



Impact of Electric Vehicle Charging Loads on the Performance of the IEEE 33-Bus Distribution Network

Scenario-Based Load Flow, Voltage-Constrained Hosting Capacity, and a Separate Charger Model

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Abstract

Concentrated electric-vehicle (EV) charging can compromise radial feeder voltage and increase resistive losses, yet the severity also depends on connection location. This paper studies the 12.66 kV IEEE 33-bus network using a balanced backward/forward-sweep solver. Five prescribed EV demand levels (0–80% of the 3,715 kW base demand) are evaluated with coincidence factors of 0.60 and 1.00; the resulting active-power increments are distributed equally among buses 18, 25, and 33 at unity power factor. At the highest evening demand (2,972 kW), the minimum voltage declines from 0.913090 to 0.795866 p.u., and feeder loss increases from 202.677 to 835.423 kW. A separate sensitivity test places the same 743 kW load individually at buses 6, 18, and 33. The corresponding minimum voltages are 0.90141, 0.84753, and 0.87908 p.u. Under a 0.90 p.u. voltage-only criterion, the maximum additional loads at these locations are 831.46, 160.71, and 339.06 kW, respectively. An independent Simscape charger test records 8.678 A and 3.385 kW at the battery terminals over a short operating interval. Together, these results quantify both demand- and site-dependent impacts while distinguishing voltage-constrained hosting estimates from equipment ratings and charger dynamics.

Keywords—EV charging; IEEE 33-bus network; load flow; charging-site sensitivity; voltage-constrained hosting capacity; feeder losses.

1. Introduction

Electric-vehicle charging is often discussed in terms of fleet size or installed charger capacity, yet distribution feeders respond directly to coincident electrical demand. Where charging is concentrated toward the ends of a radial circuit, additional current must travel through several upstream branches. The resulting voltage drops and conductor losses depend on feeder impedance, existing loads, and the location and timing of the new demand. These effects make local network analysis a necessary part of charging-infrastructure planning [1], [2].

The IEEE 33-bus radial feeder is a useful benchmark because its topology and electrical data are established, allowing changes in voltage and loss to be traced to the chosen loading assumptions [3], [4]. Published EV integration studies now include probabilistic travel and charging models, charger-placement optimization, controlled charging, and detailed power-quality assessments [5]–[7], [2], [8]. Such approaches address different planning questions and often require information unavailable in a preliminary network study. A simpler scenario-based analysis remains informative when its inputs, numerical treatment, and intended interpretation are stated precisely.

This paper first evaluates the IEEE 33-bus feeder under five EV charging-demand settings at three predetermined nodes and two illustrative coincidence factors. It then compares concentrated equal-power charging at three alternative buses and estimates the maximum additional load at each site under a 0.90 p.u. voltage screen. A separate, short-duration Simscape simulation demonstrates a representative 3.7 kW-class charger operating point. These linked but non-coupled analyses provide reproducible demand- and location-dependent feeder evidence without claiming an optimal network-wide charging allocation.

2. Related Research and Positioning

The distribution-network consequences of EV charging have been extensively documented. Ahmed et al. [1] review the principal technical concerns and measures that may reduce them, while Ibrahim et al. [2] investigate interacting network effects associated with EV penetration. Mariscotti et al. [8] further show that converter-connected charging equipment can influence the grid beyond fundamental-frequency power flow, including harmonics, unbalance, and impedance-dependent effects. These studies establish the broader physical context for the present voltage, current, and loss calculations.

Other studies focus on decisions that arise after a network weakness has been identified. Abdelaziz et al. [5] address optimal charging-station allocation, Pinnarelli et al. [9] evaluate station placement under varied demand and renewable-generation conditions, and Cañigüeral et al. [6] investigate smart charging with dynamic local limits. The present scenarios hold charging locations and control assumptions fixed, making the resulting trends useful for understanding the network response at those selected connection points.

Demand diversity adds another layer of complexity. Nascimento et al. [7] construct a probabilistic assessment from charging behavior, Mehta et al. [10] examine residential charging strategies, and Callanan et al. [11] consider aggregation at a higher voltage level. The selected daytime and evening multipliers in this paper serve instead as illustrative demand factors. Studies of real distribution-connected charging systems [12] and converter-control or harmonic-mitigation methods [13], [14] complement the short charger operating-point simulation but involve phenomena not represented in the feeder load-flow model.

These research strands address different questions: optimization selects operating decisions, probabilistic models describe uncertainty, and detailed power-quality studies resolve dynamics beyond a balanced power-flow approximation. The contribution here is a consistently defined feeder sensitivity benchmark, supplemented by site-by-site voltage-constrained charging limits at three candidate buses. These limits offer a transparent screening comparison rather than a globally optimal siting solution.

3. System Model and Study Design

3.1. Feeder data and solution

The nominal 12.66 kV, 33-bus radial feeder has 32 closed branches, with bus 1 represented as the fixed-voltage source. The benchmark constant-power demand is 3,715 kW and 2,300 kVAr. Resistances, reactances, and nodal loads follow the MATPOWER case33bw dataset [4], which identifies Baran and Wu [3] as its source. The open tie branches are excluded. The analysis uses a balanced three-phase equivalent without on-load tap-changing, capacitor-control action, distributed generation, or explicit phase unbalance.

A backward/forward sweep [15] determines bus and branch phasors. Let P_i (kW) and Q_i (kVAr) denote total three-phase bus demands, V_i the phase-to-neutral voltage in volts, and $Z_{ij} = R_{ij} + jX_{ij}$ the per-phase branch impedance in ohms. With $C(j)$ denoting the set of downstream child buses of bus j , the iterative load-current, branch-current, and voltage relations are:

$$I_i^{\text{load}} = \text{conj} \left(\frac{10^3(P_i + jQ_i)}{3V_i} \right). \quad (1)$$

$$I_{ij} = I_j^{\text{load}} + \sum_{k \in C(j)} I_{jk}. \quad (2)$$

$$V_j = V_i - Z_{ij} I_{ij}. \quad (3)$$

After convergence, the feeder active loss and per-unit bus-voltage magnitude are calculated as follows (branch resistance in ohms and current in amperes):

$$P_{\text{loss}} [\text{kW}] = 10^{-3} \sum_{(i,j) \in \mathcal{E}} 3 R_{ij} |I_{ij}|^2. \quad (4)$$

$$V_{i,\text{pu}} = \frac{|V_i|}{(12.66 \times 10^3) / \sqrt{3}}. \quad (5)$$

Iteration stops when the largest voltage change is below 10^{-7} V, subject to a 500-iteration ceiling. The archived ten-case run converged in 10–17 iterations. As this is a steady-state constant-power analysis, it does not resolve charging-switching transients, nonlinear power-electronic waveforms, or harmonic propagation.

3.2. Charging scenarios and reporting indices

The nominal parameter α represents the EV demand fraction of the unchanged base feeder active load. Applying the illustrative coincidence multiplier m gives:

$$P_{EV}(\alpha, m) = \alpha m P_{base}, \quad P_{base} = 3715 \text{ kW}. \quad (6)$$

The study uses $\alpha \in \{0, 0.20, 0.40, 0.60, 0.80\}$, with $m = 0.60$ for daytime and $m = 1.00$ for evening demand. These multipliers are explicit modeling assumptions rather than sampled charging profiles or statistical coincidence estimates. Base non-EV demand remains fixed. Each increment is shared equally among buses 18, 25, and 33 at unity power factor, and no other network input is altered.

Care is required in describing α : for instance, nominal $\alpha = 80\%$ corresponds to an effective 48% of baseline demand in the daytime case and 80% in the evening case. It does not express EV fleet adoption, household ownership, or measured simultaneity. Dividing the imposed EV demand by the 3.7 kW nominal charger rating gives only a continuous power-equivalent count, not a verified number of simultaneously operating chargers.

Minimum voltage is compared against an explicitly chosen 0.90 p.u. screening level, consistent with the lower bus voltage bound in case33bw [4]; this alone does not establish compliance with a local statutory voltage standard. Because branch ampacities and transformer ratings are unavailable, the ratio of the maximum observed branch current to the baseline maximum is a comparative stress index, not a fraction of available thermal capacity.

Table 1. Fixed assumptions and numerical definitions.

Source: feeder input from MATPOWER case33bw [4]; charging assumptions defined for this study.

Element	Specification
Network / source	33 buses; 32 closed radial branches; 12.66 kV line-to-line; bus 1 fixed source
Unmodified demand	3,715 kW + j2,300 kVAr in both charging profiles
Imposed EV demand	Nominal $\alpha = 0, 20, 40, 60, 80\%$ of 3,715 kW, multiplied by m
Locations / EV PF	Buses 18, 25 and 33; equal shares; added Q = 0
Prescribed multipliers	Daytime $m = 0.60$; evening $m = 1.00$
Numerics / screening	BFS tolerance 10^{-7} V; max. 500 iterations; low-voltage screen 0.90 p.u.

3.3. Candidate-site tests and voltage-limited capacity

To isolate location effects from total charging demand, a second set of cases assigns the same 743.0 kW active-power increment (20% of the 3,715 kW base load with $m = 1.00$) entirely to bus 6, 18, or 33, one site at a time. Baseline demand, network topology, and reactive power remain unchanged. These tests differ from the three-way allocation in Section 3.2: they compare individual hypothetical connection sites rather than distributing a common aggregate load.

For each site b , the voltage-constrained additional-load limit H_b is the greatest nonnegative single-bus increment for which the balanced load flow converges and all bus voltages remain at or above 0.90 p.u. It is defined by

$$H_b = \max\{\Delta P \geq 0: V_{\min}(\Delta P; b) \geq 0.90\}. \quad (7)$$

A 24-step bisection search over 0–5,000 kW is applied independently at each candidate bus. The feasibility check requires both convergence and the voltage criterion throughout the feeder. This 0.90 p.u. screening bound follows the benchmark input [4]; the resulting values are not thermal, transformer, protection, regulatory, or probabilistic hosting-capacity limits.

3.4. Independent charger operating-point model

The archived Simulink/Simscape model contains a three-phase AC/DC front end, an approximately 800 V DC link, a controlled DC/DC stage, and a battery with nominal values of 400 V and 60 Ah. The model initializes the battery charge at 30 Ah (a nominal 50% state-of-charge estimate). An external series resistor of $2\ \Omega$ and an inductor of $45.2\ \mu\text{H}$ remain in the charge path. The DC/DC voltage reference is 407.5 V, the stage power setting is 3,700 W, and the AC/DC power-balance dynamics are enabled. These are model settings, not laboratory measurements.

The battery path is switched into circuit at 1.0 s in a simulation ending at 1.5 s. Operating-point means are calculated from 1.2–1.5 s, while the DC/DC output power maximum is checked over the complete connected interval. A current-integrated SOC estimate is reported. The short test checks positive charging current, preconnection isolation, and an output-power bound within the modeled interval; it does not demonstrate a full constant-current/constant-voltage sequence, a complete charge cycle, hardware efficiency, or harmonic compliance.

3.5. Computation record and numerical checks

The feeder study was implemented in MATLAB R2024b using the stated radial network and charging-demand assumptions. For each of the ten original cases, saved outputs include bus voltages, branch currents, feeder losses, and convergence information. The additional location test uses the same solver and input data, with the single-bus active-power increment as its only electrical change. Its three fixed-demand cases and three voltage-limited searches were independently reproduced from the network data. Branch currents and impedances were also used to check the original feeder loss calculations. The separate Simscape model supplies charger voltage, current, power, and battery-terminal measurements over its recorded interval.

4. Feeder Results

4.1. Voltage and active loss

The no-EV reference has a minimum voltage of 0.913090 p.u., located at bus 18, and an active feeder loss of 202.677 kW. At $\alpha = 0$ the daytime and evening cases coincide because their EV demand is zero and the original feeder load is unchanged. For every positive charging-demand setting, minimum voltage declines while feeder losses increase. Table 2 lists the applied charging power and electrical response for all ten model cases; Figs. 1 and 2 illustrate their progression.

Table 2. Archived feeder outcomes (α applied before the profile multiplier).
Source: authors' load-flow calculations using MATPOWER case33bw data [4].

Profile	α (%)	EV (kW)	$V_{\min}$ (p.u.)	P_{loss} (kW)	$I_{\max}/\text{base}$ (%)	Buses <0.90
Day	0	0.0	0.913090	202.677	100.0	0
Day	20	445.8	0.897843	256.448	109.7	2
Day	40	891.6	0.881934	322.392	120.0	9
Day	60	1,337.4	0.865279	401.732	130.8	11
Day	80	1,783.2	0.847778	495.951	142.0	14
Evening	0	0.0	0.913090	202.677	100.0	0
Evening	20	743.0	0.887315	298.987	116.5	7
Evening	40	1,486.0	0.859545	431.403	134.5	14
Evening	60	2,229.0	0.829301	606.875	153.8	16
Evening	80	2,972.0	0.795866	835.423	174.7	18

With $\alpha = 80\%$ and the evening multiplier of 1.00, the added charging load reaches 2,972.0 kW. Minimum voltage decreases by 0.117225 p.u. relative to the no-EV case, while active loss rises to 835.423 kW, an increase of approximately 312.2%. At the same nominal α under the daytime multiplier, the effective EV demand is 1,783.2 kW; minimum voltage is then 0.847778 p.u. and active loss is 495.951 kW. The

difference between the profiles reflects the prescribed coincident power rather than independent, measured daily load patterns.

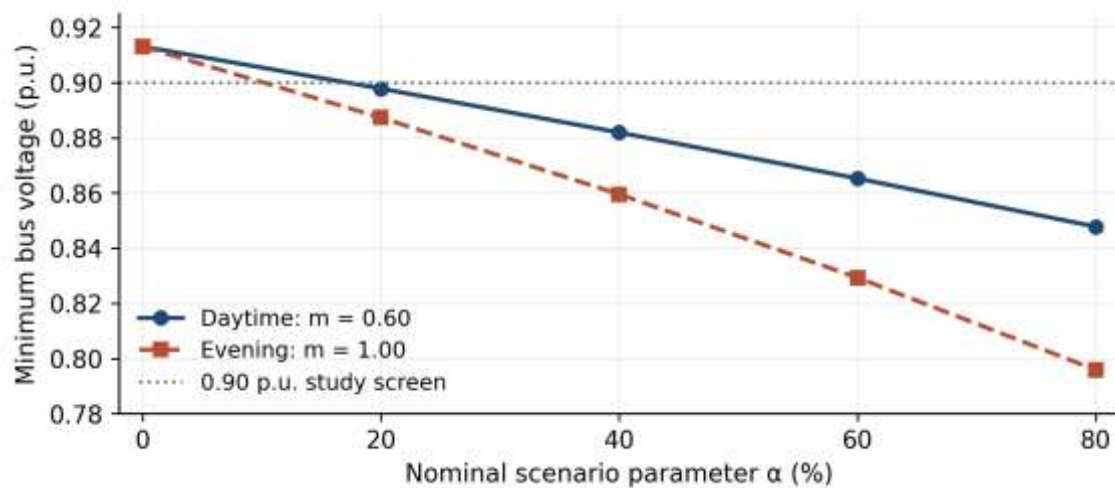


Fig. 1. Minimum bus voltage by nominal charging-demand level. The dotted line marks the 0.90 p.u. screening threshold. Source: authors' MATLAB load-flow results based on case33bw [4].

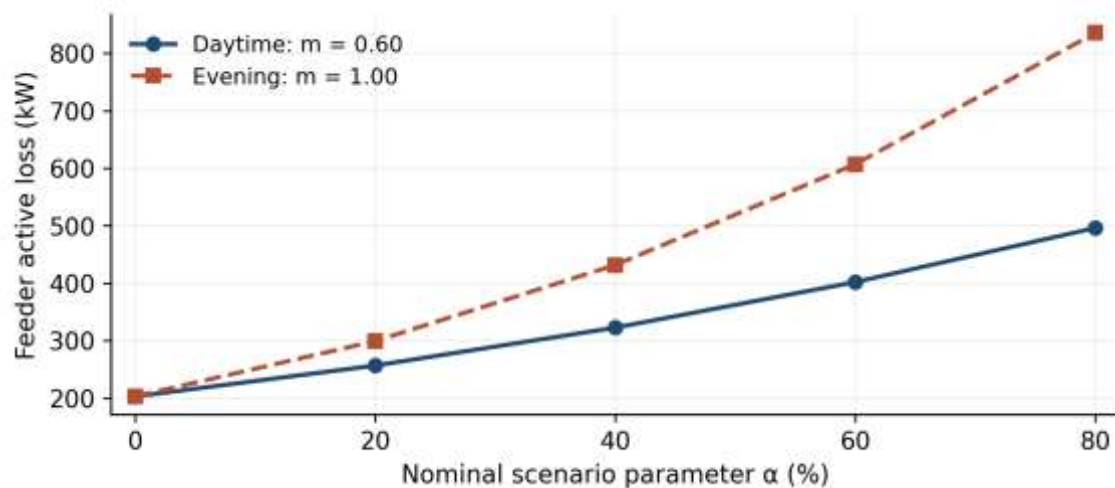


Fig. 2. Total active feeder loss under the prescribed EV loading cases. Source: authors' MATLAB load-flow results based on case33bw [4].

4.2. Spatial voltage response and branch current

Bus 18 has the minimum voltage in all ten runs, but voltage degradation is not uniform across the network. In the evening sequence, further voltage reductions appear across downstream parts of the radial feeder (Fig. 3). No reference-case bus is below 0.90 p.u. At $\alpha = 20\%$, two daytime buses and seven evening buses cross that screening threshold; the count rises to 14 and 18, respectively, at $\alpha = 80\%$. The benchmark itself has 21 buses below an alternative 0.95 p.u. screen, emphasizing the sensitivity of compliance language to the selected criterion.

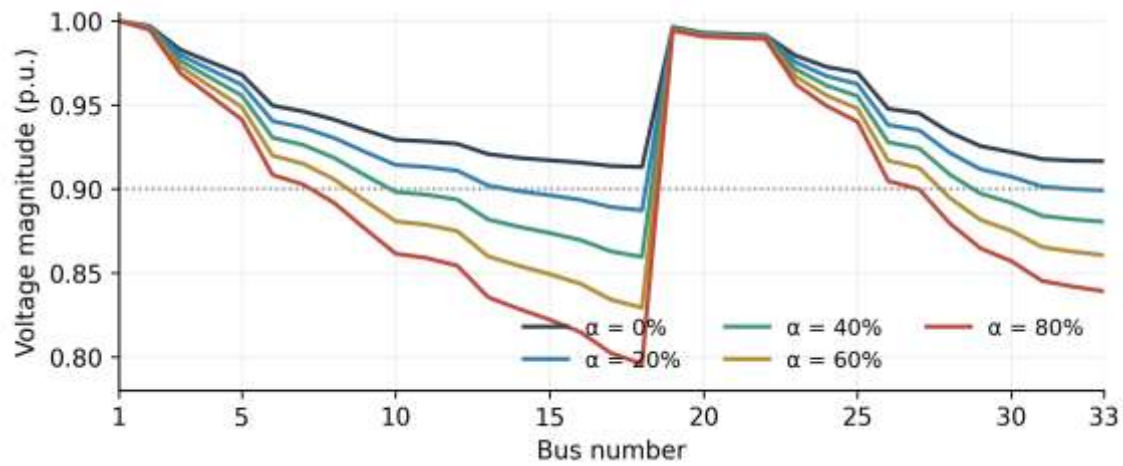


Fig. 3. Evening-case bus-voltage profiles; the horizontal line indicates 0.90 p.u.

Source: authors' MATLAB load-flow results based on case33bw [4].

The maximum branch current grows from 210.364 A in the reference feeder to 367.486 A in the 80% evening case. The latter corresponds to 174.69% of the reference maximum (Fig. 4). This metric uses maxima from the two cases; it is not a per-line percentage of rated cable current and does not by itself establish equipment overloading. Determining thermal adequacy requires actual branch and transformer ratings, which the adopted network data do not provide.

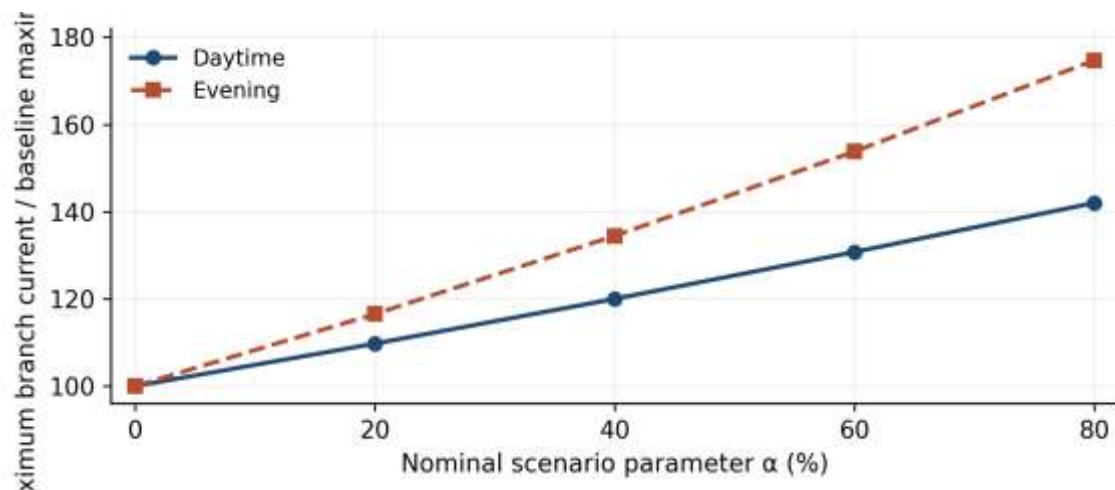


Fig. 4. Maximum branch current relative to the no-EV case (a comparative index, not an ampacity rating).

Source: authors' MATLAB load-flow results based on case33bw [4].

5. Separate Charger Operating-Point Results

The archived charger waveform shows negligible charging-path current before the 1.0 s connection, followed by a positive value approaching 8.678 A (Fig. 5). During 1.2–1.5 s, mean battery-terminal voltage is 390.058 V and mean terminal power is 3,384.853 W. The modeled DC/DC output averages 407.5 V and 3,536.215 W. Its recorded peak power over the connected interval is 3,536.375 W, which is below the model's stated 3,700 W stage parameter for this particular run.

Table 3. Logged charger quantities (1.2–1.5 s averages unless specified).
Source: authors' saved Simscape charger measurements.

Quantity	Recorded value
Battery charging current	8.677829 A
Battery terminal voltage	390.057564 V
Battery terminal electrical power	3,384.853 W
DC/DC output voltage	407.5 V
DC/DC output electrical power	3,536.215 W
Peak DC/DC output, $t = 1.0\text{--}1.5$ s	3,536.375 W
External $2\ \Omega$ resistor dissipation	150.609 W
Nominal coulomb-counted SOC estimate	50.000000% to 50.002009%

The difference between average DC/DC output and battery-terminal power is approximately 151.362 W, of which 150.609 W is accounted for by the external series resistor in the saved measurements. Their ratio is therefore not an intrinsic converter-efficiency measure. Similarly, the minute modeled change in the coulomb-counted SOC estimate reflects the short observation interval, not a demonstrated charging regime transition. The nominal 3.7 kW stage rating cannot be used to infer the aggregate loads assumed in Section 3.2 without an explicit network–charger interface.

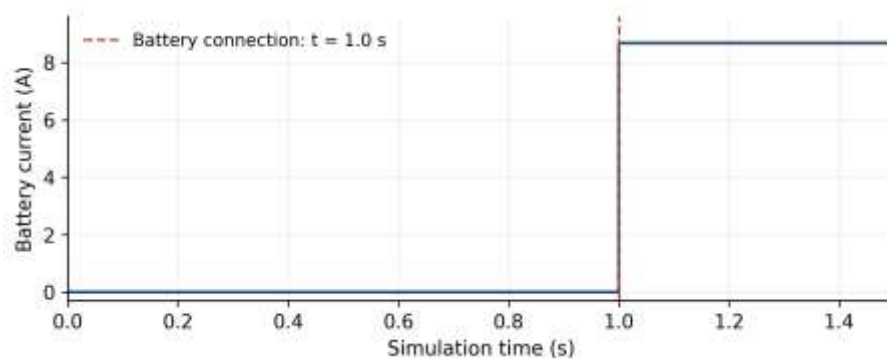


Fig. 5. Charging-path current from the Simscape model; the battery connection closes at 1.0 s.
Source: authors' archived Simscape simulation.

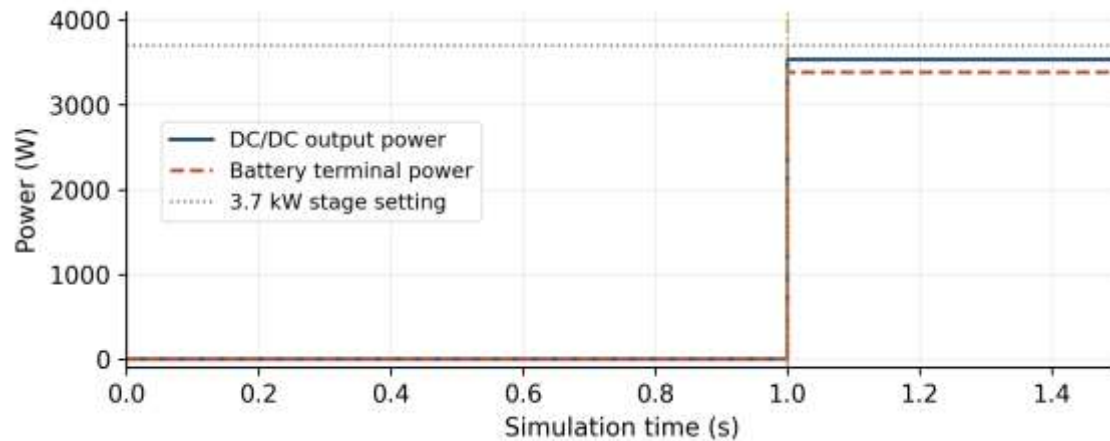


Fig. 6. DC/DC output and battery-terminal power during the simulated charging interval.
Source: authors' archived Simscape simulation.

6. Discussion

The feeder response follows the electrical behavior expected of a heavily loaded radial network. Each increase in imposed EV power raises current in the paths supplying the selected buses. The larger current produces greater series-impedance drops, while resistive losses increase with the square of branch-current magnitude. Consequently, equal additions of EV power need not cause equal increments in loss. The

recorded cases show a progressively steeper loss response as loading rises, particularly under the evening multiplier.

Voltage screening and equipment adequacy must also be distinguished. The no-EV feeder already has 21 buses below 0.95 p.u., although none falls below the selected 0.90 p.u. study threshold. The stricter screen therefore flags conditions that the 0.90 p.u. count alone does not reveal. In the same way, a branch-current ratio relative to the baseline is a useful indicator of increasing stress but cannot determine whether a conductor or transformer exceeds its rating. A site-specific decision would require the applicable operating limits, thermal ratings, network-control settings, and time-varying demands.

The results are best interpreted alongside, rather than in place of, more elaborate EV integration methods. Probabilistic charging profiles [7], controlled charging [6], and alternative station allocation [5], [9] could change both the location and duration of high loading. Conversely, the voltage and loss values reported here provide a defined base case for examining those changes. The independent charger model contributes an operating-point example but does not supply the aggregate feeder demand directly; its dynamic output and the static network cases answer separate questions.

6.1. Incremental voltage and loss response

The finite differences between adjacent model cases make the nonlinear loss response more apparent than the end points alone. Table 4 divides each increase in feeder loss by the corresponding increase in imposed EV power; it also reports the reduction in minimum voltage across the same interval. These are numerical differences between specified steady-state cases, not derivatives of an estimated load curve or measures of charger efficiency.

Table 4. Finite differences between adjacent charging-demand levels calculated from the saved scenario results.
Source: authors' calculations from the archived load-flow results [4].

Nominal α interval (%)	$\Delta P_{\text{loss}}/\Delta P_{\text{EV}}$, day (kW/kW)	$\Delta P_{\text{loss}}/\Delta P_{\text{EV}}$, evening (kW/kW)	ΔV_{min} , day (p.u.)	ΔV_{min} , evening (p.u.)
0–20	0.121	0.130	0.01525	0.02578
20–40	0.148	0.178	0.01591	0.02777
40–60	0.178	0.236	0.01665	0.03024
60–80	0.211	0.308	0.01750	0.03343

For the daytime sequence, the incremental loss ratio increases from 0.121 to 0.211 kW per additional kW of imposed EV demand. In the evening sequence, it rises from 0.130 to 0.308 kW/kW. Although the 20-point steps in nominal α are identical, their effective power increments differ between the profiles: 445.8 kW by day and 743.0 kW in the evening. The comparison shows how strongly the selected operating point affects the additional loss associated with a further loading step. It does not establish an optimum demand level or a universal threshold for other feeders.

6.2. Charging-site sensitivity and voltage-constrained hosting capacity

The single-site comparison reveals markedly different feeder responses to the same 743.0 kW of charging demand. Table 5 shows that placing the entire increment at bus 6 yields a minimum network voltage of 0.90141 p.u., whereas placements at buses 18 and 33 reduce the minimum to 0.84753 and 0.87908 p.u., respectively. Feeder losses are 271.79, 380.65, and 333.98 kW in the same order, compared with 202.677 kW without EV demand. Thus, only the bus 6 case satisfies the selected voltage screen at this common load. In contrast, the original evening $\alpha = 20\%$ scenario splits 743.0 kW across three nodes; the two configurations must not be interpreted as equivalent.

Table 5. Fixed-load site comparison and additional EV capacity under a 0.90 p.u. voltage screen.
Source: authors' backward/forward-sweep results using the case33bw feeder [4].

Metric	Bus 6	Bus 18	Bus 33
Added EV demand in comparison (kW)	743.0	743.0	743.0
Minimum voltage for 743 kW (p.u.)	0.90141	0.84753	0.87908
Feeder active loss for 743 kW (kW)	271.79	380.65	333.98
Loss increase from no-EV case (%)	34.10	87.81	64.78
Buses below 0.90 p.u.	0	9	5
Voltage-limited additional EV capacity (kW)	831.46	160.71	339.06

The bisection searches locate site-dependent voltage-limited additional demands of 831.46 kW at bus 6, 160.71 kW at bus 18, and 339.06 kW at bus 33 (Fig. 7). In this three-site comparison, bus 6 accommodates approximately 5.17 times the added demand permitted at bus 18 under the same criterion. These numerical limits apply only to the fixed baseline loading, balanced model, unity-power-factor increment, and 0.90 p.u. screening threshold. They should not be treated as available charger nameplate capacity or network-wide optimal connection limits.

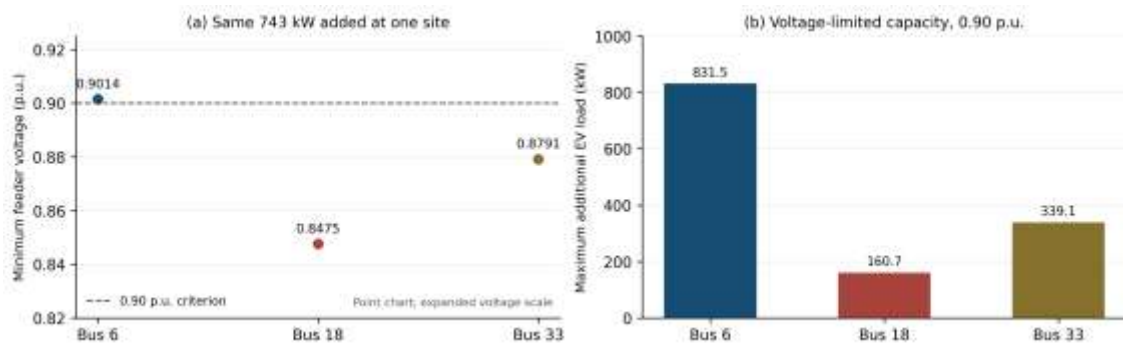


Fig. 7. Voltage response to 743 kW single-site charging (left; expanded ordinate, shown as points) and voltage-constrained additional demand at 0.90 p.u. (right; zero-based bars).
Source: load-flow calculations using case33bw data [4].

6.3. Relation to other EV-integration approaches

Table 6 highlights how the questions examined here differ from representative contemporary studies. The comparison also indicates where additional data or controls would be needed to extend the present voltage-screening results toward a complete engineering planning study.

Table 6. Scope of representative EV integration studies relative to the present assessment.
Source: authors' comparison of the studies cited in the first column.

Work	Principal emphasis	Relationship to this study
Abdelaziz et al. [5]	Optimal station allocation	Three individual candidate buses are compared; no network-wide site optimization is performed.
Cañigüeral et al. [6]	Smart charging subject to dynamic network limits	The 0.90 p.u. limit screens fixed power injections; no charging schedule or dynamic control is applied.
Nascimento et al. [7]	Data-driven probabilistic charging and network impact	Demand levels here are prescribed rather than sampled.
Pinnarelli et al. [9]	Siting under varying demand and renewable generation	The original loads and topology remain fixed.
Ibrahim et al. [2]	Multidimensional EV-related network effects	Only balanced fundamental-frequency voltage, current, and loss are assessed.
Mariscotti et al. [8]	Wide-ranging grid and power-quality interactions	Harmonic, unbalance, and impedance-frequency effects are outside the load-flow model.

This comparison suggests a practical path for subsequent investigation. The fixed baseline and location-specific estimates identify sensitivity under explicit assumptions, whereas a complete planning study would also examine multiple simultaneous site loads, the trade-off between losses and charging access, conductor

and transformer ratings, and protection settings. Measured charging profiles, uncertainty analysis, and applicable statutory voltage standards would be needed before the numerical limits could inform deployment decisions. The present screening results are not presented as globally optimal or probabilistically guaranteed hosting capacities.

6.4. Interpreting the independent charger result

At the charger level, the measured 3.385 kW battery-terminal power and 3.536 kW DC/DC output power describe the short simulated interval after the charge path closes. Most of the difference corresponds to the modeled external series resistance. At the feeder level, by contrast, EV demand is introduced as a balanced constant-power increment that is not generated from those waveforms. This separation matters: a stable charging current in the converter test supports the behavior of the tested circuit at that operating point, but it is not evidence of feeder-wide converter efficiency, harmonic performance, or coordinated charging.

7. Limitations and Future Work

The findings depend on the IEEE 33-bus topology, a balanced constant-power model, and unity-power-factor EV demand. In the main scenarios, additional load is shared equally among buses 18, 25, and 33; the candidate-site tests instead place it wholly at one bus. The coincidence factors are illustrative and original demand remains fixed. The bisection-based values are voltage-only limits derived from a single base operating point, not verified thermal, transformer, protection, or regulatory hosting capacities. Time-dependent customer loads, voltage regulation, network reconfiguration, phase imbalance, uncertainty, and simultaneous occupancy of multiple proposed charging sites are outside the present model.

The converter simulation describes a brief charging operating point rather than a complete battery charge cycle. Future analysis should test alternative base-load levels, charger reactive-power demand, thermal component ratings, coordinated multi-site charging, and measured charging schedules. A coupled, validated feeder-and-charger model would also be necessary to examine interactions involving switching transients, harmonics, and phase unbalance.

8. Conclusion

Prescribed EV charging demand at buses 18, 25, and 33 produces a consistent reduction in minimum voltage and an increase in feeder resistive losses on the IEEE 33-bus test system. With 2,972 kW of evening EV demand, minimum voltage decreases from 0.913090 to 0.795866 p.u., losses rise from 202.677 to 835.423 kW, and 18 buses fall below the selected 0.90 p.u. screen. Incremental loss penalties also grow with load. A further fixed-demand comparison demonstrates material connection-point sensitivity: concentrated 743 kW charging produces minimum voltages of 0.90141, 0.84753, and 0.87908 p.u. at buses 6, 18, and 33, respectively. The corresponding additional voltage-limited hosting estimates are 831.46, 160.71, and 339.06 kW. These differences underline the importance of site selection, but the numerical estimates cannot establish thermal adequacy or general network-wide optimum siting. A separate Simscape model records 8.678 A charging current and 3.385 kW mean battery-terminal power over a short operating interval. Collectively, the results provide a reproducible, explicitly bounded load- and location-sensitivity benchmark for subsequent EV infrastructure planning studies.

Data and Code Availability

The IEEE 33-bus input data, MATLAB scripts, numerical scenario results, candidate-site capacity calculations, and the separate Simscape charger model accompany the study in the supplementary research archive. Additional execution details may be obtained from the corresponding author.

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