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# A non-linear optimization model assessment for the economic dispatch of isolated microgrids

# Evaluación de un modelo de optimización no lineal para el despacho económico de microrredes aisladas

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## Abstract

The present research work presents the optimal energy management of an isolated microgrid based on unconventional renewable energy sources. For this purpose, an economic dispatch problem is proposed that seeks to supply the electrical demand at the lowest possible operating cost, based on a mixed integer nonlinear optimization problem. The nonlinearity of the algorithm is presented by including the characteristic equation that describes the real operation of the generating set in the optimization model. The input data to the economic dispatch, such as solar radiation and wind speed, were obtained from the NASA platform located on the Santa Cruz Island, Galapagos province, Ecuador. In addition, the electricity demand data was obtained from real measurements of the area. The economic dispatch problem has been solved for 12, 24 and 168 hours, obtaining a proportional energy distribution for each case of 50.40% supplied by the photovoltaic generator, 23.92% by the diesel generator, 17.14% by the battery bank and 5.53% by the wind generator; therefore, the demand was totally supplied, meeting the objective that the generating set does not exhibit intermittencies and obtaining the lowest operating cost of the system.

***Keywords***: Economic dispatch, mixed-integer nonlinear optimization problem, non-conventional renewable energy, isolated microgrid.

## Resumen

El presente trabajo de investigación muestra la gestión óptima de la energía de una microrred aislada basada en fuentes de energía renovable no convencional. Para lo cual se plantea un problema de despacho económico que busca abastecer la demanda eléctrica al menor costo de operación posible, a partir de un problema de optimización no lineal entero mixto. La no linealidad del algoritmo se presenta al incluir la ecuación característica del funcionamiento real del grupo electrógeno en el modelo de optimización. Los datos de entrada al despacho económico como radiación solar y velocidad del viento fueron obtenidos de la plataforma de la NASA situada sobre la isla Santa Cruz, provincia de Galápagos, Ecuador. Además, los datos de la demanda eléctrica fueron obtenidos de mediciones reales del sector. El problema de despacho económico se ha resultado para 12, 24 y 168 horas respectivamente, obteniendo una distribución energética proporcional para cada caso del 50.40 % suministrada por el generador fotovoltaico, 23.92 % por el generador diésel, 17.14 % por el banco de baterías y 5.53 % por el generador eólico, por lo que la demanda fue abastecida en su totalidad cumpliendo con el objetivo de que el grupo electrógeno no presente intermitencias y obteniendo el menor costo de operación del sistema.

***Palabras clave***: despacho económico, problema de optimización no lineal entero mixto, energía renovable no convencional, microrred aislada

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## 1. Introduction

At present, the population growth has led to a significant increase in the electrical consumption rate, and conventional generation units are not capable of completely fulfilling the power demand of large cities. In addition, these resources do not reach the entire population, due to either the distance from the electric network to the end user, or to economic conditions that do not allow to extend transmission lines to supply isolated areas [1–3]. This led to the alternative of initiating supply projects based of unconventional renewable energy sources, such as solar, wind, biomass, among others. These projects seek to supply the electrical demand of isolated areas or are a supplement for the general energy sector [4, 5].

The implementation of small electric generation plants has gained strength in recent years, due to the electric power supply shortfalls in the region, and especially in Ecuador, where the electric demand of its continental territory is mainly supplied by hydroelectric generation, but it maintains a deficit in the electric supply in the island territory, thus widely relying on polluting generation units such as diesel generators [6, 7].

In light of the electrical energy deficit in the island region and the increasing use of generation units based on alternative energy sources, the idea arises to supply the electrical demand of isolated areas through unconventional renewable energy [8, 9]. For this purpose, it is necessary to develop an energy management system that solves the economic dispatch problem through an association between operating costs and power generated, optimally and efficiently balancing the supply of the electrical demand [10, 11].

In this context, this research presents the evaluation of an optimization model that seeks to supply the electrical demand of an isolated microgrid using unconventional renewable energy. It incorporates a quadratic equation that models the real operation of the diesel generator in the objective function, enabling the solution of a mixed-integer nonlinear economic dispatch problem for 24, 48, and 168 hours of operation under various constraints.

### 1.1. Related works

A literature review of different research works about economic dispatch of isolated microgrids is presented below.

The use of quadratic programming for solving economic dispatch problems is promoted in [12], where the quadratic function is determined using the variable scaling method to minimize system operating costs. On the other hand, [13] presents a predictive control strategy that employs an algorithm based on fuzzy logic to address an economic dispatch problem, considering different variables and potential scenarios of load and renewable energy generation capacity.

The issue of the uncertainty associated to unconventional renewable energies, which limits their usage, is addressed in [14]. However, a parameter simplification approach can be used to tackle the stochastic nature of these energies. In addition, [15, 16] propose the inclusion and solution of the uncertainty of unconventional renewable energies, by means of a consensus algorithm through centralized and distributed economic dispatch, highlighting the importance of these constraint conditions to enhance the performance of the final dispatch.

On the other hand, the use of quadratic dynamic programming is proposed in [17, 18], as a solution aimed at improving the control of load losses in the economic dispatch. In addition, in [19] it is sought to ensure the supply of electrical energy for an isolated microgrid, using prediction algorithms that enable to identify load data as input to the economic dispatch. Using a batch processing method, the performance of the model is enhanced.

Finally, Table 1 presents a literature review of the last three years, analyzing various research works that validate the possibility of posing a mixed-integer nonlinear optimization problem, seeking to minimize system operating costs with the purpose of completely supplying the electrical demand, considering different dispatchable and non-dispatchable generation units from unconventional renewable energy sources and a model of a generating set.

**Table 1.** Literature review

| | Publication year | Authors | Description | Reference |
|---|---|---|---|---|
| 1 | 2022 | E. López-Garza, R. F. Domínguez-Cruz, F. Martell-Chávez, and I. Salgado-Tránsito | This paper presents a hybrid economic dispatch model that combines a linear model with a fuzzy logic system, aiming to minimize and maximize the levels of wind and hydroelectric generation to meet the electrical demand in Mexico. | [20] |
| 2 | 2020 | H. Xu, Z. Meng, and Y. Wang | This paper presents an optimization model that incorporates the uncertainty of unconventional renewable energies within economic dispatch. Its goal is to display the response of the demand considering the impact of the variation of transferable loads and identifying customer satisfaction. | [21] |
| 3 | 2020 | L. Jian, Z. Qian, Z. Liangang, and Y. Mengkai | This paper presents a comparison between the centralized and distributed economic dispatch problems in terms of system structure, performance requirements and solution processes. The aim is to establish the advantages and disadvantages of each approach. | [22] |
| 4 | 2022 | K. Chen, Z. Zhu, and J. Wang | This paper presents a quasi-quadratic online adaptive dynamic optimization problem, aimed at supplying the demand of smart buildings through the proposed economic dispatch. It incorporates demand uncertainty and shows to outperform traditional algorithms. | [23] |
| 5 | 2022 | Xu, F., Zhang, X., Ma, X., Mao, X., Lu, Z., Wang, L., and Zhu, L. | This paper presents an economic dispatch problem for a microgrid, which incorporates load prediction using various types of neural networks. The aim is to supply the demand of the system in conjunction with the electrical grid; better results were obtained when including the load uncertainty in the optimization problem. | [24] |

## 1.2. Nomenclature

### Objective function

- T: Evaluation horizon.
- $t$: Time.
- $C_D$: Diesel generator cost.
- $Q_{dt}$: Diesel consumption from the power as a function of time.
- $C_{ENS}$: Unsupplied power cost.
- $P_{ENS_t}$: Unsupplied power as a function of time.
- $C_{SH}$: Spillage power cost.
- $P_{SH_t}$: Spillage power as a function of time.
- $CU_{BESS}$: Battery bank usage cost.
- $P_{B_t}^C$: Power of the batteries in charge mode as a function of time.
- $P_{B_t}^D$: Power of the batteries in discharge mode as a function of time.
- $\eta^C$: Efficiency of the batteries in charge mode.
- $\eta^D$: Efficiency of the batteries in discharge mode.

### Equation of the battery bank costs

- $CI_{BESS}$: BESS investment cost.
- $E_{max}$: Maximum energy.
- $N_{ciclos}$: Number of battery cycles.

### Balance equation

- $P_{D_t}$: Diesel power as a function of time.
- $P_{S_T}$: Solar power as a function of time.
- $P_{W_t}$: Wind power as a function of time.
- $D_t$: Demand as a function of time.

### Diesel power constraint equation

- $P_{D_{min}}$: Minimum diesel power.
- $P_{D_{max}}$: Maximum diesel power.

### Diesel quadratic equation

- $A$: First constant of the quadratic equation.
- $a$: Second constant of the quadratic equation.
- $c$: Third constant of the quadratic equation.

### BESS constraint equation

- $E_t$: Energy of the battery bank as a function of time.
- $E_0$: Initial energy of the battery bank.
- $E_{t-1}$: Energy as a function of time that determines the actual conditions of the battery bank.
- $E_{min}$: Minimum energy.

### Equation of the BESS binary variables

- $X_t^C$: Battery charge mode as a function of time.
- $X_t^D$: Battery discharge mode as a function of time.

### SOC equations

- $SOC_t$: Battery state of charge as a function of time.
- $SOC_{min}$: Minimum battery state of charge.
- $SOC_{max}$: Maximum battery state of charge.

## 2. Materials and methods

Economic dispatch ensures the optimal operation of all generation units, by supplying electrical demand at the lowest operating cost [25, 26]. Figure 1 displays the methodology to carry out the proposed economic dispatch problem. First, it is essential to gather the input data that enable to supply the demand of the isolated microgrid. Then, the mixed-integer nonlinear optimization problem must be defined and, finally, it is necessary to evaluate the response of the economic dispatch to obtain different results.

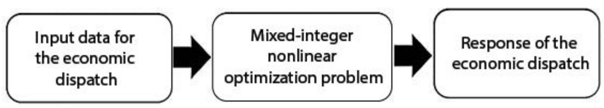


**Figure 1.** Economic dispatch methodology

### 2.1. Input data for the economic dispatch

The input data for the economic dispatch are depicted in the block diagram in Figure 2, where the solar power aims to supply most of the electrical demand, given that the Galápagos province experiences the highest values of solar irradiation in the country, as evidenced in Ecuador's solar map [27]. This map identifies the maximum value of global solar irradiation scale at around 6 kWh/m$^2$day, as shown in Figure 3.

Next, it is shown the behavior of the unconventional renewable energy generation units used, as input data for economic dispatch. The solar irradiation and wind speed values were obtained from [28], then converted into electrical power based on the needs of the case study and plotted for the 168 hours. Figure 4 depicts the solar power behavior over a 24-hour period, while Figure 5 displays the wind power behavior throughout the same 24-hour period. It can be observed that solar power reaches a maximum value of 70 kW, whereas wind power only reaches a maximum of 3 kW.

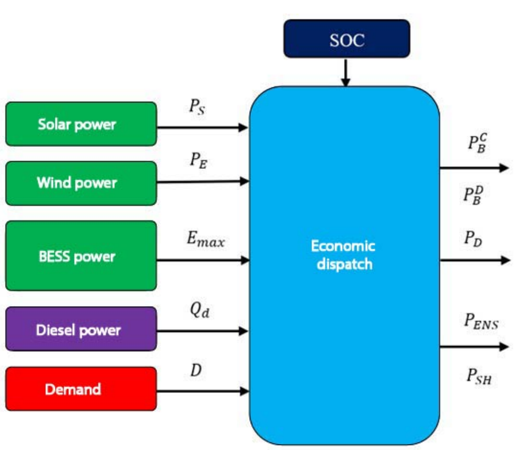


**Figure 2.** Block diagram used in economic dispatch

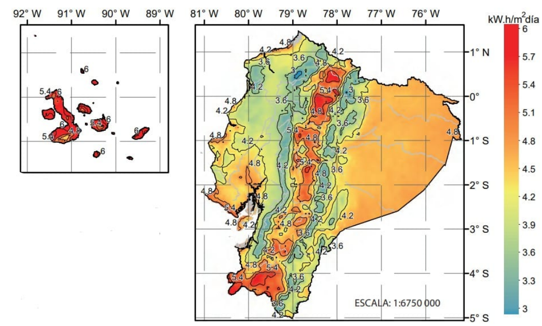


**Figure 3.** Global Solar Irradiation in Ecuador [27]

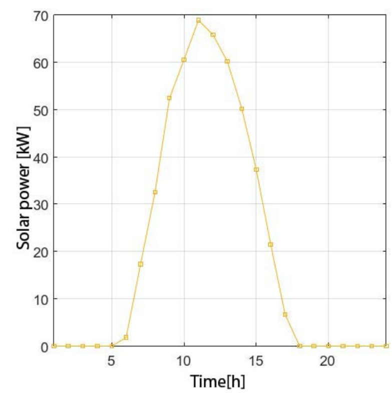


**Figure 4.** Solar power generation

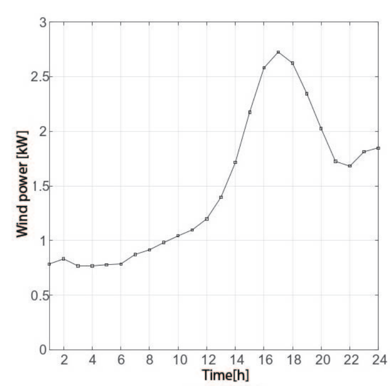


**Figure 5.** Wind power generation

Furthermore, the remaining input units described in Figure 2 correspond to the BESS (Battery Energy Storage System) power, consisting of a total of 165 batteries that will be charged with electrical energy by the solar generation unit. Table 2 displays the technical features of the battery utilized, a RELION lithium-ion battery [29] selected due its deep cycle features, providing a depth of discharge of 42% with a life cycle of 2500 cycles. In addition, based on the battery parameters and specifications, the BESS operating cost and its efficiencies in both charge and discharge modes were obtained.

**Table 2.** Battery manufacturer´s data [29]

| Model | RELION BATTERRY RB100T | | |
|---|---|---|---|
| Nominal voltage | 12.8 V | Nominal capacity | 100 Ah |
| Charge voltage | 13.5 V | Charge current | 5 A – 50 A |
| Maximum charge current | 280 A + 50 A (32+10 ms) | Cut-off voltage | 14.2 V – 14.6 V |
| Operation temperature | Discharge: –20 °C a + 60 °C Charge: –20 °C a + 45 °C | | |
| Life cycle | 2500 cycles (42%DOD) | | |
| | 3500 cycles (20%DOD) | | |

The diesel power belongs to the generating set; in this case, this corresponds to a diesel generator that requires a quantity of fossil fuel for its operation. The hourly consumption ratio is limited by the power output of the diesel generator. For this purpose, a quadratic equation has been established, derived from a second-order polynomial nonlinear approximation due to its similarity with the real behavior of the generating set. The amount of fuel as a function of the power delivered by the diesel generator is defined in equation (7); furthermore, equation (4) bounds the diesel power consumption between a maximum and minimum value established by the manufacturer.

On the other hand, the electrical demand has been obtained from a load study of a real household in Santa Cruz Island, part of the Galápagos Province in Ecuador. The electrical demand data used as input for the economic dispatch, is depicted in Figure 6 for a 24-hour interval, where a maximum consumption value of 40 kW can be identified. At last, the outputs of the economic dispatch establish the technological mix for proper system operation based on the BESS power in charge/discharge mode, diesel generator power, power spillage and unsupplied energy.

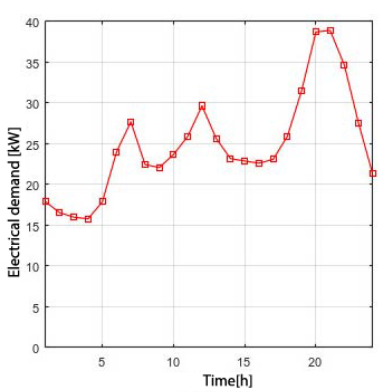


**Figure 6.** Electric demand

## 2.2. Mixed-integer nonlinear optimization problem

Building upon the mixed-integer linear programming (MILP) optimization problem demonstrated in [30], a mixed-integer nonlinear programming (MINLP) model has been established, which proposes the use of a quadratic function consistent with the real behavior of the diesel generator curve. This model aims to minimize the operating costs within the optimization problem, while ensuring the supply of electrical demand for an isolated microgrid. The proposed optimization model is described below.

### 2.2.1. Objective function

From the optimization problem stated in [30], it may be established the objective function shown in equation (1), which seeks to minimize the operating cost of an isolated microgrid in a time interval of 168 hours (one week).

$$J = Min \sum_{t=1}^{T} \Bigg( C_D Q_{d_t} + C_{ENS} P_{ENS_t} + C_{SH} P_{SH_t} + + (CU_{BESS}) \left( P_{B_t}^{C} \eta^{C} + \frac{P_{B_t}^{D}}{\eta^{D}} \right) \Bigg) \quad (1)$$

Where $C_D$ represents the diesel generation cost, $Q_{d_t}$ quantifies the amount of fuel based on the power established by the diesel generator, $C_{ENS}$ identifies the cost of the unsupplied energy, $P_{ENS_t}$ represents the unsupplied energy, $C_{SH}$ is the cost attributed to power spillage, $P_{SH_t}$ represents the power spillage.

On the other hand, $CU_{BESS}$ is the cost of using the battery bank system (BESS), which is calculated by means of equation (2) from the investment cost of the BESS ($CI_{BESS}$), the maximum energy that the BESS may deliver ($E_{max}$) and the number of cycles ($N_{cycles}$) of the BESS life span. $\eta^C$ and $\eta^D$ represent the charge and discharge efficiency of the BESS according to its mode of use. At last, $P_{B_t}^{C}$ y $P_{B_t}^{D}$ identify the charge and discharge power, respectively.

$$CU_{BESS} = \frac{Cl_{BESS}}{E_{max} \cdot N_{ciclos}} \quad (2)$$

### 2.2.2. Constraints

The objective function involves various constraints that ensure a proper solution of the optimization problem. For instance, the power balance is depicted in equation (3).

$$P_{D_t} + P_{S_t} + P_{W_t} - P_{SH_t} + P_{B_t}^{D} = D_t - P_{ENS_t} + P_{B_t}^{C} \quad (3)$$

The bounds of the objective function are presented in equation (4), which delimits the power of the diesel generator, equation (5), which restricts the unsupplied energy, and equation (6), which constrains the spillage power.

$$P_{D_{min}} \leq P_{D_t} \leq P_{D_{min}} \quad (4)$$

$$0 \leq P_{ENS_t} \leq D_t \tag{5}$$

$$0 \leq P_{SH_t} \leq P_{S_t} + P_{W_t} \tag{6}$$

Equation (7) defines the quadratic function responsible for controlling the diesel generator, where the coefficients (a, b, c) are determined through the analysis of the real behavior of the diesel generator.

$$Q_{D_t} = a{P_{D_t}}^2 + bP_{D_t} + c \tag{7}$$

Equation (8) establishes the initial conditions of the BESS to obtain preliminary energy information, while equation (9) enables to calculate the BESS energy for t>0. Equation (10) constrains the BESS energy.

$$E_t = E_0 + \left(P^C_{B_t} * \eta^C\right) - \left(\frac{P^D_{B_t}}{\eta^D}\right) \tag{8}$$

$$E_t = E_{t-1} + \left(P^C_{B_t} * \eta^C\right) - \left(\frac{P^D_{B_t}}{\eta^D}\right) \tag{9}$$

$$E_{min} \leq E_t \leq E_{max} \tag{10}$$

The use of binary variables is represented in equations (11), (12) and (13), which will enable to know the state of the BESS in any of its two modes of use: charge/discharge. It is important to clarify that the BESS can only operate in one mode of use at a time.

$$X^C_t + X^D_t \leq 1 \tag{11}$$

$$E_{min} \geq P^C_{B_t} \geq -E_{max} * X^C_t \tag{12}$$

$$E_{min} \leq P^D_{B_t} \leq E_{max} * X^D_t \tag{13}$$

The state of charge (SOC) of the BESS may be obtained through equation (14), where $E_t$ is the current energy and $E_{max}$ is the maximum energy. This equation is constrained by equation (15), where the range of the SOC has been established as (100-0)%.

$$SOC_t = \frac{E_t}{E_{max}} \tag{14}$$

$$SOC_{min} \leq SOC_t \leq SOC_{max} \tag{15}$$

### 2.3. Response of the economic dispatch

The methodology used to solve the optimization problem is shown in Figure 7, which depicts the flow diagram for the validation of the economic dispatch. Initially, the input data for the optimization problem must be entered, including electrical demand, solar and wind power, BESS data, and diesel generator power for every hour.

Next, it is sought to solve the mixed-integer nonlinear optimization problem (MINLP) using specific software; in this case, the FICO XPRESS OPTIMIZATION SUITE [31] has been used due to its ease for generating and interpretating the results. It is necessary to validate the economic dispatch response under, at least, three usage criteria: achieving the minimization of the objective function costs, ensuring compliance of all constraints, and eliminating the intermittencies produced by the generating set.

If the economic dispatch response is unsatisfactory, the optimization model should be adjusted to correct its functioning. On the other hand, if the economic dispatch response is satisfactory, the results from the specialized software can be exported, interpreted and plotted.

Finally, this procedure has been used for all case studies proposed in this research work. Merely by altering the runtime of the optimization problem, results for the economic dispatch may be obtained for 24, 48, and 168 hours.

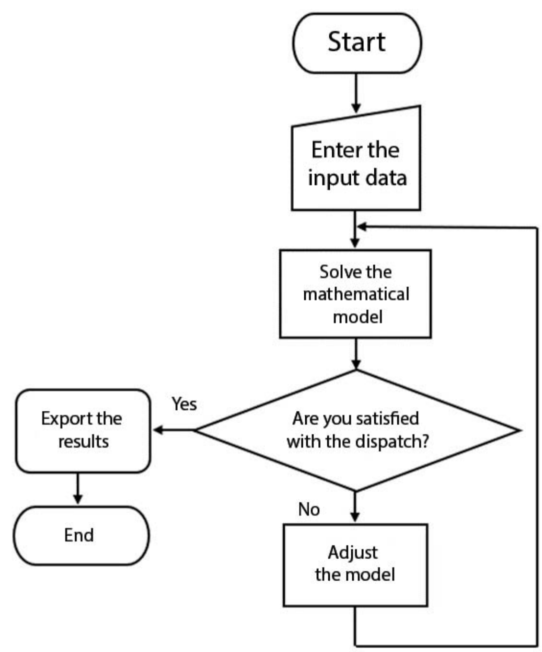


**Figure 7.** Flow diagram of the economic dispatch

## 3. Results and discussion

This section presents the parameters of the isolated microgrid used as a case study for the proposed economic dispatch problem. Figure 8 depicts a didactic scheme that illustrates the operation of the microgrid utilized in this research work, considering dispatchable and non-dispatchable generation units aimed at supplying the demand continuously.

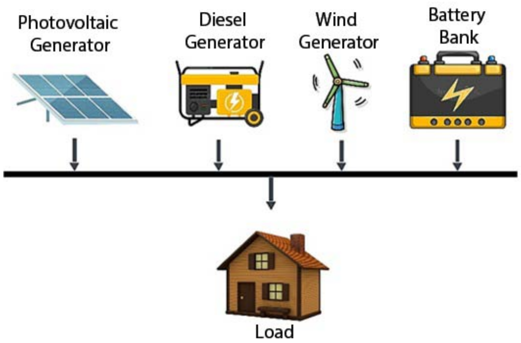


**Figure 8.** Diagram of the isolated microgrid based on ERNC

Table 3 displays the bounds of the different generation units used in the proposed economic dispatch, including the bounds of the power demanded by the isolated microgrid. Table 4 presents the parameters used to model the Battery Energy Storage System (BESS), highlighting the efficiencies in charge/discharge mode, the degradation percentage, and the state of charge bounds. Table 5 shows the operating costs used in the optimization problem, such as the BESS investment cost obtained from the total cost of the battery bank, the BESS usage cost calculated using equation (2) and the diesel operation cost defined from [32]. Finally, the spillage energy cost corresponds to 10% of the diesel inherent value, and the unsupplied energy cost is set as 5 times the diesel cost.

**Table 3.** Installed capacity and power demanded by the microgrid

| Element | P_min (kW) | P_max (kW) |
|---|---|---|
| BESS | 0 | 211 |
| Diesel generator | 10 | 40 |
| Solar generator | 0 | 135 |
| Wind generator | 0 | 1.2 |
| Demand | 15.19 | 41.4 |

**Table 4.** BESS parameters

| Name | Variable | Valor | Unidad |
|---|---|---|---|
| Maximum nominal energy | $E_{max}$ | 211 | kWh |
| Life time | $N_{ciclos}$ | 2500 | Ciclos |
| Percentage degradation | % degradación | 80 | % |
| Discharge efficiency | $\eta_D$ | 88 | % |
| Charge efficiency | $\eta_C$ | 85 | % |
| Minimum state of charge | $SOC_{min}$ | 0 | % |
| Maximum state of charge | $SOC_{max}$ | 100 | % |

**Table 5.** Operating costs

| Name | Variable | Value | Unit |
|---|---|---|---|
| BESS investment cost | CIBESS | 189750 | USD |
| BESS usage cost | CUBESS | 0.36 | USD/ciclo |
| Diesel operating cost | CD | 1.25 | USD/litro |
| Unsupplied energy cost | CENS | 6.25 | USD/kW |
| Spillage energy cost | CESH | 1.37 | USD |

### 3.1. Response of the economic dispatch

Figure 9 illustrates the performance of the different electrical energy sources that entirely supply the energy demand over a 24-hour interval, with a contribution of 56.50% from solar power, 4.23% from wind power, 17.23% from the battery bank, and 21.96% from the diesel generator, fulfilling the entire electrical demand.

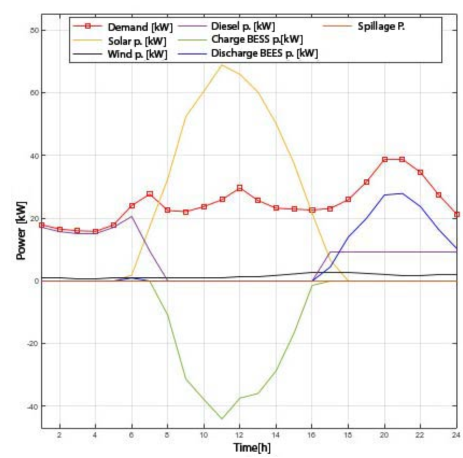


**Figure 9.** Economic dispatch for 24 hours

Figure 10 depicts the economic dispatch behavior over 48 hours, which exhibits slight differences compared to the economic dispatch response over 24 hours in terms of the technological mix. In this case, the entire electrical demand is also met with 0% unsupplied energy, where solar power contributes 56.88%, wind power 4.81%, the diesel generator 19.20% and the battery bank 19.11%.

Figure 11 displays the results obtained when solving the economic dispatch problem for a time period of 168 hours (one week), highlighting a harmonious interaction across all days of the proposed week. It evidences slight differences compared to the previous two study cases, with solar power contributing 50.40% to the electrical demand, wind power 5.53%, the diesel generator 23.92% and the battery bank 17.14%.

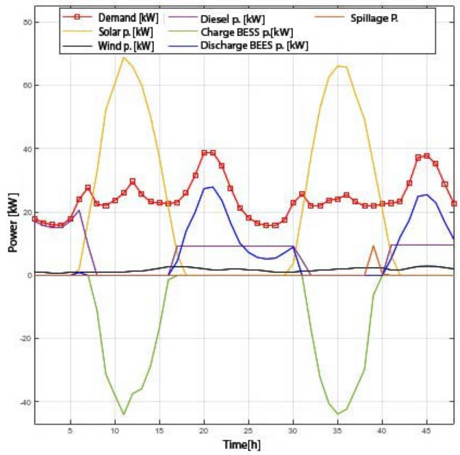


**Figure 10.** Economic dispatch for 48 hours

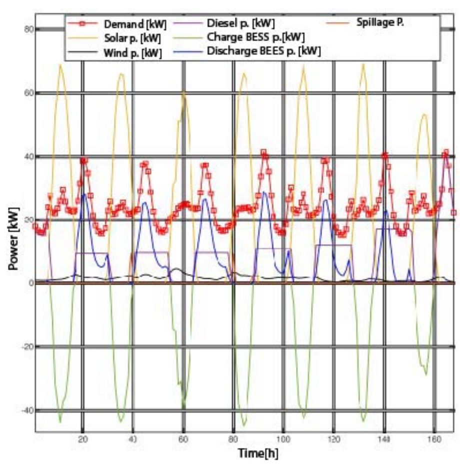


**Figure 11.** Economic dispatch for 168 hours (1 week)

In addition, the previous graphs show that the diesel generator maintains a continuous ignition point due to the modeling used in the proposed optimization problem. The incorporation of the generator through a quadratic equation eliminates its intermittencies, resulting in continuous on/off moments along time. This occurred for all three proposed study cases of 24, 48 and 168 hours.

## 3.2. Discussion of the economic dispatch

A discussion of the results obtained for the three case studies shown in Figures 9, 10 and 11 is now presented.

For instance, in response to the 24-hour economic dispatch simulation (Figure 9), it is evident that in the early hours of the day, the electrical demand is entirely supplied by the diesel generator, with minimal contribution from the wind generator. From 6:00 AM, the solar generator begins its operation, gradually taking over the electrical demand until it exceeds the demand value. At this point, the surplus energy is stored by the battery bank, which switches to charging mode. From 4:00 PM onwards, the diesel generator comes into operation, supported by the battery bank in discharge mode and minimally by the wind generator, successfully supplying the remaining hours of the day until reaching 12:00 AM.

Figure 10 displays a behavior similar to the first day, with slight variations in the hours of interaction among different energy sources due to the unpredictable nature of the Unconventional Renewable Energy (URE) Sources. It is worth noting that the power of the Battery Energy Storage System (BESS) in the charging state represents an electrical energy consumption, thus becoming part of the demand. The batteries store energy when they are discharged and supply energy when they reach their maximum charge; in this case, they achieve 100% state of charge (SOC).

Finally, in Figure 11 a satisfactory supply of electrical demand is analyzed. There is a recurrence in the behavior of energy sources, displaying a pattern especially noticeable in the diesel generator, which maintains intervals of complete shutdown during certain hours of the day, reducing operating costs and continually supporting the Battery Energy Storage System (BESS). It is important to note that the wind power maintains a constant, albeit minimal, continuous energy contribution due to the climatic conditions of the isolated microgrid, with slight fluctuations. Despite these fluctuations, it continues to provide electrical energy 24 hours a day throughout the entire week under analysis.

On the other hand, Figure 12 illustrates the BESS usage cycle, which relates the power in charge/discharge mode with the BESS state of charge, following a positive (charge) and negative (discharge) cycle within a 24-hour interval. The BESS reaches its maximum energy charge around 2:00 PM due to the available solar resources, enabling it to cover the demand and charge the BESS. Meanwhile, from 6:00 PM, it begins to discharge, reaching complete discharge around 12:00 AM.

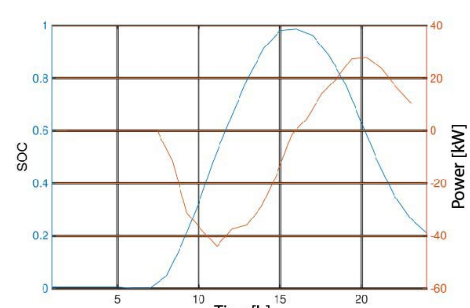


**Figure 12.** BESS usage cycle in 24 hours

Figure 13 depicts the BESS usage cycle over a 48-hour interval, demonstrating the similarities between the curves. This similarity arises from the energy supplied by the solar generator, which provides different daily peaks of charge and discharge every day.

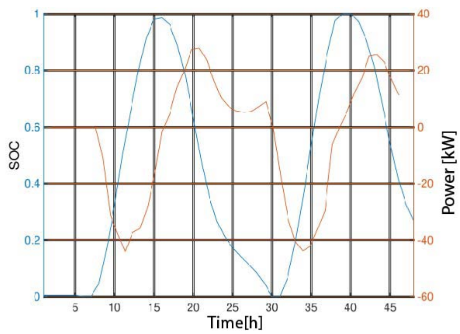


**Figure 13.** BESS usage cycle in 48 hours

Finally, Figure 14 illustrates the BESS usage cycle over 168 hours, demonstrating a cyclic process throughout the entire week. It is evident that the battery bank achieves maximum charges of 100% SOC and complete discharges to 0% SOC, which validates its operation within the proposed economic dispatch problem. Thus, it may be concluded that the BESS contributes continuously and efficiently to the electrical demand.

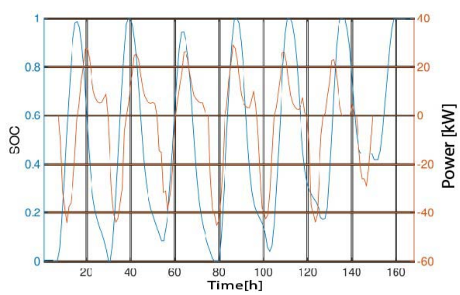


**Figure 14.** BESS usage cycle in 168 hours

## 4. Conclusions

The present research work presents the assessment of an economic dispatch problem through a mixed-integer nonlinear programming optimization model, which incorporates the modeling of the actual behavior of the diesel generator as a second-degree polynomial equation.

The input data for the economic dispatch were obtained from Santa Cruz Island in the Galápagos Province, Ecuador. Solar irradiation and wind speed values were identified using the NASA web platform, while the electrical demand data correspond to real data from the actual location. In addition, a battery bank and a diesel generator were dimensioned to meet the demand of the region in case of unconventional renewable energy deficiency.

The economic dispatch results were obtained for 24, 48, and 168 hours at an hourly resolution, showing the contribution of all generation units to meet the demand proportionally: solar generator 54.40%, BESS 17.14%, diesel generator 23.92% and wind generator 4.43%.

The intermittent behavior of the generating set was effectively controlled, limiting the operation of the diesel generator to a maximum of 8 hours, while simultaneously achieving minimization of operating costs and meeting the entire electrical demand.

Finally, as future work it is proposed to incorporate the uncertainty of the input data into the economic dispatch problem, to obtain a stochastic optimization problem. In addition, it could be also carried out a comparison between the response of the mixed-integer nonlinear economic dispatch and a mixed-integer linear economic dispatch, which includes modeling the generating set using piecewise linearization.

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