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Investigating and sensitivity analyzing the of operating microgrids in the presence of electric vehicles

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Abstract

The use of electric vehicles (EVs) is increasing daily owing to the lack of fossil fuels on the one hand and the emission of pollution caused by the burning of fossil fuels. In this research, to produce fuel for EVs from renewable sources, a power grid with renewable energy sources such as wind turbines and photovoltaic cells was considered. After modeling, optimization was performed to supply the energy needed by EVs using wind turbines and photovoltaic cells, and the main purpose of this optimization was to reduce environmental pollution by providing maximum energy. One of the important results is the $1601941 investment cost of the wind turbine and photovoltaic cell system.

1. Introduction

For a long time, the national electricity grid has been used to supply the electric energy needed by the cities, and the arrangement of the power plants has always been of special importance about the required loads. Become One of the solutions to reduce losses is the use of scattered production with the approach of using renewable energy sources, and with the production of electric vehicles, this device is also considered as a power grid. These effects can include an increase in the maximum load, an increase in losses, a decrease in the voltage and load factor of the system, etc. [1].

Various research has been done in the field of how to charge and discharge electrical vehicles by the power grid [2]. In reference [3], has provided voltage and energy control in distribution systems in the presence of flexible loads considering coordinated charging of EVs. The purpose of this method is to charge in low load hours with low energy prices and at the same time meet the technical limitations of the network. Search methods and neural networks are used to make decisions in this system. Reference [4] study provides a review of the existing coupler, compensation topologies, and control schemes to determine their effectiveness in achieving the desired control objectives. In addition, it introduces practical metrics for a system designer to consider when developing the magnetics and power electronics for a DWPT system to ensure good controllability. It also shows how the delay in communication can affect the control performance and impact recommendations for high-speed vehicle charging. In [5], this study analyses the effectiveness of an off-grid solar photovoltaic system for the charging of EVs in a long-term parking lot. The effectiveness of charging is investigated through analysis of the states of charge (SoC) at the departure of EVs plugged in at the parking lot over the simulated year.

References [6] and [7] have discussed the technical and economic impact of the introduction of EVs on the electric grid of the United States of America. These articles show that the increase in the arrival of vehicles can cause difficulty in the work of the network operator and lower the reliability of the network. In these articles, the use of intelligent charging planning and also vehicle-to-grid (V2G) capability is proposed as a way to overcome this problem. In [8] and [9], have provided inductive power transfer charging infrastructure for EVs: A New Zealand case study. Reference [10] has addressed the issue of the effect of EVs on the reliability of the distribution network. In this study, accumulators are considered battery exchange stations. Here, an algorithm is used that divides the time into different intervals in such a way that load fluctuations can be ignored. Accordingly, in each interval, the probability distribution function of the batteries' energy has been taken into account, taking into account the drivers' battery replacement pattern. In this article, the behavior of drivers is considered based on their behavior at gas stations. The study is done on a 34-bus system IEEE [10].

Reference [11] has provided a Technical Review of Advanced Approaches for EV Charging Demand Management, Part I: Applications in Electric Power Market and Renewable Energy Integration. In reference [12], presented the Impact of EV charging demand on distribution transformers in an office area and determination of flexibility potential. In Reference [13, 14], the coordinator tries to find the most optimal charging program for EVs by implementing an optimization problem with the objective function of minimizing network operation costs by satisfying the condition of supplying the load required by vehicles. In this article, both modes of modeling the coordinator as a price receiver and affecting the price offered to vehicle owners are considered.

An optimization-based approach is introduced in [15] to properly allocate multiple wind turbine generation systems (WTGS) in distribution systems in the presence of (plug-in electric vehicles) PEVs. The proposed approach considers 1) uncertainty models of WTGS, PEV, and loads, 2) DSTATCOM functionality of WTGS, and 3) various system constraints. In [16], a dual-solver framework based on model predictive control is proposed, E-solver and L-solver. The economic scheduling problem is formulated using mixed-integer linear programming, which can be solved efficiently way by using a commercial solver.

Recent research has shown that smart charging of EVs could improve the synergy between photovoltaic, EVs, and electricity consumption, leading to both technical and economic advantages. Reference [17] presents a reputation-based framework for allocating power to plug-in EVs in the smart grid. In this framework, the available capacity of the distribution network measured by distribution-level phasor measurement units is divided in a proportionally fair manner among connected EVs, considering their demands and self-declared deadlines. In [18] main aspects of smart charging reviewed are objectives, configurations, algorithms, and mathematical models, and the commonly employed optimization techniques and rule-based algorithms for smart charging are reviewed.

With the growing concerns about energy depletion and the reduction of CO_2 emissions, EVs have gained popularity in the transport sector due to clean and reliable energy sources. Reference [19] aims to investigate the optimal EV coordination with the V2G technology for the cost-benefit analysis. Battery degradation cost is formulated for real-time analysis taking the depth of discharge at each time interval. The firefly algorithm has been used to optimize the system cost.

Proper accommodation of EVs poses significant challenges to distribution system planning and operations. In [20] two scheduling strategies are implemented considering active power dispatch and reactive power dispatch from the EVs. The objective of both strategies is to minimize losses in the system by utilizing the V_2G operation of the EVs. In [21], the authors investigate the achievement of energy management strategies in the EV system, which reduces fuel consumption and carbon dioxide emissions. The novelty of this article is an update on the most advanced technology in the field of V_2G and energy management strategy.

Many researchers try to optimize the charging and discharging pattern of EVs by using a centralized approach and considering a series of predetermined criteria.

Simultaneous consideration of the effects of distributed generation, especially of the renewable type and types of EVs, is another important issue in the studies of distribution networks. This point affects the future power systems of many countries. In this regard, some of the studies carried out are given below.

When both renewable energy sources generation and utilization occur simultaneously, energy storage costs can be reduced, and voltage oscillation and system instability caused by renewable energy sources grid connection can be reduced. Reference [22] constructs a microgrid model that includes EVs, defines the charge and discharge capacity of EVs, and uses the flexibility of EVs to overcome the intermittency and volatility of renewable energy sources.

Managing uncertainty is key to enhancing robustness in microgrids. In [23], the authors focus on the uncertainties in aggregated EVs and establish a two-layer model predictive control strategy for charging EVs with a microgrid. The main concern related to renewable-based distributed generators, especially photovoltaic and wind turbine generators, is the continuous variations in their output powers due to variations in solar irradiance and wind speed, which leads to uncertainties in the power system. Reference [24] proposes an efficient stochastic framework for the optimal planning of distribution systems with optimal inclusion of renewable-based distributed generators, considering the uncertainties of load demands and the output powers of the distributed generators.

The researchers in reference [25] stated that the simultaneous presence of all types of EVs as well as a large number of wind turbines with low capacity has created many technical challenges for distribution network operators to provide reliable energy and optimize energy distribution. Three different approaches for the simultaneous distribution of these small generation sources (wind turbines) and potential distributed reserves (EVs) are introduced. The electricity in a microgrid is such that this energy is provided in time intervals with low load. For this purpose, a condition has been added that it cannot be interrupted when the vehicle charging process starts. The results of applying this method to the sample network show give that this method with this stipulation cannot direct a load of vehicles in a direction that is most compatible with the generation power of wind turbines. In the second method used under the title of interruptible distribution, the same goal as the previous method is used. The vector is followed with the difference that it can be in this approach the process of charging vehicles intermittently in studies. The third method, called the spread method with different charging rates, like the previous two methods, tries to optimize the charging process of vehicles to have the most agreement with the generation graph of wind turbines, with the difference that it considers different charging rates for different vehicles.

Reference [26] describes a two-level planning model. In the proposed model, resource planning has been done at the two levels of aggregators and system operators. In the first stage, after the aggregators have received all the information related to vehicles and distributed renewable generation sources, they inform the operator of the amount of energy they need or their excess energy by performing calculations. In the second stage, the system operator plans energy generation and storage to reduce costs. The results of this research show that with the proper management of EVs, the electric load of the network does not increase sharply during peak hours, in other words, the use of the proposed planning model has flattened the network load curve.

Studies show that less research has been done on the simultaneous management of distributed generation resources and EVs as two completely independent and private entities, and on the other hand, the owners of distributed generation resources and EVs are looking for maximum profit, this factor can cause problems such as increasing losses, line congestion, increasing network strengthening costs, etc. in distribution networks. Therefore, in this article, by presenting a two-stage planning framework, EVs and dispersed generation resources with private ownership, whose goal is to maximize their respective profits, will be managed in such a way that in addition to their high satisfaction This important issue, i.e. reduction of operating costs, should be addressed by considering network limitations.

The innovative aspects of the article are described as follows:

- A two-stage planning framework for managing energy resources in a distribution network is presented to achieve an application and take into account the demands and needs of different agents.
- The optimization problem related to the planning of charging and discharging of EVs has been modeled from the point of view of their owners and considering their uncertainty.
- The optimization problem related to the planning of distributed generation resources has been modeled and solved, and its effect has been included in the planning problem of energy resources of the distribution network.
- The problem of optimizing the use of energy resources is linearized.

The article is organized in such a way that in the second part of the problem statement, the proposed planning framework and formulation of the problem are discussed. The case study is described in the third section and finally, the results are presented in the fourth section.

2. Materials and Methods

2.1. Statements of the problem

In this part, the modeling process of energy planning in the distribution network with the proposed method is described. First, the planning framework of the proposed model is described. Then the formulation of the problem is given along with the planning constraints.

Proposed energy planning framework

Due to the increase in the presence of EVs and distributed sources of generation in distribution networks, the need for a suitable control program to control the process of charging and discharging vehicles as a new load and sources of distributed generation as a source of energy generation is felt more and more [27, 28]. In the following, a two-stage algorithm is presented to achieve a comprehensive planning framework in which not only the technical constraints of the network are met, but also the privacy and convenience of EV owners, distributed generation resources, and other actors are considered. The proposed planning framework consists of two stages.

In the first stage, the coordinators of EVs and the owners of distributed generation resources try to maximize their profit during the planning period by implementing a separate optimization program, taking into account their demands and limitations. For this purpose, the owners of EVs provide the coordinators with information such as the time to arrive at the parking lot, the time to leave the parking lot, the initial charging status, and the final charging status, so that the optimal charging/discharging program for the vehicles can be obtained; And on the other hand, the owners of distributed generation resources try to maximize their profits by having information about distributed generation resources and electricity market prices. After the end of the first stage of the proposed planning, the optimal charging/discharging program related to the vehicles and the generation pattern of the units will be reported to the network operator.

In the second stage of the proposed energy planning, after receiving the optimal charge/discharge plan for vehicles and the plan for the generation of distributed generation sources, in each scenario, by purchasing energy from the market, the network operator tries to change the optimal generation plan of the distributed generation sources and change The optimal vehicle charging/discharging program will plan the energy of the available resources in such a way as to reduce the operating costs while providing the required load of the network. The resource usage pattern, EV charging/discharging schedule along with the power purchased from the grid are the primary outputs of this planning stage. Further, although these outputs are optimal from the point of view of vehicle owners and distributed generation resources, they do not provide any guarantee regarding the technical limitations of the network. Therefore, the network operator checks all the technical restrictions of the network after carrying out the load distribution calculations and if any of the restrictions are not met, he repeats the second stage of optimization by applying new restrictions. This work continues until all network constraints are met. Below is the formulation for each step.

2.2. Formulation of the problem

Formulation of the first stage of the proposed planning

In the first stage of the planning framework, coordinators and owners of distributed generation resources seek to maximize their profits by implementing optimization problems, below are the relationships related to each.

Formulation related to the coordinator of vehicles

The objective function related to maximizing the profit of vehicles is calculated from Equation (1).

$$f_{1,1} = max\left(\sum_{t=1}^{T}\left[\sum_{v=1}^{V}\begin{cases}P_{EV}^{Dcharge}(v,t)\times Pr_{EV}^{Dcharge}(t \\ -P_{EV}^{Charge}(v,t)\times Pr_{EV}^{Charge}(t\end{cases}\right.\right. \times \Delta t\Bigg) \quad (1)$$

The restrictions related to vehicles are as follows [26]:

In planning the charging and discharging of a vehicle, it should be noted that the vehicle should not be programmed in two charging and discharging modes at the same time.

$$X(v,t)+Y(v,t)\leq 1\ \forall t\in\{1,2,\dots,T\};\ \forall v\in\{1,2,\dots,V\}; X,Y\in\{0,1\} \quad (2)$$

The time continuity equation of vehicle charging and discharging during the planning period is given as the following relationship.

$$E_s(v,t)=E_s(v,t-1)+\eta_v^{Charge}\times P_{EV}^{Charge}(v,t)\times\Delta t-\frac{1}{\eta_v^{Dcharge}}\times\left(P_{EV}^{Dcharge}(v,t)\times\Delta t\right)\quad \forall t\in\{1,2,\dots,T\};\ \forall v\in\{1,2,\dots,V\} \quad (3)$$

The limit of chargeable power and battery discharge of each vehicle in each period are as follows:

$$P_{EV}^{Charge}(v,t)\leq P_{Charge,v}^{Max}\times X(v,t)\ \forall t\in\{1,2,\dots,T\};\ \forall v\in\{1,2,\dots,V\} \quad (4)$$

$$P_{EV}^{Dcharge}(v,t)\leq P_{Dcharge,v}^{Max}\times Y(v,t)\ \forall t\in\{1,2,\dots,T\};\ \forall v\in\{1,2,\dots,V\} \quad (5)$$

Discharging the battery of an EV up to a certain maximum value ψ_v^{Min} and charging it up to a certain maximum value ψ_v^{Max} will prevent the premature breakdown of the battery and increase its useful life [26].

$$E_s(v,t) \le \psi_v^{Max}\ \forall t \in \{1,2,\dots,T\};\ \forall v \in \{1,2,\dots,V\} \quad (6)$$

$$E_s(v,t) \ge \psi_v^{Min}\ \forall t \in \{1,2,\dots,T\};\ \forall v \in \{1,2,\dots,V\} \quad (7)$$

Where ψ_v^{Min} and ψ_v^{Max} are calculated as follows:

$$\psi_v^{Max} = \varphi_v^{Max} \times E_{BatCap,v}\ \ \forall v \in \{1,2,\dots,V\} \quad (8)$$

$$\psi_v^{Min} = \varphi_v^{Min} \times E_{BatCap,v}\ \ \forall v \in \{1,2,\dots,V\} \quad (9)$$

The limitation of charging and discharging the battery every hour is applied according to the amount of energy stored in the battery in the previous period and the maximum capacity of the battery [26]:

$$\frac{1}{\eta_v^{Dcharge}} \times \left(P_{EV}^{Dcharge}(v,t) \times \Delta t\right) \le E_s(v,t-1)\ \forall t \in \{1,2,\dots,T\};\ \forall v \in \{1,2,\dots,V\} \quad (10)$$

$$\eta_v^{Charge} \times P_{EV}^{Charge}(v,t) \times \Delta t \le \left(\psi_v^{Max} - E_s(v,t-1)\right)\ \forall t \in \{1,2,\dots,T\};\ \forall v \in \{1,2,\dots,V\} \quad (11)$$

The optimal amount of stored energy in the battery of each vehicle at the time of leaving the parking lot is given in the following equation:

$$SOC_{des}^{v} = SOC_{initial}^{v} + randnumber(0,[1 - SOC_{initial}^{v}])\forall v \in \{1,2,\dots,V\} \quad (12)$$

The limit of the number of times the status changes from charging to discharging and vice versa according to the life of the vehicle battery is given in the following equation [28]:

$$D^v \le NS^{MAX} \quad (13)$$

By performing linear programming with binary variables, the desired charge/discharge profile of vehicles is obtained as follows.

$$\mathrm{P}_{Des}^{Charge}(v) = \left[P_{EV}^{Charge}(v,t)\right]\ v \in [1-V], t \in \{1-T\} \quad (14)$$

$$\mathrm{P}_{Des}^{Dcharge}(v) = \left[P_{EV}^{Dcharge}(v,t)\right]\ v \in [1-V], t \in \{1-T\} \quad (15)$$

Formulation related to distributed non-renewable generation sources

Since non-renewable distributed generation resources are considered to be privately owned, the objective function related to them (maximizing profit) is in the form of Equation (16).

$$f_{1,2} = max\left(\sum_{t=1}^{T}\left[\sum_{j=1}^{J}\{P_{DG}(j,t) \times Pr_{MRT}(t) - C_{DG}(j,t)\}\right] \times \Delta t\right) \quad (16)$$

The restrictions related to distributed non-renewable generation sources are as follows:

The cost of non-renewable resources is modeled as a function of their output power. To use the optimization method of linear programming, the cost functions with a suitable approximation are considered as follows [28].

$$C_{DG}(j,t) = a_j + b_j \times P_{DG}(j,t)\ \forall t \in \{1,2,\dots,T\};\ \forall j \in \{1,2,\dots,J\} \quad (17)$$

Limits on the maximum and minimum generation capacity of distributed non-renewable generators are in the form of the following equations:

$$P_{DG}(j,t) \le P_{DG,j}^{Max} \times u(j,t)\ \forall t \in \{1,2,\dots,T\};\ \forall j \in \{1,2,\dots,J\} \quad (18)$$

$$P_{DG}(j,t) \ge P_{DG,j}^{Min} \times u(j,t)\ \forall t \in \{1,2,\dots,T\};\ \forall j \in \{1,2,\dots,J\} \quad (19)$$

The cost of setting up non-renewable distributed generation generators is calculated as follows [28]:

$$SU(j,t) = Sc_j \times (u(j,t) - u(j,t-1)) \quad (20)$$

$$SU(j,t) \ge 0 \quad (21)$$

The limit of the rate of increase and decrease of power related to non-renewable distributed generation sources is as follows:

$$(P_{DG}(j,t+1) - P_{DG}(j,t)) \le RUP_{DG}^{j} \quad (22)$$

$$(P_{DG}(j,t) - P_{DG}(j,t+1)) \le RDN_{DG}^{j} \quad (23)$$

By performing linear programming with binary variables, the optimal generation pattern of distributed generation resources is obtained as follows.

$$\mathrm{P}_{Des}^{DG}(j) = [P_{DG}(j,t)]\ j \in [1-J], t \in \{1-T\} \quad (24)$$

Formulation of the second stage of the proposed planning

In the second stage, the network operator, after receiving the information of the first stage (14, 15, and 16 equations) in each scenario, tries to change the optimal generation plan of distributed generation resources and also change the optimal charge/discharge profile of vehicles, by purchasing energy from the market, planning energy resources to do the existing in such a way as to guarantee the supply of EV owners and distributed generation resources, reduce the network's technical limitations and operating costs. To achieve these goals, the following optimization program is performed by the system operator for all scenarios:

$$f_2 = min\left(\sum_{t=1}^{T}\left[P_{NTW}(t)\times Pr_{MRT}(t) + P_{LOSS}(t)\times Pr_{LOSS}(t) + \left|\sum_{j=1}^{J}\{P_{DG}(j,t) - P_{Des}^{DG}(j,t)\}\right|\times K_{DG} + \left|\sum_{v=1}^{V}\{P_{EV}^{Charge}(v,t) - P_{Des}^{Charge}(v,t)\}\right|\times K_{Charge} + \left|\sum_{v=1}^{V}\{P_{EV}^{Dcharge}(v,t) - P_{Des}^{Dcharge}(v,t)\}\right|\times K_{Dcharge}\right]\times\Delta t\right) \quad (25)$$

As it is clear from Equation (25), the objective function of the optimization program at this stage includes four parts. The first part shows the cost of energy purchased from the market and the cost of losses. The cost paid to owners of distributed generation resources and EV owners Electric to participate in the proposed program is given in the second, third, and fourth parts.

2.3. Network restrictions

Adverb of power balance

The total power produced along with the power purchased from the flash market should be equal to the amount of consumption.

$$\mathrm{P}_{NTW}(t) + \sum_{w=1}^{W}P_w(t) + \sum_{pv=1}^{PV}P_{pv}(t) + \sum_{j=1}^{J}P_{DG}(j,t) + \sum_{v=1}^{V}P_{EV}^{Dcharge}(v,t) = \sum_{v=1}^{V}P_{EV}^{Charge}(v,t) + P_{LOAD}(v,t) + P_{LOSS}(t)\ \forall t \in \{1,2,\dots,T\} \quad (26)$$

Network technical restrictions

The technical limitations related to the network are given below [21]:

$$P_n(t) = \sum_{m=1}^{N}|V_n(t)||V_m(t)||Y_{n,m}(t)|\cos(\delta_m(t) - \delta_n(t) + \theta_{n,m})\ \forall n,t \quad (27)$$

$$Q_n(t) = -\sum_{m=1}^{N}|V_n(t)||V_m(t)||Y_{n,m}(t)|\sin(\delta_m(t) - \delta_n(t) + \theta_{n,m})\ \forall n,t \quad (28)$$

$$|S(n,m,t)| \le S_{n,m}^{max}\ \forall t \in \{1,2,\dots,T\};\ \forall n,m \in \{1,2,\dots,N\} \quad (29)$$

$$V_n^{min} \le V(n,t) \le V_n^{max}\ \forall t \in \{1,2,\dots,T\};\ \forall n \in \{1,2,\dots,N\} \quad (30)$$

$$P_{NTW}(t) \le P_{NTW}^{max}\ \forall t \in \{1,2,\dots,24\} \quad (31)$$

$$P_{TRANS}(n,t) \le P_{TRANS}^{max}\ \forall t \in \{1,2,\dots,T\};\ \forall n \in \{1,2,\dots,N\} \quad (32)$$

Restrictions related to EVs

Equations 2-13 are constraints related to EVs that should be considered in this phase of energy planning.

2.4. Restrictions related to distributed generation sources

Non-renewable resources

Equations 18-23 are constraints related to distributed non-renewable generation sources that must be considered in energy planning.

Renewable resources

Since the primary energy source of wind turbines and photovoltaic units is the wind and the sun, in the existing studies, probabilistic functions are used to model their output power, which will be described below.

Probability model of the photovoltaic system

In this study, the beta probability density function is used to model the power of the photovoltaic system [29].

$$f(I_r^t) = \begin{cases} \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)}\times I_r^{t(\alpha-1)}\times(1-I_r^t)^{\beta-1} \\ for\ 0\le I_r^t\le 1, \alpha\ge 0, \beta\ge 0 \\ 0 \qquad otherwise \end{cases} \quad (33)$$

According to the radiation intensity distribution predicted in each area and the radiation-to-power conversion function, the output power of the photovoltaic system can be calculated for each radiation intensity at any time [30].

$$P_{pv} = \eta^{pv}\times S_r^{pv}\times I_r^t(1-0.005\times(T_a - 25)) \quad (34)$$

Wind turbine probabilistic model

In this study, Rayleigh's probability density function is used to model wind speed behavior [31].

$$f(v_f^t) = \left(k/c\right)\times\left(v_f^t/c\right)^{(k-1)} e^{-\left(v_f^t/c\right)^k}\ 0 \le v_f^t \le \infty \quad (35)$$

Also, the output power of the wind turbine at any moment can be calculated using the power conversion function given in the following relationship [32].

$$P_w = \begin{cases} 0 & 0 \le v_f^t \le v_{ci} \\ \mathrm{P}_{rated} \times \dfrac{(v_f^t - v_{ci})}{(v_r - v_{ci})} & v_{ci} \le v_f^t \le v_r \\ \mathrm{P}_{rated} & v_r \le v_f^t \le v_{co} \\ 0 & v_{co} \le v_f^t \end{cases} \quad (36)$$

Figure 1 shows the flowchart of the proposed energy planning. As it is clear, the coordinators and owners of distributed generation resources have obtained the charging/discharging profile of vehicles and the generation pattern of distributed generation resources by implementing the optimization program. Then, for all scenarios, the operator should implement non-linear programming with binary variables (equation 25) of the output power corresponding to each of the distributed generation sources, the power purchased from the network, and the charging correction strategy to determine the discharge related to the number of vehicles. Since the second stage of optimization has non-linear terms (the absolute value terms in equation 25), there is no guarantee to extract the absolute optimal solution. Therefore, at first, these relations are sub-linearized [33].

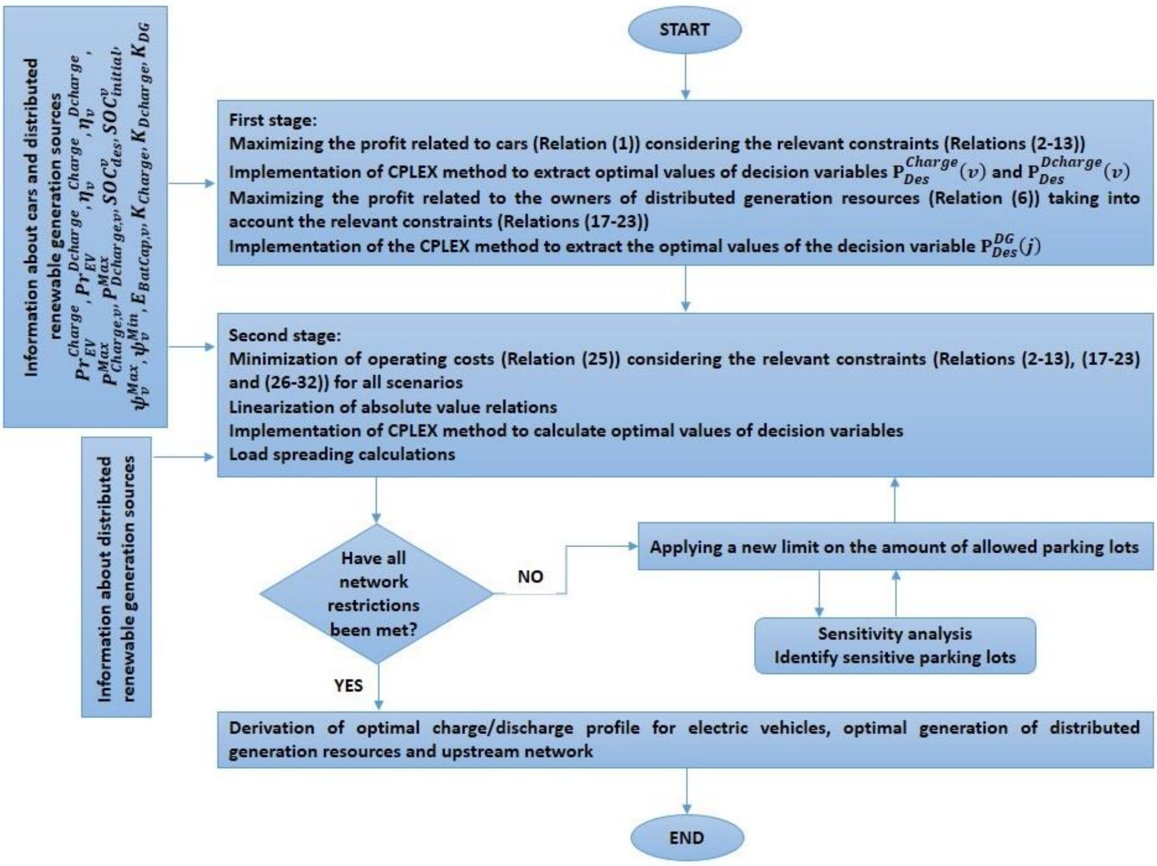


Figure 1. Proposed energy planning flowchart.

Assuming that two variables ε and γ are positive:

$$minimize|f(x)| \rightarrow minimize\ \gamma + \varepsilon$$
$$f(x) = \gamma - \varepsilon$$
$$\gamma, \varepsilon \ge 0$$

Finally, the network operator checks the technical limitations of the network in Equations (29-32) by implementing the load distribution. If any of the restrictions are not met, the second stage of planning is repeated by applying restrictions on the amount of load related to sensitive parking lots (sensitive tires) until the restrictions are fully met. It should be noted that sensitivity analysis was used to determine the sensitive parking lots, that is, for each period, for each parking lot, the load of the parking lot increased by 10%, and the changes related to the voltage of the parking lots were saved. After applying this algorithm, sensitive parking lots are identified each period.

2.5. Case studies

Introduction of the studied system

The proposed planning framework has been tested on a distribution network connected to bus 5 of the

RBTS sample network, which has 4 feeders at a voltage of 20 kV [34]. For this network, the data related to the type and number of subscribers connected to different load points, the average load of each of them are presented in table 1. This network along with the division of the areas related to the coordinators is shown in Figure 2. The voltage limit of the bus bars is considered equal to 0.9-1.05 per unit.

Table 1. The type and average amount of load and the number of subscribers of different load points in the distribution network under study.

Number of subscribers	Average load (MW)	Subscriber type	Load points
180	0.4569	Residential	1-2-20-21
2	0.6646	Official	3-5-8-17-23
250	0.4771	Residential	4-6-15-25
2	0.4089	Commercial	7-14-18-22-24
210	0.2513	Residential	9-10-11-13-26
2	0.4086	Official	12-16-19

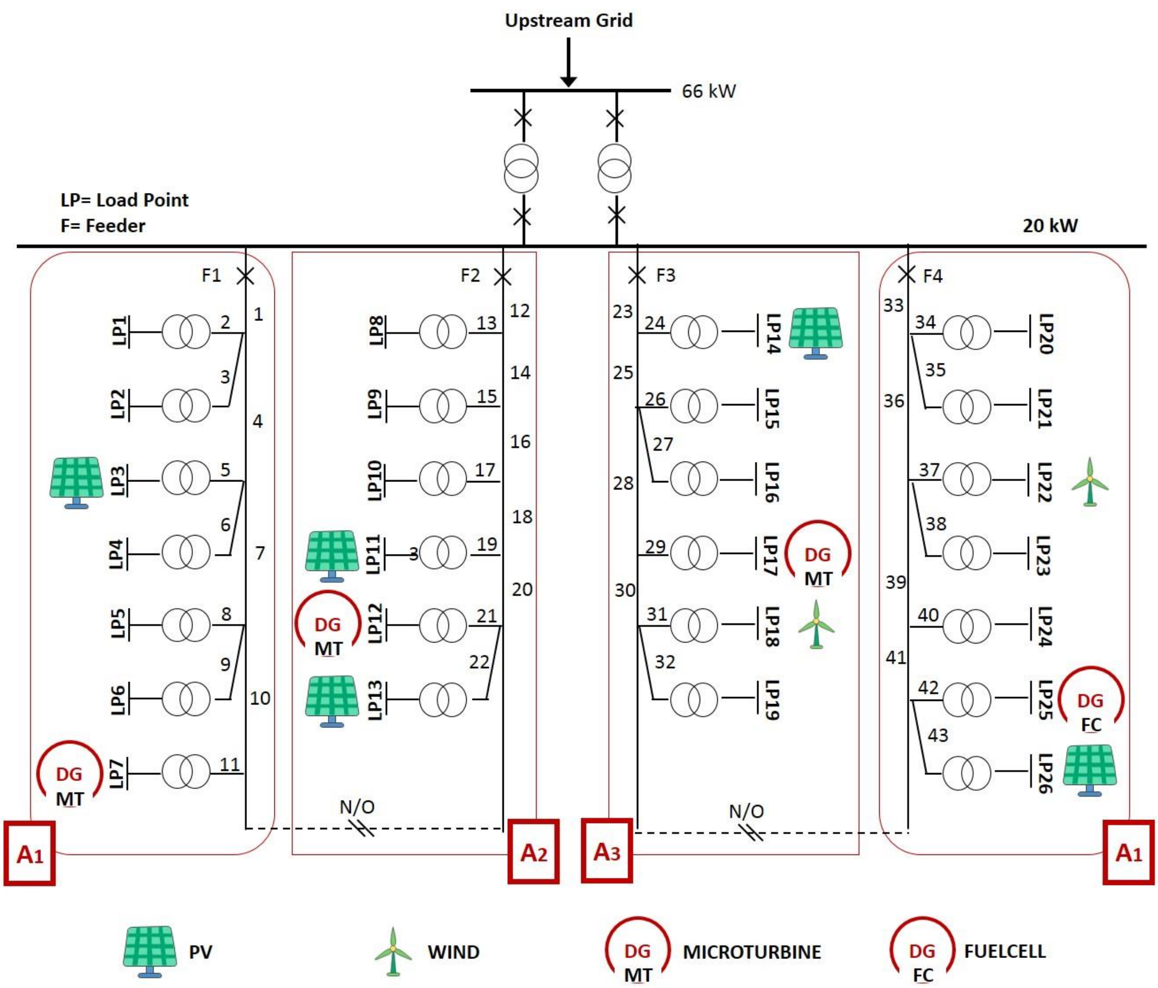


Figure 2. One-line diagram of the distribution network connected to bus 5 of the RBTS sample network.

The hourly price of the electricity market is given in table 2 [35]. The capacity of medium-pressure and low-pressure transformers of the network is considered to be MVA 1 and MVA 15 respectively. In this network, there are four coordinators named A1, A2, A3, and A4 are considered. The predicted hourly load of each of the coordinators in the 24-hour planning period is shown in Figure 3.

Table 2. Hourly electricity market price.

Hour	Price ($/kWh)	Hour	Price ($/kWh)
1	0.033	13	0.215
2	0.027	14	0.572
3	0.02	15	0.286
4	0.017	16	0.279
5	0.017	17	0.086
6	0.029	18	0.059
7	0.033	19	0.05
8	0.054	20	0.061
9	0.215	21	0.181
10	0.572	22	0.077
11	0.572	23	0.043
12	0.572	24	0.037

Also, three microturbine units and one fuel cell unit have been installed in this network. The specifications of the cost functions of each of the units are given in table 3. The maximum rate of increase and decrease of power related to each of the units in each period is equal to 20% of their maximum capacity.

Table 3. Characteristics of distributed non-renewable generation units.

Gen type	a ($)	b ($/kW)	P_{DG}^{Min} (kW)	P_{DG}^{Max} (kW)
MT	20	0.2	50	350
MT	40	0.3	50	250
MT	20	0.2	50	350
FC	90	0.35	50	250

The pattern of using vehicles has been obtained according to a statistical study in the city of Tehran. The obtained information includes the entry and exit times of the vehicles, the amount of initial energy when entering the parking lots, and other information related to the vehicles. A summary of information on the behavior pattern of vehicle owners in using their vehicles is given in Table 4.

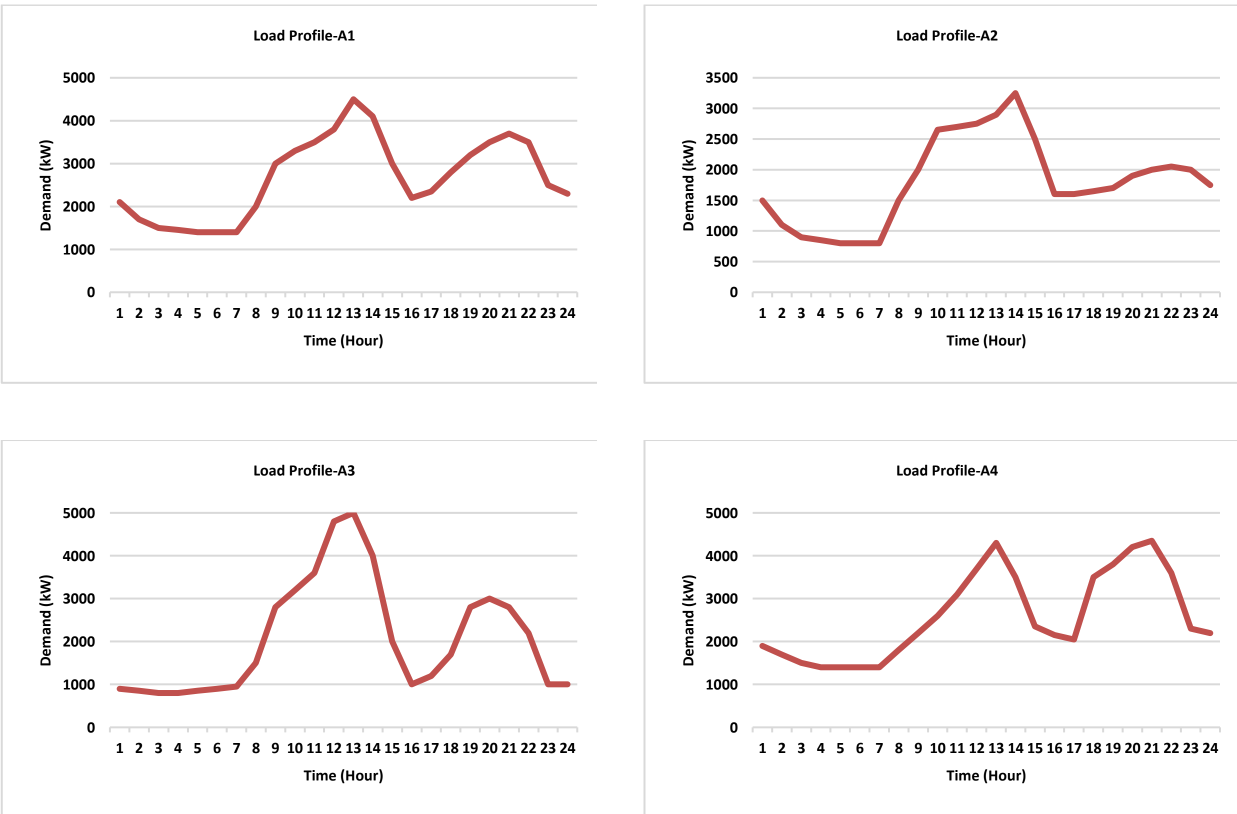


Figure 3. Hourly load demand of coordinators.

Table 4. Statistical information on EVs.

Type	Arrival time (H)	Departure time (H)	
Residential	Norm (19, 5)	Norm (7, 2)	I [0.1, 0.5]
Official	Norm (7, 1)	Norm (15, 1)	I [0.5, 0.8]
Commercial	Norm (9, 2)	Norm (20, 2)	I [0.3, 0.6]

To calculate the total number of vehicles, the first step is to know the number of residential subscribers covered by the network. In this regard, the information presented in table 1 was used and finally, for 35% penetration, the total number of vehicles in the network was estimated to be 4004 vehicles. To conduct studies, in addition to the number of vehicles, their class is also according to [36] considered.

Battery capacity is one of the important features of vehicles. According to [36], the range of battery capacity in each class is considered in Table 5. It should be noted that a uniform distribution has been used to distribute the capacity of batteries in each class.

Table 5. Battery capacity range for each class.

Class	Minimum capacity (kWh)	Maximum capacity (kWh)
1	8	12
2	10	14
3	17	21
4	19	24

The maximum charging and discharging rate of vehicles is 4 kWh and the weighted coefficients of charging and discharging are equal to 60% of the market peak price. Usually, some energy is lost in the process of charging and discharging vehicle batteries, therefore, the efficiency coefficient of charging and discharging vehicles is considered to be 90% and 95% [26]. Also, to prevent premature aging of vehicle batteries, battery discharge is allowed up to 85%, and the number of switching times allowed is considered according to table 6. It should be noted for the vehicles under study; their battery life is randomly selected.

Table 6. The number of times allowed to replace vehicle batteries according to their lifespan.

AOB<4	4<=AOB<6	6<=AOB<8	8<=AOB	Battery life
8	6	4	2	NS^{Max}

In this study, it is assumed that all the wind turbines installed in the network are of the same model and their specifications are according to table 7 [28].

Table 7. Information about wind turbines.

Vco (m/s)	Vr (m/s)	Vci (m/s)	Prated (kW)
30	12	3	500

Also, photovoltaic systems with a power of 100 kW (10 panels of 10 kW) have been installed at the network level, whose specifications are given in Table 8 [26]. In all studies, it is assumed that the photovoltaic system and wind turbines are operated at the unit power factor.

Table 8. Photovoltaic system information.

η (%)	S(m^2)	Ta (ºC)
18.6	10	25

To generate scenarios for each planning interval, the distribution function of wind speed and solar radiation is divided into five intervals, so that these functions are converted from continuous to discrete. To reduce the execution time and the complexity of the program, the number of scenarios was first reduced with the help of the backward scenario reduction technique [37] and then the wind and solar power scenarios were combined to obtain the final scenarios. In this study, the number of final scenarios is 10.

Simulation process

The proposed programming method is coded in OpenDSS, GAMS, and MATLAB software. The first and second stages of this planning are linearly implemented and the CPLEX calculation method is used to solve the problem.

3. Results and Discussion

The results of the planning done in both stages of the proposed planning are shown in Figures 4 and 5. The results show that the charging of most of the vehicles took place during the low load hours of the network (1-7 in the morning) because, during these hours, the price of the electricity market is low. Also, the discharge of vehicles during peak hours of the network has reduced the peak load of the network and met the technical limitations of the network. It should be noted that according to figures 4 and 5, the highest cost paid to vehicles in the direction of participation was during peak hours. Figure 6 shows the planned power of distributed non-renewable generation resources for two stages of the proposed algorithm.

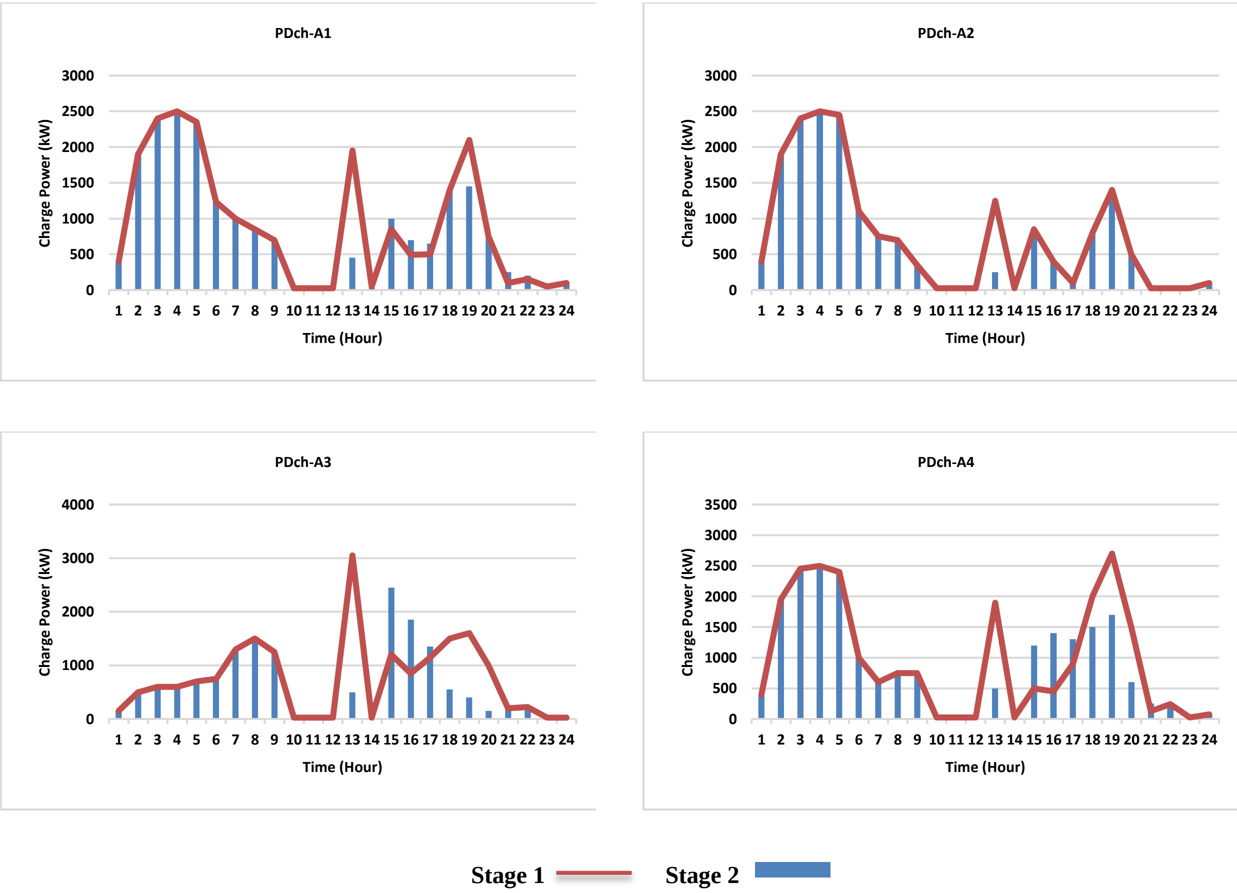
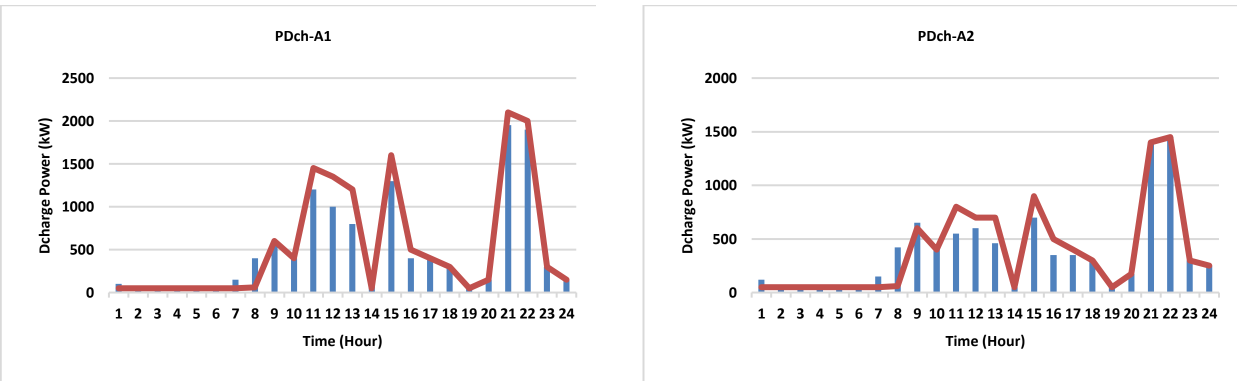


Figure 4: Charging profile of EVs in different areas after applying the proposed two-stage algorithm



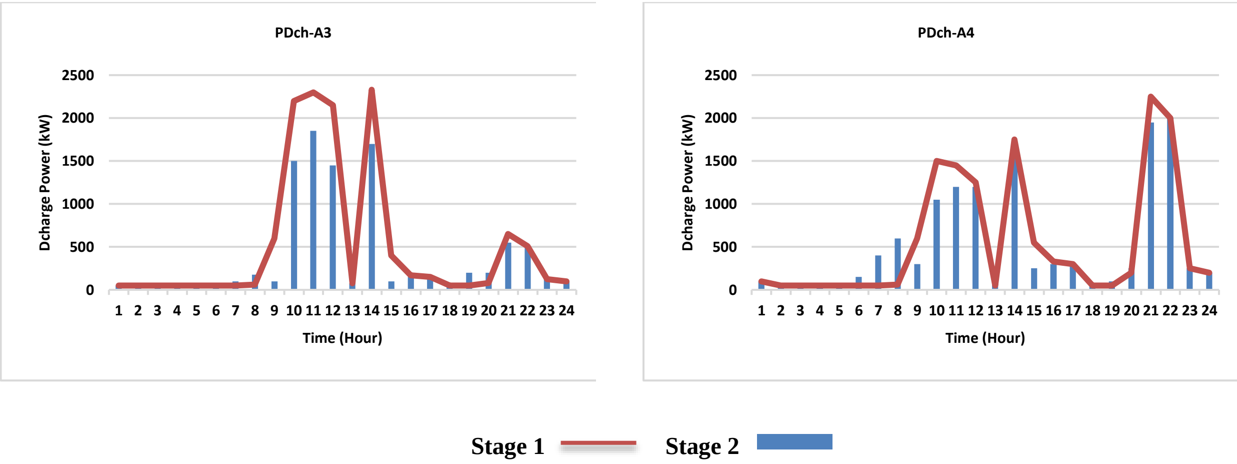


Figure 5. Discharge profile of EVs in different areas after applying the proposed two-stage algorithm.

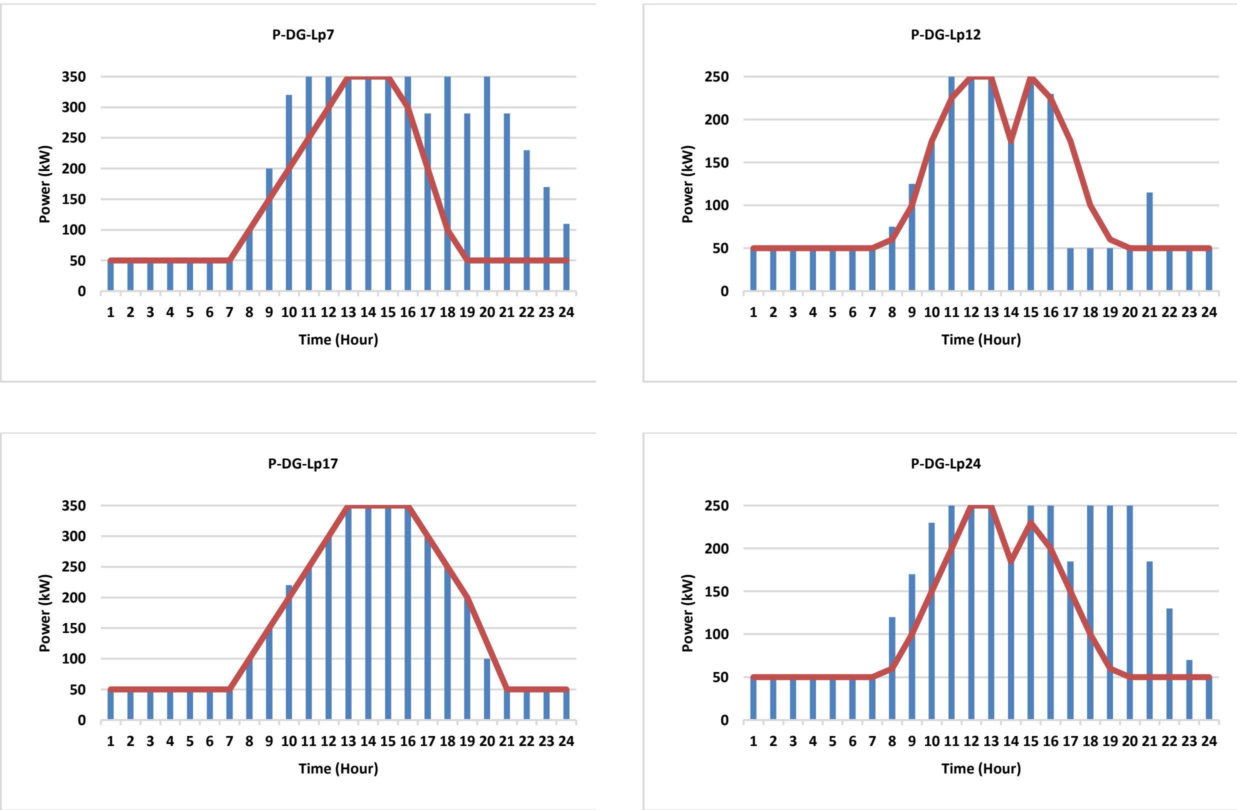


Figure 6. The generation capacity of each non-renewable distributed generation source (first stage-second stage).

(The dashed line curve represents the first stage of the proposed algorithm and the load curve corresponds to the second stage of the proposed algorithm). As it is known, non-renewable resources produce their maximum power during the peak hours of the network due to the high price of the energy market and in Low load hours due to the low price of the electricity market, the minimum power is produced and the available load is supplied by the upstream network.

Figure 7 shows the network load profile for three different network operation situations. As it is clear, the presence of EVs as a new load has changed the shape of the network load profile (gray color curve - vehicles cause an increase of about 6 megawatts have become the peak load of the network. The application of the proposed planning framework has caused the electric load of the network to not increase much during peak hours (dashed line curve). The load has increased, which has made the network load profile curve more uniform.

Further, to check the efficiency of the proposed algorithm, studies have been carried out for cases where vehicles and distributed generation sources do not participate in the proposed plan. According

to the obtained results, it was found that the existing network is not sufficient to provide the load required by the vehicles (the peak load of the network has increased by almost 7 megawatts) and there is a need to strengthen the network.
Therefore, for comparison, the costs related to one year of implementation of the proposed plan were compared with the costs related to the network strengthening plan.
The network strengthening plan has been carried out in such a way that the studies related to the network strengthening plan with 35% penetration of vehicles for a 20-year horizon were carried out and the related costs were obtained. Finally, for comparison, the costs of strengthening the network were obtained by considering the interest rate of 10% for one year of equalization. Table 9 shows the costs obtained after the implementation of the two plans, as it is clear that the increase in the costs of strengthening the network is more than 5 times the increase in the costs of implementing the proposed plan.

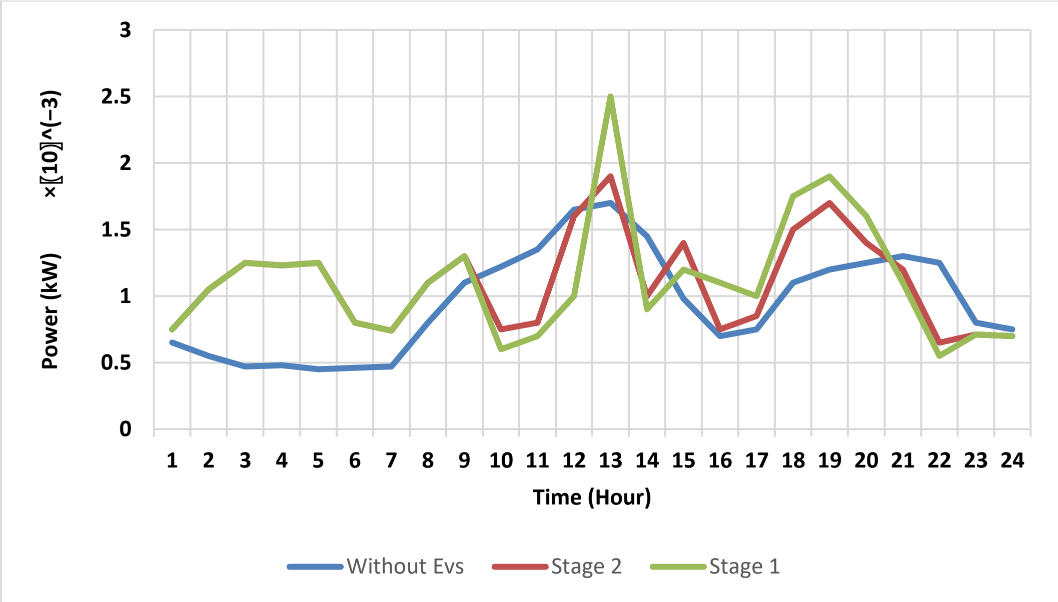


Figure 7. Network load profiles for three different operating states.

Table 9. Increase in costs.

Plan	Increase in the annual cost of implementing the proposed plan ($)
Proposed plan	1601941
Network strengthening plan	9058207

4. Conclusions

In this article, a two-stage planning framework for the optimal management of EVs and dispersed generation resources with private ownership was analyzed in a centralized manner. The basic approach in this article was the optimal charging/discharging planning of EVs along with distributed generation sources to reduce operating costs by considering the wishes of vehicle owners and distributed generation sources. To implement the proposed algorithm, at first EVs were modeled probabilistically and the uncertainty related to distributed renewable generation sources was considered, then the CPLEX optimization method was used for different scenarios to solve the problem. Finally, as the results show, the use of the proposed planning model, in addition to the high satisfaction of EVs and distributed generation resources, can on the one hand minimize the operating costs and on the other hand reduce and postpone the network strengthening costs.

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Data Availability Statement: All data used to support the findings of this study are included within the article.

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

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List of symptoms:

Binary Variables	
Electric vehicle charging and discharging status v at t hour	$X(v,t)/Y(v,t)$
Generator on or off status j at t hour	$U(j,t)$
Continuous variables	
Electric vehicle discharge power v at t hour	$P_{EV}^{Dcharge}(v,t)$
Electric vehicle charging power v at t hour	$P_{EV}^{Charge}(v,t)$
Electric vehicle energy v at t hour	$E_S(v,t)$
Optimal charge profile for V electric vehicle	$P_{Des}^{Charge}(v)$
Optimal discharge profile for V electric vehicle	$P_{Des}^{Dcharge}(v)$
The number of switching states from charging to discharging or vice versa for a V electric vehicle	D^v
Power purchased from the main grid per t hour	$P_{NTW}(t)$
Wind turbine power per t hour	$P_w(t)$
Power of the photovoltaic system per t hour and s scenario	$P_{pv}(t)$
The output power of distributed generation source j at t hour	$P_{DG}(j,t)$
Active power loss per t hour	$P_{LOSS}(t)$
Radiation intensity per t hour	I_r^r
Network load per t hour	$P_{LOAD}(t)$
Electricity market price per t hour	$Pr_{MRT}(t)$
Price of electric vehicle charging per t hour	$Pr_{EV}^{Charge}(t)$
Price of electric vehicle discharge per t hour	$Pr_{EV}^{Dcharge}(t)$
Price of power loss per t hour	$Pr_{LOSS}(t)$
Active power injected into the bus n per t hour	$P_n(t)$
Reactive power injected into the bus n per t hour	$Q_n(t)$
The power transferring through the transformer n per t hour	$P_{TRANS}(n,t)$
Wind turbine speed per t hour	V_f^t
Objective function related to the profit of electric vehicles	$f_{1,1}$
Objective function related to the profit of distributed production resources	$f_{1,2}$
The objective function of operating costs	f_2
Voltage angle in the bus n per hour t	$\delta_n(t)$
The size of the array (m, n) in the network admittance matrix	$\lvert\gamma_{n,m}\rvert$
The angle of the array (m, n) in the network admittance matrix	$\theta_{n,m}$
Parameters	
Wind turbine rated power	P_{rated}
Wind turbine rated speed	V_r
Low cutoff speed of wind turbine	V_{ci}
High cutoff speed of wind turbine	V_{co}
Efficiency coefficient of a photovoltaic system	η^{PV}
The entire surface of the photovoltaic system	S^{PV}
Ambient temperature	T_a
Efficiency coefficient of electric V vehicle charging	η_v^{Charge}
Efficiency coefficient of electric V vehicle discharge	$\eta_v^{Dcharge}$
Maximum dischargeable power of the V electric vehicle	$P_{Dcharge,v}^{Max}$
Maximum chargeable power of the V electric vehicle	$P_{Charge,v}^{Max}$
The optimal charging level of the V electric vehicle	SOC_{des}^v
The initial charge level of the V electric vehicle's	$SOC_{initial}^v$
Maximum limit of the battery capacity of the electric vehicle	ψ_v^{Max}
Minimum limit of the battery capacity of the electric vehicle	ψ_v^{Min}

Maximum usable percentage of the V electric vehicle's battery capacity	φ_v^{Max}
Minimum usable percentage of the V electric vehicle's battery capacity	φ_v^{Min}
The battery capacity of V electric vehicle	$E_{BatCap,v}$
The weighting factor related to electric vehicle charging	K_{charge}
The weighting factor related to the discharge of electric vehicles	$K_{Dcharge}$
Maximum number of switching states from charge state to discharging or vice versa for any electric vehicle	NS^{Max}
Maximum allowed power that can be received from the upstream network	P_{NTW}^{Max}
Maximum capacity of the transformer	P_{TRANS}^{Max}
The apparent power flowing from the bus n to m per hour t	$S(n,m,t)$
Maximum lines capacity	$S_{n,m}^{Max}$
The voltage on the bus n	$V(n,t)$
Minimum and maximum voltage allowed on the bus n	V_n^{Min}/V_n^{Max}
The maximum output power of the distributed generation source j	$P_{DG,j}^{Max}$
The minimum output power of distributed generation source j	$P_{DG,j}^{Min}$
The cost of setting up a distributed generation resource j	Sc_j
Coefficients of the cost function of the distributed production source j	$a(j),b(j)$
Power increase rate of distributed generation source j	RUP_{DG}^{j}
The power reduction rate of distributed generation source j	RDN_{DG}^{j}
Shape factor	α, K
Scale factor	β, c
The length of the time interval	Δt
Collections	
The index corresponding to the source number of distributed generation	j
Index related to the number of network buses	n, m
Index related to optimization time intervals	t
The index corresponding to the scenario number	s
Index related to the number of electric vehicles	v