23rd International Conference on Renewable Energies and Power Quality (ICREPQ'25)
Tenerife (Spain), 25th to 27th June 2025
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, Volume No.23, September 2025

A MILP Approach to Optimising Energy Storage in a Commercial Building

Tomás Barosa Santos, Filipe Tadeu Oliveira and Hermano Bernardo

Centre for Power and Energy Systems
INESC TEC
Porto, Portugal

Abstract. To achieve carbon neutrality by 2050, commercial buildings have installed photovoltaic systems to reduce carbon emissions and operational costs. Nevertheless, PV generation does not always match the building's energy demand profile, therefore storage systems are needed to store excess energy and supply it when necessary. This paper presents a Mixed Integer Linear Programming optimisation algorithm designed to schedule the operation of the electric storage system, aiming to minimise the building's energy-related costs. An annual hourly simulation of the optimised system was performed to assess the cost reduction. To prevent excessive operation of the electric storage system, an approach to penalise low energy charging was studied, with results showing a significant increase in the system's lifespan.

Key words. MILP, optimisation, renewable energy, energy storage system, commercial building

1. Introduction

Buildings' energy consumption accounts for 40% of the total energy consumption in the European Union (EU), and with the European Green Deal aiming for carbon neutrality by 2050 [1], the energy consumed must be carbon-free. Therefore, many commercial buildings are installing photovoltaic (PV) systems to reduce carbon emissions and energy costs.

For a few hours each day, the PV generation does not align with the building's energy demand profile, resulting in excess generated energy that is wasted. To maximise the use of on-site PV energy, storage systems have been deployed to store this excess energy and supply it when needed. These systems can also be used to store energy when energy market prices are low and supply it later, when prices peak.

Previous works have approached objectives like those of this paper. In [2], a Mixed Integer Linear Programming (MILP) optimization model was developed for a domestic PV-Battery system, using two-day-ahead forecasts of energy demand and PV-energy generation. This model achieved significant reductions in energy costs and improved the PV self-consumption. However, it did not allow the storage system to charge directly from the grid, and its main goal was to minimise grid energy exchange. In [3], the focus was on optimising a power dispatch strategy for a small neighbourhood. A Linear Programming (LP) model was used to minimise power purchases from the grid, resulting in a substantial cost reduction, mainly due to the system's ability to sell excess PV energy. In [4], the optimization problem aimed to maximise PV self-consumption while considering the number of batteries used and their lifespan. The study compared results with and without lifespan-increasing constraints. In [5], the optimization model for a battery management system in a multi-source building was presented, using LP and tested with various solvers.

This paper aims at presenting an optimisation algorithm designed to schedule the operation of an electric storage system for a large commercial building, minimising the overall energy-related costs. The storage system can be charged from the excess PV on-site generation or directly from the electrical grid, allowing greater savings by charging when the electricity market prices are low and discharging when prices are high.

The paper is structured into five sections. The current section outlines the motivation and framework of the study. Section 2 describes the model developed to optimise the energy storage in a large commercial building, including the mathematical formulation representing the system's operation. Section 3 presents the key characteristics of the building and its systems, which serve as the case study for applying the MILP optimisation algorithm. Section 4 shows the results of an annual hourly simulation of the optimization model, highlighting one week to illustrate the system's performance. Finally, conclusions and an outlook of further research work are presented in Section 5.

2. Methodology

The proposed model was based on the work presented in [2] and [5] and has been adapted to accurately represent the system's operation in the commercial building case study.

The building's electrical system comprises a solar PV generation system and an energy storage system. The PV system generates electricity only when there is sufficient solar irradiance; therefore, its combined use with the storage system helps reduce overall energy costs.

The model optimises the scheduling of the storage system's charging and discharging by taking advantage of PV-generated energy and the electricity market prices, minimising energy-related costs.

Fig. 1 illustrates the algorithm's step-by-step operation. Equation (1) defines the objective function, while equations (2) to (8) outline the algorithm's constraints.

The optimisation problem was implemented in Python using Pyomo [6] and solved with CPLEX [7]. Subsection A provides a detailed description of the model's mathematical formulation, while Subsection B presents the computation of some variables.

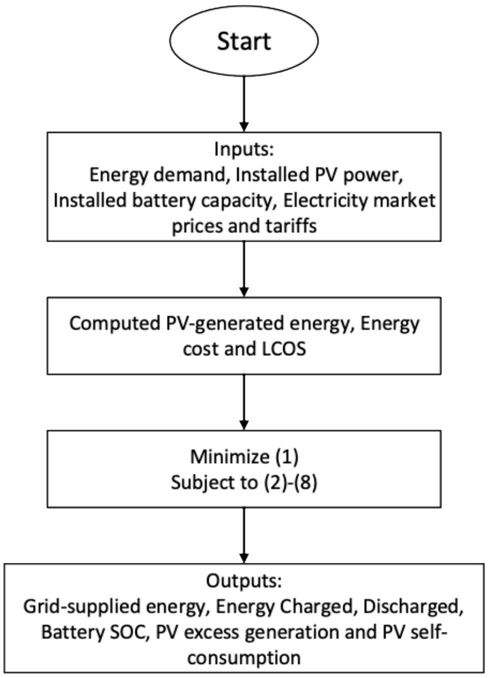

Fig. 1. Algorithm's step-by-step operation.

A. Model Formulation

The optimisation problem is formulated as a MILP, with the objective function – defined in Equation (1) – minimising energy-related costs.

$$Min \sum_{t=1}^{N=24} \begin{matrix} EGrid_E[t] \times Cost_{Grid}[t] + \\ EBatt_{Discharge}[t] \times LCOS \end{matrix} \tag{1}$$

The energy-related costs can be divided into two components: the costs of grid-supplied energy and the cost of using the electric battery. The latter serves as a penalty, discouraging the algorithm from using the battery for minor cost savings that might otherwise reduce its lifespan. Section 4 presents results where this effect is analysed in greater detail.

Equation (1) computes the total costs by multiplying the grid-supplied energy, $EGrid_E$, , at a given hour, t, by the electricity market price at that hour, $Cost_{Grid}$. This product is then added to the amount of energy discharged, $EBatt_{Discharge}$, multiplied by the levelised cost of storage (LCOS), which is computed according to Equation (9).

Since the optimisation problem is applied to a building, it must ensure that the building is supplied with the necessary energy at each hour. Therefore, (2) defines the amount of energy charged and discharged from the electric storage system.

$$\begin{aligned} & EE_{Demand}[t] = EGrid_E[t] + EPV_E[t] + \\ & \left(EBatt_{Discharge}[t] - EBatt_{Charge}[t]\right) \end{aligned} \tag{2}$$

At any given time, the electric energy demand, EE_{Demand}, can be met either by grid-supplied energy, PV-generated energy, EPV_E, or energy from the electrical storage system. Thus, the same equation also handles both the charging, $EBatt_{Charge}$, and discharging of the storage system, with charging energy drawn from any of these sources.

Equations (3) and (4) describe, respectively, the operation and the constraints of PV energy generation. The generated energy, EPV_{Gen}, can be used either to meet the demand or to charge the storage system. If PV generation exceeds the demand, a slack variable, EPV_{Excess}, is used to absorb the surplus energy.

$$EPV_{Gen}[t] = EPV_E[t] + EPV_{Excess}[t] \tag{3}$$

$$EPV_{Gen}[t] \geq EPV_{Excess}[t] \tag{4}$$

The maximum charging and discharging rates are established by Equations (5) and (6), respectively. These rates are computed by multiplying the battery's C-Rate, $CRate$, by the battery capacity, $Batt_{Capacity}$, which yields the maximum rate of energy transfer. The variable $Batt_{Binary}$ is a binary decision variable that ensures the electric storage system cannot charge and discharge simultaneously. When its value is 1, the storage system is charging; when it is 0, it is discharging.

$$EBatt_{Charge}[t] \leq Batt_{Binary}[t] \times CRate \times Batt_{Capacity} \tag{5}$$

$$\begin{aligned} & EBatt_{Discharge} \leq (1 - Batt_{Binary}[t]) \times CRate \\ & \times Batt_{Capacity} \end{aligned} \tag{6}$$

The State of Charge (SOC) of the electric storage system, SOC_{Batt}, is constrained between 20% and 80% of its capacity, as shown in Equation (7). Equation (8) updates the stored energy, properly accounting for the charging and discharging efficiency, η_{Batt}.

$$SOC_{BattMin} \leq SOC_{Batt}[t] \leq SOC_{BattMax} \tag{7}$$

$$SOC_{Batt}[t] = SOC_{Batt}[t-1] + \begin{pmatrix} EBatt_{Charge}[t] \times \eta_{Batt} \\ - \dfrac{EBatt_{Discharge}[t]}{\eta_{Batt}} \end{pmatrix} \tag{8}$$

B. Variable Computing

The energy cost per hour in the objective function is based on the Portuguese tariff composition explained in [6]. This composition includes only time-variable costs, such as the Iberian Electricity Market (MIBEL) marginal energy price for Portugal and the grid access tariff, including a charge for average peak power. Since all other costs are considered fixed, regardless of energy consumption, they have not been included.

The LCOS is computed using Equation (9), a simplified version of the equation presented in [7]. It is computed by dividing the sum of the total investment costs, "CAPEX" , and the total operation and maintenance costs, "OPEX" , by the total energy discharged from the storage system over its lifespan.

$$LCOS = \frac{CAPEX + OPEX}{Batt_{Capacity} \times NrCycles} \tag{9}$$

The total energy discharged from the storage system is determined by the product of the expected number of cycles, NrCycles, over the storage system's lifetime, and its energy capacity $Batt_{Capacity}$.

3. Case Study

The commercial building, used as a case study for implementing the optimisation model, has an annual consumption of 7 GWh, resulting in considerable energy costs. A PV generation system with a rated power of 1200 kWp was installed to reduce costs, with an expected annual energy generation of approximately 1.6 GWh. While most of the PV-generated energy is consumed due to the building's high power demand, there are a few hours each day – mainly before the building opens - when the excess energy generation is wasted.

Although this small amount of excess energy alone does not justify investing in an electric storage system, allowing the storage system to charge directly from the electric grid when market electricity prices are low could make the investment worthwhile.

The electric storage system considered for this case study is an 800 kWh battery, with a C-Rate of 1 and an expected lifespan of 3000 cycles. The investment cost for the storage system was €270 per kWh of storage capacity. Operation and maintenance costs were not considered, resulting in a LCOS of €0.09 per kWh.

Fig. 2 presents a visual representation of the building's electric system, illustrating the various sources and energy flows available to meet its energy needs.

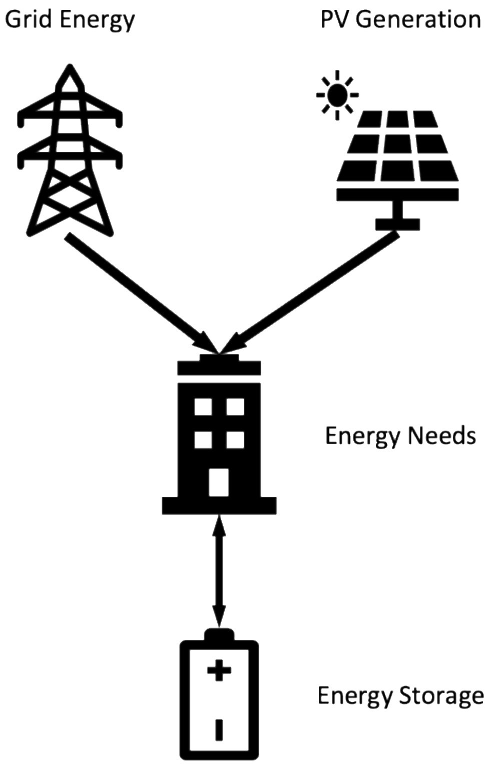

Fig. 2. Schematic illustration of the building's electric system.

4. Results and Discussion

The following results were obtained through an annual hourly simulation of the model using historical data from the case study building. The simulation covered the entire calendar year of 2022.

To assess the model's performance and evaluate the impact of using the LCOS as a penalty factor for extending battery lifespan, several key metrics were analysed, including energy costs, the percentage of excess PV generation fed into the grid for free, and the number of cycles performed by the storage system.

Therefore, Table I presents a summary of the three scenarios selected to illustrate the system's operation:

- Scenario 1: Energy demand and PV generation without any optimisation algorithm.
- Scenario 2: Energy demand and PV generation, including the battery operating with the optimisation algorithm but without LCOS penalisation.
- Scenario 3: Energy demand and PV generation, including the battery operating with the optimisation algorithm considering LCOS penalisation.

Fig. 3, Fig. 4 and Fig. 5 provide a detailed view of a selected week of the year, offering deeper insight into the system's operation in the previously presented scenarios.

Table I - Summary of the results obtained for the three selected scenarios.

Scenarios	Energy costs [€]	Excess PV generation [%]	Number of battery cycles
Reference Scenario	998,282.86	4.13	0
Second Scenario	969,665.41	1.10	459
Third Scenario	977,602.01	1.09	131

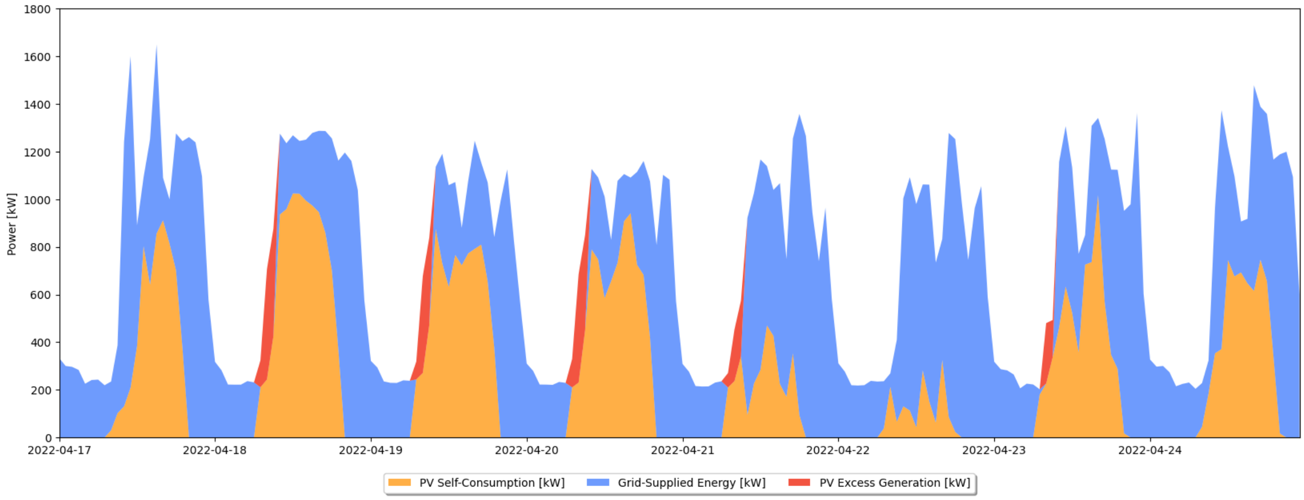

Fig. 3. Weekly system operation profile – scenario 1.

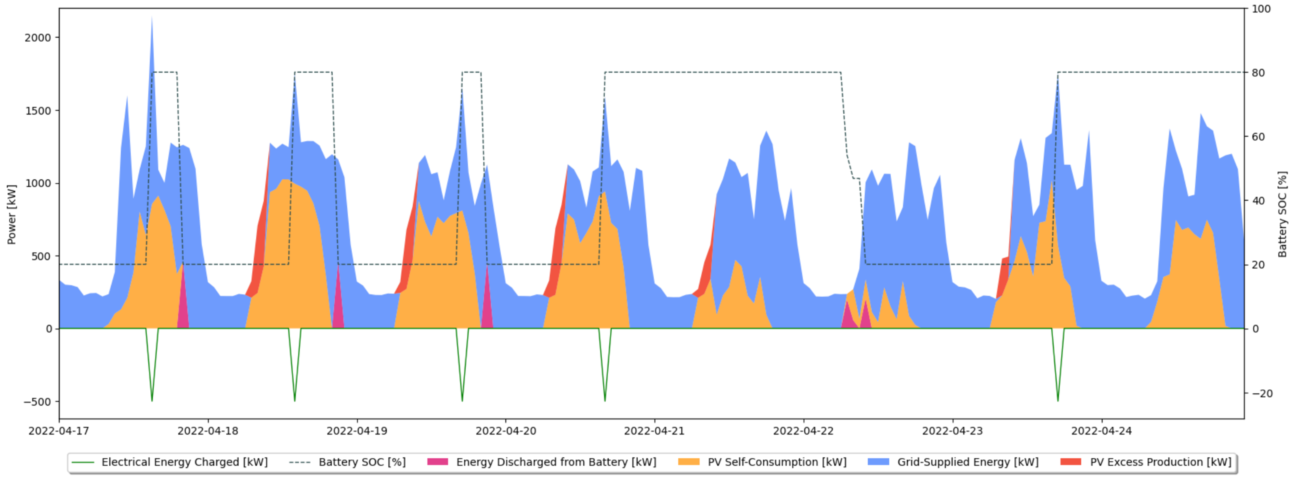

Fig. 4. Weekly system operation profile – scenario 2.

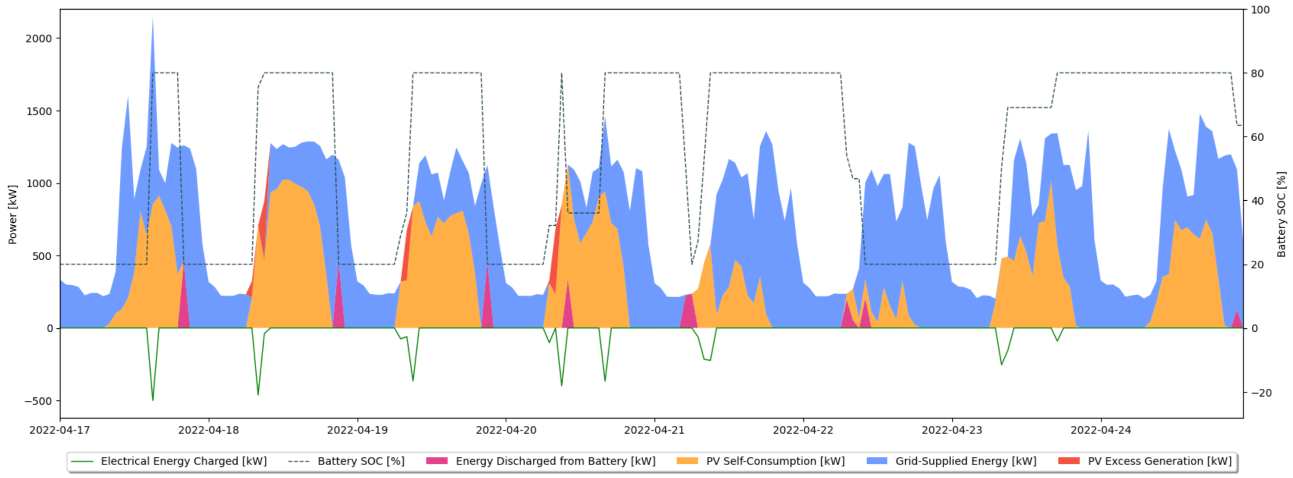

Fig. 5. Weekly system operation profile – scenario 3.

Fig. 3 illustrates the results for Scenario 1, showing that PV energy generation is insufficient to meet the building's energy demand on a typical day. However, there are a few hours of excess PV generation, which is wasted and fed into the grid for free, amounting to 4% of the total annual energy generated.

Fig. 4 presents the results for Scenario 2, where the algorithm optimises battery charging during periods of excess PV generation. This approach reduces wasted energy, lowering the total annual excess PV generation to 1.1%. At certain times, grid energy is also used to charge the storage system, as indicated by an increase in the SOC when no excess PV generation is available. The battery undergoes multiple charge and discharge cycles within a single day, resulting in a total of 459 full cycles performed throughout the year. The savings achieved under this scenario amounted to €29,000.

The LCOS penalisation was applied to address the high number of battery cycles performed, thereby extending its lifespan. Its impact on the optimal solution is evident in Fig. 5, which shows a significant reduction in the number of charging and discharging cycles. This outcome can be attributed to the fact that the savings previously achieved by charging from the grid were not substantial enough to justify the use of the storage system. As a result, the total number of full cycles performed was nearly 3.5 times lower than without the LCOS penalisation factor. Nevertheless, despite the considerable reduction in cycles, the system still achieved significant cost savings.

The high number of cycles performed over one year in Scenario 2 could impact the lifespan of the storage system, potentially making it an unviable investment. Considering an investment cost of €216,000 and an expected 3000 cycles for the storage system, a simple payback period analysis indicates that Scenario 3 would take 10.5 years to become profitable, while Scenario 2 would take 7.5 years. However, given the high number of cycles required to achieve the greater savings in Scenario 2, the battery would only last 6.5 years, which is shorter than the 7.5-year payback period. This means the storage system would need to be replaced before reaching profitability, making Scenario 2 financially unviable. In contrast, the storage system in Scenario 3 would theoretically last up to twenty years, well beyond its 10.5-year payback period.

Overall, it can be concluded that the LCOS penalisation factor effectively reduces the number of cycles performed by the storage system, which will undoubtedly extend the system's lifespan while still delivering significant cost savings.

5. Conclusion and Outlook

This paper presents a MILP-based optimisation algorithm to minimise energy costs in a large commercial building with PV generation and storage systems. By taking advantage of market electricity prices, the model maximises storage efficiency. Incorporating the LCOS penalisation factor improved performance, reducing battery cycles while maintaining significant cost savings and enhancing investment viability.

This optimisation algorithm is designed to enable broad application and deployment across all building typologies, regardless of size, delivering reliable cost reductions while preserving the storage system's lifespan.

Future work will include accounting for battery degradation over time. Additionally, the potential to sell excess PV generation to the grid could be explored. Another approach that may be followed is the optimal sizing of the PV generation and energy storage systems using the Net Present Value.

Acknowledgement

This research is co-financed by Component 5 – Capitalization and Business Innovation, integrated in the Resilience Dimension of the Recovery and Resilience Plan within the scope of the Recovery and Resilience Mechanism (MRR) of the European Union (EU), framed in the Next Generation EU, for the period 2021 - 2026, within project ATE, with reference 56.

References

[1] Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024 on the energy performance of buildings (recast) (Text with EEA relevance). 2024. Accessed: Jan. 31, 2025. Available: http://data.europa.eu/eli/dir/2024/1275/oj/eng

[2] 'MILP Optimized Management of Domestic PV-Battery Using Two Days-Ahead Forecasts | IEEE Journals & Magazine | IEEE Xplore'. Accessed: Jan. 13, 2025. [Online]. Available: https://ieeexplore.ieee.org/document/9732432

[3] R. Martins, P. Musilek, and H. C. Hesse, 'Optimization of photovoltaic power self-consumption using linear programming', in 2016 IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC), Jun. 2016, pp. 1–5. doi: 10.1109/EEEIC.2016.7555581.

[4] F. Lucchetta and A. Corsini, 'A Mixed-Integer Linear Programming approach for the Optimization of Residential PV-Battery Energy Storage System'.

[5] G. Warkozek, S. Ploix, F. Wurtz, M. Jacomino, and B. Delinchant, 'Problem Formulation And analysis for optimal energy management in multisources Systems: W effect', COMPEL: The International Journal for Computation and Mathematics in Electrical and Electronic Engineering, vol. 31, pp. 904–919, May 2012, doi: 10.1108/03321641211209799.

[6] 'Pyomo', Pyomo. Accessed: May 22, 2024. [Online]. Available: http://www.pyomo.org

[7] 'IBM ILOG CPLEX Optimization Studio'. Accessed: Feb. 21, 2025. Available: https://www.ibm.com/products/ilog-cplex-optimization-studio

[8] 'Additive tariffs in the electricity sector | IEEE Conference Publication | IEEE Xplore'. Accessed: Jan. 23, 2025. [Online]. Available: https://ieeexplore.ieee.org/document/1709499

[9] O. Schmidt, S. Melchior, A. Hawkes, and I. Staffell, 'Projecting the Future Levelized Cost of Electricity Storage Technologies', Joule, vol. 3, no. 1, pp. 81–100, Jan. 2019, doi: 10.1016/j.joule.2018.12.008.