Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676, p-ISSN: 2320-3331, Volume 20, Issue 6 Ser. 1 (Nov. – Dec. 2025), PP 09-18
www.iosrjournals.org

Determination Of Hosting Capacity For The Connection Of Distributed Mini-Generation To The Electric Power Distribution Network

Henrique Gesser, Cresencio Silvio Segura Salas, Lúcio De Medeiros
(Campolarguense Power Company – Cocel, Brazil)
(Institute Lactec, Brazil)
(Institute Lactec, Brazil)

Abstract:
Background: *The article presents the application of a methodology for determining the Hosting Capacity (HC) for the connection of Distributed Mini-Generation (MNGD) to the electric power distribution network, enabling utilities to efficiently and safely assess the technical feasibility of the connection during the access request while maintaining operational characteristics.*
Materials and Methods: *The methodology models the distributed mini-generation requested in the access application using the Open Distribution System Simulator (OpenDSS), as well as the utility's feeder data contained in the Distributor's Geographic Database (BDGD), to compute the unbalanced three-phase power flow, evaluate reverse power flow, analyze the steady-state voltage profile, assess the energy dispatch capacity, and determine the HC of the connection to the utility's feeder while staying within operational limits. To validate the approach, this study simulated an access request for an MNGD unit to connect to the "MT1562" line with a nominal power of 3.000 kW on feeder 10_DCL_1 of Campolarguense Energy Company (COCEL), the utility serving the municipality of Campo Largo in the state of Paraná, southern Brazil.*
Results: *The power flow analysis identified violations in the steady-state voltage and reverse power flow criteria, making the connection of the MNGD unfeasible under the initial conditions. The critical power flow scenario occurred at 14:00, with -332.28 kW. With gradual reductions in power, the flow became positive at 1,594.3 kW. After nine iterations, the voltage level was adjusted to meet ANEEL's limits, establishing the hosting capacity at 1,291.4 kW.*
Conclusion: *The results indicate that the integration of the MNGD into the network is not technically feasible without exceeding the steady-state voltage level limits and reverse power flow constraints. Furthermore, it was observed that the hosting capacity at the connection point on the bus is limited to a maximum power of 1.291.4 kW, representing 43.04% of the requested access capacity.*
Key Word: *Electrical distribution network; Photovoltaic system; Simulation; OpenDSS; Hosting capacity.*

Date of Submission: 01-11-2025 Date of Acceptance: 10-11-2025

I. Introduction

Distributed Generation (DG), especially photovoltaic Distributed Mini-Generation (MNGD), has been growing rapidly[1], driven by environmental concerns and technological advances that make these systems more accessible and efficient.

DG refers to a mode of electricity generation in which energy production occurs on a small scale in a decentralized manner, usually close to consumption points[2], in contrast to centralized generation, such as large hydroelectric plants. Within DG, two main categories stand out: Micro-Distributed Generation (MCGD), predominantly used in homes and small businesses with a maximum capacity of 75 kW, and Mini-Distributed Generation (MNGD), which operates at medium voltage with a capacity greater than 75 kW and up to 5 MW for dispatchable energy sources, or 3 MW for other sources that do not qualify as dispatchable generation plants. For consumer units connected before January 7, 2022, the limit remains 5 MW, according to the Brazilian Electricity Regulatory Agency (ANEEL), which oversees electricity distribution utilities in Brazil.

DG connections begin with an access request submitted by the consumer to the power distribution utility. However, as these systems have evolved, utilities have faced increasing challenges, particularly regarding the technical feasibility assessment of whether or not to approve the connection to the electricity distribution network.

The integration of DG into the distribution network presents several obstacles, one of the main ones being the possibility of bidirectional power flow in electrical grids[3]. The reversal of power flow causes an electric current to flow in the opposite direction of the original design—toward the substation—resulting in a voltage at the consumer's connection point that is higher than the substation voltage.

For small utilities, such as the Campolarguense Energy Company (COCEL), which serves the municipality of Campo Largo in the state of Paraná, southern Brazil, these challenges are even more critical. Reverse power flow at the substation can lead to penalties and energy losses when the utility is not registered as an electricity generator in the Electric Energy Commercialization Chamber (CCEE), which operates the free energy market.

ANEEL regulates acceptable voltage levels in distribution networks, establishing limits through Module 8 of the Electricity Distribution Procedures in the National Electric System (PRODIST) [4]. Additionally, utilities must determine the Hosting Capacity (HC) of their feeders—that is, the maximum amount of DG that can be integrated without exceeding operational limits.

To calculate HC and assess the impacts of DG on the grid, conducting power flow studies is essential. Among the available tools, the Open Distribution System Simulator (OpenDSS) stands out due to its flexibility and ability to integrate with other platforms, such as MATLAB, Python, and VBA. OpenDSS is widely used for modeling and simulating distribution networks.

An effective approach involves using the Distributor's Geographic Database (BDGD), a simplified geographic model designed to represent the utility’s electrical system. This model aims to capture both the actual layout of assets and relevant technical and commercial information[5].

II. Material And Methods

Hosting capacity

Hosting Capacity is the maximum amount of distributed generation (DG) that a system can accommodate without compromising its performance. This concept is related to power quality indicators such as voltage and current imbalance, harmonics, undervoltage, and overvoltage. Exceeding these limits may restrict the integration of DG into the system[6].

With the growth of DG, assessing hosting capacity becomes essential to mitigate impacts and ensure quality and regulatory compliance.

The deterioration of the grid caused by power injection from wind or photovoltaic sources occurs progressively, with hosting capacity being reached when this deterioration exceeds an acceptable limit[7].

Two main evaluation criteria can be defined: overvoltage and overcurrent. System performance declines as DG increases, remaining acceptable for small amounts but becoming inadequate when exceeding a critical level.

In a simplified manner, hosting capacity can be determined through the following steps:

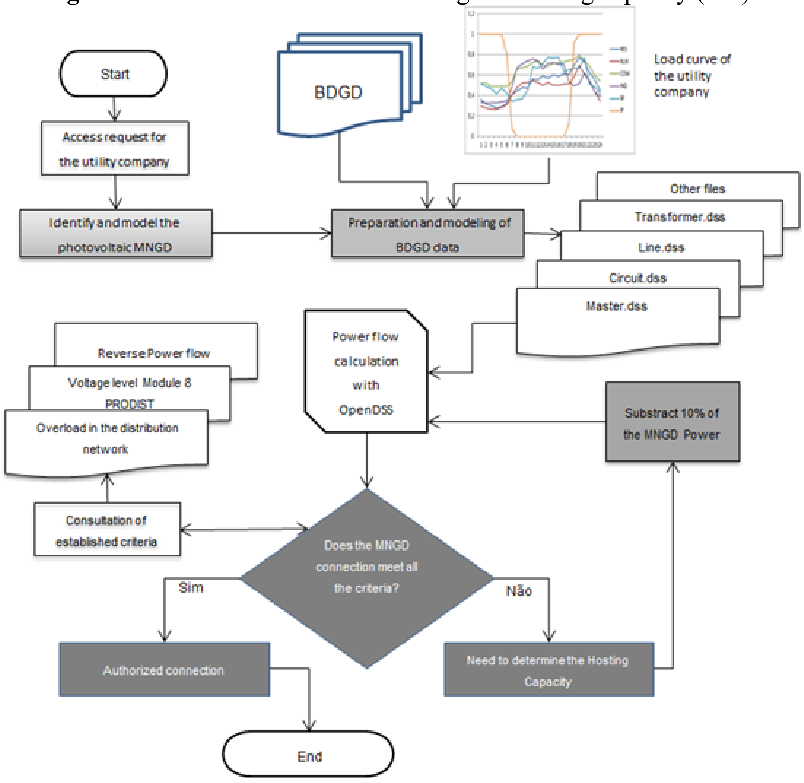
a) Select an electrical phenomenon and its performance indicators;
b) Define appropriate limits for this phenomenon;
c) Calculate the impact of DG on system performance;
d) Determine the hosting capacity through estimated or experimental analyses.

Proposed method

The study proposes a methodology to analyze and determine the hosting capacity of Distributed Generation (DG) in electric power distribution networks, using the OpenDSS software and data from the Distributor's Geographic Database (BDGD). The study allows for the identification of the impact prior to the connection of the DG, considering reverse power flow at the substation exit, voltage profile in steady state, and energy flow capacity, ensuring that operational limits are respected.

The determination of hosting capacity requires the application of the proposed method, as illustrated in Figure no 1.

Figure no 1: Flowchart for determining the hosting capacity (HC)



The flowchart shows the steps of the process from the access request to the approval of the access request for Distributor's Geographic Database (BDGD) in the electric power distributor, indicating the access request for the installation of the system at a specific point with the distributor, based on the technical and economic guidelines of the project.

The methodology consists of identifying the connection point of the photovoltaic DG to the distribution network, the type of Medium Voltage (MV) network, as well as the feeder to which it will be connected. It is also necessary to model the new DG for the execution of power flow in OpenDSS.

Modeling of the distribution network

The modeling of the electric power network is based on the GDB and follows the guidelines established in the BDGD Instruction Manual and in Module 10 of PRODIST[8].

The BDGD corresponds to the set of information that is submitted by the distributor to ANEEL, in a predefined structure and organized into two sets of entities defined as geographic and non-geographic. The entities are the abstract data model aimed at representing networks, structures, equipment, access points, among others.

For all the information present in the BDGD to be used in the analysis, it is essential to employ a methodology for power flow calculation. However, each power flow software has its own interpretation language, which makes it necessary to convert and prepare the GDB data appropriately to enable power flow calculation.

One way to convert the BDGD into scripts is by using ProgGeoPerdas, which is owned by ANEEL and provided to electric power distributors for calculating technical and non-technical losses. Another approach is to use auxiliary software such as MatLab and/or Python, using specific scripts that can read BDGD files and rewrite them in OpenDSS language.

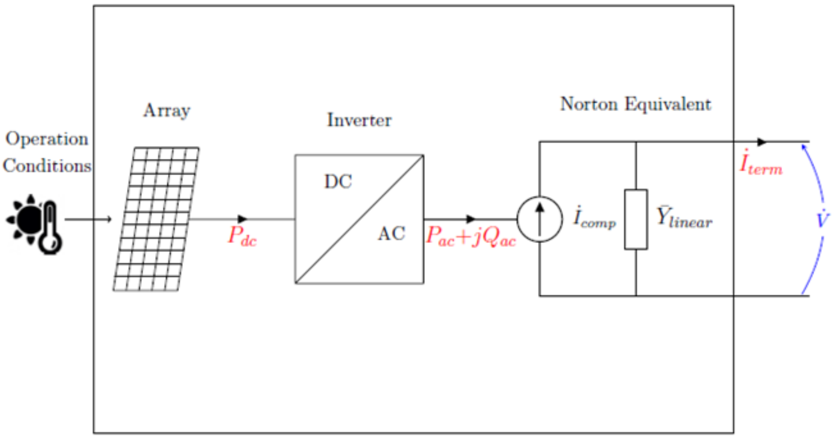
In this study, the conversion was carried out from scripts extracted from the Geographic Information System (GIS) of the distributor. This software, through a loss calculation process, exports the basic scripts of the feeder to be studied, allowing adjustments and improvements as needed for modeling and simulation in OpenDSS.

OpenDSS is a software specialized in simulating electric distribution circuits, operating in the frequency domain. This means that voltages and currents are analyzed in steady-state sinusoidal operation (RPS). Its power flow algorithms solve algebraic equations based on the network’s nodal admittance matrix, considering voltage phasors and injected nodal currents.

Modeling of the DG system

The modeling of the photovoltaic system is based on the block diagram presented in Figure no 2, where the model combines the photovoltaic system and the inverter.

Figure no 2: Block diagram of the PVSystem model



The necessary properties for modeling the photovoltaic system for use in OpenDSS can be divided into three groups:

a) Properties of the photovoltaic arrangement;
b) Properties of the photovoltaic inverter;
c) Properties of the operating conditions.

The properties of the photovoltaic arrangement that need to be defined in the model are the maximum power of the photovoltaic array (in kW) and the correction factor of the photovoltaic arrangement per unit of maximum power as a function of the photovoltaic module temperature[9].

For the inverter property, the efficiency curve of the inverter must be observed. This curve characterizes the variation in inverter efficiency as a function of the power of the photovoltaic arrangement (in kVA). For each DC bus voltage, there is an efficiency curve of the inverter, which characterizes the variation as a function of the photovoltaic array power (Pdc) per unit of kVA of the inverter. For each DC bus voltage of the inverter, there is an efficiency curve; however, this studied model defines only one curve, which corresponds to the nominal voltage of the DC bus.

The operational condition property is based on irradiance, defined in kW/m² for simulations in OpenDSS. This curve is characterized by the variation in irradiance as a function of the hours of the day.

Modeling of the loads

The modeling of the loads follows the model adopted by ANEEL in Module 7 – Loss Calculation in Distribution of Regulatory Resolution 956 of 2021[10], called the ZIP model, consisting of the following characteristics:

a) Active component: 50% constant power and 50% constant impedance;
b) Reactive component: 100% constant impedance.

The ZIP load model is so named due to the type of loads with constant impedance, current, and power. It is a polynomial model defined by Equations 1 and 2. These equations describe the active power and reactive power consumption of the load as a function of the network's frequency and voltage. The parameters of P_0 e Q_0 determine the active and reactive power of the load when it is subjected to a nominal voltage V_0.
The sums of these models fully represent the active power P_{load} and reactive power Q_{load}[11].

$$P_{load} = P_0[Z_p\left(\frac{V}{V_0}\right)^2 + I_p\left(\frac{V}{V_0}\right) + P_p](1 + K_{fp} * \Delta f) \quad (1)$$

$$Q_{load} = Q_0[Z_q\left(\frac{V}{V_0}\right)^2 + I_q\left(\frac{V}{V_0}\right) + P_q](1 + K_{fp} * \Delta f) \quad (2)$$

Where:
V_0 – Nominal voltage;
P_0 – Active power when applied to the voltage V_0;
Q_0 – Reactive power when applied to the voltage V_0;
f_0 – Nominal frequency.

Where K_{fp} and Δf represent the sensitivity coefficient and the frequency variation, where $\Delta f = f - f_0$, given that f_0 defines the nominal frequency of the system.

$$Z_p + I_p + P_p = 1 \quad (3)$$
$$Z_q + I_q + P_q = 1 \quad (4)$$

In the steady-state power flow analysis, the frequency dependence in the load modeling is usually neglected, since the typical variation is around 0.05% of the nominal frequency. Therefore, the ZIP load model can be simplified solely as a function of voltage, as shown in Equations 5 and 6, while respecting the load composition constraints established by Equations 3 and 4.

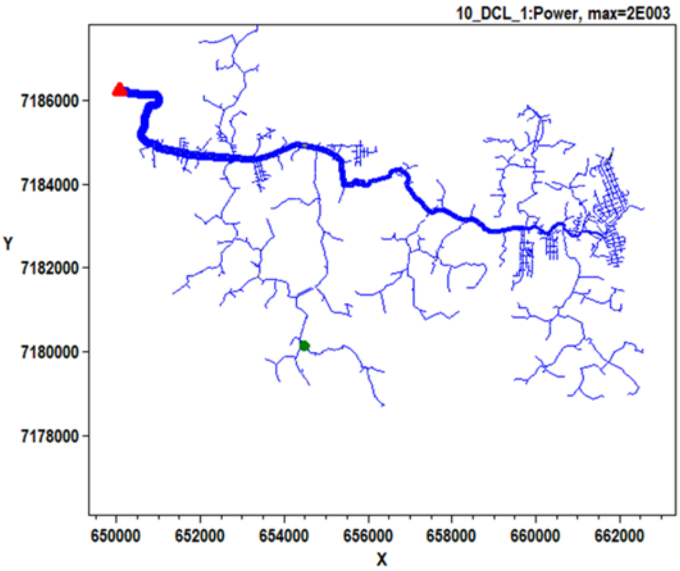
$$P_{load} = P_0\left[Z_p\left(\frac{V}{V_0}\right)^2 + I_p\left(\frac{V}{V_0}\right) + P_p\right] \quad (5)$$
$$Q_{load} = Q_0[Z_q\left(\frac{V}{V_0}\right)^2 + I_q\left(\frac{V}{V_0}\right) + P_q] \quad (6)$$

For this analysis, six load curve profiles are considered according to the class defined by ANEEL: residential, commercial, rural, industrial, public service, and public lighting. Each class has load curves divided into different consumption ranges. These ranges are used to determine the specific load curves for each consumer unit.

Case of application

Medium voltage circuit data: The analyses were conducted on the distribution feeder named 10_DCl_1, owned by Campolarguense Energy Company (COCEL), as illustrated in Figure no 3. The simulation software OpenDSS, recommended by ANEEL for calculating technical losses in distribution systems, was used.

Figure no 3: Feeder 10_DCL_1 – COCEL



The feeder 10_DCL_1 has a nominal voltage of 13.8 kV, is a three-phase circuit connected to the substation (SE), highlighted by the red triangle, and exhibits unidirectional power flow, as shown in Figure no 3. The detailed information of the feeder is presented in Table 1. It is important to note that this analysis is conducted considering the feeder without the influence of the distributed generation load from the access request.

Table no 1: Shows Feeder Characteristics 10_DCL_1

Description of the parameters	Quantity
Nominal voltage (kV)	13.2
Number of buses	11.926
Number of nodes	37.310
Number of transformers	417
Total transformer power (kVA)	14.445

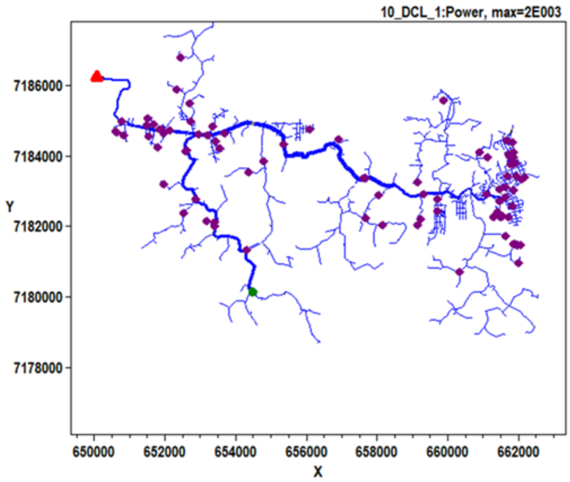
Number of voltage regulators	1
Number of consumer units BT	6.821
Number of consumer units MT	23
Number of generating units BT	97
Number of generating units MT	1
Total generation power (kVA)	1.048.27
Primary network extension (km)	136.22

The analyzed feeder has a length of 136.22 km of primary network, classified as medium-sized for the distributor, serving 6.844 consumers. Among them, 98 are prosumers operating under the electricity compensation model, with a total installed generation capacity of 1.048.27 kVA.

Distributed generation data: The simulations were based on a hypothetical access request for the connection of a photovoltaic DG system with a nominal power of 3.000 kW, connected to the 13.8 kV network on line "MT1562", at a distance of 11.1 km from the substation of feeder 10_DCL_1.

Figure no 4 highlights the location of the new DG, indicated by a green circular marker, while the purple markers represent the already existing generating units on the feeder, both low and medium voltage.

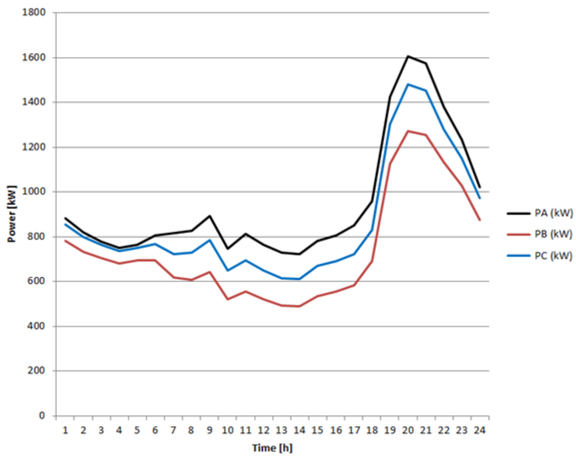
Figure no 4: Location of MNGD and MCGD systems on the feeder



Temporal power flow analysis: The power flow analysis was conducted using the OpenDSS software in daily simulation mode, with the purpose of evaluating the impact of connecting the MNGD to feeder 10_DCL_1 throughout the day. During this analysis, the criteria that could be violated and the specific times when these violations occurred were checked.

The first phase of the study involved solving the power flow on feeder 10_DCL_1 without considering the connection of the new DG, allowing for the verification of the actual loading of the feeder. Figure no 5 presents the demand curve of the feeder at the substation exit.

Figure no 5: Real feeder demand

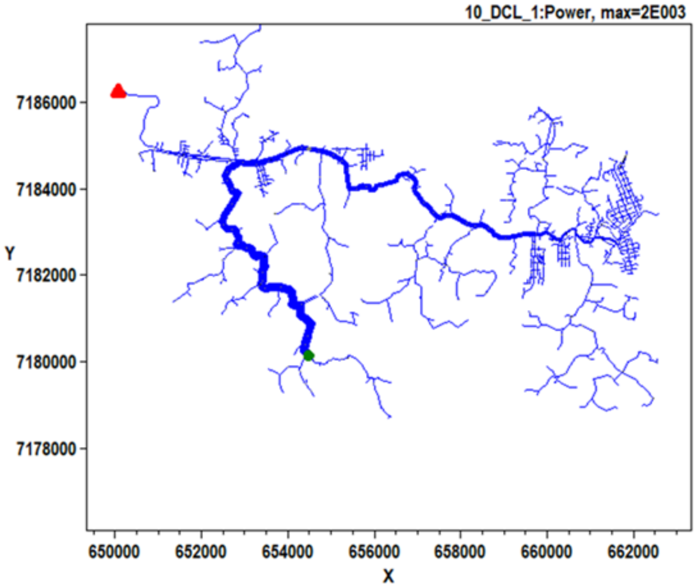


In this simulation, it was observed that the feeder shows an unbalanced load distribution, evidenced by the distinct power values, where P1, P2, and P3 correspond to the powers of phases A, B, and C, respectively. Additionally, it was possible to deduce that the feeder has a predominance of residential load, as the demand curve showed higher peaks at the end of the day, between 18:00 and 22:00.

In other periods of the day, the power variations are not significant compared to the peak hours of the electrical system.

The second phase of the study integrated the MNGD into the simulation, and the power flow was executed in the same formats as the first phase. Figure no 6 shows the direction of the power flow from the feeder at 15:00. Additionally, it is possible to verify, through the thickness of the lines on the map, that energy flows from the MNGD to the distribution network, meaning that energy is dispatched from the MNGD to the system.

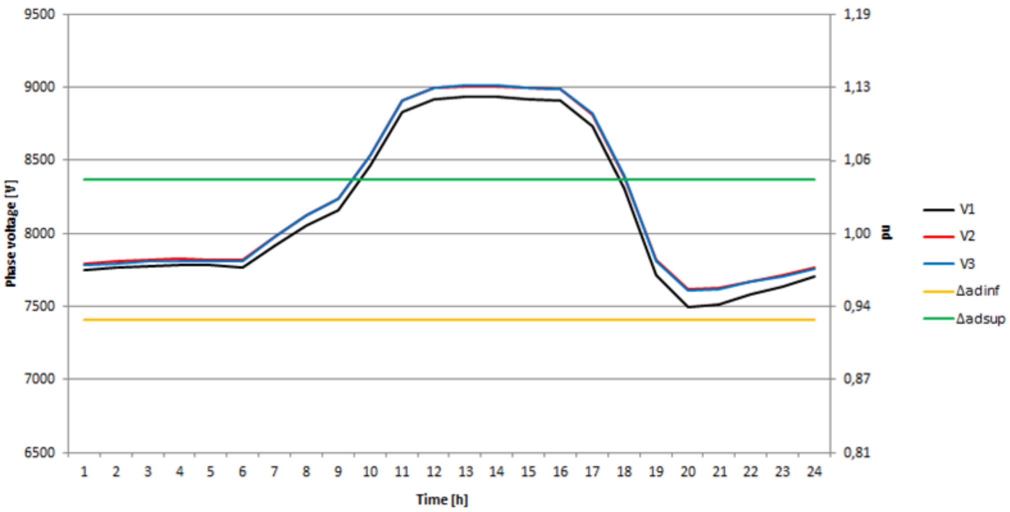
Figure no 6: Feeder 10_DCL_1 with MNGD connected to the grid



III. Results

Considering the voltage level criterion in steady-state operation, the connection of the MNGD to the feeder generates voltage values outside the limits established by ANEEL. As can be seen in Figure no 7, the voltage values in phase A (V1), phase B (V2), and phase C (V3) exceeded the ANEEL limit of 1.05 pu at 10:00, and remained outside the limits until 18:00. The maximum voltage level observed in the analysis was 9,011.81 V or 1.13 pu, which was recorded in phase C at 14:00.

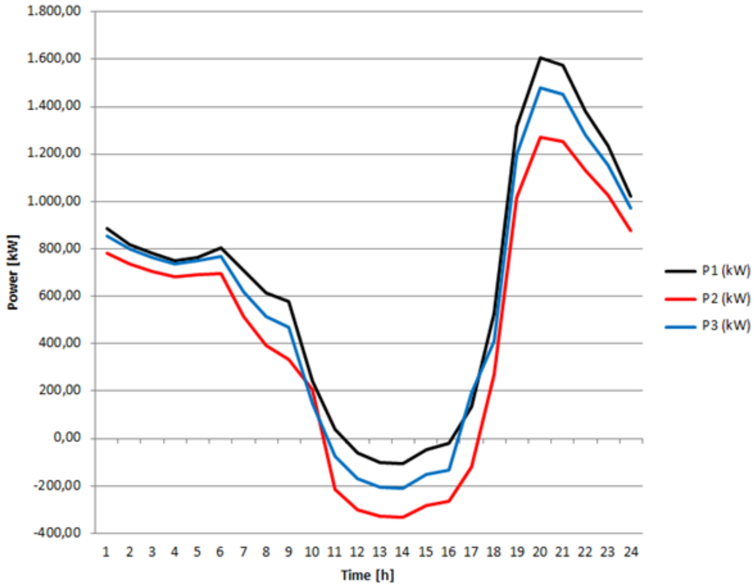
Figure no 7: Voltage level in steady-state operation at the MNGD connection point



The line Δ_{ADINF} Represents the lower acceptable variation limit and the line Δ_{ADSUP} Represents the upper acceptable voltage variation limit, indices that must be met by electric power distribution companies.

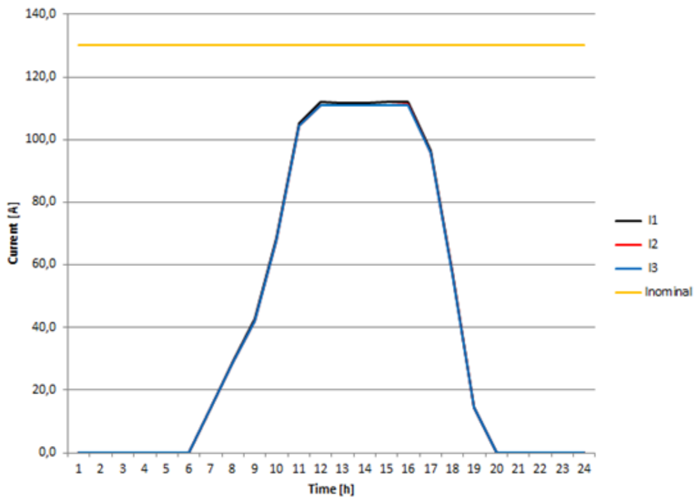
According to the reverse power flow criterion, as shown in Figure no 8, the demand curve of the feeder with the MNGD connected revealed the occurrence of reverse power flow at the substation, where P1, P2, and P3 correspond to the powers of phases A, B, and C, respectively. With the MNGD integrated into the grid, a reversal of the power flow in phases B and C was observed at 11:00, and in phase A at 12:00. The return to normal flow was only noticed at 16:00 in phases A and C, and at 17:00 in phase B. The maximum reverse power level observed in phase B at 14:00 was -332.28 kW.

Figure no 8: Reverse power flow at the substation output



The analysis of the energy evacuation capacity criterion revealed that the current in the line where the MNGD is connected remained below the current-carrying limit of the 4CAA AWG conductor, whose nominal capacity adopted by COCEL is 130 A, as indicated in Figure no 9.

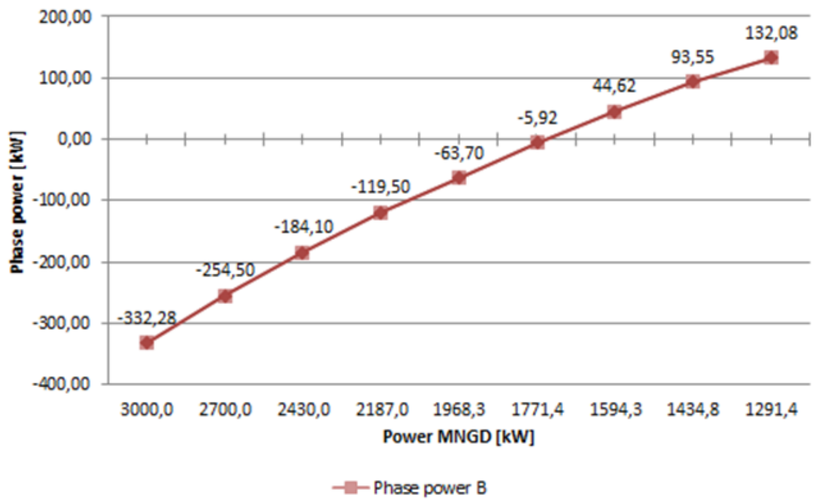
Figure no 9: Energy evacuation capacity at the MNGD connection point



The analysis of the power flow revealed violations in two criteria, making the connection of the MNGD unfeasible. The most critical scenario was identified at 14:00, with issues related to steady-state voltage and reverse power flow at the substation, demanding a specific evaluation of the hosting capacity at that time.

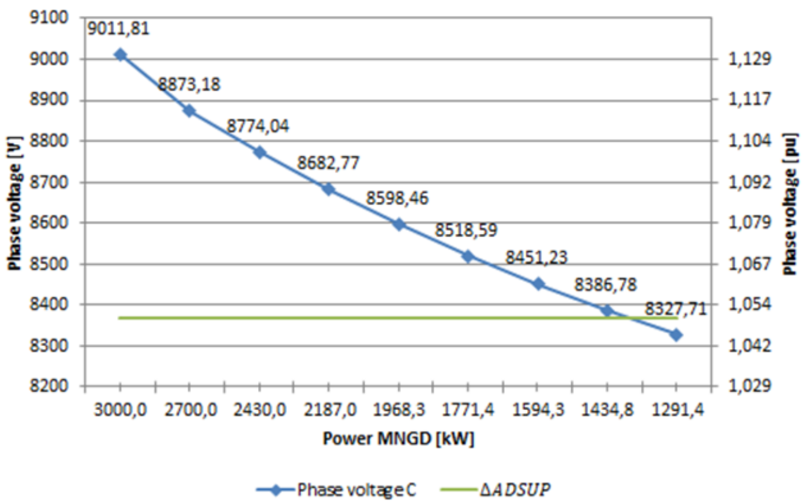
Figure no 10 illustrates the evolution of the reverse power flow at the substation output, considering phase B, which was identified as the worst-case scenario in the first iteration. At this initial point, the reverse power recorded was -332.28 kW. With the gradual reduction of the MNGD connection power, the reverse power also decreased. In the seventh iteration, i.e., at 1.594.3 kW, the power flow became positive, reaching 44.62 kW at the substation, thus meeting the criterion for the absence of reverse power flow.

Figure no 10: Reverse power flow iteration



With nine iterations to determine the hosting capacity, as shown in Figure no 11, the voltage level was progressively adjusted until it fit within the limits established by ANEEL. With the MNGD connected at 3.000 kW, the voltage at the connection point reached 9.011.81 V, corresponding to 1.13 pu on phase C. As the power was reduced in each iteration, the voltage also decreased, reaching 8.327.71 V, or 1.045 pu, in the ninth and final iteration, considering an MNGD power of 1.291.4 kW.

Figure no 11: Steady-state voltage level iterations



IV. Discussion

The increasing integration of distributed generation (DG) systems, especially photovoltaic distributed minigeneration (MNDG), has presented technical and regulatory challenges for electric power distribution companies, such as voltages outside the permitted limits and bidirectional power flows.

In addition to technical difficulties, regulatory and commercial issues affect DG integration. Distributors that purchase energy in the free market and are not registered as generators face restrictions on injecting energy into the grid, potentially incurring penalties. Thus, a balance between the expansion of DG and the stability of the electrical system becomes necessary. Modeling and simulation tools, such as OpenDSS, are essential to assess the viability of DG on the grid. OpenDSS allows for simulating the impacts of DG integration.

In this study, feeder 10_DCL_1 of Campolarguense Energy Company (COCEL) was modeled based on the Distributor's Geographic Database (BDGD). The detailed network modeling allowed for the evaluation of the impact of connecting a Distributed Minigeneration (MNGD) unit on the MT1562 line.

The power flow simulations showed that the initial connection request would not meet the technical criteria. The voltage would reach 1.13 pu on phase C at 14:00, exceeding the 1.05 pu limit set by ANEEL, which could result in penalties for the distributor.

In addition, reverse power flow was identified, with a power of -332.28 kW on phase B at 14:00. The flow reversal began at 11:00 and only returned to unidirectional operation from 16:00 for some phases, demonstrating that the connection could compromise the feeder's operation.

Given the infeasibility of the connection at the total requested power, a methodology was adopted to determine the hosting capacity. The nominal power was gradually reduced by 10%, and the power flow was recalculated until the voltage and reverse flow criteria were within regulatory limits.

The reverse power flow was observed until the MNGD power was reduced to 1.594.3 kW. Meanwhile, the voltage remained above the allowed limit until the power was adjusted to 1.291.4 kW.

V. Conclusion

Based on the adjustments made, it was determined that the maximum hosting capacity at the studied point of feeder 10_DCL_1 is 1,291.4 kW for photovoltaic generation, making it impossible to connect at the requested power.

References

[1]. Freitas, Paulo Ricardo Radatz. Impact Of Smart Functions Of Photovoltaic System Inverters On The Operation Of Electric Power Distribution Networks. Master's Degree In Power Systems, University Of São Paulo, São Paulo, 2019. Doi: 10.11606/D.3.2019.Tde-20032020-074934. Available At: Https://Teses.Usp.Br/Teses/Disponiveis/3/3143/Tde-20032020-074934/Pt-Br.Php. Accessed On: July 18, 2023, At 2:24 P.M.

[2]. Teixeira, Lucas De Godoi. Evaluation Of The Impacts Caused By The Diffusion Of Distributed Photovoltaic Microgeneration In The Low Voltage Of Real Electric Power Distribution Networks. June 1, 2019. Belo Horizonte: Federal University Of Minas Gerais. Available At: Https://Www.Ppgee.Ufmg.Br/Defesas/1674M.PDF. Accessed On: August 14, 2023, At 4:09 P.M.

[3]. Shayani, Rafael Amaral. Method For Determining The Penetration Limit Of Distributed Photovoltaic Generation In Radial Distribution Networks. P. 161, 2010. Available At: Https://Repositorio.Unb.Br/Handle/10482/7117. Accessed On: December 6, 2024, At 8:54 A.M.

[4]. National Electric Energy Agency. Electric Energy Distribution Procedure In The National Electric System – PRODIST. Module 8. Brasília, December 7, 2021.

[5]. National Electric Energy Agency. Instruction Manual For The Distributor's Geographic Database – BDGD. Brasília, 2020.

[6]. Etherden, N., & Bollen, M. H. Increasing The Hosting Capacity Of Distribution Networks By Curtrailment Of Renewable Energy Resources. IEEE, , 2011.

[7]. Santos, I. N., Cuk, V., Almeida, P. M., Bollen, M. H., & Ribeiro, P. F. Considerations On Hosting Capacity For Harmonic Distortions On Transmission And Distribution Systems. Elsevier, 2015.

[8]. National Electric Energy Agency. Electric Energy Distribution Procedure In The National Electric System – PRODIST. Module 10. Brasília, December 7, 2021.

[9]. Rocha, Celso, Et Al. Opendss Pvsystem And Invcontrol Element Models. 2020. Available At: Https://Sourceforge.Net/Projects/Electricdss/. Accessed On: February 3, 2021, At 11:25 PM.

[10]. National Electric Energy Agency. Electric Energy Distribution Procedure In The National Electric System – PRODIST. Module 7. Brasília, December 7, 2021.

[11]. Granados, Josué Fernando Leal. Load Modeling In Electric Power Distribution Systems. Available At: Www.Ppgee.Ufmg.Br/Defesas/1498M.PDF. Accessed On: February 25, 2024, At 5:56 PM.