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A Method for Assessing the Feasibility of Integrating Planned Unidirectional EV Chargers into the Distribution Grid: A Case Study in Danang, Vietnam

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Abstract: The journey towards transportation electrification started with electric vehicles and has attracted more and more attention on a global scale in recent years. EVs are seen as a substantial, effective, and urgent solution for transportation electrification. In this paper, we investigate the operation requirements for integrating charger stations into the distribution grid in Vietnam. We also propose a simple evaluation method for assessing the feasibility of integrating planned unidirectional EV chargers into the distribution grid. The assessment method is applied to two main distribution feeders in Danang, Vietnam, where the new charger stations are already planned to be deployed in 2025 and 2030. The results showed that with addition of pre-planned EV chargers, both feeders still meet operation requirements in 2025 and 2030. However, the feeder with voltage indices close to the limit needs to be considered for an upgrade in configuration.

Keywords: electric vehicles; unidirectional charger; distribution grid; fast chargers

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1. Introduction

Electric vehicles offer numerous benefits in terms of energy efficiency, fuel cost savings, operation, and maintenance. They also confirm their critical role in transportation electrification, such as lowering greenhouse gas emissions, air pollution, and noise, reducing reliance on fossil fuels, encouraging industrial development, and expanding the usage of renewable energy. Therefore, EVs are considered a significant, effective, and urgent solution in the electrification of the transportation sector, which has been the main source of environmental pollution for the last few years [1–3]. According to global statistics, the number of electric vehicles sold in 2020 was 3.2 million, accounting for 5% of all vehicle sales. This number is expected to rise to 20% in the following four years, 40% by 2030, and 85% by 2035 [4]. The numbers of global EV in stock by year from 2010 to 2021 are shown in Figure 1.

With the growing popularity of electric vehicles, the development of public charging station networks has emerged as a key priority. The expansion of charging stations will particularly have an impact on the performance and quality of the electricity network. There is a possibility that a significant number of charging stations connected to the distribution grid would interfere with the reliable operation of the power system and overload the local power grid. When energizing the charging stations, which add new loads to the distribution grid, the added load will fluctuate the voltage and change the power flow of the system as well. As a result, it is important to investigate and assess the feasibility of integrating charger stations in the distribution system.

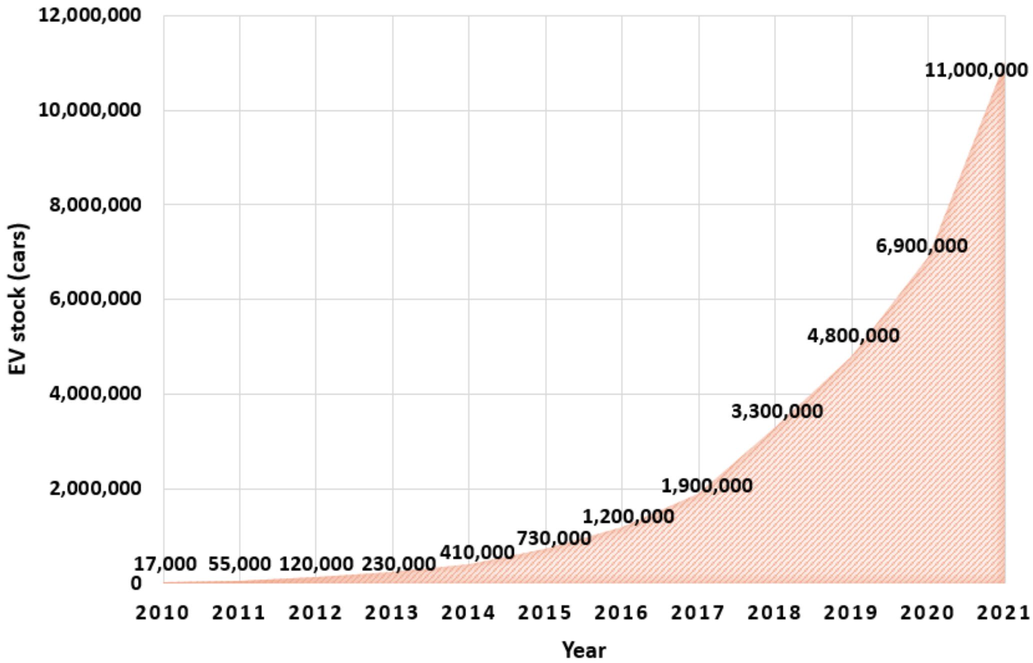


Figure 1. Global electric car stock from 2010 to 2021 [5].

Different articles have mentioned and investigated the effects of integrating charging stations into the distribution grid. Figure 2 listed the possible impacted parameters [6–8].

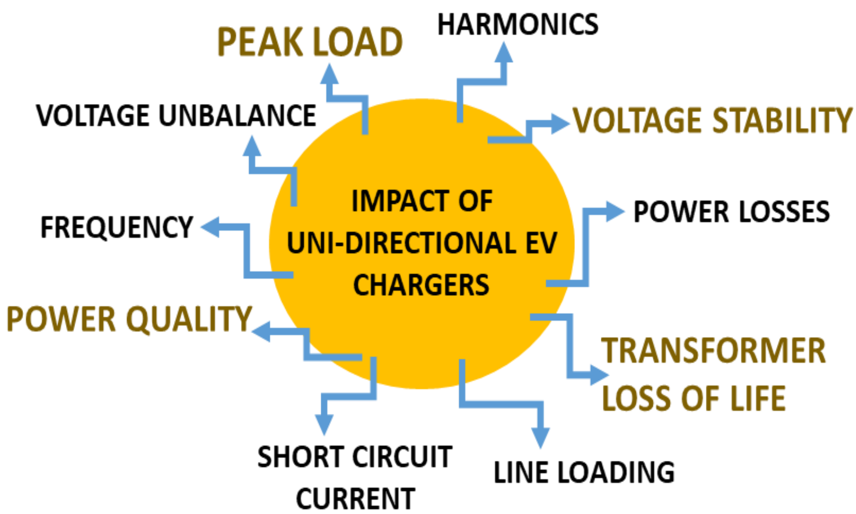


Figure 2. Possible parameters affected by the integration of the chargers into the distribution grid.

Four main factors can be affected by integrating EV charging stations on the distribution grid: peak load, voltage stability, power stability, and transformer life.

- Peak load: Although the power demand will not significantly increase as a result of integrating EV chargers into the distribution grid, the load curve will probably change. As people charge their EVs when they get home from work, the evening peak loads will most noticeably rise. The peak loads will significantly increase around these residential hotspots and other EV charging concentration points, such as public EV fast-charging stations and commercial vehicle depots. According to the analysis, the local peak load in an area with a 25% EV penetration would rise by about 30% [9].
- Voltage stability: The installation of EV chargers will result in a significant increase in a system's load curve; the higher peak time demand may have an undesirable influence on the network's voltage stability [10,11]. This component of distribution networks

is crucial to their safety. As a result, this component must be considered during the planning stage to avoid any unexpected faults.

- Power quality: The charging stations have a great impact on the utility grid due to the presence of the power electronic converters in it. EV chargers, which have nonlinear loads, will cause high harmonics, poor voltage profiles, and a reduction in the overall network power quality [12,13].
- Transformer life: The load demand grows as more charging stations are connected to the distribution transformer's secondary side. The increase of the peak load at the transformers will lead to the transformer being overloaded during peak hours [14,15]. In this case, the electric utilities should have a plan to replace or upgrade the transformers accordingly.

The EV's effects on the distribution network through the variety of steady-state and dynamic modeling results at different levels of EV's load demands are demonstrated in [16,17]. The papers also assess the impacts of EV penetration on selected buses of a distribution network, taking into account driving profiles, type of vehicle, travelling distance, and road conditions. In [18–20], analyses of voltage unbalance impact of EVs charging on a LV distribution system are presented in different scenarios. Paper [21,22] proposed a method to determine the EV hosting capacity on the distribution grid based on the only voltage criteria. However, using voltage criteria alone is not enough to decide whether it is safe to integrate new EV chargers into the grid. It is necessary to consider additional criteria before determining the number of EVs that can be connected to the distribution grid. Paper [23] offers a list of power grid operation parameters including system losses, voltage fluctuation, and load-peak valley that could be impacted by the EV charging network. The power quality issues under EV charge integrating scenarios were demonstrated in the paper [24–26]. The results showed that the EV chargers' load has a major impact on the distribution grid. In [27,28], the integrating standards for EV chargers to the distribution grid are mentioned, but, as with the other references, there is no clear instruction to assess the ability to integrate them into the distribution grid. However, these effects are evaluated individually, making it difficult for distribution grid operators to have a comprehensive view of how large the effects are for the entire distribution grid. The lack of a holistic view can make it challenging for grid operators to evaluate the cumulative effects of charging stations on the grid and make informed decisions on how to design and operate the grid effectively.

Normally, charging station placements are predetermined in electricity master planning based on location assessment and usage demands of each area. To make an accurate assessment of whether or not to integrate charging stations into the distribution grid, a more holistic approach is required. In this paper, a simple method to evaluate the feasibility of integrating electric vehicle chargers into the distribution network is presented. Along with technical requirements being introduced, Danang's distribution grid is evaluated in different simulation scenarios for comprehensive analysis. The results are discussed, and recommendations are made to minimize the negative impacts as well as maximize the positive impacts of electric vehicles on the distribution grid. If the power grid is incapable of accommodating the integration charging stations, it is essential to develop a better integration strategy. The main contributions of the paper are

- Investigate grid operation requirements to integrate planned EV chargers into the distribution grid in Vietnam.
- Propose a two-level evaluation method for assessing the feasibility of integrating the planned EV chargers into the distribution network.
- Evaluate the feasibility of integrating EV chargers into Danang's distribution grid based on the number of planned EV chargers in the area.

The remaining parts are organized as follows: Section 2 presents the data requirements provided to the model. Section 3 explains the proposed approach implementing the power flow and voltage stability analysis. Section 4 shows the simulation results and makes a discussion to point out the necessary solutions. The conclusions and future work are summarized in Section 5.

2. EV Charger Specifications and Operation Standards for Distribution Grid in Vietnam

2.1. EV Charger Specifications

The deployment of charging stations has increased in tandem with the rapid development of the electric vehicle market. Charger stations with varying charging powers and speeds are being explored and produced in response to various charging demands. There are three main EV charger levels: charger level 1, charger level 2, and charger level 3 [29].

- Charger level 1: These chargers are usually installed in residential areas. Level 1 chargers operate at 120 V (AC) and have a current rating of 15 A or 20 A. This type of charger takes between 8 and 16 h to fully charge an electric vehicle with a battery capacity of 20 kWh. The advantages of the chargers are that they are less expensive and require no additional charging equipment.
- Charger level 2: They are usually located in residential and commercial areas. Level 2 chargers require a voltage source of 240 V (AC) with rated current up to 40 A in residential areas. Public charging stations require 400 V three-phase AC with up to 80 A current handling capacity. Level 2 chargers need about 4 to 8 h to fully charge a 20 kWh electric vehicle battery. This charging station has a rated capacity from 5.2 to 25.6 kW.
- Charger level 3—Direct current fast charger: This type of charger, which is the most efficient and fastest type of electric vehicle charging, is commonly located in commercial and public areas. This charging station can charge up to 80% of the battery capacity in only 10–15 min. Level 3 chargers require a three-phase 480 V or greater circuit.

The common specifications of three charger levels are presented in Table 1.

Table 1. Three charger levels for charging Electric vehicles.

Parameters	Level 1	Level 2	Level 3
Voltage	120/230 Vac	208/430 Vac	308–600 Vac
Current	12–16 A	15–80 A	400 A
Power rate	<3 kW	<25.6 kW	>50 kW
Charging duration	17 h	8 h	<30 min
Phase	1 Phase	1 Phase/3 Phase	3 Phase
Charger speed	Slow	Fast	Rapid
Typical locations	Home	Home, workplace and public	Public

2.2. Distribution Grid Operation Requirements for Integrating New EV Charger Load in Vietnam

EV chargers can have negative effects on the power grid, especially if the penetration is high. The negative effects include overloading transmission lines, phase unbalance, voltage drop, etc. Depending on the size and location of the chargers, the effects may differ. To reduce negative impacts, grid-connected chargers need to comply with regulations on operating requirements for distribution grid systems. However, Vietnam has not issued any formal requirements for integrating EV chargers into the distribution grid. As a result, investors are still hesitant to invest in building a charging station system, and the approval process for integration is slowing [30]. In this section, the authors will introduce the most important requirements which are required while integrating charging stations into the distribution grid using the requirements of operation of the electrical distribution system in the Vietnam's Circular No. 39/2015/TT-BCT, stipulating the electrical distribution system [31]; and the Circular No. 30/2019/TT-BCT amendments and supplements to several articles of circular No. 25/2016/TT-BCT and circular No. 39/2015/TT-BCT on the electricity distribution system [32].

It should be noted that the nominal frequency in Vietnam is 50 Hz. The electrical distribution system's normal voltage (V) levels are 110 kV, 35 kV, 22 kV, 15 kV, 10 kV, 6 kV, and 0.4 kV and the normal low voltage levels are 308 V and 220 V. There are two levels of the requirements that can be classified below: high-level integration requirements and low-level integration requirements.

- ***High-level integration requirements***

The high-level requirements include power frequency, voltage supply, and power losses. These requirements are put in place to ensure that the distribution grid can operate safely and stably.

- **Power frequency**

The nominal frequency of Vietnam's national power system is 50 Hz. The requirements of the operation frequency (f) are

+ In the normal operation mode 49.8 Hz $\leq$ f $\leq$ 50.2 Hz;
+ In the unstable operation mode: 49.5 Hz $\leq$ f $\leq$ 50.5 Hz

- **Voltage supply**

The electrical distribution system's nominal voltage (V) levels are 35 kV, 22 kV, 15 kV, 10 kV, 6 kV, and 0.4 kV. The allowances for working voltage deviation from normal voltage (ΔV) at the connection point are as follows:

+ In the normal operation mode:
  ▪ At the customer's connection point: V − 5% $\leq \Delta$V $\leq$ V + 5%;
  ▪ At the power plant's connection point: V − 5% $\leq \Delta$V $\leq$ V + 10%;
+ In the single fault or post-fault service restoration mode:

$$\mathrm{V} - 10\% \leq \Delta\mathrm{V} \leq \mathrm{V} + 5\%$$

+ In the serious fault mode of the electrical transmission system:

$$\mathrm{V} - 10\% \leq \Delta\mathrm{V} \leq \mathrm{V} + 10\%$$

- **Power losses**

Power losses on the distribution grid include power loss caused by the physical characteristics of the distribution grid's electrical equipment and power loss caused by the effects of power business management factors. The power losses require a smaller proportion of 10% of the feeder's total distributed power.

- ***Low-level integration requirements***

The low-level requirements include voltage unbalance, flicker severity, harmonics, short circuit, and incident elimination time. These requirements are put in place to ensure that the low voltage grid can operate stably and reliably.

- **Voltage unbalance**

In the normal operational mode, the negative sequence component of the phase voltage is required to be smaller than 5% of the normal voltage.

- **Harmonics**

The harmonic distortion can be computed by dividing the RMS value of all harmonics by the RMS value of the fundamental component (by%), as stated in the following formula:

$$\mathrm{THD} = \frac{\sqrt{\sum_{i=2}^{N} V_i^2}}{V_1} * 100\%$$

where: THD: Total harmonic distortion; V_i: RMS value of the harmonics at level i; and N refers to the highest level of the harmonics in question. V_1: RMS value of the voltage at the fundamental level (frequency of 50 Hz).

The THD at all connection points for medium and low voltage should not exceed 6.5%, and the individual distortions should not exceed 3.0%.

- **Flicker severity**
- The 95% short-term flicker (Pst95%) at the medium and low voltage measured for 10 min with standardized measurement equipment should not exceed 0.9.
- The long-term flicker (Plt95%) calculated from 12 continuous measurement results of Pst should not exceed 0.7.

3. Assessment Methodology for Integrating Planned Unidirectional EV Chargers into the Distribution Grid in Vietnam

In Section 2, details of charging station connection requirements were mentioned in 2 different levels. The assessment of the feasibility of integrating charging stations into the distribution grid can be done based on these 2 levels of requirements. To accurately assess the low-level requirements of the distribution grid, it is essential to collect data at a high resolution. However, the data currently available is only provided at 30 min intervals. To overcome this limitation and simplify the assessment process, the paper focuses on evaluating important grid parameters based on high-level requirements. Specifically, the paper will evaluate voltage and power loss within a 24 h period on a typical day in a year. Since the frequency on the distribution grid is relatively stable, this parameter will be ignored in the assessment.

The process has three important steps:

- Collect inputs: This step involves gathering data about the distribution grid, including the feeder configuration, load profiles, and pre-planned locations for EV chargers. This is one of the most important steps: the more detailed information of the grid can be collected, the higher accuracy can be achieved through the assessment process.
- Simulation process: Simulations are implemented using PSS/ADEPT software to analyze the performance of the distribution grid with and without EV chargers. There are two scenarios that were considered:
+ Scenario 1: In this scenario, the aggregated information is validated, and the current distribution system is simulated. Then, the power analysis is done on a snapshot during peak hour of a typical day. This helps establish a baseline for the distribution grid's performance.
+ Scenario 2: In this scenario, pre-planned EV chargers are added to the considered distribution power system. The power analysis is then run again on a snapshot during the peak hour of a typical day to determine how the added loads and EV chargers affect the distribution grid's performance.
- Evaluation process: This step evaluates the simulation results and determines the feasibility of integrating EV chargers into the feeders. The following tasks are carried out:
+ Results recording: The simulation results are recorded, including bus voltages, branches, power losses, etc.
+ Check distribution grid operation requirements: The results are checked to ensure that they meet the voltage limitations and power loss requirements of the distribution grid.

The voltage performance indices ($\Delta V(\%)$) of the buses on the distribution grid are calculated using the following equation:

$$\Delta V(\%) = \frac{|V - V_{nominal}|}{V_{nominal}} * 100\%$$

where: V is the bus voltage; $V_{nominal}$ is the nominal voltage of the feeder.

The power losses index (Plosses (%)) of the considered feeder is calculated using the following equation:

$$\text{Plosses } (\%) = \frac{P_{losses}(MW)}{P_{Load}(MW)} * 100\%$$

where: P_{losses} and P_{Load} is the total losses and total load of the considering feeder.

+ Evaluate feasibility: The simulation results are evaluated to determine the feasibility of integrating EV chargers into the feeders. This includes determining whether the addition of EV chargers will cause any problems with the grid's performance and identifying any necessary changes that must be made to the distribution grid to accommodate the additional EV chargers.

Figure 3 describes the research approach to determine the feasibility of integrating the charger stations on the local power grid.

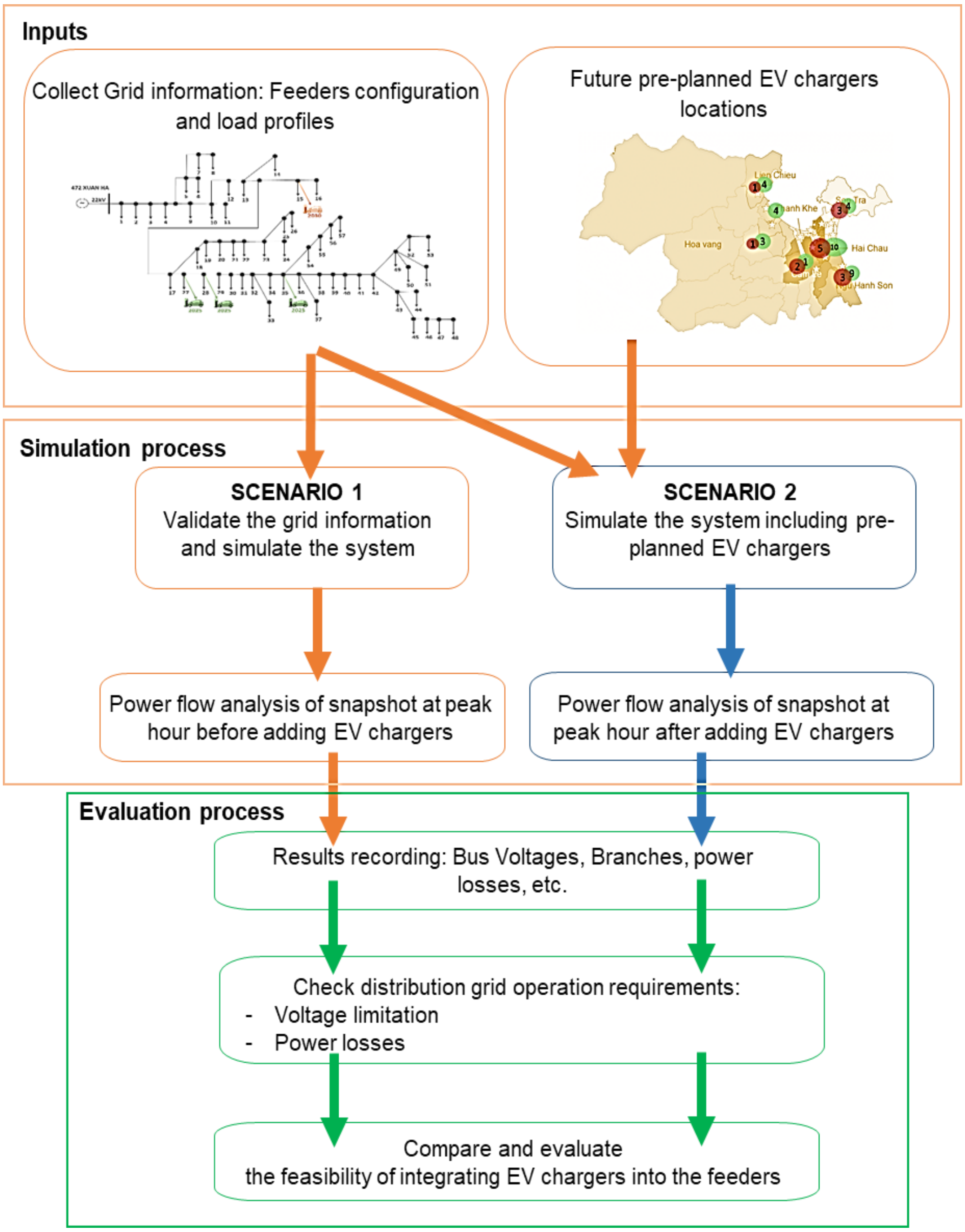


Figure 3. The flowchart of the assessing methodology for integrating planned unidirectional EV chargers into the distribution grid.

4. Applications on Danang's Distribution Grid

Vietnam is on track to achieve net zero emissions by 2050 through a sustainable energy transition [33,34]. Therefore, it will be a potential market for EV development to support reducing emissions as well as promoting renewable energy deployment in Vietnam [35]. In 2019, the number of imported electric vehicles was only 140 cars. It rose to 900 cars in 2020 and was over 1000 cars by the end of 2021 [36]. The government also supported the initiative by issuing the Decree 10/2022/ND-CP, which stipulates that the registration fee for battery electric cars will be 0% for 3 years, beginning from 1 March 2022. Danang is a very active city in developing and has a sustainable development goal to create a brand name for the city that is dynamic, green, and clean. They have pioneered the development of electric charging infrastructure to support the development of EVs in the city. In 2021, Danang announced a plan to propose locations to build a charging station system and several mechanisms for encouraging electric car development and charging stations. According to this plan, Danang aims to build 165 electric vehicle charging stations by 2025: 150 charging stations are on level 1 or 2, and 15 are on level 3. By 2030, the city is expected to have 300 charging stations, mostly in levels 1 or 2. Those charging stations will be located in parking areas, commercial centers, urban areas, schools, petrol stations, industrial parks, and resorts [37]. The estimated numbers of EV charging stations for 2020–2025, and the number of chargers envisioned by 2030, sorted by charger type, are shown in Table 2. The estimated numbers of fast EV charging stations for 2020–2025 by districts in Danang city are presented in Figure 4 [38,39]. The star located the center of each districts. The red dot shows the estimated number of fast EV charging stations which are planned to integrate in each district in period 2020–2025. The green dot shows the estimated number of fast EV charging stations which are planned to integrate in each district in period 2025–2030.

Table 2. Estimated number of EV charging stations for 2020–2025, vision to 2030.

Charger Type	**Number of Chargers**	
	2020–2025	**2025–2030**
Charger level 1, 2	150	250
Charger level 3—Fast charging	15	50
Total	165	300

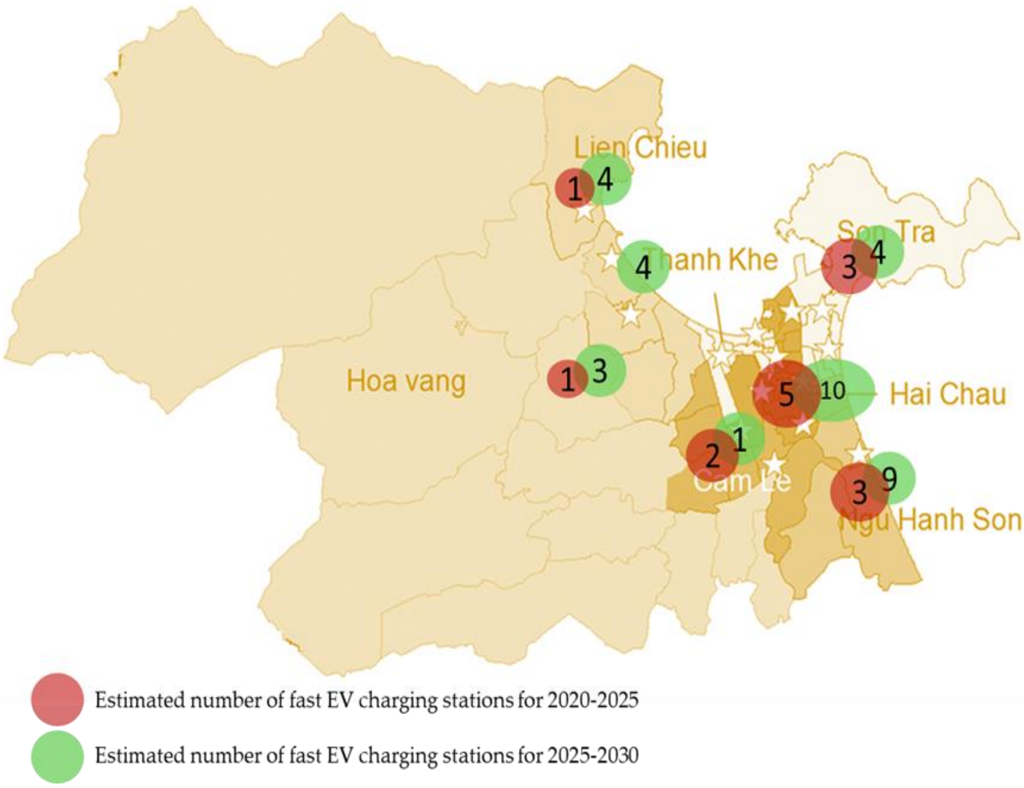


Figure 4. Estimated number of fast EV charging stations for 2020–2025 by district in Danang city.

Danang has also announced incentive policies to support the development of electric vehicles in the city, including

- Encouraging public procurement and use of electric cars in departments and state agencies in Danang based on compliance with the provisions of the law [40];
- Creating a roadmap to convert petrol-based public buses to electric buses [41];
- Proposing a lower interest rate to support projects that produce or use clean technology, clean energy, and renewable energy to subsidize interest rates on charging station loans [42].
- For government areas: encouraging investment under the public–private partnership (PPP) mechanism or other incentive policies to promote and support the investment in charging stations at public offices.

Danang receives electricity through 12 substations with a total power capacity of 1099 MVA and 85 22 kV-transmission lines. The city's power demand in 2020 reached 10.2 million kWh with a maximum power of 510 MW; the overall power losses were 2.67% [42]. The distribution network is spread over a large area with interlaced networks and many radial branches. The Danang's distribution network map was presented in Figure 5.

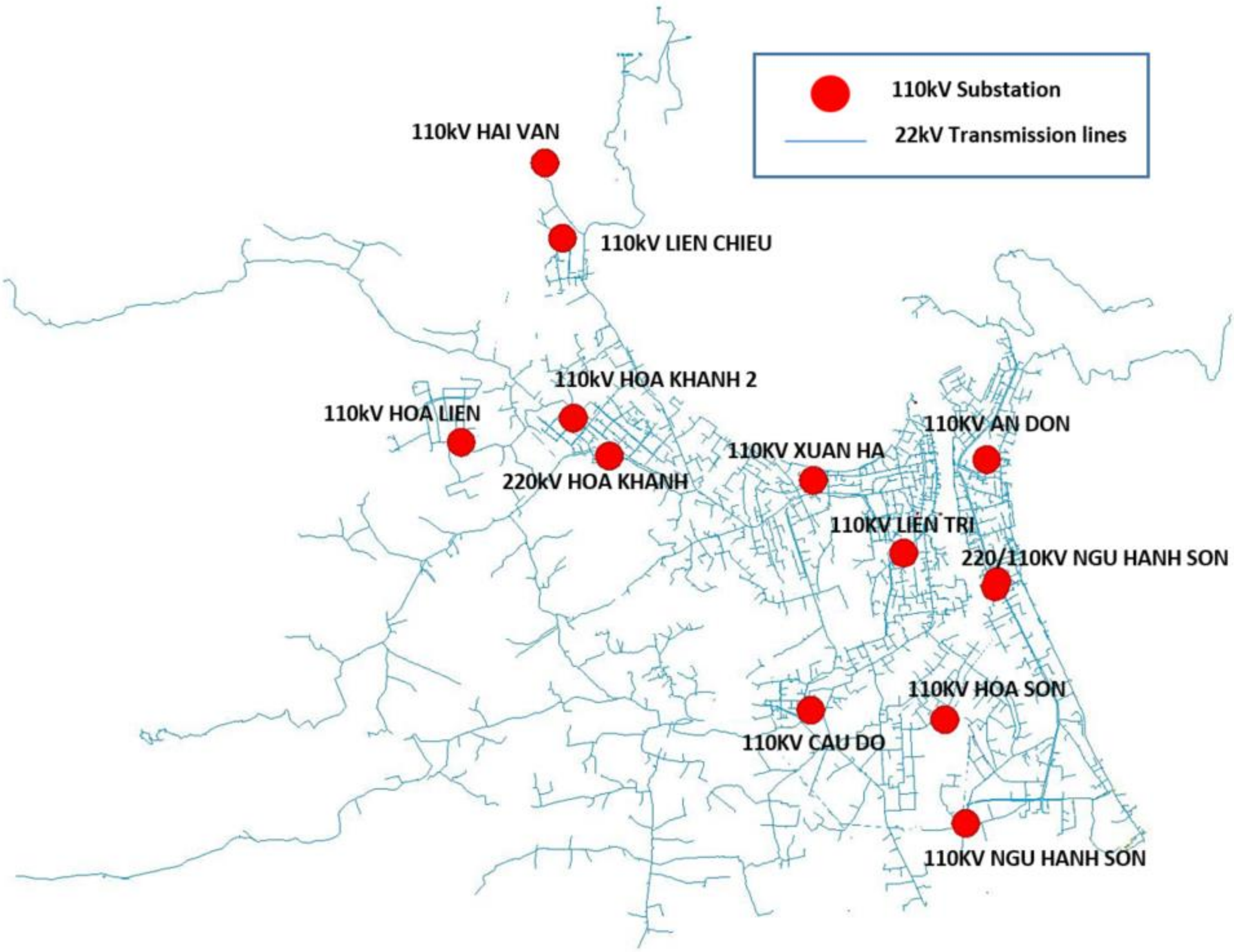


Figure 5. The map of the Danang city distribution network.

Since the resident can build charger level 1 and 2 themselves at home for use, there are no specific locations for them. The authors only have location information of fast charging stations. Therefore, this article will focus on assessing the feasibility of installing fast charging stations into the distribution grid of Danang province. Two feeders which have a large number of connected charging stations, including one 22 kV feeder receiving electricity from 110 kV Xuan Ha (XHA) and one 22 kV feeder receiving electricity from 110 kV Ngu Hanh Son (NHS), namely 472 XHA and 474 NHS, respectively, will be evaluated in this paper. These feeders have high load density and include multiple substations and compensation systems along the transmission line. Charging stations are usually connected at the secondary side of the service transformers. They receive electricity from nearby existing or newly built distribution substations. The data were collected from Central Power Corporation and Danang Power Company. The operation requirements for a 22 kV power grid are described in Table 3 based on the general requirements presented in Section 2.

Table 3. The operation requirements for 22 kV network.

Requirements	Limits
Frequency	49.8 Hz ≤ f ≤ 50.2 Hz
Voltage supply	20.9 kV ≤ V ≤ 23.1 kV
Power losses	≤10%

5. Results and Discussion

In this section, the results are presented and the findings on the feasibility of installing charging stations into these feeders of the Danang's distribution grid are discussed. The changing of load profiles in each case study are described in the two periods of time: 2020–2025 and 2025–2030. Then, the results across the seven columns of the table demonstrating the operation of the distribution grid feeders under different scenarios are compared.

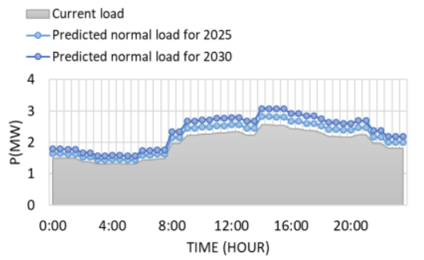
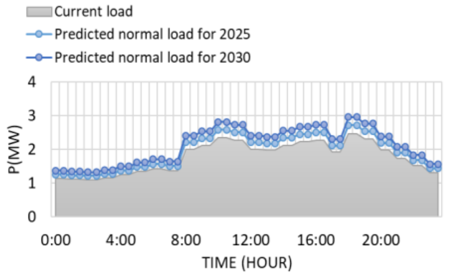
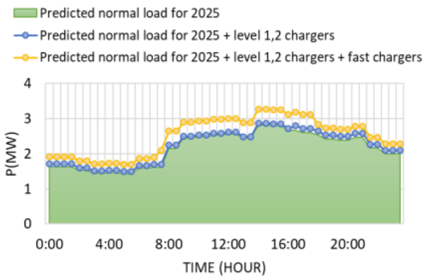
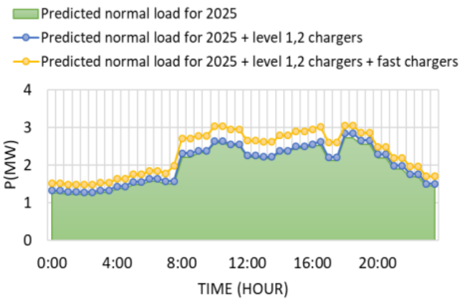
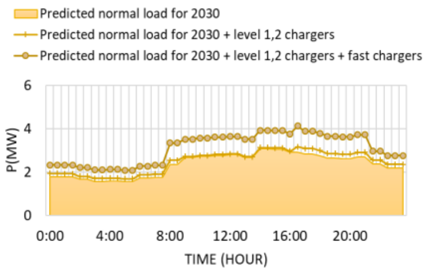
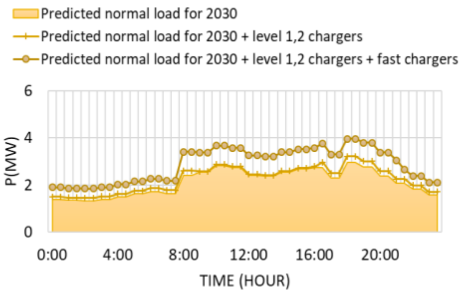
It was assumed that the feeder's load is forecasted to increase 10% by 2025 and 20% by 2030. It was also assumed that the level 1 and 2 chargers are integrated randomly to load buses. The predefined locations of the 250 kVA fast chargers are going to be integrated to the distribution grid by 2025 and 2030. The power changing (Pmax) in Scenario 2 not only includes increasing load, but also includes adding of charging load. The worst case considers chargers continuously charging at the same time from 7:00 a.m until 9:00 p.m. The low charging hours are from 9:00 p.m until 7:00 a.m. These assumptions are included in the simulation to evaluate the feasibility of integrating charging stations comprehensively. The load profile for two feeders according to the current year and expected load profile in 2025 and 2030 before and after integrating the charging stations are described in Table 4.

As mentioned in Section 3, two main scenarios are considered to thoroughly analyze the feasibility of installing fast charging stations into the distribution grid. Three case studies will be conducted for each time period, 2020–2025 and 2025–2030. The list of scenarios and case studies are described as follows:

- Scenario 1: Assessing the current distribution grid's operation.
- Scenario 2.1: Assessing the distribution grid's operation for the time period of 2020–2025.
+ Case 2.1.1: Assessing the distribution grid's operation with a 10% increase in normal load compared to the current distribution grid for 2025.
+ Case 2.1.2: Assessing the distribution grid's operation with a 10% increase in normal load compared to the current distribution grid and the addition of level 1 and 2 chargers to the distribution grid for 2025.
+ Case 2.1.3: Assessing the distribution grid's operation with a 10% increase in normal load compared to the current distribution grid and the addition of level 1 and 2 chargers, as well as predefined fast chargers, to the distribution grid for 2025.
- Scenario 2.2: Assessing the distribution grid's operation for 2030.
+ Case 2.2.1: Assessing the distribution grid's operation with a 10% increase in normal load compared to the 2025 distribution grid for 2030.
+ Case 2.2.2: Assessing the distribution grid's operation with a 10% increase in normal load compared to the 2025 distribution grid and the addition of level 1 and 2 chargers to the distribution grid for 2030.

+ Case 2.2.3: Assessing the distribution grid's operation with a 10% increase in normal load compared to the 2025 distribution grid and the addition of level 1 and 2 chargers, as well as predefined fast chargers, to the distribution grid for 2030.

Table 4. The load profile in the current year and expectation of feeders in 2025 and 2030.

472-XHA	474-NHS
	
	
	

The results after conducting analysis will be presented, respectively, in seven columns of a table, as shown in Table 5.

Table 5. The structure of the results table.

Column	1	2	3	4	5	6	7
Corresponding scenario	Scenario 1	Scenario 2.1.1	Scenario 2.1.2	Scenario 2.1.3	Scenario 2.2.1	Scenario 2.2.2	Scenario 2.2.3
Considered year	Current	2025	2025	2025	2030	2030	2030

- **Feeder 472:** This 22 kV feeder is responsible for delivering electricity to a network of 57 buses. The total current load on the feeder is 2.56 MW. To meet the growing demand for electric vehicles, there are plans to integrate four fast chargers into the feeder. A total of 3 250 kVA fast chargers will be installed at buses 27, 28, and 35 in 2025. In addition to these 3 fast chargers, there is a plan to install 1 more 250 kVA fast charger at bus 15 in 2030. This charger will be strategically located to provide electric vehicle drivers with a convenient and reliable charging option, helping to promote the adoption of electric vehicles in the area. The feeder single line with predefined location of fast chargers in 2025 and 2030 is shown in Figure 6 below. The simulation results for seven cases of two scenarios are shown in Table 6.

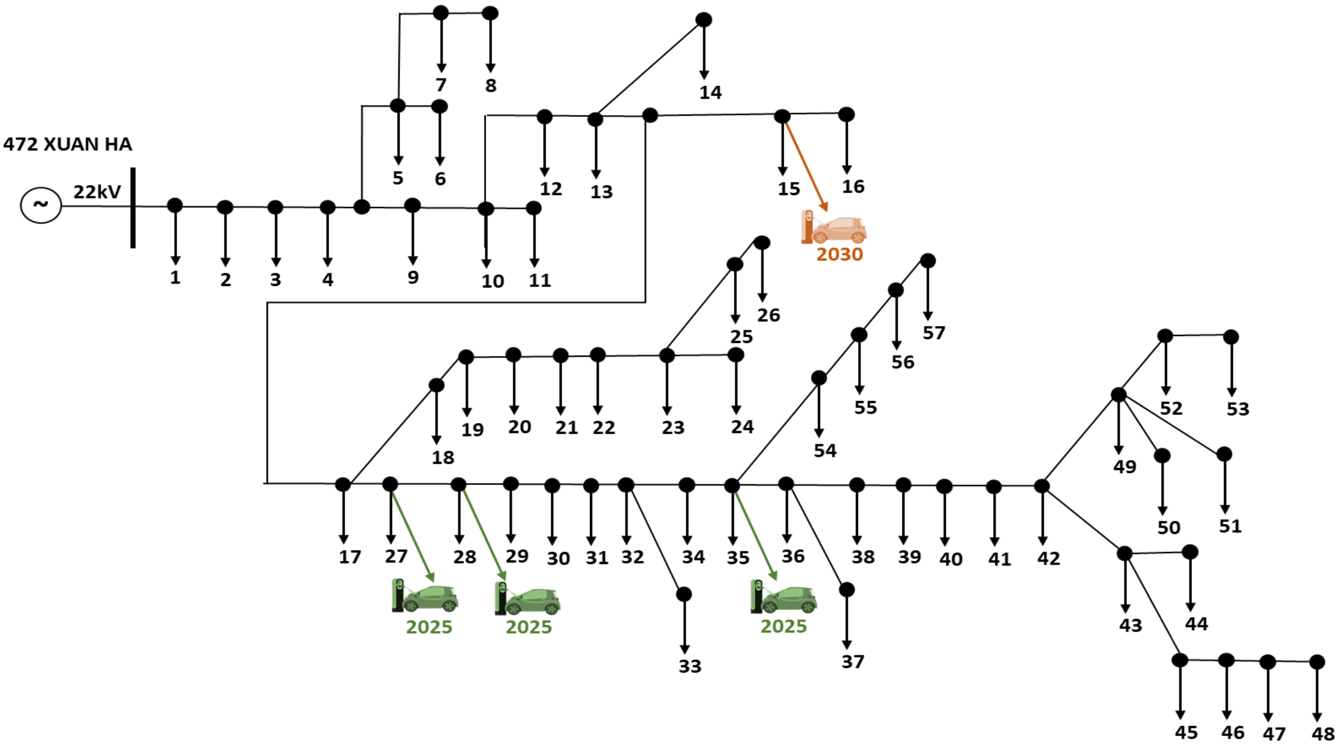


Figure 6. Feeder 472 single line diagram with predefined location of fast chargers in 2025 and 2030.

Table 6. Simulation results for 7 cases of 2 scenarios on feeder 472.

Parameters	1	2	3	4	5	6	7
	Current		**2025**			**2030**	
Integrated Charger level 1 and 2 capacity (kVA)	0	0	180	180	0	340	340
Integrated Fast charger level 3 capacity (kVA)	0	0	0	750	0	0	1000
Pmax (MW)	2.5598	2.8161	2.9445	3.5440	3.0720	3.3280	4.1280
Min_V (kV)	21.25	21.18	21.14	21.07	21.09	21.02	20.94
ΔV (%)	3.39	3.74	3.92	4.22	4.10	4.46	4.82
Plosses (MW)	0.0626	0.0763	0.0837	0.1026	0.0915	0.1081	0.1343
Plosses (%)	2.39	2.64	2.77	2.81	2.89	3.15	3.16
QLosses (MVAr)	0.0751	0.0916	0.1004	0.1230	0.1097	0.1296	0.1611

Where: Pmax (MW) represents the maximum power that can be delivered by the system; MinU (kV) represents the minimum operating voltage on the feeder; delU (%) represents the voltage deviation percentage from the nominal value; Plosses (MW) represents the real power losses incurred by the system; Plosses (%) represents the power losses in percentage from the current corresponding delivered real power; and QLosses (MVAr) represents the reactive power losses incurred by the system.

From Table 5, it can be seen that while the power demand increases in each case from 2.56 MW to 3.54 MW in 2025 and to 4.13 MW in 2030, the minimum voltage range on the feeder also drops from 21.25 kV to 20.94 kV. The values of ΔV fluctuate, respectively, from 2.39% to 4.2% in 2025 and to 4.82% in 2030, which is still within the limitation ranges. It should be noticed that the voltage drop in 2030 was high and near the edge of the limitation. In order to ensure the reliable operation of the grid, the integration of EV chargers needs to be carried out with more consideration, and potential upgrades to the grid infrastructure may be required to avoid voltage drops or overloading.

The real power losses also increase from 0.0439 MW (2.39%) to 0.1026 MW (2.81%) in 2025 and 0.1343 MW (3.16%) in 2030; all these values satisfy the loss standard. These parameters indicate that the system is capable of delivering a significant amount of power and maintaining a relatively stable voltage level. Overall, the feeder is capable of integrating

180 kVA level 1 and 2 chargers and three 250 kVA fast chargers in 2025; and 340 kVA level 1 and 2 chargers and one more fast charger in 2030.

- **Feeder 474:** This 22 kV feeder is responsible for delivering electricity to a network of 36 buses. The total current load on the feeder is 2.43 MW. Just as with feeder 472, there are 4 fast chargers going to be integrated into the feeder 474. Two 250 kVA fast chargers are going to be integrated at buses three and four in 2025. A total of 2 more will be integrated at buses 29 and 30 in 2030. The capacities of integrated chargers of levels one and two are 160 kVA and 330 kVA by 2025 and 2030, respectively. The feeder single line with predefined location of fast chargers in 2025 and 2030 is shown in Figure 7 below. The simulation results for seven cases of two scenarios are shown in Table 7.

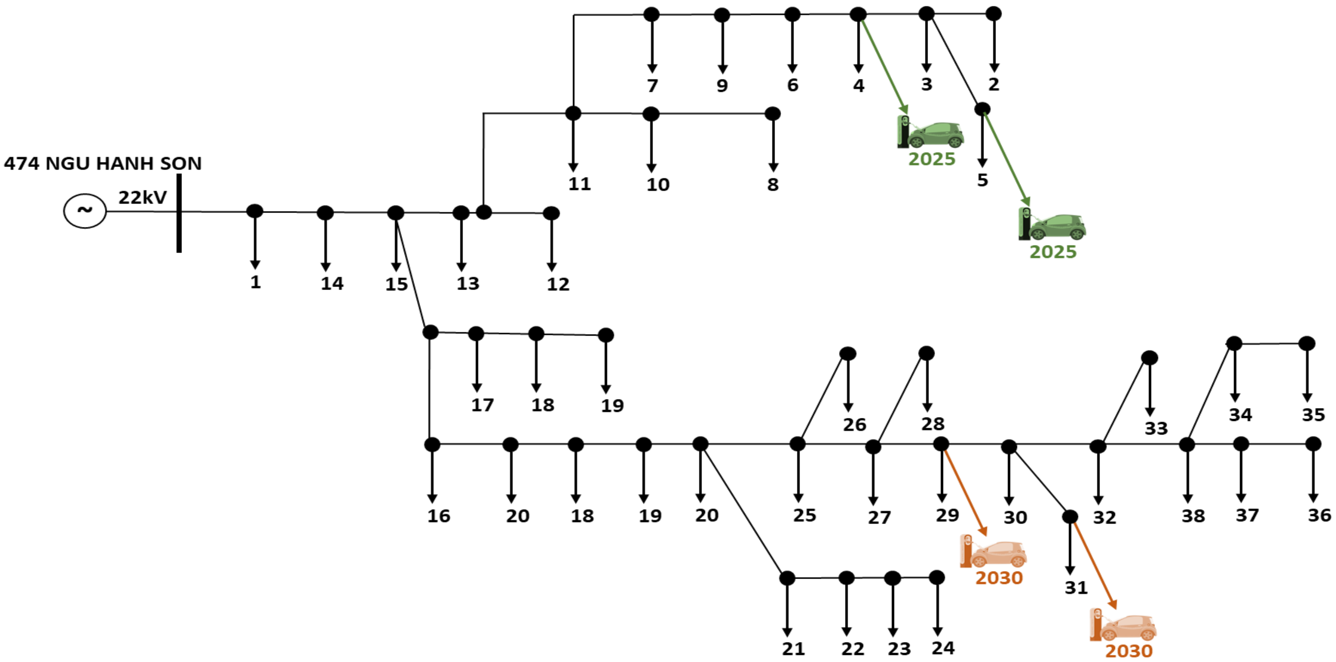


Figure 7. Feeder 474 single line diagram with predefined location of fast chargers in 2025 and 2030.

Table 7. Simulation results for 7 cases of 2 scenarios on Feeder 474.

Parameters	1	2	3	4	5	6	7
	Current		2025			2030	
Integrated Charger level 1 and 2 capacity (kVA)	0	0	160	160	0	330	330
Integrated Fast charger level 3 capacity (kVA)	0	0	0	500	0	0	1000
Pmax (MW)	2.4301	2.6727	2.7945	3.1945	2.9161	3.1591	3.959
Min_V (kV)	21.78	21.76	21.75	21.71	21.74	21.72	21.67
ΔV (%)	0.97	1.07	1.12	1.3	1.17	1.26	1.50
Plosses (MW)	0.0153	0.0185	0.0203	0.0281	0.0221	0.0260	0.0396
Plosses (%)	0.62	0.6885	0.72	0.87	0.75	0.82	0.99
QLosses (MVAr)	0.0183	0.0222	0.0243	0.0336	0.0264	0.0311	0.0474

The results in Table 6 show that the feeders are currently operationally stable. The power demand increases in each case from 2.43 MW to 3.19 MW in 2025 and to 3.96 MW in 2030; and the minimum voltage range on the feeder slightly drops from 21.78 kV (0.97%) to 21.71 kV (1.3%) in 2025 and to 21.67 kV (1.5%). The values of ΔV are within the 5% allowable range. It can be observed that the level of load demand on the feeders remains reasonable, ensuring that the operation requirements are met while connecting the charging station system in the near future. The voltage results also reveal that the integration of charging stations with the current expected capacity has not had an effect on the quality of the feeder voltage.

The real power losses also increase from 0.0153 MW (0.62%) to 0.0281 MW (0.87%) in 2025 and 0.0369 MW (0.99%) in 2030: these values are very low compared to the loss standard. These parameters indicate that the system is capable of delivering a significant amount of power and maintaining a relatively stable voltage level. The feeder is capable of integrating 160 kVA chargers of level 1 and 2 and two 250 kVA fast chargers in 2025; and 330 kVA chargers of level 1 and 2 and two more fast chargers in 2030.

6. Conclusions

In this paper, an evaluation method is given to access the feasibility of integrating EV chargers into the distribution grid. Based on the current operation requirements for distribution grid in Vietnam, this paper determined the most critical parameters that must be considered when analyzing the feasibility of integrating EV chargers into the distribution grid, including voltage, losses, and harmonics. The suggested method was tested on two 22 kV distribution feeders, 472XHA and 474NHS, in Danang, Vietnam. The evaluation was conducted for two time periods: 2020–2025 and 2025–2030. The results demonstrated that the feeders under consideration have enough capacity to accommodate new EV charging stations while still meeting operating standards in both evaluation periods. However, the voltage reduction on feeder 472XHA in 2030 is very close to the voltage limitation. It is recommended that feeder 472XHA should be upgraded or the load should be shared with the other nearby feeders in 2030 to ensure reliable power supply to the loads. Due to its simplicity, the method can be widely applied to other distribution systems. For further work, the method will be continuously developed using higher resolution measured data in order to put more evaluation indices into practice. These studies will help to provide a more precise assessment of the distribution system.

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