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# Economic Dispatch for Optimal Management of Isolated Microgrids Using Random Input Data

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This work presents the economic dispatch of an isolated non-conventional renewable energy (NCRE) microgrid in conjunction with a diesel generator and a BESS battery bank. For the development of the model, random input scenarios were used based on real measured data of solar radiation and wind speed. Three evaluation scenarios were established using the Monte Carlo method, with synthetic series less than, equal to, and greater than the average. Likewise, the economic dispatch is proposed as a mixed integer linear optimization model MILP, which includes the use of the diesel generator by means of linearization by sections. The economic dispatch is solved for 24 hours for the three possible scenarios, where in the first scenario the demand is supplied in 31.7% by solar power, 12.2% based on the BESS, 1.2% of wind power and 54.9% from the diesel generator, in the second scenario there is 32.5% of solar power, 21.3% of BESS, 4.2% of wind power and 41.9% from the diesel generator. Finally, in the third scenario, 57.7% of the demand is met by solar power, 21% by BESS, 7.7% by wind power and 41.9% by the diesel generator, thus meeting the demand in its entirety for all the proposed scenarios.
**Keywords:** Economic dispatch, mixed integer linear optimization problem, random input scenarios, non-conventional renewable energy.

## 1. Introduction

An electrical system must be reliable and stable, for this reason it is necessary to prioritize monetary savings when supplying a load, so to achieve optimal management of energy resources, the demand must be supplied in its entirety, mainly considering the economic factor in the project to be developed. For this reason, the need arises to establish an economic dispatch problem whose purpose is to obtain in an optimal way and at the lowest possible cost the set points to supply the energy demand, managing the available energy generation units and respecting the restrictions of the system. The combination of generation technologies that intervene to meet demand in recent times has acquired a focus on the use of non-conventional renewable energies NCRE [1-4].

To promote the use and transition of conventional generation systems to NCRE, economic dispatch problems are presented as a great option, due to their contribution to the reduction of greenhouse gases and their evaluation based on the operating costs of the system. However, it should be considered that although NCRE works as a good strategy compared to conventional means of generation, these types of technology come from natural phenomena whose behavior is random since they come from stochastic data [5-8].

In this context, in this research work, the realization of the economic dispatch of an isolated microgrid with the use of NCRE in conjunction with a thermal generation unit such as the diesel generator is proposed. Synthetic series based on real measurement data on solar radiation and wind speed are used as input scenarios. Using the Monte Carlo method, the randomness of the variables is interpreted and three available input scenarios are presented for the evaluation of the economic dispatch problem.

For the resolution of the economic dispatch, a mixed integer linear optimization model (MILP) was used, for this it was necessary to adapt a thermal generation unit whose cost function is non-linear to a linear one using linearization by sections. The proposed model was executed in three different scenarios that seek to simulate cases in which energy resources are scarce, behave on average and are abundant. Ultimately, the answers are analyzed to corroborate whether the results of the economic dispatch are optimal.

## 1.1. State of the art

Below is a state of the art of the different related works. Where in [9] an economic dispatch was developed considering environmental restrictions, where with the use of renewable energy generating units, such as wind turbines and photovoltaic panels, it was possible to reduce the emission of pollutants, corroborating the environmental importance of including NCRE in distributed generation systems.

In [10] he shows as an option the resolution of a nonlinear optimization model for the economic dispatch of an isolated microgrid located on Santa Cruz Island in Galapagos, Ecuador. As inputs, the use of solar energy, wind energy and a thermal generation unit in conjunction with an energy storage system is presented.

The generation of synthetic series of natural phenomena to be used as random input scenarios has been proven in the literature as a viable option. As in [11] where it was possible to evaluate the generation of synthetic series for the prediction of the standardized precipitation index in sectors of Iran.

Two short-term stochastic forecasting models of solar radiation based on real historical data were successfully developed in [12]. The prediction was transformed into solar power and when compared with standard forecasting mechanisms, accurate and optimal results were obtained. While the work carried out by [13] presents a very short-term economic dispatch that seeks to compensate for the uncertainty that wind energy has.

## 2. Materials and Methods

This section details the process carried out for the resolution of the economic dispatch, considering as energy demand an isolated microgrid, that is, a low-voltage distribution system composed of distributed energy resources, energy storage systems and controllable loads, this system is located in the city of Latacunga, Ecuador. Here, the use of photovoltaic and wind energy potential is established as energy sources with the contribution of a diesel generator [14, 15].

In the Figure 1 The three stages that make up the methodology used for the economic dispatch problem are identified. In the first instance, the generation and entry of the random scenarios must be carried out, then the mixed integer linear optimization model is proposed and, finally, the resolution of the economic dispatch is carried out.

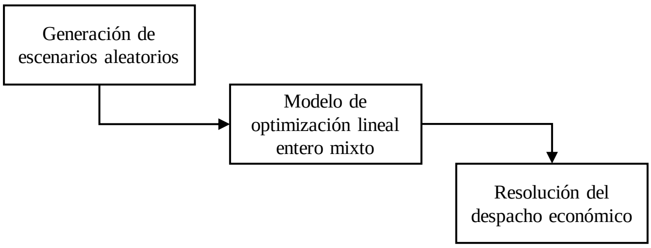


Figure 1. Stages for the resolution of the economic dispatch. In original language English

2.1. Generating random scenarios

In this section, the first stage of the work will be addressed, which is the generation of random scenarios, which are solar radiation and wind speed, both parameters are variable in time, since they depend on aspects such as climate change and geographical location, however these can be characterized stochastically. For this reason, the idea of generating synthetic series of the Sun's radiation and wind speed was postulated to later develop the conversion to solar and wind power, all this from real data on the behavior of the parameters, which have been obtained from the measurements taken by a meteorological station in the sector of interest for the work.

To this end, the Monte Carlo method was used, in which, a considerable amount of real data of the parameters of interest, are characterized probabilistically so that through the use of a probability distribution function, a prediction of new data is randomly generated which are random and vary in each generation [16, 17].

In this work, for the case of solar radiation and wind speed, the normal probability distribution function was used. To do this, the real data of solar radiation and hourly wind speed of each day during the year 2023 were used, from these data it was necessary to find the mean and the standard deviation, two necessary input arguments to apply Matlab's normrnd function, which takes the mean of the data as a basis and varies them considering the standard deviation of these and yields a series of new data different from the real ones, but with the possibility of happening. The means and standard deviation are saved as a database in an Excel document.

It was necessary to establish a criterion for the evaluation of the synthetic series generated, for this the root of the mean square error and/or the root of the normalized mean square error (NRMSE) can be used. In [18] the author points out that the use of the RMSE is admissible in cases with normally distributed variables and that they have a tendency to produce normally distributed errors. However, when normalizing the RMSE, a clearer idea is obtained as the NRMSE is expressed as a percentage, the latter has been used as an indicator of the performance of prediction models as in [19].

The permissible NRMSE error in the generation of the synthetic series, both for solar radiation and for wind speed, was established by dividing the RMSE of the actual data by the standard deviation of the mean of said data.

For the generation of both solar and wind synthetic series, the process shown in Figure 2 is developed. Where in the first instance the mean and standard deviation of the actual data recorded are imported from the database document, in addition the data of 10 real series are also imported, which will be used to make a graphical comparison. Next, you must indicate the number of synthetic series that you want to generate. For the evaluation of the synthetic series, a permissible NRMSE is established for the solar synthetic series is 5% and for the wind synthetic series it is 10%. Once the synthetic series have been evaluated, the conversion of solar radiation to solar power and wind speed to wind power is carried out, to finally export the created scenario.

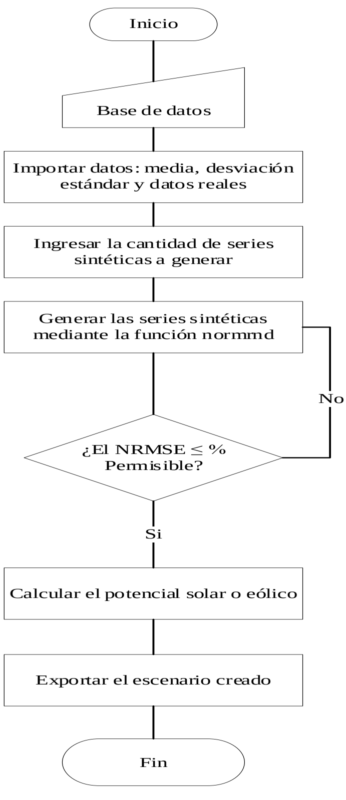


Figure 2. Process of generating synthetic solar-wind series and converting them to solar-wind power. In original language English

For the conversion of solar radiation to solar power, it was taken into account that photovoltaic panels that generate a nominal power of 450W were used when there is a solar radiation of , based on this relationship, equation (1) was proposed, where is the solar power generated in watts, is the solar radiation at that time in , is the nominal photovoltaic power of the panels in Watts and is the number of photovoltaic panels.$1000\ W/m^2 P_s R_{solar}\ W/m^2\ P_{nomfv} N_p$

$$P_s = R_{solar} \cdot \frac{P_{nomfv}}{1000\ W/m^2} \cdot N_p \qquad (1)$$

To convert wind speed into wind power, equation (2) was used, where is the wind power generated in watts, is the wind density, is the area of the wind turbine blades, is the wind speed, is the performance of the wind turbine and corresponds to the value of the Betz parameter [20].$P_e \rho A v \eta B$

$$P_e = \frac{1}{2} \cdot \rho \cdot A \cdot v^2 \cdot \eta \cdot B \qquad (2)$$

For solar radiation and wind speed, three different scenarios are proposed, in the first scenario the resource will be greater than the average data, the second is a scenario with a resource lower than the average identifying very low energy and in the last scenario the resource is greater than the average identifying the highest energy.

Figure 3 shows the result of the generation of the solar synthetic series for the three scenarios, where in red the synthetic series generated with the scenario of lower radiation is represented, in magenta the synthetic series is shown whose radiation fits the mean and in blue the graphed series corresponds to the scenario of greater solar radiation. In addition, the 10 real series graphed in grayscale are included.

Figure 4, on the other hand, shows the three scenarios generated for the wind speed, i.e. in red the series generated with a wind speed lower than the average, in magenta the series with the wind speed most adjusted to the average and finally the series with the highest wind speed represented in blue. The 10 real series are also included in grayscale.

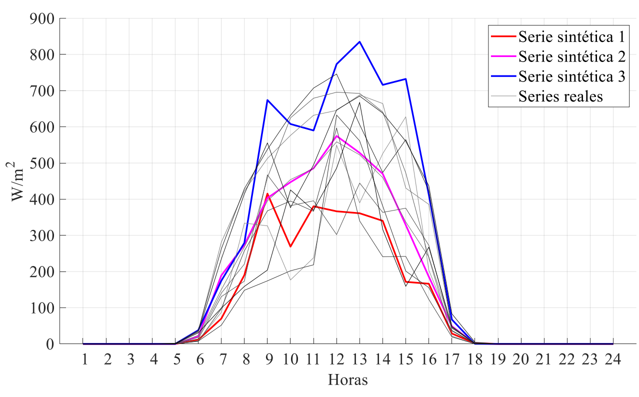


Figure 3. Solar synthetic series generated for the three scenarios. In original language English

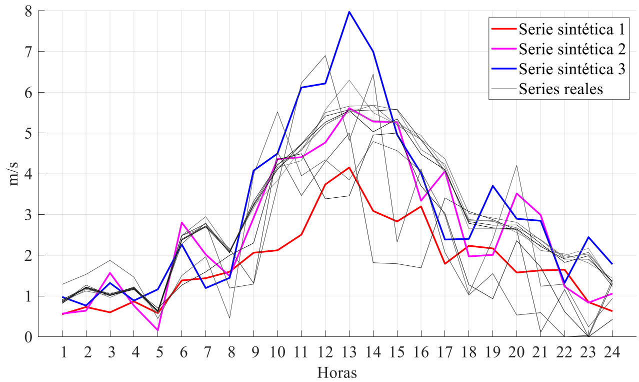


Figure 4. Synthetic wind series generated for the three scenarios. In original language English

## 2.2. Mixed integer linear optimization model

This section explains the development of the proposed mixed integer linear optimization model that meets the objective of supplying the demand of an isolated microgrid at the lowest possible operating cost, where what was demonstrated by [21] was considered. The application of linearization by sections in the diesel generator is taken into account as a viable option since it resembles reality and it is possible to adapt this type of generating unit to this model.

### 2.2.1. Objective function

The objective function established to solve the economic dispatch in a period T, is based on the work performed by [22] and is shown in equation (3), in this work it is considered to solve the problem for a period of time of 24 hours.

$$\boldsymbol{Min \sum_{t=1}^{T} \left[ C_D \cdot q(t) + C_{ENS} \cdot P_{ENS}(t) + C_{SH} \cdot P_{SH}(t) + C_{UBESS} \left( P_B^C(t) \cdot \eta^C + \frac{P_B^D(t)}{\eta^D} \right) \right]} \quad (3)$$

Where T is the period of time, it corresponds to the international cost of diesel, it represents the amount of fuel that is used as a function of the power produced by the diesel generator, it is the cost of the energy not supplied, it is the value of the energy not supplied, it corresponds to the cost of the spill which is the energy that is wasted,  is the amount of energy discharged, it is attributed to the cost of using the BESS which is the battery bank system, it represents the charging power of the battery bank, while it is the discharge power of the battery bank, finally and correspond to the efficiency in the state of charge and discharge respectively. $\boldsymbol{C_D q(t) C_{ENS} P_{ENS}(t) C_{SH} P_{SH}(t) C_{UBESS} P_B^C(t) P_B^D(t) \eta^C \eta^D}$

2.2.3. Restrictions

To achieve an optimal response from the economic dispatch, several constraints must be established for the target function. The amount of fuel that the diesel generator occupies is given as a function of the power it produces, this relationship is represented by a quadratic function, that is, non-linear, developing a linearization by sections of the quadratic function of the fuel consumption of the diesel generator can be passed from a non-linear function to a linear approximation [23-25].

Figure 5 shows the relationship between the power produced by the diesel generator and fuel consumption, where it can be seen that the curve of the quadratic function can be expressed in linearized sections to calculate the amount of fuel used given a value of power generated within the limits of each section.$\boldsymbol{q(t) P}$

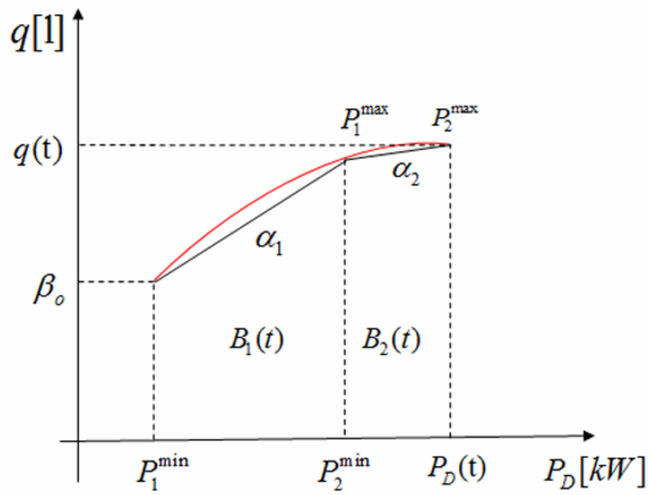


Figure 5. Linearization by sections of the diesel generator fuel consumption function [21].

For the calculation of equation (4) is used, this being a representation of the second form of the equation of the line, where it represents the slope of the linearized section, it is the value of the power produced by the diesel generator in a specific range for the section, it is the point of origin on the axis of the ordinates and it is a binary variable that represents the start-up of the generator.$\boldsymbol{q(t) \alpha P_D(t) \beta B(t)}$

$$\boldsymbol{q(t) = \alpha \cdot P_D(t) + \beta \cdot B(t)} \quad (4)$$

Equation (5) corresponds to the energy balance, on the other hand, equation (6) establishes the power range of the diesel generator, equations (7) and (8) delimit the energy not supplied and the power discharge respectively.

$$\boldsymbol{P_D(t) + P_s(t) + P_e(t) - P_{SH}(t) + P_B^C(t)} = \boldsymbol{D(t) - P_{\mathrm{ENS}}}(\mathrm{t}) + \mathrm{P_B^D}(\mathrm{t}) \quad (5)$$

$$\mathrm{P_{Dmin}} \leq \mathrm{P_D}(\mathrm{t}) \leq \mathrm{P_{Dmax}} \quad (6)$$

$$0 \leq \mathrm{P_{ENS}}(\mathrm{t}) \leq \mathrm{D}(\mathrm{t}) \quad (7)$$

$$0 \leq \mathrm{P_{SH}}(\mathrm{t}) \leq \mathrm{P_s}(\mathrm{t}) + \mathrm{P_e}(\mathrm{t}) \quad (8)$$

In the initial state, the energy of the BESS is represented by equation (9), while equation (10) expresses the energy of the BESS during the rest of the period. The energy of the BESS has a range with the limits expressed in equation (11).$t = 0t > 0$

$$\mathrm{E}(\mathrm{t}) = \mathrm{E_o} + \left(\mathrm{P_B^C}(\mathrm{t}) \cdot \eta^{\mathrm{C}}\right) - \frac{\mathrm{P_B^D}(\mathrm{t})}{\eta^{\mathrm{D}}} \quad (9)$$

$$\mathrm{E}(\mathrm{t}) = \mathrm{E_{t-1}} + \left(\mathrm{P_B^C}(\mathrm{t}) \cdot \eta^{\mathrm{C}}\right) - \frac{\mathrm{P_B^D}(\mathrm{t})}{\eta^{\mathrm{D}}} \quad (10)$$

$$\mathrm{E_{min}} \leq \mathrm{E}(\mathrm{t}) \leq \mathrm{E_{max}} \quad (11)$$

The BESS only has two modes of use, charging and discharging energy, to determine the state in which the BESS is used, binary variables represented in equations (12), (13) and (14) are used.

$$\mathrm{X_C}(\mathrm{t}) + \mathrm{X_D}(\mathrm{t}) \leq 1 \quad (12)$$

$$\mathrm{E_{min}} \geq \mathrm{P_B^C}(\mathrm{t}) \geq -\mathrm{E_{max}} \cdot \mathrm{X_C}(\mathrm{t}) \quad (13)$$

$$E_{min} \geq P_B^D(t) \geq -E_{max} \cdot X_D(t) \quad (14)$$

Equation (15) determines the state of charge (SOC) of the BESS as a function of the energy at a point in the period and the maximum energy. The SOC is considered to have a range of 100% to 0% and is delimited by equation (16).

$$SOC(t) = \frac{E(t)}{E_{max}} \quad (15)$$

$$SOC_{min} \leq SOC(t) \leq SOC_{max} \quad (16)$$

2.3. Resolution of the economic dispatch

For the resolution of the economic dispatch, the process shown in Figure 6 was developed. In the first instance, the subprogram for the generation of synthetic series and their conversion to both solar and wind power is executed, in addition to the data on energy demand, the BESS and the arguments for the generation of diesel power.

Then, considering the MILP mixed integer linear optimization model described above, the FICO Xpress solver was used to solve the proposed model [26].

Finally, it is analyzed if the results are optimal, this with the verification that mainly there is no energy not supplied and preferably not too much discharge, if it is the case of having energy not supplied, the number of panels and batteries is resized to take advantage of the optimal amount of energy.

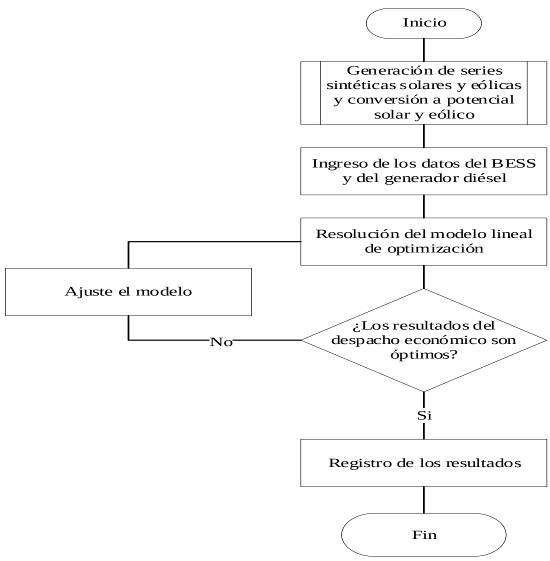


Figure 6. Process for the resolution of the economic dispatch. In original language English

## 3. Results and Discussion

The methodology described throughout section 2 is summarised in Figure 7, where it can be seen graphically how the cargo is supplied through economic dispatch and the use of random input scenarios.

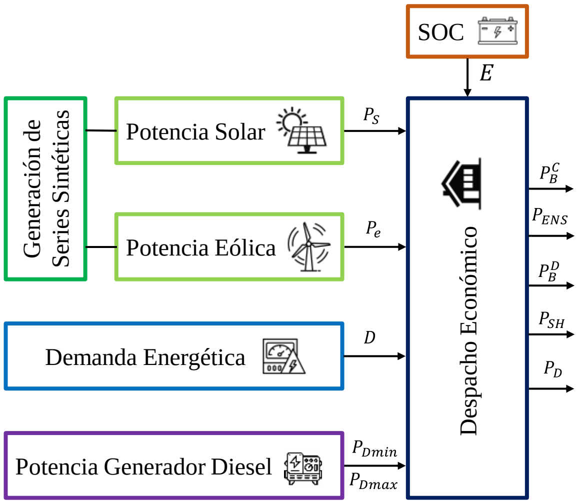


Figure 7. Summary diagram of the optimization model. In original language English

This section shows the results of the work carried out with the development of all that is set out in section 2. To this end, it has been considered to resolve the economic dispatch of the isolated microgrid for the three case studies presented above in a period of 24 hours for each case. Subsequently, the results are described and analyzed in order to validate the optimization model.

### 3.1. Input Data Scenario 1

Figure 8 shows the response of the model for a period of 24 hours, considering a scenario of generation of synthetic series with low usable resources, that is, a solar radiation and wind speed lower than the averages. The demand is seen in red with square markers, in orange it represents the solar power which is the one that is mostly responsible for supplying the demand and charging energy to the battery bank in the hours of peak solar energy, on the other hand the wind power is expressed in black and provides less power but helps the energy supply, The diesel generator corresponds to the purple color and is the one that supplies the demand in the hours of absence of power from the other sources. The operation of the battery bank in power charge and discharge mode are expressed by the colors green and blue respectively, while the energy not supplied and the energy discharge are represented by the colors yellow and wine respectively.

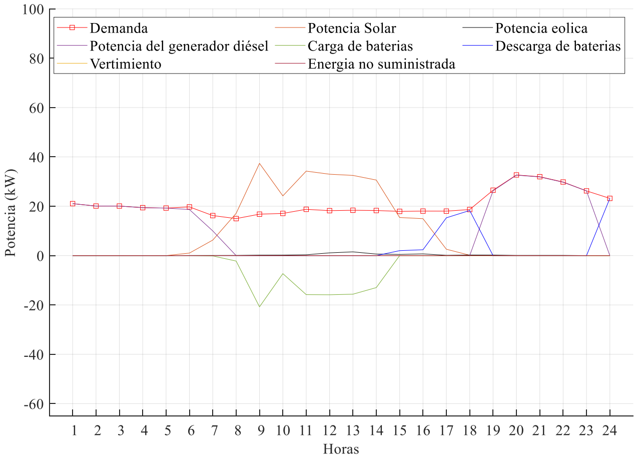


Figure 8. Results of the model for the case of minor resources. In original language English

In Figure 8, you can see how the first hours and part of the last hours the diesel generator comes into operation, since there is an absence of solar radiation, supplying the demand by 54.9%. At the beginning of the hours of sunshine, the demand is supplied with solar power by 31.7% and the battery bank is also charged using all the available solar energy. The BESS meets the demand by 12.2%, in addition the use of the BESS and the diesel generator is exchanged at one time in order not to overload either of them. Finally, the contribution of wind power to meet demand is 1.2%.

It can be seen that the diesel generator supplies the demand for a longer time and in a greater percentage because the batteries are not fully charged due to the limited amount of usable energy, it should be noted that, although this scenario considers resources lower than the averages, there is no value of energy not supplied or discharged.  that is, no energy is wasted or lost.

### 3.2. Input Data Scenario 2

Figure 9 shows the response of the model this time considering a scenario of generation of synthetic series with values adjusted to the mean, that is, an average solar radiation and wind speed. The same color relationship is used as for the first case, which is observed in the box of legends.

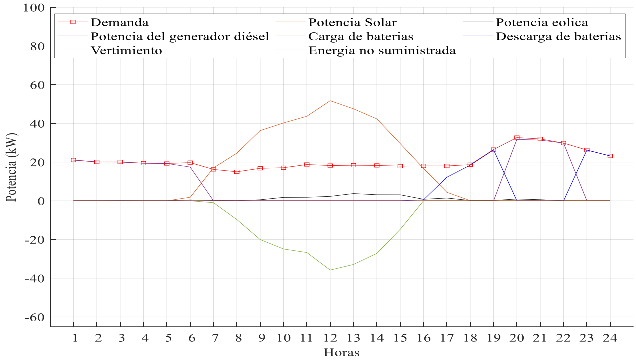


Figure 9. Model results for the case of average resources. In original language English

As shown in Figure 9, during the first hours and part of the last hours, the demand is supplied by the diesel generator by 41.9%. But during the hours of solar radiation, the demand is supplied by 32.5% with solar power, being a similar contribution, although greater than in scenario 1. However, in the case of the BESS, there is now a contribution to supply the demand of 21.3%, which is much higher than in scenario 1, this is the result of having more solar resources to charge the BESS, which reaches a load of 80% of its capacity. Finally, the contribution of wind power to meet demand is 4.2%, double that of scenario 1.

As in scenario 1, the BESS and the diesel generator are exchanged for use at a time so as not to be overloaded. Unlike the first case, here the diesel generator is less used since the battery bank could be charged more, and in this case there is no presence of unsupplied energy either.

3.3. Input Data Scenario 3

Figure 10 shows the response of the model, but considering a scenario of generation of synthetic series with values that exceed the mean, that is, a greater amount of solar radiation and wind speed. The same color ratio is used as for the first and second cases, which is observed in the box of legends.

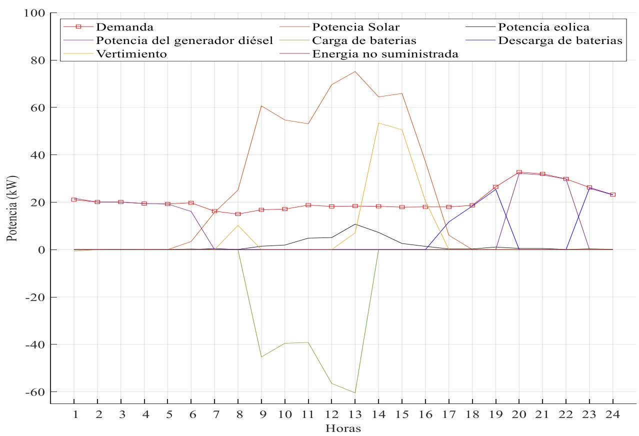


Figure 8. Results of the model for the case of greater resources. In original language English

Figure 10 shows, in the same way as in the previous cases, that in the first and last hours the demand is supplied by the contribution of the diesel generator by 41.9%. While in this scenario solar power supplies demand by 57.7%, this clearly arises from having excess solar resources taking advantage of much more of the sun unlike previous scenarios. As for the BESS, it contributes by supplying the demand by 21%, which is lower than that of case 2 is due to the fact that the hours of sunshine are better used and the BESS will have to discharge a little less than in scenario 2, it should be noted that the BESS reaches its maximum storage load, for this very reason there is a discharge of energy because it is at the top of the storage. Finally, wind power contributes by supplying demand by 7.7%, a much higher contribution than the previous scenarios.

As in the previous scenarios, there is no energy not supplied, nor is there an overload in the BESS or the diesel generator. However, if there is dumping due to having more solar resources than the average, 26.7% of all the solar resources are discharged, so the large amount of solar radiation has been used as best as possible.

## 4. Conclusions

It has been possible to evaluate a mixed integer linear optimization model for the resolution of the economic dispatch of an isolated microgrid considering random input scenarios, in addition, the modeling of a diesel generator in a linear way is also included through linearization by sections, all this using real data of demand, solar radiation and wind speed.

For the generation of random input scenarios, it was possible to apply the Monte Carlo method, where from finding the mean and standard deviation of the real data, using the normal probability distribution function, synthetic series of solar radiation and wind speed were generated, which were evaluated by NMRSE. 5% being the maximum allowable for solar series and 10% for wind power. Thus, 3 scenarios were contemplated for the generation of synthetic series, a scenario with low resources, another with average resources and finally one with resources higher than average, for conversion to solar and wind potential, they will be used as input for the economic dispatch.

The economic dispatch was solved by means of a MILP model, where for the mathematical modeling of the behavior of the diesel generator the linearization by sections of the quadratic curve of fuel consumption as a function of the power generated was developed, which resulted in an ideal approximation to apply it in the proposed model and thus be able to solve the economic dispatch with linear programming.

It was possible to obtain results from the economic dispatch for 24 hours, in each of the three proposed scenarios. In the first scenario, all units deliver energy to meet demand, with solar generation contributing with 31.7%, BESS with 12.2%, wind generation with 1.2% and diesel generator with 54.9%. In the second scenario, on the other hand, demand is supplied by 32.5% by solar generation, 21.3% by BESS, 4.2% by wind generation and 41.9% by diesel generator. Finally, in scenario 3, the generation units provide energy to meet demand, with 57.7% contributing solar generation, 21% from BESS, 7.7% from wind generation and 41.9% from diesel generator. In all scenarios, there is no power of non-supplied energy, that is, demand is completely supplied in all three scenarios. While only in the scenario of greater resources does dumping occur, which is normal considering that the BESS reaches the maximum load and cannot store the excessive resource.

Finally, it is recommended for future work to include a new random input scenario referring to demand, in addition to using other solvers to compare the response that several of them may yield. On the other hand, a model that contemplates other generation options can be included, for example, analyzing the potential of a Biomass generator to evaluate a model with a higher percentage of NCRE.

Gratitude

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