Optimal sizing of a grid-connected microgrid and operation validation using HOMER Pro and DIgSILENT

Dimensionamiento óptimo y validación de la operación de una microrred conectada utilizando HOMER Pro y DIgSILENT

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Artículo de investigación científica y tecnológica

***Abstract*— The adoption of microgrids is increasing globally for various reasons, such as integrating renewable generation, providing energy to rural areas, reducing CO2 emissions, or achieving energy independence. However, planning, and operating microgrids can be challenging due to the complex interplay of economic, technical, and environmental factors. This work presents a methodology for planning and validating grid-connected microgrids using two well-known software tools: HOMER Pro for sizing and selecting appropriate generation sources and Dig SILENT for validating the implementation on a real distribution network. The methodology is demonstrated through numerical results for a university campus based on real data and technical validation according to Colombian regulatory requirements.**

***Index Terms*— Microgrids planning methodology, Microgrids operation, HOMER Pro, DIgSILENT.**

***Resumen*— La adopción de microrredes está aumentando en todo el mundo por diversas razones, como la integración de la generación renovable, el suministro de energía a zonas rurales, la reducción de las emisiones de CO2 o la consecución de la independencia energética. Sin embargo, la planificación y el funcionamiento de las microrredes pueden resultar complicados debido a la compleja interacción de factores económicos, técnicos y medioambientales. Este trabajo presenta una metodología para planificar y validar microrredes conectadas a la red utilizando dos conocidas herramientas de software: HOMER Pro para dimensionar y seleccionar las fuentes de generación adecuadas y Dig SILENT para validar la implementación en una red de distribución real. La metodología se demuestra mediante resultados numéricos para un campus universitario basados en datos reales y la validación técnica de acuerdo con los requisitos normativos colombianos.**

***Palabras claves*— DIgSILENT, HOMER Pro, Operación de microrredes, Planificación de microrredes.**

I. Introduction

MICROGRIDS play an important role in the integration of renewable energy in urban and rural locations. There are many reasons to choose microgrids as a strategy for electrification, turning the current power grid into a smarter and more modern network. Microgrids have many advantages such as enabling users as producers and consumers, allowing the participation of new electrical loads (electric vehicles, bikes, and storages systems), the energy distribution is more efficient, clean, and the cost of energy is decreasing supported by technology developments. In numbers, microgrids installed capacity has been duplicated to 3000 MW from 2015 to 2019 in the U.S., with a projected installation of about 7500 MW by 2024. The overview is similar for Latin America, expecting 1000 MW installed by 2024 [1]. Specifically, Colombia supports the adoption of renewable energy by UPME through Indicative Plan Coverage Expansion Energy (PIEC 2019 - 2023), which based on economic and technical studies, recommends installing more than 1000 PV systems and 257 autonomous microgrids to enable energy access in rural zones [2].

On the other hand, microgrids planning involves many economic and technical variables into a complex decision-making process. Given the importance of this topic, there are many studies addressing the planning process as an optimization problem [3]. Usually, the objective function is proposed in terms of implementation and operation costs, and

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the constraints are the technical limitations of generators or storage systems. In addition, these kind of planning methodologies require an extensive database with information about renewable resources and electrical user load. However, the optimization process is flexible to adapt to specific scenarios and the solutions are very accurate.

Recently, some software tools have achieved high popularity because they facilitate the microgrid planning steps. For instance, some applications incorporate databases supplying irradiance, wind speed, temperature data, among others. In addition, they provide tools to design and evaluate a microgrid, including the optimal sizing of the generation units. Some authors present microgrids planning methodologies adapted to particular contexts, which considers legal and regulatory issues, analyzing capital costs [4]–[6]. Other studies show the application of planning methodologies using specialized tools, such as HOMER Pro, highlighting the mathematical models of components and the software's methodology [7]–[9]. HOMER Pro is a powerful software to evaluate designs from a technical and economical point of view. It has tools to evaluate the cost in grid-connected and stand-alone scenarios and performs sensitivity analyses considering price or resource availability and changes [10]–[12].

Although most of the studies focus on technical and economic analysis, they do not present a complete process for validating the operation of the microgrid in real scenarios. This work presents a simple method for planning and validating a microgrid using HOMER Pro and DIgSILENT Power Factory. It focuses on practical validation in a constrained distribution system through numerical indicators as voltage profiles and power losses in the grid-connected microgrid. In addition, the methodology includes an economic analysis in terms of cost of energy, net-present cost (NPC), and incomes for purchases of energy in a case study for a connected microgrid.

The main contributions of this work consist on proposing a planning methodology to make an optimal sizing of components and validate the operation of microgrid based on simulation of a local power grid obtaining technical indicators as voltage profiles, power losses, among others. Moreover, the method is applied to a real case study in terms of economic incomes for a local energy market.

This paper is organized as follows. First, it describes the methodology to size the components of a connected microgrid using HOMER Pro. Then, Section III describes the methodology to validate the operation of the microgrid using DIgSILENT. Next, the case study is presented with the economic and technical details, and regulatory issues. Finally, numerical results, conclusions, and discussion about the complete process are presented.

II. Optimal sizing using HOMER Pro

HOMER Pro is a software to evaluate electric power systems as microgrids from economical and technical points of view. This software incorporates several components and tools to build and evaluate electric pre-designs, including different components as alternative and conventional generators, power grid, storage systems, and power interfaces. Besides, it has tools to build electric load profiles and to download databases with information about irradiance, wind speed, temperature, among others environmental variables. One of the key components of HOMER Pro is the optimization tool for evaluating designs. The optimization tool allows HOMER Pro to calculate an optimal number of components that minimizes the net present post (NPC) to satisfy all the electric load needs.

A. *Sizing methodology description*

Optimal sizing of the microgrids using HOMER is carried out according to the diagram in Fig 1.

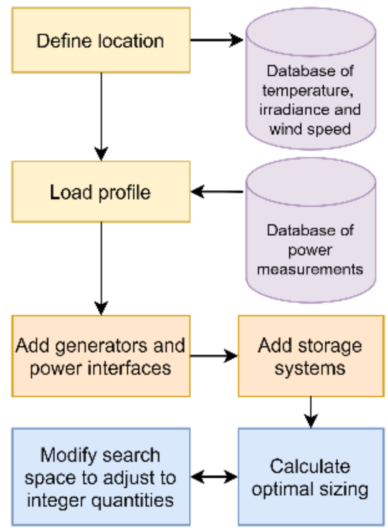

Fig. 1. Sizing methodology using HOMER Pro.

First, the location is defined in terms of latitude and longitude, which allow the application to download yearly profiles of irradiance, wind speed, and temperature. Second, an aggregated load profile is created according to power measurements carried out in local loads of the microgrid (e.g., buildings). Some variations may be added in terms of energy-per-day and energy-per-hour, not exceeding 10%.

With the site and load definitions, generators and power grid are added as energy resources, including the power interfaces related to each generator. In this step, important information such as maximum and minimum power generation constraints and capital and maintenance costs are considered. This data must be as precise as possible since the type and quantity of generators depend directly on these features.

The storage systems are then added as energy support with all technical and economic information. Finally, the optimal sizing of components is calculated according to the described information. Without extra constraints, it is highly probable that the sizing of some components does not correspond to commercial specifications or integer values, therefore, it could be necessary to run HOMER Pro considering some additional conditions in the search space. Moreover, some discrete design quantities (e.g., number of PV panels or batteries) should be limited to the technical possible arranges. In fact, most electric designs require organizing batteries and PV panels in strings to fulfill voltage or current requirements according to the power interfaces used. This is highly important from a practical point of view.

B. Costs and economical parameters

HOMER Pro requires as inputs the capital, maintenance, replacement, and operational costs for each component as generators, energy storage, and power interfaces. In addition, a project lifetime, discount rate, inflation rate, among others economical parameters are required. Costs and economical parameters are used to calculate the NPC for lifetime project, which is the minimization criteria to choose the optimal sizing of components. NPC is calculated by

$$NPC = \frac{C_{T,A}}{CRF(d,l)}, \quad (1)$$

where $C_{T,A}$ is total annualized cost, d is the annual interest rate, l is the lifetime project in years. The Capital Recovery Factor (*CRF*) is given by

$$CRF(d,l) = \frac{d(1+d)^n}{((1+d)^n - 1)}, \quad (2)$$

where n is the number of years.

Essentially, NPC is a function of components size, costs, and economical parameters, which represents a complex, nonlinear, and integer-mixed function. NPC is minimized by the HOMER optimization tool getting as a result an optimal size of components.

Another useful metric is the cost of energy (COE), which is is given in $/kWh and is comparable with the electricity fee by purchase energy to the utility. This metric can be used to evaluate the economic feasibility of a microgrid in comparison with conventional systems as the power grid or diesel plants. COE is given by

$$COE = \frac{C_{T,A}}{E}, \quad (3)$$

where E is the total energy provided to the loads plus energy sold to the power grid.

III. VALIDATION OF OPERATION USING DIGSILENT

DIgSILENT Power Factory is a powerful software to simulate electric power systems evaluating power flows, voltage profiles, currents through lines, the load factor of components, and power losses, among other analyses. Microgrids designs can be built and tested easily given that the tool has a set of generators and power interfaces such as PV systems, wind turbines, power converters, and batteries. Following steps can be carried out as a guide to probe an electrical microgrid in DIgSILENT and obtain some indicators to evaluate the microgrid performance.

A. Validation methodology description

Validation is the development of tests to the microgrid design obtaining numerical indicators to qualify the operation performance. By validation, real operational conditions can be tested before carrying a real implementation. Moreover, changes of electrical loads, available resources for generation, and transition to isolated modes can be performed easily.

Fig. 2 presents a validation methodology using DIgSILENT, where first, a local grid corresponding to the microgrid must be built. This process requires, as much as possible, precise information about the grid as length and wire type of the lines, location and voltage levels of the electric buses, and location and connection of transformers. In addition, the optimal sizing of components obtained from HOMER are loaded in DIgSILENT's units (i.e., the capacity of generators and storage systems).

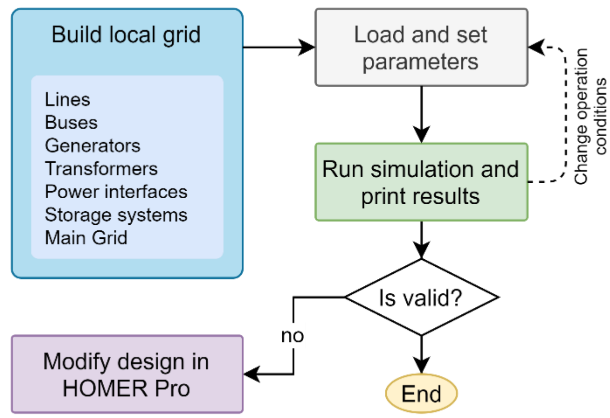

Fig. 2. Validation methodology using DIgSILENT.

Also, power interfaces are configured according to their capacity curve in DIgSILENT. For instance, Fig. 3 shows a capacity curve that describes the relationship between active and reactive powers. The gray cone is the set of operation points for a power inverter associated to renewable generators.

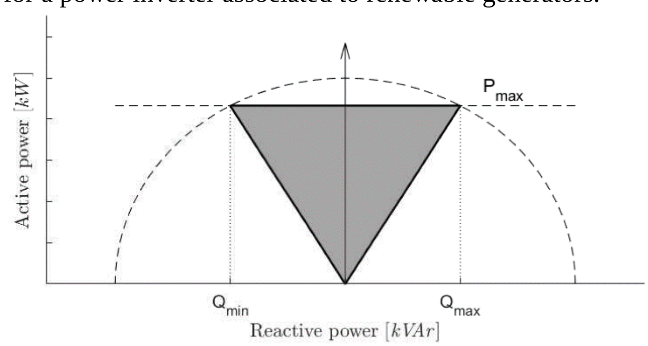

Fig. 3. Capacity curve of a power inverter [13].

Second, all the grid's parameters must be loaded into the DIgSILENT microgrid model, where some of the more important ones areconductances and susceptances of lines, voltages of busbars and transformers, active and reactive power operation points of generators and batteries, active and reactive power consumption of electrical loads, and capacity curve of power interfaces. Some parameters can be changed depending on the testing scenario.

Finally, running and printing results are performed to get numerical indicators under different simulation scenarios. Depending on the local regulation rules, frequency, voltage, power losses, currents by the lines, and load factors of some critical components should be checked. In the same way, the microgrid design can be tested in a variety of critical scenarios as maximum electric load, scarcity of renewable resources, and shutdowns of generators. An invalid or technically incorrect designs can be detected by metrics out of the allowed ranges. In such a case, a new design must be calculated using HOMER, changing parameters related to the components in conflict.

IV. Description of the Case Study

A. *Location and data recopilation*

The proposed microgrid corresponds to a simple distribution system in CESMAG University, which is located in Pasto – Colombia with coordinates 1°12'32" North latitude and 77°16'42" West longitude. The climatological data of temperature and solar radiation are taken from the NASA database, which is the information system accessed by HOMER Pro.

Insolation data is taken from a Davis Pro meteorological station located in the campus. Data range from 2013 to 2020, whose average by month is shown in Fig. 4, with an average insolation of 3.5 kWh/m^2/day. Notice that the months with higher insolation are from October to December with values of 3.9 to 3.7 kWh/m^2/day.

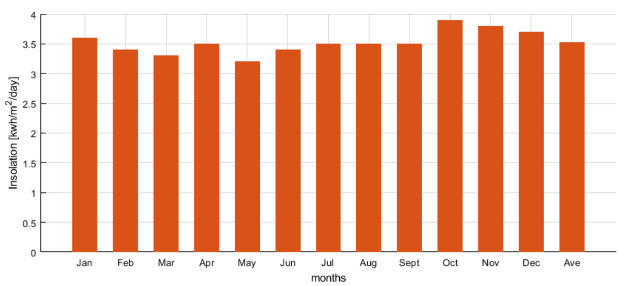

Fig. 4. Average monthly data of insolation.

B. *Electrical load profile*

The electrical load profile of the CESMAG University corresponds to the average electricity demand given in a 24-hours period. Individual load profiles are measured with HIOKI 3197 energy quality analyzer, and then all loads are aggregated in the load profiles of active and reactive powers. The measurements areperformed in busbars in Holanda-Italia, San Francisco and Sede B buildings. Fig. 5 shows the aggregated active and reactive load profile.

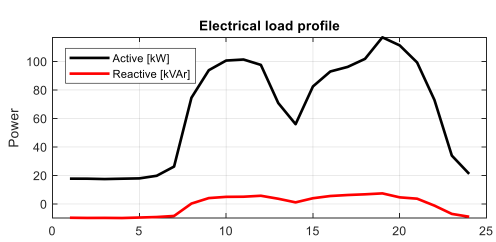

Fig. 5. Electrical load profiles.

C. *Costs*

Table I presents the information of the components of the study microgrid, including real costs of capital, replacement, and operation and maintenance (O&M) requirements. The values are adjusted according with Colombian context in 2021.

TABLE I. Cost related with microgrid components

Component	Capacity	Capital [$]	Replacement [$]	O&M [$/year]
Solar Panel	530 W	322.93	322.93	3.23
Converter	10 kW	4984.4	4984.34	49.84
Battery	83.4 Ah	324.93	324.93	3.24
Gen Diesel	180 kW	0	51902.28	0.06

*$=USD

In addition, the prices of interchange energy with external power grid should be estimated. University purchases energy at 0.152 $/kWh, and according to the Colombian regulation agency for energy - CREG (Colombian law 1715/ 2014 and resolution 030/2018) the University could sale energy to utilities with a price of 0.043 $/kWh.

D. *Operatinal constraints*

Available space for PV panels in CESMAG University is located on roofs of Sede B, Holanda-Italia, and San Francisco buildings, with areas of 1413.19 m^2, 645.371 m^2, 1138 m^2 respectively (Fig. 6).

Fig. 6. Available areas for PV roofs within the University Campus.

Maximum peak power for available area is calculated by

$$P_{TA} = \frac{A_{TA}}{A_P} P_P, \quad (4)$$

where P_P and A_P are the nominal power and area of a solar panel, and P_{TA} and A_{TA} are total power and available area. Table II shows the estimation for peak power that can be reached with solar panels of 2.56 m^2 and 530 Wp in each building.

TABLE II. Available area and peak power maximum

Campus Buildings	Area [m^2]	Nº Panels	Peak power [kW]
Sede B	1413.19	553	293
Holanda-Italia	645.37	253	134
San Francisco	1138.16	445	236
		TOTAL	663

Similarly, the measurements of lengths and impedances of lines between buildings are estimated to build the simulation model of local power grid. In addition, existent components such as transformers, batteries, or generators must be included in the model. In this case, San Francisco building has an Olympian diesel generator (genset) with nominal apparent power of 225 kVA, 180 kW of active power, and 135 kVAr of reactive power with a power factor of 0.8.

E. General and Colombian regulatory aspects

According to the IEEE 1159-2019 recommendation [14], electromagnetic phenomena affecting the power quality can be of three types:

- Variations in the RMS value of voltage or current.
- Disturbances of a transitory nature.
- Deformations in the waveform.

Table III presents the summary of the allowed ranges for each category. The proposed design for the microgrid focuses on short- and long-duration variation.

TABLE III. CHARACTERISTICS OF ELECTROMAGNETIC VARIATIONS, DISTURBANCES AND DEFORMATIONS [14]

Categories	Typical duration	Typical voltage magnitude
TEMPORARY		
Interruptions	>3 s- 1min	<0.1 pu
Sag	>3 s- 1min	0.1-1.9 pu
Swell	>3 s- 1min	1.1- 1.2 pu
LONG-TERM VARIATION		
Sustained interruptions	>1 min	0.0 pu
Low voltage	>1 min	0.8 - 0.9 pu
Over voltages	>1 min	1.1 - 1.2 pu
Voltage unbalance	Steady state	0.5 - 2%

Similarly, it is worth noting that, for Colombia, the limits are defined by CREG resolution 024 of 2005 between + 10% and -10% of the nominal voltage.

V. RESULTS AND DISCUSSION

A. Sizing results with HOMER Pro

Table IV shows the results of the sizing methodology described. From an economical point of view, the best option is to get energy from a pure PV system, while batteries and other diesel generators are discarded by high operational and capital costs. The existent diesel generator is preserved as a backup source for emergencies, discarding batteries by high capital cost and low lifetime.

TABLE IV. OPTIMAL SIZE OF COMPONENTS

Component	**Size**
PVs total peak power	552 kW
Power Inverters	285 kW
Batteries [1kWh]	0
Genset	180 kW

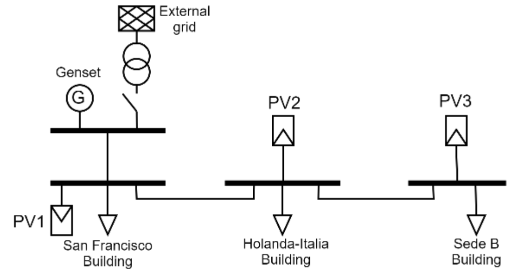

Fig 7. Microgrid local power grid.

Fig. 7 shows the local power grid with the distributed generation located according with available area. The unit G is the existent genset, and PV1, PV2, and PV3 are the optimal PV systems with sizes of 196.55 kW, 111.45 kW, and 244.01 kW, respectively. It is remarkable that the optimal design does not fill all the available area with solar panels.

In order to support the optimality of the chosen design and compare with other possible PV sizes, Fig. 8 shows the graphs of COE and NPC vs the PV system peak power. The optimal size of the PV system considers the area availability as constraint. Notice that COE is higher for small PV systems sizes, and as peak power increases, it reaches its minimum value at the same point as the NPC. If the area constraints are not respected, COE decreases slightly over the constrained optimal PV system but the NPC increaces rapidly.

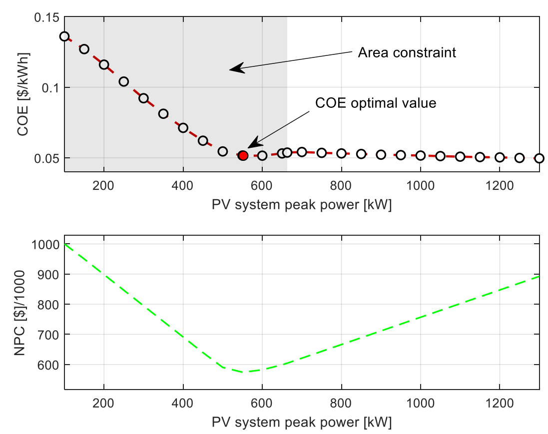

Fig 8. Comparison of COE and NPC for different sizes of PV systems.

B. Validation results with DIgSILENT

To analyze the microgrid performance in DIgSILENT, a typical day is taken into account to illustrate the effect of the inclusion of PV generation in the campus. For instance, Fig. 9 shows active power profiles for loads and PV generation at July 1st 2017, when generation overpass the electrical demand in some time periods along the day.

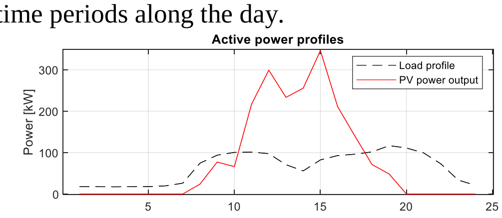

Fig. 9. Active power profiles of electrical load and total PV power output.

Fig. 10 shows the voltage profiles of the busbars in the three buildings. Solid line represents the voltage profiles considering PV systems and external power grid as energy supplies, and dotted line reprsentes the scenario considering only the external power grid as energy supply. Sede B and Holanda-Italia buildings improves their voltage profiles with the addition of distributed generation while San Francisco's voltage profile does not change significally. In general, the effect of the DGs is positive maintaining the voltage profiles in the allowed range [0.9, 1.1] p.u.

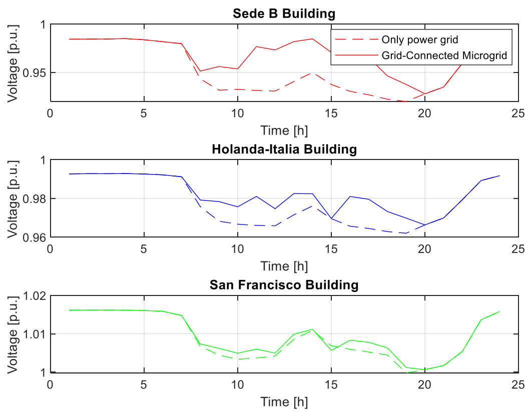

Fig. 10. Voltage profiles for buildings.

On the other hand, Fig. 11 shows the distribution power losses for both cases with and without PV systems. Losses decrease by the DGs at non-peak hours (8 am to 10 am and 5 pm to 8 pm), but increase significantly at peak hours between 10 am to 5 pm when PVs system production overpass the electrical load and power flows to external power grid. This unfortunate effect is due to the increasing current on the power lines from the roofs of each building. To reduce the active power losses, a redesign of the wire gauge in the main buses should be included to avoid possible heating.

Despite the losses in the high sunshine hours, the regulation is respected with less than a 3% over the peak. Besides it is remarkable that in the proposed scenario, all the allowed ranges in Table III are respected, so the design is a valid microgrid accordign to general and local standards.

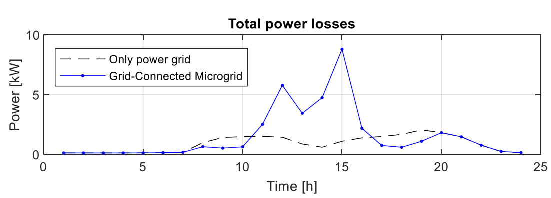

Fig. 11. Distribution Power losses.

CONCLUSIONS

This work has presented a simplification for planning and validating a microgrid using HOMER Pro and DIgSILENT Power Factory. The method allows the designers and constructors to achieve optimal COE and NPV with solutions that can be implemented in real scenarios. For instance, in the study case, an optimal COE is obtained using a lower intervention area in comparison with all the available roofs. This situation relates a bigger area with higher capital and operational costs, while incomes for energy excess are low according to Colombian regulation CREG 121-2017.

FUTURE WORK

This research work will be extended toward the evaluation of hybrid systems with other renewable energy resources like wind turbines, hydro turbines, and batteries extending the methodology to design bigger microgrids from the economic and technical points of view.

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REFERENCES

[1] A. Aram, "Microgrid Market in the USA," *Hitachi Review*, vol. 66, no. 5, pp. 454–455, 2017.

[2] UPME, "Plan Indicativo de Expansión de Cobertura de Energía Eléctrica PIEC 2019-2023," *UPME, Colombia*, no. 69, p. 141, 2019.

[3] F. A. Zuñiga, E. F. Caicedo, and D. M. López, "Gestión Óptima de la Potencia Eléctrica en una Microgrid Conectada, basada en el Algoritmo Genético para Optimización Multiobjetivo MOGA," *Revista UIS Ingenierías*, vol. 15, no. 2, pp. 17–33, 2017.

[4] J. D. Garzón-Hidalgo and A. J. Saavedra-Montes, "Una metodología de diseño de micro redes para zonas no interconectadas de Colombia," *TecnoLógicas*, vol. 20, no. 39, pp. 39–53, 2017.

[5] R. Rodríguez, G. Osma, and G. Ordóñez, "Retos de la planificación energética de micro-redes en regiones rurales remotas con cargas dispersas Energy planning challenges of microgrid in remote rural regions with scattered loads," pp. 1–8, 2017.

[6] N. Beere, D. McPhail, and R. Sharma, "A general methodology for utility microgrid planning: A Cairns case study," *Asia-Pacific Power and Energy Engineering Conference, APPEEC*, vol. 2016-Janua, 2016.

[7] G. Sandeep and V. S. Vakula, "Optimal combination and sizing of a standalone hybrid power system using HOMER," *International Conference on Electrical, Electronics, and Optimization Techniques, ICEEOT 2016*, pp. 4141–4144, 2016.

[8] R. G. Thomas, S. K. Saraswat, A. Rastogi, and A. K. DIgalwar, "On-grid system evaluation for EV charging stations using renewable sources of energy," *2020 IEEE International Power and Renewable Energy Conference, IPRECON 2020*, pp. 31–34, 2020.

[9] J. A. Weber, D. W. Gao, and T. Gao, "Affordable mobile hybrid integrated renewable energy system power plant optimized using HOMER Pro," *NAPS 2016 - 48th North American Power Symposium, Proceedings*, pp. 1–6, 2016.

[10] R. L. Dash, L. Behera, B. Mohanty, and P. Kumar Hota, "Cost and sensitivity analysis of a microgrid using HOMER-Pro software in both grid connected and standalone mode," *2018 International Conference on Recent Innovations in Electrical, Electronics and Communication Engineering, ICRIEECE 2018*, pp. 3444–3449, 2018.

[11] S. Mehta and P. Basak, "A case study on PV assisted microgrid using HOMER pro for variation of solar irradiance affecting cost of energy,"

PIICON 2020 - 9th IEEE Power India International Conference, 2020.

[12] M. S. Miah, M. A. Momen Swazal, S. Mittro, and M. M. Islam, “Design of A Grid-Tied Solar Plant Using Homer Pro and an Optimal Home Energy Management System,” *2020 IEEE International Conference for Innovation in Technology, INOCON 2020*, pp. 1–7, 2020.

[13] N. España, J. Barco-Jiménez, A. Pantoja, and N. Quijano, “Distributed population dynamics for active and reactive power dispatch in islanded microgrids,” *International Journal of Electrical Power and Energy Systems*, vol. 125, no. July 2020, p. 106407, 2021.

[14] Institute of Electrical and Electronics Engineers, *IEEE Std 1159 - IEEE Recommended Practice for Monitoring Electric Power Quality.*, vol. 2009, no. June. 2009.

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