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The Impact of Electric Vehicles on The Grid

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Abstract – The unlimited nature of consumption and needs contrasts with the scarcity of usable resources, necessitating the optimal use of available resources. Alongside the careful protection of the environment and human health, it is crucial to meet needs with maximum efficiency. With the aid of measuring instruments and sensors added to traditional grids, grids are becoming smart, allowing for rapid resolution of system failures, security issues, losses, and requirements through detection, monitoring, and control. The quick and minimal-error communication between grid elements is of great importance. This paper aims to raise awareness about the economic benefits for the grid and users through a V2G (Vehicle-to-Grid) technology simulation, focusing on the advantages and disadvantages of using V2G technology, ensuring that the energy needs between the producer and consumer are met promptly and adequately without any system disruption within a smart grid infrastructure aided by 5G communication technology.

Keywords – EV, Electric vehicle, V2G, G2V, 5G

I. INTRODUCTION

Due to environmental pollution, global warming, dwindling fossil fuel reserves, and rising prices, the search for alternative energy sources has intensified, particularly in vehicles where electricity is increasingly used in place of petroleum and derivative fuels. Electric vehicles (EVs) offer advantages such as zero exhaust emissions, quiet operation, and lower energy consumption compared to internal combustion engines. However, they face disadvantages like range anxiety, high costs, battery technology issues, and insufficient charging stations.

According to the International Energy Agency (IEA), the stock and sales of EVs worldwide have been gaining dominance in the automotive sector. The EV stock exceeded 40 million in 2023, with sales surpassing 16 million in 2024, leading to a rise in both fast and slow charging stations. [1], [2], [3], [4]

The IEA's Global EV Outlook 2024 report predicts that by 2030, the number of charging points will exceed 15 million, with electricity consumption from EVs making up 8.1% of final electricity consumption, up from 0.5% in 2023. The EV fleet is expected to displace 6 million barrels per day (mb/d) of diesel and gasoline by 2030. [5]

The concept of EVs exchanging power with the grid first emerged in 1997 through the work of Kempton and Letendre [6], who coined the terms G2V (Grid-to-Vehicle) for charging and V2G (Vehicle-to-Grid) for discharging, investigating the economic potential of energy flow. The increasing number of EVs, technological advancements in smart grids, and daily fluctuations in energy demands drive this change. Price fluctuations in energy due to these daily variations allow EV owners to charge at lower costs and profit during peak demand times. Thus, EVs can act both as energy consumers and distributed storage devices, supporting the grid.

The increasing number of electric vehicles and their simultaneous charging as distributed loads on the grid during the day necessitate alternative studies to prevent significant grid imbalances. These studies include literature reviews compiling academic research on G2V (Grid-to-Vehicle) and V2G (Vehicle-to-Grid) Technologies [7], [8], [9], [10], [11], [12], [13], steps to be taken for the development of V2G technology, including policy regulations [14], research aimed at resolving the range issue of electric vehicles, efforts to shorten charging times, studies on the criteria for selecting the locations of charging stations, advances in battery technology, research on the electric motors used in electric vehicles, studies on the microprocessors found in electric vehicles and charging stations, V2G studies focusing on the supportive impact of electric vehicles on the grid, instead of being a load, and the economic gains for the electric vehicle user, advantages in the energy system and disadvantages in the case of unplanned charging [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30], [31], [32], [33], [34], implemetations of V2G technology [35], [36] etc. These areas of research have collectively inspired many dimensions of electric vehicle technology.

Although the electronic equipment in electric vehicles causes some issues in the grid, there are also solutions to these problems. The power electronics equipment in electric vehicles, the charging times, the differences in power values, and the uncertainties in the charging locations affect the stability of the power system. If electric vehicles are charged by drawing power from the grid in an unplanned manner, it causes instability in the grid voltage. To eliminate this negative effect, the location and power of electric charging stations should be planned considering the total load profile in the network structure of the energy grid. The excess/deficiency in the power drawn from the grid and the amount of energy produced in the system causes deviations in the grid frequency. If more power is needed than the existing energy supply in the grid, there will be a drop in grid frequency; if more energy is supplied than the demanded power, there will be an increase in grid frequency. Small-scale fluctuations occur in the grid due to changes in the energy consumption/production values of electric vehicles and the amount of energy produced in the grid. If these fluctuations are not controlled, they may cause aging in the units of the energy system, leading to sudden outages in the grid. Planned control charging and strategies for load management should be developed against such adverse effects.

Electric vehicles and charging stations contain a lot of electronics. The electronic equipment gives electric vehicles and charging stations a nonlinear characteristic, causing harmonics in the current drawn from the grid. Current harmonics lead to overheating of components/equipment in electric vehicles and charging stations and reduce their lifespan. When electric vehicles draw power from the grid, the main voltage drops, and disconnecting them causes a voltage rise. This situation damages circuit equipment. When electric vehicles are loaded on a single phase of the grid, unbalanced loading occurs. This causes different amplitude values in the three phases of the grid, leading to overheating of protective equipment on the phases. Wide-area controls should be implemented in the grid against such adverse effects, and harmonic filtering systems should be used. Many electric vehicles connected to the grid as a load will require additional power from the grid, necessitating extra energy production. This situation will lead to overloading of system connection elements and a reduction in transformer lifespan. Load management strategies should be developed against such adverse effects, coordinated charging applications should be established, and distributed charging systems should be created in the grid.

Electric vehicles also provide positive contributions to the grid. The amount of energy drawn from the grid varies throughout the day. With energy management, the energy demand that may occur during high peak times can be spread over time, thus managing the grid loads, supporting renewable energy sources, increasing energy efficiency, improving the system power factor, and achieving energy savings. The stored energy in electric vehicles can be supplied to the grid during high demand times and they can be charged when the demand is low. When there is an energy flow as a fleet of vehicles, it will have a relieving effect on the grid. This also contributes to the efficient use of energy. Balancing supply and demand will support keeping the grid frequency stable. The integration of electric vehicles into the grid, with filtering and reactive power compensation circuit elements for improving harmonics and power factor, contributes to improving the power quality of the grid.

Electric vehicles integrated into the grid both in V2G (discharge mode) and G2V (charge mode) situations assist the grid as both producers and consumers. Energy planning can be done by processing the data obtained from electric vehicles and the grid through the network. Assigning the electric vehicle as a production unit like an energy storage unit when consumption is high and as a grid load when energy demand is low can support grid stability. The planning should consider the times when the electric vehicle will be used for driving, the amount of energy it will consume, its waiting times in parking areas, and its charging status while parked.

II. MATERIALS AND METHOD

A. 5G SYSTEM PERFORMANCE

The development process in 5G communication has culminated with the works of Claude E. Shannon (Shannon Theory), Robert G. Gallager (Low-Density Parity-Check Code), and most recently Erdal Arıkan (Polar Coding). The transition to 5G was achieved through the test studies conducted in the laboratory environment by Erdal Arıkan related to polar coding.

Polar coding is an algorithm that ensures secure and fast data transmission in a noisy environment. It significantly enhances 5G communication performance by minimizing the losses experienced in communication due to noise. [37]

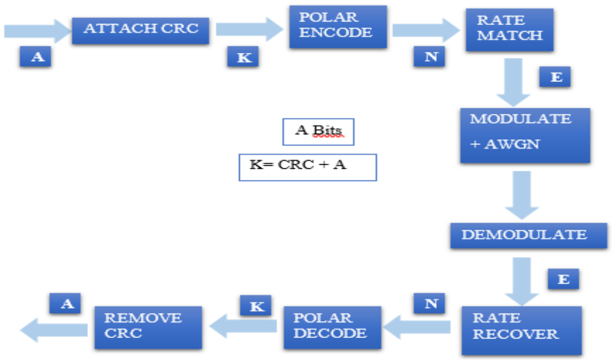


Fig. 1 5G Communication Topology

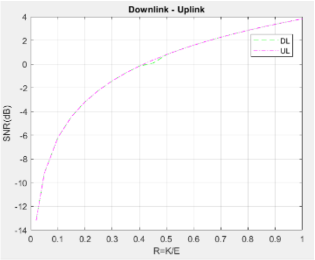
In 5G communication, the data in bits transmitted by the sender is first encrypted through polar coding to ensure it is sent with minimal errors and then passed on to modulation. With modulation, the data is superimposed on a much higher frequency carrier signal to be sent over long distances. Subsequently, noise that may exist in the environment is introduced into the process, and demodulation is performed in the channel to remove the modulation. Finally, the encrypted data is decrypted and the final data is transmitted to the receiver. (Figure 1)

A simulation study was conducted in MATLAB to analyze the performance of data flow with polar coding. The data (A) entering polar coding, when following the flow shown in Figure 2, was analyzed in terms of the variation in SNR (dB) noise value depending on the R=K/E ratio, both in the downlink and uplink directions. The R=K/E ratio was examined separately for downlink and uplink directions, increasing from approximately 0 to 1 in increments of 0.05, and the data flows were analyzed individually.

In the downlink and uplink directions, the value A was kept as a fixed bit value with intermittent increments. In the downlink direction, a 24-bit CRC was added, and in the uplink direction, an 11-bit CRC was added to form the K value. The E value was adjusted based on the increase in the R value. The N polar code value was kept constant at 128. The SNR (dB) noise value exhibited a logarithmic change, ranging from approximately -13 to +3.8. (Graph 1)

	DL (DOWNLINK) CRC=24 (A+CRC=K)							UL (UPLINK) CRC=11 (A+CRC=K)					
A	N	K	E	K/E	SNR (dB)	BLER	BER	K	E	K/E	SNR (dB)	BLER	BER
24	128	48	2400	0	-13,179	0	0	35	1750	0	-13,179	0	0
26	128	50	1000	0,1	-9,2	0	0	37	740	0,1	-9,2	0	0
28	128	52	520	0,1	-6,1897	0	0	39	390	0,1	-6,1897	0	0
30	128	54	360	0,2	-4,4288	0	0	41	272	0,2	-4,4076	0,1	0,033
32	128	56	280	0,2	-3,1794	0	0	43	216	0,2	-3,1996	0	0
34	128	58	232	0,3	-2,2103	0	0	45	180	0,3	-2,2103	0,2	0,094
36	128	60	200	0,3	-1,4185	0,1	0,058	47	158	0,3	-1,4553	0,1	0,039
38	128	62	178	0,3	-0,77	0	0	49	140	0,4	-0,749	0	0
40	128	64	160	0,4	-0,1691	0,1	0,038	51	126	0,4	-0,1177	0,1	0,058
42	128	66	146	0,5	0,09069	0,2	0,05	53	118	0,4	0,33424	0,1	0,038
44	128	68	136	0,5	0,8	0,3	0,091	55	110	0,5	0,8	0,1	0,05
46	128	70	128	0,5	1,1892	0,3	0,117	57	104	0,5	1,1987	0,1	0,046
48	128	72	120	0,6	1,5918	0,3	0,121	59	98	0,6	1,6066	0,4	0,196
50	128	74	114	0,6	1,9336	0,5	0,142	61	94	0,6	1,9323	0,3	0,072
52	128	76	110	0,7	2,2045	0,4	0,14	63	90	0,7	2,2613	0,4	0,131
54	128	78	104	0,8	2,5609	0,1	0,044	65	86	0,8	2,5944	0,6	0,219
56	128	80	100	0,8	2,8412	0,8	0,273	67	84	0,8	2,8283	0,5	0,188
58	128	82	96	0,9	3,1257	0,9	0,397	69	82	0,8	3,0607	0,7	0,181
60	128	84	94	0,9	3,3218	0,8	0,28	71	80	0,9	3,292	0,9	0,288
63	128	87	92	0,9	3,5676	0,9	0,357	74	78	0,9	3,5817	0,9	0,232
65	128	89	90	1	3,7618	1	0,282	76	76	1	3,8103	0,9	0,242

Table 1. 5G Communication Performance



Graph 1. SNR (dB) – K/E Change

B. V2G Analysis

An electric vehicle integrated into the grid with V2G (discharge mode) and G2V (charge mode) can act as both a producer and a consumer. During the day, it can draw energy from or supply energy to the grid depending on the energy prices in the electricity market and the supply/demand of energy. In situations where energy demand is low and energy prices are low during the day, it acts as a consumer in G2V (charge mode). When energy demand is high and energy prices are high, it supplies the energy stored in its battery to the grid in V2G (discharge mode). To visualize the contribution of electric vehicles to the grid in V2G (discharge mode) and the load they create in G2V (charge mode), a simulation was created using MATLAB Simulink by modeling a section of the grid. The system analysis was carried out based on the number of vehicles at the charging station. The analyzed section of the grid consists of five parts. In a 60Hz system, a 15MW diesel power plant acts as the central power station, and the energy needed by the grid is supplied by a 4.5MW wind power plant (WPP) and an 8MW solar power plant (SPP) as renewable energy sources that support the central power station. On the energy consumption side, there is a residential load of 10MW with a power factor of 0.15, an industrial load of 0.16 MVA, and a total electric vehicle load of 8MW with 200 vehicles (200*0.4MW). The analysis was performed using MATLAB Simulink (Figure 2).

To reflect reality, the electric vehicles were divided into 10 charging stations with a variable number of vehicles at each station (Figure 3).

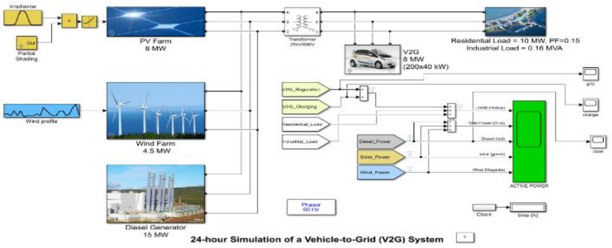


Fig. 2 Sampled System

In the analysis, the WPP and SPP data were based on daily meteorological data (wind speed, humidity, sunlight angle, sunlight duration, etc.), and the amount of energy they could produce hourly over 24 hours was considered constant. In this system example, the diesel power plant acts as the central power station, meeting demand with energy production data that varies according to the user's consumption data at hourly intervals throughout the day. The analysis compared the diesel power plant's production data based on the electric vehicle consumption data, assuming the WPP, SPP, residential load, and industrial load were fixed variables. In the analysis, for 200 vehicles across 10 charging stations: in case 1, with 60 vehicles charging (30%) and 140 vehicles feeding the grid (70%); in case 2, with 120 vehicles charging (60%) and 80 vehicles feeding the grid (40%); and in case 3, with 180 vehicles charging (90%) and 20 vehicles feeding the grid (10%), it was observed that electric vehicles functioned as both consumers and energy storage units at varying times of the day. They were able to trade energy by taking advantage of fluctuating energy prices and could contribute to central power plants and renewable energy production sources during times of high demand. The most important assumption in the analysis was that a communication network and infrastructure based on 5G technology existed, the electric vehicles had G2V and V2G capabilities, and the sampled grid section was part of a smart grid connection.

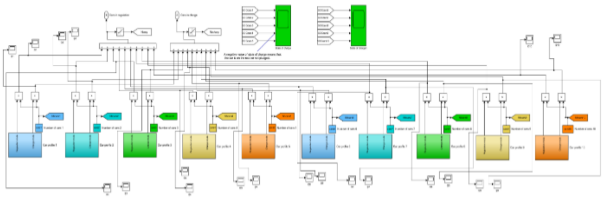
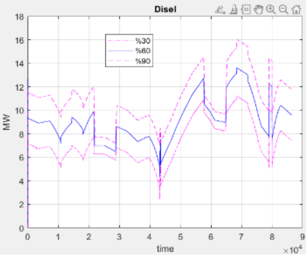


Fig. 3 Electric Vehicles Connected to Charging Stations

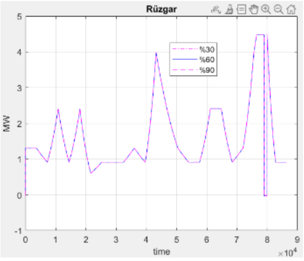
	1. CASE (%30 C / 70% D)		2. CASE (%60 C / 40% D)		3. CASE (%90 C / 10% D)	
CHARGING STATION	G2V	V2G	G2V	V2G	G2V	V2G
1.	21	0	42	0	63	0
2.	15	0	30	0	45	0
3.	6	0	12	0	18	0
4.	12	0	24	0	36	0
5.	6	0	12	0	18	0
6.	0	49	0	28	0	7
7.	0	35	0	20	0	5
8.	0	14	0	8	0	2
9.	0	28	0	16	0	4
10.	0	14	0	8	0	2
TOTAL	60	140	120	80	180	20

Table 2. Vehicles in V2G – G2V Charging Stations for Three Scenarios

The change in total power drawn from the grid by the diesel power plant, wind power plant, solar power plant, and electric vehicles was monitored for the three different scenarios.

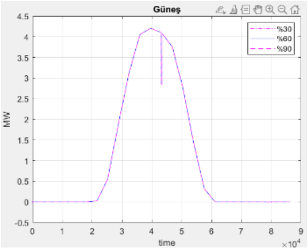


Graph 2. Diesel Power Plant Energy Production

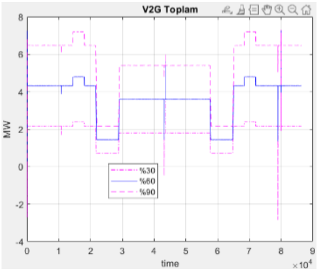


Graph 3. WPP Energy Production

In scenarios with 30% G2V – 70% V2G (1st case), 60% G2V – 40% V2G (2nd case), and 90% G2V – 10% V2G (3rd case), it was observed that the diesel power plant worked harder to meet the demand in the grid when the number of vehicles drawing energy for charging increased. Conversely, when the number of vehicles feeding the grid in V2G mode increased, the diesel power plant operated to meet the lower demand in the grid (Graph 2).



Graph 4. SPP Energy Production



Graph 5. EV Cumulative Impact

Since the meteorological data was assumed to be constant in all three scenarios, there was no change in the energy production of the wind power plant and solar power plant over 24 hours (Graph 3) (Graph 4).

In all three scenarios, when the cumulative effect of the G2V and V2G modes of the electric vehicles on the total energy drawn from the grid was monitored, an increase in the total energy drawn from the grid was observed as the number of charging vehicles increased (Graph 5).

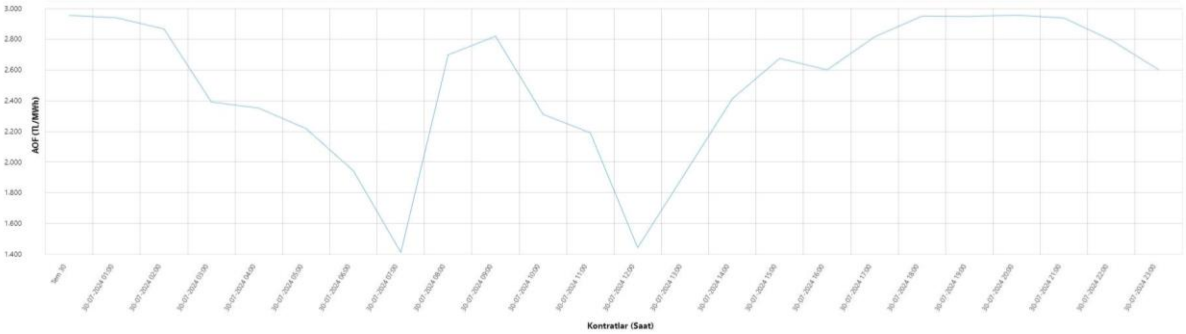
III. RESULTS

In the analysis study, considering the impact of electric vehicles on the grid in G2V and V2G modes, depending on the vehicle density at charging stations, an interpretation based on the pricing mechanism in the energy market during the day will help better understand the decision-making process of an electric vehicle as a producer/consumer. Here, the decision is influenced not only by energy market pricing but also by the equipment and features of the electric vehicle, and most importantly, by the battery's aging characteristics in G2V and V2G modes, as well as the vehicle's usage during the day. Therefore, it is necessary to examine the cumulative effect of the owner's preferences and the renewal of the vehicle's equipment by including detailed variables such as these in the process.

IV. DISCUSSION

Energy Market Operations Inc. (EPİAŞ) data has been used to make interpretations based on the daily market pricing in the energy market, disregarding the detailed variables affecting the choice.

Through the "Transparency Platform" created by EPİAŞ, it is possible to access the pricing curves formed in the energy market on daily, weekly, monthly, and yearly bases. Here, the pricing curve formed during the day is in TL/MWh based on the weighted average price. Graph 6 shows the pricing curve that occurred on 30.07.2024.



Graph 6. EPİAŞ GIP (Intraday Market) Weighted Average Price on 30.07.2024

According to EPİAŞ data on 30.07.2024, an electric vehicle can achieve a high profit in V2G (discharge mode) at an energy price peak of 2,955 TL/MWh (at the hours of 00:00-01:00-18:00-19:00-20:00-21:00), while it can benefit from low prices in G2V (charge mode) at an energy price range of 1,411 TL/MWh - 1,441 TL/MWh (at the hours of 07:00-12:00). Assuming the highest and lowest pricing and that the electric vehicle returns to a charged state once, a profit of 1,544 TL/MWh (2,955-1,411) can be achieved. If this situation is repeated twice during the day (charge-discharge), the profit can be doubled.

V. CONCLUSION

With globalization and technological developments, electricity consumption and the number of electricity consumers have increased. Environmental needs are as indispensable in life as energy needs. Environmental concerns and the depletion of energy resources have led countries to develop strategies focused on renewable energy sources and maximizing the efficiency of the energy produced. In this direction, academic studies that support each other and pave the way for future research have been guiding.

Technological advancements in charging technologies, battery capacity and sizes, maximum range at full charge, charging time, and easy access to charging stations will contribute to the increasing market share of electric vehicles. Additionally, electric vehicles will help reduce environmental pollution by replacing internal combustion engines.

Within the scope of this study, the potential negative impacts of V2G technology on the grid, as well as proposed solutions, and the contributions of V2G technology to the grid and vehicle owners, have been emphasized. Through simulations, the contribution that vehicles equipped with V2G technology can make to the economy and meeting energy demand while remaining idle at charging stations has been demonstrated in a case study.

V2G technology, smart grids, and 5G communication are systems open to development that support each other. Each stage of development in these systems will support employment processes and provide different types of employment opportunities. The most significant development will be the efficient use of energy, where individuals who are consumers within the energy system during the day will support the grid as energy producers, leading to the consumption of fewer fossil-based energy sources by central power stations. Another important development is that consumers will be able to cover their transportation costs more cheaply by taking advantage of low energy prices at different times of the day.

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