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Efficient hosting capacity computation using the bisection method for rapid grid capacity assessment

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ABSTRACT

This paper introduces a novel approach for computing Hosting Capacity (HC) by employing the bisection method as an alternative to the traditional step method. The primary objective is to achieve nodal and global HC results with significantly reduced computation time while preserving the accuracy characteristic of the step generator method. This fast and reliable technique is particularly well-suited for the iterative calculations required by large energy utilities to determine the maximum grid capacity for integrating new loads and distributed energy resources. The proposed method leverages grid linearization, incorporating the concept of compensation admittance at each node. The validity and effectiveness of the bisection-based HC computation are demonstrated through a comparative analysis against classical step method results, confirming its accuracy and computational efficiency.

1. Introduction

The increasing integration of distributed generation (DG) into medium- and low-voltage (MV/LV) distribution grids has introduced several technical challenges for distribution system operators (DSOs) worldwide [1–3]. One of the key concerns is determining the maximum amount of DG that can be connected to the existing network without violating operational constraints, a metric commonly referred to as *Hosting Capacity* (HC) [4–6]. HC serves as a crucial Key Performance Indicator (KPI) for assessing the robustness and flexibility of power distribution systems under high DG penetration. The hosting capacity of a grid is primarily constrained by technical limitations such as voltage deviations, line thermal limits, reverse power flow through transformers, and short-circuit current thresholds. These constraints are typically defined by national and international standards and must be strictly respected to ensure safe and reliable grid operation [7–9]. Violating these limits may lead to equipment damage, protection malfunctions, and financial penalties for grid operators [10–12]. Among the most significant impacts of high DG penetration are:

- **Power flow reversal:** Traditional distribution networks were designed for unidirectional power flow from high-voltage (HV) to LV levels. The bidirectional injection of power from DG units alters voltage profiles and stresses existing infrastructure, particularly transformers.
- **Islanding conditions:** Unintentional islanding may occur when DG continues to supply local loads after disconnection from the main grid, posing safety risks and complicating fault management.
- **Voltage fluctuations:** DG units can cause both slow and fast voltage variations depending on their output dynamics and location within the network.
- **Protection coordination issues:** The presence of DG can interfere with conventional overcurrent and short-circuit protection schemes, leading to miscoordination, false tripping, or failure to isolate faults.

Given these challenges, accurate and computationally efficient methods for HC assessment are essential to support planning and real-time operation of modern distribution systems. Traditional approaches often rely on iterative load flow analyses using fixed power steps to determine the maximum allowable DG size at each node. However, these methods can be time-consuming, especially when applied to large-scale networks or used in optimization loops for global HC estimation. This paper proposes a novel and efficient method for computing nodal HC based on the bisection algorithm. Compared to the classical step-wise power increment approach, the proposed method significantly reduces computational effort while maintaining high accuracy. The technique exploits grid linearization and compensation admittance concepts to accelerate convergence, making it suitable for rapid grid capacity assessments in large networks.

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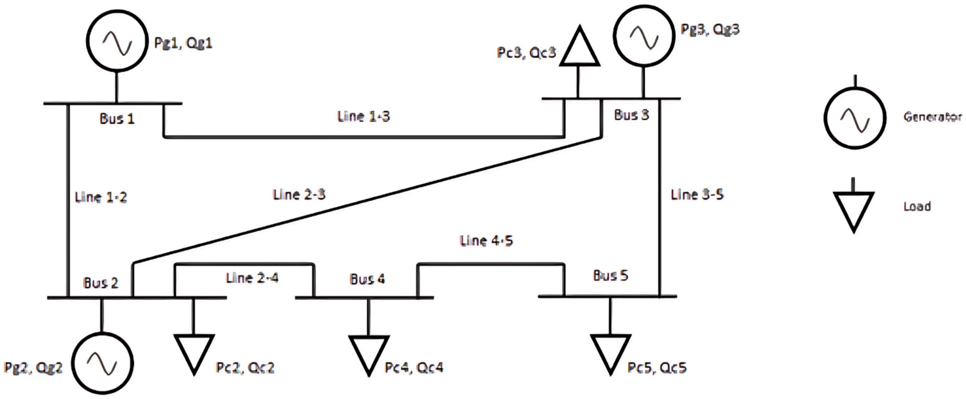

Fig. 1. Typical scheme of a load flow power grid.

2. HC computation

The calculation of Hosting Capacity involves an iterative process that requires solving the power grid, which includes determining all voltages and currents in the grid [10,13–17]. However, distributed generation is connected to the national power grid through inverters that feed power from sources such as the sun and wind, and loads absorb a certain amount of complex power. Therefore, the focus of the resolution is on nodal voltages, such as modulus and phase, with known complex power absorbed or delivered at the nodes. This is the power flow problem on the network, which we will briefly discuss. Load flow analysis is a fundamental analysis in power systems that examines the grid from the perspective of electrical flows [3,18–21]. As load and generator schematics change over time, load flow analysis determines the nodal voltages and power flowing through the lines connecting these nodes at a specific moment in time. Because this period only lasts for a few minutes while loads remain constant, the system is considered to be in a steady-state. In order to maintain constant active and reactive power during load flow computations, nodal and generator voltages are changed in terms of magnitudes and phases, making the problem inherently nonlinear and iterative. Fig. 1 below shows the typical electrical circuit for load flow problems, with active and reactive powers representing generators and loads, respectively.

Fig. 2 shows the representation of the power system as a network of nodes and branches, where the nodes represent the buses and the branches represent the trans-mission lines or transformers. The voltage and the power flows at each bus and branch are indicated by their respective values. In load flow analysis, the nodal voltages and the active and reactive power flows on the branches are calculated iteratively until they converge to a stable solution. The load flow analysis is critical in power system planning, operation, and control, as it provides information on the performance of the power system under different operating conditions and helps in identifying potential problems such as voltage instability, overloading, and voltage violations.

Eq. (1) expresses the active power P_k and reactive power Q_k of the k bus-bar as the difference between the generated power P_{gk} and the consumed power P_{ck} (for active power) or $Q_c k$ (for reactive power).

$$P_k = P_{gk} - P_{ck}; \qquad Q_k = Q_{gk} - Q_{ck}; \tag{1}$$

Eq. (2) defines the complex power S_k of the k bus-bar as the product of its voltage V_k and the complex conjugate of its current I_k. The complex power S_k can also be written as $P_k + jQ_k$, where j is the imaginary unit.

$$S_k = V_k \dot{I}_k^* = P_k + jQ_k \tag{2}$$

Substituting the transmission lines equivalent model, Fig. 3 shows the transformed grid considering only admittances:

For easy inspection, the admittance bus matrix (Y_{bus}) can be written. The diagonal elements of Y_{ii} and Y_{ij} are called self-admittances and mutual admittances, respectively. Therefore, the following Eq. (3) provides a short way to express:

$$I_b us = Y_{bus} \cdot V_{bus} \tag{3}$$

where I_{bus} is the vector of currents at all busbars, Y_{bus} is the bus admittance matrix, and V_{bus} is the vector of voltages at all busbars. Nodal voltages can be obtained by solving matrices of linear algebraic equations Let's analyze Eq. (3) which has a less compact form represented by Eq. (4):

$$I_k = \sum_{n=1}^{N} Y_{kn} \cdot V_n \tag{4}$$

This equation expresses the current at the kth busbar as the sum of the products of the admittances between the kth and nth busbars and the voltage at the nth busbar, where n ranges from 1 to N. Expanding this equation for each element I_k of the I_{bus} vector, we get Eq. (6):

$$P_k + jQ_k = V_k \cdot I_k^* \tag{5}$$

Substituting Eq. (4) in Eq. (5) we get:

$$P_k + jQ_k = V_k \cdot \left[\sum_{n=1}^{N} Y_{kn} \cdot V_n \right]^* \tag{6}$$

with k = 1, 2,…, N nodes. Now, considering polar form for nodal voltages and circuit admittances as in (7):

$$V_n = |V_n| e^{j\partial n}; \qquad Y_{kn} = |Y_{kn}| e^{j\theta kn}; \tag{7}$$

substituting Eq. (7) in Eq. (6), we get Eq. (8):

$$P_k + jQ_k = V_k \cdot \sum_{n=1}^{N} Y_{kn} \cdot V_n \cdot e^{j(\partial n - \partial k - \theta kn)} \tag{8}$$

Applying then Euler's formula in Eq. (8) we finally get power flow in Eqs. (9,10):

$$P_k = V_k \cdot \sum_{n=1}^{N} Y_{kn} \cdot V_n \cdot \cos(\partial n - \partial k - \theta kn) \tag{9}$$

$$Q_k = V_k \cdot \sum_{n=1}^{N} Y_{kn} \cdot V_n \cdot \sin(\partial n - \partial k - \theta kn) \tag{10}$$

In Eqs. (9,10), P_k and Q_k are expressed in terms of the nodal voltages and admittance matrix elements of the power grid. These equations represent the power flow equations, which relate the active and reactive power of each bus to the voltage magnitudes and phases of the buses. Since the power flow equations contain trigonometric functions and nodal voltages, they are nonlinear and require iterative numerical computation. Traditional methods like the NR and GS techniques can be used to solve these equations, but they can be time-consuming, especially for

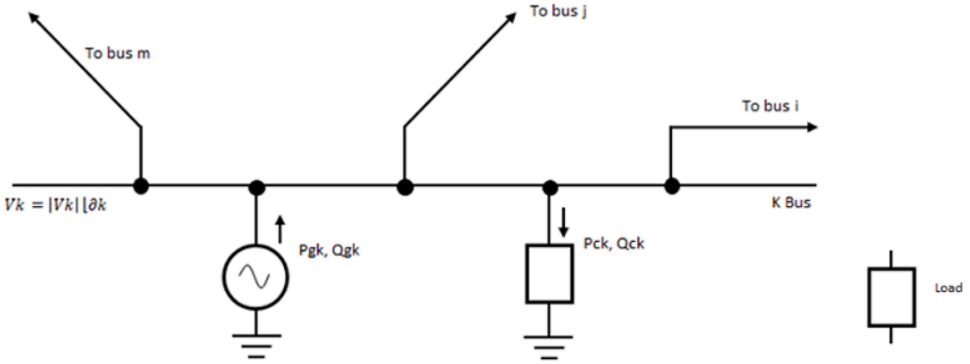

Fig. 2. Detail of k-bus of Fig. 1 generic grid.

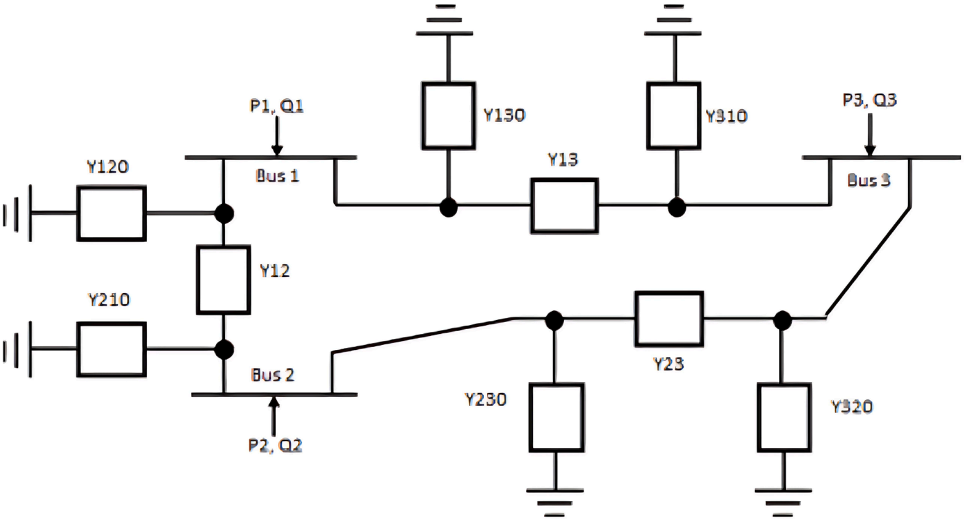

Fig. 3. A three buses power grid, considering complete lines model.

large power grids. Therefore, there is always interest in developing new methods for calculating power grids, such as the recently proposed CALF method, which are optimized for fast execution time while maintaining accuracy. It is important to note that the accuracy and timing of the LF more efficient is the HC calculation. This is why new methods of calculating power grids, leading to time effectiveness, should be explored. But now let us focus on HC classical method to better understand the numerical algorithms to calculate this KPI and which is our new proposal. The nodal HC calculation classical algorithm, is based on inserting a test generator on one node while leaving the others unchanged.

The algorithm involves increasing the value of the active power input from the generator in predefined steps and performing a load flow (LF) analysis on the network to check whether any network constraint is violated. If a constraint is violated, the previous value of the test generator is considered as the nodal HC. Conversely, if there is no constraint violation, the LF analysis is repeated by increasing the power of the test generator by the predefined step. The algorithm continues until no network constraint violation is found. However, this computational approach is highly dependent on the value of the HC to be estimated, and the presence of multiple iterations means that the HC calculation time depends on the LF algorithm used. The accuracy of the LF calcula-tion is also crucial, as an inadequate accuracy may lead to an underestimation or over-estimation of the maximum HC at that node. Furthermore, the inherent accuracy of the method is limited by the amplitude of the power step used to increase the test genera-tor's power at each iteration. Therefore, if one wishes to determine the HC more accu-rately, the amplitude of the power step must be decreased, although this will increase the total computation time. Fig. 5 shows a typical power step HC algorithm graph, where the test generator's power is increased in small steps until the power representing the HC is reached.

It is essential to note that the global hosting capacity, which determines how much new generation a network can accommodate, is a much more complex problem that involves inserting test generators on each node and evaluating all possible combinations of testable values on the nodes, making it a typical problem solvable by heuristic optimization algorithms. Finally let us briefly focus on the concept of global hosting capacity. This concept refers to the maximum amount of distributed generation that can be integrated into a distribution network without causing any violations or overloads. Unlike the nodal HC calculation algorithm discussed earlier, the global HC calculation is far more complex as it requires testing all possible combinations of values testable on each node, following all the permutations limited by the power step alone. This would involve inserting test generators on each node, which is a computationally disadvantageous study condition. Therefore, solving the global HC problem requires the use of heuristic optimization algorithms, which is beyond the scope of this discussion. In this article, we focus on proposing a new method for computing nodal HC. In summary, classical method for computing nodal HC is based on a power step algorithm that involves increasing the test generator's power in small steps and performing LF analyses until no network constraint violation is found. However, the accuracy and computational time of the method depend on the LF algorithm used and the amplitude of the power step.

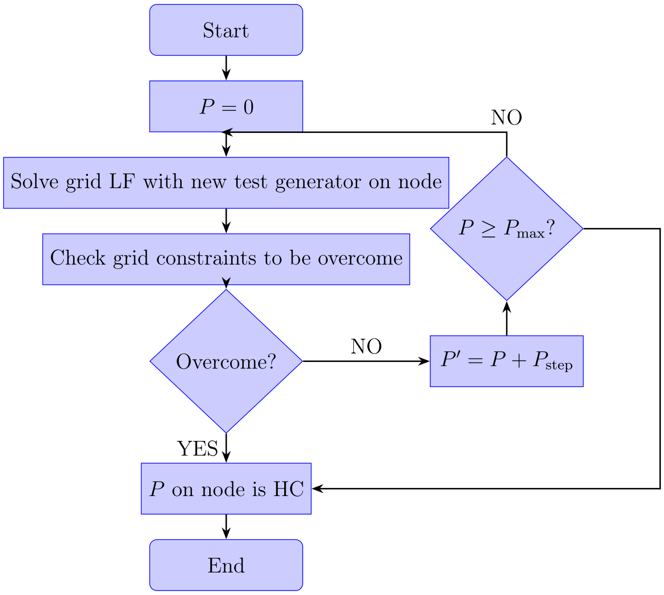

Fig. 4. Flowchart for hosting capacity computation.

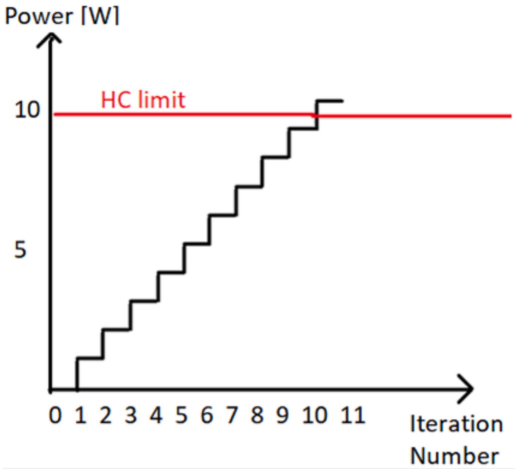

Fig. 5. Power step HC algorithm graph.

3. HC new computation method

The new algorithm for calculating nodal HC aims to optimize the execution time by reducing the number of iterations required to find the power that, when applied via a test generator on a specific node, causes one of the network constraints to be overrun. The bisection method is applied to achieve this goal, as illustrated in Fig. 7.

The test generator's power is initialized at half the maximum power that can be connected to the grid, and a LF calculation is performed to determine the grid magnitudes necessary to verify the network constraint overrun. If the verification is successful, the HC must be in the previous half of the possible power values that can be installed on that node, otherwise, the power of the test generator is increased by positioning it in the middle of the next half. The LF and subsequent subdivisions are repeated until the change in the next step generator power relative to the current value goes below a certain tolerance. Compared to the traditional power-step approach, the bisection algorithm is more effective in calculating HC because it reaches the solution with a more direct trend. This approach performs a more articulated true sensing of the solution, as shown in Fig. 7.

The bisection algorithm is more efficient, and the number of iterations required depends on the value of HC to be calculated. However, the time saved by using this algorithm can be used to obtain a more accurate HC result since the classical power-step algorithm's precision is restricted by the amplitude of the power step set for the calculation. The bisection algorithm can stop at a determined tolerance, making it less sensitive to accuracy in terms of execution, leading to a more accurate solution in less time.

3.1. *Bisection method for hosting capacity calculation*

The bisection method is a numerical approach to efficiently determine the maximum distributed generation (DG) power that can be integrated into a grid without violating operational constraints. This method iteratively narrows down the feasible range of DG power until convergence is achieved.

Mathematical Formulation For a node with initial power bounds $[P_{\text{low}}^{(0)}, P_{\text{high}}^{(0)}]$, the bisection method updates these bounds at each iteration k:

$$P_{\text{mid}}^{(k)} = \frac{P_{\text{low}}^{(k)} + P_{\text{high}}^{(k)}}{2}$$

The power $P_{\text{mid}}^{(k)}$ is tested using a load flow (LF) method (e.g., Compensation Admittance Load Flow [1]) to check voltage constraints:

$$v_{\min} \leq v_i(P_{\text{mid}}^{(k)}) \leq v_{\max} \quad \forall i \in \text{nodes}$$

If constraints are satisfied, $P_{\text{low}}^{(k+1)} = P_{\text{mid}}^{(k)}$; otherwise, $P_{\text{high}}^{(k+1)} = P_{\text{mid}}^{(k)}$.

Algorithm Steps

1. **Initialization:** Define tolerance τ (e.g., 1 % [3]) and maximum iterations.
2. **Iteration:** - Compute P_{mid}. - Solve LF for P_{mid} and validate constraints. - Update bounds based on constraint violations.
3. **Convergence:** Terminate when $\frac{P_{\text{high}}^{(k)} - P_{\text{low}}^{(k)}}{P_{\text{high}}^{(k)}} \leq \tau$ [1][3].

Advantages

- **Speed**: Reduces computational time compared to stepwise methods [1].
- **Accuracy**: Maintains precision by leveraging convexity in voltage-power relationships [4].
- **Example Application** For a feeder with $P_{\text{low}}^{(0)} = 0$ and $P_{\text{high}}^{(0)} = 400$ kW, the bisection method converges to $P_{\text{HC}} = 315$ kW within 10 iterations (tolerance $\tau = 1$ %) [1][3].

3.2. *Selected parameters and their relationship to the power grid model*

The calculation of Hosting Capacity (HC) relies on a set of electrical and operational parameters that directly reflect the physical and regulatory constraints of the power grid. These parameters are critical for accurately modeling the grid and ensuring that the integration of Distributed Generation (DG) does not violate technical standards or compromise system reliability. Below, we detail the main parameters selected for HC assessment and their roles within the grid model.

- **Voltage Limits ($v_{\min}, v_{\max}$):** The allowable voltage range at each node, typically defined by standards (e.g., EN 50160), ensures that customer equipment operates safely. Exceeding these bounds can damage equipment or lead to regulatory penalties. In the grid model, voltage at each node is computed as a function of power injections and network impedance.
- **Short-Circuit Parameters (R_{cc}, X_{cc}):** The short-circuit resistance (R_{cc}) and reactance (X_{cc}) as seen from each node are fundamental for calculating voltage drops and short-circuit currents. They influence the maximum permissible DG power by determining how much the voltage will rise or fall with additional generation.

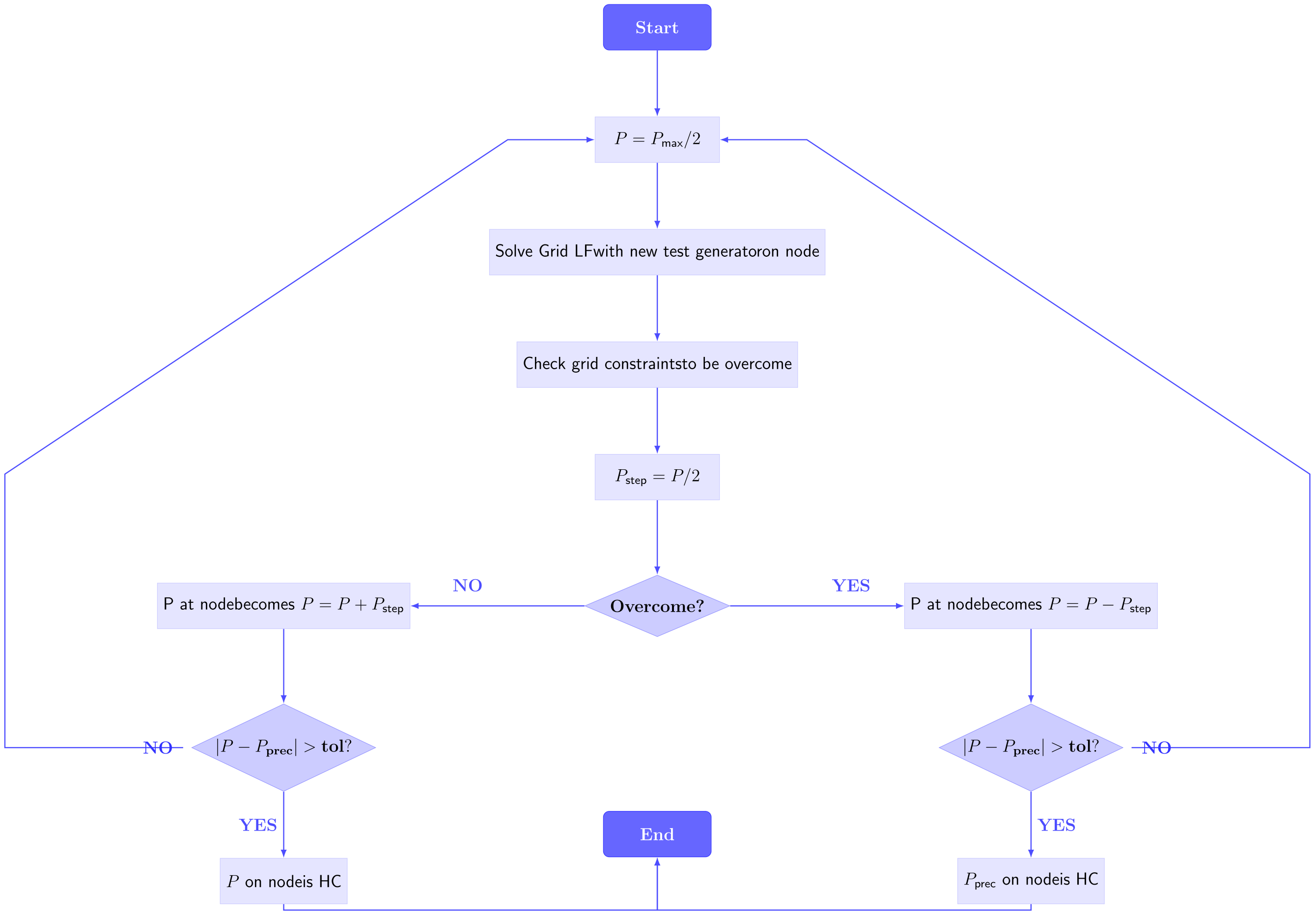

Fig. 6. Bisection HC algorithm graph.

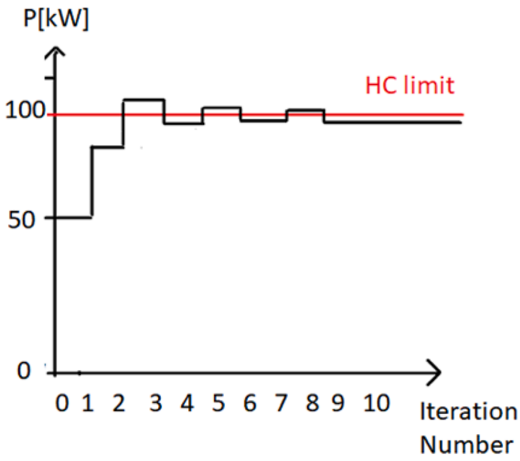

Fig. 7. Bisection HC algorithm graph.

- **Active and Reactive Power (P, Q):** The active (P) and reactive (Q) power absorbed or injected at each node affect both voltage profiles and current flows. The relationship:

$$\Delta U = R_{cc} \cdot P + X_{cc} \cdot Q$$

quantifies the voltage variation due to power exchanges, guiding the assessment of how much DG can be installed without breaching voltage limits.

- **Current Ratings and Thermal Limits (I, I_z):** Each line and transformer has a maximum continuous current rating (I_z), determined by its thermal limits. The total current at each node, given by:

$$I = \frac{|P + jQ|}{U}$$

must not exceed I_z to avoid overheating and insulation damage. This constraint directly limits the size of DG that can be hosted at each point in the network.

- **Protection Settings (I_n, I_p):** Overcurrent (I_n) and short-circuit (I_p) protection thresholds ensure safety and selectivity. The presence of DG can alter fault current levels and directions, potentially causing unwanted tripping or blinding of protections. The grid model must account for these changes to maintain protection coordination.
- **Grid Topology and Node Location:** The physical layout of the network, including the distance from the substation and the position of loads and generators, affects impedance, voltage profiles, and the impact of DG integration. Nodes farther from the substation typically experience greater voltage fluctuations for the same power injection.
- **Load Profiles:** The temporal variation of loads at each node influences the available margin for DG integration. High load conditions may allow more DG without violating constraints, while low load periods may be more restrictive.
- **Compensation Admittance (CALF Method):** The Compensation Admittance Load Flow (CALF) method introduces compensation admittance at each node, enabling a linearized and efficient calculation of voltage responses to DG injections. This parameterization is key to the bisection-based HC calculation proposed by Risi et al.

Table 1
Key differences between the proposed and traditional bisection methods.

Feature	Proposed Method	Traditional Bisection
Application	Hosting Capacity (DG integration limits)	General root-finding, voltage stability, OPF
Objective	Maximize DG without constraint violation	Solve nonlinear equations, find equilibrium
Constraint Handling	Explicit multi-constraint checking (voltage, current, flow reversal)	Scalar or single constraint focus
Algorithm Integration	Combined with fast LF solver (CALF)	Paired with standard LF methods (NR/GS)
Speed vs. Accuracy	Optimized for HC estimation efficiency	Focus on numerical convergence
Use Case	Distribution network planning with DG	Transmission systems, motor analysis, OPF

Relationship to the Power Grid Model:
All these parameters are embedded within the power flow equations and the grid's admittance matrix. The HC calculation iteratively adjusts the DG power at selected nodes, using the bisection method, and checks compliance with all constraints (voltage, current, protection, etc.) at each step. The interplay of these parameters defines the technical hosting capacity of the grid, ensuring safe and reliable operation under increasing DG penetration.

3.3. *Comparison with traditional bisection methods in power systems*

The bisection method introduced in this paper for computing Hosting Capacity (HC) differs significantly from traditional implementations of the bisection method used in general power system applications. While both approaches share the common numerical foundation of iterative root-finding, the application context, algorithm design, and integration with power flow solvers distinguish the proposed method. The primary objective of the proposed method is to determine the maximum level of distributed generation (DG) that can be integrated into a distribution network without violating operational constraints such as voltage limits, line thermal capacity, transformer reversal, and short-circuit current thresholds. This contrasts with classical uses of the bisection method, which are typically applied to solve nonlinear equations in load flow analysis, voltage stability studies, or optimal power flow (OPF) problems. Algorithmically, the proposed method applies the bisection technique within a bounded search space defined by the DG penetration level at each node. Starting from a midpoint value, it performs a Load Flow (LF) analysis to evaluate constraint violations and adjusts the interval accordingly. This approach reduces the number of required LF iterations compared to the conventional step-by-step increase method. In contrast, traditional bisection methods are generally employed for scalar root-finding tasks, such as determining critical loading conditions or equilibrium points, rather than constraint boundary detection in the context of renewable energy integration. A key innovation lies in the integration of the bisection method with a novel, fast-converging LF solver called Compensation Admittance Load Flow (CALF). CALF linearizes the grid using a compensation admittance concept, enabling faster execution times while maintaining high accuracy. This synergy allows for rapid convergence to HC thresholds across multiple nodes and scenarios. Traditional implementations typically rely on standard LF solvers such as Newton-Raphson (NR) or Gauss-Seidel (GS), which may not be optimized for speed or specific constraint evaluations relevant to DG hosting capacity. Furthermore, the proposed method explicitly checks for multiple technical constraints during each LF iteration, dynamically narrowing the DG capacity range based on which constraint is violated first. This multi-constraint handling capability is more advanced than typical bisection-based root-finding, which often focuses on single-variable or scalar constraints. Finally, the method is tailored for large-scale distribution networks with high DG penetration, demonstrating scalability and efficiency in systems ranging from 2-node to 101-node grids. In contrast, traditional bisection applications tend to be generic and less structured for domain-specific challenges such as reverse power flow, voltage rise, or protection coordination issues caused by distributed energy resources. Table 1 summarizes the main differences between the proposed method and traditional bisection applications in power systems.

Table 2
Comparison of HC algorithms in terms of number of iterations on standard grids.

Grid nodes	#iteration classical method	#iteration bisection method
2	75	63
19	95	80
101	120	100

Table 3
Execution time for total nodal HC calculation for new and classic algorithm.

Grid nodes	classical method exe time (ms)	bisection method exe time (ms)
2	0.15	0.12
19	2.1720	1.0141
101	761.4170	94.5930

Table 4
Execution time for total nodal HC calculation using different LF methods and HC algorithms (CALF is optimized).

Grid nodes	classical method exe time (ms)			bisection method exe time (ms)		
	GS	NR	CALF	GS	NR	CALF
2	0.0900	0.1500	0.0800	0.0800	0.1200	0.0700
19	1.5209	2.1160	1.5228	1.5216	3.0276	1.5183
101	20.4718	67.0526	9.5151	9.3869	20.5915	9.0766

4. Mathematical foundations of the bisection method for hosting capacity calculation

The bisection method, traditionally employed in numerical analysis for root-finding problems, has been adapted in this study to efficiently determine the Hosting Capacity (HC) of distributed generation (DG) units within distribution networks. Unlike classical applications that target scalar roots of nonlinear equations, the proposed method leverages the bisection framework to identify the threshold DG capacity at which one or more network constraints are violated. This section outlines the mathematical formulation and convergence properties of the proposed bisection-based HC computation algorithm, emphasizing its suitability for power system applications involving constraint boundary detection.

4.1. *Problem formulation*

Let $P_{\mathrm{DG}} \in [P_{\min}, P_{\max}]$ represent the active power injected by a DG unit connected at a specific node of the distribution network. The hosting capacity P_{HC} at that node is defined as the maximum value of P_{DG} such that all operational constraints-such as voltage limits, line thermal limits, transformer flow reversal, and short-circuit current thresholds–are satisfied. Mathematically, this can be expressed as:

$$P_{\mathrm{HC}} = \sup \left\{ P_{\mathrm{DG}} \in [0, P_{\max}] \mid g_i(P_{\mathrm{DG}}) \le 0, \forall i \in C \right\}, \tag{11}$$

where $g_i(P_{\mathrm{DG}})$ represents the ith inequality constraint function over the set C of operational constraints. Each constraint function g_i depends on the power flow solution derived from the nodal admittance matrix and the corresponding load flow (LF) model. Since these functions are generally continuous and monotonic with respect to P_{DG}, the problem becomes well-suited for a bisection approach.

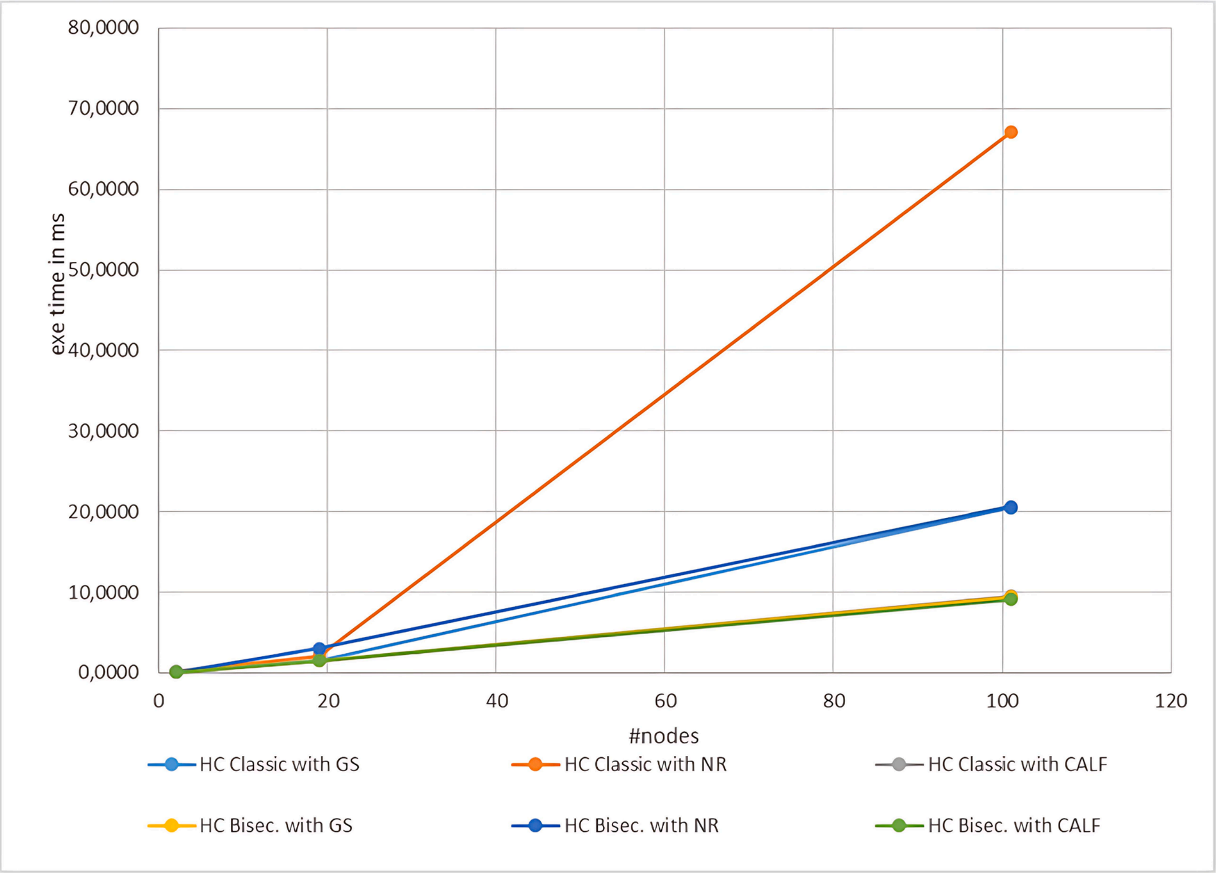

Fig. 8. Time saving for HC usage of time effective algorithm for LF.

4.2. Bisection algorithm framework

The bisection method iteratively narrows down the interval $[a, b]$ containing P_{HC} based on the sign of constraint violations evaluated at the midpoint $c = \frac{a+b}{2}$. Starting with an initial interval $[0, P_{\max}]$, the algorithm proceeds as follows: This iterative process ensures convergence to a solution within the specified tolerance ϵ, assuming that the constraint functions g_i change monotonically with increasing P_{DG}, which is typically valid for practical distribution networks under normal operating conditions.

Algorithm 1 Bisection-based HC computation.

```
Initialize: $a \leftarrow 0$, $b \leftarrow P_{\max}$
Set tolerance $\epsilon > 0$
while $b - a > \epsilon$ do
    $c \leftarrow \frac{a+b}{2}$
    Perform LF analysis with $P_{\mathrm{DG}} = c$
    if all constraints are satisfied then
        $a \leftarrow c$
    else
        $b \leftarrow c$
    end if
end while
Return $P_{\mathrm{HC}} \approx \frac{a+b}{2}$
```

4.3. Convergence and complexity analysis

The bisection method guarantees linear convergence, reducing the search interval by half at each iteration. The number of iterations required to achieve a given accuracy ϵ is approximately:

$$N_{\mathrm{iter}} \approx \log_2 \left(\frac{P_{\max}}{\epsilon} \right). \tag{12}$$

This logarithmic dependence on ϵ makes the method significantly more efficient than classical step-wise methods, which scale linearly with $\frac{1}{\Delta P}$, where ΔP is the power step size. Moreover, the computational efficiency of the algorithm is further enhanced when combined with fast-converging load flow solvers such as the Compensation Admittance Load Flow (CALF), which linearizes the grid and reduces the complexity of each LF evaluation.

4.4. Constraint violation detection

At each iteration, the LF solution provides the vector of nodal voltages $\mathbf{V}$ and branch currents $\mathbf{I}$, allowing for direct evaluation of constraint violations. For example, voltage constraints are checked using:

$$V_{\min} \leq |V_k| \leq V_{\max}, \quad \forall k \in \mathcal{N}, \tag{13}$$

where $\mathcal{N}$ denotes the set of nodes. Similarly, thermal limits are enforced via:

$$|I_{ij}| \leq I_{\max,ij}, \quad \forall (i,j) \in \mathcal{L}, \tag{14}$$

with $\mathcal{L}$ representing the set of branches. These checks ensure that the bisection loop accurately identifies the first constraint violation point, enabling precise estimation of P_{HC}.

4.5. Comparison with classical methods

Unlike classical step-wise methods that require multiple LF evaluations spaced by fixed increments ΔP, the bisection method dynamically

Table 5
Execution times comparison between HC classic and HC bisection algorithms for power flow calculation in electrical grids.

Power step [kW]	Grid nodes	classical method exe time (ms)	bisection method exe time (ms)
0.1	2	0.170	0.160
	19	29.329	20.583
	101	897.070	117.723
0.2	2	0.170	0.160
	19	21.220	18.873
	101	766.240	114.213
0.5	2	0.170	0.170
	19	17.927	17.826
	101	567.515	113.530
1	2	0.160	0.160
	19	15.401	15.244
	101	447.802	105.040
2	2	0.150	0.160
	19	15.388	15.607
	101	301.322	104.150
5	2	0.140	0.140
	19	10.389	11.073
	101	110.104	98.541
10	2	0.140	0.140
	19	10.141	10.184
	101	105.315	94.853

adjusts the search space based on constraint satisfaction feedback. This results in fewer LF calls and faster convergence without compromising accuracy. Additionally, the bisection method allows for adaptive tolerance settings, making it suitable for both coarse and fine-grained HC estimations depending on application requirements.

5. Results

5.1. Iteration and time savings

The number of iterations and execution time required for each node using both HC algorithms for the different grids were compared. The results are shown in Table 2:

As shown in Table 2, the bisection method required fewer iterations than the classical power-step approach. Table 3 presents the total execution time required by the two algorithms when launched sequentially for each node of the grid, with the results separated per grid and per algorithm:

The bisection method required less execution time than the classical power-step approach for all three grids. In addition, as shown in Table 4 and related Fig. 8, using the bisection method with a time-efficient load flow algorithm [22] resulted in significant time savings:

Fig. 8 shows the time savings achieved by using a time-efficient load flow algorithm in combination with the bisection method for HC calculation. As we can see, for all three grids, there is a significant reduction in computation time when the time-efficient load flow algorithm is used. This is particularly evident for the larger 101-node grid, where the time savings very large compared to the traditional power-step method with Gauss Seidel and Newton Raphson load flow. This confirms the importance of using efficient load flow algorithms in combination with HC calculation methods to reduce computation time and increase computational efficiency.

6. Iteration vs accuracy

In this section, the output accuracy of the new bisection method and the classical power-step method for HC calculation were compared. The classical power-step algorithm's accuracy depends on the predefined power step at each iteration the test generator is incremented.The larger the step, the less precision that is achieved, combined with a much greater execution time. The new bisection method aims to set a predefined tolerance in result accuracy and shows less time-dependence from the tolerance set. Table 5 shows the dependence of the average number of iterations (and thus execution time) for different grids and methods on different tolerance settings:

The execution times of the "HC classic" algorithm are compared with those of the "HC bisection" algorithm. The results indicate that the HC bisection algorithm is generally faster than the HC classic algorithm for power steps up to 4000 W, while for higher steps (> 5000 W) the HC classic algorithm seems to be more efficient. Additionally, the execution time also depends on the number of nodes in the electric network, which could be due to the structural complexity of the network itself. Overall, these results could be useful for selecting the most appropriate algorithm to use based on the specific operating conditions of electric grid.

7. Conclusion

In this paper, a new method for calculating nodal hosting capacity using the bisection algorithm instead of the classical step power algorithm was presented. The proposed method aims to reduce the number of iterations required to find the power level that causes a network constraint to be exceeded. Results from simulations on three different sized grids showed that the new algorithm can save time and reduce the number of iterations required for HC computation compared to the classical method. The results also showed that the accuracy of the new algorithm is less dependent on the power step size than the classical method. The proposed method can be useful for large energy utilities to solve the problem of quantifying the maximum grid acceptance capacity of new energy from renewable sources and can also be an advantage for grid utilities to determine how much new generator can be installed in an optimized way. Future work can explore the dependence of HC on grid parameters such as line length and section.

CRediT authorship contribution statement

Benedetto Risi: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization; **Michele Quercio:** Writing – review

& editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization; **Francesco Riganti Fulginei:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Data availability

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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