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RESILIENT POWER SUPPLY OF A MICROGRID

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The study analyses the operating scenarios of the equipment that make up a designed microgrid system. The aim of the study is to highlight the resilience of the power supply to user receivers. Thus, a system was designed and configured to manage the equipment operating sequence according to the desired priority in order to enhance resilience. To this end, power supply solutions from the public grid, from a Diesel generator, from energy storage batteries and from fuel cell were explored. The software developed ensures the supply of microgrid receivers by programming the existing sources appropriately. The basic scheme is to supply from a Diesel generator given that, because of the distance to the public grid it becomes uneconomical and does not ensure the quality of the supply service.

The microgrid receiver power supply scheme takes into account the specific operating conditions for critical receivers, priority receivers and common receivers (non-priority). The management of the equipment power system is done with a PLC (programmable logic controller) and the measurement of the microgrid parameters will be provided by the Grid Analyzer and HMI (human machine interface).

Keywords: Microgrid, PLC (Programmable Logic Controller) Command and Control, Grid Analyzer.

1. Introduction

This study refers to "microgrids" as one of the energy system development solutions for achieving the decarbonation goals through an efficient use of local energy sources.

Efficient, deep and affordable decarbonation of the European economy in line with the Paris Agreement and the UN 2030 Agenda for Sustainable Development is on the agenda of all experts in the field [1, 2].

Renewable energy sources such as solar, wind or hydrogen will be increasingly used to produce electricity. Solar and wind sources are weather-dependent (being weather sensitive) and cannot produce energy constantly and at the desired quality.

The solution to this problem are smart (controllable) grids. They have huge potential to make our power systems more reliable and provide cleaner energy.

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In the EU strategy, the aim is for solar sources to deliver over 320 GW of electricity to the grid by 2025 (more than double compared to 2020) and almost 600 GW by 2030.

The hydrogen from renewable sources will be essential to replace natural gas, coal and oil in hard-to-decarbonation industries and the transport sector. The REPowerEU plan sets a target of 10 million tonnes of domestically produced and 10 million tonnes of imported hydrogen from renewable sources by 2030.

A microgrid can be a small-scale power system that includes one or more generation sources that can operate independently of or connected to the national power system. Their main characteristics are [3, 4]:

Autonomy - Microgrids have autonomous generation, storage and consumption and can operate autonomously or connected to the grid. By developing microgrids, we can minimize CO2 emissions, while maximizing the need for renewable energy and minimizing the need for fossil fuel, thus resulting in a reduction of carbon dioxide emissions in the area

Stability – a microgrid can be stable under nominal operating conditions and transient events in the public network;

Flexibility -microgrids are technology neutral and capable of incorporating various energy sources using renewable sources. It also offers solutions in case of faults in the public network.

Remote control and monitoring – can ensure demand response, optimizing energy costs.

Efficiency – provides energy independence in case of events with the power grid.

The analysed microgrid consists of sources and users grouped around an isolated (site) high-frequency transmission facility. The conditions of power supply reliability imposed require the construction of a network fed from multiple power sources so that interruptions during operation are minimized. The proposed system is able to manage this principle through intelligent management of the energy sources. The microgrid includes transmission-reception facilities, auxiliary facilities, electric lighting, ventilation and heating.

In this study, the proposed system (microgrid) has a Diesel generator as primary energy source, and the storage system (accumulators) and the hydrogen fuel cell as secondary energy sources, thus ensuring the resilience of the power supply to the equipment in all cases, depending on the desired scenarios. [5,6,7].

In case of failure of the main source, the resupply from the accumulators takes place in 10 ms which is the duration of the connection of the fast switch. If this source also fails, the fuel cell connects after 20 ms.

Particularly important is the development of microgrids in remote areas or in areas where supply from the public grid is unreliable and users include critical receivers that cannot be interrupted. In this respect, the work analyses and proposes a solution for powering a telecommunications transmission station located in an area with an insufficiently secure energy infrastructure [8,9].

In view of the continuity conditions imposed on the microgrid receivers, a system was proposed and designed to be able to supply electricity to the telecommunication sites of telephone operators at 230 V alternating voltage or 48 V direct voltage. The proposed scheme can also be extended to power other such sites [8].

The designed system can be paralleled with the distributors' voltage network ensuring redundancy in case of voltage interruptions or failures. It is equipped with high-performance equipment and automation so that it can switch itself from off-line to on-line status. With the help of PLC-like command-and-control equipment, all the desired scenarios can be configured and set, so that the collected data can be stored or sent to the operators via various telecommunication routes (fibre optic network connected to LAN, Swich/Router) or GSM equipment [10, 11].

An appropriate choice of the user's power system scheme must allow for reliable power supply to critical receivers, appropriate use of the type of source depending on its response and ensure specific power quality conditions.

The main conditions required for a resilient power system are the following [4, 12]:

- ensure reduction of critical receiver outage duration by at least 3 orders of magnitude compared to standard power supply, depending on the type of UPS, the characteristics of the powered receiver and the service level of the equipment;
- achieving a minimum 99.999 % probability of operation;
- ensuring virtually uninterruptible power supply (at most hundreds of milliseconds).

Achieving 99.999% performance leads to an accepted outage of no more than 4.8 minutes per year.

2. Single-line diagram and definition of parameters for the analysed system

Fig. 1 shows the proposed architecture of the electrical system powering the user receivers and Fig. 2 shows the operation diagram of the proposed system. [13, 14].

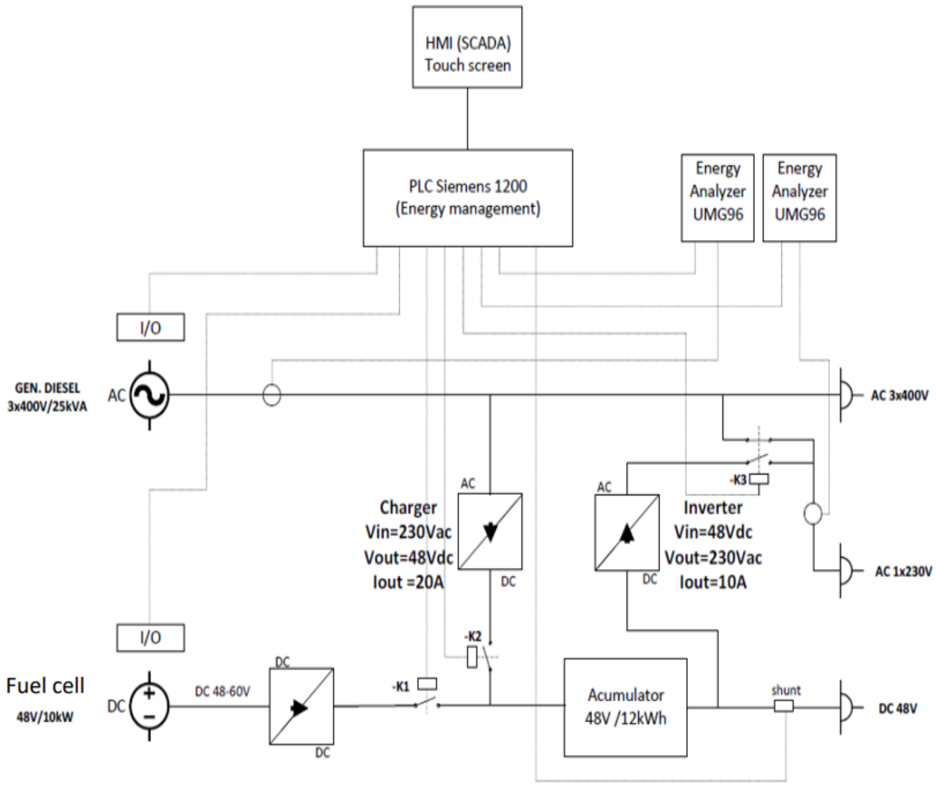

Fig.1 System Architecture

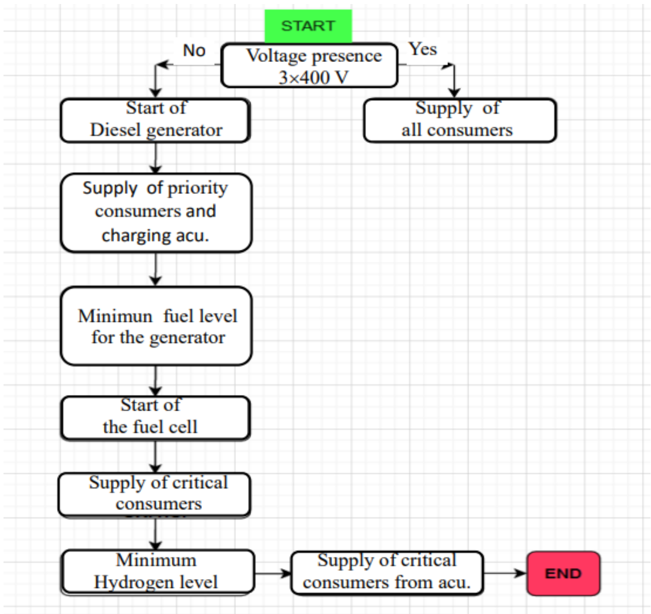

Fig.2 Operation diagram

"I" inputs and "Q" outputs have been defined in the TIA-PORTAL program used for system management. Table 1 shows the inputs and outputs of the proposed control system.

Table 1

Control system inputs and outputs

No.	DIGITAL INPUTS	ANALOG INPUTS	DIGITAL OUTPUTS
1	Main voltage present	Battery charge level	Starting the Diesel generator
2	Minimum Diesel level	Continuous electrical current output	Fuel cell ignition
3	Minimum H2 level		Starting the battery charging
4	Diesel generator alarm		Starting the inverter 230 V AV voltage
5	Fuel cell alarm		
6	Generator Voltage OK		

Table 2 shows the signals that are generated during the operation of the scheme.

Table 2

Signals generated at the operation of the scheme

SYMBOL	NAME	INPUT/OUTPUT	ACTION	CONTACT
I0	Grid voltage present	Digital input	Signal from the network presence surveillance relay (1=voltage present, 0=no voltage)	Normally Open Contact
I1	Minimum diesel level	Digital input	Signal from the diesel fuel level probe (1=voltage present, 0=good level)	Normally Open Contact
I2	Minimum H2 level	Digital input	Signal from the hydrogen level probe (pressure sensor) (1=voltage present, 0=good level)	Normally Open Contact
I3	Diesel gen. alarm	Digital input	Alarm/failure signal from the Diesel generator (1=alarm, 0=operating state)	Normally Open Contact
I4	Fuel cell alarm	Digital input	Alarm/failure signal from the fuel cell (1=alarm, 0=operating state)	Normally Open Contact
I5	Presence of voltage in the Diesel gen.	Digital input	Signal from the voltage presence surveillance relay Diesel generator (1=voltage present, 0=no voltage)	Normally Open Contact
AI0	Battery voltage	Digital input	Battery voltage analogue signal (48V c.c.) Resistive voltage divider	0-10V
AI1	Battery current	Analogue input	Battery current analogue signal (48V c.c. output) Shunt +signal conditioner	0-10V
O0	Starting the diesel gen.	Digital output (relay)	Diesel generator start switch (1=on, 0=off)	Normally Open Contact
O1	Starting the fuel cel	Digital output (relay)	 (1=on, 0=off)	Normally Open Contact
O2	Starting the battery charging	Digital output (relay)	 (1=on, 0=off)	Normally Open Contact
O3	Starting the 230 invertor	Digital output (relay)	230V c.a. invertor start switch (1=on, 0=off)	Normally Open Contact

To simulate different scenarios, a potentiometer was connected to the PLC and the voltage was adjusted, e.g. to simulate the voltage level in the accumulators and a manual switch was connected to the PLC to simulate the closing of certain circuits. The proposed system will operate on 4 x 12V, 250 Ah batteries. Thus, the input data will be: 48 V voltage, maximum stored load 250 Ah, stored energy 12 kWh. The state of charge level of the battery deduced from the voltage measured on the battery according to the AGM-GEL characteristics is shown in Table 3. Properties of AGM-GEL batteries. Each 48V battery consists of two 24V batteries connected in series. We kept the battery charging characteristics for both 24/48V thresholds.

Table 3

Battery state of charge

48V	24V	
Voltage	**Voltage**	**Capacity**
51.54	25.77	100%
51.12	25.56	90%
50.62	25.31	80%
50.04	25.02	70%
49.62	24.81	60%
48.9	24.45	50%
48.42	24.21	40%
47.82	23.91	30%
47.22	23.61	20%
46.8	23.4	10%
46.5	23.25	0%

3. Experimental Setup

By programming the PLC (programmable logic controller) equipment, the sequence of operation of the equipment is defined according to the desired priority in order to achieve good resilience in terms of power supply.

The grid analyser Janitza UMG 604 was used for the experimental assembly, that measures the parameters of the grid (voltage, electricity, current) transmitted to PLC through the MODBUS TC protocol. The analyser is set up from the GRIDVIS application.

The data transfer and tag definition are done from the HMI (human machine interface) control panel. PLC is defined as MASTER and analyzer as SLAVE (fig. 3).

Using the GRIDVIS interface, Figs. 4 and 5 show the recorded values of electric currents and power consumption as well as the related voltages and frequency.

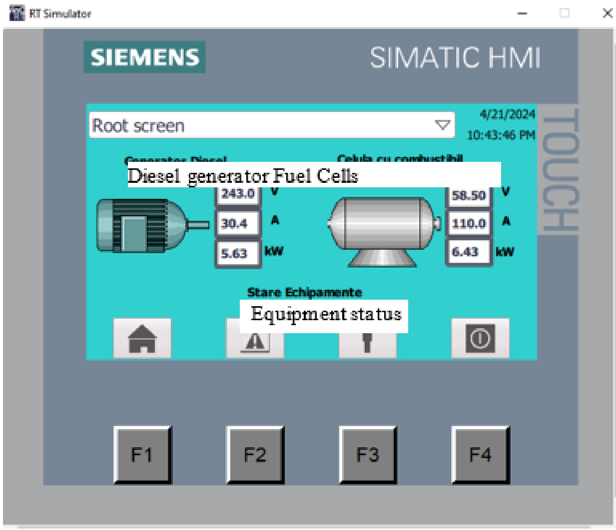

Fig.3 Defining tags in the HMI control panel

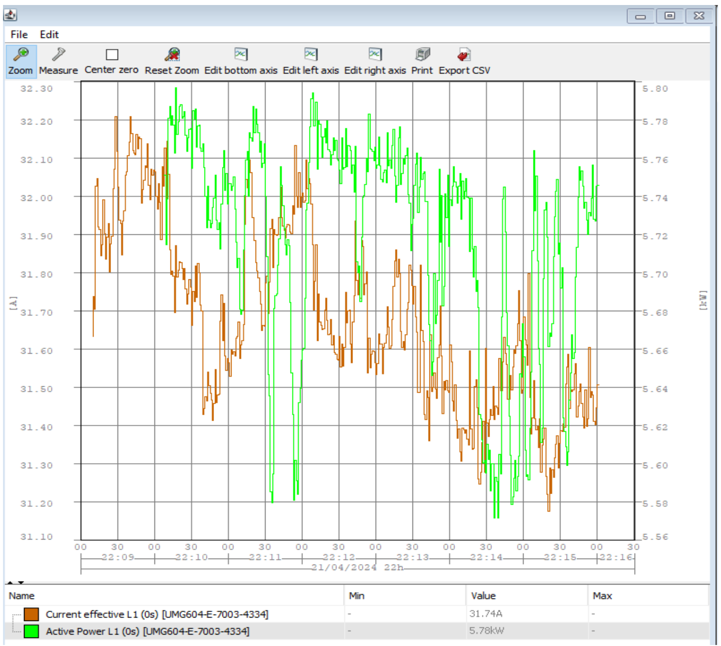

Fig.4 Measured values of electric current and active power at the Diesel generator terminals

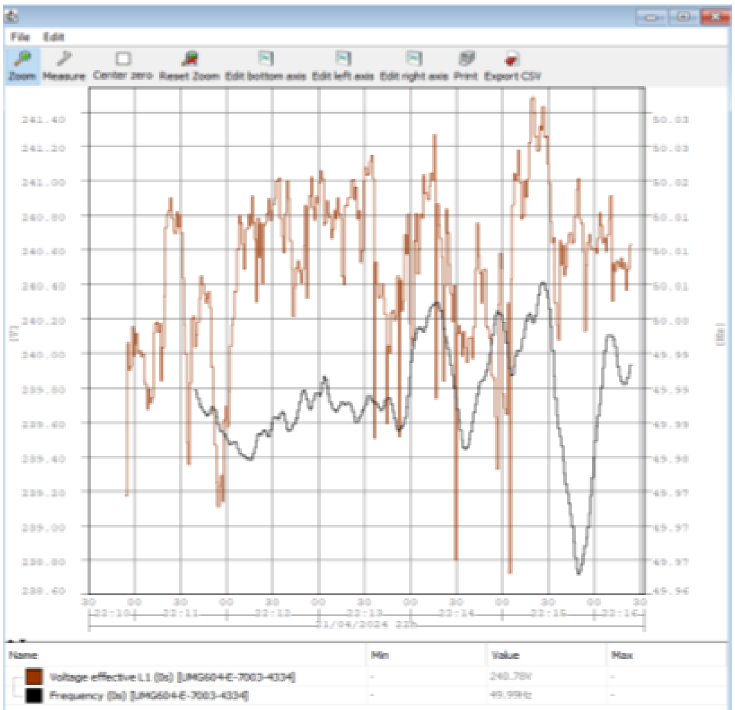

Fig.5 Measuring the voltage and frequency at the Diesel generator terminals

Fig. 6 shows the modbus communication module indicating the voltage value measured by the analyzer and transmitted to the PLC.

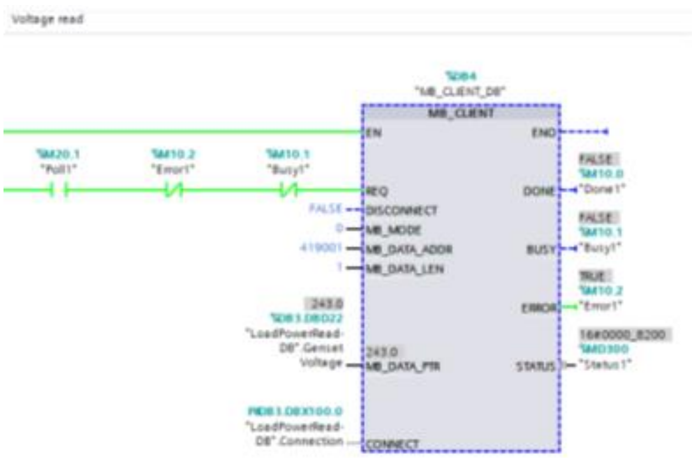

Fig.6 Modbus communication software module illustrating the voltage value indicated by the analyzer and transmitted to the PLC.

Figure 7 shows the modbus communication module indicating the value of the active power measured by the analyser and transmitted to the PLC.

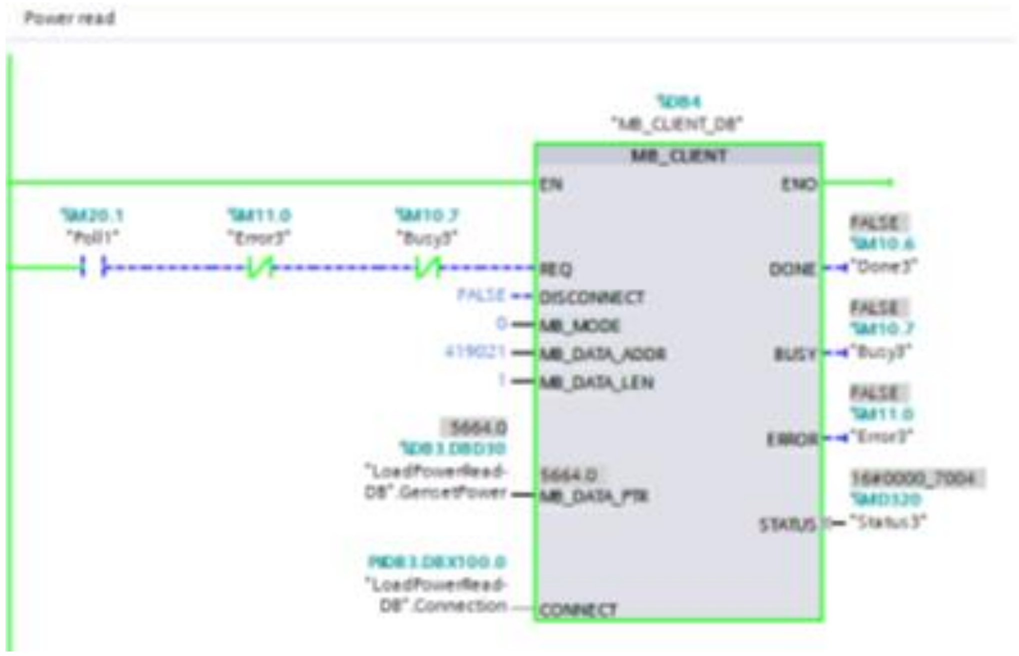

Fig.7 Modbus communication software module illustrating the active power value indicated by the analyzer.

For example, the logic diagram for setting the Diesel generator as the primary power source for the equipment is shown in Fig. 8.

Fig. 7 shows the modbus communication module indicating the value of the active power measured by the analyser and transmitted to the PLC.

Fig.8 Simulated operation of the diesel generator as a primary energy source

The simulation program for measuring the voltage at the battery terminals is shown in Fig. 9.

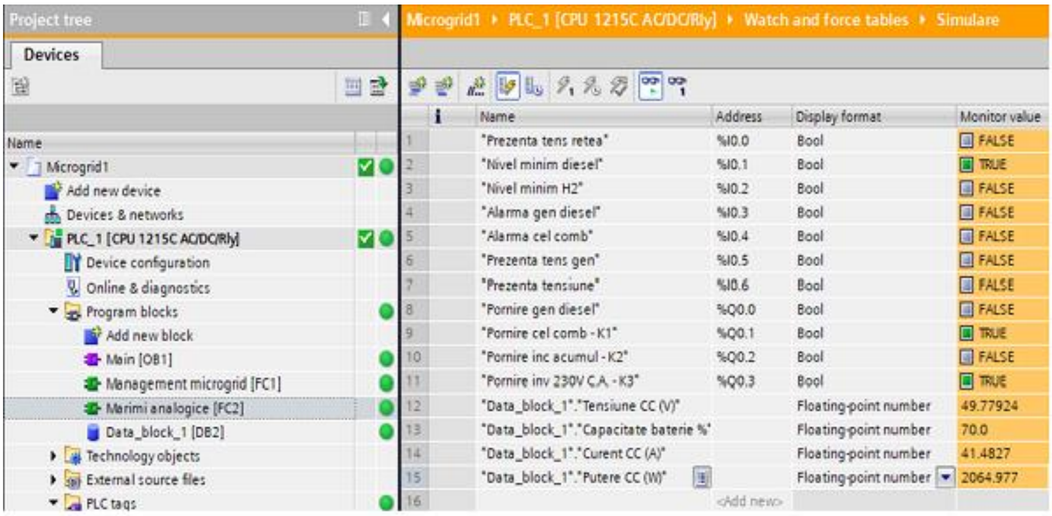

Fig.9 Simulation program for measuring voltage in batteries

4. Hydrogen fuelling

In order to analyse the efficiency of the main powering from a fuel cell using hydrogen as fuel, we compared the costs of the diesel generator with the costs and problems of using the fuel cell.

For the operation of the hydrogen generator, we calculated the costs for continuous operation for one week (168 hours):

- Generator purchase cost: 6.000 € (RON 30.000);
- Price pe 1 Liter of diesel fuel: RON 8

Fuel consumption (diesel fuel)/hour: 4 litres;

- Fuel consumption /week: 4 litres * 24 h * 7 = 672 litres;
- Diesel cost/week: 672 litres * RON 8 = RON 5376

For independent operation of the hydrogen fuel cell for 7 days (one week, 168 hours).

- The power generated by 1 Nm3 of hydrogen is of approx. 3.5 kWh.
- Estimated system power: 10 kW
- Operating time of the designed system: 7 days x 24 hours = 168 hours
- Required test power : 168 hours x 10 kWh = 1680 kWh
- Hydrogen generated power: approx. 3,5 kWh/Nm3
- Capacity/no. of cylinders (12 cylinders of 50 l; filling pressure 20 MPa (200 bar): 106.80 Nm3.
- Necessary hydrogen : 1680 kWh : 3.5 kWh/Nm3 = about 480 Nm3.

In order to ensure continuity of hydrogen supply, these batteries should be connected in a pressure reduction system/station. In this case, from a technical point of view, the optimal solution is to use 3.8 hydrogen batteries (purity

99.98%). Approximate costs for running the system for one week using only hydrogen fuel cells:

480 mc H2 x 12 Euro/mc= 5.760 Euro; Approximately RON 28.512.

5. Tools used

A series of experimental checks were carried out to validate the programs used. The set-up and measuring equipment used for this purpose are shown in Fig. 10:

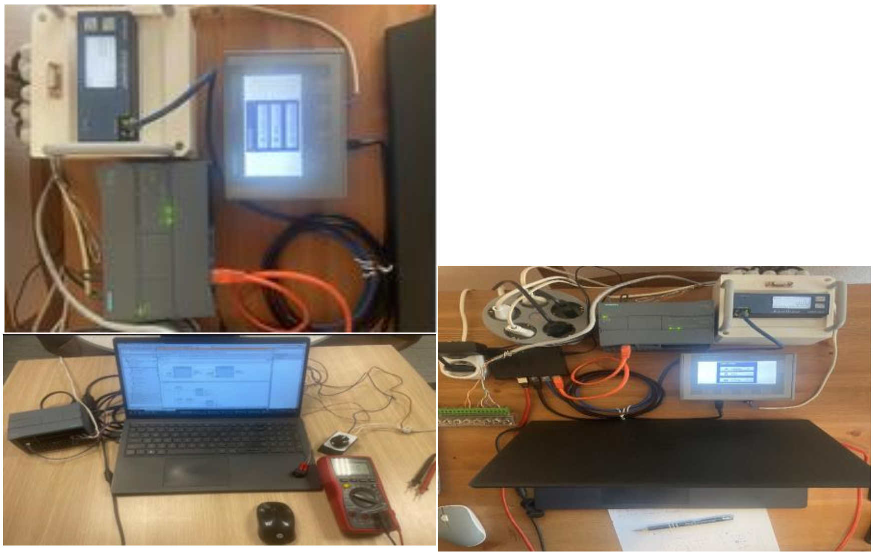

Fig.10 Experimental set-up used for validation

6. Conclusions

A proper prioritization of the power supply to the microgrid receivers was achieved through the management and control of the equipment, which ensured a good energy resilience.

In this paper, the emphasis was placed on the avoidance of interruptions in the power supply, this aspect being the most important quality indicator for the microgrid analysed. The solutions presented ensure the necessary level of power quality.

The proposed solution for the electricity supply corresponds to the conditions imposed for the microgrid receivers; the studied option of using hydrogen fuel cells turned out to be economically unjustified. Currently, the strict use of hydrogen to power the proposed system is extremely expensive compared to the use of other energy sources.

The determination of a user's electrical supply scheme and the structure of the internal power system are based on the user's supply characteristics and their requirements related to the quality of the supply service. For critical receivers because they cannot accept the risk of power cuts, UPS and power storage systems will be used.

R E F E R E N C ES

[1]*** National Integrated Energy and Climate Change Plan 2021-2030 (April 2020).

[2]*** Regulation No 2018/842/EU of the European Parliament and of the Council on the binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet their commitments under the Paris Agreement and amending Regulation No 525/2013/EU

[3] Puianu M., Flangea R.O., Arghira N., Iliescu S.S., Microgrid control simulation and testing, Sci. Bull., U.P.B. Series C, Vol. 80, Iss. 2, 2018

[4] Cañizares C.A., Palma-Behnke R., Olivares D.E., Mehrizi-Sani A., Trends in microgrid control, IEEE Trans. Smart Grid 5 (4), 2020.

[5]Younesi A., Shayeghi H., Wang Z., Siano P., Mehrizi-Sani A., Safari A., Trends in modern power systems resilience: State-of-the-art review, Renewable and Sustainable Energy Reviews 162, 2022.

[6] Zabetian-Hosseini A., Sangsefidi Y., Mehrizi-Sani A., Model predictive control of a fuel cell-based power unit. IECON 2017-43rd Annual Conference of the IEEE Industrial Electronics

[7] Felseghi R.A., Carcadea E., Raboaca M.S., Trufin C.N., Filote C., Hydrogen fuel cell technology for the sustainable future of stationary applications, Energies, 2019,12 (23), hpps://doi. Org/10.3390/en 12234593

[8] Minea V.L., Minea M., Semenescu A., Efficiency of application monitoring in improving mobile communication networcs'rezilience – a case study, U.P.B. Sci. Bull., Series C, Vol. 83, Iss. 4, 2021

[9] Scott N., *Microgrid. A Guide to Their Issues ans Value*, prepared or Highlands and Enterprise in partnership with Scottish Government, Issued 2016, Rep 1499/002/001B

[10] Golovanov N. ş.a.,Quality of electricity. Solutions for improving the continuity of electricity supply,AGIR,Bucharest 2013,ISBN 978-973-720-497-4

[11] ABB-IEE 2030.7 "https://new.abb.com/medium-voltage/packaging-and-solutions/digital-systems/microgrid---the-future-of-energy-management

[12] ***Improving reliability with standby power supply,https:// www.lpqi.com

[13] SIEMENS type 12XX DC/DC/RLY,https://ro.rsdelivers.com/product/siemens /6es7211-1be40-0xb0/siemens-simatic-s7-1200-series-plc-cpu-for-use-s7/8624455”,Siemens-6ES7211-1BE40-0XB0

[14]***The 2021-2030 Integrated National Energy an Climate Plan. Deloitte calculations based on information provided by the Inter-institutional Working Group on the NICE and the COM recommendations.