Generation of methodology for making benchmark microgrids and application in ESUSCON microgrid

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Keywords

Microgrid, Test bench, Smart grids, Renewable energy systems, Energy management system

Abstract

A novel methodology for the generation of benchmark microgrids is proposed. For validation purposes, the methodology is applied to the case of the Chilean microgrid ESUSCON. More than 220,000 operating data points are generated, and subsequently validated according to the proposed methodology. Finally, all the estimates and assumptions are published.

Introduction

Over the years, microgrids have increasingly been implemented in the world. An example is the case of the European project "MORE MICROGRIDS", where the number of microgrids projects on the continent was significantly increased. From the information generated by this type of projects, particular implementations, and other investigations, various studies on microgrids have been published by research and development centers, studies that can be distributed in the following categories [1]: 1) Operation and system control; 2) Planning and design; 3) Quality of supply; 4) Protections and 5) Stability. From such studies, several have been carried out in various benchmark microgrids (or test networks), which have different sizes, architectures, and volumes of information. This renders the comparison of aspects such as performance challenging [2].

Existing benchmark microgrids can be divided into two categories: a) Benchmarks made from real data, such as those of an existing microgrid, obtaining data with a deterministic approach [3,4] and b) Benchmark made from fictitious or reconstructed data [1,5], such as those that can be obtained through assumptions and stochastic models already known. In the first category, these data can be formed from historical demand profiles, composition, and topology of the microgrid, failure history, among others. In the second category, the real data of a microgrid are not considered, so the benchmark is generated from topologies available in the literature and variations of these. In addition, the operation data can be modeled from data from other studies, such as line parameters, Distributed Generation (DG) parameters, among others. Demand profiles, failure rates, and meteorological conditions can also be modeled using a stochastic approach.

Due to the difficulties raised when comparing benchmark microgrids that are not easily comparable to each other, having benchmarks that allow comparative studies to be carried out, where optimal approaches can be identified and evaluated for specific studies, is necessary. For this purpose, this work proposes the use of the data sets that the ESUSCON microgrid project has generated [6], to create a microgrid benchmark. In the ESUSCON microgrid, the isolated characteristic stands out, thus imposing that the focus of this work is this type of microgrid. By the use of these data sets, a robust benchmark is generated that meets the conditions already indicated for isolated microgrids, making full use of such data. The data to be used for the benchmark are provided by the University of Chile due to its participation in the ESUSCON project. This benchmark enables multiple studies, including power flows, voltage/frequency control, reliability, and energy management. It is intended to be used for steady-state and dynamic simulations of the operation of an isolated microgrid. In this work, the benchmark is validated with an application of an energy management system.

Benchmark generation methodology

The proposed methodology uses as a reference the workflow proposed in [3], which is complemented with the lessons learned from the operation of the ESUSCON microgrid [6]. The methodology guides the designer of the benchmark in initial instances, such as the compilation of general characteristics of a microgrid, until the final steps conclude with the generation of the microgrid benchmark. The proposed methodology is presented in Fig. 1.

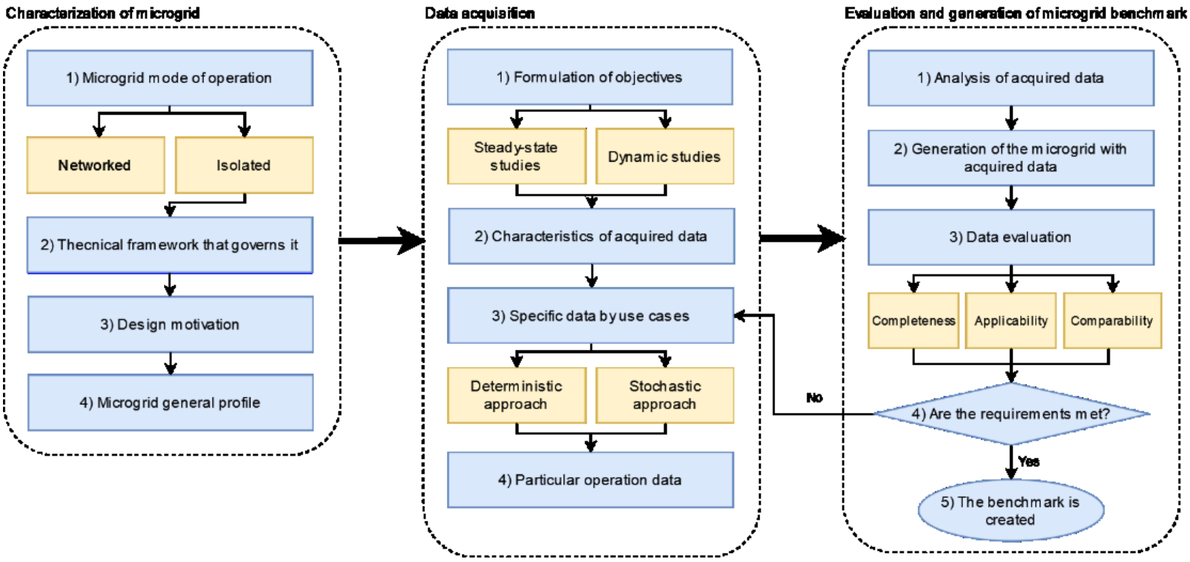


Fig. 1: Proposed methodology.

Within Fig. 1, three main stages stand out:

1. Characterization of the microgrid.
2. Data acquisition.
3. Evaluation and generation of the microgrid benchmark.

The proposed methodology, although it is intended to be applicable for the specific case of isolated microgrids, can be adapted to future iterations where it is possible to identify all the necessary measures to characterize a benchmark microgrid connected to the grid. This is possible because the stages of "Data acquisition" and "Evaluation and generation of microgrid benchmark" consider a data collection according to the specific objectives that are raised, so it is only necessary to change the initial structure of the first stage.

The first stage of the methodology, although it proposes a characterization of the microgrid to be generated, also serves to publish important information that corresponds to the technical operation data required in the second and third stages. This information serves to give context to what the microgrid benchmark proposes and what it is designed for.

The second stage of the methodology corresponds to an iteration where the data to be published are obtained. In this stage, some steps allow for the generation of useful and related data for the benchmark. In this stage the work that exists before the step "Specific data by use cases" is noteworthy. In the first and second step of this stage, the objectives of the benchmark are formulated, and the characteristics of the data collected are made explicit. Therefore, the data obtained are subject to what is decided in these first two steps, which highlights the relevance of the proposed objectives.

In the third and last stage of the methodology, the benchmark is evaluated, to be subsequently generated. In this stage of the methodology, attention is paid to the consideration that is taken to return to the second stage in case of having a negative evaluation in some aspect of the microgrid to be generated. This part of the stage allows for new or updated data to be obtained from the previous stage, so that the subsequent evaluations are positive, allowing for the correct generation of a benchmark microgrid.

In summary, the methodology is presented with the necessary steps to make a microgrid benchmark of the isolated type. This methodology has room for various criteria to be used for obtaining its data, as well as evaluations on them. The order of the methodology steps aims to be coherent with the idea of going from general to specifics: it begins with general characteristics of the microgrid, goes through specific data, and culminates with the evaluation and generation of the proposed benchmark.

Application of the methodology in the ESUSCON microgrid

Characterization of the microgrid

ESUSCON's microgrid is of the isolated type. From the technical point of view, this network corresponds to a three-phase system, feeding the demand through single-phase connections to households. The rated voltage of the network is 220/380 [V]. This network is classified as a low voltage isolated microgrid with overhead lines. Finally, the operating frequency of the microgrid is 50 [Hz].

The isolated microgrid of the ESUSCON project is in the north of Chile, specifically in Huatacondo, where an existing distribution network was upgraded to a renewable energy based microgrid that allows for uninterrupted supply of electricity. This project fostered the development of basic needs as well as entrepreneurial activities that required 24-hour electricity use, significantly improving the quality of life of the inhabitants [7]. The parameters of the microgrid [8] of this project are presented in Table I. Fig. 2 shows a diagram of the local distribution network.

Table I: ESUSCON microgrid design parameters.

Parameter	Value	Unit
Photovoltaic panel power	22.68	kW
Wind turbine power	3.00	kW
Maximum storage power	40	kW
Storage capacity	150	kWh
Diesel generator maximum power	120	kVA
Diesel generator minimum power	10	kVA

The main motivation in the generation of this benchmark microgrid is the use of the large amount of data generated in the almost 9 years in which the interdisciplinary team of the University of Chile carried out the design and operation of the microgrid in Huatacondo [7], called by the community ESUSCON (*Energía Sustentable Cóndor*).

Another motivation is to make better use of all the lessons learned and documentation made during the ESUSCON project. Due to the extensive work that was carried out by the team, there is a large amount of information on the operation, failures events, and growth of the demand in the electrical system of the Huatacondo community. The present work is intended to give added value to the work carried out by students, engineers, and professors in the design and operation of the microgrid present in Huatacondo.

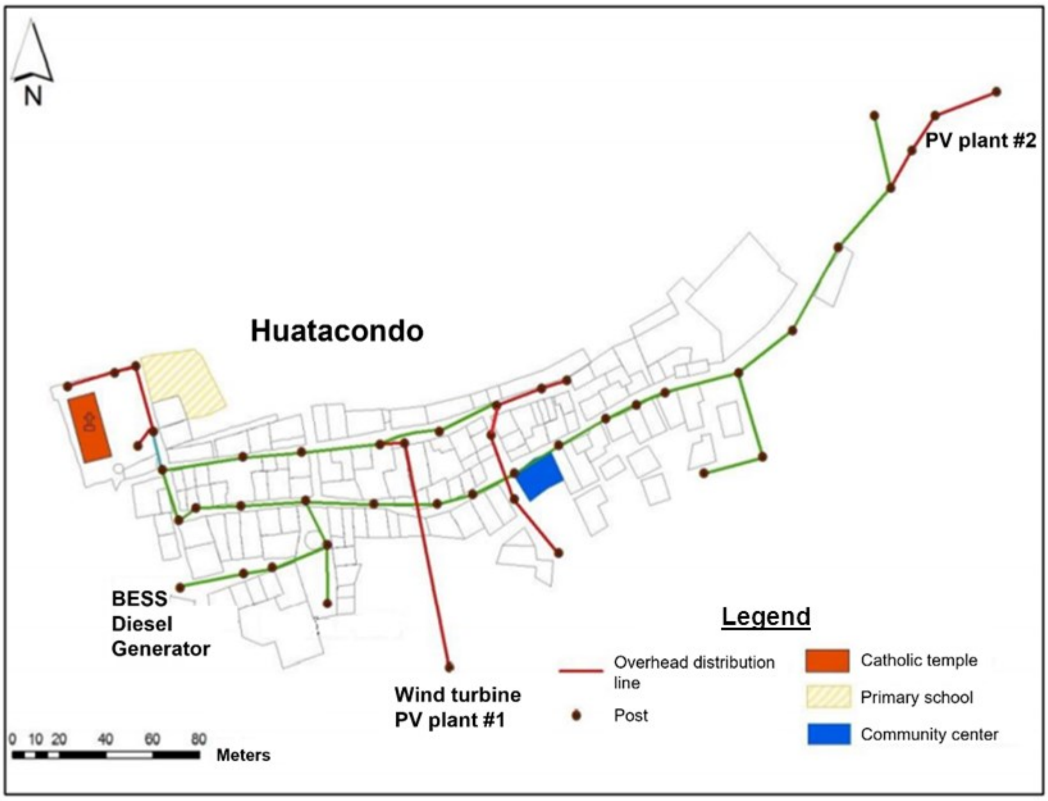


Fig. 2: Huatacondo distribution network.

The University of Chile supported the operation of the microgrid from 2011 to 2019. There is a wide set of operational data corresponding to this period (close to 2,220,000 data points) covering generation and demand, smart metering, and battery state of charge, among others.

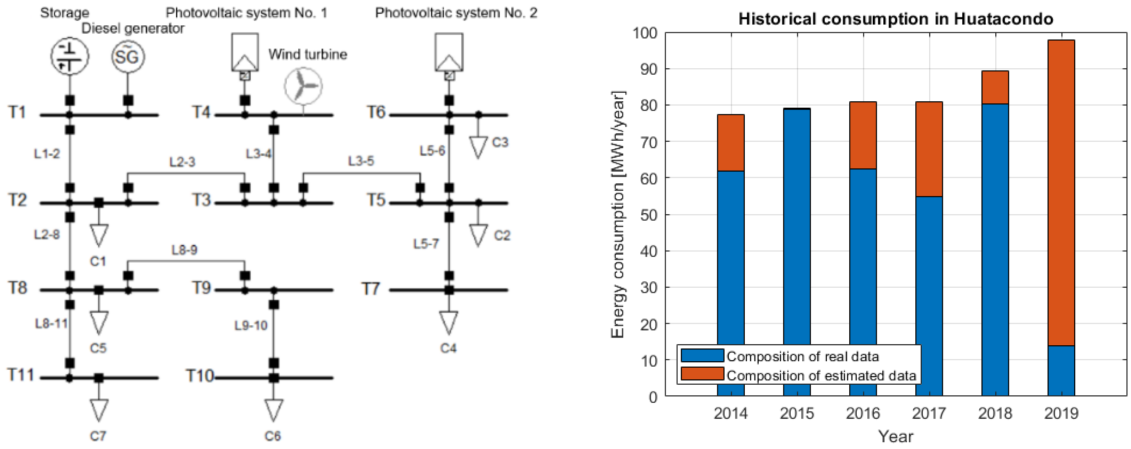
Data acquisition

For the utilization of the generated benchmark microgrid, the following study objectives are formulated: network architecture planning, energy management, power flow, supply reliability, and network resilience. Furthermore, for the set of proposed studies, various parameters are required to generate an adequate benchmark microgrid. The necessary data sets are microgrid topology, demand profiles, loads within the network, generation and storage units, distribution line parameters, generation profiles, and fault/disturbance events.

We proceed to present the most relevant data sets for the work carried out, which correspond to microgrid topology, demand profiles and generation attributes.

Microgrid topology and electricity demand profiles

The microgrid topology corresponds to that of a radial distribution network. This is presented in Fig. 3.a). The operational data of the ESUSCON benchmark microgrid are in a temporary resolution of 15 minutes. As an example of the evolution of demand through the years, a histogram is shown in Fig. 3.b), where the “estimated data” is created for the purposes of the benchmark.



a) Microgrid topology b) Historical electricity consumption

Fig. 3: ESUSCON benchmark microgrid schematic and historical electricity consumption.

The data used for this set are those of solar/wind generation, diesel generation, and power from the battery energy storage system (BESS). The data comprise both active and reactive power. The demand is obtained from computation using the aforementioned data, hence, already includes power losses in the overhead lines.

Evaluation and generation of the benchmark

As a summary, the benchmark completeness metric is presented, where all the annual operational data are counted and contrasted with those expected and estimated. These results are presented in

Table II. The publication of these data is carried out in a repository of public access.

Table II: Comparison of the number of expected samples with samples obtained (15-minute sampling).

Year	No. hours	Expected samples	Existing samples	Estimated samples	Completeness (existent+estimated) [%]
2014	8,760	35,040	28,129	6,911	100
2015	8,760	35,040	34,464	576	100
2016	8,784	35,136	25,151	9,985	100
2017	8,760	35,040	323,809	11,231	100
2018	8,760	35,040	31,488	3,552	100
2019	8,760	35,040	5,087	29,953	100

Benchmark validation proposal

To perform a validation on the data generated for the benchmark, it is proposed to simulate the behavior of an Energy Management System (EMS) with the generated data, to later compare it with the real operation data in Huatacondo, where the configuration of the microgrid contemplates its operation under the same EMS [9]. A simplified EMS is implemented for the benchmark, as presented in Fig. 4.

The configurations that were used for the simulation of the EMS are presented in the next section. These simulation options take into consideration a variety of performance indicators, to be used for comparing the benchmark with the real operation, where results such as diesel consumption, solar generation and renewable penetration can be obtained in the proposed evaluation.

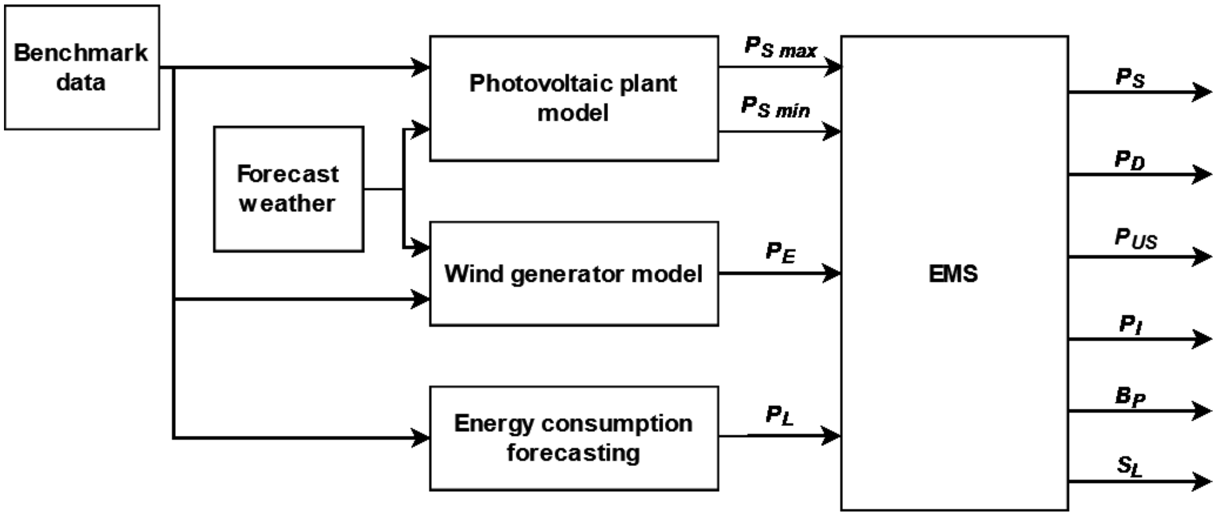


Fig. 4: EMS used in operation simulation according to ESUSCON design.

It is expected that the results of the EMS simulation show similarities with the behavior of the historical operation of the microgrid. The EMS implemented in ESUSCON contemplates the use of data sampled every 15 minutes, and the benchmark can easily adapt to that dynamic (i.e., it will also use a 15-minute sample). The results to be presented consider the forecasts for diesel generation, power setpoints for the BESS, and expected renewable generation.

The input and output variables with which the EMS operates are the following:

- Input variables:
  - $P_{S\,max}$: prediction of maximum possible solar power.
  - $P_{S\,max}$: prediction of minimum possible solar power.
  - P_E: wind power.
  - P_L: expected demand.
- Output variables:
  - P_S: expected solar power:
  - P_D: reference power for diesel generator.
  - P_{US}: fault power.
  - P_I: potencia del inversor del banco de baterías.
  - B_P: battery bank inverter power.
  - S_L: signs of demand slippage.

The objective (cost) function to be minimized in the proposed EMS is the following:

$$J = \delta_t \sum_{t=1}^{T} C_{com}(t) + \sum_{t=1}^{T} C_{par}(t) + \delta_t C_{man} T_{man} + \delta_t C_f \sum_{t=1}^{T} P_f(t) + \delta_t C_{ver} \sum_{t=1}^{T} P_{ver}(t) + C_{inv} SoH_{per} \quad (1)$$

where direct costs are:

- $\delta_t \sum_{t=1}^{T} C_{com}(t)$: represents the fuel cost per use of the thermal unit.
- $\sum_{t=1}^{T} C_{par}(t)$: represents the starting costs of the thermal unit, and estimation of fuel used for a cold start.
- $\delta_t C_{man} T_{man}$: represents the costs associated with the maintenance of the thermal unit based on the hours of use. Here T_{man} is the number of intervals in which the thermal unit was operating.

In addition, there are indirect costs:

- $\delta_t C_f \sum_{t=1}^{T} P_f(t)$: represents the cost of loss load.
- $\delta_t C_{ver} \sum_{t=1}^{T} P_{ver}(t)$: represents the cost associated with renewable energy surplus due to generation in excess.
- $C_{inv} SoH_{per}$: represents the cost of lost battery life (degradation).

The simulations will be carried out for 2 scenarios:

- Short-term simulation: considers a time window of 2 days (December 27 and 28, 2017).
- Long-term simulation: considers a time window of 6 months (second half of 2017).

The variables to study will be the energy supplied by the diesel generator, the photovoltaic generator, the battery bank, and the total energy injected into the system.

Validation of results

Short-term results

The results obtained in the short-term for the costs associated with the operation are shown in Table III, where C_{die} is the diesel generator fuel cost, C_{par} is the starting cost, C_f is the cost of loss load, C_{ver} is the cost of renewable energy surplus, C_{bat} is the cost of battery life, and C_{tot} is the total operating cost. In addition, the results obtained for the penetration of solar energy in the short term are presented in Fig. 5. It can be seen in this figure that the EMS simulation closely matches the real operation in terms of total generated energy, although the demand ("Total Energy Supplied") is lower on the real operation, due to excess solar energy not used, hence the higher C_{ver}. In terms of cost, diesel generation shares basically the same costs. As the real operation has lower demand, it also has lower battery usage, hence lower battery degradation cost.

Table III: Summary of short-term operating costs.

Summary of short-term costs [USD]						
Scenario	C_{die}	C_{par}	C_f	C_{ver}	C_{bat}	C_{tot}
Real Operation	47,08	4,87	0	0,95	14,26	67,17
Benchmark EMS	47,11	4,87	0	0,17	26,77	78,92

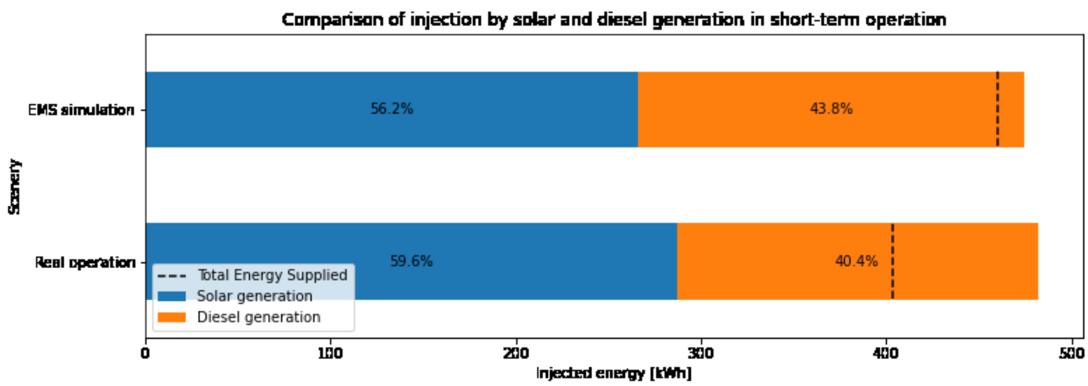


Fig. 5: Renewable penetration for EMS simulation scenario and real operation of the microgrid in the short-term.

A comparison between the real operation and the simulated operation by EMS is presented using the magnitudes and proportions of the amount of energy supplied through diesel generation and by the battery bank in Fig. 6. It can be readily seen in this figure that the real operation and benchmark simulation, although slightly differing in magnitudes, match in their proportions.

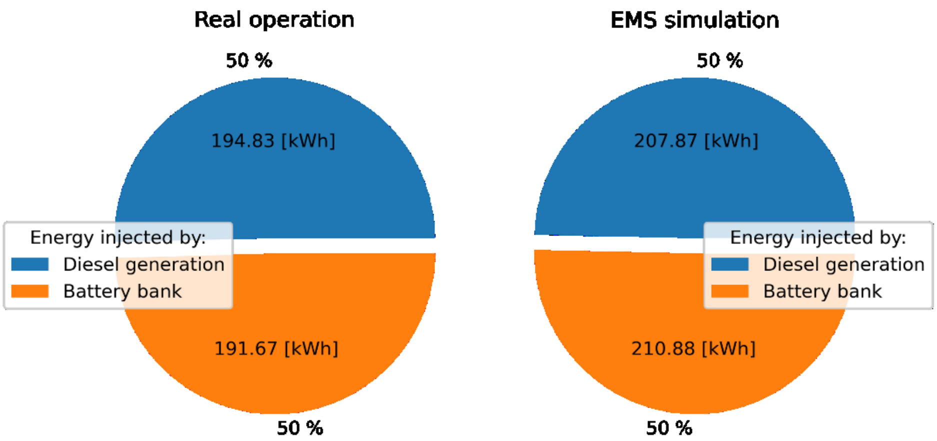


Fig. 6: Comparison of injected energy for both scenarios in the short-term.

Long-term results

The results obtained in the long-term for the costs associated with the operation are shown in Table IV. In addition, the results obtained for the penetration of solar energy in the long term are presented in Fig. 7. In the long term, although individual costs differ, overall total cost is similar. Also, as seen in Fig. 7, the demand ("Total Energy Supplied") is basically identical in both cases.

Table IV: Summary of long-term operating costs.

Summary of long-term costs [USD]						
Scenery	C_{die}	C_{par}	C_f	C_{ver}	C_{bat}	C_{tot}
Real Operation	6538,41	717,98	0	613,81	1083,07	8953,28
Benchmark EMS	5301,59	489,2	0	564,59	2482,92	8838,29

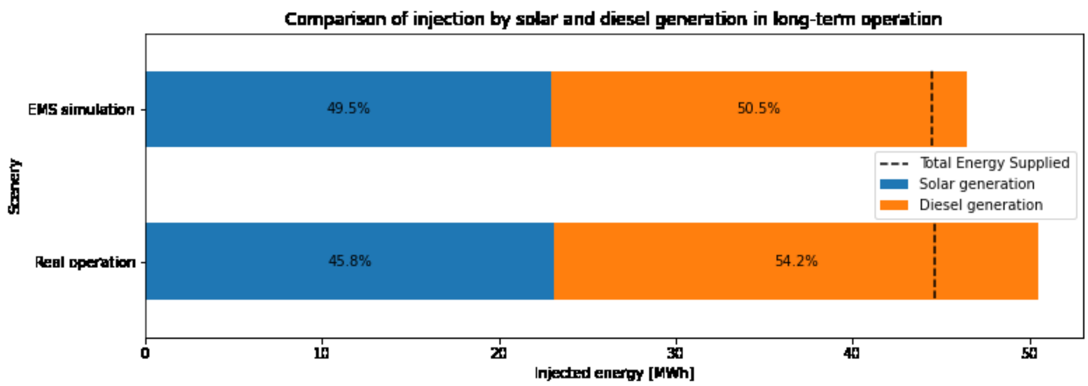


Fig. 7: Renewable penetration for EMS simulation scenario and real operation of the microgrid in the long-term.

Subsequently, a comparison between the real operation and the operation simulated by EMS is presented in Fig. 8, with the magnitudes and proportions of the amount of energy supplied by diesel generation and by the battery bank. The proportion of battery use is larger on the EMS simulation, which coincides with a bigger C_{bat} in Table IV. Conversely, the real operation does not use the battery as intensively, hence a larger use of the diesel generator.

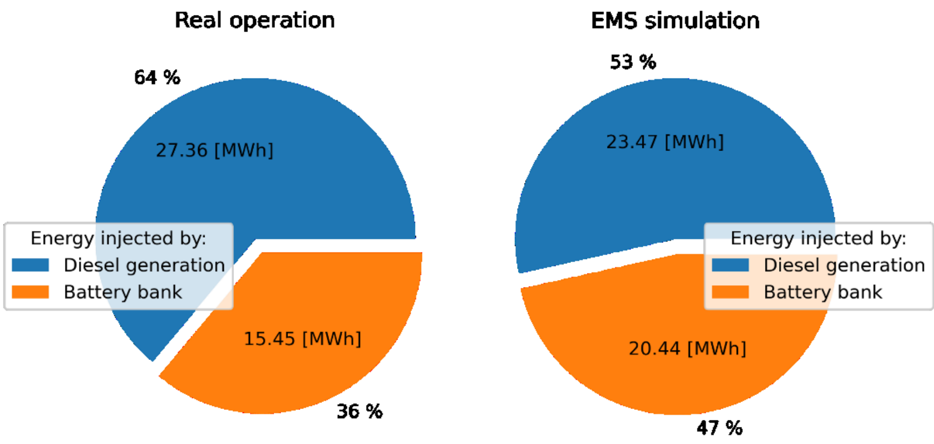


Fig. 8: Comparison of injected energy for both scenarios in the long-term.

Overall comparison

As a general analysis, the percentage differences for the variables studied in the two proposed scenarios are presented in Fig. 9. In general, the long-term results show less difference for the renewable generation and demand, although the simulated EMS performs a more efficient operation (with 15% lower diesel and battery usage). In the long-term, the variability is not perceived as in the short-term, where differences are more noticeable. Nevertheless, the benchmark demonstrates its usefulness for the evaluation of the EMS strategy.

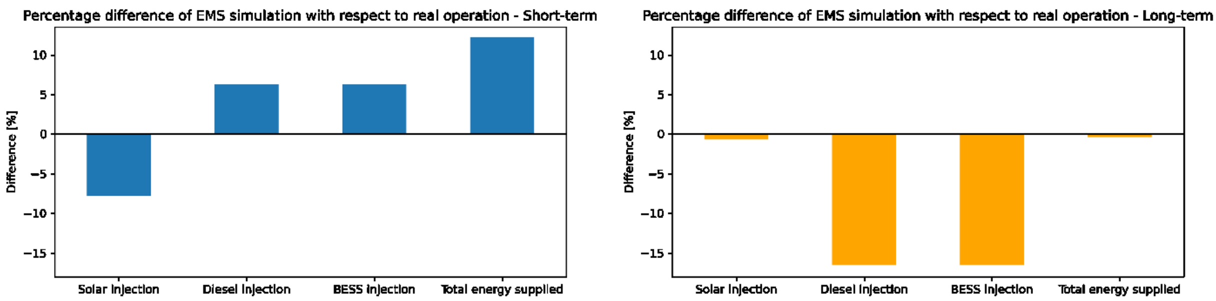


Fig. 9: Percentage differences for the two scenarios studied.

Conclusion

The application of the methodology is carried out in the ESUSCON microgrid, culminating in the generation of a benchmark microgrid with satisfactory performance. In this benchmark, more than 210,000 operational data corresponding to 6 years (2014 to 2019) were generated, together with complementary information that allows the proposed studies to be carried out. The generalized nature of the iterative steps of the methodology stands out, where the maximum use of the available data is sought for each generated benchmark.

Regarding the validation on the benchmark, the simulations carried out present satisfactory results, having as metrics the different energy injections that are in the system. In these simulations, it happens that for cases where there is a certainty of real operation under EMS, the BESS and diesel injections have similar behavior, while for solar injection and total energy supplied are not as similar. It is estimated that these variables, in the long term, approach each other for the two scenarios. Although it should be pointed out that the EMS always operates with a 48-hour rolling horizon.

In summary, the preparation of a methodology that allows the generation of benchmark isolated microgrids is achieved, thus fulfilling the main objective of this work. It is possible to fully carry out the steps proposed in the methodology. As future work, the generation of gird-connected benchmark microgrids should be addressed, where data not seen in the isolated case (such as energy prices and outages) as well as different operation philosophy (e.g. maximizing revenue rather than minimizing costs) should be considered.

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