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Reducing the losses of the distribution network in the case of charging and discharging plug-in hybrid vehicles in the presence of scattered production sources

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ABSTRACT

Background and purpose: The addition of plug-in hybrid vehicles to the distribution networks imposes additional loads on the network and can create adverse effects on the distribution network. In this article, the effects of electric vehicles on the losses of distribution networks and its reduction through power management of electric vehicles in parking lots have been investigated.
Research method: Since the parameters in the modeling of these cars are random, in the research, the parameters of the number of cars in each class, battery capacity, daily distance traveled, SOC, and the time of arrival and departure of cars are considered as probabilistic parameters. Parking lots are places with a large number of electric cars, so the simultaneous charging or discharging of the cars there can have destructive effects on the distribution network. Therefore, in this article, a charge and discharge management method for electric vehicles in parking lots is proposed to reduce network losses. The proposed method is implemented using genetic optimization algorithm.
Findings: In order to review and analyze the above method, four scenarios were investigated. In the first scenario, it was assumed that the network does not have electric vehicles. The reason for assuming this scenario without cars is to understand more easily the effect of electric cars on the distribution network. In the second scenario, it was assumed that electric cars are charged and discharged in parking lots, albeit in an uncontrolled manner. Comparison of losses and voltage in these two scenarios shows that electric vehicles increase losses if they are charged in an uncontrolled manner. Then, in the third scenario, the charge and discharge management of cars was discussed using the proposed objective function without considering the effect of DGs.
Keywords: electric cars, hybrid electric cars, plug-in hybrid cars, genetic algorithm, car charging and discharging management.

1. INTRODUCTION

A smart grid provides power from the producer to the final consumer through two-way digital technology to control consumption at the consumer's location, reduce costs and increase reliability. The smart grid has a smart monitoring system that records all the information related to production resources in the grid. The smart grid has the ability to integrate new energy sources such as sun and wind. For example, this network can automatically remove some less important loads from the network during peak hours. One of the ways to facilitate the intelligentization of the power grid is to use a microgrid at the level of the smart grid. A microgrid is an integrated energy system at a low voltage level that includes loads, distributed generation and storage and can work connected or separated from the distribution network. Microgrids often work in the state connected to the network and usually continue to work in the state of disconnection from the network in situations such as the occurrence of an error. From the point of view of the main grid, the microgrid can be considered both as an integrated load that is connected to the grid and absorbs power from the grid, and as a small source of power that is cost-effective. , injects power into the main grid. Also, from the point of view of consumers, a microgrid not only provides the electrical load and heat required by consumers like low voltage distribution networks, but also a factor for increasing reliability, reducing pollution, improving power quality, reducing losses and Reducing energy costs. It is clear that in order to achieve the above goals, it is necessary to provide an optimal and efficient management plan to establish coordination between the control and exploitation of distributed production, storage devices and controllable loads in the microgrid. In comparison between electric cars and conventional cars, Electric cars are much more efficient.

Problem description and modeling

One of these methods can be the use of PHEVs as controllable loads and controllable energy sources. By knowing the amount of energy required for charging the cars and their charging power level, the time needed to charge the cars is also easily obtained. According to what has been said, it can be concluded that the information required to obtain the load curve due to the charging of electric vehicles can be shown using a prism according to Figure 1 [1.[

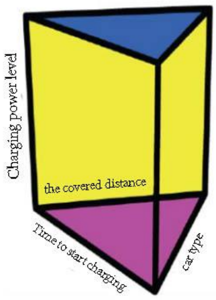

Figure 1: Chart of electric vehicle parameters

As can be seen, the sides of the base of the prism indicate the distance traveled, the type of vehicle and the time to start charging (all three of which are probabilistic factors and have uncertainty), and the height of the prism indicates the level of charging power (which is a factor is definite). In this section, the characteristics of electric vehicles and the assumptions related to them, which are needed to carry out the studies, are examined and determined. In this regard, things like energy consumption per unit of distance, all-electric distance (AER), battery capacity, level of charge (SOC), energy required for battery charging and battery charging rate are examined. It is clear that this characteristic is completely dependent on the size, weight and power of the vehicle. In order to include this issue in calculating the battery capacity of electric vehicles, equation (1) can be used:

$$C = ECPM \times AER \tag{1}$$

In this regard, C is the battery capacity, EPCM is the electrical energy consumed per mile, and AER is the all-electric range. This relationship actually obtains the battery capacity by multiplying the travel distance of electric vehicles by the amount of electrical energy they consume per unit of distance. According to the previous table, the battery capacity of each of the four types of different classes of electric vehicles can be obtained in a range. Based on this and according to their class, it can be calculated as a normal distribution function using the table below.

Obtaining the daily distance traveled for office travel purposes leads to a more accurate model of the initial charge level of electric vehicles. In order to obtain the initial charge level, equation (2) is used.

$$SOC_{ini} = \begin{cases} \left(1 - \dfrac{D \times ECPM}{C}\right) \times 100 & D \le AER \\ 0 & D \ge AER \end{cases} \quad (2)$$

In this regard, the initial charge level, the daily distance traveled, the electric energy consumed per mile, the battery capacity and the all-electric distance. It should be noted that if the distance traveled by the electric car exceeds its all-electric distance, the energy stored in the battery will be completely consumed and its charge level will be zero. In modeling the arrival and departure time, we need a precise behavior of the cars. In [2], in order to calculate the profit of parking lot owners, the time of entry and exit of cars to the parking lot has been considered as the behavior of charging cars in houses. In other words, it is assumed that when the cars return home, it is the time to start charging. Also, in reference [3], the modeling of entry and exit time is considered only administratively. Since public parking lots can have customers with administrative and commercial behaviors during the day and also domestic behavior at night, and on the other hand, modeling the time of entry and exit of cars on the profit of the parking lot owners and on the management of charging and discharging of cars. It affects, therefore, modeling the arrival and departure time of cars by separating daily trips can be efficient.

For parameters such as the daily distance traveled [4,5] and the time to reach the parking lot [6], which follow the normal probability distribution function, these parameters can be similar to what is presented in relation (3). Made

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right) \Rightarrow X = Inv\int_0^x f(x) \quad (3)$$

In the above relationship, the probability parameter studied is the distance traveled, which can be calculated based on the average value ( ) and standard deviation ( ) of the probability distribution function of the relevant data. In general, in distribution networks, the losses of the entire network can be minimized by minimizing the current passing through the network feeders. To calculate these losses for each distribution network, a suitable load distribution method is needed. Forward/Backward Sweep technique is used in this thesis. This method consists of two steps as follows:

Backward sweep: In this step, we obtain the load flow in a bus network, in each bus, from equation (4.(

$$\bar{I}_L^m = \left\{ \frac{P_L^m - jQ_L^m}{\overline{V_L^m}} \right\} \qquad [m = 1, 2, 3, \ldots N] \quad (4)$$

In the above relation

: Active power of Amin Bass load : Reactive power of Amin Bass load : Phasor voltage of Amin Bass : Phasor current of Amin Bass

*Therefore, the flow of each branch of the network is obtained from the following relationshi*p:

$$\bar{I}_{m,n} = \bar{I}_L^n + \sum_{m \in \Gamma} \bar{I}_L^m \quad (5)$$

Forward sweep: This step is done after the previous step, so the voltage of each bus of the distribution network is obtained from the following relationship.

$$\bar{V}_n = \bar{V}_m - \bar{I}_{n,m} \ Z_{n,m} \qquad (6)$$

In the relation above: Amin-bus conjugate voltage: Amin-bus conjugate voltage: Impedance between Amin-bus and Amin-bus

In order to solve the load distribution using the mentioned technique, we must first explain the following three concepts.

Formation of BIBC matrix

We can convert the injection power in each bus to the injection equivalent current using the previous relationship, and we can compare the current obtained from this method with the current obtained from Kirschoff's laws. Each current in each branch of the network is a function of the equivalent injected current. According to Figure 2, we can define the currents of each branch of the above network as follows.

$$\begin{aligned} IB_5 &= I_6 \\ IB_4 &= I_5 \\ IB_3 &= I_4 + I_5 \\ IB_2 &= I_6 + I_3 + I_4 + I_5 \\ IB_1 &= I_2 + I_3 + I_4 + I_5 + I_6 \end{aligned} \qquad (7)$$

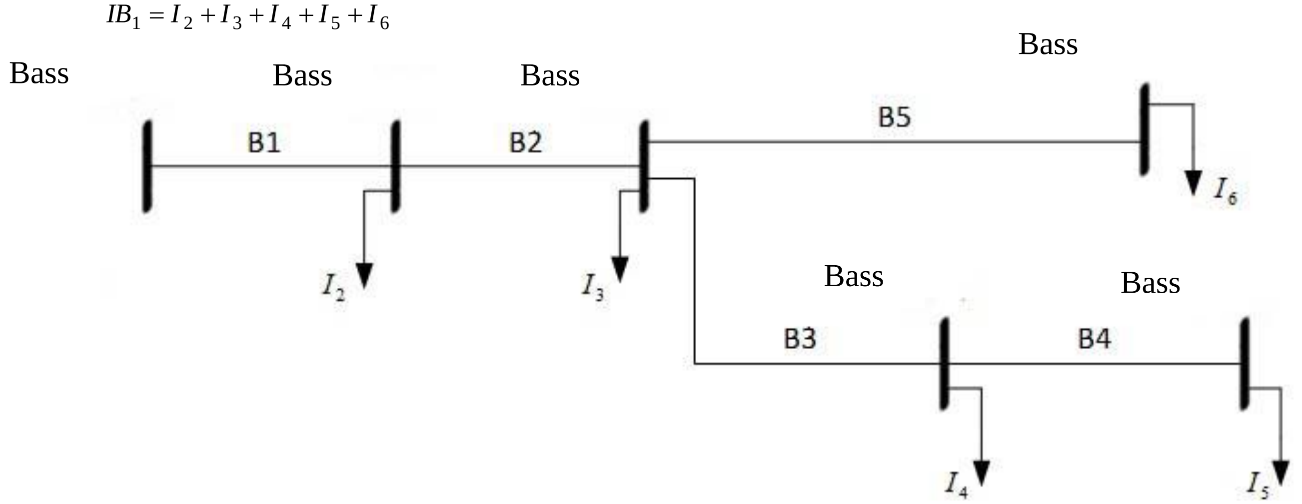

Figure 2: Sample network to illustrate the load distribution used

For the above equations, the BIBC matrix can be defined as follows.

$$\begin{bmatrix} IB_1 \\ IB_2 \\ IB_3 \\ IB_4 \\ IB_5 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \\ I_5 \end{bmatrix} \qquad (8)$$

And in general, we show the above matrix with relation (8.(

$$[IB] = [BIBC][I] \qquad (9)$$

BCBV briefly shows the connection between current lines and *voltage buses. This relationship can be easily obtained by using Kirshehf's voltage law. In Figure 2, the voltage of buses 2, 3 and 4 can be defined as follows*.

Using the above relations, the voltage of bus 4 can be rewritten as below.

$$V_4 = V_1 - IB_1 Z_{12} - IB_2 Z_{23} - IB_3 Z_{34} \qquad (10)$$

Using this relationship, we can understand that the voltage of each network bus depends on the line currents, line parameters and substation voltage (first bus). With a similar approach, the voltage of other buses and thus the BCBV matrix can be obtained as follows.

$$\begin{bmatrix} V_1 \\ V_1 \\ V_1 \\ V_1 \\ V_1 \end{bmatrix} - \begin{bmatrix} V_2 \\ V_3 \\ V_4 \\ V_5 \\ V_6 \end{bmatrix} = \begin{bmatrix} Z_{12} & 0 & 0 & 0 & 0 \\ Z_{12} & Z_{23} & 0 & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & Z_{45} & 0 \\ Z_{12} & Z_{23} & 0 & 0 & Z_{56} \end{bmatrix} \begin{bmatrix} IB_1 \\ IB_2 \\ IB_3 \\ IB_4 \\ IB_5 \end{bmatrix} \quad (11)$$

And in general, the following relationship can be defined.

$$[\Delta \mathrm{V}] = [BCBV][IB] \quad (12)$$

According to what was said in the previous part, it is clear that BIBC and BCBV matrices are dependent on the structure of the studied network. BIBC is generally a matrix that shows the relationship between the currents injected into the buses and the currents of the lines. This connection provides a simple solution for changing the line currents that result from changing the bus injection currents. BCBV is also a matrix that shows the relationship between line current and bus voltage. As a result, with this matrix, it is possible to obtain the change in the bus voltage caused by the change in the current of the lines. Now, the relationship between the current injected into the buses and the voltage of the network buses can be obtained as follows.

$$[\Delta V] = [BCBV].[BIBC].[I] \quad (13)$$

$$[DLF] = [BCBV][BIBC] \quad (14)$$

$$[\Delta V] = [DLF].[I] \quad (15)$$

Therefore, by solving equations (13), (14) and (15), it is possible to get load distribution from the desired network.

$$I_i^k = I_i^r(V_i^k) + jI_i^i(V_i^k) = \left(\frac{P_i + Q_i}{V_i^k}\right)^* \quad (16)$$

$$\left[\Delta V^{k+1}\right] = [DLF].\left[I^k\right] \quad (17)$$

$$\left[V^{k+1}\right] = \left[V^0\right] + \left[\Delta V^{k+1}\right] \quad (18)$$

In this part, an objective function is proposed for the intelligent management of charging and discharging of PHEVs to minimize the losses of the distribution network. In order to manage the charging and discharging of cars, the objective function is considered as equation (19.(

$$Minimize\ OF = \sum_{\Delta t \in T} \sum_{m \in N} R_{n,m} \left(\left| V_n^t - V_m^t \right| \times \left| y_{n,m} \right| \right)^2 \times \Delta t \quad (19)$$

which in the above relationship: resistance between buses and: amplitude in the voltage of the node in the time interval: amplitude in the voltage of the node in the time interval: admittance between the buses and: time interval for the calculation of ergy losses

To obtain bus voltages in relation (19), relations (20), (21) and (22) related to network load distribution are used. Also, relationships (23) and (24) express the limits of the allowed voltage in each bus and the allowed power of each line.

$$I_i^{k,t} = I_i^r(V_i^{k,t}) + jI_i^i(V_i^{k,t}) = \left(\frac{P_i^t + Q_i^t}{V_i^{k,t}}\right)^* \quad (20)$$

$$\left[\Delta V^{k+1,t}\right] = [DLF].\left[I^{k,t}\right] \quad (21)$$

$$\left[V^{k+1,t}\right] = \left[V^0\right] + \left[\Delta V^{k+1,t}\right] \quad (22)$$

$$V_{\min} \le V^{k+1} \le V_{\max} \quad (23)$$

$$S^{l,t} \le S_{\max} \quad (24)$$

which in the above relations are the injected active power and the injected reactive power in time and in Amin Bass and are obtained from the following relations:

$$P_i^t = P_{L_i}^t + \varphi_{PL_n} P_{PL_n}^t - \varphi_{DG_m} P_{DG_m}^t \qquad \varphi_{PL_n}, \varphi_{DG_m} \in [0,1] \tag{25}$$

$$Q_i^t = Q_{L_i}^t \tag{26}$$

In the above relations: active power of normal load in Amin bus: reactive power of normal load in Amin bus: power of parking lot in time: distributed generation power in time: binary variable that indicates presence or absence of parking lot in Amin bus: A binary variable that indicates the presence or absence of scattered production in Amin Bass.

According to the said contents and the relationships above, the factor that is used to reduce casualties is the power of electric car parking lots. This parameter is dependent on the behavior of electric cars (the time they enter and leave the parking lot, their initial charge level and also their battery type). Therefore, it is a parameter that, in addition to connecting the way of charging and discharging of electric vehicles to network losses, causes the uncertainty of electric vehicles to be affected in the calculation of losses. The capacity of each parking lot is obtained from the following relationship.

$$P_{PL_n}^t = \sum_{v=1}^{N_v^n} \sum_{t_a^v}^{t_d^v} \left(P_{ch}^{t,v} \times \lambda_{ch}^{t,v} - P_{dch}^{t,v} \times \lambda_{dch}^{t,v} \right) \times \Delta t \tag{27}$$

which in the above relationships: : the amount of charging power of my car in time : the amount of power of discharging my car in time : the variable of the charging state of my car in time : the variable of the discharging state of my car in time : the time of my car entering the parking lot : the time of leaving my car to Parking: the number of cars in the parking lot: the battery capacity of the car: charging efficiency: discharging efficiency

The amount of charge or discharge power in each time period depends on the charge level of the battery of electric vehicles. The charge level of cars in each time period is obtained from the following relationship.

$$SOC^{v,t} = \begin{cases} SOC^{v,t-1} + \lambda_{ch}^{t,v} \times \eta_{ch} & \lambda_{ch}^{t,v} = 1 \quad \lambda_{dch}^{t,v} = 0 \\ SOC^{v,t-1} - \lambda_{dch}^{t,v} \times 1/\eta_{dch} & \lambda_{ch}^{t,v} = 0 \quad \lambda_{dch}^{t,v} = 1 \\ SOC^{v,t-1} & \lambda_{ch}^{t,v} = 0 \quad \lambda_{dch}^{t,v} = 0 \end{cases} \tag{28}$$

In this regard, the charge level of the car is in time.

The point that should be noted in this section is that PHEV batteries, especially lithium-ion batteries, can be very dangerous if not used properly. Because they may explode due to high heat or due to charging to high voltage. In addition, they may be damaged by discharge up to a certain voltage. In order to reduce the risk of injury, lithium batteries generally include a small circuit so that if the battery capacity falls below a threshold during discharge and exceeds a certain value during charging, the circuit will be cut [85]. Therefore, in this article, the upper limit and lower limit of SOC are equal to 80% and 10%, respectively. The following relationship expresses this adverb.

$$SOC_{\min}^v \le SOC^{v,t} \le SOC_{\max}^v \tag{29}$$

Another limitation that must be considered when charging and discharging electric cars is the level of charge requested by car owners when leaving the parking lot. In this article, the output charge level of cars is equal to the maximum charge level and it is assumed that every car must leave the parking lot with a fully charged battery.

$$SOC_{des}^v = SOC_{\max}^v$$

2. Simulation and results

The following proposed scenario is considered for simulating and comparing the results:

- Scenario 1: The distribution network is without electric vehicles.
- Scenario 2: There are electric cars, but they lack controlled charging.
- Scenario 3: Electric vehicles have managed charging to reduce losses, but the grid lacks distributed generation.
- Scenario 4: The third state with the presence of distributed production.

Analysis of the first scenario:
In this scenario, it is assumed that no electric vehicle is connected to the grid. Network losses in the first scenario have been calculated for each 15-minute time step. According to the calculations, the highest loss is at 11:45 and its value is 910.20 kilowatts.

3. Analysis of the second scenario

In this scenario, PHEVs are considered without any charging management. In other words, it is assumed that the cars will be charged as soon as they enter the parking lot. The simulation in this part has been done for the penetration coefficient of 50% to 100% in steps of 10%. As an example, network losses in this scenario with 90% PHEVs penetration in the network for each time step of 15 minutes are given.

Figure 3 shows the total network losses for scenario 2 and for different car penetration rates. As can be seen, with the increase in the percentage of penetration of electric vehicles, the network losses increase. Also, in the time period of 40 to 50, because most of the PHEVs are in discharge mode, the network losses in this time period are reduced by increasing the penetration coefficient of cars.

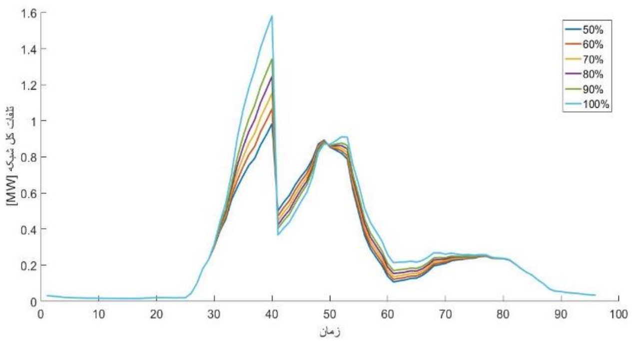

Figure 3: Total network losses in one day for scenario 2

4. Analysis of the third scenario

In this scenario, the management of charging and discharging of electric vehicles in the parking lots has been done in order to reduce the losses of the distribution network. The management is done based on the genetic algorithm. The genetic algorithm will converge after 1000 iterations. Some convergence is equal to the losses of the entire distribution network in the optimal state. This value is equal to 26.7772 MW.

In this scenario, the charging and discharging management of electric vehicles has been done in such a way that network losses are minimized according to the model proposed in the third chapter. In this case, the distribution network does not have scattered production. Similar to the previous scenario, the simulation has been done for the penetration coefficient of 50% to 90% in 10% steps. As an example, the losses of the distribution network in this scenario have been calculated for the penetration factor of 90% of cars for each time step of 15 minutes. According to calculations, the highest loss is at 12:00 and its amount is 1196.9 kilowatts.

The total network losses for scenario 3 and different penetration coefficients of electric vehicles are shown in the figure. In this scenario, due to the managed charging of the cars, the loss peak, which was in the range of 30-40 in scenario 2, is moved to the range of 50-60. This change will reduce overall network losses. According to this figure, the higher the car penetration rate, the higher the losses during the period when most electric cars are charging. On the other hand, by increasing the car penetration rate during the discharge period of most cars, network losses will decrease.

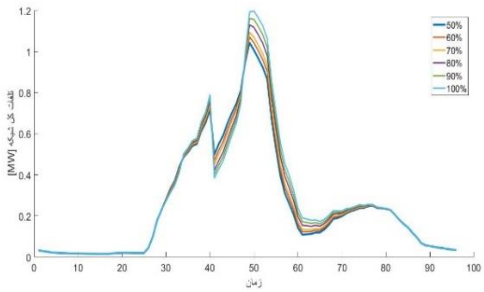

Figure 4: Total network losses in one day for scenario 3

Analysis of the fourth scenario:

In this scenario, in addition to the electric cars in the parking lots having intelligent charge and discharge management, the distribution network also has scattered productions. Similar to the previous scenario, the simulation has been done for the penetration coefficient of 50% to 90% in steps of 10%. As an example, the losses of the distribution network in this scenario have been calculated for the penetration factor of 90% of cars for each time step of 15 minutes. According to calculations, the highest loss is at 12:00 and its value is 998.64 kilowatts. It represents the losses of the entire distribution network for scenario 4 and in the presence of different penetration percentages of electric vehicles. In this way, with the increase in the penetration of cars, the losses have increased in the case where the cars are in charging mode and decreased in the case where the cars are in discharging mode.

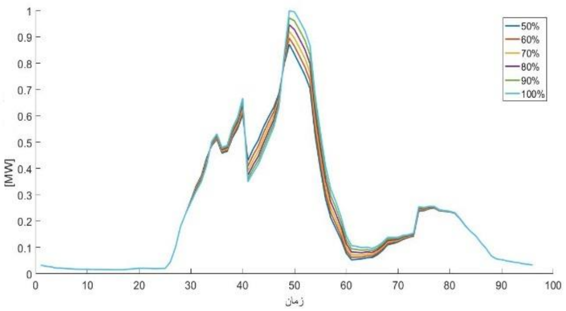

Figure 5: Total network losses in one day for scenario 4

5. Comparison and analysis of different scenarios:

In order to compare the results of different presented scenarios, the losses of the entire network are given in the table. As can be seen, in the second case, the loss of the entire network increases to 5.9349 megawatts compared to the first case, and this means a 25% increase in the distribution network loss compared to the case where there is no electric vehicle in the network. This result shows the importance of proper management of charging and discharging of electric vehicles.

Table 1: Total network losses for each scenario

Scenario 4	Scenario 3	Scenario 2	Scenario 1	
22.1648	26.7772	29.4171	23.4822	network losses

By comparing the losses of the entire network in the second and third scenarios, it can be seen that the losses are reduced by 2.6399 megawatts in the third scenario compared to the second scenario. In other words, when we have a managed charge, losses are reduced by 10% compared to when we do not have charge management. From this, we can conclude that the managed charging of electric vehicles is very important from the point of view of the distribution network. One of the advantages of using distributed production in distribution networks is that it eliminates the centralization of the distribution path of production power. In general, distributed generation can reduce network losses if they are placed in the right place and inject the right power into the network at the right time. In this article, according to reference [7], where the optimal location and capacity of the parking lots for the network studied in this thesis have been used. By comparing the third and fourth scenarios, we will find that the network losses have decreased by 4.6124 megawatts in the fourth scenario compared to the third scenario. Considering the location and suitable capacity of DGs, we also had an expectation. This reduction in casualties is 17%. By comparing the first and fourth scenarios, it can be realized that if it is possible to use scattered productions correctly and on the other hand, managing the charging and discharging of cars, scattered productions will be able to reduce the losses resulting from the presence of cars in the compensate the network. They can also reduce some of the network losses that are independent of cars. Also, the fourth scenario states that as expected, the presence of dispersed production will improve the network voltage. In the third scenario, the charging and discharging management of cars is done with the aim of improving losses. As can be seen, in this case, some of the power consumption of the network moves from the 30 to 40 time period, which has a large peak in the second case, to the 50 to 60 time period. Therefore, the power consumption curve of the network is improved in the third state compared to the second state. In other words, this displacement of the charging of cars causes that in the range of around 40, when the network is under other peak loads, both less cars are charged and the cars in the range of 40 to 50 are in discharge mode and help the network to respond to the load. do In the fourth case, due to the lack of effect of distributed production on the network consumption load curve, the load curve in this case corresponds to the third case.

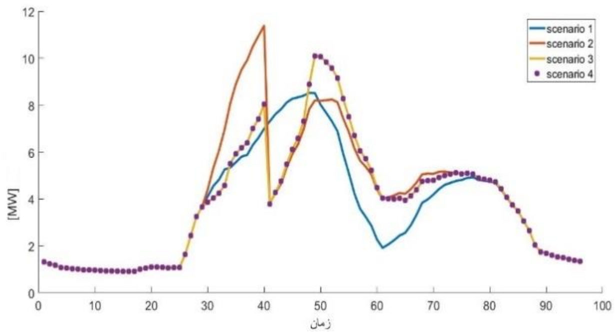

Figure 6: Comparison of the power consumption of the entire network in a period of one day in each scenario

It is shown in the curve of the set of losses of the distribution network in the period of one day and night. In the first scenario, the loss curve has a lower value due to the absence of cars. In the second scenario, due to the uncontrolled charging of cars, there is a sudden jump in the loss curve between 30 and 40. Also, in the period of 40 to 50, due to the uncontrolled discharge of cars and the fact that a large number of cars inject energy into the network in this period of time, it causes a surge in this period of time. In the third scenario, the loss curve does not have a jump in the second scenario, because in this scenario, the managed charging is done with the aim of reducing losses. In this scenario, due to changing the charging time of most cars to another time (between 50 and 60), network losses will be significantly reduced in the 30 to 40 time period compared to the second scenario. In the fourth case, due to the presence of scattered productions, the network loss curve decreases compared to the third scenario, because scattered productions cause a decrease

Network losses are distributed. According to the loss curve in this case, the loss of the entire system in the time periods when scattered productions are present in the network has decreased compared to the third scenario.

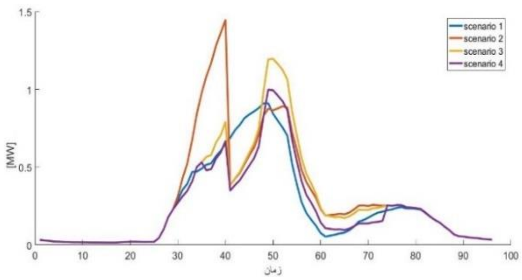

Figure 7: Comparison of total network losses in one day in each scenario

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