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Location of distributed resources in rural-urban marginal power grids considering the voltage collapse prediction index

Localización de recursos distribuidos en redes eléctricas rurales-urbanas marginales considerando el índice de predicción de colapso de tensión

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Abstract

This research focuses on the georeferenced location of distributed resources, specifically the injection of active power through distributed generation. A rural-urban marginal feeder of a distribution company in Ecuador with georeferenced information was taken as a case study, which has a three-phase primary link at a medium voltage and several single-phase branches at a medium voltage of great length to supply users who are far away from the local company's network. Consequently, to analyze the behavior of the electrical network, the Cymdist software was used to perform simulations in a steady state without and with the insertion of distributed generation. For the location of the distributed generation, the voltage collapse prediction index was used as a technique for quantifying and identifying problems in the network nodes. Moreover, based on the proposed methodology, the suitable georeferencing of the sites where it is necessary to inject active power to improve the voltage profiles and reduce the voltage collapse prediction index was obtained.

Keywords: Distributed generation, Distributed generation, Voltage collapse prediction index, Distributed resources, Electric power systems

Resumen

Esta investigación se centra en la localización georreferenciada de los recursos distribuidos, concretamente en la inyección de potencia activa a través de la generación distribuida. Se tomó como caso de estudio un alimentador marginal rural-urbano de una empresa distribuidora de Ecuador con información georreferenciada, que cuenta con un enlace primario trifásico a media tensión y varios ramales monofásicos a media tensión de gran longitud para abastecer a usuarios alejados de la red de la empresa local. En consecuencia, para analizar el comportamiento de la red eléctrica, se utilizó el software Cymdist para realizar simulaciones en estado estacionario sin y con la inserción de generación distribuida. Para la ubicación de la generación distribuida, se utilizó el índice de predicción de colapso de tensión como técnica para cuantificar e identificar problemas en los nodos de la red. Además, a partir de la metodología propuesta, se obtuvo la georreferenciación idónea de los sitios donde es necesario inyectar potencia activa para mejorar los perfiles de tensión y reducir el índice de predicción de colapso de tensión.

Palabras clave: Generación distribuida, Índice de predicción de colapso de voltaje, Recursos distribuidos, Sistemas eléctricos de potencia

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1. Introduction

Electric power systems (EPS) are currently seeking to optimize non-conventional renewable resources, and that is why many of them have begun to change their energy matrix, betting on solar photovoltaic, low and high enthalpy solar thermal, on-shore and off-shore wind, and geothermal power plants. These generation plants have incorporated new variables in the decision and optimization processes in operation and dispatch of energy [1, 2].

The advantage of this type of solution is that it is possible to reduce the losses in the electric transmission systems, and therefore, it can be assured that the power system is efficient. The presence of DG poses new challenges in the management and operation of electricity grids. To date, it represents about 20% of the total generation of some power systems, and this figure is gradually increasing based on the energy policies of each region. An example of this change can be seen in Europe, where an energy system with less dependence on non-renewable resources, with the introduction of emission reduction policies that significantly impact electricity markets [3–6].

Another solution to this problem is the insertion of distributed energy resources (DER), which have also increased on the planet, thus seeking a sustainable energy system with fewer environmental problems and greater energy efficiency. Thus, DER management concepts have been generated, and virtual power plants (VPP) have been created. A VPP is a single actor in the electricity market and comprises several DERs. Within this new concept, the owners of the VPPs can access the electricity market while compensating for the power deficit due to intermittency in the wind and solar energy sources, accompanied by uncertainty in the behavior of demand [7–9].

With the increased penetration of DER in the electric grid, more flexibility is required on the consumption side. The flexibility in DER deployed on a distribution grid can become an attractive asset for trading in electricity markets. A VPP can provide a demand response to an aggregator operating in the market. However, this flexibility may be subject to user behavior, and local regulations in the residential sector [10].

Currently, the principle of operation of VPPs is based on demand response (DR), the most widely used and researched technique. Thus commercial and industrial load management and distributed generation are the main focus of these studies. Several factors define the business models under which VPPs operate, such as financing method (market or incentives), target market (system services, imbalance management, a day ahead, during the day, balancing market), motivation factor (pricing structure, environmental aspect, system aspect), customer type (residential, commercial, industrial and street lighting), consumption characteristics (responsiveness, capacity, reliability, frequency, duration), DG characteristics (primary resource, responsiveness, capacity, reliability, frequency, duration), activation type (response time, duration, changes, capacity) and control mode (manual, semi-automatic or automatic) [11, 12].

Generally speaking, VPPs can respond to two types of markets: marginal markets where all generators receive the same price at the highest marginal dispatch price and pay-per-bid markets where VPPs receive the price bid by them. The operational management of the EPS depends on power flow studies using optimization and simulation techniques. The optimal DC (OPF-AC) and AC (OPF-AC) flows are the most commonly used techniques for power flow optimization. On the other hand, specialized software such as Digsilent power factory and Cymdist is used for simulation, which allows the implementation of georeferenced power flow studies, from which the different electrical parameters such as node voltage, angle, active and reactive power flows, generation dispatch and power factor can be obtained [13, 14].

Most studies have focused on studying DER in urban distribution networks, where the load is concentrated, and the benefits are achieved by establishing a technical-economic balance. However, the studies are scarce for rural and marginal urban distribution networks, so this research focuses on identifying the DER connection point based on simulation techniques in a rural georeferenced distribution system [15–17].

Through the results obtained from the simulation, the voltage collapse prediction index is determined in each node. In the nodes where the index is close to 1, it becomes a candidate node to locate a DER so that the DER connection points are determined later through the proposed heuristic methodology. For this purpose, the voltage profile, the loss reduction, and the power factor improvement are verified. Figure 1 shows the conceptualization of ideas raised in this research.

The article is organized as follows: section 2 refers to the concepts related to distributed resources, section 3 defines the problem and the case studies, section 4 analyzes the results, and section 5 shows the main conclusions.

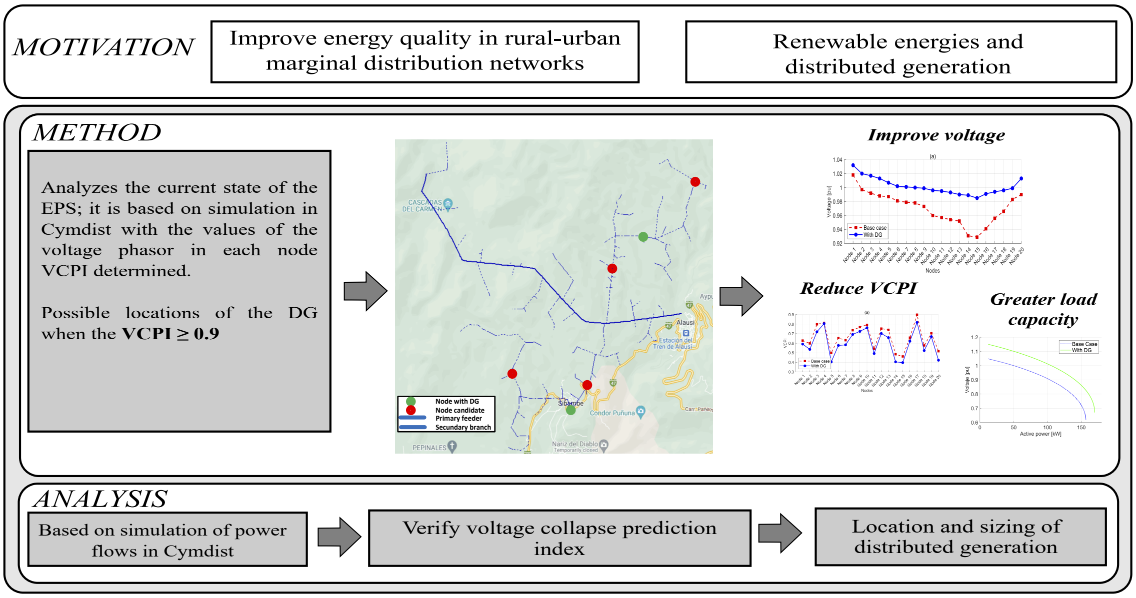


Figure 1. Research conceptualization

1.1. Related Works

One of the alternatives available in current EPS to alleviate congestion in the distribution and transmission networks is distributed energy resources (DER), a set of technologies that can be deployed in the electric grid. Among these is distributed generation, which seeks to generate electricity very close to the consumption points. Other technologies used are the Battery Energy Storage Systems (BESS), which seek to store the energy that is not used during low-demand hours so that it can be used during peak hours, thus reducing the demand for a centralized generation.

1.1.1. Distributed generation

Distributed generation has become one of the primary sources of non-conventional natural resources for electricity generation at sites very close to the load. Thus, DG is connected to distribution networks at medium or low voltage levels, depending on the type of contract and its power. The leading primary energy used for electricity generation in DG is solar, specifically solar photovoltaic, which can be implemented from small plants located on the terraces of residences to generation complexes that can reach up to MW of installed power [18–20].

The DG has made it necessary for distribution systems to become bi-directional networks, thereby reducing congestion in transmission networks and losses in power systems. Now users can be part of the electricity market, producing their energy and injecting the surplus into the public grid, [21, 22]. The energy management of the DG is carried out through the VPPs that allow an optimal dispatch of resources based on measurement and monitoring systems of the DG, the BESS, and controllable load resources. The control strategy of VPPs can be divided into three different patterns: centralized control, distributed control, and fully distributed control; according to their structure and information, depending on the roles and responsibility, VPP is distinguished as commercial VPP (CVPP), technical VPP (TVPP) and combined VPP [7, 23].

Communications play a fundamental role in the operation and management of the VPP. It is possible to have an online measurement in time of the primary energy resources that are used for electricity generation, the necessary demand in each time interval, imbalances in the networks, and uncovered energy needs that must be imported from public networks for adequate demand management [24, 25].

1.1.2. Voltage collapse prediction index

In the operation of power systems, many parameters define the behavior of EPS, such as power quality indexes, stability indexes, reliability indexes, voltage profile, and line chargeability, among others. Power flow studies allow quantifying each of the electrical parameters in the EPS steady-state operation and are the mathematical tool used by simulators to show the behavior of power systems under different generation and demand scenarios.

There are different reliability and stability indexes to verify the state of power systems. For example, the EPS are analyzed under the N-1 contingency state to study reliability. For this purpose, the contingency ranking index is used to determine the degree of contingency affectation, thus obtaining information that will help plan the expansion and improvement of the EPS. On the other hand, different indexes have been proposed to identify voltage, angle, frequency, chargeability, and load fluctuation failures [26–29].

The identification of the operative limits allows determining nodes with a deficiency in which the power system must be improved so that through the VCPI, it is possible to locate problem nodes in which, before any change in the load the power system can collapse, the VCPI is determined through (1) [30]. VCPI is based on the electrical network's voltage phasors and admittance characteristics and calculated for each node of the EPS. The VCPI values are between 0 and 1, and the closer it is to 1, the higher the probability of voltage collapse at that node.

$$VCPI_k = \left| 1 - \frac{\sum_{\substack{m=1 \\ m \neq k}}^{n} V'_m}{V_k} \right| \tag{1}$$

$$V'_m = \frac{Y_{km}}{\sum_{\substack{j=1 \\ j \neq k}}^{n} Y_{kj}} V_m \tag{2}$$

Where:

V_m is the voltage phasor at node m,
V_k is the voltage phasor at node k,
Y_{km} is the admittance between nodes k and m,
Y_{kj} is the admittance between nodes k and j.

The VCPI is a global technique that considers the effects of the loads in the other nodes on a particular node, which can be linked to the voltage stability studies achieved by analyzing the P-V curves; therefore, it can be said that the VCPI can predict a node in which voltage instability may occur in power systems.

Table 1 shows significant contributions in planning electrical distribution systems, which in recent years have focused on topics such as renewable energies, distributed resources, distributed generation, virtual power plants, and demand management. The principal electrical parameters analyzing by other authors are voltage, congestion, power factor, and Geo-referenced.

Table 1. Summary of related works

Author	Year	Objetives	Parameters considered				Thematic		
			Voltage	Congestion	Stability	Geo-referenced	Distributed generation	Virtual power plant	Planning
Sena [20]	2022	Electrical network evaluation	✓	✓	-	-	✓	-	✓
Heang [18]	2022	Reduces active power losses	✓	-	-	-	-	-	✓
Quinteros [13]	2022	Power system restoration	✓	✓	✓	-	-	-	✓
Carrión [28]	2021	Improve electrical power systems	✓	✓	✓	✓	-	-	✓
Aderibigbe [19]	2021	Optimal placement of distributed generators	✓	✓	-	-	✓	✓	✓
Mosquera [3]	2020	Optimal virtual power plant location	✓	-	-	-	-	✓	✓
Valenzuela [23]	2019	Management of electrical distribution networks	✓	-	-	✓	-	-	✓
Valenzuela [25]	2019	Planning underground distribution networks	-	✓	-	✓	-	-	✓
Danish [26]	2019	Voltage stability index	✓	✓	-	✓	-	-	-
Inga [22]	2018	Planning electrical distribution network	✓	✓	-	✓	-	-	✓
Present work		Planning and sizing of electrical distribution network	✓	✓	✓	✓	✓	-	✓

2. Materials and methods

2.1. Problem and Methodology

Feeder 1500090T01 of the Riobamba electric company (EERSA S.A.) has been taken as a case of analysis since the concession area of the distribution company corresponds to rural and marginal urban networks in its more significant percentage. Feeder 1500090T01 is shown in figure 2, in which it can be seen that it has two (2) links to the sub-transmission ring and two single-phase derivations to the users; as can be seen, the coverage of this feeder is 100% rural, where its users are far away from each other, and there are service quality problems. As it is a marginal urban, rural network, only the primary link is three-phase, and all the branches are single-phase, which generates an additional problem about the power balance, so it is assumed that the location of the proposed DG will be adapted to the voltage profiles and several phases existing at the connection point.

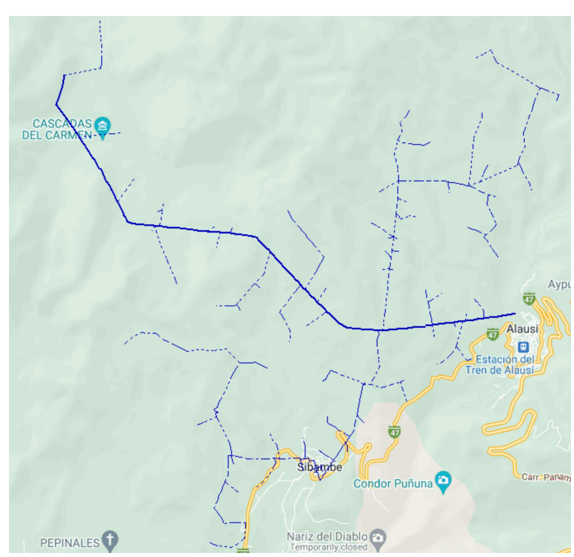


Figure 2. Feeder 1500090T01 of EERSA S.A. Source: Cymdist

Figure 3 shows the equivalent single-line diagram of the power system considered for the analysis, in which the two secondary branches can be distinguished. The nodes of the secondary branches are identified by the letter U for the upper branch. And by the letter D for the lower branch. The upper branch comprises 20 nodes connected by the end-users, and the lower branch has 26 nodes.

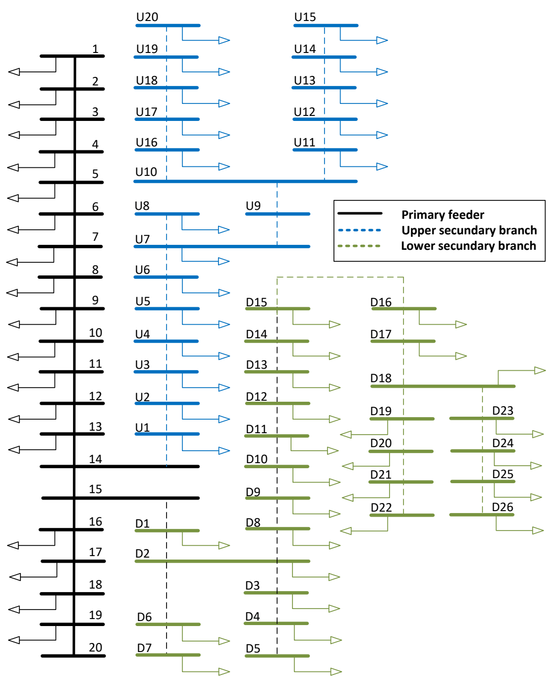


Figure 3. Feeder 1500090T01 of EERSA S.A. Source: Cymdist

The analysis of the power flows performed through simulation in Cymdist, with which the current state of the network is obtained, data that are the starting point for the location of distributed resources in the network; with these values, we proceed to determine the VCPI. Since there are different voltage profiles, the studies will be carried out in p.u., values whose base is referred to as the main three-phase link, in such a way that the different electrical variables are unified. Algorithm 1 defines the methodology for DG insertion in the nodes that present a VCPI very close to 1, assuming the existence of the primary resource, physical space, and without generating a more significant environmental impact.

Table 2. Variables related to the mathematical model

Symbol	Description
V_i	Voltage at node i.
$P_{i,j}$	Active power flow between nodes i and j.
$Q_{i,j}$	Reactive power flow between nodes i and j.
Pd_i	Active power demand at node i.
Qd_i	Reactive power demand at node i.
n	Number of EPS nodes.
Pot_{DG_i}	DG active power.

Algorithm 1 DG location based on VCPI

Step: 1 Input data
  Electrical Power System Parameterization
  Generators, lines, transformers, loads, connectivity matrix
  Steady state simulation by Cymdist
  Save $[V_i,\ P_{i,j},\ Q_{i,j}, Pd_i,\ Qd_i]$.

Step: 2 VCPI determination
  for $i = 1 : n$
    $VCPI_i = VCPI_k$
  end for

Step: 3 Possible nodes for DG
    Sort VCPI
  for $i = 1 : n$
    $VCPI_i \geq 0.9$
    Select node $cand_i = i$
  end for

Step: 4 DG location and sizing
  Locate DG in $node_i$
  $Pot_{DG} = 1$
  If $VCPI \geq 0.9$
    Discarf node
  else
    for $i = 1 : length(cand)$
      while $VCPI_i \geq 0.9$
        $Pot_{DG_i} = Pot_{DG_i} + 1$
      end while
    end for
  end if

Step: 5 Show results
  $cand_i, Pot_{DG_i}, P_{i,j}, Q_{i,j}, V_i$

The methodology to ideal deploy DG in power systems is shown in Algorithm 1, in which VCPI is considered the primary constraint; in Step 1, the EPS steady-state simulation in Cymdist is considered, and the different electrical parameters are stored. In Step 2, the steady-state of the power system is analyzed, and the VCPI at each node is determined. In Step 3, the VCPI comparison is performed, and the highest VCPI values are taken as possible DG locations. In Step 4, the location and sizing of the DG are performed. Finally, in Step 5, the results of the proposed methodology applied in the simulation in Cymdist are shown. For the sizing of the DG, 1 kW steps were considered, comparing the previous VCPI with the new one, as well as voltage profiles and line congestion. Table 2 shows the notation of variables used in Algorithm 1.

The proposed methodology analyzes the current state of the EPS; it is based on simulation in Cymdist, with the values of the voltage phasor in each node VCPI determined. This index is the decision parameter for the possible locations of the DG when the VCPI ≥ 0.9, each node which, after implementing DG, reduces its VCPI ≤ 0.9 is considered like nodes in which DG should be implemented. In this way, once it has the possible locations, place the DG in those nodes, and if it does not reduce the VCPI, the node is discarded. For DG sizing, incremental steps of 1kW were performed until the EPS obtains a VCPI value of ≤ 0.9 at all nodes. Once the nodes in which DG should be implemented and its power capacity are determined, the current state is analyzed, and it is verified if it improved the voltage profile and stability by analyzing the P-V crossovers.

3. Results and discussions

3.1. Analysis of Results

This index identified the possible nodes where DG can be located to improve the indicator above without affecting the other electrical parameters. Based on the simulation in the Cymdist software, the EPS steady-state power flows were obtained, and with this, applying algorithm one and based on the voltage phasors, the VCPI at each node was determined. The location of the possible nodes and the final location of the DG can be seen in Figure 2.

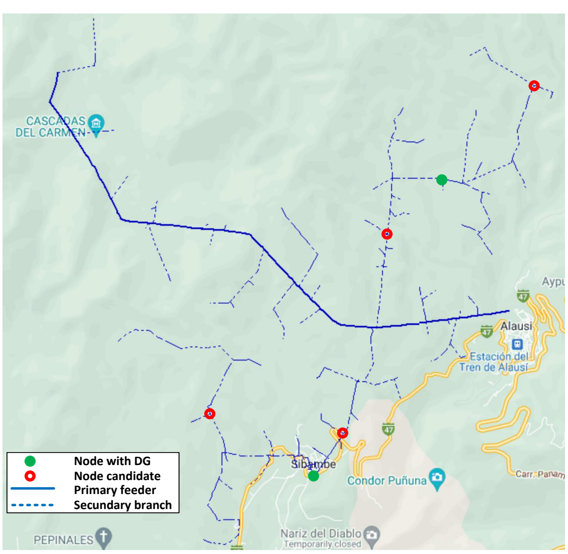


Figure 4. DG georeferenced location

As shown in Figure 4, the location of the DG is not in the three-phase network but in two of the single-phase branches, which is why the DG systems must also be single-phase. The DG system in the upper branch is sized with a value of 17 kW at node U8, whose coordinates are Lat.: -2.1669009, Long.: -78.8633971. The value includes the VCPI improved in all the nodes of that branch. On the other hand, in the lower branch, the DG power was 32 kW at node D12, whose coordinates are Lat.: -2.2292529, Long.: -78.8900419, which, as in the lower branch, improves the VCPI of the entire branch.

The voltage profile in the main feeder can be seen in Figure 5 (a) and in the upper branch Figure 5 (b) and lower Figure 5 (c); in the three cases, it can be seen how the voltage improves after the DG enters the points selected by the proposed methodology. On the other hand, Figure 6 shows the comparison of the VCPI before and after DG insertion, both for the main feeder (a) and the upper (b) and lower (c) branches.

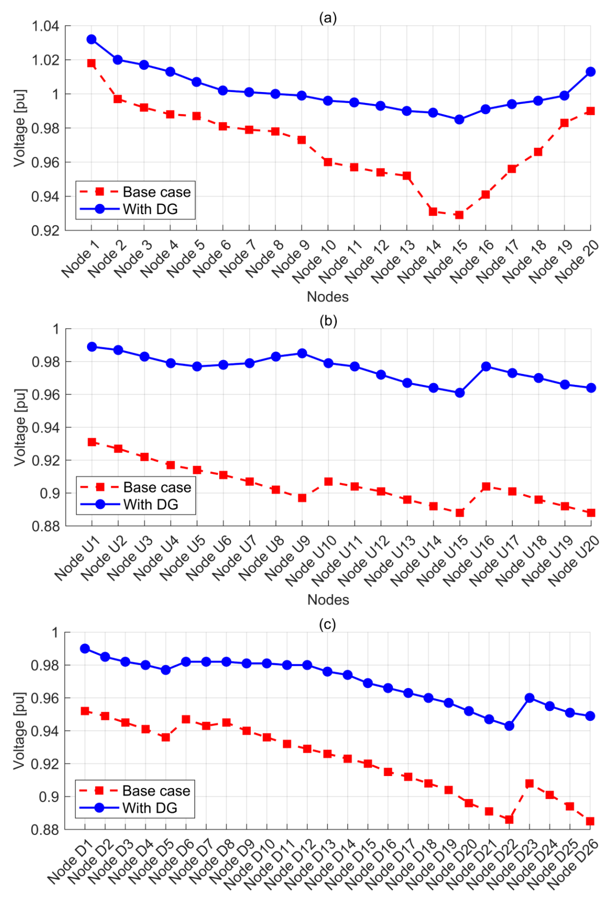


Figure 5. Voltage profile at nodes

VCPI try to reduce their original values, so it can be asserted that the quality of electrical service improves in these branches, which is undoubtedly one of the electrical parameters that power system planners are looking for nowadays.

Considering that modifications have been made to the EPS compared to its initial state, it is necessary to verify the overall operation of the distribution network, and one way to do this is to analyze the system's stability. For the proposed case based on the VCPI, it is necessary to study the voltage stability, which is done through the P - V curves. Consequently, the nodes of the main feeder where the secondary branches are connected, nodes 14 and 15, have been considered.

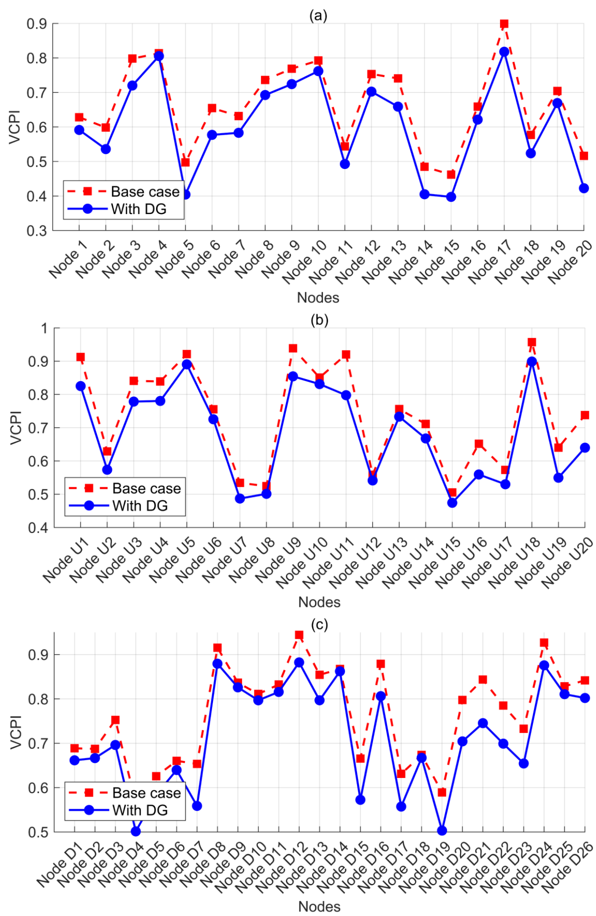
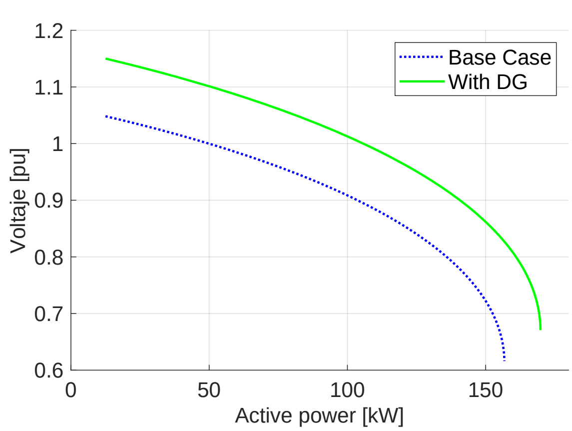
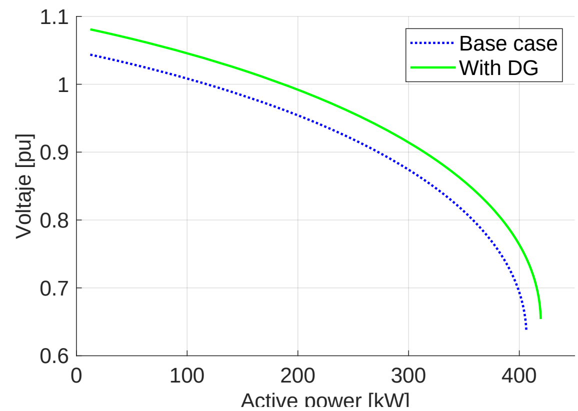


Figure 6. VCPI at nodes

Figure 7 (a) shows the P-V curve for node 14. It can be seen how the voltage increases with the fluctuation of the total load of the upper branch, similar to the Hopf bifurcation shifts to the right. A similar situation can be seen in Figure 7 (b), showing the results at node 15, which feeds the lower branch.



(**a**) P-V curve in node 14



(**b**) P-V curve in node 15

Figure 7. P - V curves (**a**) Node 14. (**b**) Node 15

4. Conclusions

The different studies that can be achieved through simulation techniques are innumerable. They are often despised due to the lack of interface or knowledge to extract their parameters and use them in modeling programs such as Matlab or Phyton. For the case study presented, the databases of the results were extracted. Through Matlab, the proposed methodology was implemented based on the results, thus ideal locating the possible points at which power can be injected from a DG. The location and sizing of the DG improved the voltage profiles of the entire EPS, contrary to what happens when reactive compensation is performed, which only improves the voltage profile in the vicinity of the reactive injection point.

It was possible to demonstrate that through the VCPI, it is possible to detect nodes with weaknesses in the power system, and this can be used for different studies; for the case proposed through the analysis of this parameter, it was possible to locate and dimension two active power injection points in a distribution network.

It is possible to analyze georeferenced power systems with georeferenced data and not only have the examples stipulated in the literature, such as the CIGRÉ and IEEE models. It is now possible to access the databases of distribution companies and provide real solutions to their problems. It is essential to highlight that through Cymdist.

The georeferencing of the active power injection point is very useful to contrast with the existing primary resources at the site and determine what type of primary energy can be used to solve the drawbacks of the power grid.

References

[1] P. Del Río and P. Mir-Artigues, "Combinations of support instruments for renewable electricity in Europe: A review," *Renewable and Sustainable Energy Reviews*, vol. 40, pp. 287–295, 2014. [Online]. Available: https://doi.org/10.1016/j.rser.2014.07.039

[2] M. A. Salmani, A. Anzalchi, and S. Salmani, "Virtual Power Plant: New Solution for Managing Distributed Generations in Decentralized Power Systems," in *2010 International Conference on Management and Service Science*, 2010, pp. 1–6. [Online]. Available: https://doi.org/10.1109/ICMSS.2010.5577383

[3] F. Mosquera, "Localización óptima de plantas virtuales de generación en sistemas eléctricos de potencia basados en flujos óptimos de potencia," *I+D Tecnológico*, vol. 16, no. 2, 2020. [Online]. Available: https://doi.org/10.33412/idt.v16.2.2827

[4] A. Riofrio and D. Carrión, "Approach and Deployment of Distributed Generation. State-of-art Based on Induction Cooker System," in *ANDESCON 2014*, 2014. [Online]. Available: https://doi.org/10.1109/ANDESCON.2014.7098544

[5] S. Singh, A. R. Gautam, and D. Fulwani, "Constant power loads and their effects in DC distributed power systems: A review," *Renewable and Sustainable Energy Reviews*, vol. 72, no. December 2015, pp. 407–421, 2017. [Online]. Available: https://doi.org/10.1016/j.rser.2017.01.027

[6] Z. Ren, W. Yan, C. Ding, J. Yu, and X. Zhao, "Probabilistic optimal power flow analysis of virtual power plant containing photovoltaic generation," *Asia-Pacific Power and Energy Engineering Conference, APPEEC*, vol. 2015-March, no. March, 2014. [Online]. Available: https://doi.org/10.1109/APPEEC.2014.7066012

[7] H. Saboori, M. Mohammadi, and R. Taghe, "Virtual power plant (VPP), definition, concept, components and types," *Asia-Pacific Power and Energy Engineering Conference, APPEEC*, 2011. [Online]. Available: https://doi.org/10.1109/APPEEC.2011.5749026

[8] P. Nezamabadi and G. Gharehpetian, "Electrical energy management of virtual power plants in distribution networks with renewable energy resources and energy storage systems," *16th Electrical Power Distribution Networks Conference*, pp. 1–5, 2011. [Online]. Available: https://bit.ly/3ygQznn

[9] M. Peikherfeh, H. Seifi, and M. K. Sheikh-El-Eslami, "Optimal dispatch of distributed energy resources included in a virtual power plant for participating in a day-ahead market," *3rd International Conference on Clean Electrical Power: Renewable Energy Resources Impact, ICCEP 2011*, pp. 204–210, 2011. [Online]. Available: https://doi.org/10.1109/ICCEP.2011.6036275

[10] L. Exel and G. Frey, "Toward a decentralized forecast system for distributed power generation," *ENERGYCON 2014 - IEEE International Energy Conference*, pp. 1210–1217, 2014. [Online]. Available: https://doi.org/10.1109/ENERGYCON.2014.6850577

[11] L. Hernandez, C. Baladron, J. Aguiar, B. Carro, A. Sanchez-Esguevillas, J. Lloret, and J. Massana, "A Survey on Electric Power Demand Forecasting: Future Trends in Smart Grids, Microgrids and Smart Buildings," *Communications Surveys & Tutorials, IEEE*, no. 99, pp. 1–36, 2014. [Online]. Available: https://doi.org/10.1109/SURV.2014.032014.00094

[12] P. Asmus, "Microgrids, Virtual Power Plants and Our Distributed Energy Future," *The Electricity Journal*, vol. 23, no. 10, pp. 72–82, 2010. [Online]. Available: https://doi.org/10.1016/j.tej.2010.11.001

[13] F. Quinteros, D. Carrión, and M. Jaramillo, "Optimal Power Systems Restoration Based on Energy Quality and Stability Criteria," *Energies*, vol. 15, no. 6, 2022. [Online]. Available: https://doi.org/10.3390/en15062062

[14] T. Kishore and S. Singal, "Optimal economic planning of power transmission lines: A review," *Renewable and Sustainable Energy Reviews*, vol. 39, pp. 949–974, 2014. [Online]. Available: https://doi.org/10.1016/j.rser.2014.07.125

[15] V. C. Güngör, D. Sahin, T. Kocak, S. Ergüt, C. Buccella, S. Member, C. Cecati, and G. P. Hancke, "Smart Grid Technologies : Communication Technologies and Standards," *IEEE Transactions on Industrial Informatics*, vol. 7, no. 4, pp. 529–539, 2011. [Online]. Available: https://doi.org/10.1109/TII.2011.2166794

[16] U. Akpan, M. Essien, and S. Isihak, "The impact of rural electrification on rural micro-enterprises in niger delta, nigeria," *Energy for Sustainable Development*, vol. 17, no. 5, pp. 504–509, 2013. [Online]. Available: http://dx.doi.org/10.1016/j.esd.2013.06.004

[17] D. Carrion, E. García, J. Gonzalez, I. Isaac, G. Lopez, and R. Hincapie, "Método Heurístico de Ubicación Óptima de Centros de Transformación

y Enrutamiento de Redes Eléctricas de Distribución," *Revista Técnica "Energía"*, vol. 4, no. 2, p. 20, 2015. [Online]. Available: https://doi.org/10.37116/REVISTAENERGIA.V13.N1.2017.11

[18] S. Heang and V. Vai, "Optimal Network Reconfiguration with DGs Placement and Sizing in a Distribution System Using Hybrid SOE and GA," in *2022 19th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON)*, no. 1. IEEE, 2022, pp. 2–5. [Online]. Available: https://doi.org/10.1109/ECTI-CON54298.2022.9795530

[19] M. A. Aderibigbe, A. U. Adoghe, F. Agbetuyi, and A. E. Airoboman, "A review on optimal placement of distributed generators for reliability improvement on distribution network," *2021 IEEE PES/IAS PowerAfrica, PowerAfrica 2021*, 2021. [Online]. Available: https://doi.org/10.1109/PowerAfrica52236.2021.9543266

[20] S. K. Sena, "An Approach to Detect Islanding in Photovoltaic Based Distributed Generation Systems using Sequence Components of Voltage," in *2022 IEEE International Conference on Distributed Computing and Electrical Circuits and Electronics (ICDCECE)*. IEEE, 2022, pp. 1–6. [Online]. Available: https://doi.org/10.1109/ICDCECE53908.2022.9792918

[21] W. Pavón, E. Inga, and S. Simani, "Optimal routing an ungrounded electrical distribution system based on heuristic method with micro grids integration," *Sustainability*, vol. 11, no. 6, pp. 1–18, 2019. [Online]. Available: https://doi.org/10.3390/su11061607

[22] E. Inga, M. Campaña, and R. Hincapié, "Optimal Sizing of Electrical Distribution Networks considering Scalable Demand and Voltage," *2018 IEEE 1st Colombian Conference on Applications in Computational Intelligence, ColCACI 2018 - Proceedings*, vol. 1, no. 1, pp. 1–6, 2018. [Online]. Available: https://doi.org/10.1109/ColCACI.2018.8484859

[23] A. Valenzuela, I. Montalvo, and E. Inga, "A decision-making tool for electric distribution network planning based on heuristics and georeferenced data," *Energies*, vol. 12, no. 21, 2019. [Online]. Available: https://doi.org/10.3390/en12214065

[24] F. Heimgaertner and M. Menth, "Distributed Controller Communication in Virtual Power Plants Using Smart Meter Gateways," *2018 IEEE International Conference on Engineering, Technology and Innovation, ICE/ITMC 2018 - Proceedings*, pp. 1–6, 2018. [Online]. Available: https://doi.org/10.1109/ICE.2018.8436311

[25] A. Valenzuela, E. Inga, and S. Simani, "Planning of a Resilient Underground Distribution Network Using Georeferenced Data," *Energies*, vol. 12, no. 4, p. 644, 2019. [Online]. Available: http://www.mdpi.com/1996-1073/12/4/644

[26] M. S. S. Danish, T. Senjyu, S. M. S. Danish, N. R. Sabory, K. Narayanan, and P. Mandal, "A recap of voltage stability indices in the past three decades," *Energies*, vol. 12, no. 8, pp. 1–18, 2019. [Online]. Available: https://doi.org/10.3390/en12081544

[27] R. Mahanty and P. Gupta, "Voltage stability analysis in unbalanced power systems by optimal power flow," *IEE Proceedings - Generation, Transmission and Distribution*, vol. 151, no. 3, pp. 201–212, 2004. [Online]. Available: https://doi.org/10.1049/ip-gtd:20050011

[28] D. Carrión, E. García, M. Jaramillo, and J. W. González, "A Novel Methodology for Optimal SVC Location Considering N-1 Contingencies and Reactive Power Flows Reconfiguration," *Energies*, vol. 14, no. 20, pp. 1–17, 2021. [Online]. Available: https://doi.org/10.3390/en14206652

[29] D. Carrión, J. Palacios, M. Espinel, and J. W. González, "Transmission Expansion Planning Considering Grid Topology Changes and N-1 Contingencies Criteria," in *Recent Advances in Electrical Engineering, Electronics and Energy*, Springer, Ed. Springer, pp. 266–279. [Online]. Available: https://doi.org/10.1007/978-3-030-72208-1_20

[30] I. A. Samuel, J. Katende, C. O. Awosope, and A. A. Awelewa, "Prediction of voltage collapse in electrical power system networks using a new voltage stability index," *International Journal of Applied Engineering Research*, vol. 12, no. 2, pp. 190–199, 2017. [Online]. Available: https://bit.ly/39Orhn8