Knowledge exchange on microgrids and joint development of an Energy Management System to strengthen energy supply in rural areas in Morocco based on renewable energy

Aissam Ait-Omar[1], Imane Hammou ou ali[1], Da Wang[2], Raf Ponnette[2], Hichame Laabassi[1], Abdelali Djdiaa[1], Carlo Mol[2], Hichame Bouzekri[1]

[1] R&D department, Moroccan Agency for Sustainable Energy (MASEN), Rabat, Morocco

[2] Flemish Institute for Technological Research (VITO/EnergyVille), Genk, Belgium

Overview: The goal of the project is to analyze the challenges that microgrids, based on mainly renewable energy combined with battery systems, are facing in rural Morocco and to stimulate their uptake. To arrive at this end, it is important to have a good knowledge of the energy market and end user needs and to make the right choices when designing and operating microgrids to optimize investment and operational costs. Within this project the focus will be mainly on developing an Energy Management System (EMS) for microgrids that is ready for industrialization. Besides the EMS, specific attention will be given to the integration of battery systems which are crucial in renewable energy based microgrids for balancing supply with demand. The project has received funding from the Government of Flanders and will be jointly implemented by VITO and Masen, the group responsible for managing renewable energy in Morocco. The technical developments will be executed on the Masen R&D Platform for energy technologies which is located in the megawatt-scale "Solar Complex of NOOR Ouarzazate", Morocco**.** MASEN's R&D platform incorporates several demonstrators with different technologies. This group of demonstrators can be viewed as Multi-microgrid system, and it constitutes a medium voltage electrical network that is connected to the national grid. Furthermore, MASEN comprises a dedicated laboratory for microgrid related Hardware In the Loop (HIL), Controlled Hardware in the Loop (CHIL), and Power Hardware In the Loop (PHIL) simulations. In this laboratory, we will perform validation tests for the developed EMS solutions, replicating real-world scenarios that emulate the intended use cases.

Africa's renewable resources potential and electrification status

Africa is currently facing a contrasting reality. On one hand, the continent has significant reserves of energy resources, both fossil and renewable, but on the other hand, it must confront numerous energy challenges. Despite their abundance, these resources remain underutilized, while 570 million people in sub-Saharan Africa did not have access to electricity by the end of 2020 (77.5% of the global total). Despite accounting for 17% of the world's population, the continent consumes only 5.9% of the energy produced globally. According to IRENA, RE's global capacity in Africa reached 55.7 GW in 2021, which is a 4% increase compared to 2020. However, this represents only 2% of the total installed capacity for electricity production from renewable sources worldwide. In Africa, the share of EnR in installed power capacity was only 23.1%, while Europe had 52.1%, South America had 68.5%, North America had 32.1%, and Asia had 37.7%. The fruits of this project can be later extrapolated to the rest of Africa.

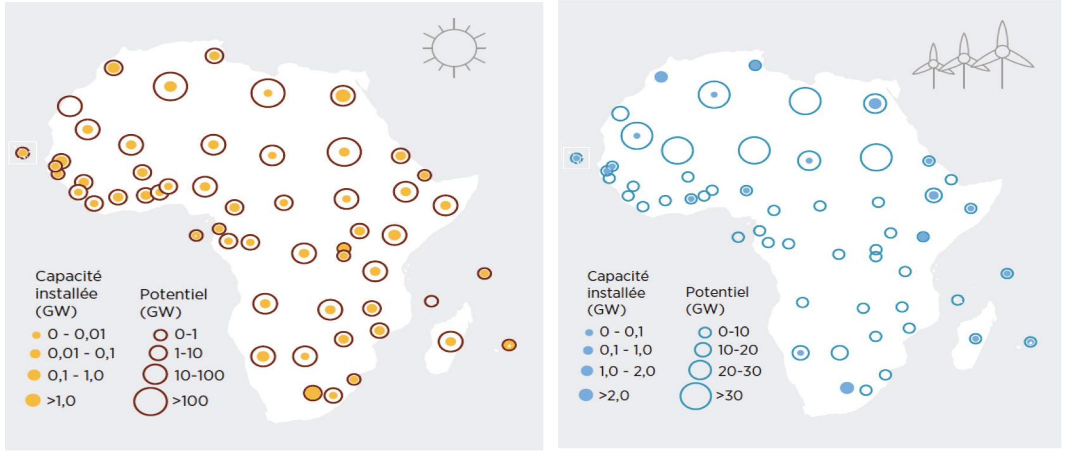


Fig. 1 Capacity Vs Potential of PV and Wind in Africa

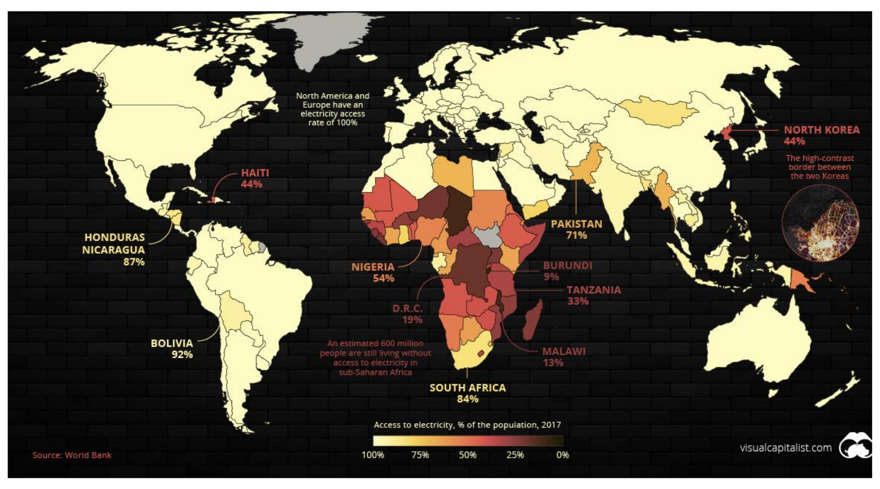


Fig. 2 Electrification status in the world

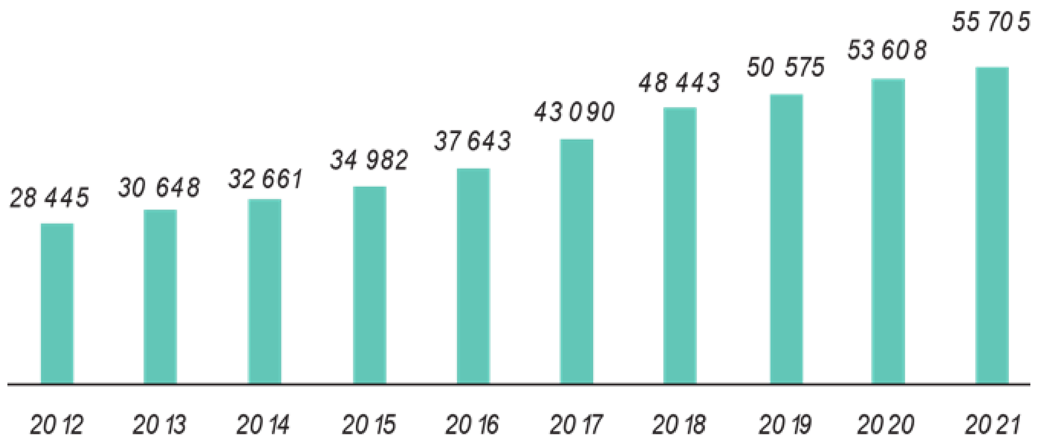


Fig. 3 Evolution of total RE production capacity in Africa (in MW)

Electrification situation in Morocco

Zooming in on the northern tip of Africa, Morocco emerges as a prime example of a nation with remarkable untapped energy potential. As seen in Fig. 5, Morocco is favored by an important renewable energy sources potential. To date, almost 4100 MW of RES projects are operational in Morocco with an additional 6 GW of RES projects to be added by MASEN in the horizon of 2030. Morocco's rural electrification journey highlights a remarkable growth trajectory, with the electrification rate steadily rising from 18% in 1995 to an impressive 99.83% in 2021. This progress can be attributed to the sustained investment of approximately €2.5 billion by the National Office of Electricity (ONE) between 1998 and 2015. The transformative impact of electricity access has positively influenced rural communities, fostered development and improved living standards across the country. However, these numbers cover areas where only basic needs are met from lighting to refrigeration and some sockets for phone chargers. The deployment of microgrids could be n effective method to increase access to higher levels of energy for people living in those areas.

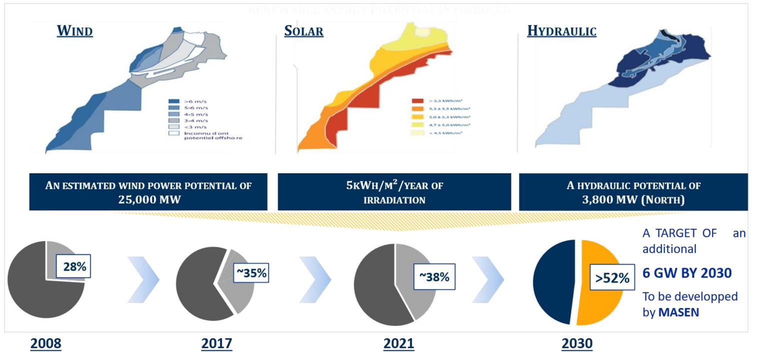


Fig. 5 Renewable energy Potential in Morocco

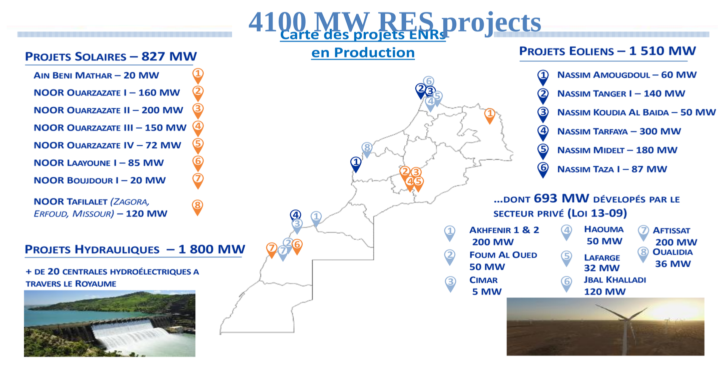


Fig. 6 Renewable Energy projects in Morocco

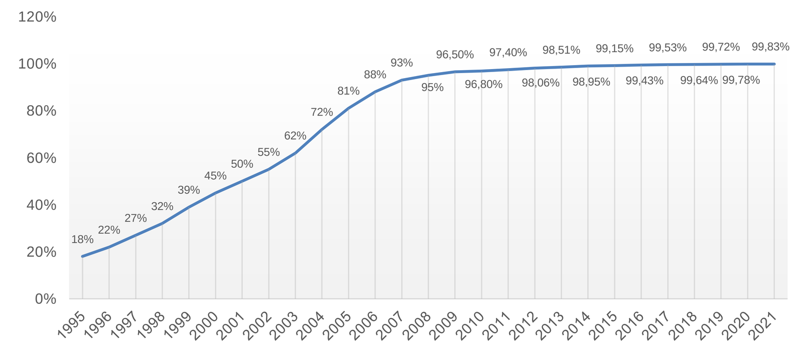


Fig. 7 Rural electrification status in Morocco (ONEE)

Microgrids for rural Morocco

Microgrids rely on a hierarchical control structure to efficiently manage distributed energy resources. At the top level, there's a central controller that oversees the entire microgrid, optimizing its operation based on grid conditions and user requirements. Below this, local controllers manage individual components like generators, storage systems, and loads. Coupling mechanisms ensure seamless energy exchange between these components, allowing for dynamic load balancing and grid resilience. Inverters play a pivotal role in this setup, converting DC power from sources like solar panels and batteries into AC power that can be used within the microgrid or exported to the main grid, enabling flexible energy integration and grid stability.

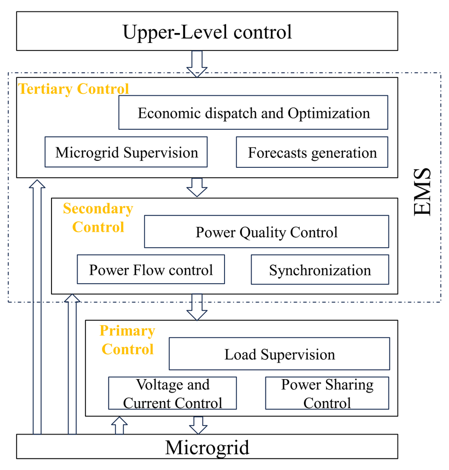


Fig.8 MGs 'hierarchical control structures

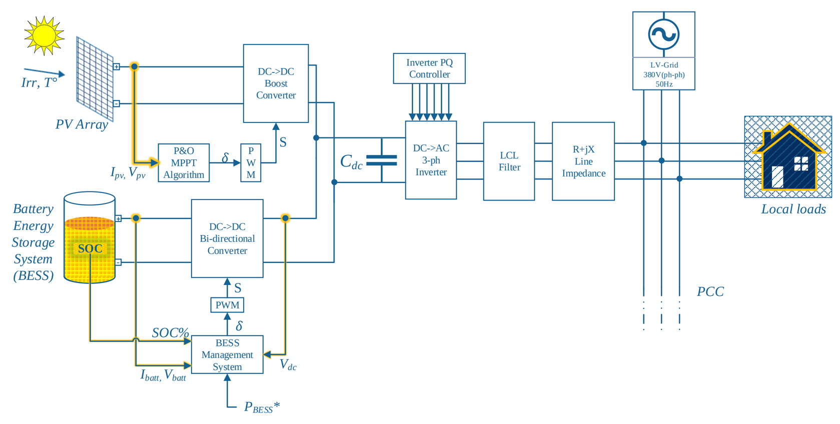
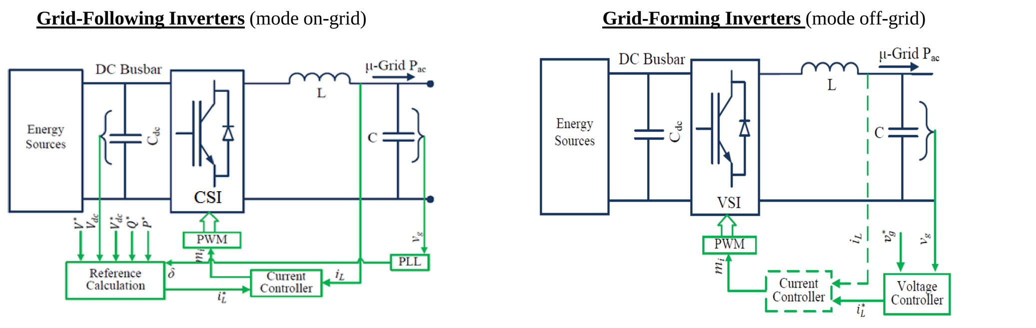


Fig.9 AC coupled MG



- The inverter acts as a current source.
- The voltage is regulated by the grid.
- The user sets the active/reactive powers references.

- The inverter acts as a voltage source.
- The voltage is regulated by the inverter.
- The load dictates the current (output power).

Fig. 10 Inverters in a MG

Energy Management System (EMS)

Microgrid Energy Management Systems (EMS) are vital for an efficient energy control. The architecture consists of a local controller managing distributed energy resources and loads, connected to a central controller overseeing the entire microgrid. Centralized and decentralized topologies are also common, with the choice depending on the scale and complexity of the microgrid. Techniques such as demand response, load forecasting, and real-time optimization play a pivotal role in ensuring reliable and efficient energy distribution within microgrids, enhancing their resilience and sustainability.

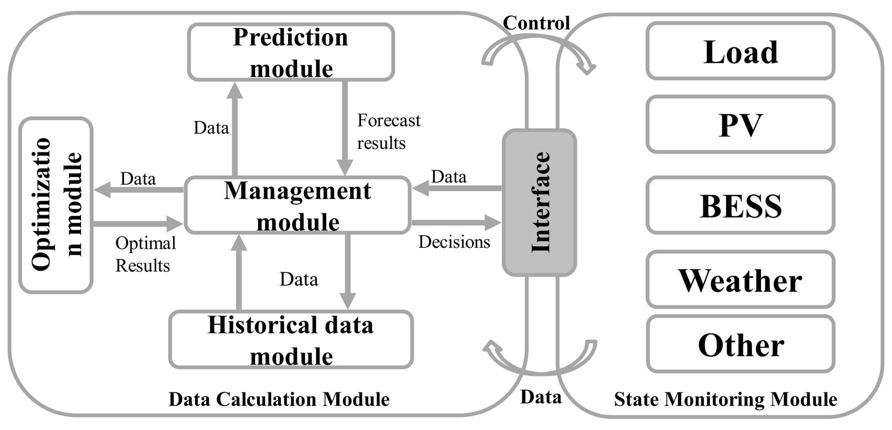


Fig. 11 An EMS's typical architecture

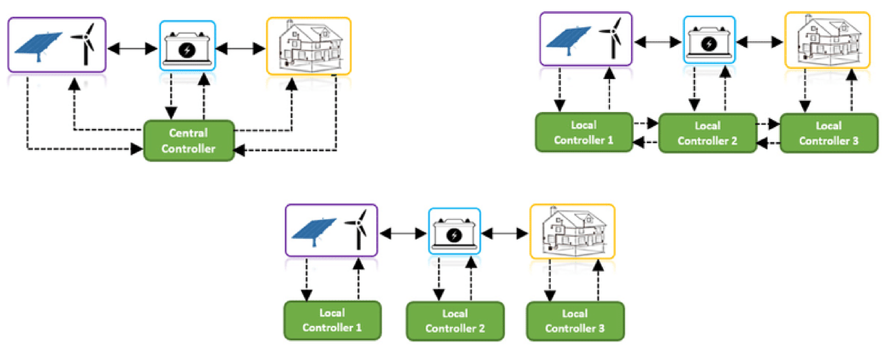


Fig. 12 EMS's structures

Microgrid R&D laboratory

Model in the Loop (MIL) simulation involves integrating mathematical models into a testing environment for interactive development and analysis. Rapid Control Simulation (RCS) focuses on control algorithm development and real-time testing. Hardware in the Loop (HIL) takes it further by integrating physical hardware components, providing realistic testing and cost benefits. System validation encompasses these techniques to ensure that a system meets requirements, complies with standards, and operates safely, with data collection and documentation throughout the process. The laboratory in Ouarzazate/Morocco will allow the hardware in the loop, the control hardware in the loop, and the power hardware in the loop testing of the developed EMS solutions and the R&D platform can be used for the system validation which is the final development stage. The available equipment in the laboratory enables the emulation of DC and AC microgrids with PV and ESS that operates in grid-tied or standalone modes. The current configuration doesn't allow HIL simulations for inverters control strategies, but the supplementary equipment necessary are being acquired by MASEN.

Step of Development	System	
	Controller	Plant
MILS[Model In the Loop Simulation]	Model	Model
RCP Rapid Control Prototyping]	Model	Real
HILS [Hardware In the Loop Simulation]	Real	Model (Digital Twin)
System Validation	Real	Real

(Digital Twin) Same — Same

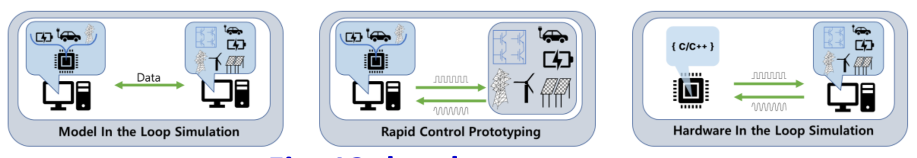


Fig. 13 development stages

Fig. 14 MGs laboratory in Ouarzazate

1. Speedgoat Base model
2. ESS PCS
3. PV PCS
4. PV simulator
5. Battery simulator
6. RLC load simulator
7. Line impedance
8. AC source simulator

Fig. 15 Overview of the laboratory equipment