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The future of the Hebron electrical grid with growing demand for electric cars

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ABSTRACT

This article studies the future state of the electrical network in Hebron city when seven electric car charging stations will be established in the city. The main aim of the research is to develop and improve the capacity of the network for accommodating the presence of charging car stations on it. Four different types of Electric Vehicles (EVs) will be tested, the EVs contain batteries of different capacities and different charging technology as well as various charging levels. 58 cars in the peak period of demand in all charging stations will be assumed. Consequently, in this period the research focus on the total demand in each electric substation and losses in the grid of the city. The Electrical Transient Analyser Program (ETAP) will be used to apply this study. The main result is the network of the city will face some overloading problems at maximum demand of charging. This paper also presents some practical procedures for solving the expected overloading in the network.

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1. INTRODUCTION

The world is witnessing a huge demand for EVs, as most forecasts indicate that the era of EVs may begin soon. It is predicted some electric cars will become less expensive than petrol cars by 2025, and about 500 million electric vehicles will be on the roads by 2030. The station types and infrastructure for the charging of EVs will be the major factor to enhance the technologies of electric mobility. Therefore, The EV charging power has to be provided by the distribution network and with maximum reliability [1]. Penetration of EVs into distribution networks increases the necessity of improvement of the network; such as control system, protection system, as well as communication infrastructure through power line carriers, internet connection or mobile phone networks, and possibly protocol standardization [2].

The main problems may appear when using the charging stations of EVs in the network: voltage drop, changing the transformer thermal limits as well the cables increase the losses of the network, voltage unbalance, change the system frequency, and introduce harmonics in the network [3]. In general, there are many methods used to reduce energy loss and enhance the performance of the distribution network, for instance: Network reconfiguration and reconductoring, Distribution transformer sizing and location, increasing voltage level, Flexible Alternating Current Transmission System (FACTS), adding the new substations and adding Distributed Generators (DGs) [4 -6].

There are three essential types of EVs, classified by the degree that which electricity is used as their energy source. Battery Electric Vehicles (BEVs), Plug-in Hybrid Electric Vehicles (PHEVs), and Hybrid Electric Vehicles (HEVs) [7, 8]. BMW/is3, Fiat/500e, Nissan/leaf are some models of BEVs. BMW/i8 Coupe, Toyota/Prius Prime are some models of PHEV, whereas Toyota /Prius Hybrid, Honda/ Civic Hybrid, Toyota Camry Hybrid are some of HEV [8, 9].

In EVs, the rechargeable battery served as an energy source for all its driving parts which involve an electric motor for the propulsion system and also other auxiliary components. The driving range is closely related to the energy capacity of the battery. Consequently, the very long driving distance requires a high energy capacity of the battery [10, 11]. Therefore, the popular batteries used in EVs are Lead Acid, Nickle-Metal-Hydride (NiMH), Nickel-Cadmium (NiCad), and Lithium-Ion (Li-ion) [10, 12]. The Li-ion and NiMH batteries are the leading batteries used in electric car technologies [13]. The Li-ion battery wins over Nickle chemistries due to various factors which include more energy capacity, low self-discharge, perfect temperature performance, friendly for the environment, and most of all their components are recyclable. EVs charging station supplies energy

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for the recharging of all types of electric vehicles. Many charging stations are on-street facilities provided by electric utility companies; mobile charging stations have been recently introduced [14].

Table 1 summarizes modes of charging EVs based on IEC 61851-1 the standard [15]. In general, the modes of flow energy of electric cars are from car to grid, from grid to the car, or from home to the car [2]. The transportation methodologies that can be used for planning the location of gasoline stations and Plug-in Electric Vehicles (PEV) charging stations are Nodal demand-based planning [16], Transportation simulation-based planning [17], and Traffic flow-based planning [18]. Additionally, nowadays Electrical approach is used to site the charging stations of EVs in distribution networks to satisfy the electrical system economic or security operation constraints while minimizing the investment costs for the charging stations [19].

Table 1. EVs charging modes based on IEC 61851-1 [15, 20].

Connection mode	*Grid connection*	*AC voltage (V)*	*AC (A)*	*Type of charge*
MODE 1 (AC)	1 Phase	230	16	Slow
Household socket and extension cord	3 Phase	400	16	Slow
MODE 2 (AC)	1 Phase	230	32	Slow
Domestic socket and cable with protection	3 Phase	400	32	Slow
MODE 3 (AC)	1 Phase	230	32	Slow
A specific socket on a dedicated circuit	3 Phase	690	250	Medium
MODE 4 (DC) Direct current connection for fast charging	Not Appl.	600	400	Fast

Estimated profiles of electric loads such as charging a load of EVs in conventional and smart distribution grids help electrical companies in many fields for example; covering the energy of charging stations and other consumers, assessment of economic and management decisions, and improving the performance of networks [21].

The research sections are presented as follows: Section two presents the network of Hebron city; substations, grid capacity, losses, number of transforms, etc. The expected location and load of charging stations in Hebron are presented in section three. The type of cars and their charging profiles are presented in the same section. Section four introduces the results and discussion of the Hebron grid at charging a maximum number of cars, and also presents the numerical results of solution the overloading problems in the network. Finally, the conclusions are summarized in section 5.

2. HEBRON CITY NETWORK

Hebron is a Palestinian city, and it is far about 35 km south of Jerusalem, its population in 2016 reached about 215 thousand people, and its area of 42 km^2. The number of electricity customers in the Hebron area is 50409 until the end of 2017 [22]. The electric distribution company which covers Hebron city is called Hebron Electric Power Company (HEPCo) with total demand of 110 MW and total losses of 3.635 MW. HEPCo has seven substations 33/11kV given in Figure 1 and one station proposed in Halhul town. In addition, most loads are connected by distribution transformers 11/0.4 kV, whereas the total distribution transformer number is 668 with a range of 100- 1000 kVA [22]. The Hebron network was built on the ETAP program within a power factor equal to 0.92, and the loading of transformers was about 40% of the rated kVA. The loading ratio of each distribution substation is given in Figure 2.

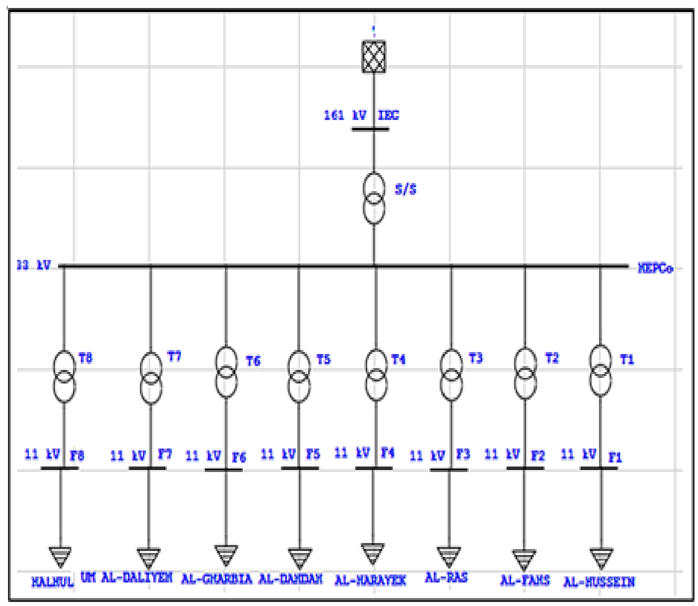

Fig. 1. Main distribution stations in HEPCo [19].

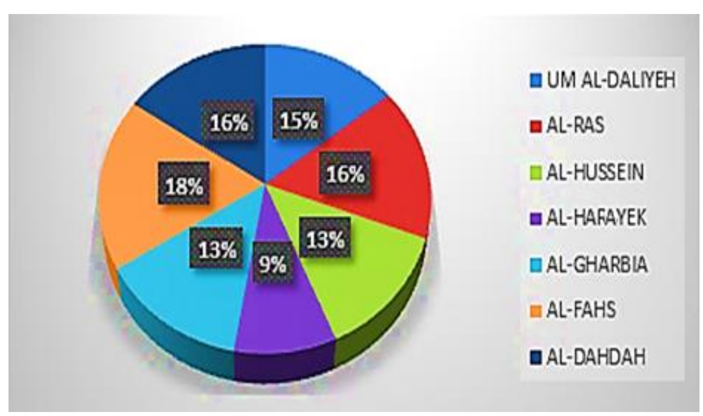

Fig. 2. Loading ratio for each substation.

3. PLANNED CHARGING STATIONS IN HEBRON

ETAP is the most comprehensive solution for the design, simulation, and analysis of generation, transmission, distribution, and industrial power systems. ETAP is used in this study for analysis of the Hebron network before and after integrating charging stations of EVs.

3.1. Locations of Stations

Based on the expected demand for EVs and their charging stations, the planning on the transportation approach is adopted to locate the stations. These planned locations aim to meet the expected needs of customers and to cover the largest geographical area in the city of Hebron. These places are Halhul Bridge, Al Salam Street, Al Tahreer Street, Jabal Al Rahmah Street, Um Al Daliyeh, Ein Sara Street, and Nimra Street. Table 2 displays the connection points of planned charging stations with the Hebron network.

Table 2. The points of connection charging stations with Hebron network.

Name of charging station	*Point of connection with the network*
Hulhul Bridge Station	T6000 (Halhul Bridge)
Al Salam Station	T601 (Electrode)
Altahreer Station	T564 (Altahreer)
Jabal Al Rahmah Station	T490 (Jabal Al Rahmah)
Um Al Daliyeh Station	T494 (Um Al daliyeh
Ein Sara Station	T350 (Alhosain building)
Nimra Station	T400 (Nimra mosque)

3.2. Type of EVs

This study discusses four types of EVs that can be used in Hebron city in the future. Table 3 and Figure 3 specify some characteristics of these EVs [23 - 25].

Table 3. EVs suggested for future use

Manufacturer	*Type*	*Battery size (kWh)*	*Maximum power (kW)*	*Rang (mile)*
BMW i3	BEV	33	47.82	114
Nissan Leaf 2012	BEV	30	45.66 (Fast Charge) 3.46 (Level 2)	156
Fiat 500e	BEV	24	20.56	84
Tesla Model S	BEV	85	56.68	256

3.3. Expected Load of Charging Stations

In this planning study, it is assumed the largest number of EVs in each station, as well as, the power consumed is supposed at the maximum level during the charging process, where this definition of maximum load occurs at a period of 19:00-21:00. Table 4 shows the number of EVs in each station and the value of the power consumed. Moreover, Figure 4 illustrates the ETAP model of the Nimra charging station as an example of a model for stations.

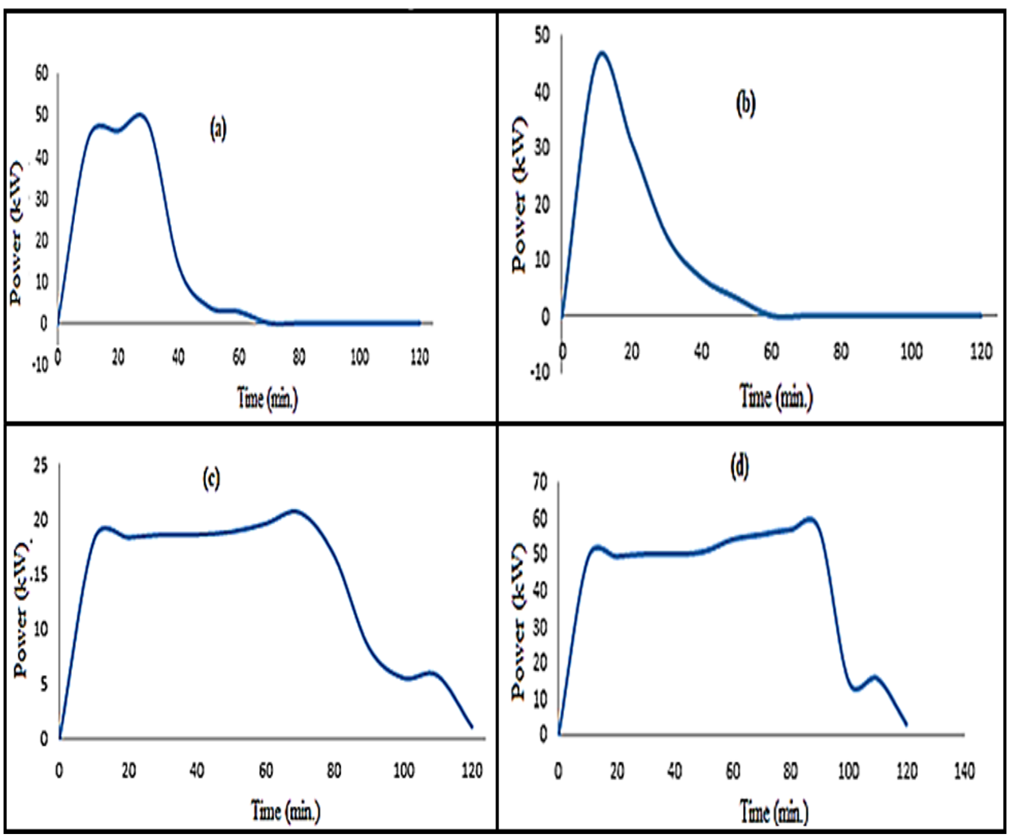

Fig. 3. Power during charge, (a) BMW i3 fast charge, (b) 2012 Nissan Leaf/Fast charge, (c) Fiat 500e fast charge, (d) Tesla model S fast charge.

Table 4. The number of EVs and power consumed at maximum load.

Stations	Type of EV						
	BMW i3	Nissan Leaf 2012 Fast charge	Nissan Leaf 2012 Level 2	Fiat 500e	Tesla Model S	Total EV's in the station	Total power in the station (kW)
Halhul Bridge	2	2	4	1	1	10	278.04
Al Salam Street	2	2	3	2	2	11	351.82
Al Tahreer	1	1	2	2	1	7	198.2
Jabal Al Rahmah	1	1	2	1	2	7	234.32
Um Al Daliyeh	1	1	1	2	1	6	194.74
Ein Sara Street	2	1	5	2	1	11	256.4
Nimra Street	1	1	2	1	1	6	177.64
Total	10	9	19	11	9	58	1691.16

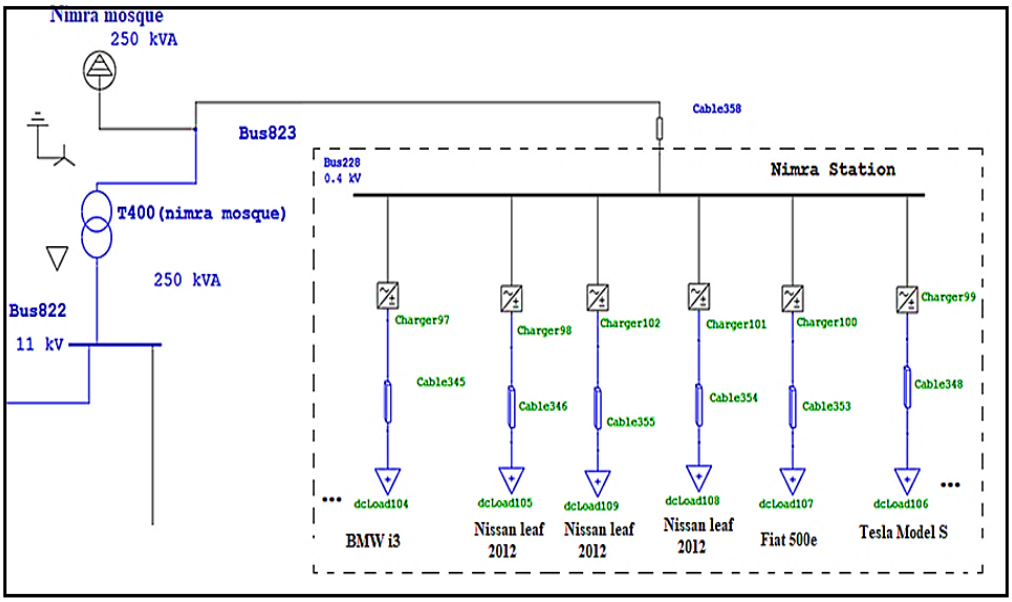

Fig. 4. ETAP model of Nimra charging station.

4. RESULTS AND DISCUSSION

4.1. Network Specifications at Charging Maximum Number of EVs

Initially, the Hebron electricity network was chosen to develop a strategic future planning for the loads expected to enter the Hebron electricity network by adding EV charging stations. Table 5 shows the distribution of substations loads when a maximum number of EVs in each charging station is assumed. As result, the new total demand including the value of power drop-in the charging station will become 112.2 MW, and the real loss in the network is 4.3 MW. However, some distribution transformers and cables will become overloaded as shown in Table 6. The technical solution for this problem is discussed in the following section.

4.2. Solving the Overloading Problems in the Network

The proposed solution of overloaded is given in the following procedures:

- Adding two new transformers in the new station of 'Al-sala Al-riyadia' with a capacity of 13 MVA for each one.
- Reconfiguration of loads in the vicinity of 'Al-sala Al-riyadia', where the feeder 'Diwan Al-Mohtasab' was separated and this feeder was again added to 'Al-sala-Alriyadia' station.
- Separation 'Al-Mazrouk' feeder from 'Al-Dahdah' station and adding it to 'Al-sala-Alriyadia' station.
- Separation of 'Al-Gharbia' station from 'Al-Dahdah' station at Ajlouni feeder and feeding it from 'Al-sala-Al-riyadia' only in the case of a high load on 'AL-Gharbia' station.
- Adding a 10 MVA transformer to the 'Al-Ras' station.
- Reconfiguration of loads of 'Al-Fahs' and 'Um Al-Daliyeh' station.

Besides this, Table 7 proposes the solution of overloaded problems in cables and distribution transformers near the suggested location of charging stations.

After taking all previous procedures of solution into account of simulation of the Hebron network by ETAP program, all the overload problems were noted and removed. Figure 5 illustrates the loading ratio for each substation in the Hebron grid. In this case, all elements of the grid are under the nominal loading values in case of charging a maximum number of electric cars. Moreover, the simulation results show that the total demand becomes 111.9 MW, total losses 3.472 MW, and the level of power factor in substations between 0.89 and 0.95.

Table 5. Distribution of substations loads at charging the maximum number of EVs.

Name of substation	*Voltage (V) (kV)*	*Active Power (P) (MW)*	*Reactive Power (Q) (MVAr)*	*Ampere (I) (A)*	*Power Factor (%PF)*
UM AL-DALIYEH	33	16.459	7.416	315.8	91.17
AL-RAS	33	19.51	9.958	383.2	89.07
AL-HUSSEIN	33	15.382	8.203	305	88.24
AL-HARAYEK	33	10.64	5.421	208.9	89.1
AL-GHARBIA	33	15.408	7.978	303.6	88.8
AL-FAHS	33	20.49	6.487	376	95.34
AL-DAHDAH	33	18.609	8.182	355.6	91.54
TOTAL		116.498	53.645		

Table 6. The overloaded transformers and cables at charging the maximum number of EVs.

Transformers		*Cables*	
Transformer connection point	*Output Loading (%)*	*Name of cable*	*Cables Loading (%)*
T1 AL-RAS	104.9	Cable 43	217.04
T2 AL-RAS	104.9	Cable 303	103.69
T350 (Al Hossain Building)	116.1	Cable 344	107.92
T400 (Nimra Mosque)	151.2	Cable 362	129.69
T490 (Jabal Al Rahmah)	256.4	Cable 362	153.48
T564 (Al Tahreer)	302.1	Cable 401	166.11
T6000 (Halhul Bridge)	118.1	Cable 2387	126.86
		Cable 2389	130.68
		Cable 2517	146.69
		Cable 2594	144.22

Table 7. The solution proposed for the affected charging stations.

Station	*Solution*
Halhul Bridge	Adding a new 630 kVA transformer to the network and connecting the station with two cables on the two busses to distribute the loads to them.
Jabal Al Rahmah	Replace the transformer from 160 kVA to 400 kVA.
Al Tahreer	Replace the transformer from 100 kVA to 630 kVA.
Ein Sara	Connecting the charging station to the new 630 kVA transformer where this transformer is located in the '*Al-sala Al-riyadia'* station. In addition, connecting the station to this transformer with two cables on two busses to distribute the loads to them.
Nimra	Replace the transformer from 400 kVA to 630 kVA.

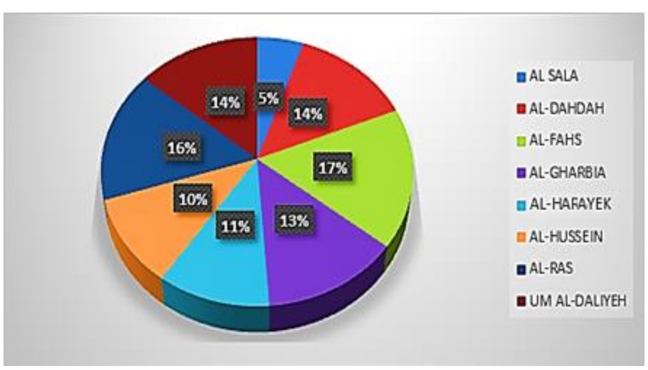

Fig. 5. Loading ratio for each substation after considering solution procedures.

5. CONCLUSION

This article presents a planning study for measuring the ability of the Hebron distribution grid on overcoming of growing demand for EVs. This study foresees seven electrical charging stations in Hebron city in the future. As well as assumes the maximum number of EVs in all stations at the same moment is 58 different types of electric cars. The total demand of the Hebron grid without considering charging stations is 110 MW and total losses 3.635 MW, while the simulation results of the grid with taking charging stations and solving overloading problems into account show that the total demand becomes 111.9 MW, and total losses 3.472 MW. The improvement of the medium voltage network and the reduction of energy losses on it will positively affect the low voltage network. It is possible to add charging stations for electric cars to the Hebron electricity grid, but within the solutions that were developed. The main conclusion of this paper is the Hebron network can bear the growing demand for EVs but with doing some modifications on the grid such as reconfiguration some feeders, reconductoring some cables, and building a new substation as well as adding some distribution transformers.

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