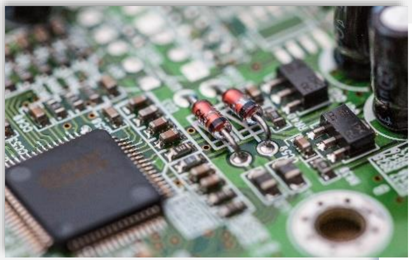

Gestión de energía para sistemas híbridos de generación renovable y almacenamiento en baterías

Universidad Carlos III de Madrid

Luis Azuara Grande

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Introduction

- Power generation from diesel gensets plays a key role for industrial companies and rural communities all over the world, especially in remote regions without a good grid infrastructure. **They allow to create simple off-grid systems with a moderate initial investment**.
- However, these applications have some disadvantages. First, the grid they create is totally dependent on diesel, which is a non-renewable. On the other hand, **the energy generated is expensive due to high prices of fuel and the difficulty of supplying in remote regions**. Furthermore, diesel-based systems have to face constant price increases and high operational expenditures (OPEX) directly related to the use of fuel. Apart from that, CO2 emissions increase with the use of gensets.
- **PV system prices have fallen in the last years, allowing nowadays generating energy at a more competitive cost compared to fuel**. In regions with high solar irradiation levels and expensive fuel prices, PV systems can be amortized in less than four years. Furthermore, PV plants require low maintenance, they can be configured according to specific energy demands and do not produce CO2 emissions .
- In addition, **in recent years due to technological advances in the field of electrochemical batteries, they are beginning to have a key role in on-grid and off-grid projects**. Being a fundamental element for isolated hybrid systems to integrate maximum energy from the PV plants and minimizing the use of diesel.

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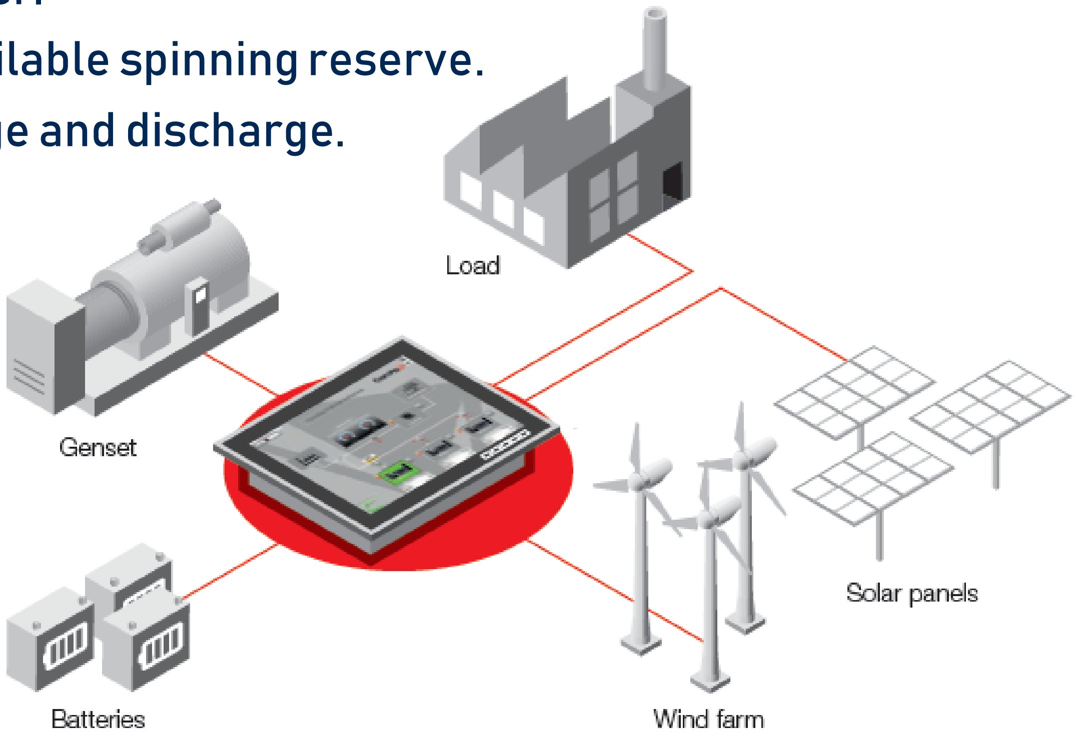
Energy management system (EMS)

Challenges of EMS:

- Maximize renewable energy integration.
- Limit minimum diesel power.
- Maintain a minimum of available spinning reserve.
- Management battery charge and discharge.



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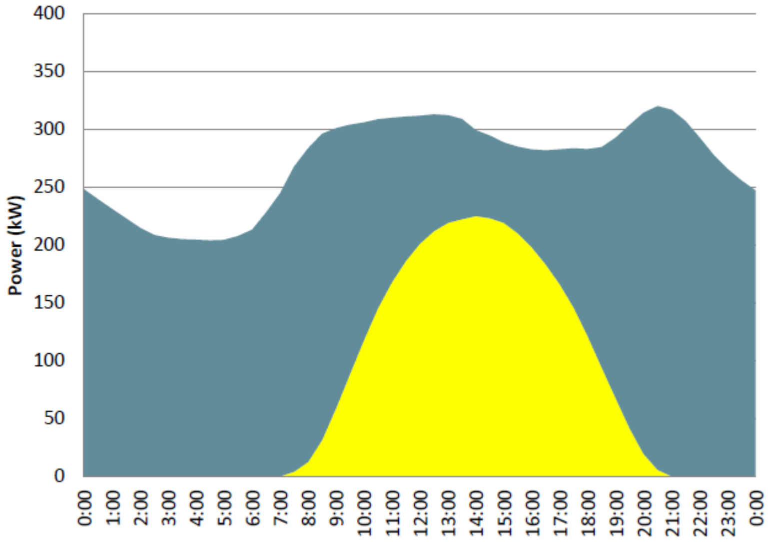

$$P_{FV} = P_{LOAD} - P_{GEN,\,min}$$

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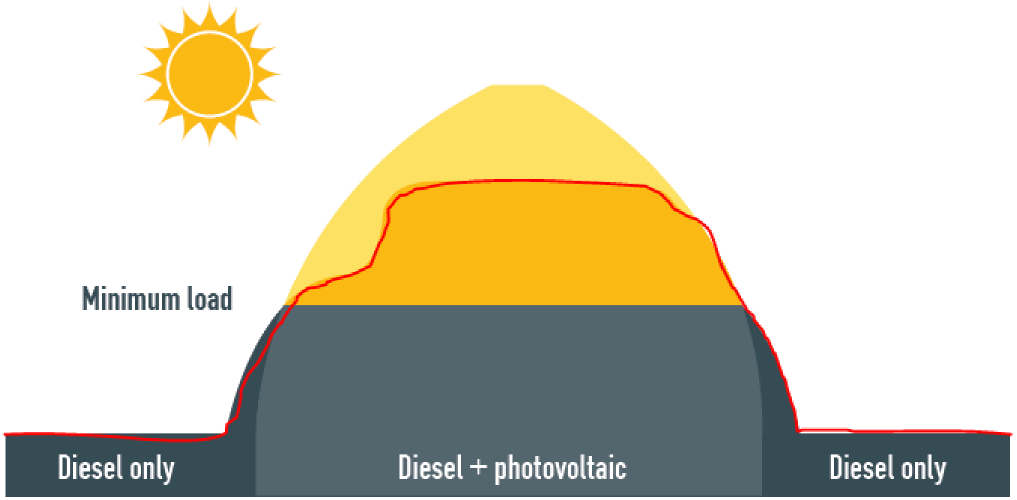

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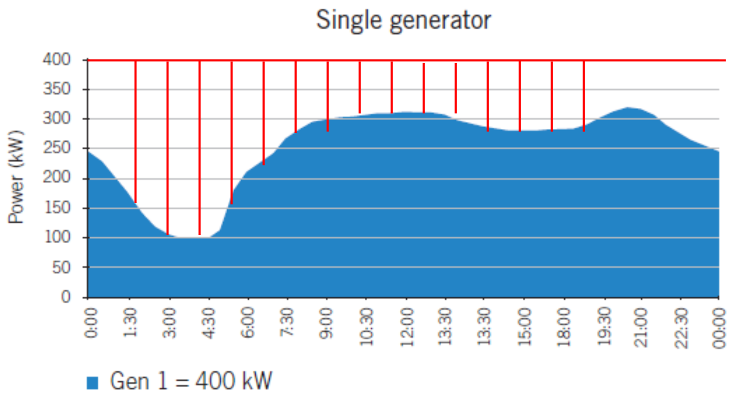

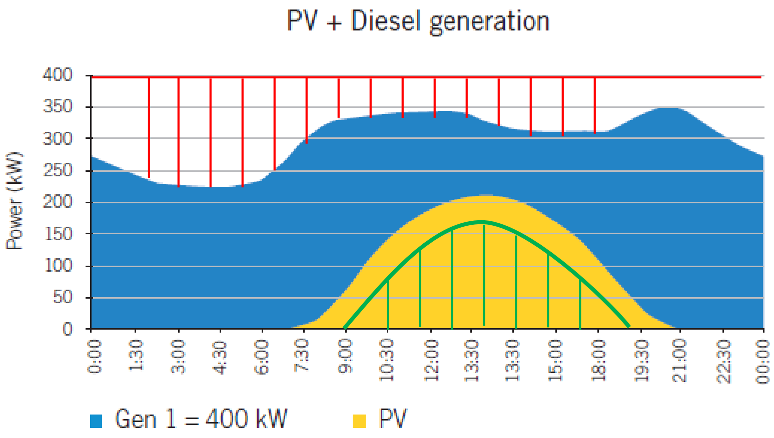

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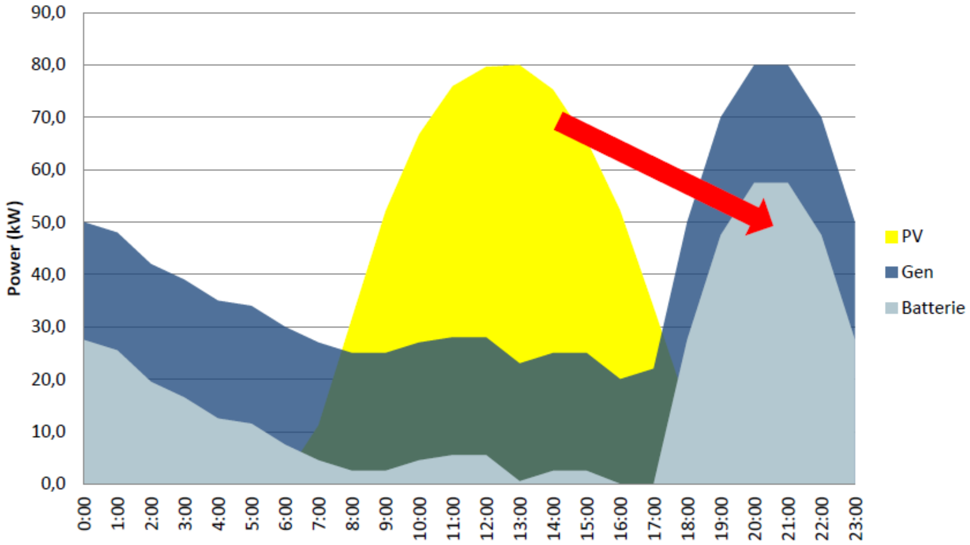


Proposals

- **Most of the proposed EMS strategies in the literature are on off-line applications and they have not been developed with specifications for the microgrid operation in real-time.** In this way, the EMS must be support real-time control of the electric power grid. And thus, guarantee the stability thanks to continuous real-time monitoring and control of the isolated hybrid microgrid.
- The problem that needs to be solved regarding real-time operation is not related to computation time, since the EMS optimizations usually run at relatively long-time steps. **The problem is to properly integrate an energy management strategy with the remaining controls of the microgrid that guarantee its stability, safely managing diesel consumption, PV curtailments and battery operation under unexpected load and PV resource changes, while staying as close as possible to optimal operation.**

Proposals

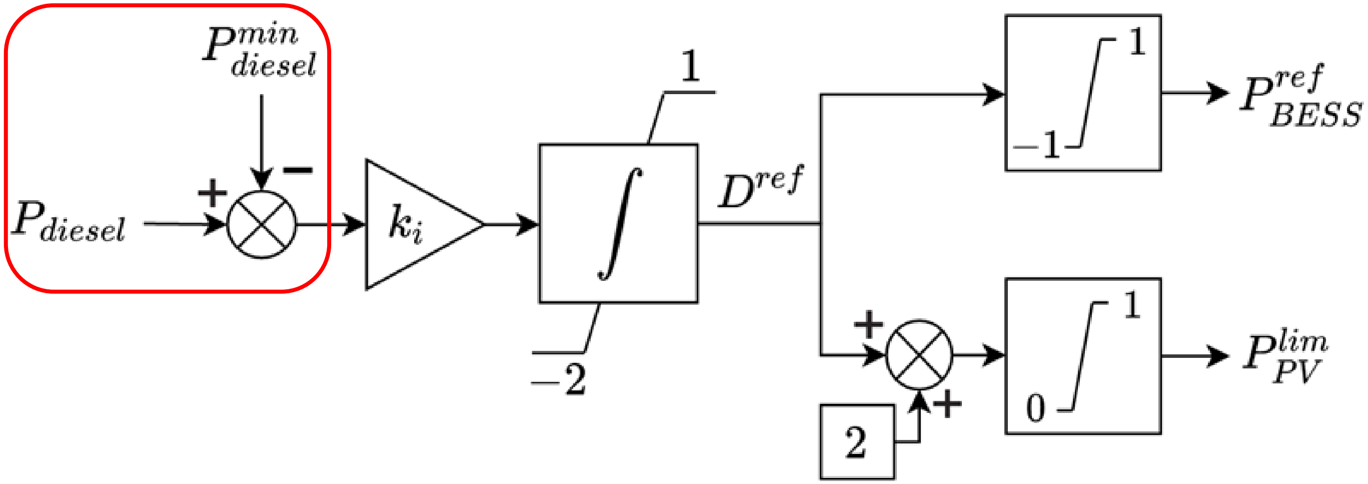
- The objective of this study was to develop EMS strategies for the real-time operation of isolated hybrid microgrids so that they can be applied to real environments. Accordingly, two EMS strategies were developed using a dynamic model of the microgrid, simulating the conditions of a real-time operation. The first, called the **priority EMS strategy**, works by assigning a priority order, while the **optimal EMS strategy** responds to an optimization criterion, which is set to the minimum marginal cost in this case.

- Azuara-Grande, L. S., Arnaltes, S., Alonso-Martinez, J., & Rodriguez-Amenedo, J. L. (2020, June). EMS for fuel saving in an isolated hybrid system (solar/diesel/battery). In 2020 IEEE International Conference on Environment and Electrical Engineering and 2020 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe) (pp. 1-4). IEEE.
- Azuara-Grande, L. S., Arnaltes, S., Alonso-Martinez, J., & Rodriguez-Amenedo, J. L. Distributed Control Strategy for Isolated Electrical Hybrid Power Systems.

Priority EMS strategy

- The priority EMS strategy is based on a decentralized architecture. **The corresponding algorithm implements a fixed set of rules that describe the dispatch priority for each energy source present in the microgrid**. In this case, the dispatch priority rules of the EMS strategy are the following, in order:
  - Minimize diesel power generation but keep each running genset above its technical minimum power setpoint if possible.
  - Maximize PV power generation. Only curtail if strictly necessary.
  - Charge the BESS only with excess energy and discharge it only if this reduces diesel consumption.
- **The priority EMS strategy is implemented using two local controllers: a diesel controller and a joint PV-BESS EMS controller**. Communication between these two controllers is minimized to increase robustness.
  - Diesel power plant controller.
  - PV-BESS EMS controller.

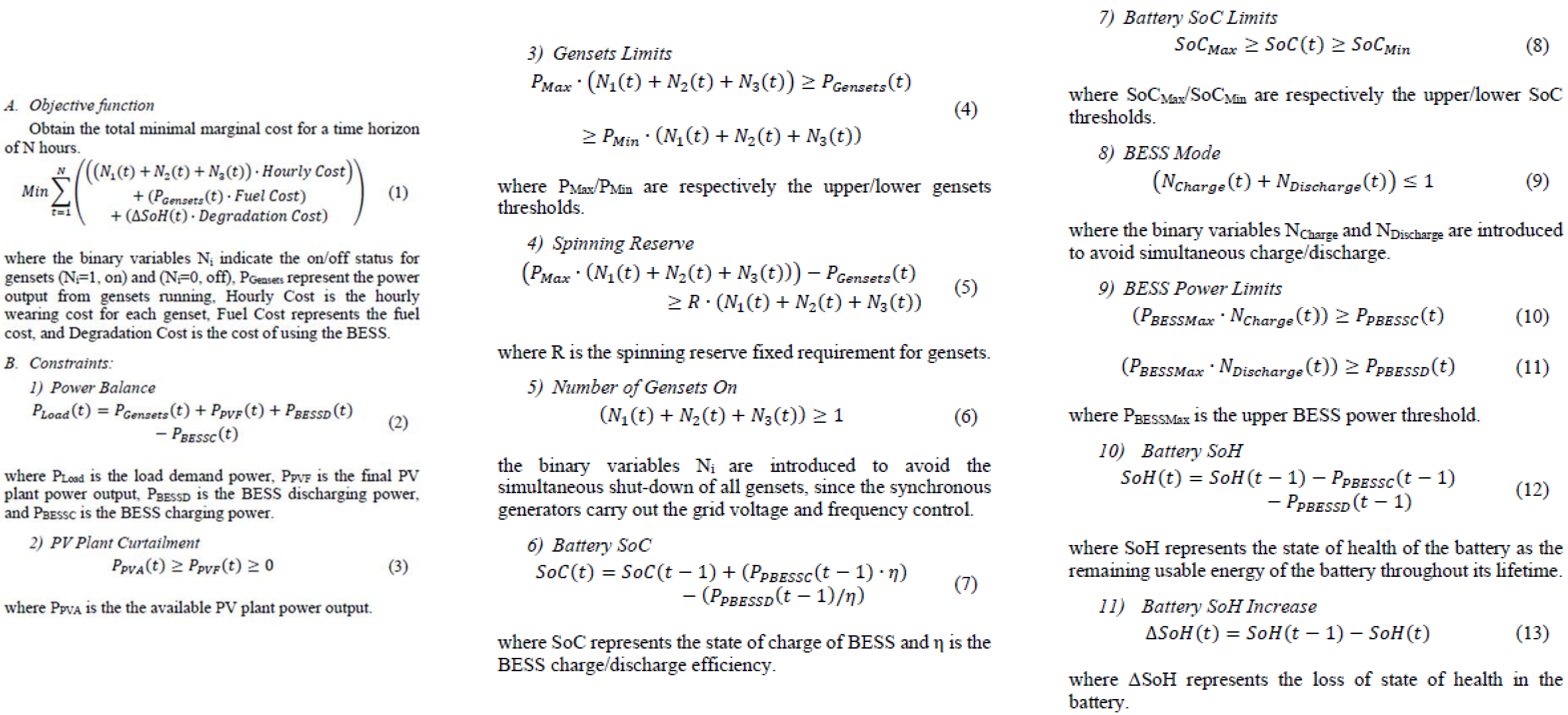
Priority EMS strategy



Optimal EMS strategy

- The optimal EMS strategy is based on a centralized architecture. It optimizes the management of the dispatch based on the chosen variable, such as costs, emissions, or energy. Once the variable is selected, the EMS itself decides how to manage the dispatch. **In this case, it is decided that the optimization is based on the marginal costs of each generation technology of the hybrid microgrid**. The only inputs to the EMS are the marginal costs assigned by the power system operator to each generation technology; therefore, **the objective of the EMS is to find the optimal solution to the problem**.
- Accordingly, **the problem is formulated as a rolling horizon control (RHC) scheme that periodically updates input data information** from the dynamic microgrid model. **The optimization problem is solved at each time step to determine the operating schedule of the system over a fixed time horizon**, but only the first output from this plan is applied to the system. In the next time step, the process is repeated; in other words, **a new optimization problem is solved with the time horizon shifted one step forward**. The optimization problem takes into account the forecasting of future values based on available forecasts at each time step.
- However, unlike other optimization strategies using RHC reported in the literature, **the proposed optimal EMS strategy allows the solution of the optimization problem to be applied to real-time operation because, of the entire operation plan that is obtained from the optimization at each time step, only the first time-step output from BESS power reference is applied to the operation in real-time**. Further, the PV plant power curtailment is still controlled by the priority EMS strategy.

Optimal EMS strategy



A. Objective function

Obtain the total minimal marginal cost for a time horizon of N hours.

$$Min \sum_{t=1}^{N} \begin{pmatrix} \left((N_1(t) + N_2(t) + N_3(t)) \cdot Hourly\ Cost \right) \\ + (P_{Gensets}(t) \cdot Fuel\ Cost) \\ + (\Delta SoH(t) \cdot Degradation\ Cost) \end{pmatrix} \quad (1)$$

where the binary variables N_i indicate the on/off status for gensets (N_i=1, on) and (N_i=0, off), $P_{Gensets}$ represent the power output from gensets running, Hourly Cost is the hourly wearing cost for each genset, Fuel Cost represents the fuel cost, and Degradation Cost is the cost of using the BESS.

B. Constraints:

1) Power Balance

$$P_{Load}(t) = P_{Gensets}(t) + P_{PVF}(t) + P_{BESSD}(t) - P_{BESSC}(t) \quad (2)$$

where P_{Load} is the load demand power, P_{PVF} is the final PV plant power output, P_{BESSD} is the BESS discharging power, and P_{BESSC} is the BESS charging power.

2) PV Plant Curtailment

$$P_{PVA}(t) \geq P_{PVF}(t) \geq 0 \quad (3)$$

where P_{PVA} is the the available PV plant power output.

3) Gensets Limits

$$P_{Max} \cdot \left(N_1(t) + N_2(t) + N_3(t)\right) \geq P_{Gensets}(t) \geq P_{Min} \cdot \left(N_1(t) + N_2(t) + N_3(t)\right) \quad (4)$$

where P_{Max}/P_{Min} are respectively the upper/lower gensets thresholds.

4) Spinning Reserve

$$\left(P_{Max} \cdot (N_1(t) + N_2(t) + N_3(t))\right) - P_{Gensets}(t) \geq R \cdot (N_1(t) + N_2(t) + N_3(t)) \quad (5)$$

where R is the spinning reserve fixed requirement for gensets.

5) Number of Gensets On

$$(N_1(t) + N_2(t) + N_3(t)) \geq 1 \quad (6)$$

the binary variables N_i are introduced to avoid the simultaneous shut-down of all gensets, since the synchronous generators carry out the grid voltage and frequency control.

6) Battery SoC

$$SoC(t) = SoC(t-1) + (P_{PBESSC}(t-1) \cdot \eta) - (P_{PBESSD}(t-1)/\eta) \quad (7)$$

where SoC represents the state of charge of BESS and η is the BESS charge/discharge efficiency.

7) Battery SoC Limits

$$SoC_{Max} \geq SoC(t) \geq SoC_{Min} \quad (8)$$

where SoC_{Max}/SoC_{Min} are respectively the upper/lower SoC thresholds.

8) BESS Mode

$$\left(N_{Charge}(t) + N_{Discharge}(t)\right) \leq 1 \quad (9)$$

where the binary variables N_{Charge} and $N_{Discharge}$ are introduced to avoid simultaneous charge/discharge.

9) BESS Power Limits

$$(P_{BESSMax} \cdot N_{Charge}(t)) \geq P_{PBESSC}(t) \quad (10)$$

$$(P_{BESSMax} \cdot N_{Discharge}(t)) \geq P_{PBESSD}(t) \quad (11)$$

where $P_{BESSMax}$ is the upper BESS power threshold.

10) Battery SoH

$$SoH(t) = SoH(t-1) - P_{PBESSC}(t-1) - P_{PBESSD}(t-1) \quad (12)$$

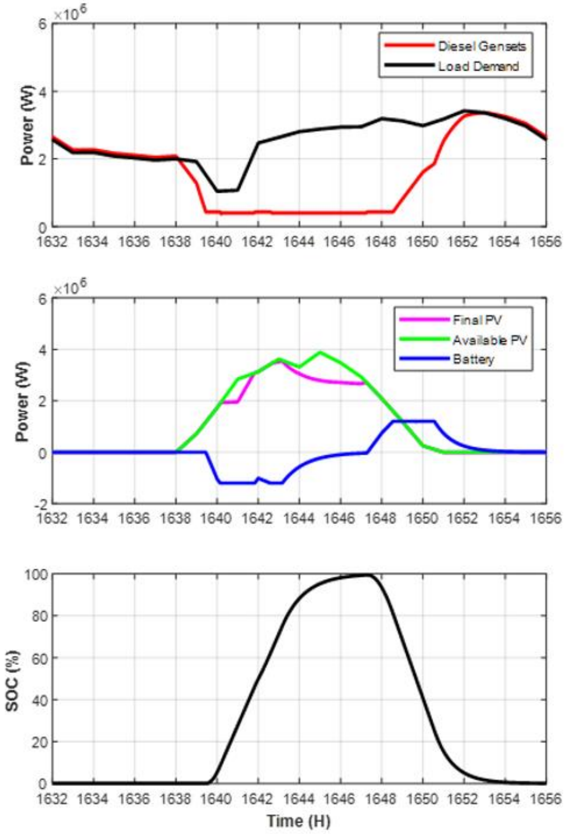
where SoH represents the state of health of the battery as the remaining usable energy of the battery throughout its lifetime.

11) Battery SoH Increase

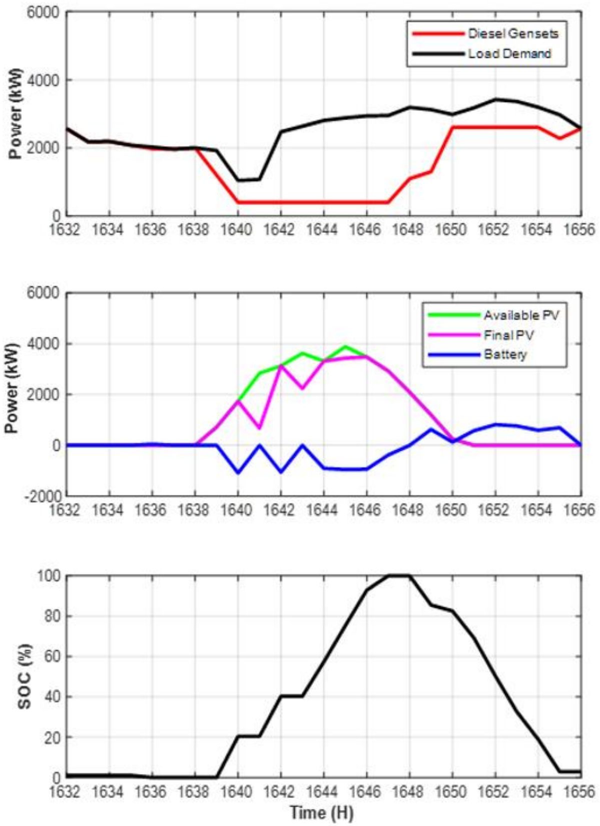
$$\Delta SoH(t) = SoH(t-1) - SoH(t) \quad (13)$$

where ΔSoH represents the loss of state of health in the battery.

Results



Microgrid operation for one day in summer using the priority EMS Strategy.



Microgrid operation for one day in summer using the optimal EMS Strategy.

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Results

1 Year Simulation		Priority EMS	Optimal EMS
PV plant	Energy Total (kWh)	7,179,052	7,179,052
	Energy Final (kWh)	6,525,180	6,783,870
	Excess (kWh)	649,240	395,182
Diesel Gensets	Energy Total (kWh)	15,982,320	15,741,236
BESS	Energy Throughput (kWh)	956,947	1,038,597
	Energy In (kWh)	1,055,020	1,145,473
	Energy Out (kWh)	858,875	931,721
Load (kWh)		22,311,355	22,311,355
Total Costs of Energy (€)		3,226,029	3,185,149

¡Muchas gracias por vuestra atención!

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