B&H Electrical Engineering, Volume 20, Issue 1, 2026
ISSN:2566-3143, eISSN:2566-3151, DOI: 10.2478/bhee-2026-0011

**Original scientific paper**

*Submitted: May 5, 2025*

*Accepted: October 18, 2025*

# HYBRID RENEWABLE AND STORAGE SOLUTIONS FOR EFFICIENT PUBLIC BUILDING ENERGY MANAGEMENT

**Mia Lešić Aganović[1,5], Šejla Aganović-Hajdin[2], Jasna Hivzefendić[3], Tatjana Konjić[4], Lejla Vuić[2]**

**Abstract:** This paper presents a smart Energy Management System (EMS) for public buildings integrating photovoltaic (PV) generation and battery storage to enhance energy efficiency and reduce grid dependence. Using HOMER for system design and MATLAB/Simulink for control modelling, the EMS optimizes energy use, prioritizes solar and stored energy, and enables island or grid-connected operation as needed. Simulation results show improved energy efficiency, reliability, and cost savings while reducing carbon footprint. The proposed EMS offers a sustainable, scalable, and cost-effective solution for managing renewable energy variability in public infrastructure.

**Keywords:** hybrid renewable and storage solutions, renewable energy sources, energy management system

## INTRODUCTION

The growing global emphasis on sustainability and carbon footprint reduction has accelerated the adoption of renewable energy sources in various sectors. Public buildings, including hospitals, schools, and government offices, are among the largest energy consumers, necessitating efficient energy management strategies to reduce reliance on conventional power sources [1]. On-site generation offers two key benefits: the use of locally accessible renewable resources and the elimination of costs and inefficiencies associated with centralized transmission and distribution networks [2]. However, the intermittent nature of renewable energy, particularly solar power, presents challenges in ensuring a stable and reliable energy supply. Integrating renewables with battery storage and a smart EMS is an effective solution to improve energy efficiency and ensure uninterrupted operation [3, 4, 5].

Energy efficiency policies are fundamental aspects of corporate sustainability and responsible environmental practices. Expert energy management can lead to a reduction in energy costs and consumption. Nevertheless, many small and medium-sized enterprises (SMEs) lack specialized energy management expertise. Even energy-intensive businesses often lack long-term planning, resulting in ad hoc and inconsistent energy strategies. In such cases, energy use is frequently influenced by personal routines, values, and workplace habits rather than strategic considerations. Modern digital innovations offer new opportunities for improving energy management. These technologies enable detailed data collection, potentially transforming how buildings and SMEs control and optimize their energy use [6, 7].

The digitalization of EMS systems has the potential to revolutionize energy management in both public and private sectors. By providing access to critical energy data and facilitating the implementation of specialized energy management strategies, digitalization can significantly enhance the efficiency and sustainability of electrical networks and systems, benefiting both businesses and the environment. Early EMS primarily utilized direct load control architectures to regulate energy demand across multiple residential buildings [8]. More advanced systems now use stochastic optimization methods that consider seasonal load fluctuations, renewable generation, and cost minimization [9]. Within smart grids, demand-side management (DSM) allows consumers to adjust usage based on real-time pricing or incentives, supporting grid stability and energy savings [10, 11].

This paper presents the design and implementation of an EMS for a public building equipped with a rooftop photovoltaic (PV) system and battery storage. The EMS coordinates the energy supply from the PV system, battery, and main grid to optimize performance. The goal is to determine whether such systems can improve energy efficiency and occupant comfort in public buildings using advanced power electronics and intelligent control. The most important contributions of the proposed research are as follows:

- Development of an advanced EMS designed for public buildings that integrate photovoltaic systems with battery storage.

This paper was submitted to the Conference of the South-East European Regional Council of CIGRE (SEERC 2025), held in Sarajevo, Bosnia and Herzegovina, on June 4–5, 2025.

[1] *Elektroprenos BiH a.d. Banja Luka, OP Tuzla, Bosnia and Herzegovina*
[2] *International BURCH University, Bosnia and Herzegovina*
[3] *Sarajevo School of Science and Technology, Bosnia and Herzegovina*
[4] *Faculty of Electrical Engineering,University of Tuzla, Bosnia and Herzegovina*
[5] *Correspondence email: mia.lesic@fet.ba*

- Renewable energy intermittency is addressed while a solution to mitigate the variability of solar energy through battery storage and intelligent EMS algorithms is proposed.
- Integration of digital technologies in EMS highlights the role of digitalization in transforming energy management.

To present the research, the paper is organized into five sections. After the introductory section, the Energy Management System overview is presented in the first section. The applied methodology is presented in the second section, and a discussion of the results is given in Section 3. Concluding remarks and future directions are presented in the last section.

## 1. ENERGY MANAGEMENT AND HYBRID POWER SYSTEMS

In the late 1960s, the concept of a Supervisory Control and Data Acquisition (SCADA) framework was established, and by the 1970s, an EMS arrangement with a set of functions based on SCADA data was introduced [12]. Over the past 50 years, numerous capabilities have been added to EMS, and SCADA has undergone enhancements. An overarching software system known as an Energy Management System is employed to monitor the load and real-time operational status of the microgrid. The EMS concurrently manages various activities, including collecting and forecasting energy production, storing, and requesting data from Distributed Energy Resources (DER), Distributed Energy Storage (DES), and load information, while staying in communication with various users [13]. The EMS oversees not only short-term power balance but also long-term energy management. These criteria include the following:

1. Short-term (power balancing):
- The ability to maintain the power quality limitations of essential loads.
- The ability to transfer actual power among DERs to provide proper voltage and frequency regulation as well as load-following capabilities.
- The capacity to sustain real-time responsiveness and frequency or voltage restoration during power fluctuations.
2. Long-term (energy management):
- Each DER's needs or constraints, such as generation costs, maintenance costs, unit type, service life, and environmental conditions, are considered.
- The capacity to maintain a suitable power demand response as well as restore controlled (nonsensitive) loads that were not considered during a power outage.
- The ability to constantly maintain an acceptable amount of storage capacity that is appropriate for an ideal operating point of DER production, is determined through optimization procedures.

Every type of management system requires an effective control approach to achieve its intended objectives. An EMS is a diverse component-based energy management system employing two distinct control methods [14]:
- Centralized control from a central hub,
- Decentralized control.

Control mechanisms, whether centralized or decentralized, follow a straightforward hierarchical structure. This structure can be divided into three layers:
- Distribution Network Operator (DNO) and Market Operator (MO)
- Microgrid Central Controller (MGCC)
- Local controllers (LCs).

The centralized EMS features a single, high-performance central controller with a secure communication link for managing energy consumption. In this setup, the controller gathers data from all nodes to improve system performance and achieve optimal outcomes. This approach is particularly important in multimicrogrid systems, where multiple microgrids are connected to form a cohesive community. In such cases, a hierarchical EMS is implemented on top of a decentralized one.

The hierarchical EMS is structured into multiple control layers, each serving a distinct purpose. These typically include the supervisory, execution, and optimization control levels, usually arranged in two or three tiers. Importantly, there is no direct data exchange between adjacent levels. The EMS discussed in this paper follows the centralized model.

### 1.1. Energy management system in the public building

An EMS is designed to increase energy efficiency and reduce costs in buildings, including public institutions like schools, hospitals, and government offices. Compared with both hardware and software, the EMS collects and analyses energy data and implements control measures to optimize energy consumption and lower carbon emissions. The implementation process begins with an energy audit, followed by the development of an energy management plan. EMS can regulate various building systems, including lighting, air conditioning (HVAC), and other machinery, while integrating renewable energy sources such as solar and wind. Advanced EMS models incorporate Energy Exchange Platforms (EEPs) and Energy Storage Systems (EESSs) to optimize energy usage in smart microgrids, utilizing Mixed Integer Non-Linear Programming (MINLP) for cost-effective solutions.
In-home energy management (HEMS) and demand response (DR) tools optimize energy consumption through smart meters and AI-based load scheduling, incorporating neural networks and fuzzy logic. In grid-connected residential neighbourhoods, the EMS helps reduce energy costs while managing EVs, battery storage, and solar PV systems, with the centralized EMS proving more effective

than decentralized approaches. Ultimately, the EMS plays a crucial role in cost reduction, energy efficiency, and sustainability, demonstrating significant benefits across various applications.

EMS plays a vital role in energy policies aimed at reducing energy consumption and improving efficiency in public buildings, such as hospitals, schools, and government offices. These buildings have high energy demands, leading to increased carbon emissions and climate change concerns. EMS helps monitor and optimize energy usage, identify inefficiencies, and integrate energy-saving technologies like smart meters and LED lighting. The key benefits include the following [15]:

- Lower energy consumption (potential reduction of up to 30%),
- Cost savings, allowing funds to be redirected to building maintenance,
- Improved indoor air quality, reducing health risks,
- Better building performance and occupant comfort,
- Reduced carbon emissions, supporting sustainability goals.

## 1.2. Energy management system organization

An effective EMS is essential for optimizing energy consumption and promoting energy efficiency in public buildings. The EMS comprises a combination of hardware and software elements that function seamlessly together. Hardware components include energy meters for real-time energy monitoring, sensors for gathering environmental and occupancy data, and actuators for managing energy-consuming equipment. These components are interconnected through a communication infrastructure that utilizes both wired and wireless technologies. The EMS utilizes data gathering and control software to ensure smooth integration of hardware components, along with energy management software for data analysis, visualization, and optimization. Additionally, analytics and optimization software are employed to identify opportunities for energy savings and enhance overall efficiency. An EMS enables seamless integration with renewable energy sources, such as solar power plants, through protocols such as Modbus and BACnet. This allows for real-time monitoring and management of energy generation and consumption.

EMS provides user-friendly interfaces for monitoring, controlling, and reporting energy use, along with alarms and notifications to enhance communication. In public buildings, the EMS helps optimize energy consumption, maximize resource usage, and promote sustainability by integrating rooftop PV systems and managing the bidirectional energy flow between the grid and storage systems.

The key functions of the EMS in renewable energy integration include [16, 17]:

- Excess solar energy is stored in batteries for later use.
- Grid-connected operations such as net metering or selling surplus energy.
- Energy use can be optimized through load shifting, setpoint adjustments, and peak demand reduction.

By adopting an EMS with renewable integration, public buildings can reduce energy costs, increase efficiency, and the lower carbon footprint, contributing to a more sustainable future.

## 1.3. Hybrid power systems

Hybrid electrical networks combine various energy sources and storage systems to enhance efficiency, reliability, and sustainability. Advanced power electronics and control systems enable seamless integration of renewable and conventional energy sources.

Hybrid Energy Systems (HESs) were originally combined with diesel generators and battery storage (BESSs) but have evolved to fully renewable setups, including PV, wind, fuel cells, and supercapacitors. These systems range from small off-grid solutions to large megawatt-scale, grid-connected configurations, with power electronics converters tailored to specific applications. A key application of HESs is in microgrids, which integrate renewable energy, batteries, and backup generators to create self-sufficient, low-voltage networks. These can function independently or alongside the main grid, making them ideal for remote locations with limited grid access. Hybrid systems also offer cost-effective, eco-friendly solutions for companies, public buildings, and residential communities, helping to reduce electricity costs while promoting renewable energy adoption. Figure 1. illustrates an exemplary hybrid energy system, highlighting the diverse functions of power electronics within this integrated framework. The following describes the basic components of the hybrid system chosen as the optimal system for this paper.

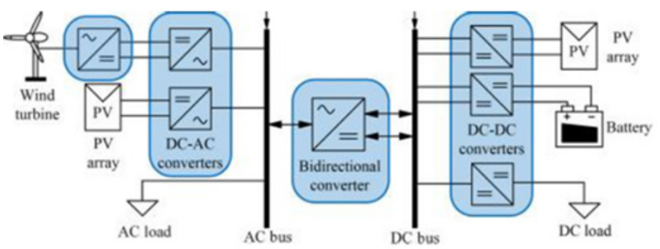

Figure 1: Hybrid Energy System and Power Electronics Roles [18]

## 2. APPLIED METHODOLOGY

The applied methodology is based on input data used to calculate the building's load profile. By utilizing the load profile, HOMER software is employed to design an optimal hybrid power system for the proposed building, to achieve independence from the main grid most of the time. The goal of this independence is to reduce electricity costs and demonstrate how hybrid systems, in conjunction with the EMS, can contribute to cost savings and enhance comfort within the building. The proposed system is then developed in the Simulink software, in which the EMS algorithm, implemented through the MATLAB function, is applied to obtain valuable results.

The method and algorithm developed in this paper are applied to a specific public building. The chosen public building is utilized an administrative building and receives an average of approximately 100 visitors daily, while the number of employees is approximately 50. The space is configured with approximately 15 office rooms, two halls, and sanitary rooms, covering an area of approximately 1.033,25 m2. It consists of a single floor and is constructed with three rectangular shapes of varying dimensions. The total roof area is approximately 700 m2, with the main orientation from west to east. The building's location is illustrated in Figure 2.

The decision to select this building was influenced by two key factors: the absence of space constraints for shading the PV power plant and the availability of ample land nearby, which could be utilized for storage facilities, additional PV cells, or even electric car parking. A brief analysis indicates that the area boasts excellent solar potential. The building's accessibility further facilitates the installation of PV cells and the potential integration of the entire system. The decision to conduct the study on this facility was driven by the favourable presence of all the necessary factors.

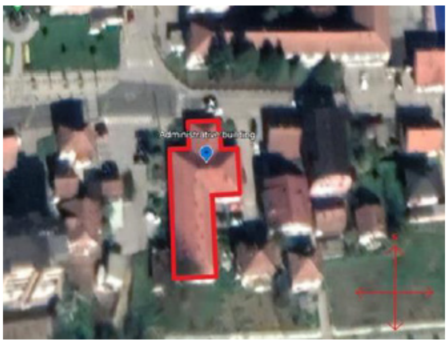


Figure 2: Location of the public building

## 2.1. HOMER input data

A public building is considered a facility for the implementation of an EMS system. The entire system consists of an AC load connected to a PV power plant installed on the roof, along with all accompanying electronics, a battery, and a switch to the main grid. The consumer provided 15-minute readings of energy consumption for 2021. These data, in the hourly approximation, are input into the HOMER Software. Based on the energy consumption and components added to the network, HOMER calculates the best solution composed of the components needed for the proposed system.

The solar irradiation statistics for PV power generation were obtained after the location in the software was selected. The costs of each component, along with their replacement and operating and maintenance (O&M) expenses, were also included in the model to address the economic aspects of the research. The analysis was conducted over a 25-year period. The proposed design comprises an electrical load, a main grid, a PV power plant, a battery, and a DC/AC converter. The design of the network in HOMER is illustrated in Figure 3, and the system design is presented in Table 1. Table 1. includes details on the installed capacities of each system component, the energy required for storage technology the dispatch method, as well as the names of the components. The cycle charging strategy is a dispatch strategy in which, whenever a generator is needed, it operates at full capacity, while surplus power charges the battery bank.

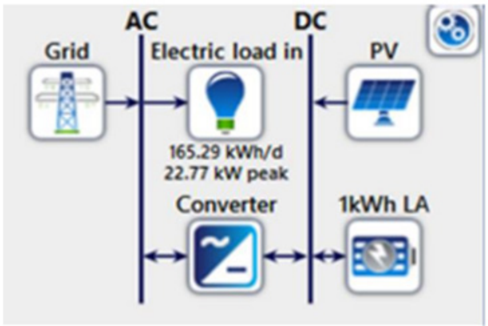


Figure 3: System description (left) and system design (right) in HOMER

Table I: System architecture in HOMER

| Component | Name | Size | Unit |
|---|---|---|---|
| PV | Generic flat plate PV | 59,0 | kW |
| Storage | Generic 1 kWh Lead Acid | 1 | Strings |
| System converter | System Converter | 33,3 | kW |
| Main grid | Grid | 1,00 | quantity |
| Dispatch strategy | HOMER Cycle charging | | |

Solar radiation data were extracted from a global library, taking the specific location into consideration, and the daily characteristics are illustrated in Figure 4.a. The daily radiation varies from 1.15 kWh/m2/day to 5.83 kWh/m2/day, and clearness index ranges from 0,371 to 0,523. The average monthly values of temperature, presented in degrees Celsius, are shown in Figure 4.b. The temperature ranged from -1,42 °C (January) to 19,97 °C (August). The annual average temperature is 9,06 °C.

ISSN:2566-3143, eISSN:2566-3151, DOI: 10.2478/bhee-2026-0011

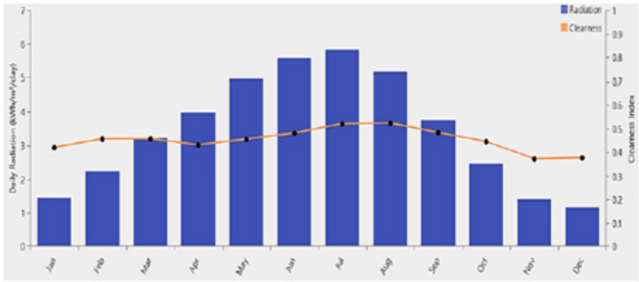


Figure 4.a: Solar radiation data and clearness index

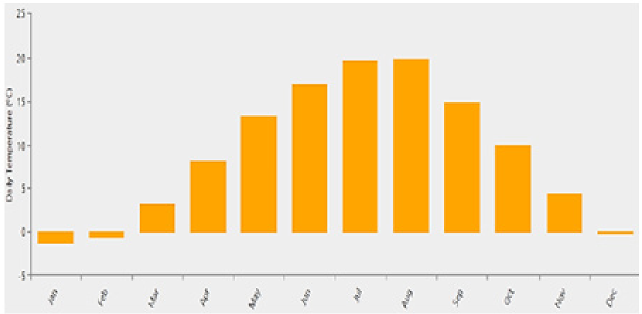


Figure 4.b: Average monthly values of temperature

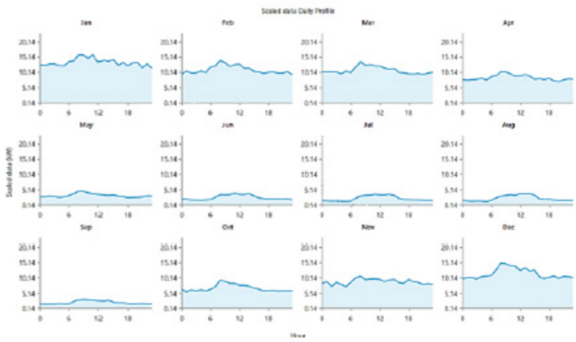

Figure 5.a: Average daily load profile on an annual basis

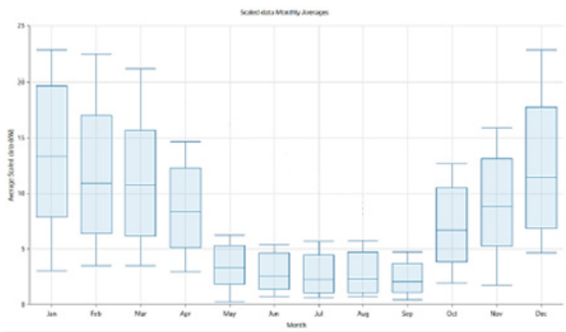

Figure 5.b: Seasonal load profile

The data provided by the Public Electric Utility were used to create a load profile for a building in 15-minute intervals for one year (2021), and it was implemented in the HOMER software. The scaled peak load of this load profile is 22,77 kW, and the average load is 165,29 kWh/day. The real load amounts, on average, to 40,39 kW with a peak in winter of 133,53 kW, as shown in Figure 5. (daily (a) and seasonal (b) load profiles). The daily load profile represents a typical day in January, derived from the yearly load data. The highest energy consumption occurs between 8 AM and 3 PM, corresponding to the working hours of the staff in the building. The seasonal load profile reveals reduced electrical consumption from May to September, which corresponds to the vacation period.

The load data are input manually on an hourly basis for each month. The PV power plant is set to Generic flat plate PV, with the aim that the HOMER Optimizer provides the best possible solution for this system. The input data include the price of the solar plant per 1 kW in the local currency. According to market research, the average price entered is 1,250.00 BAM, both for installation and replacement. The O&M costs are set at 20 BAM per 1 kW of installed power. Instead of defined battery types, a set of generic battery Lead Acid type of 1 kWh is used to obtain the best possible solutions for the system. The capital cost for one battery is 450 BAM, as are the replacement costs, whereas 10 BAM are set for O&M. The converter is also a generic system converter, with a cost of 300 BAM per 1 kW of converter capacity. The O&M costs are set to 20.00 BAM. The main grid is set with simple rate calculations, with a grid power price of 0.2 BAM per 1 kW of purchased energy. The controller is a type of HOMER Cycle Charging. The cycle charging strategy is a dispatch approach in which a generator, once activated to meet the primary load demand, operates at its full rated capacity. Any excess energy generated beyond the immediate load requirement is directed toward lower-priority objectives, such as supplying deferrable loads, charging the battery storage system, or powering an electrolyser. In this context, the surplus energy is used specifically to charge the battery bank. The capital costs of the controller are set at 700 BAM, as well as replacement costs, while operation and maintenance costs are 20 BAM. However, this cost increases the total cost to 1,053.87 BAM if it is taken into consideration.

## 2.2. MATLAB input data

In this section, the system modelled in the Simulink software is presented. The system proposed from the HOMER software was implemented in Simulink, and then the EMS code was programmed to control and manage the system as defined at the beginning. Simulink system schematics are shown in Figure 6.

The PV power plant has a power of 59 kW, whereas the AC load has a power of 40.39 kW. PV production is dependent on solar irradiance, which ranges from 1.15 kWh/m2/day to 5.83 kWh/m2/day. The storage capacity is used only to cover the load, and the battery is charged only if the difference between the total production of the PV and the total load is positive. If the difference is negative, the battery will provide energy from its capacity (if available) until the sign of observed difference is changed. Otherwise, the battery will wait empty for the difference to become greater than zero again. If the battery is fully charged, and the difference is still a positive value, all excess power can be sold to the grid, but in this case, it is not considered. The batteries are used mainly to supply demand that cannot be met by renewables or to store excess energy.

The MATLAB code implements the explained strategy and is used to obtain the battery characteristics. Importantly, in the HOMER analysis, an analysis of charging and discharging the battery while the system is on the grid could not be obtained. The main reason for this lies in the fact that the grid is a much larger source than the PV power plant is, so HOMER optimizes for the best possible and easiest solution, which, in this case, is without a battery to reduce costs. Therefore, any lack of energy is defined to be automatically compensated from the grid, and vice versa. Therefore, two systems were considered in HOMER, with and without the grid, to find out the size of the needed battery in HOMER. In Simulink, control of the system is possible, so it was possible to add a charging/discharging controller in this simulation, where it has been charging from the PV system and discharging from the AC load.

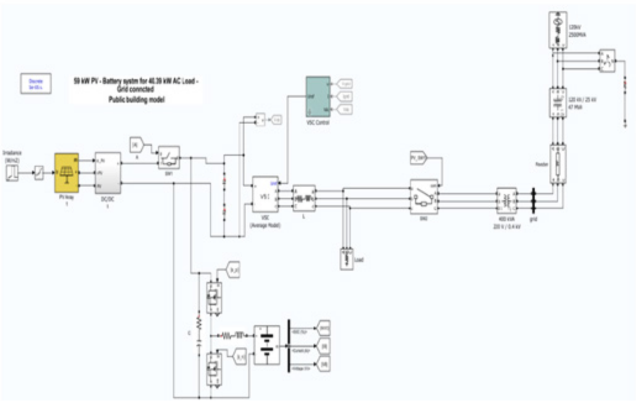

Figure 6: Simulink system schematics

## 2.3. EMS algorithm and strategy

The control of the system is mostly based on power control. The main control of the system is performed via the powers of the PV system (Ppv), load (Pload), and battery state of charge (SOC), which represent the inputs of the algorithm. The system is modelled such that the PV system supplies the load whenever enough energy is produced, regardless of whether the main grid is connected to the system or not. If the power of the PV system is equal to or greater than the power of the load, the system will be supplied from the PV plant. If the difference between Ppv and Pload is positive, and the SOC is less than or equal to 80%, the plant will also supply the battery with surplus produced energy. However, if there is not enough energy produced from the PV, the system will observe whether there is enough energy in the battery, and if the SOC is greater than or equal to 40%. If yes, the load will be supplied by the battery; otherwise, the load will be supplied by the main grid. The new required power will be the difference between Pload and Ppv. With the implementation of the EMS, the control of the system will be automated. In that way, the supply of the load will be very efficient, leading to cuts in costs for the energy purchased from the grid as well as savings in energy consumption. The implementation of this system in Simulink is performed through the MATLAB function, as shown in Figure 7.

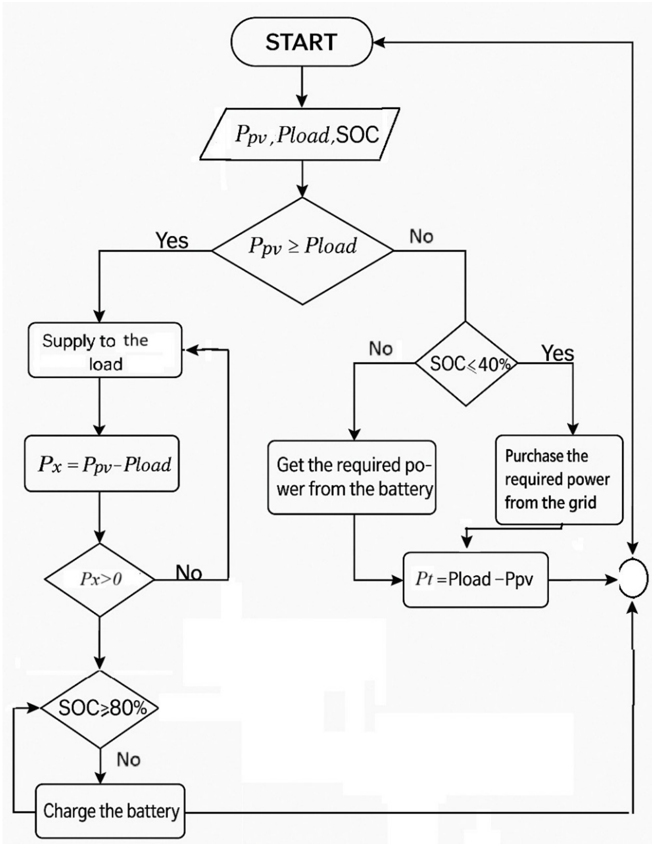


Figure 7: EMS algorithm

## 3. RESULTS AND DISCUSSION

After all the system characteristics, such as the expected system components, electrical and thermal loads, current equipment prices, and possible installed capacities, are entered, HOMER performs the optimization calculations to find the most cost-effective solution that satisfies all the system requirements. The results revealed that the PV power plant, grid, battery, and converter form the optimum design, considering the economic and technical factors. The net present cost (NPC) summary is shown in Table 2. All the prices for each of the components are presented separately. Starting with the initial capital, the operating costs, replacement costs, salvage costs, and resources are also considered, and the final NPC is 117.699,10 BAM. The most expensive component is the PV system, which requires the highest investment, with capital investments of 58.970,93 BAM and total

ISSN:2566-3143, eISSN:2566-3151, DOI: 10.2478/bhee-2026-0011

costs of 79.839,12 BAM. NPC presented in Table 2. presents the cost of a system and its components over 25 years. The proposed system has a return on investment (ROI) of 9,0%, an internal rate of return (IRR) of 12,5%, a simple payback of 7,26 years, and a discounted payback of 8,26 years, according to the HOMER analysis. Based on these data, the system has a positive return on investment, and it is proposed to be implemented.

The production summary from the system proposed by the HOMER software is shown in Table 3. The total generation is distinguished between the main grid and PV generation, but in the end, there is a greater PV contribution to the total electricity production. A graphical representation of the monthly energy production contribution is shown in Figure 8. The total consumption in HOMER is shared between the AC Primary Load, DC Primary Load, and Deferrable Load. The main load in this system is AC Primary load, and the other two do not affect the consumption. When the total production and consumption are compared, there is more production. The battery will store all the possible energy that fits its capacity, and the rest of it can be returned (sold) to the network. The energy that is defined as the energy sold to the grid will eventually be defined in MATLAB/Simulink as the energy stored in the battery.

Table II: Net present costs summary

| Name | Capital (BAM) | Operating (BAM) | Replace-ment (BAM) | Salvage (BAM) |
|---|---|---|---|---|
| Generic 1 kWh Lead Acid | 4.500,00 | 1.769,36 | 5.956,89 | -1.112,55 |
| **Total (BAM)** | | | | **11.113,70** |
| Generic flat rate PV | 58.970,93 | 20.868,19 | 0,00 | 0,00 |
| **Total (BAM)** | | | | **79.839,12** |
| Grid | 0,00 | 36,14 | 0,00 | 0,00 |
| **Total (BAM)** | | | | **36.14** |
| System converter | 10.003,40 | 34.473,38 | 6.555,88 | -1.648,79 |
| **Total (BAM)** | | | | **26.710,18** |
| System | 73.474,33 | 34.473,37 | 12.512,77 | -2.761,34 |
| **Total (BAM)** | | | | **117.699,13** |

Table III: Production summary

| Component | Production (kWh/year) | Percent (%) |
|---|---|---|
| Generic flat rate PV | 67.790 | 63,7 |
| Grid purchase | 38.612 | 36,3 |
| Total | 106.402 | 100 |

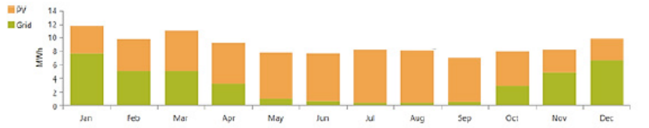


Figure 8. Electrical power generation

The assumed price for electrical energy is 0,2 KM. If it is not considered that the energy is produced from RESs, and if that value is multiplied by the value of excess electricity that can be sold to the public electric utility, the obtained amount of at least 859 KM/year can be used to decrease the annualized costs. In 25 years, the profit will be approximately 21.475 KM.

For the proposed PV system with an installed capacity of 59,0 kW, the total electrical production of 67.790 kWh/year, which is 63,7% of the total system production. The PV penetration rate is 112%, and the calculated hours of operation are 4.392 hrs/year. There were limitations in the HOMER software, so it could not propose a system that would operate both with the grid and the battery. Therefore, the second system was designed, without a grid with the same other components and their characteristics, as in the system with the grid, where the focus was on the battery. The input energy is 38.602 kWh/year, as the energy that is in the first system is defined as "grid sales," whereas the output energy is 35.092 kWh/year, and the energy flow loss is 4.295 kWh/year. The storage system consists of 109 batteries, connected in parallel strings, and is of the generic 1 kWh Lead Acid type. The battery has autonomy for 196 hours. The nominal capacity is 1.687 kWh, which is the value obtained after the HOMER analysis, and usable nominal capacity is 1,012 kWh. Annual throughput is 36.880 kWh/year, while the Lifetime Throughput is 568.842 kWh. The entire quantity of energy that passes through the storage bank in a year is referred to as battery throughput. The battery will require replacement because its expected life is 15,4 years. For the system converter energy flow losses are minimal for estimated hours of operation. The main grid will deliver 38.612 kWh/year of electrical energy, which is 36,3% of the total purchased energy according to HOMER.

In 2021, the real electrical energy demand of the objective building was 356.783,93 kWh/year, which multiplied by the price of electrical energy, resulted in a cost of 71.356,786 BAM/year. With this analysis, the electrical energy demand is quite large for a building of this size, so some measures of energy efficiency must be taken into consideration. Therefore, a system in which electrical energy demand will be supplied from one's own production to minimize energy purchases from the grid and to avoid unnecessary costs is proposed. Additionally, there is excess electrical energy of 4.295 kWh/year which can be sold back to the utility grid. The source of that excess electricity is a renewable energy resource, the sun, where the price for such energy amounts to 0,54 KM/kWh. Therefore, if the PV energy was sold to the grid, the profit would be 2.319,3 KM/year. Low pollutant emissions, a dependable and affordable power supply, ease of maintenance, and high penetration of renewable energy sources are further benefits of this system arrangement.

The model proposed by the HOMER software and algorithm were created in Simulink/MATLAB software. Two operation modes were considered: grid-connected mode and island mode, with a focus on the total generation and demand and power flow through the system. The PV power plant and/or battery storage will supply all electrical energy to the AC load until PV generation and stored battery energy become insufficient. The system will have autonomy, and during the day hours, it will be supplied with energy by the PV power plant, and a surplus of produced energy will charge the battery, whereas during the night hours, the AC load will use electrical energy from the battery, if available. However, when there is not enough PV production that can supply the load or enough energy stored in the battery, from which the load could take energy, the system will have to operate in Grid-connected mode. The switches between the grid and the AC load will be then closed, and the AC load will be entirely supplied with the electrical energy from the main grid. The power flow is controlled by the EMS code. The EMS is organized such that the switches in the system are controlled, which determines whether the system works in island or grid-connected mode.

To gather the results from the Simulink mode, a Control panel is created, which shows the state of the network conditioned by the different cases in the network, as shown in Figure 9. The EMS Algorithm is implemented in the Simulink network, which is also shown in Figure 9.

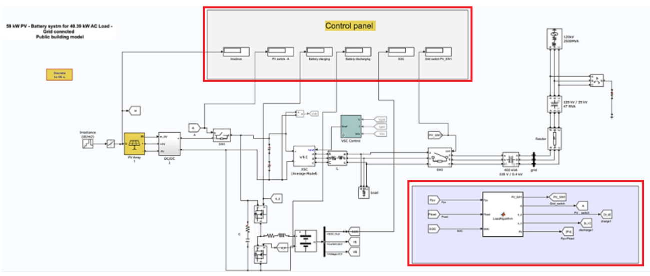


Figure 9. Virtual EMS Design Platform

Several cases are studied: the time of the night, noon time, noon time with battery backup and noon time with no surplus of produced energy. The results are presented in Table 4. The first shows the grid-connected mode of the network, where there is no PV production and where the SOC of the battery is under the minimum required to supply the load, which can be categorized as the nighttime. The second case represents the case in which PV production is almost at its peak, and there is a surplus of energy. When there is a surplus of produced energy and the SOC of the battery is less than 80%, the battery is charging. The third case occurs at noon (midday), when the battery is fully charged. Therefore, the load is supplied with energy from the battery until it discharges to its minimum state of charge. The fourth case shows how the network behaves when there is production from the PV but is only enough to satisfy the load demand. In this case, the system works in island mode, but the battery is not charging or discharging, while there is no surplus energy produced.

The simulation results align closely with the findings in [19], where an EMS was deployed in educational buildings, and [20], which explored the codesign of an EMS in a public building setting. Both studies underscore the potential of integrating solar PV and battery storage to improve energy efficiency and reduce operational costs in public buildings. Comparing the results of the simulation given in this paper with practical findings provides valuable insights into the applicability and potential real-world performance of our proposed EMS model. In [21] a MILP-based Model Predictive Control strategy for an EMS in a residential building was implemented, and real-world deployment validated the efficacy of model-based predictive algorithms for optimizing energy flows and reducing grid dependency. While the EMS proposed in this paper does not incorporate predictive control, the simulation logic and battery-PV prioritization strategy align well with the energy efficiency targets demonstrated in the given studies.

Table IV: Virtual EMS Design Platform – Results of the simulation

| | | | | |
|---|---|---|---|---|
| **Case / Setup** | **Nighttime – Grid supplied** | **Midday – PV Surplus available** | **Midday – Load supplied by battery** | **Midday – No battery action** |
| Irradiance (kWh/m$^2$) | 0 | 1000 (peak) | 0 | 788,35 |
| Production from PV | NO | HIGH | NO | Load power |
| Battery SOC | 20 % | 20 % | 100 % | No charge or dis-charge |
| Result | Grid sup-plies the load | PV sup-plies the load and charges the battery | Battery supplies the load | Island mode |

## 4. CONCLUSION

The utilization of DER offers numerous advantages, including increased economic benefits, reduced pollution emissions, and the sustainability of the energy supply. Another application for a microgrid is supplying energy to a unique building, especially if it can harness desirable renewable energy sources. In terms of component costs and sizes, the HOMER software provides the optimal system design. The best system design resulted from considering various technologies with different potential sizes. The proposed system is designed via Simulink software, which incorporates advanced power electronics. The EMS code is implemented on the basis of an algorithm that defines the logic used during system programming. The primary concept is to design a smart power system capable of operating independently of human intervention. The main input data required to generate the EMS code include the PV power output, average AC load demand, and battery state of charge. According to the obtained results, the system can operate fully independently if the input data for the EMS code are available. The primary system control is performed using advanced power electronics, particularly switches and the bidirectional charge controller of the battery. The system operates in island mode unless there is sufficient electrical energy production from the PV power plant or adequate energy stored in the battery. If these two criteria are not met, the system operates in grid-connected mode. The entire network can be controlled through the SCADA system or another user-friendly interface. In this paper, the results are presented via a control panel, which is assumed to be used as the main control panel of the central PC in the control room.

The proposed EMS architecture is capable of autonomous operation without human intervention, making it a reliable solution for public buildings with fixed operational hours. By leveraging solar energy during daylight and battery storage during off-hours, the system significantly reduces electricity purchases from the grid. Additionally, it enables surplus renewable energy to be stored or sold, further improving cost-effectiveness and sustainability. The use of microgrid technology allows the building to function in island mode, drawing power from the stored energy in the battery or PV power plant, if necessary. A virtual control panel developed in Simulink allows users to monitor and manage the system in real time, simulating the experience of a centralized control interface such as SCADA. This feature enhances system usability and demonstrates the potential for real-world deployment.

The scalability of the system stems from the parameterized EMS algorithm, which allows it to adapt to varying load demands, PV capacities, and battery sizes. For example, increasing the number of PV panels or battery units can be accommodated by adjusting a few input parameters without modifying the core control logic. The replicability of this system is further supported by its use of widely available simulation platforms and commercially available hardware components. Public buildings with rooftop solar potential, especially in regions with similar irradiance levels and building energy profiles (e.g., across southeastern Europe), can adopt this EMS strategy with minimal customization. Moreover, the decentralized control principles embedded in the system allow it to function both as a standalone solution and as a component of a larger smart microgrid network. With increasing policy focus on local energy generation and resilience, this EMS model offers a practical pathway for municipalities and facility managers to transition towards low-carbon, self-reliant energy infrastructures.

The proposed EMS framework can be further enhanced through the integration of advanced technologies such as artificial intelligence and machine learning. Predictive analytics can improve energy scheduling by forecasting load demand based on weather patterns, historical usage, and occupancy. Self-learning algorithms can continuously optimize system performance in real time. Future EMS implementations can incorporate artificial intelligence and machine learning algorithms to enhance energy scheduling, consumption forecasting, and system adaptation. By leveraging predictive analytics, the EMS can anticipate energy demand fluctuations based on historical data, weather conditions, and occupancy patterns, allowing for optimal energy dispatch and storage management. An intelligent EMS should dynamically adjust control parameters to maximize efficiency under varying operational conditions. These advancements ensure that public buildings operate efficiently, reduce their carbon footprint, and maximize the utilization of renewable energy sources in a rapidly evolving energy landscape.

## REFERENCES

[1] M. S. Bakare, A. Abdulkarim, A. N. Shuaibu, M. M. Muhamad "Energy management controllers: strategies, coordination, and applications", Energy Informatics, 7(1), 57, Chicago, USA, 2024.

[2] K. H. M Azmi, N. A. M. Radzi, N. A. Azhar, F. S. Samidi, I. T. Zulkifli, A. M. Zainal "Active electric distribution network: applications, challenges, and opportunities", IEEE Access, 10, 2022.

[3] M. A. A.Mazlan, N. Y.Dahlan "Energy management strategies of solar rooftop campus with battery energy storage system (BESS) And EV supply equipment (EVSE) using HOMER", IOP Conference Series: Earth and Environmental Science, Vol. 1281, No. 1, p. 012022, IOP Publishing, 2022.

[4] M. S. Javadi, A. E.Nezhad, P. H.Nardelli, M. Gough, M. Lotfi, S. Santos, J. P. Catalão "Self-scheduling model for home energy management systems considering the end-users discomfort index within price-based demand response programs", Sustainable Cities and Society, 68, 102792, 2021.

[5] Z. M. Ali, M. Calasan, S. H. A. Aleem, F. Jurado, F. H. Gandoman "Applications of energy storage systems in enhancing energy management and access in microgrids: A review", Energies, 16(16), 5930, 2023.
[6] Z. Yousaf, M. Radulescu, C. I. Sinisi, L. Serbanescu, L. M. Păunescu "Towards sustainable digital innovation of SMEs from the developing countries in the context of the digital economy and frugal environment", Sustainability, 13(10), 5715, 2023.
[7] V. Scuotto, E. Arrigo, E. Candelo, M. Nicotra "Ambidextrous innovation orientation effected by the digital transformation", Bus. Process. Manag, 2019.
[8] A. R. Singh et al "State-of-the-art review on energy management and control of networked microgrids", Sustain Energy Technol Assess, 2023.
[9] Y. Dagdougui, A. Ouammi, R. Benchrifa "Energy management-based predictive controller for a smart building powered by renewable energy", Sustainability 12(10):4264, 2020.
[10] M. S. Bakare et al "A comprehensive overview on demand side energy management towards smart grids: challenges, solutions, and future direction", Energy Inform 6(1):4, 2024.
[11] H. M. Hussain et al "An efficient demand side management system with a new optimized home energy management controller in smart grid", Energies 11(1):190, 2018.
[12] N. TIB „Supervisory control and data acquisition (SCADA) systems", National Communications System, TIB, Tech. Rep. 2004.
[13] M. Kermani, B. Adelmanesh, E. Shirdare, C. A. Sima, D. L. Carnì, L. Martirano „Intelligent energy management based on SCADA system in a real Microgrid for smart building applications", Renewable Energy, 171, 1115-1127, 2021.
[14] A. Kudzin, S. Takayama, A. Ishigame „Energy Management Systems (EMS) for a Decentralized Grid: A Review and Analysis of the Generation and Control Methods Impact on EMS Type and Topology", IET Renewable Power Generation, 19(1), e70008, 2025.
[15] D. Lee, C. C. Cheng „Energy savings by energy management systems: A review", Renewable and Sustainable Energy Reviews, 56, 760-777, 2016.
[16] S. Basnet, K. Deschinkel, L. Le Moyne, M. C. Péra, „A review on recent standalone and grid integrated hybrid renewable energy systems: System optimization and energy management strategies", Renewable Energy Focus, 46, 103-125, 2023.
[17] C. P. Ohanu, S. A. Rufai, U. C. Oluchi „A comprehensive review of recent developments in smart grid through renewable energy resources integration", Heliyon, 10 3, 2024.
[18] G. Konstantinou, B. Hredzak „Power electronics for hybrid energy systems", Hybrid Renewable Energy Systems and Microgrids, 2021.
[19] J. Mestelic, L. Emery, D. Previdoli, L. Papilloud, F. Cimmino, S. Genoud „Energy management in a public building: A case study co-designing the building energy management system", International Conference on Engineering, Technology and Innovation (ICE/ITMC), 2017.
[20] X. Binli „Xiao, Binli. "Maximizing Energy Cost Savings: A MILP-based Energy Management System: in Educational Buildings: Case Study in Stockholm", 2024.
[21] I. L. R. Gomes, M. G. Ruano, A. E. Ruano „MILP-based model predictive control for home energy management systems: A real case study in Algarve, Portugal", Energy and building 281, 2023.

## BIOGRAPHY

**Mia Lešić Aganović** is a Lead Engineer for Planning, Development, and Investment at the Transmission System Operator Elektroprenos-Elektroprijenos BiH, and a Senior Teaching Assistant at the Faculty of Electrical Engineering, University of Tuzla. She earned her Master's degree in Electrical Engineering – Electrical Power Networks and Systems from the University of Tuzla in 2016 and is currently pursuing a Ph.D. at the same institution. She is the author of several academic publications, and her research interests include power system analysis, renewable energy integration, and smart grid technologies.

**Šejla Aganović-Hajdin** received her M.Sc. degree in 2024 at the Department of Electrical and Electronics Engineering – Smart Grid Technologies, Faculty of Engineering, Natural and Medical Sciences, International Burch University in Sarajevo. Her professional experience so far has included the design of photovoltaic (PV) power plants, conducting energy audits, and preparing main electrical design projects for the rehabilitation of old public buildings. Her research interests include renewable energy sources, energy management systems design, smart buildings design, and green energy transitions.

**Jasna Hivzefendić** received the Ph.D. degree in Electrical Engineering from the University of Tuzla, BiH, in 2014. She is currently a full professor at the Department of Computer Science, at Sarajevo School of Science and Technology. Her research interests include integration of RES into the electrical grid and electrical distribution system planning and optimization. She is a member of IEEE, IEEE PES and BH K CIGRE."

**Tatjana Konjić** received her Ph.D. degree in Electrical Engineering from the Faculty of Electrical Engineering at the University of Tuzla, Bosnia and Herzegovina, in 2003. Since 1990, she has been affiliated with the Faculty of Electrical Engineering at the University of Tuzla, where she is currently a full professor. She has led international projects and has served as a chairperson or member of scientific committees at international conferences, as well as a reviewer for international journals. She is

ISSN:2566-3143, eISSN:2566-3151, DOI: 10.2478/bhee-2026-0011

the author of a number of academic publications. Her research and teaching interests include the application of artificial intelligence to power systems, power system analysis, load forecasting, distributed generation, and smart grids. She is a member of IEEE, IEEE PES, IEEE CIS, International CIGRE, and BH K CIGRE.

**Lejla Vuić** received her PhD in Electrical and Electronics Engineering from International Burch University in 2023, where she currently works as an Assistant Professor in the field of power engineering. She has participated in several national and international projects and is the author of multiple academic publications. Her research focuses on the integration of renewable energy sources and energy storage systems into microgrids.