A Test Bench for a Blockchain-based Management of Smart Prosumers' Flexibility

P. Gallo, F. Massaro, E. Riva Sanseverino, S. Ruffino, G. Sciumé, A. Vasile, G. Zizzo

Engineering Department

University of Palermo

Palermo, Italy

Abstract— **To date, the European regulatory framework requires the development of new energy policies at the national level that can reduce overall consumption and support the implementation of customer-focused control and management systems. Therefore, it is necessary to study the feasibility of the various strategies available, especially for the involvement of residential users in services that can contribute to the management of the electricity grid. The advent of blockchain technology has enabled the development of new business models for the electricity market, opening this world to end users who previously did not have the opportunity to participate in energy trading and allowing the implementation of services to ensure the proper operation of the power grid. Due to its characteristics, blockchain could be the solution to balancing problems caused by the penetration of unpredictable renewable sources. This paper describes a test bench for a Smart Prosumer simulation with the goal of emulating a user who is both a consumer and a producer, but also able to be smart, i.e., to optimally manage production and consumption and to communicate with a blockchain network for the provision of energy services. The document shows the different components of the test bench and how it is connected to a local blockchain implemented in the framework of the Blorin research project.**

Keywords—laboratory, blockchain, prosumer, renewables

I. Introduction

There are many possible applications of blockchain technology in the energy sector, and most of them target peer-to-peer (P2P) energy trading [1]-[4]. The parties involved in the exchange are varied: electric vehicles [5],[6], manageable loads [7], producers or consumers, and energy storage systems [8]. However, there are other popular applications of blockchain technology to the energy sector, such as the certification and tracking of renewable energy or the provision of energy services such as Demand-Response (DR) [9]-[11] and Vehicle-to-Grid (V2G) [12],[13]. DR actions, whether occurring in a renewable energy community context or not, must include remuneration for the user since they always involve a change in habits and a higher cost of installed devices to realize flexibility and to communicate with an aggregator or DSO. In this context, the blockchain can be used to record consumption modification actions by users in response to external demand. The blockchain ensures immutability of data and makes it possible to make each user's contribution visible to all system users and power profile change requestors, which will be the basis for calculating remuneration. The smart meters installed at the user's premises will be able to send consumption data to the blockchain in which a specific distributed algorithm (smart contract) will compare the predicted consumption data with the measured data and, having also verified the activation of one of the devices deputed to the provision of the flexibility service to the grid, will be able to record and certify the user's participation in the power profile variation action. The blockchain will be able to be used to record and certify the energy shared by the users of a REC. In fact, the energy community, according to Legislative Decree 199/2021, is configured as a legal entity that is responsible for the allocation of shared energy among the members of the EC and to which the management of payment and collection items to sellers and the GSE can be delegated. The relationship between the EC and its members is governed by a private contract. The distribution of incentives from maximizing shared energy could then be regulated in proportion to users' self-consumption or other criteria. The use of the blockchain would make it possible to make it known to all users how each member of the energy community participates in the formation of shared energy with his or her share of self-consumption, and to distribute the incentive income equitably. Finally, the use of blockchain allows for local recording of the transactions made by each user participating in aggregation programs, thereby avoiding possible service disruptions due to communication difficulties.

In this context, the Blorin research project [14] aims to create a blockchain-based platform for energy service delivery. The platform is based on a Hyperledger Fabric blockchain and supports both V2G and DR programs. In the Blorin platform, all members are enrolled through a trusted Membership Service Provider (MSP). As a result, transaction validation and network security do not require complex algorithms such as "proof of work," and this results in a major difference from open, so-called permissionless systems, which allow unknown identities to access the platform with write capabilities. Among other innovations, this project offers several mechanisms and tools that can be combined allowing easy integration with existing technologies. Currently, the Blorin network includes 7 nodes, each representing specific interests in the energy scenario. Two nodes are managed by *Regalgrid*, a systems integrator and service provider, and *Exalto*, the Blorin project coordinator. Other partners are the grid operators of the two islands involved in the project. The *SEA* distribution company on the island of Favignana is responsible for managing the V2G service, and the *SELIS* distribution company is responsible for managing the DR service on the island of Lampedusa. The University of Palermo includes 2 nodes, at SNAPPLab (Security Network Applications and Positioning Laboratory) and at SMGLab

(Smart and MicroGrid Lab). The SNAPPLab aims to develop and control the entire communication infrastructure between the different peer nodes and the blockchain itself. The SMGLab provides hardware components for testing the energy services provided by end users (DR and V2G) and their tracking through an appropriate metering system.

This paper describes the test bench for the emulation of a smart prosumer able to offer its flexibility to a DSO or an aggregator for different purposes. The test bench is located in the SMGLab at the ground floor of the Engineering Department's building 9 of the University of Palermo. In the next sections, the components of the test bench and its connection to a local blockchain developed for the Blorin project are described.

II. Description of the Test Bench

The test bench for characterizing DR control logic for domestic and tertiary users classifiable as smart prosumers is described below. The test bench is built with the objective of emulating a smart user, i.e., to optimally manage production and consumption for the provision of ancillary services to the grid or for participation in the self-consumption of an energy community. It allows for emulating both single-phase and three-phase powered users, and possibly three different users connected downstream of the same node of a Low Voltage (LV) network. The maximum power of each single-phase user was calculated based on the results of the questionnaires administered to island users, which showed that, in most cases, these users use a power of 3 kW. Regarding the sizing of the configuration used to emulate a three-phase user, it was considered a committed power of 15 kW, typical of tertiary and small commercial users (bars, grocery shops, etc.) widely present in the smaller islands. The test bench is installed inside the SMGLab located on the ground floor of the Engineering Department's building 9 of the University of Palermo and it is powered by the room's system through a pentapolar IEC 32A 400V socket located in the laboratory. The installation includes:

- an electrical cabinet containing all protection, switching, and measuring devices;
- an isolating transformer (installed to increase the level of safety for the operator);
- six variable resistors, for the simulation of passive loads of different magnitudes;
- a controllable single-phase asynchronous electric motor for simulating active loads;
- a photovoltaic inverter connected to a DC generator that can emulate the behavior of a PV array;
- a Lithium electric storage system;
- a component control system for energy exchange management;
- an intelligent monitoring system capable of communicating with remote Energy Management Systems (EMS) also via Blockchain platforms.

Fig. 1 shows the design of the test bench layout, in which:

1. 3 kW single-phase PV inverter with lithium batteries
2. lithium battery pack - 4.5 kW photovoltaic storage;
3. photovoltaic simulator;
4. IEC 2P+T 220 V 16 A socket;
5. variable resistors;
6. AC motor speed controller;
7. single-phase AC motor with flywheel;
8. control PC;
9. metal panel;
10. IEC 4P + T 400 V 32 A socket and flexible cable for five-pole mobile laying L=15 m;

C: plastic wireway with lid;

P: RK-15 32 mm pipe.

Fig. 2 shows the overall photo of the test bench installed inside the laboratory, from which all the components system can be seen.

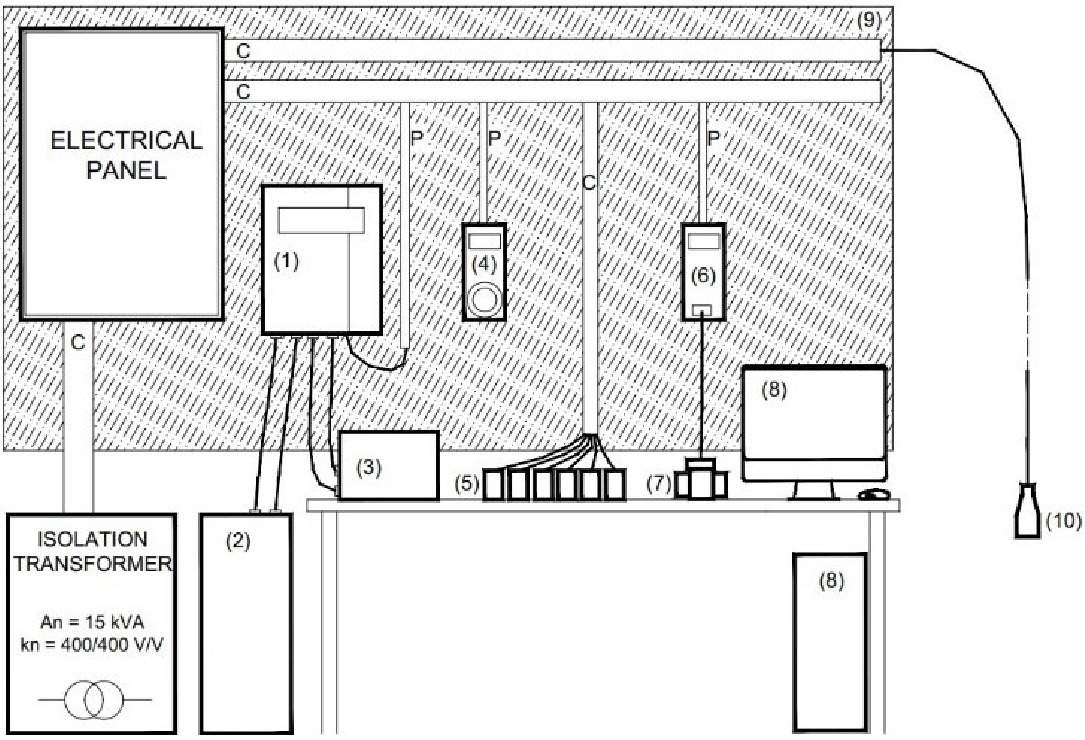

Fig. 1. Test bench components.

Fig. 2. The test bench.

The switchboard diagram was designed considering the results of previous studies [1].

The switchboard contains a control system built with Arduino and can be interfaced with a workstation via the department's LAN network.

Fig. 3 shows the single-line circuit diagram of the test bench that was electrically dimensioned using the I-project software [16].

The diagram shows the smart meters on each circuit and upstream of the entire test bench. The smart meters used are connected via an RS485 Modbus interface with four SNOCU devices, manufactured by Regalgrid® [17]. By interfacing with the Arduino, the SNOCU enables control of the electrical storage system and connection to a blockchain for managing the test bench data.

The isolating transformer, visible in the diagram, realizes an IT-type electrical system, with the aim of isolating the entire test bench from the building's power supply, limiting fault currents and dangerous overvoltages on the components supplied by the test bench. In addition, a release button was fitted on the main switch of the switchboard upstream of the isolating transformer to interrupt the power supply promptly in the event of danger to the test bench operator.

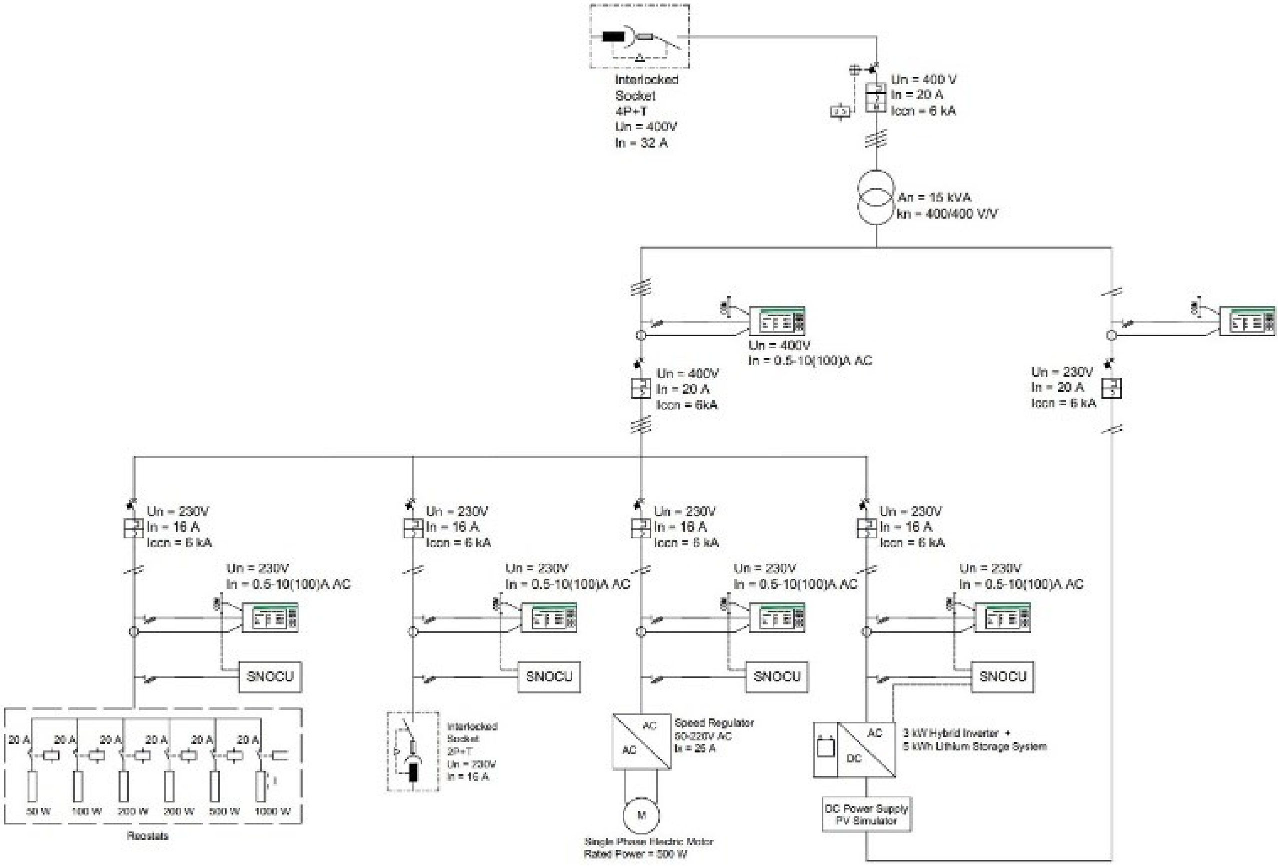

Fig. 3. Single-line circuit diagram of the test bench.

The isolating transformer is a three-phase dry-type transformer with epoxy resin insulation; it has a size of A_n =15 kVA, a transformation ratio k_n = 400/400 V/V, and group Dy11. The component is also equipped with a winding's temperature control unit.

a) 

b) 

Fig. 4. Isolating transformer (a) and temperature control unit (b).

An inverter powered by a programmable DC generator is used to simulate the presence of a PV generator. The generator can emulate the typical behaviour of a PV field and it has been dimensioned so that its output parameters respect the coupling conditions with the upstream inverter [18].

Fig. 5. Photovoltaic emulator.

To simulate a photovoltaic curve, several reference parameters specified by the manufacturers of photovoltaic panels and usually referring to standard conditions (temperature of 25 °C and irradiance of 1000 W/m^2) are required. Therefore, the first step in simulating the photovoltaic curve is to choose the photovoltaic panel to be simulated and enter its specific data into the simulator.

All the necessary parameters for the photovoltaic simulation can be configured using the desktop application through which the calculated photovoltaic curve with the entered values and the voltage and current measurements of the power supply can be displayed.

The inverter used is an HYD 3000 ES hybrid device from ZCS, which is combined with a 5-kWh lithium storage system.

a)

b)

Fig. 6. ZCS HYD 6000 ES hybrid inverter (a) and 5kWh storage system (b).

The inverter manages the battery charge/discharge mode according to user-customisable and remotely settable programmes, providing good flexibility for both domestic and non-domestic applications.

The inverter is designed to work in the presence of the grid (On-Grid mode) but also to supply privileged loads in its absence (EPS mode: Emergency Power Supply).

Passive loads are simulated with variable rheostats of the linear slider type from ItalOhm, which consist of cylindrical porcelain tubes on which an aluminum resistive winding is made. By moving the slider along with the special guide, it is possible to adjust the resistance value of the rheostats and, consequently, the power absorbed by them, simulating different load entities. The choice of these components was made in response to the need for simplicity and immediacy in the simulation of a domestic load, as well as the need for robust and durable components that can withstand the stress of laboratory tests. In addition, the component represents well the behavior of most loads connected to small and medium-sized LV systems that have a power factor between 0.95 and 1.

In total, six 200 Ω rheostats were purchased, each capable of engaging a maximum power of 1200 W with a maximum current of 2.4 A. The rheostats are connected to the test bench by means of pin connectors and connected/disconnected by controlling the closing/opening of contactors installed in the switch cabinet.

a)

b)

Fig. 7. ItalOhm single-phase slider rheostats (a) and rheostat supply panel (b).

Finally, there is also a single-phase asynchronous motor to simulate ohmic-inductive loads. The size of the load is adjusted by acting on a special speed regulator. The motor size was chosen to be 0.5 kW, which is compatible with that of loads found in ordinary households.

The presence of a UNEL 10/16A civil socket and a 230V 2P 16A industrial socket complete the test bench and provide the possibility of connecting other loads to the protection cabinet outputs.

Finally, Fig.8 shows the comparison between a simulated load profile and the one reproduced in the laboratory by controlling the resistances through the EMS. The load profile obtained by controlling the prototype is similar to the one simulated in MatLab using a Montecarlo approach. Ten weekdays were simulated and reproduced for each user, and the respective measured consumption data of meters were sent on the blockchain through SNOCUs.

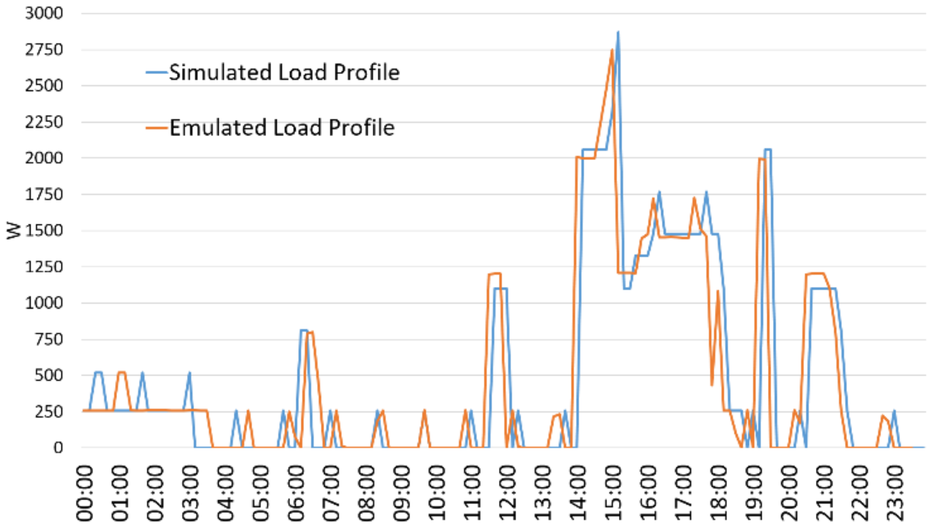

Fig. 8. Daily load profile simulated in MatLab and load profile emulated in laboratory controlling the resistors.

III. Communication with the Blorin Blockchain

The test bench framework was connected to a Hyperledger Fabric blockchain developed for various applications by the Engineering Department of the University of Palermo in collaboration with the academic spin-off Seeds [19]. The blockchain is implemented on four PCs that act as blockchain nodes.

The blockchain communicates with the Raspberry PI board of the test bench's control and protection panel, which is interfaced with the meters of the different users. The complex consisting of a meter and the Raspberry board represents the user EMS that becomes a client of the blockchain.

The Raspberry board communicates with the blockchain via the DING's LAN to which it can be connected wirelessly or wired.

Figure 9 shows the diagram of the connection of the user EMS with the blockchain.

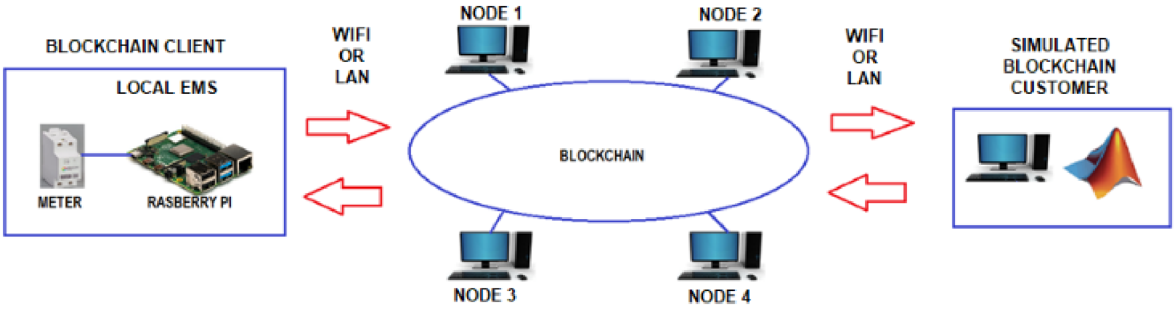

Fig. 9. Structure of the implemented blockchain.

The EMS is programmed to send data into the blockchain using a code in Python while the realised blockchain is programmed in JavaScript. In particular, the blockchain contains APIs (application programming interfaces) to translate the messages in Python language into the JavaScript language in which the smart contracts are programmed.

In addition, a code was created in Matlab to make a laboratory PC communicate with the blockchain as if it were another blockchain client. The software translates the power profiles simulated with the *dwh.m* software for simulating water heaters and heat pumps and those generated with the software implementing the Montecarlo methodology to blockchain and transmitted to it via the LAN. Similarly, the software allows reading from the blockchain as if it were an EMS receiving commands from it to implement DR actions.

The procedure for sending simulated consumption data in MatLab, via a Montecarlo method, to the implemented blockchain platform is described. The following steps are performed:

- A load profile of a user or device is simulated with the Montecarlo method in MatLab; in the MatLab code under consideration, this profile is the vector defined "Phouse".
- A text file called 'User_json.txt' is opened in MatLab, which represents the message format that the blockchain can receive; it is a standard JSON-type format.
- Using the jsondecode command, the file "User_json.txt" is transformed into a format that can be managed by MatLab (Fig. 10); that is, the data packet is converted into a MatLab structure called "User_5min".
- We proceed by implementing for loops, in which the "time" and "l1_w" fields are modified at each cycle; the former represents the date and time of the simulated measurement, and the latter represents the simulated power value. At each cycle, the "User_5min" structure is sent in JSON format directly to the blockchain via API, using the webwrite command.

It should be emphasized that the algorithm for writing data to the blockchain must only act when a specific event to be recorded occurs. Indeed, blockchain technology is still particularly energy-intensive and, consequently, the data to be recorded must be carefully chosen. Indeed, the application of blockchain to EC and DR programs still poses several challenges.

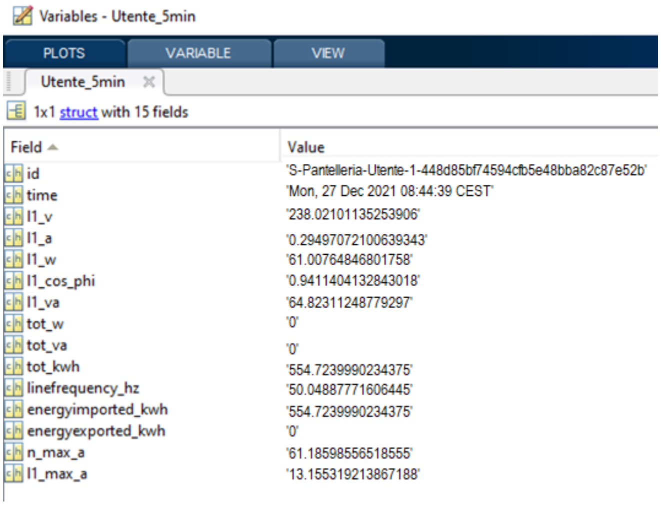

Fig. 10. Structure of the data packet to be sent to the blockchain.

IV. Conclusion

This paper describes a testbed developed in the context of the Blorin project for the emulation of a smart prosumer. Through the photovoltaic generator and hybrid inverter equipped with lithium batteries, it is possible to emulate both the production of a small PV system and an electric vehicle, while through the restistors and the motor it is possible to simulate the prosumer's load profile. In this way it is possible to emulate DR events, V2G, generic load profiles, PV production profiles, and prosumer behavior the changing environmental paramenters.

All the components are controllable through specific devices that make the testbed smart while enabling communication with the Blorin's blockchain. Further development will focus on emulating Positive Energy Districts, small energy communities and self-consumption groups, both physically and in terms of data management through the blockchain.

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