speed	Range Reached in One Hour Charge	Duration
Charge device (8 A)	1.8 kW	10 km	35 hour
1-phase AC Charger	7.4 kW	40 km	9 hour
3-phase AC Charger	22 kW	120 km	3 hour
DC Charge	25 kW	150 km	1.5 hour (up to 80%)
Fast DC Charge	50 kW	300 km	1 hour (up to 80%)
Ultra Fast DC Charge	175 kW	1000 km	15 minute (up to 80%)

The charging speed and duration of electric vehicles are related to how fast the batteries are filled. The factor that determines the charging speed of the batteries is primarily the chemicals used in the battery. It is possible to increase the charging speed and shorten the charging time by using chemicals that are more resistant to high current. The load consists of a residential load and an asynchronous machine to represent the effect of industrial inductive load on the microgrid. The variation of active power consumed by residences throughout the day is given in Figure 10.

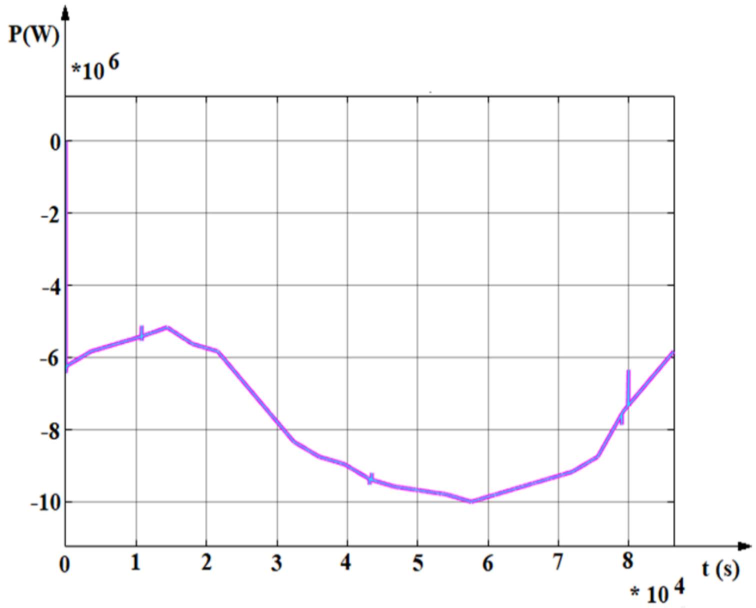

Figure 10. *Residential Load Drawn Active Power from the Microgrid during the Day*

The residential load is represented by the active power drawn at a specified power factor. The torque of the induction machine is directly proportional to the square of the rotor speed. Despite their potential benefits, there are some reasons why electric cars are not widely adopted. Electric cars are importantly more costly than a conventional internal combustion engine vehicle and hybrid electric vehicles owing to the additional cost of lithium-ion batteries. However, battery prices are decreasing with mass production and are expected to decrease further. Most internal combustion engine vehicles are considered to have unlimited range and fill their tanks at gas stations in a very short time. In contrast, EVs have less range on a single charge, and charging can take a long time. The transport sector is obliged for 24% of CO2 emissions, which is about three-quarters of CO2 emissions. For this reason, countries strongly encourage the use of electric vehicles.

4. CONCLUSION

Since the main problem in electric vehicles is the battery capacity and accordingly the range, regenerative braking is of great importance in these vehicles. The electric vehicle consumes 72 kW of power when climbing a steep slope, and the electric machine works as a generator when descending the same slope. It has been observed that it transfers a power of 24kW to the battery. It has been proven by scientific studies that electric vehicles are an alternative to internal combustion engines in terms of both efficiency and environmental pollution. Reactive power elimination is applied to secure voltage regulation of the microgrid. Reactive power support improves power factor and reduces power losses in power lines. In addition, it leads to increased productivity. Electric vehicles connected to the microgrid can provide reactive power compensation.

The charging time depends on the power source and the vehicle's charging capacity. The charging time is found by dividing the battery capacity of the electric vehicle by the charging power. The capacity value of an electric vehicle is 60 kWh. It is charged at a charging station with a charge value of 7 kW. It has been observed that the battery of this vehicle is charged up to 80 (%) in 8 hours.

Electric vehicles are modeled as harmonic current sources in microgrids due to the power electronics-based converters that exist in their structures. As electric vehicles increase day by day, necessary measures should be taken by making necessary studies on their power quality, especially on harmonic components. In proportion to the increase in electric vehicles, the number of charging stations is increasing day by day. Apart from settlements such as parking lots, shopping centers and mass housing, people can also set up electric vehicle charging stations individually in their homes. All these developments mean additional load for the electricity grid. For microgrids with high penetration of renewable energy sources and electric vehicles, the stochastic charging/discharging of the electric vehicles would result in a large impact on the secure and stable operation of the microgrids. Therefore, the coordinated control between electric vehicles and renewable energy sources becomes an important challenge for keeping the microgrid stable.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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