sustainability

MDPI

Article

Electric Vehicles in Jordan: Challenges and Limitations

Laith Shalalfeh [1,*], Ashraf AlShalalfeh [2], Khaled Alkaradsheh [3], Mahmoud Alhamarneh [4] and Ahmad Bashaireh [5]

1 Energy Engineering Department, German Jordanian University, Amman 11180, Jordan
2 Mechanical Engineering Department, Higher Colleges of Technology, Al Ain P.O. Box 17155, United Arab Emirates; ashalalfeh@hct.ac.ae
3 School of Electrical, Electronic and Computer Engineering, University of Newcastle, Newcastle NE1 7RU, UK; k.a.j.alkaradsheh2@newcastle.ac.uk
4 E.DIS Netz GmbH, 15517 Fürstenwalde/Spree, Germany; ma.alhamarneh@gmail.com
5 Department of Electrical Engineering, Jordan University of Science and Technology, Irbid 22110, Jordan; aabashaireh@just.edu.jo
* Correspondence: laith.shalalfeh@gju.edu.jo

Abstract: An increasing number of electric vehicles (EVs) are replacing gasoline vehicles in the automobile market due to the economic and environmental benefits. The high penetration of EVs is one of the main challenges in the future smart grid. As a result of EV charging, an excessive overloading is expected in different elements of the power system, especially at the distribution level. In this paper, we evaluate the impact of EVs on the distribution system under three loading conditions (light, intermediate, and full). For each case, we estimate the maximum number of EVs that can be charged simultaneously before reaching different system limitations, including the undervoltage, overcurrent, and transformer capacity limit. Finally, we use the 19-node distribution system to study these limitations under different loading conditions. The 19-node system is one of the typical distribution systems in Jordan. Our work estimates the upper limit of the possible EV penetration before reaching the system stability margins.

Keywords: electric vehicles; distribution system; load profile; power system modeling; 19-node distribution system

Citation: Shalalfeh, L.; AlShalalfeh, A.; Alkaradsheh, K.; Alhamarneh, M.; Bashaireh, A. Electric Vehicles in Jordan: Challenges and Limitations. *Sustainability* **2021**, *13*, 3199. https://doi.org/10.3390/su13063199

Academic Editors: Vítor Monteiro and João L. Afonso

Received: 14 February 2021
Accepted: 12 March 2021
Published: 15 March 2021

1. Introduction

The main source of air pollution in Jordan is the transportation sector, especially gasoline- and diesel-powered vehicles. The emissions from conventional vehicles have negative impacts on air quality and human health [1]. Air pollutants from these vehicles may cause long-term health issues, such as asthma attacks [2], lung cancer [3], and high blood pressure [4]. According to the World Health Organization (WHO), more than seven million deaths in 2012 are attributed to ambient air pollution globally [5]. Several studies showed that the adoption of electro-mobility (e-mobility) in transportation can reduce harmful exhaust components and mitigate climate change impact [6].

E-mobility is emerging rapidly as a green and sustainable technology in transportation systems. It includes all vehicles (bikes, cars, buses, and trains) with electric powertrain technology. In the transportation system, EV infrastructure resources, such as charging stations, parking lots, and roads, represent the supply side that electric vehicle owners (as the demand side) will take advantage of [7]. There are many dynamic factors (location, time, and scale) that could affect EV infrastructure resources and restrict the travel demand by EV drivers [8].

The supply part will be represented as charging stations with predefined specification, such as capacity, number of electric vehicles, time of charging, etc. In [9], the authors study the effect of EV charging in parking spots on electricity distribution network. In addition, several studies have evaluated and forecasted the power demand on charging stations to supply the EVs batteries with the required power [10]. Despite the randomness nature of EV charging, the implementation of demand response programs for EVs could help utilities in optimizing and coordinating EV charging [11]. From the demand side, the behavior of EV users, including traveled distance, parking duration, and state of charge, has been used to build a travel demand model [12]. The authors of [13] have built a demand model based on the daily electricity consumption. Moreover, the load demand has been modeled and analyzed under different EV batteries and charging characteristics in [14].

Residential charging stations are directly connected to the power distribution network. Usually, they have relatively low power rating (5–7 kW) and long charging time. On the other hand, fast charging stations have the ability to charge EVs in less time with more than 19.2 kW at level-3 charging [15]. However, high-power charging in a short time may result in heat accumulation and faster degradation of EV batteries. The optimal placement of EV infrastructure components, including charging stations, has been evaluated in several research studies [16–18]. In [19], the authors review the consumer preference for charging infrastructure location (home, work, and public). Furthermore, charging infrastructures supplied by sustainable renewable energy sources and storage system are proposed to decrease the power demand on the electric power grid [20–22].

In urban and suburban areas, EVs have a significant impact on the amount of electricity consumption per household on daily basis. EV batteries are usually charged from the standard outlet similar to other home appliances. However, charging of EV battery could consume as much as twice the typical home electricity consumption. The increase in the electricity demand is accompanied by an overloading on the different elements in the electrical distribution network. Clearly, that will influence the power quality and voltage limits in the electrical distribution network [23]. On the other hand, uncoordinated EV charging could result in different electrical issues (power losses and voltage variation) on the local network. Therefore, coordinated and supervised charging is crucial to minimize the power losses and to maximize the main grid load factor [9]. To handle the increase in EVs, electricity network should be investigated under different loading conditions.

In the literature, several studies have investigated the effect of EV charging on the electrical distribution network, including voltage profile [24–26], harmonics [27,28] and peak load [29–31]. In these studies, several parameters are taken into consideration, such as EV type (battery size and energy consumption), charging level, charging time, etc. Ultimately, the main goal is the estimation of critical number of EVs that can be integrated safely to the distribution system [32].

In this paper, we aim to study the impact of EVs on the distribution system in Jordan. Using a typical distribution system in Jordan, we estimate the maximum number of EVs that can be charged simultaneously under different loading conditions. For each loading condition, we calculate the number of EVs that can be integrated to the system before reaching three system limitations: transformer overloading, line overloading, and node undervoltage. The conducted analysis could highlight the limitation of the distribution system in handling increasing number of EVs in the future.

The rest of the paper is organized as follows. Section 2 provides an overview of the EV market in Jordan. In Section 3, the Jordanian distribution system and the test system are described. Section 4 summarizes the results and discussion. Finally, Section 5 presents the conclusions of the paper.

2. Overview of the Electric Vehicles in Jordan

Jordan is considered as one of the pioneers in transport electrification in the Middle East. Successive governments in Jordan have supported e-mobility by legislating innovative policies in electric transport. However, the required EV infrastructures (charging stations and connectors) to serve the increasing number of EVs are still developing.

The investment in electric vehicles is essential toward more economic and sustainable transportation system. Due to the high fuel prices in Jordan, the operating cost of gasoline-powered vehicles is proportionally affected and rising up. On the other hand, electric vehicles' operating cost does not increase at the same rate due to the stability in the electricity prices; therefore, it is becoming more favorable in Jordan to own an electric vehicle. In the near future, an increasing number of electric vehicles are expected to replace the conventional ones due to their eco-friendly nature and economic feasibility.

In Jordan, the key players in electric vehicle market are Nissan, Hyundai, Tesla, Fiat, and Volkswagen. The presence of these companies plays a critical role in introducing electric vehicles into public and private transportations. In public transportation, the government has replaced hundreds of gasoline-powered cars in its fleet with Tesla EVs. Moreover, it is planning to purchase 151 low emission buses, including 15 battery electric buses (BEB), as part of the rapid transit project in Amman. Similarly, several delivery and transportation companies, such as Aramex and Tawsileh, have adopted long-term strategy to electrify their fleets.

On the private side, as part of supporting e-mobility by the government, EVs are entitled for reduced registration and customs fees. As shown in Table 1, the number of registered EVs in Jordan has increased steadily over time from 2010–2017. According to the Jordanian department of statistics, more than 18,000 privately-owned EVs were registered up to 2019.

Table 1. The number of registered electric vehicles (EVs) in Jordan from 2010–2017.

Year	2010	2011	2012	2013	2014	2015	2016	2017
Number of EVs	24	23	37	57	72	253	797	6423

The investment in the Jordan electric vehicle market is expected to grow by 35% during the period 2019–2025 [33]. In addition, the implementation of the Jordan National Vision 2025 initiative by the government will be accompanied by significant investments and support to green and clean energy projects, including electric vehicles infrastructure. Therefore, the government is cooperating with private companies to adopt electric vehicles as a strategic approach amid the increase of gasoline prices. For example, the German company "eCharge" has signed an agreement with Jordanian authorities to install 10,000 charging stations for electric vehicles [34]. The charging outlets will be set up across Jordan in public places, hotels, and shopping malls.

3. The Jordanian Distribution System

3.1. Overview

Prior to 1996, a single entity, the Jordan Electricity Authority, was responsible for the energy sector from power generation to power delivery. Then, as a result of a complete restructuring of the authority in 1996, the National Electric Power company (NEPCO) emerged as a single buyer completely operated by the government. Subsequently, the energy sector has witnessed a privatization of the electrical distribution system by dividing it into three different entities. Nowadays, it is delivering power to over nine million residents all over the country.

In Jordan, there are several conventional and renewable energy generation faiclities with a total installed capacity of approximately 5236 MW at the end of 2018 [35]. The main generating power stations are connected through 132 kV and 400 kV transmission network to the load centers. In addition, the system has 230 kV and 400 kV tie lines with the Syrian and Egyption power grid. In 2017, the length of transmission lines was approximately 4600 km circuit and the capacity of substations was around 12,000 MVA.

As shown in Figure 1, the distribution system consists of three regional systems, each system managed by one of the three distribution companies. The transmission system is managed by NEPCO, and each distribution company is responsible for distributing the power to the end users from the transmission network. Firstly, Jordan Electric Power Company (JEPCO) serves the central region of Jordan, including the capital. It supplies approximately 64% of the electricity consumption in Jordan. Secondly, Electricity Distribution

Company (EDCO) supplies electricity distribution in the southern and western regions of the country. It has 8396-km length of network infrastructure capable of supplying electricity to 139,821 customers. Thirdly, Irbid District Electric Company (IDECO) contributes to electricity delivery in the northern part of Jordan with over 13,148-km length of network infrastructure. The total number of customers in IDECO is approximately 250,623.

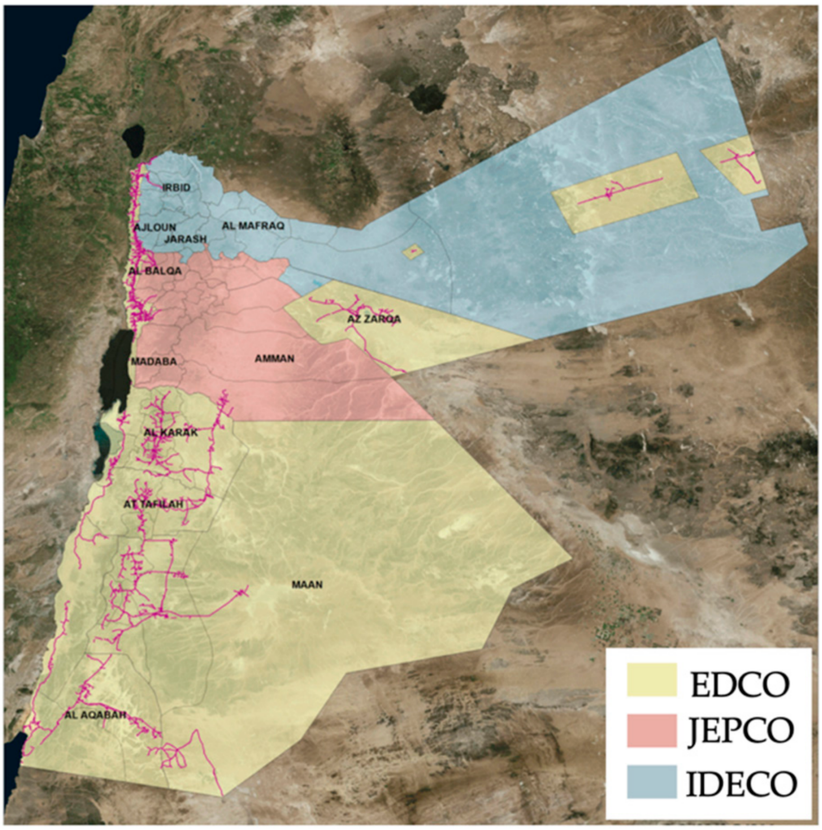

Figure 1. Distribution companies in Jordan [36].

The distribution system consists of 33 kV, 11 kV, and 415 V electricity power facilities. In addition, the electricity is distributed to the users at rated voltages of 6.6 kV or 415 V. The distribution companies operate the distribution transformers, middle voltage (MV) distribution networks, pole mounted type low voltage (LV) transformers, and LV distribution networks. Typically, the MV networks have either radial or loop configuration sectioned by normally open switches during normal operation.

3.2. The 19-Node Distribution System (Case Study)

The 19-node model is a medium-voltage radial system with a design and characteristics similar to the standard 11-kV distribution systems in Jordan. The rated voltage of the system is 11 kV, and the operating frequency is 50 Hz. As shown in Figure 2, the model has two transformers, 18 distribution lines, and 10 electrical loads. In this section, we provide an overview of the main components in the system and their ratings.

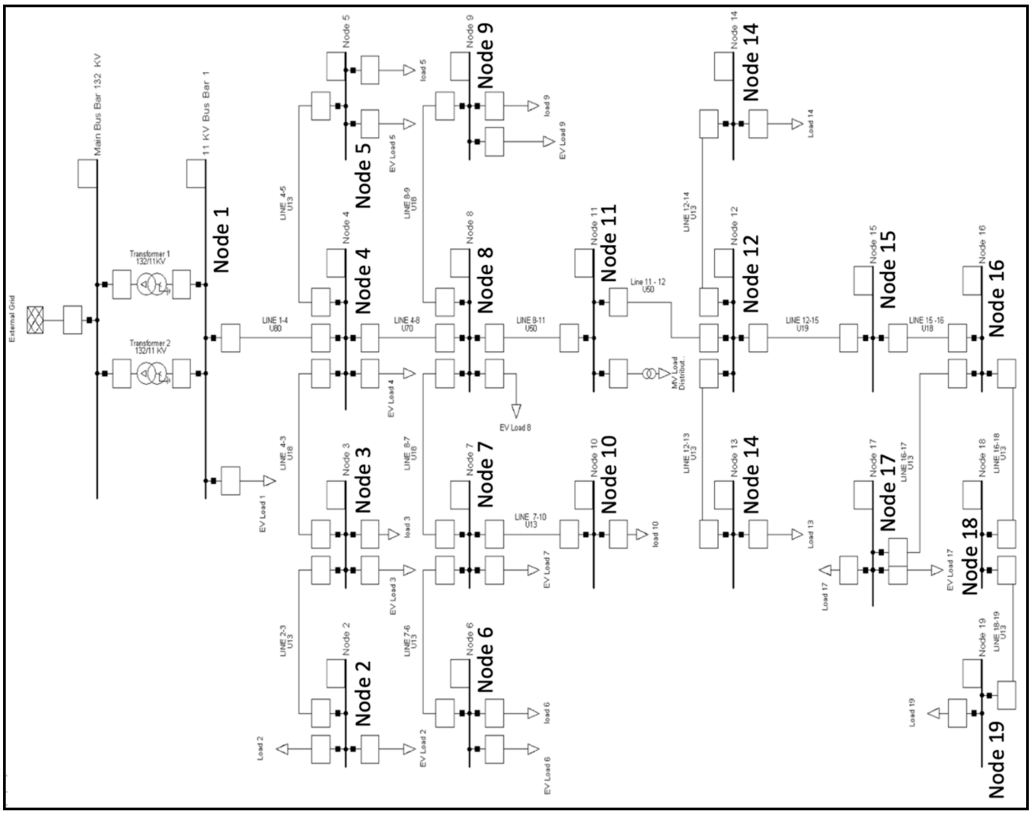

Figure 2. 19-node distribution network.

3.2.1. Transformers

In this system, the main substation contains two 5-MVA three-phase transformers connected in parallel. They are step-down transformers connecting the high-voltage transmission system at 132 kV and the secondary distribution network at 11 kV. A simplified transformer model (series winding resistance and leakage reactance) is used throughout the analysis. In Table 2, we provide a summary of ratings and initial loadings of the two transformers.

Table 2. Transformer ratings at full load condition.

Transformer	Rated Voltage (KV)	Rated Power (MVA)	Active Power (MW)	Reactive Power (MVAR)	Power Factor	Loading (%)
1	132/11	5	4.42	2.1	0.9	99.3
2	132/11	5	4.42	2.1	0.9	99.3

Using power flow analysis, we calculated the initial loadings of the two transformers under full load condition. The active and reactive powers of each transformer are 4.42 MW and 2.1 MVAR, respectively. The calculated powers represent the upper limit on the overall possible loading in the distribution system. Evidently, extended overloading of a power transformer may lead to temperature rise and thermal heating, resulting in insulation deterioration and accelerated loss of life.

3.2.2. Distribution Lines

The lines used in the model are single core, Aluminum, cross-linked polyethylene (XLPE) insulated, polyvinyl chloride (PVC) sheeted wires. The cables of the system were chosen based on the voltage level and rated current. Medium-voltage cables were selected to handle the 11-kV of the distribution system. In addition, the cross-sectional area of the cable should be capable of carrying the rated currents. Under full load condition, the currents flowing in the system are within the capacity of each line

3.2.3. Electrical Loads

The distribution system has 10 electrical loads located at different nodes, as shown in Figure 2. They are modeled as static loads represented by constant active and reactive powers. In addition, for each load, the power factor was assumed to be 0.9 lagging similar to typical residential loads. Before adding EV loads, the rated active and reactive powers of each load are shown in Table 3.

Table 3. Electrical loads at full load condition.

Load	Active Power (MW)	Reactive Power (MVAR)
Node 2	0.782	0.379
Node 3	1.562	0.757
Node 5	0.782	0.379
Node 6	0.798	0.387
Node 9	0.797	0.386
Node 10	0.798	0.386
Node 13	0.822	0.398
Node 14	0.821	0.398
Node 17	0.829	0.402
Node 19	0.832	0.403

The provided power ratings represent the consumption of each load under full load condition. To study the impact of adding EV loads, we analyzed the distribution model for different loading scenarios along a complete day. Since the power system load is varying throughout the day, a simple load profile was assumed to estimate the dynamic behavior of the load during the 24 h of the day, rather than having constant load value. As shown in Figure 3, we adopted three loading conditions (30%, 50%, and 100%) representing scaled versions of the full load condition.

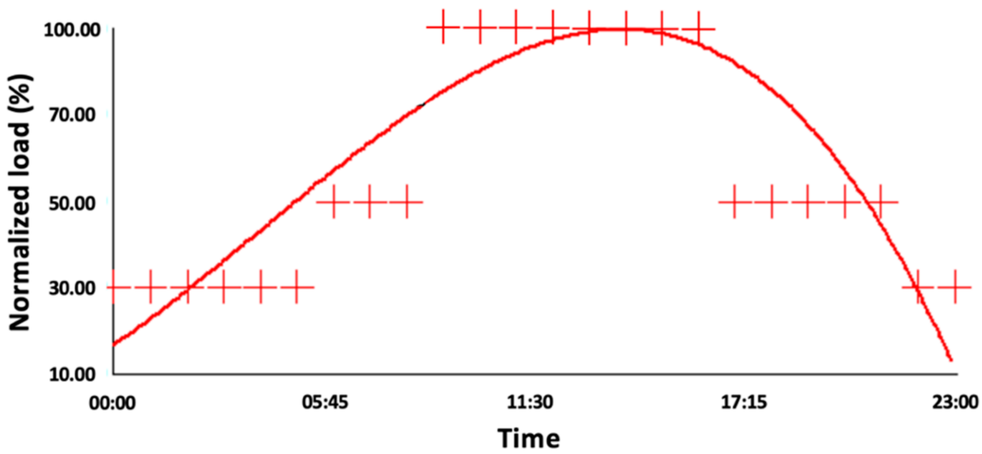

Figure 3. Typical daily load profile.

Firstly, the light loading condition represents the electrical loads scaled at 30% of the rated load. It was assumed during the hours 00:00–05:00 and 21:00–24:00. Secondly, in the intermediate loading condition, electrical loads were scaled at 50% of the rated load. It was assumed during the hours 05:00–08:00 and 16:00–21:00. In the full loading condition, the electrical loads have rated load powers during the hours 08:00–16:00.

4. Results and Discussion

In this paper, we evaluate the impact of EVs on the distribution system in Jordan. Using the 19-node model, we studied and analyzed the distribution system under different loading conditions (light, intermediate, and full) after adding the EV loads. The light, intermediate, and full loading conditions were assumed to be 30%, 50%, and 100% of the rated electrical loads. In the distribution system, the typical residential load profile can be approximated using these conditions, as shown in Figure 3.

For each loading condition, we assumed two scenarios of EV charging in the distribution network. These scenarios are distributed EV loading and concentrated EV loading. From these scenarios, we evaluated the effect of EV charging on the overall loading of the system. The distributed EV loading is similar to the typical EV charging from homes throughout the distribution system. In this scenario, we aimed to estimate the maximum possible EV loading per electrical load before reaching the voltage or current system limitations. On the other hand, the concentrated EV loading represents the effect of a high-capacity charging station installed in the system at one node. From this scenario, we can estimate the maximum possible EV loading at each load separately.

During the gradual increase in EV charging, the system may be susceptible to violations related to overloading and undervoltage conditions. Here, we focused mainly on three system limitations: transformer capacity limit (capacity = 100%), line capacity limit (capacity = 100%), and voltage limit ($0.95pu < V < 1.05pu$). We tracked these violations to estimate the maximum possible EV loading, as shown in Figure 4.

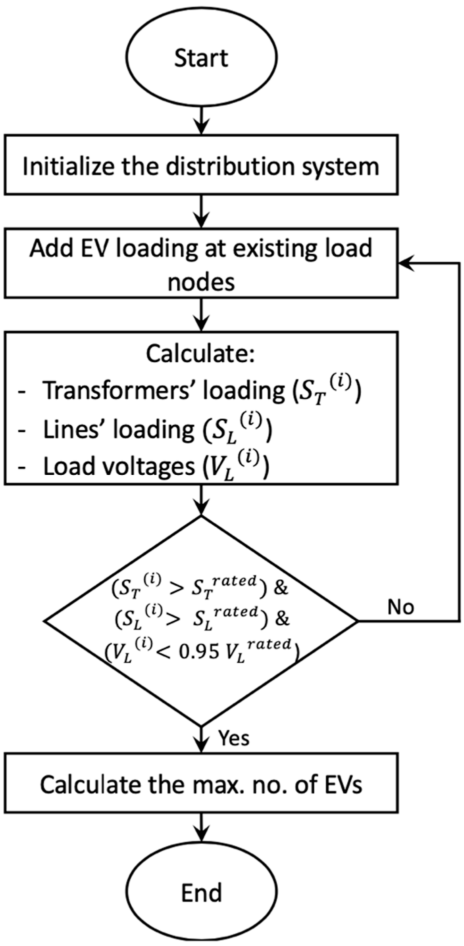

Figure 4. Flowchart for computation of the maximum number of EVs before reaching the three system violations.

4.1. Scenario 1: Distributed EV Loading

Before adding the EVs, the transformer and line loadings are below the full capacity and no violations are present in the system. In this scenario, the EV loads are integrated simultaneously on the 10 existing load nodes with increments of 5% for the full and intermediate loading cases and 10% for the light loading case. After each increment, we performed power flow analysis to calculate the MVA loadings on the transformers and distribution lines in the system. In addition, we monitored the voltage magnitude at all the load nodes. Finally, we calculated the maximum possible EV loading as percentage of the total system load before reaching each of the three system violations. In Figure 5, we show the system behavior in terms of line loading and load voltage magnitude after integrating EV loads at all load nodes simultaneously.

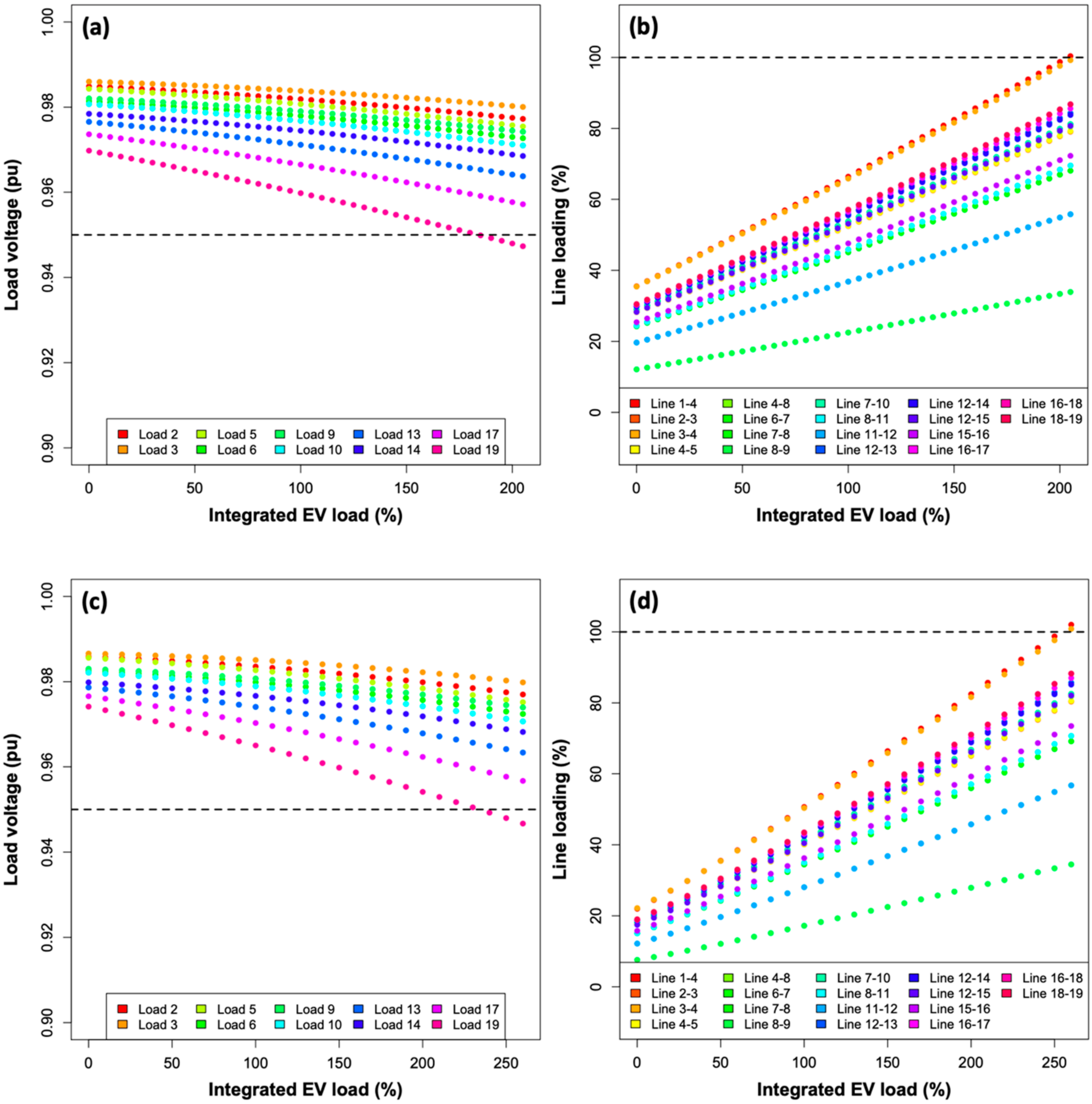

Figure 5. *Cont.*

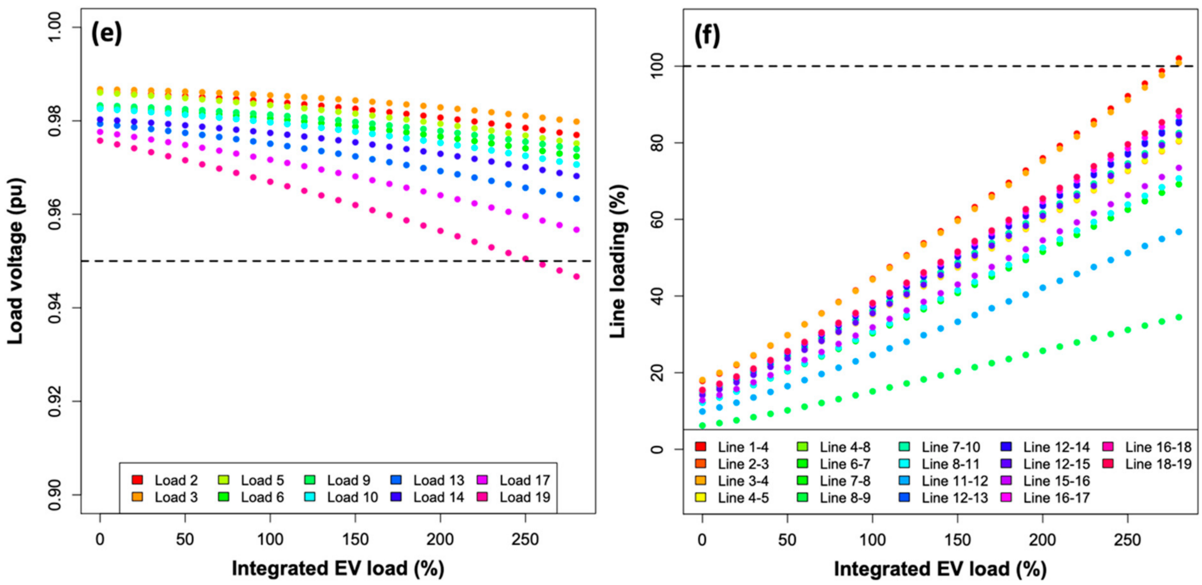

Figure 5. Scenario 1: (**a**) Load voltages at full loading condition. (**b**) Line loadings at full loading condition. (**c**) Load voltages at intermediate loading condition. (**d**) Line loadings at intermediate loading condition. (**e**) Load voltages at light loading condition. (**f**) Line loadings at light loading condition.

As shown in Figure 5a,c,e, we monitored the voltage magnitude at the load nodes during different penetration levels of EVs. Due to voltage drop across the distribution lines, higher voltage deviations were expected as we moved away from the main substation. In Table 4, it is shown that voltage violations (load voltage below 0.95 pu) start at increments of 185%, 240%, and 260% during full, intermediate, and light loading conditions, respectively. These percentages of EV loads are with respect to the rated power of each load. Assuming a level-2 charging (7.2 kW per EV), the maximum number of allowed EVs is 2267, 2941, and 3186. Under the three loading conditions, the first voltage violation occurs at node 19, which is expected as it is the as the farthest node from the substation.

Table 4. Scenario 1: Maximum possible EV loading at different loading conditions.

Loading Condition	Maximum Possible EV Loading (Maximum Number of EVs *)		
	Transformer Limit	Line Limit	Voltage Limit
Full (100%)	-	205% (2512 EV)	185% (2267 EV)
Intermediate (50%)	60% (735 EV)	260% (3186 EV)	240% (2941 EV)
Light (30%)	80% (980 EV)	280% (3431 EV)	260% (3186 EV)

* Level-2 charger with a 7.2 KW power rating.

The loadings of all distribution lines in the system at different percentages of EV loading are shown in Figure 5b,d,e. As more EVs are integrated to the system, the line loadings increase gradually and steadily toward full capacity. Moreover, lines in the neighborhood of the substation are more susceptible for excessive loading compared to the ones far from the substation. The line capacity violations start to occur at increments of 205%, 260%, and 280% during full, intermediate, and light loading conditions, respectively. At level-2 charging, that is equivalent to simultaneously charging a maximum of 2512, 3186, and 3431 EVs at each loading condition, as shown in Table 4. Among all distribution lines, the loading of line 1–4 is the first to exceed the 100% capacity limit in the three loading conditions. That is expected as line 1–4 is the closest line to the substation and it is connecting the substation to remaining elements in the distribution system.

In Figure A1, the transformer loadings are shown at different increments of EV loading. Here, we did not consider the full loading condition because transformers are fully loaded before adding any EVs. The transformer capacity violations appear firstly at increments of 60% and 80% during intermediate and light loading conditions, respectively. As shown in Table 4, the maximum possible number of EVs is 735 and 980. It is clear that exceeding transformer capacity limit is the first reached violation among the three studied ones. That means the transformer capacity will be a limiting factor for higher penetration of EVs.

4.2. Scenario 2: Concentrated EV Loading

Initially, transformer and line loadings are also below the full capacity and no violations are present in the system before adding the EVs. In this scenario, we repeated the same analysis seperately on each electrical load in the system. For each load node, EV load is integrated with increments of 10% or 20% of the load rated power at this node. After each increment, we performed power flow analysis to calculate MVA loadings on transformers and distribution lines in the system. In addition, we monitored the voltage magnitude at all the load nodes. For each load, we calculated the maximum possible EV loading as percentage of the corresponding load power before reaching each of the three violations. In this section, we discuss the effect of EV loading on node 19 only. We selected this node as it is the farthest node and could reach several violations earlier. The analyses of the remaining load nodes are summarized in Tables A1–A3 of Appendix B.

The system behavior in terms of load voltage and line loading during this scenario is shown in Figure 6. In Figure 6a,c,e, we monitored the voltage magnitude at the load nodes during different penetration levels of EVs. It is shown that the first voltage violations take place at increments of 360%, 450%, and 480% during full, intermediate, and light loading conditions, respectively. These percentages of EV loads are with respect to the rated power of load 19. Assuming a level-2 charging, the maximum number of allowed EVs is 416, 520, and 555. The first voltage violation occurs at node 19 under the three loading conditions.

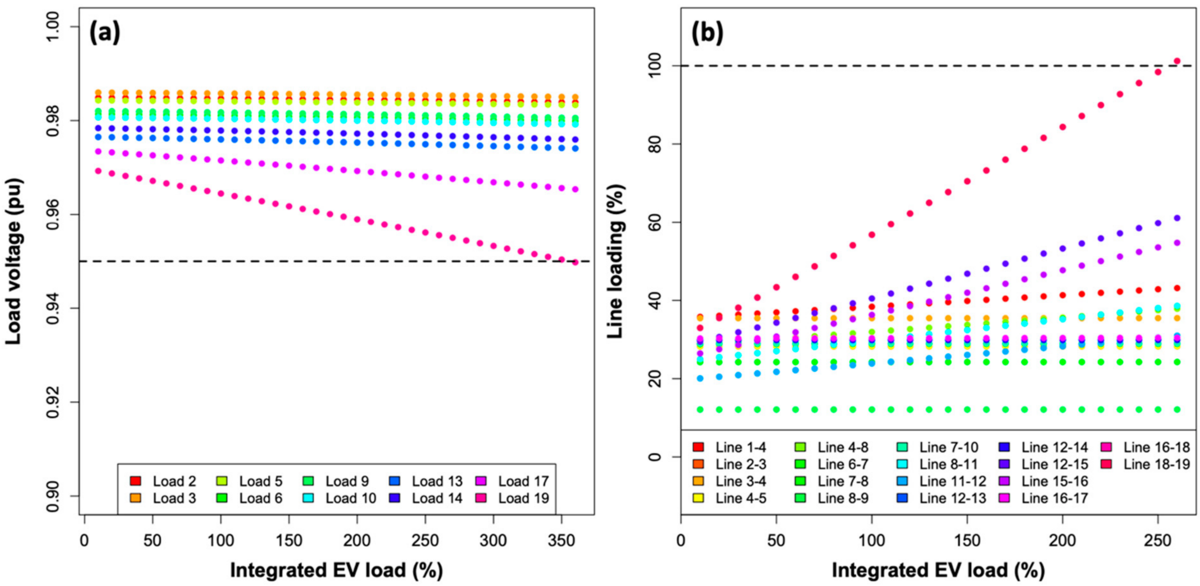

Figure 6. *Cont.*

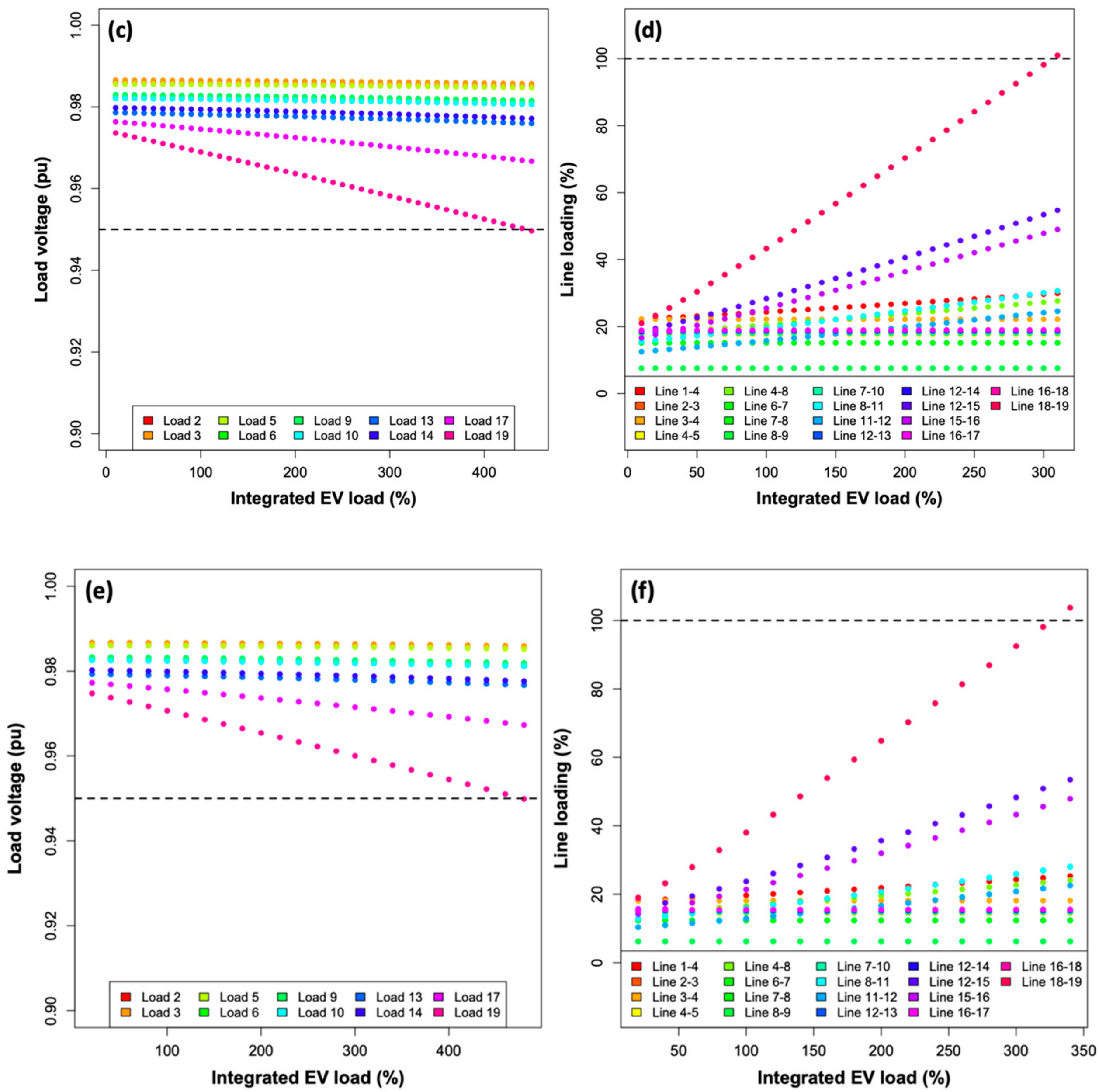

Figure 6. Scenario 2 at node 19: (**a**) Load voltages at full loading condition. (**b**) Line loadings at full loading condition. (**c**) Load voltages at intermediate loading condition. (**d**) Line loadings at intermediate loading condition. (**e**) Load voltages at light loading condition. (**f**) Line loadings at light loading condition.

The loadings of all distribution lines in the system at different percentages of EV loading are shown in Figure 6b,d,e. As more EVs are integrated at node 19, the loading increases steadily toward full capacity in the lines connecting node 19 to the substation. The first line capacity violations occur at increments of 260%, 310%, and 340% during full, intermediate, and light loading conditions, respectively. At level-2 charging, that is equivalent to simultaneously charging a maximum of 300, 358, and 393 EVs at each loading condition. Among all distribution lines, the loading of line 18–19 is the first to exceed the 100% capacity limit in the three loading conditions. That is expected as this line is the closest line to node 19 and all the excessive EV loading passes through it.

In Figure A2, the transformer loadings are shown at different increments of EV loading on node 19. Here, we do not consider the full loading condition because transformers are fully loaded before adding any EVs. The transformer capacity violations occur firstly at increments of 520% and 720% during intermediate and light loading conditions, respectively.

The maximum possible number of EVs at node 19 is 601 and 832. In scenario 2, it is clear that exceeding the line capacity limit is the first reached violation among the three studied ones. Therefore, it is supposed to be upgraded for higher penetration of EVs.

4.3. Limitations and Future Research

As a final note, it is worth mentioning that the focus of this paper is an exploratory study of the impact of EVs on the distribution grid in Jordan, and its capacity to handle EV penetration. As such, we took a static modelling approach, taking into account typical loading conditions in the system. Specifically, a static model was used to represent the loads (including the EV loads) in the system, and the daily load profile was simplified to a 3-state profile. While this is adequate for the purpose of this work, more elaborate and practical models are needed in future studies where mitigation actions are examined. For instance, dynamic models reflecting the time-varying nature of the loads and charging characteristics need to be used. In addition, the behaviors of different drivers (e.g., personal and commercial users) need to be captured. These factors create spatial and temporal variations that are not considered in the current model.

5. Conclusions

In this paper, we have provided an overview of the EV market in Jordan, including private and public sectors. Evidently, a higher penetration of EVs is expected in the near future; therefore, EV charging could lead to electricity consumption beyond the capability of electric utilities. Using the 19-node model, we have studied the effect of EVs on the Jordanian distribution system during different loading conditions (light, intermediate, and full). For each loading condition, we have proposed two scenarios, distributed and concentrated, for integrating the electric vehicle loads. Under different loading conditions and scenarios, we have estimated the maximum allowed EV loads before reaching one of three system limitations: transformer capacity limit, line capacity limit, and load voltage limit. It seems that the main limiting factors of distributed and concentrated charging are transformer capacity and line capacity, respectively.

In the future, we will investigate several other issues related to EV charging, such as higher harmonics and loss of stability. In addition, we plan to study different practical solutions to upgrade the system and overcome its limitations with respect to EV loading. These solutions include substation upgrade, line capacity increase, and reactive power compensation.

Author Contributions: Conceptualization, L.S. and A.A.; methodology, L.S. and A.A.; software, L.S. and A.B.; validation, L.S. and A.B.; formal analysis, L.S., K.A., M.A. and A.B.; investigation, L.S. and A.A.; resources, L.S. and A.A.; data curation, L.S. and A.B.; writing—original draft preparation, L.S. and A.A.; visualization, L.S. and A.B.; supervision, L.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: This work is supported by the deanship of scientific research at the German Jordanian University.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

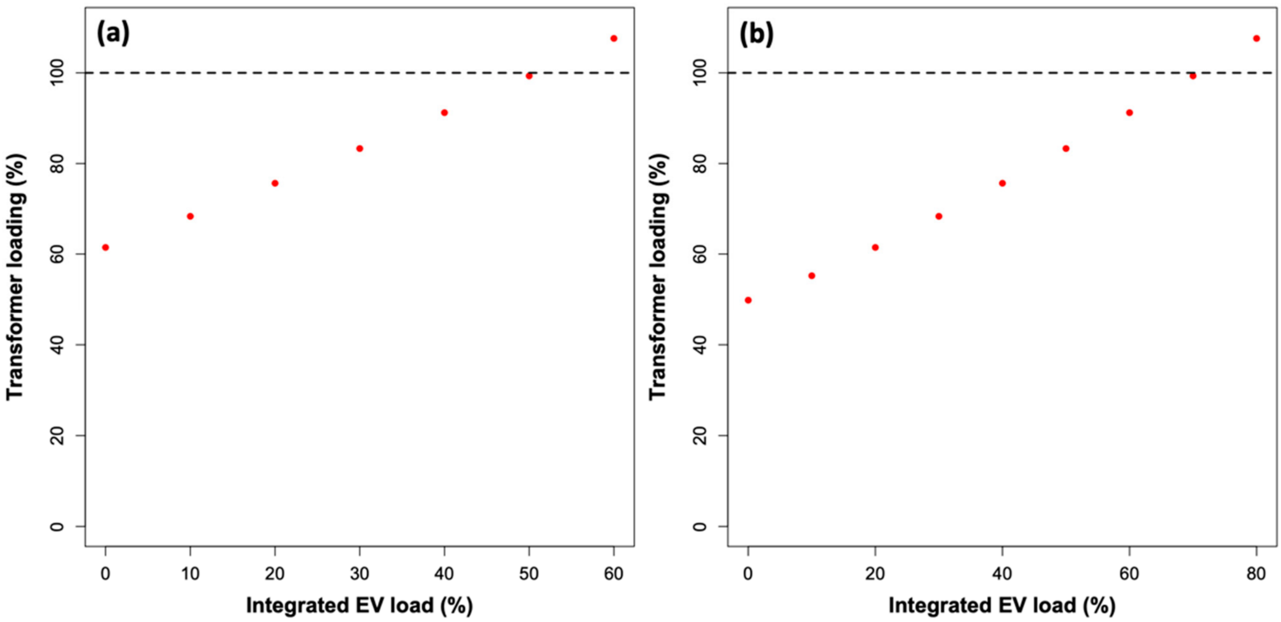

Figure A1. Scenario 1: (**a**) Transformer loading at intermediate loading condition. (**b**) Transformer loading at light loading condition.

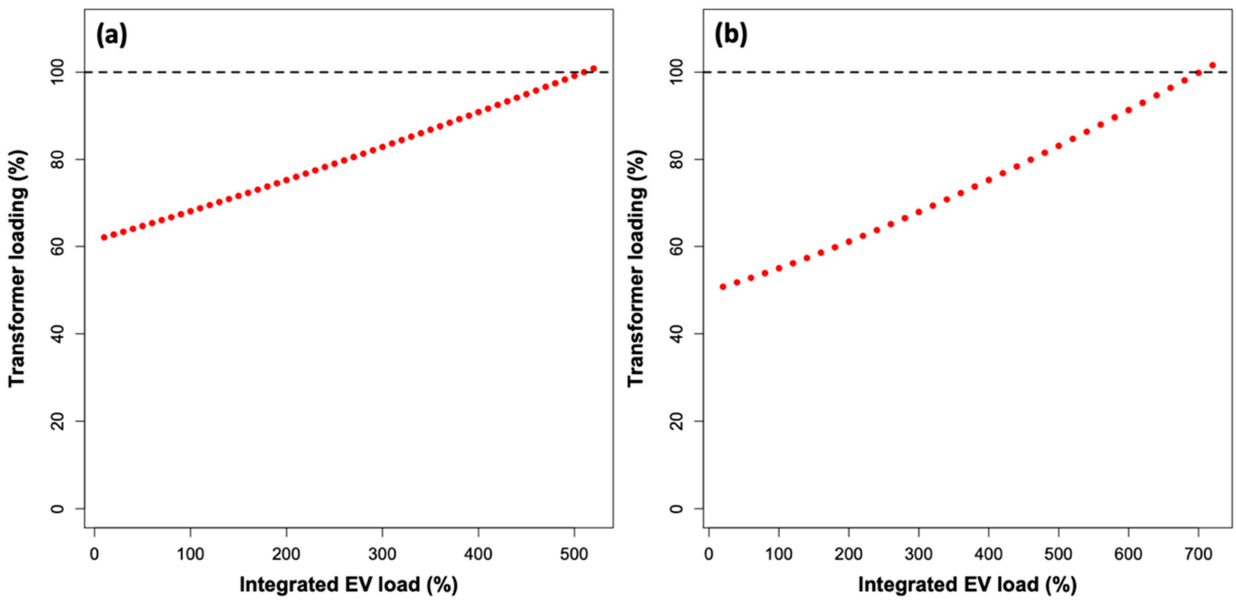

Figure A2. Scenario 2 at node 19: (**a**) Transformer loading at intermediate loading condition. (**b**) Transformer loading at light loading condition.

Appendix B

Table A1. Scenario 2: Maximum possible EV loading at full loading condition.

Load	Maximum Possible EV Loading (Maximum Number of EVs)		
	Transformer Limit	Line Limit	Voltage Limit
Node 2 (0.782 MW)	-	290% (315 EV)	2960% (3215 EV)
Node 3 (1.562 MW)	-	320% (694 EV)	3130% (6790 EV)

Table A1. *Cont.*

Load	Maximum Possible EV Loading (Maximum Number of EVs)		
	Transformer Limit	Line Limit	Voltage Limit
Node 5 (0.782 MW)	-	290% (315 EV)	1810% (1966 EV)
Node 6 (0.798 MW)	-	290% (321 EV)	2980% (3303 EV)
Node 9 (0.797 MW)	-	820% (908 EV)	3540% (3919 EV)
Node 10 (0.798 MW)	-	280% (310 EV)	2030% (2250 EV)
Node 13 (0.822 MW)	-	270% (308 EV)	1070% (1222 EV)
Node 14 (0.821 MW)	-	270% (308 EV)	2320% (2645 EV)
Node 17 (0.829 MW)	-	270% (311 EV)	850% (979 EV)
Node 19 (0.832 MW)	-	260% (300 EV)	360% (416 EV)

Table A2. Scenario 2: Maximum possible EV loading at intermediate loading condition.

Load	Maximum Possible EV Loading (Maximum Number of EVs)		
	Transformer Limit	Line Limit	Voltage Limit
Node 2 (0.782 MW)	580% (630 EV)	340% (369 EV)	3130% (3400 EV)
Node 3 (1.562 MW)	290% (629 EV)	390% (846 EV)	3720% (8070 EV)
Node 5 (0.782 MW)	580% (630 EV)	340% (369 EV)	1910% (2074 EV)
Node 6 (0.798 MW)	560% (621 EV)	340% (377 EV)	3220% (3569 EV)
Node 9 (0.797 MW)	570% (631 EV)	870% (963 EV)	3830% (4240 EV)
Node 10 (0.798 MW)	560% (621 EV)	330% (366 EV)	2190% (2427 EV)
Node 13 (0.822 MW)	540% (617 EV)	320% (365 EV)	1190% (1359 EV)
Node 14 (0.821 MW)	550% (627 EV)	320% (365 EV)	2600% (2965 EV)
Node 17 (0.829 MW)	530% (610 EV)	320% (368 EV)	1020% (1174 EV)
Node 19 (0.832 MW)	520% (601 EV)	310% (358 EV)	450% (520 EV)

Table A3. Scenario 2: Maximum possible EV loading at light loading condition.

Load	Maximum Possible EV Loading (Maximum Number of EVs)		
	Transformer Limit	Line Limit	Voltage Limit
Node 2 (0.782 MW)	800% (869 EV)	360% (391 EV)	3200% (3476 EV)
Node 3 (1.562 MW)	420% (911 EV)	420% (911 EV)	3940% (8548 EV)
Node 5 (0.782 MW)	800% (869 EV)	360% (391 EV)	1960% (2129 EV)
Node 6 (0.798 MW)	780% (865 EV)	360% (399 EV)	3320% (3680 EV)
Node 9 (0.797 MW)	800% (886 EV)	900% (996 EV)	3940% (4361 EV)
Node 10 (0.798 MW)	780% (865 EV)	360% (399 EV)	2260% (2505 EV)
Node 13 (0.822 MW)	740% (845 EV)	340% (388 EV)	1240% (1416 EV)
Node 14 (0.821 MW)	760% (867 EV)	340% (388 EV)	2700% (3079 EV)
Node 17 (0.829 MW)	740% (852 EV)	340% (391 EV)	1080% (1244 EV)
Node 19 (0.832 MW)	720% (832 EV)	340% (393 EV)	480% (555 EV)

References

1. Requia, W.J.; Mohamed, M.; Higgins, C.D.; Arain, A.; Ferguson, M. How clean are electric vehicles? Evidence-based review of the effects of electric mobility on air pollutants, greenhouse gas emissions and human health. *Atmos. Environ.* **2018**, *185*, 64–77. [CrossRef]
2. Gonzalez-Barcala, F.; Pertega, S.; Garnelo, L.; Castro, T.; Sampedro, M.; Lastres, J.; Gonzalez, M.S.J.; Bamonde, L.; Valdes, L.; Carreira, J.-M.; et al. Truck traffic related air pollution associated with asthma symptoms in young boys: A cross-sectional study. *Public Health* **2013**, *127*, 275–281. [CrossRef] [PubMed]
3. Moon, D.H.; Kwon, S.O.; Kim, S.-Y.; Kim, W.J. Air Pollution and Incidence of Lung Cancer by Histological Type in Korean Adults: A Korean National Health Insurance Service Health Examinee Cohort Study. *Int. J. Environ. Res. Public Health* **2020**, *17*, 915. [CrossRef] [PubMed]
4. Yang, B.-Y.; Qian, Z.; Howard, S.W.; Vaughn, M.G.; Fan, S.-J.; Liu, K.-K.; Dong, G.-H. Global association between ambient air pollution and blood pressure: A systematic review and meta-analysis. *Environ. Pollut.* **2018**, *235*, 576–588. [CrossRef] [PubMed]
5. World Health Organization. 7 Million Premature Deaths Annually Linked to Air Pollution. Available online: http://www.who.int/mediacentre/news/releases/2014/air-pollution/en/ (accessed on 14 March 2021).
6. Mądziel, M.; Campisi, T.; Jaworski, A.; Tesoriere, G. The Development of Strategies to Reduce Exhaust Emissions from Pas-senger Cars in Rzeszow City—Poland A Preliminary Assessment of the Results Produced by the Increase of E-Fleet. *Energies* **2021**, *14*, 1046. [CrossRef]
7. Hoch, N.; Bensler, H.P.; Abeywickrama, D.; Bureš, T.; Montanari, U. The E-mobility case study. In *Software Engineering for Collective Autonomic Systems*; Lecture Notes in Computer Science; Wirsing, M., Hölzl, M., Koch, N., Mayer, P., Eds.; Springer: Cham, Switzerland, 2015; Volume 8998.
8. Pagany, R.; Camargo, L.R.; Dorner, W. A review of spatial localization methodologies for the electric vehicle charging infrastructure. *Int. J. Sustain. Transp.* **2019**, *13*, 433–449. [CrossRef]
9. Clement-Nyns, K.; Haesen, E.; Driesen, J. The Impact of Charging Plug-In Hybrid Electric Vehicles on a Residential Distribution Grid. *IEEE Trans. Power Syst.* **2009**, *25*, 371–380. [CrossRef]
10. Jiming, H.; LingYu, K.; Yaqi, S.; Ying, L.; Wenting, X.; Hao, W. A Review of Demand Forecast for Charging Facilities of Electric Vehicles. *IOP Conf. Series Mater. Sci. Eng.* **2017**, *199*, 12040. [CrossRef]
11. Siano, P. Demand response and smart grids—A survey. *Renew. Sustain. Energy Rev.* **2014**, *30*, 461–478. [CrossRef]
12. Wang, R.; Chen, T.; Liu, Y. Electric vehicle holdings prediction using elasticity and thousand Hoidings methods. *Agricult. Equip. Vehicle Eng.* **2011**, *49*, 40–48.
13. Yin, J.B.; Wen, Y.B.; Li, R. Discussion on the demand forecasting method of electric vehicle charging facilities construction. *J. Jiangxi Power* **2010**, *34*, 1–5.
14. Qian, K.; Zhou, C.; Allan, M.; Yuan, Y. Modeling of Load Demand Due to EV Battery Charging in Distribution Systems. *IEEE Trans. Power Syst.* **2010**, *26*, 802–810. [CrossRef]
15. Khaligh, A.; Dusmez, S. Comprehensive Topological Analysis of Conductive and Inductive Charging Solutions for Plug-In Electric Vehicles. *IEEE Trans. Veh. Technol.* **2012**, *61*, 3475–3489. [CrossRef]
16. Ji, D.; Lv, M.; Yang, J.; Yi, W. Optimizing the Locations and Sizes of Solar Assisted Electric Vehicle Charging Stations in an Urban Area. *IEEE Access* **2020**, *8*, 112772–112782. [CrossRef]
17. Ali, F.; Imam, R. Optimal Locations of Charging Stations for Electric Vehicles in Amman, Jordan. *Int. Rev. Civil. Eng. (IRECE)* **2020**, *11*, 206–213.
18. Mao, D.; Wang, J.; Tan, J.; Liu, G.; Xu, Y.; Li, J. Location planning of fast charging station considering its impact on the power grid assets. In Proceedings of the 2019 IEEE Transportation Electrification Conference and Expo (ITEC), Detroit, MI, USA, 19–21 June 2019; pp. 1–5.
19. Hardman, S.; Jenn, A.; Tal, G.; Axsen, J.; Beard, G.; Daina, N.; Figenbaum, E.; Jakobsson, N.; Jochem, P.; Kinnear, N.; et al. A review of consumer preferences of and interactions with electric vehicle charging infrastructure. *Transp. Res. Part D Transp. Environ.* **2018**, *62*, 508–523. [CrossRef]
20. Moradzadeh, M.; Abdelaziz, M.M.A. A New MILP Formulation for Renewables and Energy Storage Integration in Fast Charging Stations. *IEEE Trans. Transp. Electrif.* **2020**, *6*, 181–198. [CrossRef]
21. Chellaswamy, C.; Ramesh, R. Future renewable energy option for recharging full electric vehicles. *Renew. Sustain. Energy Rev.* **2017**, *76*, 824–838. [CrossRef]
22. Chandra Mouli, G.R.; Bauer, P.; Zeman, M. System design for a solar powered electric vehicle charging station for workplaces. *Appl. Energy* **2016**, *168*, 434–443. [CrossRef]
23. Putrus, G.A.; Suwanapingkarl, P.; Johnston, D.; Bentley, E.C.; Narayana, M. Impact of electric vehicles on power distribution networks. In Proceedings of the 2009 Vehicle Power and Propulsion Conference (VPPC), Dearborn, MI, USA, 7–10 September 2009; pp. 827–831.
24. Dharmakeerthi, C.; Mithulananthan, N.; Saha, T. Impact of electric vehicle fast charging on power system voltage stability. *Int. J. Electr. Power Energy Syst.* **2014**, *57*, 241–249. [CrossRef]
25. Ul-Haq, A.; Cecati, C.; Strunz, K.; Abbasi, E. Impact of Electric Vehicle Charging on Voltage Unbalance in an Urban Distribution Network. *Intell. Ind. Syst.* **2015**, *1*, 51–60. [CrossRef]

26. Zhang, Y.; Song, X.; Gao, F.; Li, J. Research of voltage stability analysis method in distribution power system with plug-in electric vehicle. In Proceedings of the 2016 IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC), Xi'an, China, 25–28 October 2016; pp. 1–6.
27. Gómez, J.C.; Medhat, M.M. Impact of EV battery chargers on the power quality of distribution systems. *IEEE Trans. Power Deliv.* **2003**, *18*, 975–981. [CrossRef]
28. Jiang, C.; Torquato, R.; Salles, D.; Xu, W. Method to Assess the Power-Quality Impact of Plug-in Electric Vehicles. *IEEE Trans. Power Deliv.* **2014**, *29*, 958–965. [CrossRef]
29. Fan, Y.; Guo, C.; Hou, P.; Tang, Z. Impact of Electric Vehicle Charging on Power Load Based on TOU Price. *Energy Power Eng.* **2013**, *5*, 1347–1351. [CrossRef]
30. Di Silvestre, M.L.; Sanseverino, E.R.; Zizzo, G.; Graditi, G. An optimization approach for efficient management of EV parking lots with batteries recharging facilities. *J. Ambient. Intell. Humaniz. Comput.* **2013**, *4*, 641–649. [CrossRef]
31. Fakeha, S.; Manisa, P.; Rahman, S. Demand management to mitigate impacts of plug-in electric vehicle fast charge in buildings with renewables. *Energy* **2017**, *120*, 642–651.
32. Geske, M.; Komarnicki, P.; Stötzer, M.; Styczynski, Z.A. Modeling and simulation of electric car penetration in the distribution power system—Case study. In Proceedings of the International Symposium on Modern Electric Power Systems, Wroclaw, Poland, 1 September 2011; pp. 1–6.
33. Wood, L. Jordan Electric Vehicle Market Analysis & Outlook, 2019–2025: Vehicle Types, Regions, Competitive Landscape. Business Wire. 2019. Available online: https://www.businesswire.com/news/home/20190906005441/en/Jordan-Electric-Vehicle-Market-Analysis-Outlook-2019-2025 (accessed on 14 March 2021).
34. Daniel, D. Jordan to Install 10,000 Charging Stations for Electric Vehicles. Construction Week. 2018. Available online: https://www.constructionweekonline.com/article-48645-jordan-to-install-10000-charging-stations-for-electric-vehicles (accessed on 14 March 2021).
35. National Electric Power Company (NEPCO). Annual Reports, Amman, Jordan. Available online: http://www.nepco.com.jo/store/docs/web/2018_en.pdf (accessed on 14 March 2021).
36. Electricity Distribution Company. Home Page, Amman, Jordan. Available online: https://www.edco.jo/index.php/ar/ (accessed on 14 March 2021).