Analysis of the Optimized Allocation of Distributed Generation in Radial Distribution Networks Considering the Current Carrying Capacity of the Power Cables

Carlos A. Paez[1], Gian C. Garcia[2], Hayro A. Pumalloclla[3], Cristoercio A. Silva[4], Joel D. Melo [5], and Isaac Dyner[6]

[1]*Jorge Tadeo Lozano University, Bogotá Colombia, carlosa.paezc@utadeo.edu.co*
[2]*Federal University of ABC, UFABC, Santo Andre, Brazil, carlos.garcia@ufabc.edu.br*
[3] *Federal University of ABC, UFABC, Santo Andre, Brazil, hayro.pumalloclla@ufabc.edu.br*
[4] *Federal University of ABC, UFABC, Santo Andre, Brazil, cristoercio.silva@ufabc.edu.br*
[5]*Federal University of ABC, UFABC, Santo Andre, Brazil, joel.melo@ufabc.edu.br*
[6]*Jorge Tadeo Lozano University, Bogotá Colombia, issac.dynerr@utadeo.edu.co*

ABSTRACT

Due to climate change and rising temperatures, distribution network planners are faced with new challenges that can overload energy distribution networks. As a result, these overloads can bring the distribution system to operating points with low levels of safety and reliability. This work presents a case study that shows how an optimized location of distributed generation (DG) can alleviate overloads on the lines in the presence of high temperatures, resulting in the reduction of electrical losses in the distribution system. The study focuses on a distribution network of 138 countries located in Inírida, Guainía, Colombia, respecting the static thermal classification standards described according to IEEE 738-2012 directives. Also, analyze a range of three scenarios that take into account the temperature fluctuations and the growth of demand. Furthermore, the Particle Swarm Optimization (PSO) algorithm is used to determine the best locations for DG installation. The results indicate that optimized DG placement can reduce power losses by 4.1 kW when DG is integrated into the distribution network. This analysis can help energy distributors to plan the dispatch and integrate the distributed management.

Keywords: Power distribution network, current carrying capacity, renewable distributed generation, energy loss.

1 INTRODUCTION

In the current climate, described by the constant growth in energy production and the progressive increase in demand, combined with the integration of new generation sources, the electricity sector faces a series of challenges of specific magnitude. One of these significant challenges is the high temperatures that negatively affect the power transfer capacity of the electricity grid. This constraint directly affects the energy system's security, quality, and economic performance [1]. Promoting a comprehensive transformation in the grid's planning and operation procedures is essential to ensure the optimal, economic, and efficient operation of the power system. Consequently, it is crucial to estimate the maximum current capacity allowed on overhead lines accurately. This objective is achieved by preserving the mechanical characteristics by analyzing the thermal rating of overhead conductors on different time scales [2],[3]. From a physical point of view, the maximum energy transfer by a conductor is obtained by determining the current-temperature relationship, called the thermal limit (IEEE Std. 738-2002) [4].

A viable strategy to mitigate the problems mentioned above is the allocation of DG units. This DG allows more energy efficiency, reducing technical losses and environmental impacts. Among the relevant contributions is the study in [5], where he develops ampacity correlation models considering steady-state and dynamic meteorological data. In addition, in [6], a methodology for determining the dynamic ampacity of overhead power lines under various weather conditions is presented. In [7] was showsed a method that integrates distributed generation with optimal reconfiguration in radial distribution networks. In this context, this work focuses on the optimal DG allocation to prevent driver congestion due to extreme variations in ambient temperature. For this purpose, different scenarios have been defined considering the influence of temperature variation during the months of March and December based on

DOI: 10.55592/ISE.2023.3369982

weather forecasts, such as solar radiation, ambient temperature, and complying with the static thermal rating (STR) of the IEEE 738-2012 standard. Furthermore, demand forecast growth over a ten-year period, based on econometric models, is considered. Optimal DG allocation is addressed using the PSO algorithm, implemented in MATLAB software, which determines the optimal locations for DG installation within the distribution system.

2 PROPOSED METHODOLOGY

In this work, our line of study has been built around the guidelines defined by the IEEE 738 – 2012 standard. This approach is complemented by considering weather forecasts, including variables such as wind speed and direction, solar radiation, and ambient temperature, among other factors [8], [9]. Subsequently, to minimize losses, we have developed an optimization model for the location of DG. The main objective of this approach is to strengthen reliability and safety in electrical distribution systems. This standard recommends evaluating and analyzing the dynamic behavior of overhead electrical networks in response to climatic and operational design variations.

A. mathematical formulation

a) heat balance

The relationship between current and temperature is determined to calculate the heat balance, taking into account the rate of heat gain due to the Joule effect, the rate of heat gain caused by solar radiation, the rate of heat loss due to convection and the rate of heat loss due to radiation.

In this way, the current that circulates through the conductor can be calculated as shown in the formula presented in (1), where R_{Tavg} represents the electrical resistance of the conductor, and I it corresponds to the current that circulates through it.

$$I^2 + R_{Tavg} + q_s = q_c + q_r where\ I = \sqrt{\frac{q_c + q_r - q_s}{R_{Tavg}}} \tag{1}$$

B. Mathematical modeling for the optimal location of DG

a) Objective Function

$$Min = \sum_{t=1}^{T} \sum_{j=1}^{M} \sum_{i=1}^{N} R_{ij} \left[\frac{P_j^t + Q_j^t - a_j \cdot PV_j^t}{V_j} \right]^2 \tag{2}$$

Where N and M represent the number of nodes, R_{ij} denotes the resistance of the line between nodes i and j, P_j^t is the active power of node j, Q_j^t refers to the reactive power of node j, PV represents the photovoltaic generation at node j, a_j is the binary variable, and V_j indicates the voltage at node j.

b) System restrictions

$$I_{\text{min}} \Upsilon \leq I_{ij}^t \Upsilon \leq I_{\text{max}} \Upsilon \tag{3}$$

$$\mathrm{V}_j^{\text{min}} \leq \mathrm{V}_j^t \leq \mathrm{V}_j^{\text{max}} \tag{4}$$

$$P_{ss} = P_{\text{loss}} + \sum_{j=1}^{M} P_{\text{load}} - \sum_{j=1}^{M} a_j \cdot \mathrm{PV}_j \tag{5}$$

DOI: 10.55592/ISE.2023.3369982

where Υ is the constant that represents the ambient temperature level, P_{ss} is the power of the substation, P_{loss} means the technical losses of the system, P_{load} is the power required by the load, PV_j is the power generated by the photovoltaic unit, and $I_{ij}^{t}\Upsilon$ denotes the line current ij for time t and a given temperature.

C. Metaheuristic techniques used in the optimal location of GD

a) PSO technique (particle swarm optimization)

Particle swarm optimization (PSO) is a stochastic technique based on the social behavior of birds during flight [10]. The velocity and position of each particle are described in the following formulation.

$$v_i^{(k+1)} = w \cdot v_i^k + \phi_1 \cdot \text{rand}_1 \cdot (p_{\text{Best}}^{(i)} - x_i^k) + \phi_2 \cdot \text{rand}_2 \cdot (g^{(i)} - x_i^k) \tag{6}$$

$$x_i^{(k+1)} = x_i^k + v_i^{(k+1)} \tag{7}$$

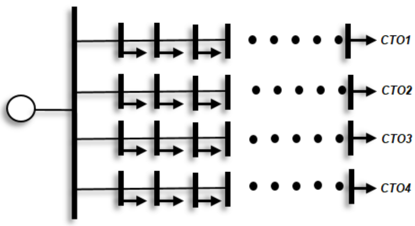
Where $v_i^{(k+1)}$ is the new velocity of particle i, w is the inertia factor of particle i, ϕ_1 and ϕ_2 are the control weights, rand_1 and rand_2 are random numbers between 0 and 1, $x_i^{(k+1)}$ is the new position of particle i, x_i^k is the previous position of particle i, and $v_i^{(k+1)}$ is the new speed.

3 CASE STUDY

a) Description of the distribution system

The 13.2 kV distribution network addressed in this investigation Fig.1, is located in the region of the municipality of Inírida, department of Guainía, Colombia. which is interconnected to the local distribution system with ACSR 2/0 AWG overhead lines. The circuit for analysis has a three-phase installed power of 3.911 MW. These feeders are connected to a system of diesel-powered generator sets, providing a nominal generating power of 9.1 MVA

Figure 1: Electrical distribution system of 138 nodes.



b) Analysis of different scenarios

As part of the study, three scenarios were proposed to assess the influence of ambient temperature variations on the distribution lines during March and December, covering demand forecasts for the years 2022, 2027, and 2032. In each of these scenarios, the technical parameters of the conductors and the meteorological variables influencing the current capacity of the power lines were adjusted, as detailed in Table 1. This approach provides a deeper understanding of the behavior of power lines under various ambient temperature conditions.

4 RESULT AND DISCUSSION

As seen in Table 2, for this study, we use the developed algorithm to simulate and analyze various scenarios that correspond to the behavior of the current on the electrical distribution networks. This

Table 1: Parameters with variation of ambient temperature.

Scenario 1: Distribution network with a nominal load corresponding to 2022
Demand curve: Nominal demand for 24 hours - 2022
Ampacity curve: 2/0 AWG line -Ambient temperature for 24 hours
* Ampacity curve month March - IEEE 738-2012
* Ampacity curve month December - IEEE 738-2012
Scenario 2: Distribution network with load projection to 2027.
Demand curve: Projected demand for 24 hours - 2027
Ampacity curve: 2/0 AWG line -Ambient temperature for 24 hours
* Ampacity curve month March - IEEE 738-2012
* Ampacity curve month December - IEEE 738-2012
Scenario 3: Distribution network with load projection to 2032.
Demand curve: Projected demand for 24 hours - 2032
Ampacity curve: 2/0 AWG line -Ambient temperature for 24 hours
* Ampacity curve month March - IEEE 738-2012
* Ampacity curve month December - IEEE 738-2012

Environmental and operational variables of 2/0 AWG lines - IEEE 738-2012		
Symbol	**Description**	**Units**
ACSR	Quail 2/0 AWG	2/0
ε	conductor emissivity	0,8
α	conductor absorption	0,8
Vw	wind speed (m/s)	0,61
He	elevation of the line above sea level (m)	95
Ts	conductor design temperature (°C)	75
Ta	air temperature (°C)	18 --- 38
Φ	wind direction angle (°)	45
ω	hour angle 11am	'-15°
ty_environ	type of environment : clean or industrial	clean
date	Lat°	Zl°
21/03/2022	79.65	109.85
21/12/2022	61.75	165.47

analysis, Figure 2., was carried out over 24 hours and focused on the two most critical months: March, when high temperatures of up to 38.25°C, and December, characterized by low temperatures of around 19 °C. The results obtained play a fundamental role in ensuring the optimal management and strategic location of Distributed Generation (DG), especially in situations where the distribution network faces extreme weather conditions.

•Scenario 1: Influence of ambient temperature on conductor capacity and rated load - year 2022. In this scenario, a comparative validation was carried out between rated load currents and conductor current capacity as a function of ambient temperature variations, also referred to as ampacity. During these tests, estimated power losses of 552 kW were observed, representing 6.07% of the total generated power of 9.1 MW. On the other hand, considering the DG allocation, the installation of 5 DGs was determined to reduce power losses to 377 kW, equivalent to 4.14% of the total power generated.

•Scenario 2: Influence of ambient temperature on conductor capacity and rated load - year 2027. Performing the same temperature variation analysis of scenario 1, and considering the electricity demand projection for the year 2027, which will experience an increase of 30%, reaching 5084 kW of peak load compared to the year 2022, where the net capacity was 3911 kW. During this analysis, estimated power losses of 956 kW are obtained, equivalent to 10.51% of the total power. On the other hand, considering the DG allocation, the installation of 6 DG was determined to reduce the power losses to 575 kW, equivalent to 6.32%. This DG integration contributes to decongesting the distribution network when temperature conditions reach extreme levels during the day, as shown in Figure 2.

•Scenario 3: Influence of ambient temperature on conductor capacity and rated load - year 2032. In this scenario, a demand projection is made for the year 2032, showing an increase in peak load, 6156 kW, which represents an increase of 57.4% with respect to the year 2022. In this analysis, estimated power losses of 1412 kW are obtained, equivalent to 15.52% of the total power without DG. On the other hand, considering the allocation of DG, the installation of 7 DG was determined, reducing power losses to 720 kW, equivalent to 8.02%. This is necessary to ensure energy security when temperature conditions reach extreme levels.

5 CONCLUSION

The results obtained in this work provide a detailed characterization of the behavior of the electrical demand and current capacity of the conductor ampacity considering climatic conditions throughout the year. In addition, the results were compared considering three different scenarios, taking into account the influence of temperature on the safety, quality, and efficiency of the electrical distribution system. This work also highlights the importance of optimizing how the resource is fundamental to increasing efficiency, reducing losses, and guaranteeing reliability and security in the supply of energy to the electrical system. A key aspect of future research focuses on economic analysis, which addresses the costs associated with implementing Distributed Generation, as well as technical and non-technical losses and interruptions in distribution lines related to high-temperature conditions. This will allow for an even more accurate assessment when considering the impact of environmental conditions on the operation of

Scenario 1						
Without DG		With DG		Allocation node	Contribution % Ploss reduction	
Ploss Kw	552,00	Ploss Kw	377,00	23, 69, 71 ,72, 81	1,92	
% Ploss	6,07	% Ploss	4,14			

Scenario 2					
Without DG		With DG		Allocation node	Contribution % Ploss reduction
Ploss Kw	956,00	Ploss Kw	575,00	26, 69, 71, 72, 81, 82	4,19
% Ploss	10,51	% Ploss	6,32		

Scenario 3					
Without DG		With DG		Allocation node	Contribution % Ploss reduction
Ploss Kw	1412,00	Ploss Kw	729,60	2, 26, 69, 71, 72, 81, 82, 83	7,50
% Ploss	15,52	% Ploss	8,02		

Table 2: Scenarios - System power losses without DG/with DG.

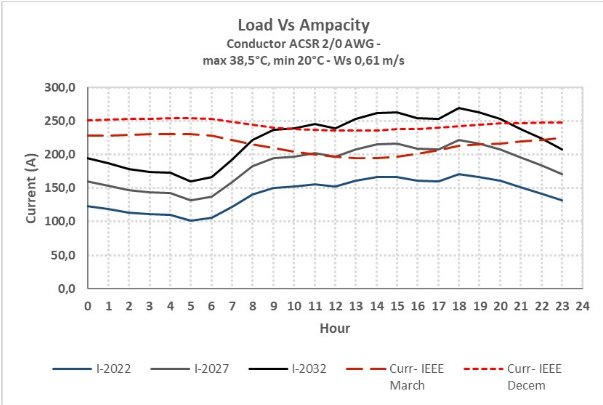


Figure 2: Load and ampacity forecast curve

electrical conductors.

References

[1] Y. Chen, G. Tang, X. Song, and X. Li, "Overload control method of transmission lines considering wind power characteristics", *Dianli Xitong Zidonghua/Automation of Electric Power Systems*, vol. 39, 13 2015, ISSN: 10001026. DOI: 10.7500/AEPS20140918008.

[2] S. Ge, J. Han, H. Liu, Y. Guo, and C. Wang, "Power supply capability determination considering constraints of transformer overloading and tie-line capacity", *Zhongguo Dianji Gongcheng Xuebao/Proceedings of the Chinese Society of Electrical Engineering*, vol. 31, 25 2011, ISSN: 02588013.

[3] H. Zhang, X. Han, and Y. Wang, "Analysis on current carrying capacity of overhead lines being operated", *Power System Technology*, vol. 32, no. 14, pp. 31–35, 2008.

[4] O. A. Lawal, "Prospects of using dynamic thermal rating for a reliable power system network: A review", in *2021 IEEE International Future Energy Electronics Conference (IFEEC)*, IEEE, 2021, pp. 1–7.

[5] Z. Yan, Y. Wang, and L. Liang, "Analysis on ampacity of overhead transmission lines being operated.", *Journal of Information Processing Systems*, vol. 13, no. 5, 2017.

[6] M. Kanalik, A. Margitová, J. Urbanský, and L. Bena, "Temperature calculation of overhead power line conductors according to the cigre technical brochure 207", May 2019, pp. 1–5. DOI: 10.1109/EPE.2019.8778173.

[7] A. Eid, "Allocation of distributed generations in radial distribution systems using adaptive pso and modified gsa multi-objective optimizations", *Alexandria Engineering Journal*, vol. 59, 6 2020, ISSN: 11100168. DOI: 10.1016/j.aej.2020.08.042.

[8] A. Michiorri, H. M. Nguyen, S. Alessandrini, *et al.*, *Forecasting for dynamic line rating*, 2015. DOI: 10.1016/j.rser.2015.07.134.

[9] I. Albizu, E. Fernandez, A. J. Mazon, and R. Alberdi, "Forecast ratio and security analysis of rating forecasting methods in an overhead line", *IET Generation, Transmission and Distribution*, vol. 11, 6 2017, ISSN: 17518687. DOI: 10.1049/iet-gtd.2016.1649.

[10] M. V. da Rocha, L. P. Sampaio, and S. A. Oliveira da Silva, "Comparative analysis of abc, bat, gwo and pso algorithms for mppt in pv systems", in *2019 8th International Conference on Renewable Energy Research and Applications (ICRERA)*, 2019, pp. 347–352. DOI: 10.1109/ICRERA47325.2019.8996520.