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Doctoral Dissertation
Doctoral Program in Electrical, Electronics and Communications Engineering
(36th Cycle)

The PVZEN lab: an energy community with PV systems and storage supplying all-electric buildings

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Politecnico di Torino
March 2024

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The active engagement of citizens is crucial to accelerate the decarbonisation of energy systems. The European Union declared its plan to involve citizens in the energy transition, both individually and jointly, with the "Clean Energy for All Europeans Package". Regarding the collective dimension of citizen engagement, Directives 2018/2001/EU and 2019/944/EU introduced the concepts of "Renewable Energy Community" and "Citizen Energy Community", respectively. Although there are some differences between the two definitions of energy community, both directives enable the aggregation of citizens for the production, consumption, sharing and storage of energy to generate environmental, economic, and social benefits.

Since energy communities have garnered significant attention in recent years as promising enablers for the clean energy transition, researchers have started investigating their energy, economic and social implications and developing technologies, strategies and other tools that can effectively support their creation and efficient operation.

This work aims to contribute to research on energy communities through the construction and operation of an experimental laboratory within the Politecnico di Torino. The laboratory, called PhotoVoltaic Zero Energy Network (PVZEN), consists of a microgrid of three prosumers, equipped with photovoltaic generators and electrochemical storage systems. The generators, the storage systems and the bi-directional inverters required for energy conversions are commercially available products installed in the laboratory. On the contrary, the energy demand of the three prosumers can be either real electrical loads within the university campus or emulated loads. Indeed, three controllable resistive loads, constituting the emulator of buildings, were installed in the laboratory for reproducing the power consumption of real-time simulated buildings. Each resistive load is associated with a photovoltaic generator equipped with a storage system. The emulator is conceived to reproduce the behaviour of all-electric buildings, where electricity satisfies all energy needs,

including those of HVAC equipment. In the microgrid, energy exchange is enabled like in an energy community and managed by a centralised control unit.

The laboratory allows the evaluation of the energy performance of photovoltaic and storage systems coupled to all-electric buildings within an energy community through experimental activities. Energy communities consisting of different combinations of buildings can be explored, as the virtual buildings to be simulated can be changed. Furthermore, it is possible to customise the algorithm that controls energy exchange between the community members, allowing the investigation of several energy sharing strategies based on energy and/or economic criteria. The microgrid can operate both on-grid and off-grid, enabling the study of different operating conditions. Finally, by monitoring the operation of the lab, the virtual model of the PVZEN microgrid was calibrated, allowing simulation studies on energy communities in different locations and involving a different number of users.

This dissertation, after a brief introduction to the research context, provides an overview of the research activities concerning energy communities conducted in recent years. Then, the PVZEN laboratory is presented, describing the methodologies for energy exchange management and the simulation and emulation of virtual buildings. Afterwards, the first operation period of the laboratory and an experimental case study carried out in summer 2023 are discussed. Finally, the development and an example application of the virtual microgrid model for simulation studies are illustrated.