

National University of Science and Technology
POLITEHNICA Bucharest
Doctoral School of the Faculty of Power Engineering

Summary of the Doctoral Thesis:

Electrical Power Supply for a Mobile Communication Unit

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Summary

This thesis presents a study of the operational scenarios of a resilient, autonomous microgrid composed primarily of a Diesel generator set, a Battery Energy Storage System (BESS), and a hydrogen-powered fuel cell, all coordinated by an automation system based on a SIEMENS 12XX DC/DC/RLY PLC.

The main objective of the research is to evaluate the reliability, efficiency, and continuity of power supply to critical loads within the microgrid, particularly in the context of main source outages or islanded operation.

To this end, a system was designed and configured to prioritize energy sources according to predefined scenarios, with its functionality validated through simulation and software-based sizing.

Dynamic and mathematical modeling of the microgrid components was carried out using Simulink (MATLAB). Short-circuit current calculations were performed using the ETAP platform, while cable and protection sizing was done with Ecodial INT V5 software and relevant technical standards.

Photometric evaluations of the lighting installation were conducted using Dialux software.

The control system architecture was designed around an industrial PLC, which manages the switching logic and sequential startup of sources and loads, based on a predefined priority matrix.

For real-time monitoring of the microgrid's operational parameters (voltages, frequency, harmonic distortions, etc.), a JANITZA network analyzer was used, and the graphical interface was implemented via an HMI (Human-Machine Interface) system.

The research also highlights the essential role of the generator set within the system architecture. Its rotor mass provides system inertia, contributing to frequency stabilization immediately after potential disturbances, ensuring continuity of power supply, and enhancing the microgrid's resilience.

Thus, the generator set is not merely a backup energy source but an active element of stability and protection in a modern microgrid.

The results obtained from simulations and validations are synthesized in the conclusions section, emphasizing improved resilience and optimized operation under islanded or backup conditions.

The research findings have been presented in articles published in specialized journals and at energy-focused conferences.

Therefore, in order to highlight the main objectives of this study—namely the reliability, efficiency, and continuity of power supply to critical loads within the microgrid, in the context of main source outages or islanded operation—I have designed and modeled, using specialized software tools, various operational scenarios, which are briefly presented below:

Data on the Analyzed Microgrid – Case Study

The proposed solution for analysis features a Diesel generator as the main energy source, rated at 3×400V/1000kVA. Additionally, the system includes battery storage units rated at 48V/12kWh and a hydrogen fuel cell rated at 48V/10kW, which is automatically controlled by a PLC.

The system is equipped with a charger with the following specifications:

- Input AC voltage: 230V
- Output DC voltage: 48V
- Output current: 20A

Figure 1 illustrates the single-line diagram of the microgrid, which includes the hydrogen fuel cell.

The inverter has the following characteristics:

- Input DC voltage: 48V
- Output AC voltage: 230V

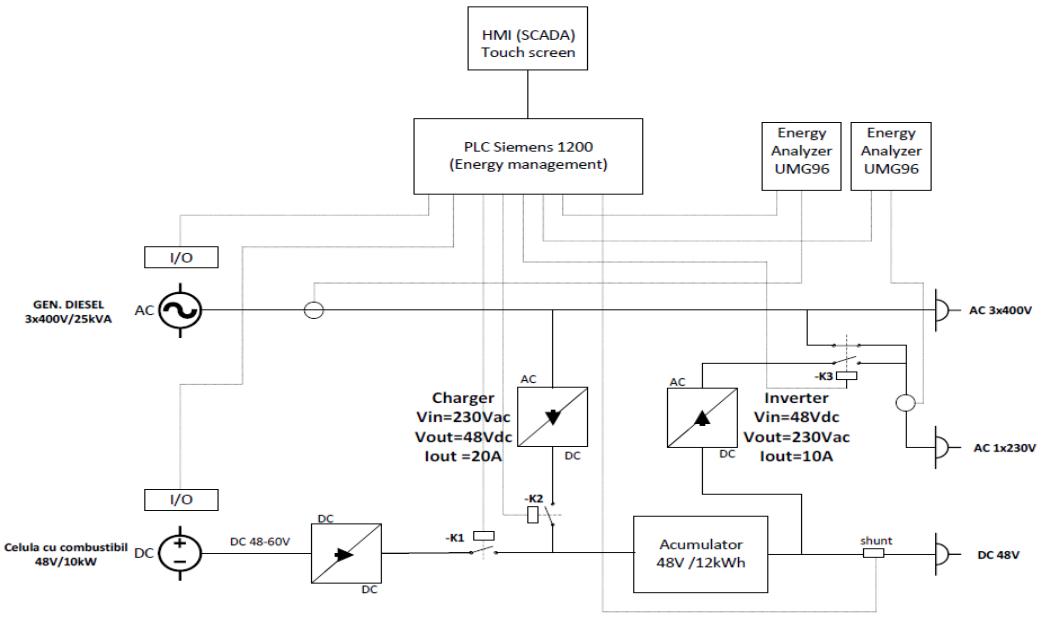


Fig.1 Single-Line Diagram of a Microgrid Including a Fuel Cell

The proposed system includes an operational management subsystem capable of automatically monitoring and controlling functions and parameters. The system is managed by a SIEMENS 12XX DC/DC/RLY PLC. It is containerized and scalable. The analyzed and designed system is intended to supply electrical power to telecommunications sites operated by service providers, either at an alternating voltage of 230 V or a direct voltage of 48 V, and can also serve other similar facilities.

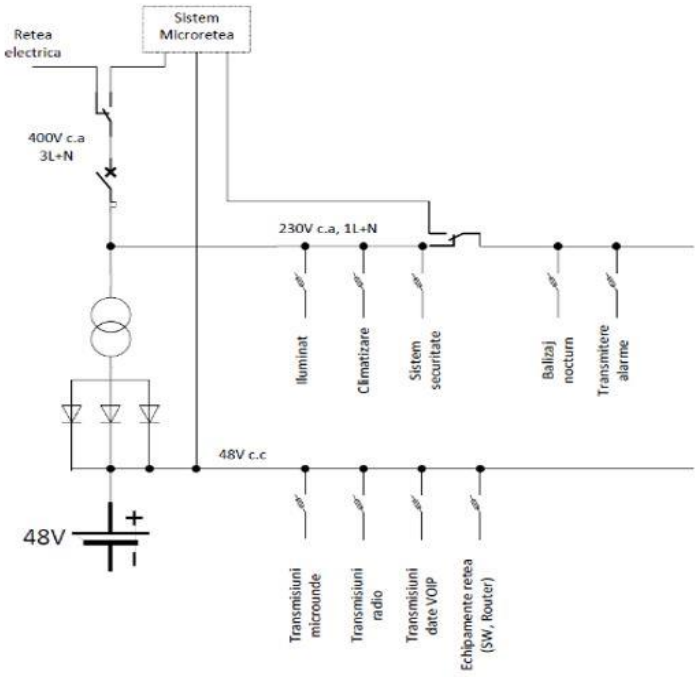


Fig. 2 Functional Diagram of the Analyzed Microgrid

The system can operate in parallel with the distribution network voltage, ensuring redundancy in the event of outages or voltage faults. It is equipped with high-performance devices and automation systems, allowing it to autonomously switch from an offline state to startup mode.

Using control and command equipment such as PLCs, all desired operational scenarios can be configured and set. The collected data can be stored or transmitted to operators via telecommunications protocols (fiber-optic network connected to network devices such as switches/routers) or GSM.

In the event of a power deficit, the system relies on the battery storage units and the Diesel generator, or even on the connection to the public electrical grid. The installation is designed to supply 70% of the required power from the hydrogen-based source and 30% from the solar source.

Under power deficit conditions, the fuel cell, the solar source, and, if necessary, the battery storage units work together to meet the energy demand.

Microgrid Modeling – Simulink-MATLAB

To highlight the importance of energy storage and the battery State of Charge (SoC), a microgrid was modeled that produces green hydrogen using solar energy and includes a storage system (battery units).
The simulation was conducted in the MATLAB/Simulink environment using the Simscape library. The following parameters were analyzed:

- T_vect: Temperature vector in Kelvin (K), converted from degrees Celsius. Represents the temperatures at which hydrogen properties were measured.
- h_vect: Specific enthalpy of hydrogen (i.e., the internal energy contained per kilogram of substance), expressed in kilojoules per kilogram.
- nu_vect: Kinematic viscosity of hydrogen, expressed in micro Pascal-seconds. Indicates the gas's internal resistance to flow (internal friction).
- cond_vect: Thermal conductivity of hydrogen (measuring how well it conducts heat), in milliwatts per meter per Kelvin.
- cp_vect: Specific heat at constant pressure, i.e., the energy required to heat one kilogram of hydrogen by one Kelvin without a change in pressure.

R_h2: Specific gas constant for hydrogen—a thermodynamic constant used in the ideal gas equation:

t_solar_profile: Time vector in seconds (from 0 to 82,800 s = 23 hours). Each value represents a specific moment of the day at which the power generated by the solar panels is known. It is used to define the daily solar radiation profile.
solar_profile: Power profile generated by the photovoltaic system, expressed in watts (W). It indicates how much power the solar panels deliver at the corresponding times in t_solar_profile. Low values (around 4 W) occur at night, while during the day the output can reach up to 200,000 W (200 kW).
temperature: The temperature at which the simulation for the solar cells is performed, expressed in degrees Celsius. This parameter is important because the efficiency of solar panels depends on temperature.
Plate dimensions (electrode/membrane): Expressed in centimeters. These are used to calculate the total surface area of the membrane and the water reservoir.

```
Electrolyzer.Np_electrodes = 3; % Number of Electrode Pairs
Electrolyzer.N_cell = 100;      % Number of Cells
```

- Structure of the electrolyzer:
- **Np_electrodes** = număr de perechi anod-catod.
- **N_cell** = numărul de celule electrochimice conectate în serie.

```
(273.15, 353.15, 5); % Temperature Vector
(0.55,0.9,5);  % Vector Efficienc [pu]
```

Electrolyzer Efficiency as a Function of Temperature:

- Temperatures (in Kelvin) at which the efficiency was measured.
- Efficiency is expressed in "pu" (per unit), meaning a fraction of 1 (e.g., 0.8 equals 80%).

The total surface area of the ion-exchange membrane, which influences the electrolysis reaction rate, is calculated based on the physical dimensions and the number of electrode pairs.

```
Electrolyzer.Xd = 2.0;          % Membrane Thickness [cm]
Electrolyzer.Resistance = 0.25; % Resistance [Ohm]
```

Physical Characteristics of the Membrane

- Xd – Membrane thickness
- Resistance – Total electrical resistance of the cell system
- Heating resistance [Ohm]
- refers to the resistance of the element used for heating water in the system.

Area – Surface area of the water reservoir, which is important for thermal transfer and the electrolysis reaction.

Hydrogen Storage Tank Information

- Volume – Expressed in cm^3
- Temperature – 0°C converted to Kelvin
- Temperature vector used for heating simulations

Heating Control Curves

- Represents the electric current flowing through the heating resistor as a function of the water temperature in the system.

Battery Parameters

- Qn – Maximum energy capacity of the battery (50 kWh)
- Qinit – Initial available energy at the start of the simulation
- Q1 – Threshold used by the control system (e.g., prevents battery discharge below 50%)
- Rs – Affects energy dissipation in the battery
- Un – Voltage at which the battery operates optimally
- U1 – Lower voltage limit – below this value, the battery is considered discharged

The diagram in Figure 3 shows an islanded direct current (DC) microgrid that uses a solar source and an energy storage system to power an electrolyzer

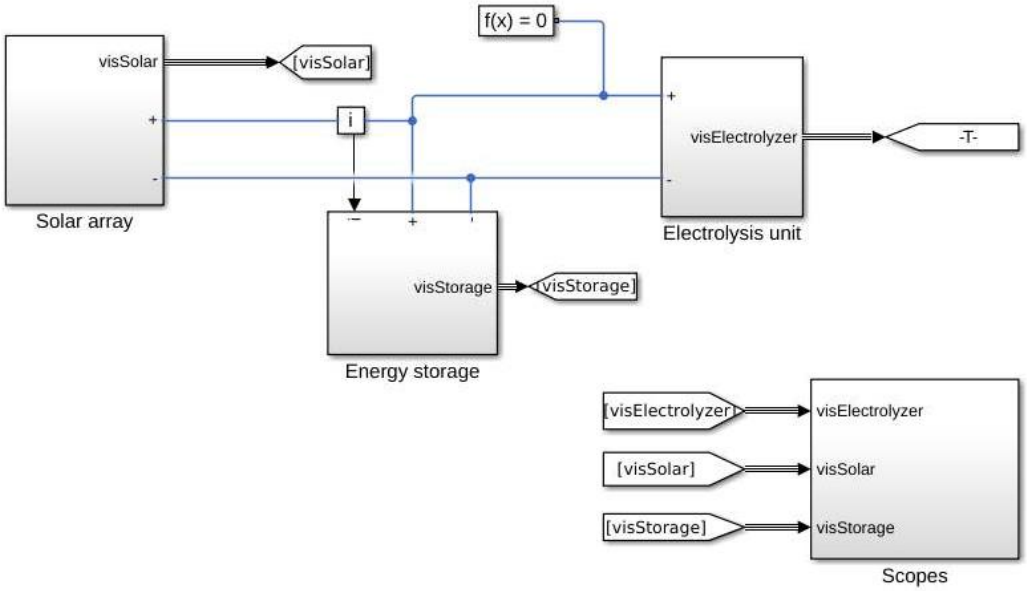


Fig. 3 Representation of the Microgrid in Simulink-MATLAB

This figure illustrates the schematic of a photovoltaic system connected to a DC-DC converter controlled by an MPPT (Maximum Power Point Tracking) algorithm, designed for high-performance energy harvesting.

- Solar energy is converted into electrical energy by the photovoltaic panels (left side).
- An MPPT block monitors voltage and current (VsSolar, Isolar) to adjust the duty cycle of the DC-DC converter.
- The converter regulates the voltage and current delivered to the load (output side).
- Voltage sensors (visSolar.v) and current sensors (visSolar.i) are used for monitoring.

Figure 4 – Complete Electrolysis System Model

This figure presents the modeling of a fully electric-powered electrolysis system, in which water is decomposed into hydrogen and oxygen.

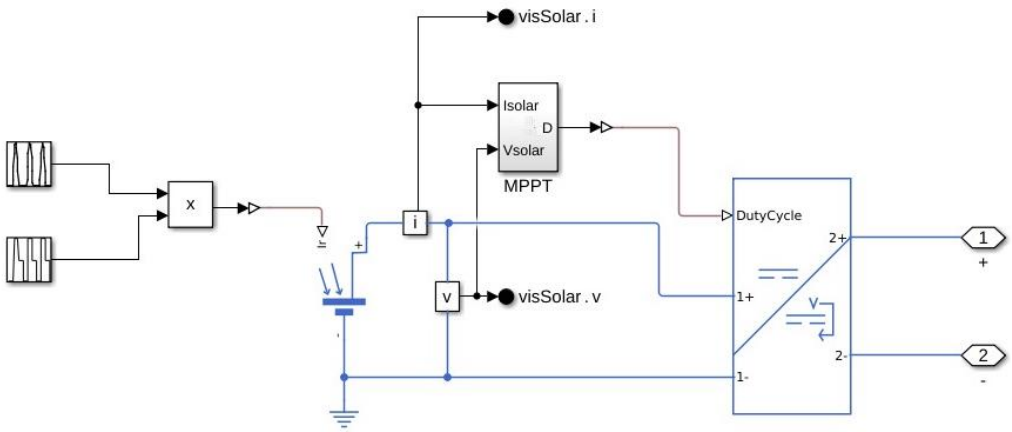


Fig.4 Modeling the Solar Power System in Simulink-MATLAB

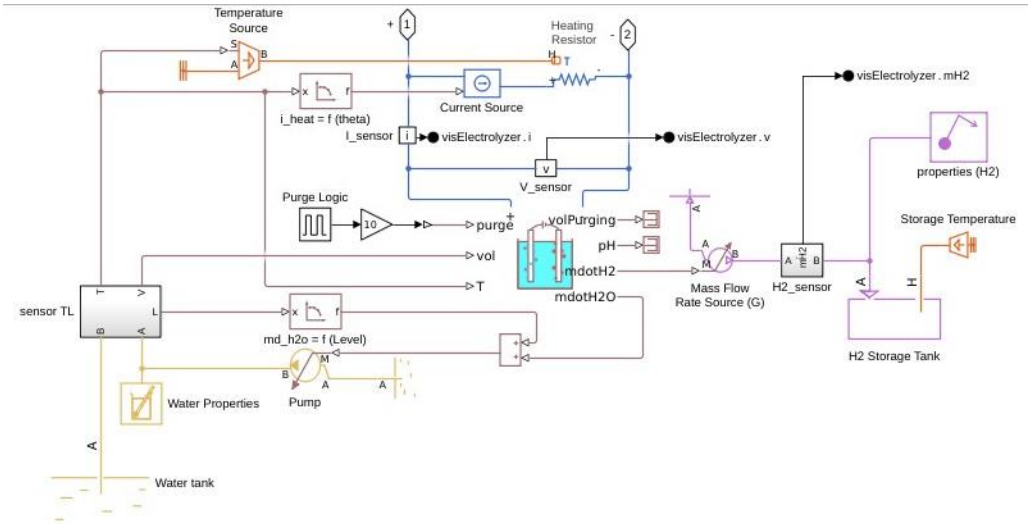


Fig. 5 Modeling the Electrolyzer in Simulink-MATLA

This figure presents the modeling of a fully electric-powered electrolysis system, in which water is decomposed into hydrogen and oxygen.

- The electrolysis cell is powered by electrical current and voltage sources.

- Sensors (I_sensor, V_sensor) measure the current and voltage applied to the electrolyzer, with outputs visualized through visElectrolyzer.i and visElectrolyzer.v.
- Water is pumped from the lower reservoir into the electrolysis cell.
- The electrolyzer generates hydrogen (mdotH2) and handles purging logic and pH regulation.
- The produced hydrogen is sent to a storage tank (H_2 Storage Tank), where the mass of hydrogen is measured using visElectrolyzer.mH2. Figure 7 – Battery Storage System with DC-DC Converter
- This figure illustrates a battery storage system connected via a DC-DC converter, which regulates the electric current based on available solar energy and battery state of charge (SOC).
- The battery is charged or discharged through a DC-DC converter controlled by a

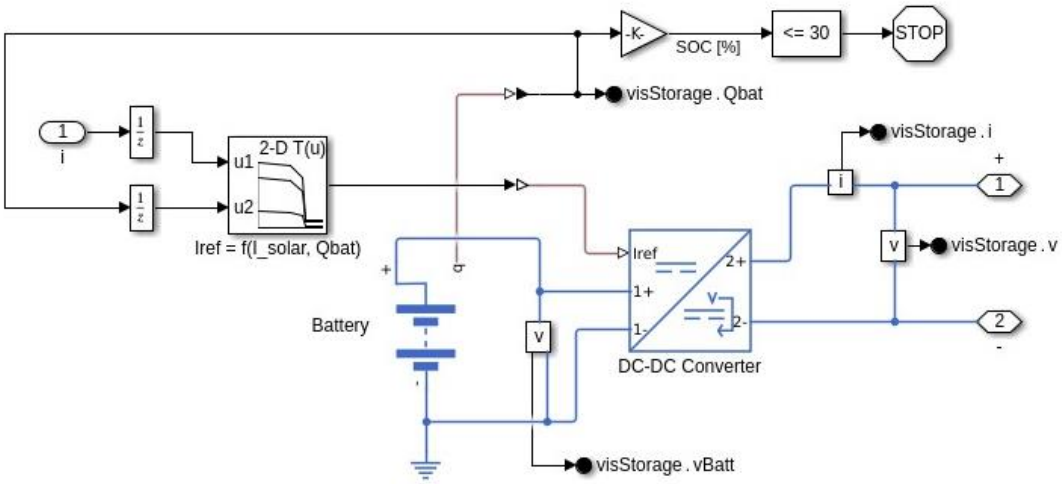


Fig. 6 Bateria (Energy Storage Block)

reference signal (Iref), calculated from the solar current and stored energy (Qbat).

- If the SOC drops below 30%, the system automatically shuts down (STOP).

Figure 7 presents the results obtained from the simulation of a microgrid system designed to produce hydrogen using solar energy and a battery-based energy storage system. The simulation was conducted in the MATLAB/Simulink environment, utilizing the Simscape library for modeling physical components and energy flows..

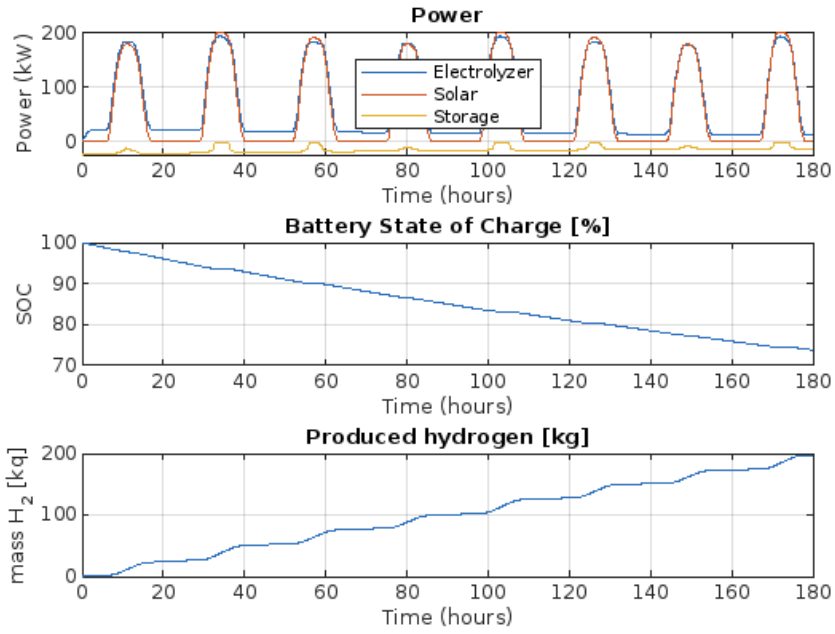


Fig.7 Representative Graphs of the Simulation Results

Graph Content Overview

- Power (kW) – Shows how the power supplied by the solar panels, the battery, and the power absorbed by the electrolyzer varies over 7 days (168 hours).
- Battery State of Charge (%) – Indicates the battery's charge level, which gradually decreases as stored energy is used during nighttime.
- Produced Hydrogen (kg) – Represents the total mass of hydrogen produced by the electrolysis system, increasing as the system operates.

Power [kW] – Power Over Time

- A clear daily cycle of solar production is observed (red curve), with peaks during daylight hours (~200 kW) and drops close to zero at night**.**

The electrolyzer (blue curve) closely follows the solar production, meaning it operates only when solar energy is available.

- Storage (yellow curve) is active only intermittently and contributes modestly, mainly around midday.

Interpretation:

→ The system is designed to power the electrolyzer directly from solar energy.

→ The battery plays a secondary role, providing stabilization or minor supplementation.

Battery State of Charge [%] – Battery Charge Level

- The charge level (SOC) gradually decreases from ~100% to ~72% over 180 hours (~7.5 days).
- No full recharge episodes are observed, only continuous discharge, indicating that solar energy is insufficient to maintain a constant SOC.

Interpretation:

→ Batteries are used consistently to supplement consumption or provide energy during sunless periods.

→ The system may become unsustainable in the long term without more efficient recharging.

Produced Hydrogen [kg] – Hydrogen Mass Produced

- The curve increases in steps, indicating intermittent production depending on energy availability.
- Consistent and linear production is observed during sunny days.
- Approximately 200 kg of hydrogen is produced over 180 hours.

Interpretation:

→ Hydrogen is efficiently produced during solar production peaks.

→ The system effectively utilizes surplus energy during those periods.

Simulation Details:

- Simulation duration: 7 days with a typical solar irradiance profile for a sunny day
- Daily cycle observed:
- Maximum energy production during the day (direct supply from solar panels)
- Battery usage during nighttime periods

Technical Conditions:

- Software used: MATLAB Simulink (Simscape)
- Simulation time: 24×3600×7 seconds = 168 hours
- Maximum solar power: 200 kW
- Storage capacity: 50 kWh
- Produced energy was used to power an electrolyzer, which generates hydrogen stored in a tank

Analysis of Microgrid Components Using Simulink-MATLAB

Automatic management of energy sources, based on real-time data regarding their status and availability, enables safe and stable operation of the microgrid. Understanding the mathematical models and characteristics of each source facilitates rational control of both energy generation and controllable loads, ensuring a continuous balance between energy supply and demand.

The proposed computational tools can be integrated into the digital model of the microgrid, programmed according to the developed algorithm and adjusted to real-world values to meet the project's objectives.

As part of this study, using the MATLAB Simulink platform, mathematical models were developed and analyzed for the following components:

- Photovoltaic (PV) Solar Installation – dynamic modeling approach
- Hydrogen Fuel Cell – dynamic modeling approach
- Battery Storage System; Electrolyzer
- Grid Management System (GMS)

This summary focuses on the first two components.

Photovoltaic (PV) Solar Installation – Dynamic Modeling

The PV system was modeled dynamically to simulate its behavior under varying solar irradiance and temperature conditions. The model includes:

- A solar irradiance profile representing typical daily variations
- Temperature-dependent efficiency curves for the PV panels
- A DC-DC converter controlled by an MPPT algorithm (Maximum Power Point Tracking) to optimize energy harvesting

Codul Matlab este indicat în continuare:

```
efficiency = 0.18;
panel_area = 1.6;
iradiance_levels = [800, 600, 400];

solar_power_output = zeros(size(iradiance_levels));

for i = 1:length(iradiance_levels)
    iradiance = iradiance_levels(i);
    solar_power_output(i) = efficiency * panel_area * iradiance;

    fprintf('Pentru o iradianta de %d W/m^2:\n', iradiance);
    fprintf(' - Puterea generata de panou: %.2f W\n\n',
solar_power_output(i));
end

figure;
plot(iradiance_levels, solar_power_output, 'r-o', 'LineWidth',
2);
xlabel('Iradianta solara [W/m^2]');
ylabel('Puterea generata [W]');
title('Puterea generata de panoul solar in functie de iradianta
solara');
grid on;
```

The results and graph in Figure 8 illustrate the direct relationship between solar irradiance and the electrical power generated by the solar panel:

- For an irradiance of 800 W/m², the panel generates 230.40 W
- For an irradiance of 600 W/m², the panel generates 172.80 W
- For an irradiance of 400 W/m², the panel generates 115.20 W

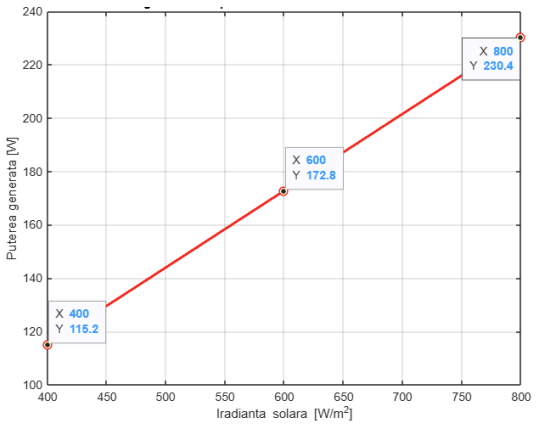


Fig.8 Graficul putere generată funcţie de iradianţa solară

The graph in Figure 8 takes the shape of a straight line, indicating a linear increase in the generated power as solar irradiance rises. This behavior is consistent with expectations, as the power output of a solar panel is directly proportional to the level of irradiance.

The Simulink simulation is shown in Figure 9.

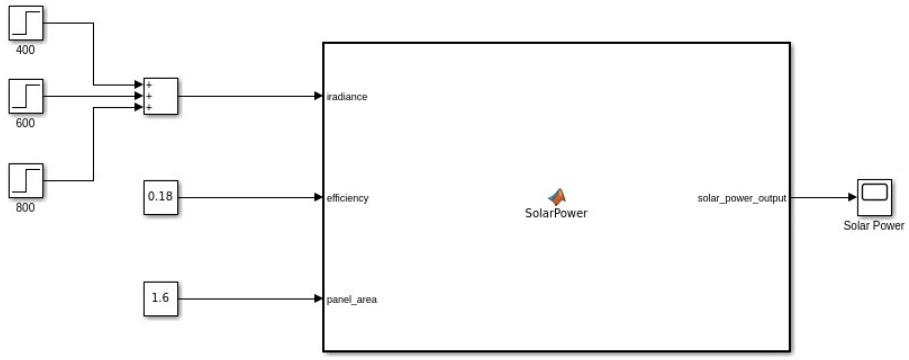


Fig.9 Simulink Simulation

Irradiance Control and Solar Power Calculation in Simulink

The Step blocks are configured to increase solar irradiance at specific time intervals:

- At time 0 seconds, irradiance is set to 400 W/m²
- At time 10 seconds, irradiance increases by 200 W/m², reaching 600 W/m²
- At time 20 seconds, it increases again by 200 W/m², reaching 800 W/m²

The Sum block combines these values into a single variable irradiance signal, which is fed into the model.

The SolarPower block receives the following inputs:

- Variable irradiance
- Panel efficiency: 0.18

Panel surface area: 1.6 m²

Based on these parameters, it calculates the generated power.

Hydrogen Fuel Cell – Dynamic Modeling Approach

The MATLAB code is provided below

```
PH = 3.31103e3;
Uc_nominal = 0.7;
N_cells = 10;

load_power_values = [2000, 4000, 6000];
hydrogen_consumption = zeros(size(load_power_values));

for i = 1:length(load_power_values)
    load_power = load_power_values(i);
    Ic = load_power / (Uc_nominal * N_cells);
    Uc = Uc_nominal * N_cells;

    hydrogen_consumption(i) = load_power / PH;

    fprintf('Pentru sarcina de iesire de %d W:\n', load_power);
    fprintf(' - Curent generat: %.2f A\n', Ic);
    fprintf(' - Tensiunea de iesire: %.2f V\n', Uc);
    fprintf(' - Consum de hidrogen: %.4f Nm^3/h\n\n',
hydrogen_consumption(i));
end

figure;
plot(load_power_values, hydrogen_consumption, 'b-o', 'LineWidth', 2);
xlabel('Sarcina de iesire [W]');
ylabel('Consum de hidrogen [Nm^3/h]');
title('Consum de hidrogen în functie de sarcina de iesire');
grid on;
```

Fuel Cell Behavior Under Varying Load Conditions

For each output load, the electric current generated by the hydrogen fuel cell increases proportionally in order to maintain a constant voltage of 7 V. The hydrogen consumption is directly proportional to the applied load:

- At 2000 W, the hydrogen consumption is 0.6040 Nm³/h
- At 4000 W, the hydrogen consumption is 1.2081 Nm³/h
- At 6000 W, the hydrogen consumption reaches 1.8121 Nm³/h

The graph in Figure 10 shows a linear relationship between output load and hydrogen consumption, indicating that as the output load increases, hydrogen consumption rises proportionally. This relationship is valuable for evaluating the efficiency of the fuel cell under variable load conditions, allowing for proper sizing of hydrogen storage tanks based on power demand..

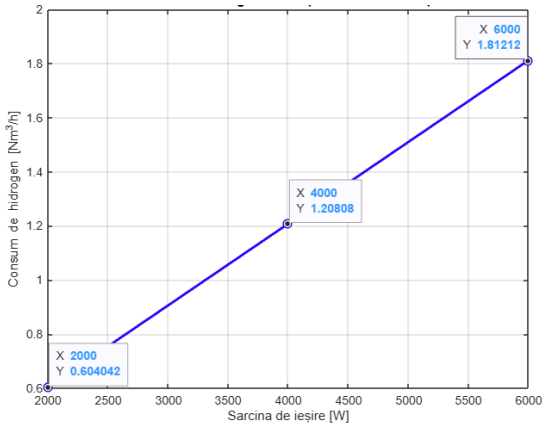


Fig.10 Hydrogen Consumption Graph as a Function of Output Load.

The Simulink simulation is shown in Figure 11.

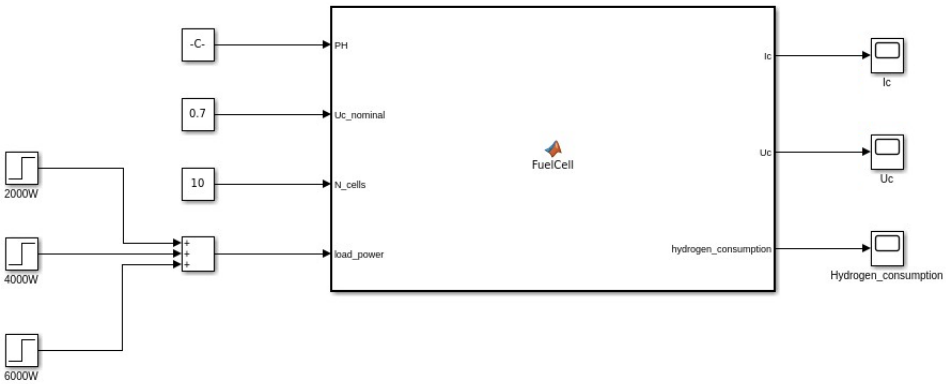


Fig.11 MATLAB Simulation – Fuel Cell

Fuel Cell Simulation Setup in Simulink

The Step blocks for 2000 W, 4000 W, and 6000 W generate discrete load steps, which are combined using a Sum block. This setup simulates a progressive increase in output load. The FuelCell block receives the following inputs:

- PH: Calorific value of hydrogen
- Uc_nominal: Nominal voltage per cell
- N_cells: Number of fuel cells
- load_power: Combined power input, obtained from the Step blocks

Outputs:

- Ic: Generated current, displayed using a Display block
- Uc: Output voltage of the fuel cell stack, displayed using a Display block

Hydrogen_consumption: Hydrogen consumption based on the applied load, displayed using a Display block

The simulation results (30-second run) are shown in Figure 12.

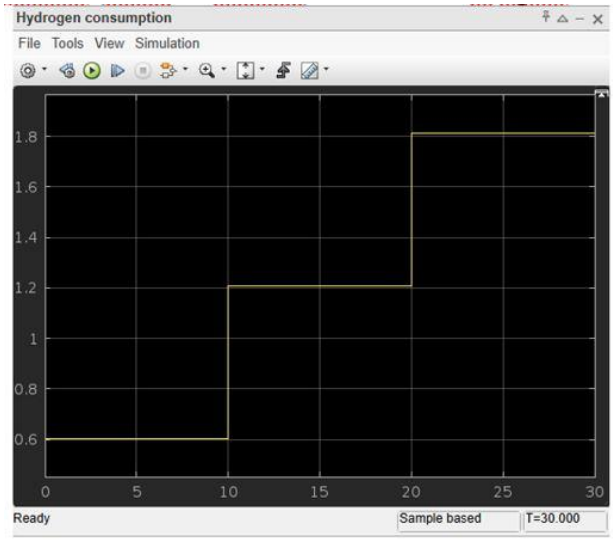


Figure 12 – Hydrogen Consumption Graph

Prioritization of Consumer Supply Criteria

The consumer operation diagram was developed using a PLC (Programmable Logic Controller). The Siemens 12XXDC/DC/RLY PLC communicates via the Modbus protocol, as illustrated in Figure 14.

To simulate various scenarios, a variable potentiometer was connected to the PLC, allowing voltage adjustment—for example, to simulate the voltage level of the battery system. Additionally, a manual switch was connected to the PLC to simulate the closing of specific circuits.

Figure 13 illustrates the action panel used during the operation of the electrical power supply system.

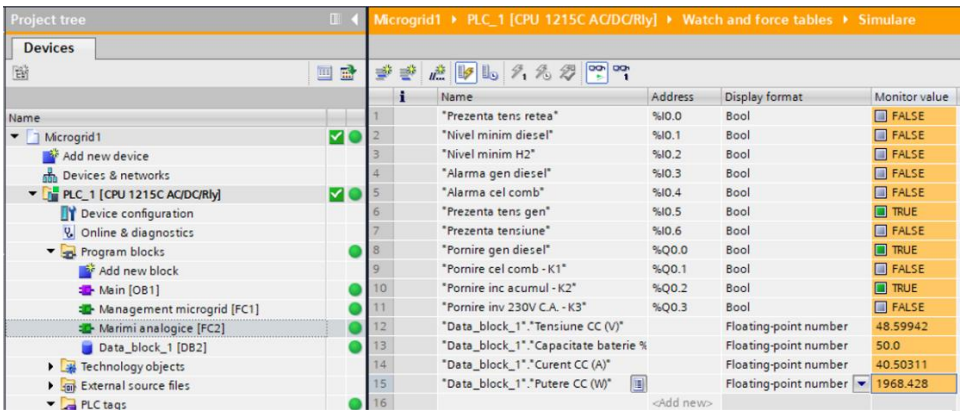


Figure 13– Control Action Panel

When grid voltage is present, all consumers are powered directly from the grid.

In the absence of grid voltage — provided the generator's fuel level is not at minimum — the generator starts automatically and supplies power to all consumers. This operation logic is illustrated in Figure 14.

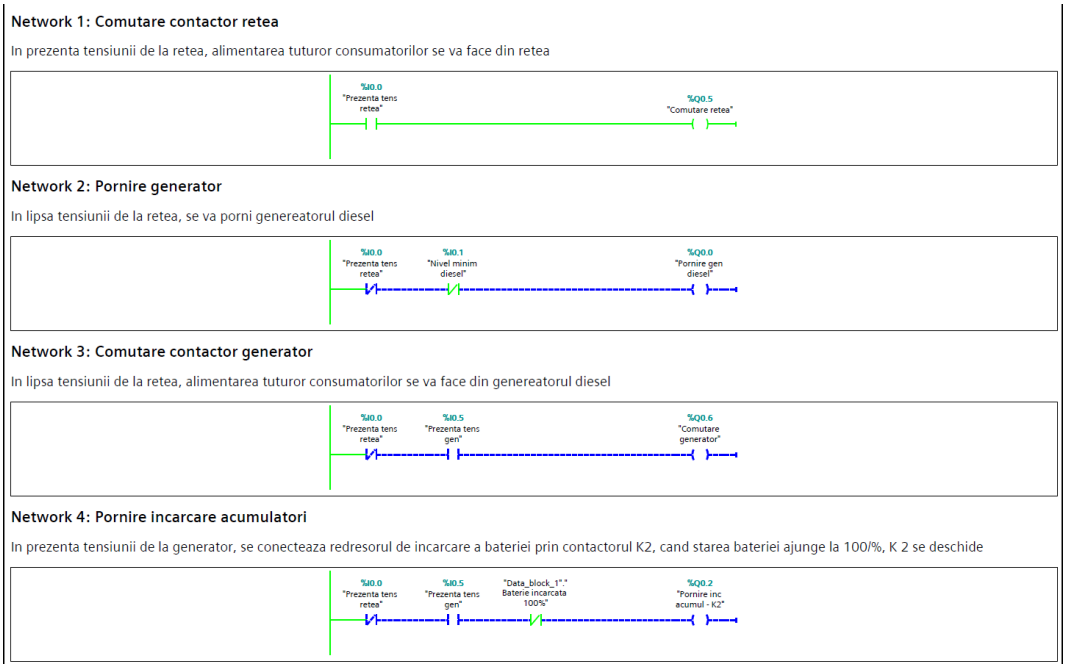


Figure 14 – Example of Equipment Switching to Grid Supply

The equipment used during the experiment included: laptop, Siemens 12XXDC/DC/RLY PLC, Janitza network analyzer, potentiometer, measuring device, various software applications (see Figure 15).

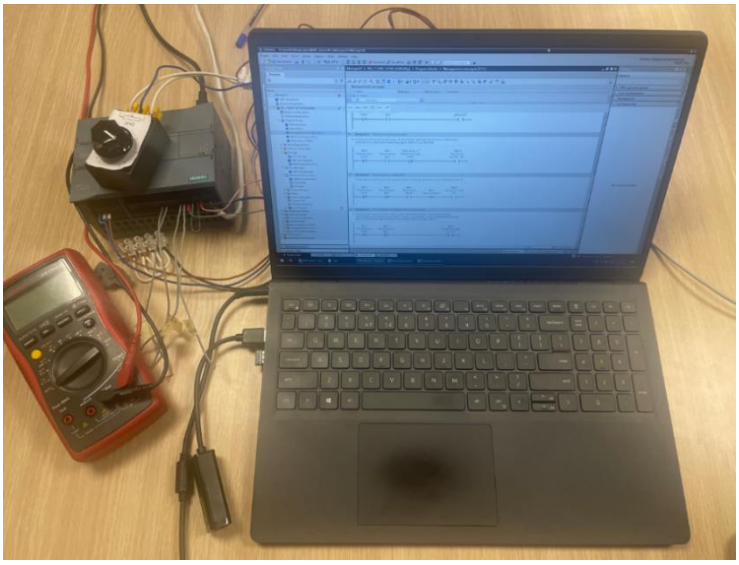


Figure 15 – Equipment Used During the Simulation

Diesel vs Hydrogen Comparison – Case Study

To highlight the costs and efficiency of hydrogen usage, a study was conducted involving the electric power supply of a consumer within the microgrid using two distinct and independent sources:

- Diesel fuel
- Hydrogen

Option 1 – System Powered by Diesel Generator

Option 1: Diesel Generator as Primary Energy Source

Cost estimation for independent operation of the generator over 7 days (one week, 168 hours):

- Generator purchase cost: €6,000 (30,000 lei)
- Diesel price: 8 lei per liter
- Fuel consumption per hour: 4 liters
- Weekly fuel consumption: (4 L × 24 h) × 7 = 672 liters
- Total diesel cost per week: 672 L × 8 lei = 5,376 lei

Option 2: Hydrogen Fuel Cell System as Sole Energy Source

Cost estimation for independent operation of hydrogen fuel cells over 7 days (one week, 168 hours):

A type 3.8 hydrogen module was analyzed, with the following specifications:

- Gas volume: 106.8 m³
- Gross mass: 1009.505 kg
- Net mass: 950.5 kg
- Price: €12.00 per m³

Considered physical characteristics:

- Operating temperature: 14 K (−259.15 °C)
- Boiling point: 20.38 K (−252.77 °C)
- Critical temperature: 33.24 K (−239.91 °C)
- Latent heat of fusion: 58.2 kJ/kg
- Relative density at 15 °C and 0.1 MPa: 0.069

Energy and system parameters:

- Energy generated by 1 Nm³ of hydrogen: approx. 3.5 kWh
- Estimated system power: 10 kW
- Operating time: 7 days × 24 hours = 168 hours
- Required energy for test: 168 hours × 10 kWh = 1680 kWh
- Hydrogen energy yield: approx. 3.5 kWh/Nm³
- Cylinder system capacity (12 cylinders of 50 L, bottled at 20 MPa): 106.80 Nm³
- Required hydrogen volume: 1680 kWh ÷ 3.5 kWh/Nm³ = approx. 480 Nm³

To meet the hydrogen demand, a cylinder system is proposed with specifications detailed in Table 5.

Table 1 – Specifications of Hydrogen 3.0 Cylinder

Specification	Single cylinder; 50 L;30MPa	Group of 12 Cylinders 50L; 30 Mpa	Group of 2X 12 Cylinders 50L; 30 Mpa
Energy	18kWh	216 kWh	432 kWh
Hydrogen Mass (H2)	1.1 kg	13.2 kg	23.4 kg
Runtime at 2.5kW	7.2 hours	86.4 hours	172.8 hours
Runtime at 5 kW	3.6 hours	43.3 hours	86.4 hours
Runtime at 10kW	1.8 hours	21.6 hours	43.2 hours
Total Mass	80 kg	1460 kg	2920 kg

To ensure continuous hydrogen supply, these cylinders should be connected to a pressure reduction system/station. In this case, from a technical standpoint, the optimal solution consists of using 3.8 hydrogen batteries (purity 99.98%).
Estimated costs for operating the system for one week using exclusively hydrogen fuel cells:
480 m^3 H_2 × 12 Euro/m^3 = 5,760 Euro; Approximately 28,512 RON
NOTE: Operational, transportation, and other related costs have not been included.

Conclusions

Developing a functional microgrid requires careful analysis of energy sources capable of covering the network's load demand. For loads that cannot tolerate interruptions in power supply, special attention must be given to designing a configuration or backup system that ensures uninterrupted power. Local sources such as solar and wind are prioritized, typically used alongside energy storage systems to compensate for weather-dependent generation. An increasingly adopted solution is the implementation of fuel cells, which obtain hydrogen either from internal electrolyzers or external sources.
Digitalization of monitoring and control processes through SCADA platforms, IoT technologies, and artificial intelligence algorithms enables real-time optimization of energy flows, anticipation of imbalances, and improved operational efficiency of the microgrid.
• Active participation of end users in the decision-making and investment process strengthens a decentralized, transparent, and sustainable energy model, where beneficiaries become co-owners of the local energy infrastructure.
• Automated energy source management, based on real-time data regarding the status and availability of sources, ensures safe and reliable microgrid operation. Understanding the mathematical models and characteristics of energy sources allows the network management system to rationally control both sources and controllable loads to meet energy demand at all times.
• The analyzed microgrid, operating independently from the public power grid, covers energy needs as follows:
• Daytime: solar → electrolyzer → H_2 production
Night/early morning: batteries → consumption
• Long-term: battery energy levels decrease → a balancing strategy is required (e.g., more solar panels, reduced consumption periods, or recharging from the grid)
• Hydrogen fuel cells become cost-effective only when hydrogen (via electrolysis) is produced using renewable energy sources (RES). Using hydrogen alone to power the proposed system is extremely expensive compared to other energy sources.

Designing the electrical supply scheme for a user and the internal power system structure must be based on the user's supply characteristics and service quality requirements.
• For critical loads, which cannot tolerate power interruptions, local UPS systems and energy storage solutions must be used.
• Alongside PLCs, automatic connection devices and smart relays are essential components for microgrid management and control.
Benefits of Using a Generator in a Microgrid

- Provides natural inertia through rotor mass, helping stabilize frequency immediately after a disturbance
- Ensures continuity of supply in the absence of the central grid or intermittent renewable sources
- Enhances microgrid resilience, enabling off-grid operation under critical conditions
- Complements renewable sources, which lack inertia, by balancing the system during transitions or load variations
- Enables smooth transitions between renewable and backup sources
- The generator is not just a backup—it is an active element of stability and protection in a modern microgrid

Cybersecurity and System Resilience:
The study demonstrates that despite increasingly sophisticated risks, it is possible to build effective detection and protection mechanisms—even in complex critical infrastructures. At the same time, the constant evolution of these systems is essential, given the dynamic nature of cyber threats and the growing integration of digital technologies in the energy sector.
Cybersecurity is no longer optional in the energy domain. It is a fundamental condition for the resilience of the national energy system and the protection of critical infrastructure. Solutions exist, but they must be responsibly adapted, tested, and integrated with a long-term vision.
Modern Urban Lighting Advantages
Replacing traditional urban lighting sources with modern systems offers benefits in the following areas:
• Financial: reduced energy demand, preventive and corrective maintenance
• Comfort and quality of life improvements
• Investment profitability (ROI) and management systems that provide cost predictability and budget savings
•Current street lighting systems equipped with modern light sources and traffic monitoring software can significantly reduce electricity consumption without compromising service quality
• LED lighting with remote management surpasses HPS sodium technology in terms of energy efficiency, lifespan, light quality, intelligent control capabilities, lower operational costs, traffic safety, and overall life quality enhancement.

Personal Contributions

Some of the research results presented in this paper were previously published as scientific articles, contributing to the dissemination and academic validation of the conclusions obtained.
Accordingly, I authored and published the following scientific papers, which reflect the main stages and directions of the study.
In this research, I analyzed a series of technical solutions aimed at improving the reliability, efficiency, and continuity of power supply to critical consumers integrated into a microgrid.I configured the equipment based on predefined scenarios, and the validation of results was carried out through software simulations. The system architecture was designed around a Programmable Logic Controller (PLC), in which I implemented the switching logic, achieving the desired response times and an optimized sequential switching of power sources for the consumers.
The study achieved very short switching times. In the event of a distribution network failure, power is restored from the batteries within a maximum of 10 ms, corresponding to the switching time of the fast breaker. If this source also becomes unavailable, the fuel cell takes over and powers the microgrid within 20 ms. Another fast-responding power source is the battery system.
I also highlighted the importance of including a diesel generator in the microgrid configuration, as it contributes to system inertia through its rotor mass, playing a key role in enhancing the operational resilience of the microgrid.
Overall, the solutions I analyzed and implemented were validated through simulations and contribute to the development of a robust technological framework capable of supporting the uninterrupted supply of critical consumers, in line with current requirements for reliability and energy efficiency.
The results confirm the feasibility and effectiveness of the proposed solutions, demonstrating the developed architecture's ability to ensure a continuous and reliable power supply to critical consumers under disturbed grid conditions.
Thus, the study contributes to strengthening the technical foundations for the implementation of smart microgrids, tailored to today's demands for resilience, energy efficiency, and secure power delivery.

Some of the research results presented in this paper were previously published as scientific articles, contributing to the dissemination and academic validation of the conclusions obtained.

Future Development Perspectives of the Study

The research conducted can be further developed in the following areas:

- Establishing a local energy management center to oversee energy production and consumption within the microgrid, with the capability for digital integration with the regional energy operator and the electricity market operator.
- Developing a local tariff system for users connected to the microgrid, along with rules for beneficiary participation in microgrid investments.