Microrredes – Solução para mitigação dos efeitos de apagões/blackouts - Caso de estudo ISR-UC

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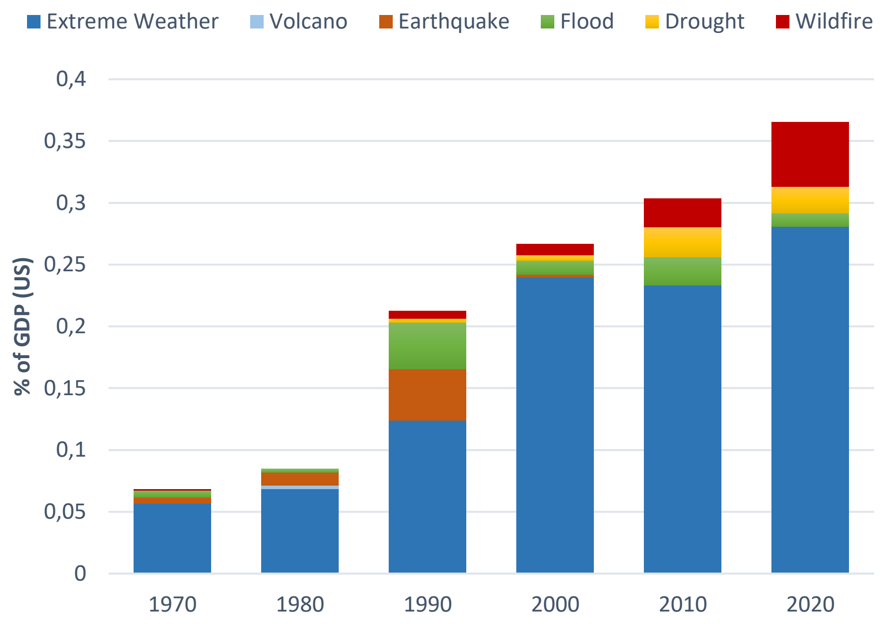
BungEES

Introduction

The frequency of natural disasters is increasing!

In the last five decades the economic impact from disasters as a share of US GDP has increased sevenfold!



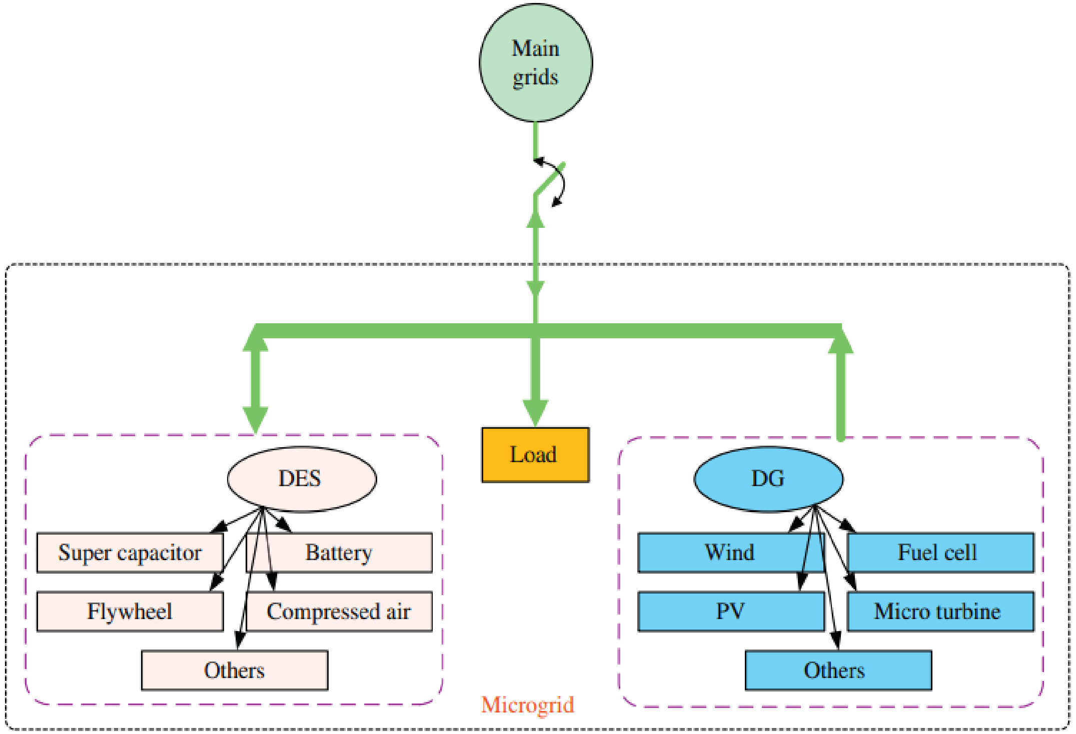
Decadal Economic impact from disasters as a share of GDP, US

Objective of this work: Propose an algorithm for the design and management of electric microgrids with a focus on resiliency towards critical and disaster situations.

Introduction

A well-designed microgrid is capable of maintaining continuity of energy supply, isolated from the utility grid, during extended periods of time.

- Local energy generation, energy storage systems, demand response and forecasting;
- Load shedding and balance between supply and consumption to maintain energy supply to critical loads during power outages;
- Operating modes based on the availability of resources and load prioritization.

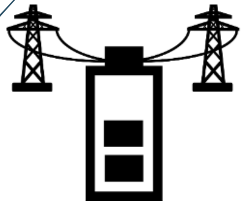


A generic microgrid schematic

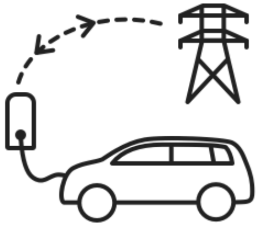
How?

- Develop innovative methodology capable of maintaining energy supply to critical loads.

Optimize local generation and increase utility grid autonomy.

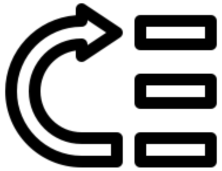


Use energy storage to smoothen power curve, absorb excess generation and contribute to grid stability.



Use vehicle-to-grid technology to complement energy storage capacity and deliver power to critical & essential loads.

Install load controllers to increase demand response capacity and grid stability.



Prioritize load consumers according to their importance to the grid or local services.

Monitor and evaluate economic and social impacts.

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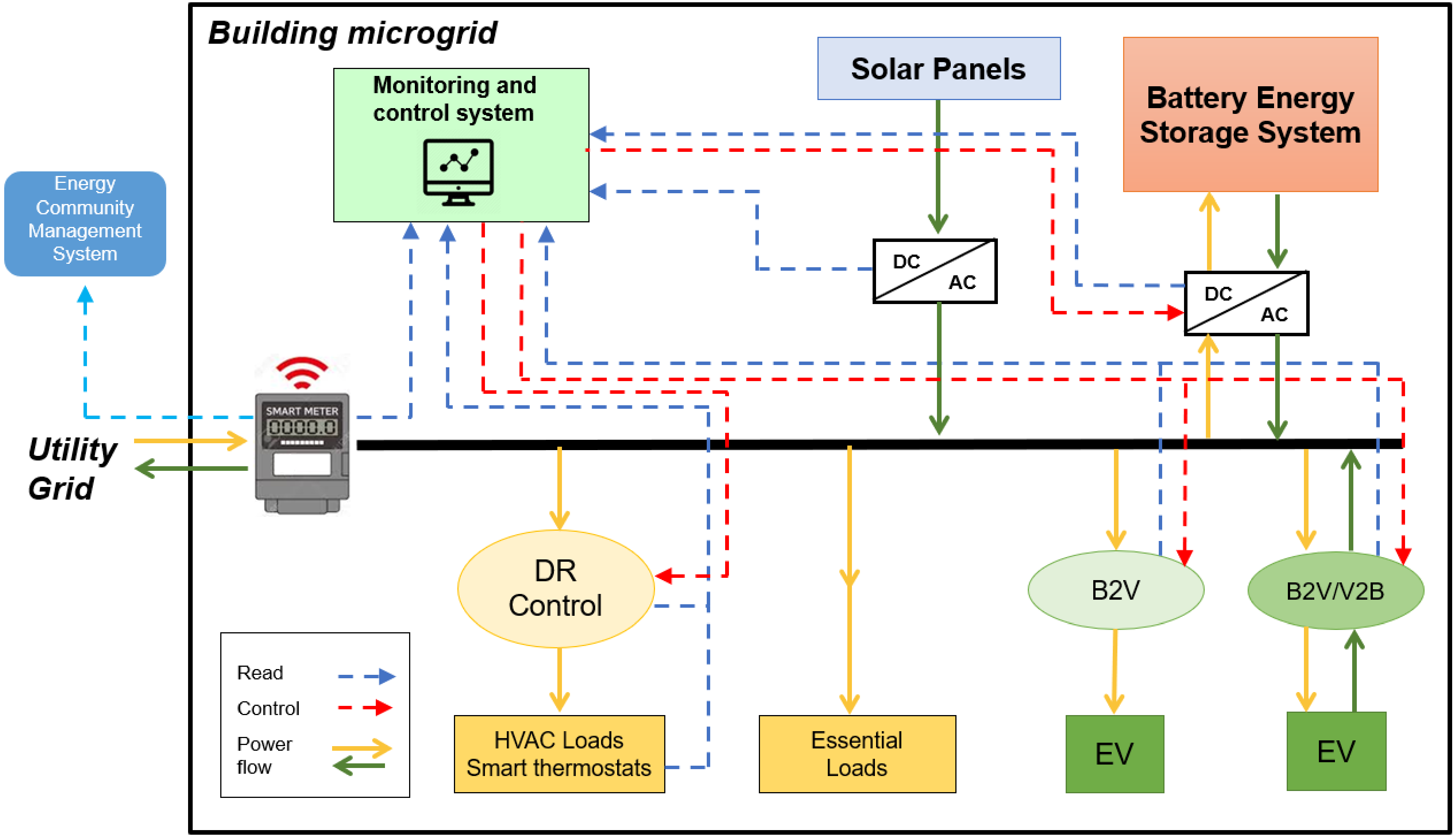
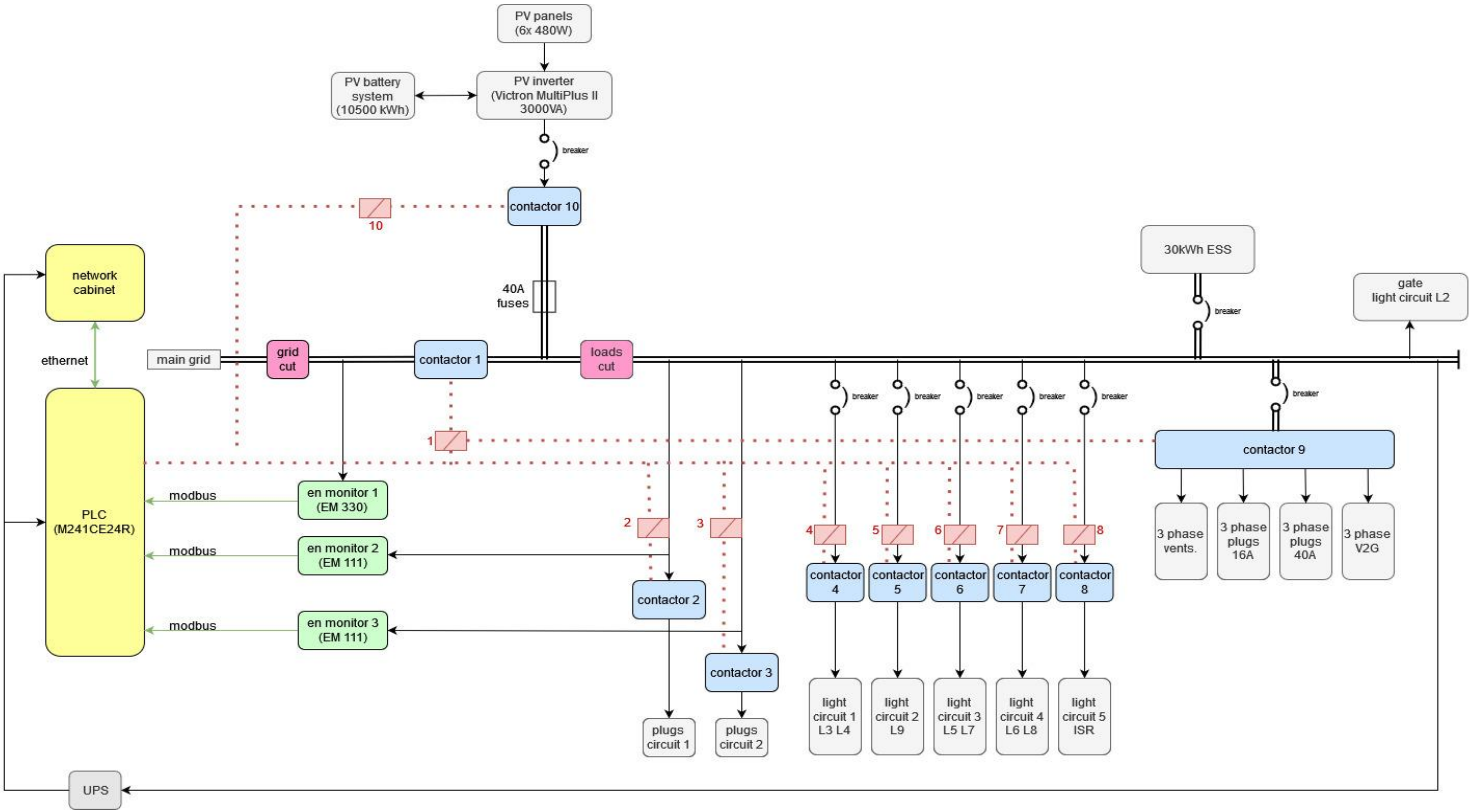
DEEC Building

- Pilot is implemented in Department of Electrical and Computer Engineering of University of Coimbra.
  - 9 floors, with a total area of about 10.000 m2 and electricity consumption of about 500 MWh/year.
  - Classrooms, offices, laboratories, administrative services, study rooms, bar, mechanical workshop and garage.
  - 70 kWp PV system, 30 kWh energy storage system, several unidirectional/bidirectional EV chargers, and controllable

Microgrid architecture



Microgrid detailed architecture



Energy Storage

- A pilot storage system was already installed in order
  to evaluate the positive impacts of the available capacity, and later a larger system will be installed.

- The battery can be used to store the surplus PV generation, as well as to take advantage of time of use rates.
  - The cost of energy during peak periods is much higher than the in super off-peak periods.
  - The energy that is going to be used during the morning peak periods is previously stored from the grid during the super off-peak period.

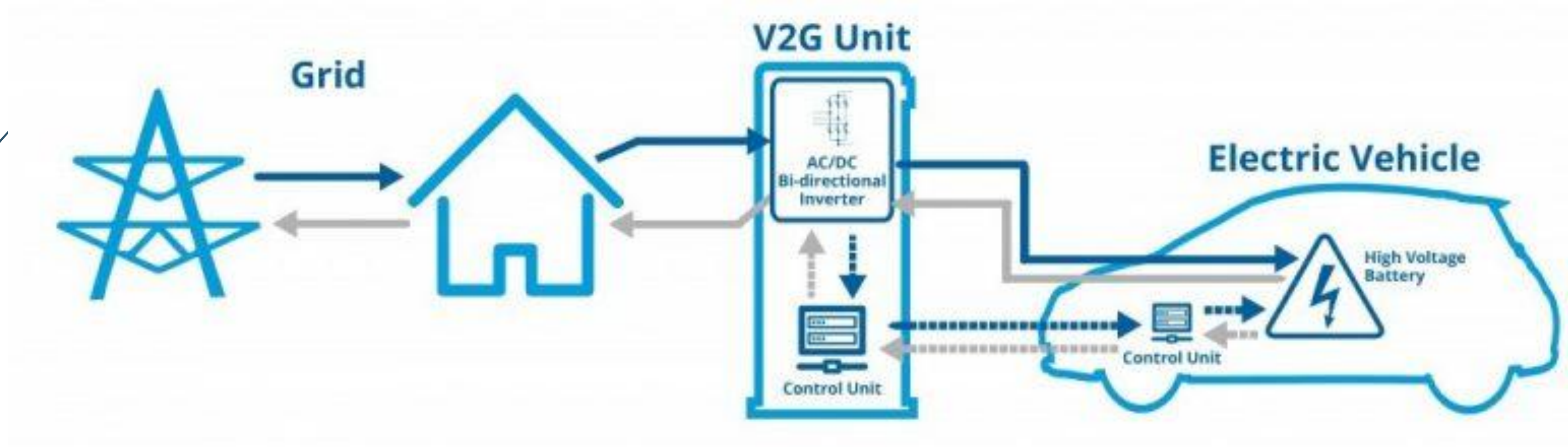
Batteries	3
Total energy	29.4 kWh
Usable energy	27.9 kWh
Power	15 kW

Power	$\eta_{Conversor}$ (charge)	$\eta_{Conversor}$ (discharge)	$\eta_{Battery}$	$\eta_{\text{round-trip}}$
0.1C	94.10%	94.43%	95.03%	84.45%
0.3C	94.80%	95.01%	95.04%	85.60%
0.5C	96.60%	96.52%	91.23%	85.34%

Vehicle-To-Grid (V2G) Charger

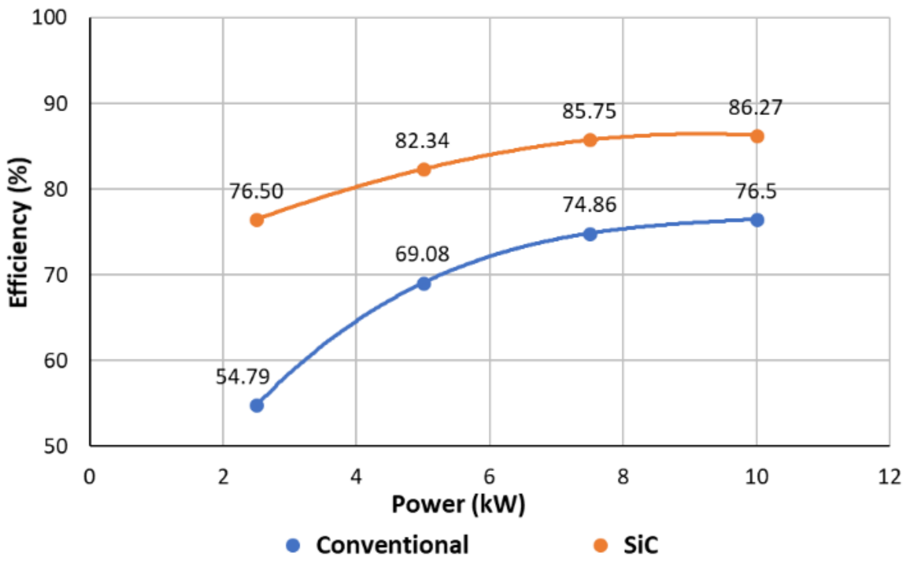
V2G – Concept developed by Prof. W. Kempton, University of Delaware, USA, 1997

- Battery performance (cost, efficiency and number of cycles) only now makes this concept feasible and potentially cost-effective.



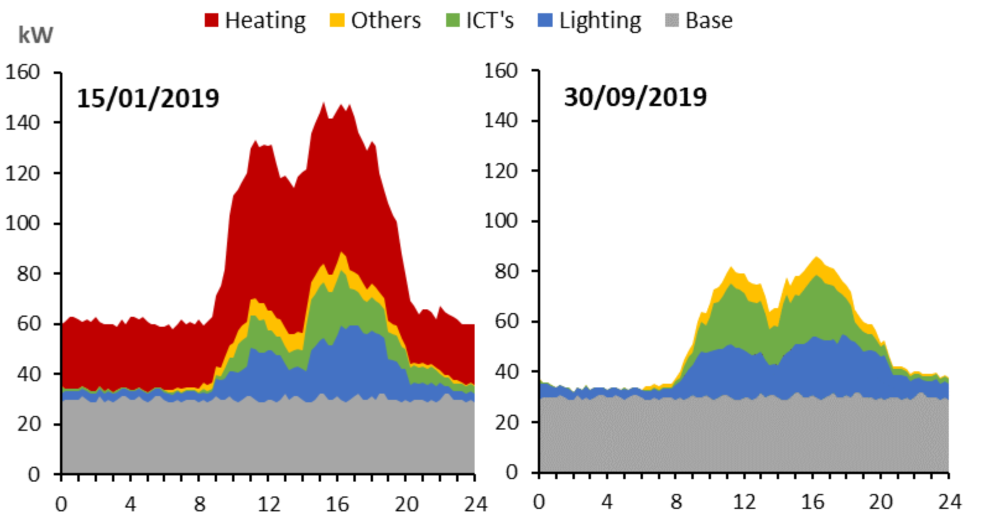
V2B and B2V

- With the aim of studying the integration of EVs in microgrids, 2 bidirectional chargers with an output power of 10 kW, have been installed in the DEEC garage.
  - One charger uses conventional silicon, and the other uses SiC technology.
- The chargers were then used in performance tests to assess their charging/discharging efficiency and round-trip efficiency.
  - **The SiC charger ensures an efficiency gain of 9.77% at the rated power** (10 kW) and more than 21.27% with a 2.5 kW power.



Demand Response

- Heating is responsible for an increase of 50 to 60% of the load diagram of the building.
- Since the building has about 40 mono-split reversible heat-pumps, smart controllers were used to enable the monitoring and control.
- The smart controllers allow to control the temperature setpoint, provide information about the real-time consumption and local temperature, as well as enable the On/Off or variable load (for inverter based units) control of each system, being the data sent to a local server.
- Such system enables the implementation of control actions, turning off or reducing the HVAC systems during short periods.



Microgrid Conversion Efficiency

- Different microgrid control operating strategies lead to different efficiencies in the power flows, relevant for cost and losses reduction.

Equipment	Conversion		TRF Grid	Charge EV	Discharge EV	Battery ESS	Battery Car	Round-trip Eff.
Operation	DC-AC	AC-DC						
PV-Grid	95%*		99%*					**94%**
Grid-BESS		97,01%	99%*			91,23%		**87,62%**
BESS-Grid	96,35%		99%*			91,23%		**87,02%**
ESS-EV		97,01%		91,10%		91,23%	95,00%*	**76,59%**
ESS-EV Sic		97,01%		95,46%		91,23%	95,00%*	**80,26%**
G2V			99%*	91,10%			95,00%*	**85,68%**
G2V sic			99%*	95,46%			95,00%*	**89,78%**
V2G			99%*		88,25%		95,00%*	**83,00%**
V2G sic			99%*		96,23%		95,00%*	**90,50%**
V2B		97,01%			88,25%	91,23%	95,00%*	**74,20%**
V2B sic		97,01%			96,23%	91,23%	95,00%*	**80,91%**

Resilience

The "R's" of Resilience:

Robustness – *Withstand shock without loss of supply.*

- Reinforced hardware (power lines), reliable communications, adequate maintenance;

Redundancy – *Eliminate single points of failure.*

- Backup elements, diversify and decentralize energy and storage sources;

Resourcefulness – *Strategic management of resources to mitigate damage.*

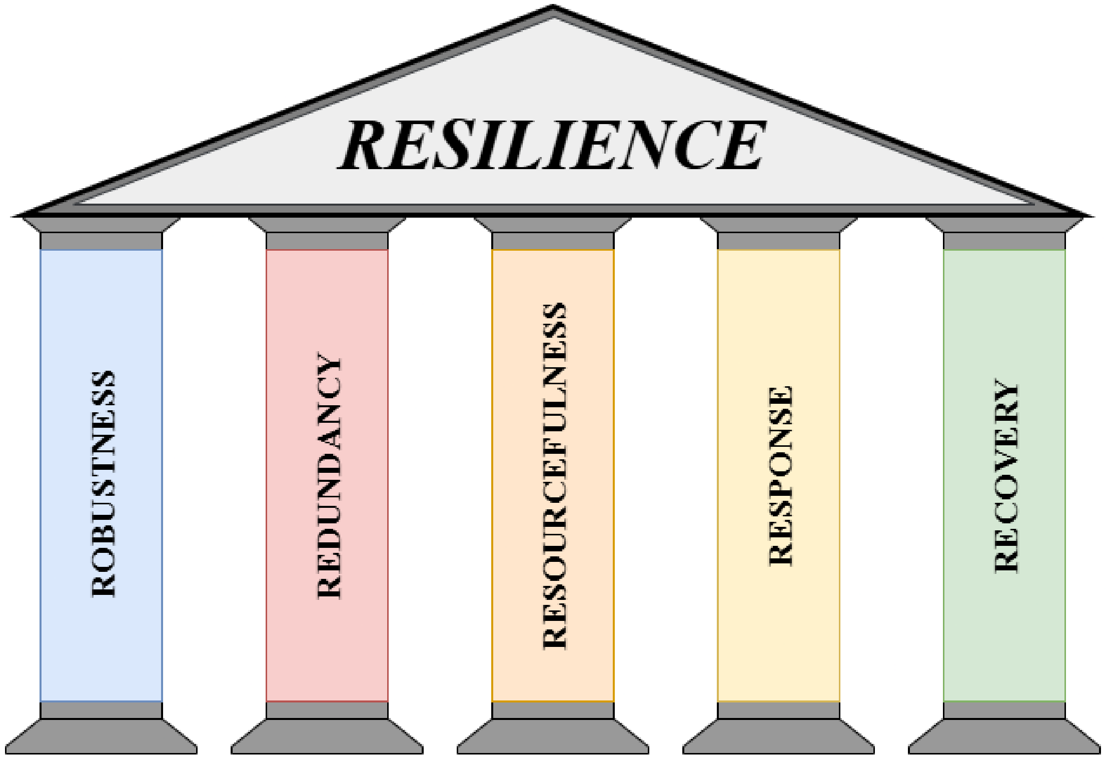
- Demand response, load shedding and energy reserve management;

Responsiveness – *Ability to react during fault.*

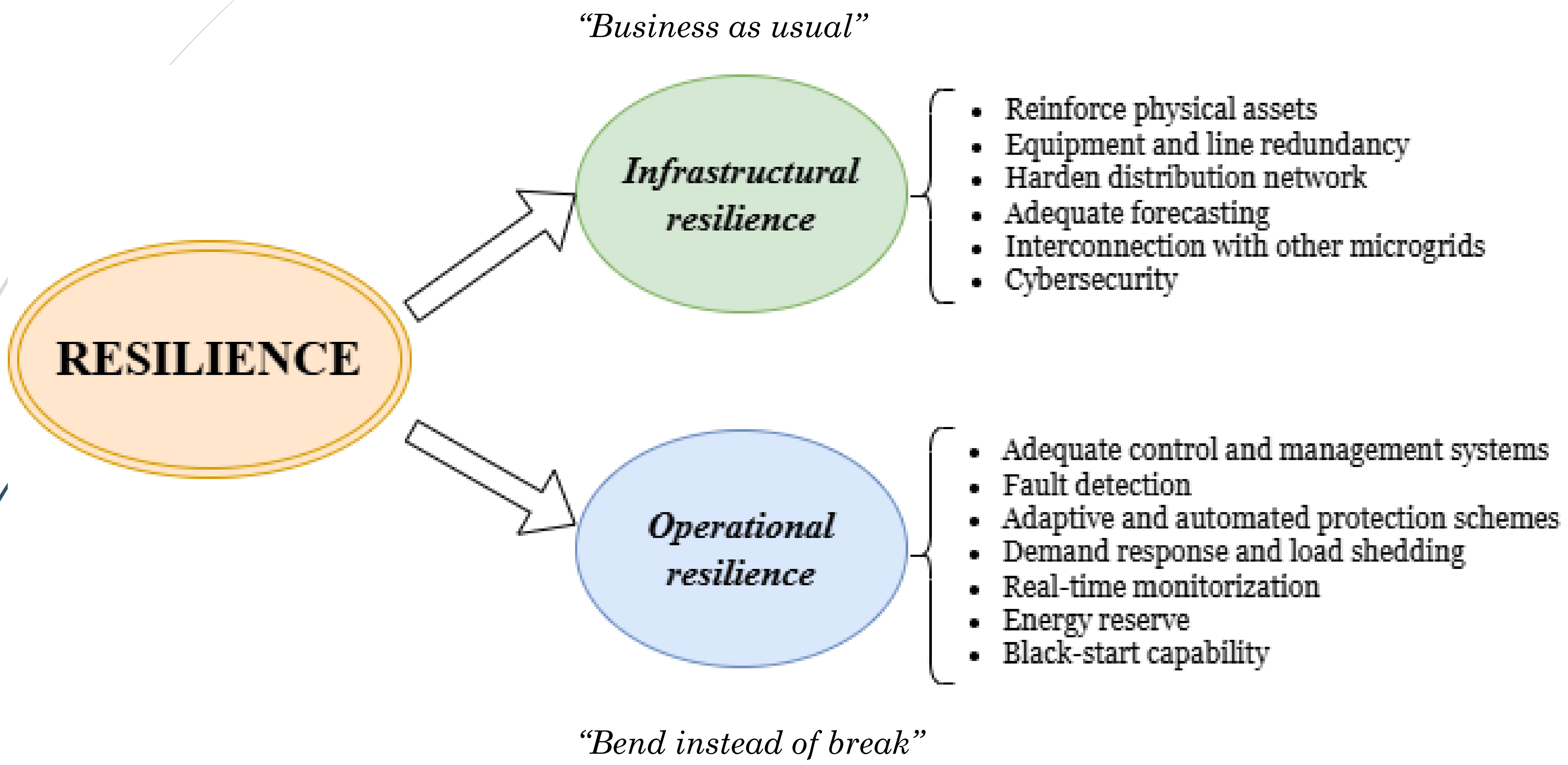
- Advanced control, monitoring and forecast systems, fault identification and isolation, and emergency protocols;

Recovery – *How quickly can the system recover;*

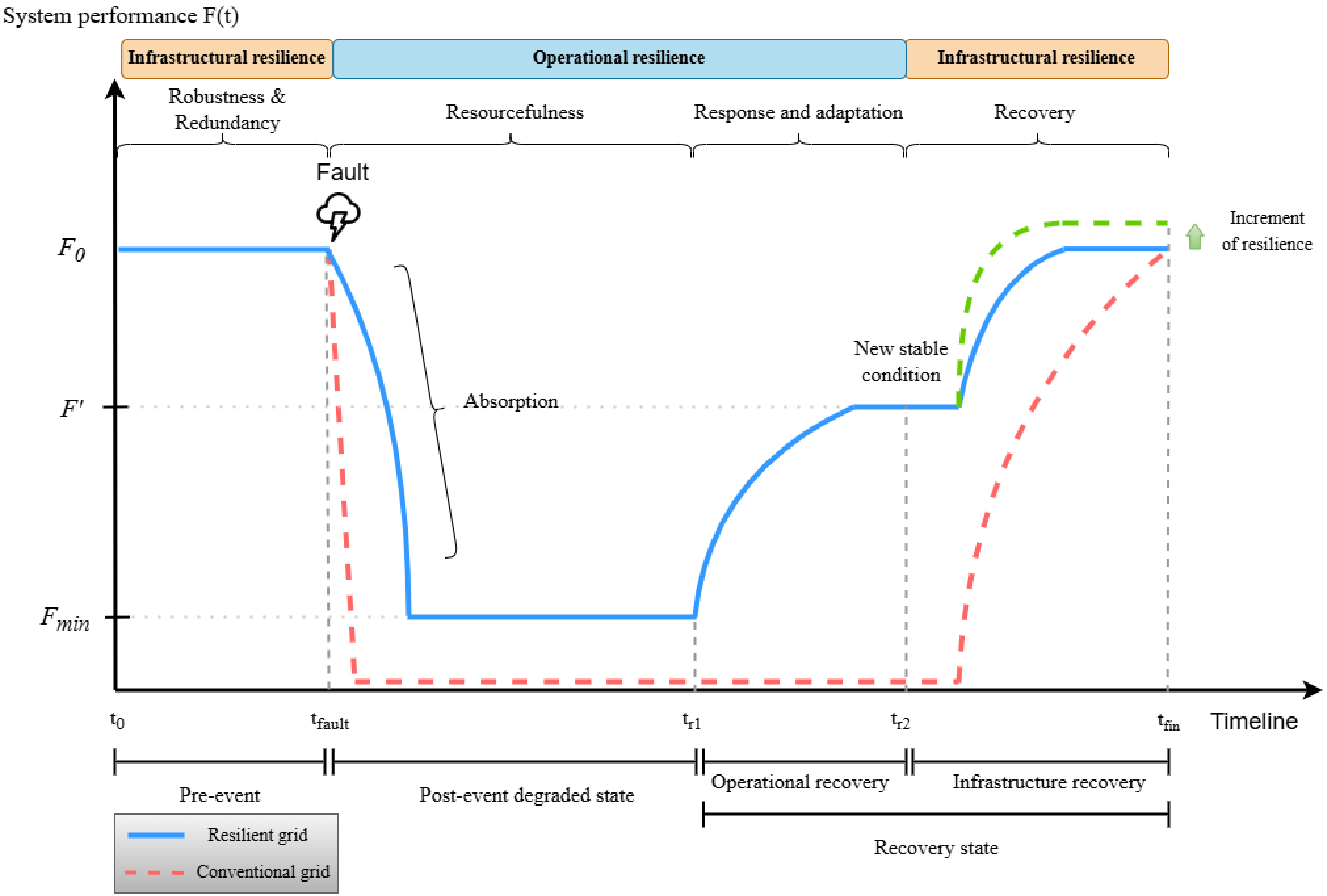
- Black-start schemes, time to repair (spare parts), microgrid reconfiguration



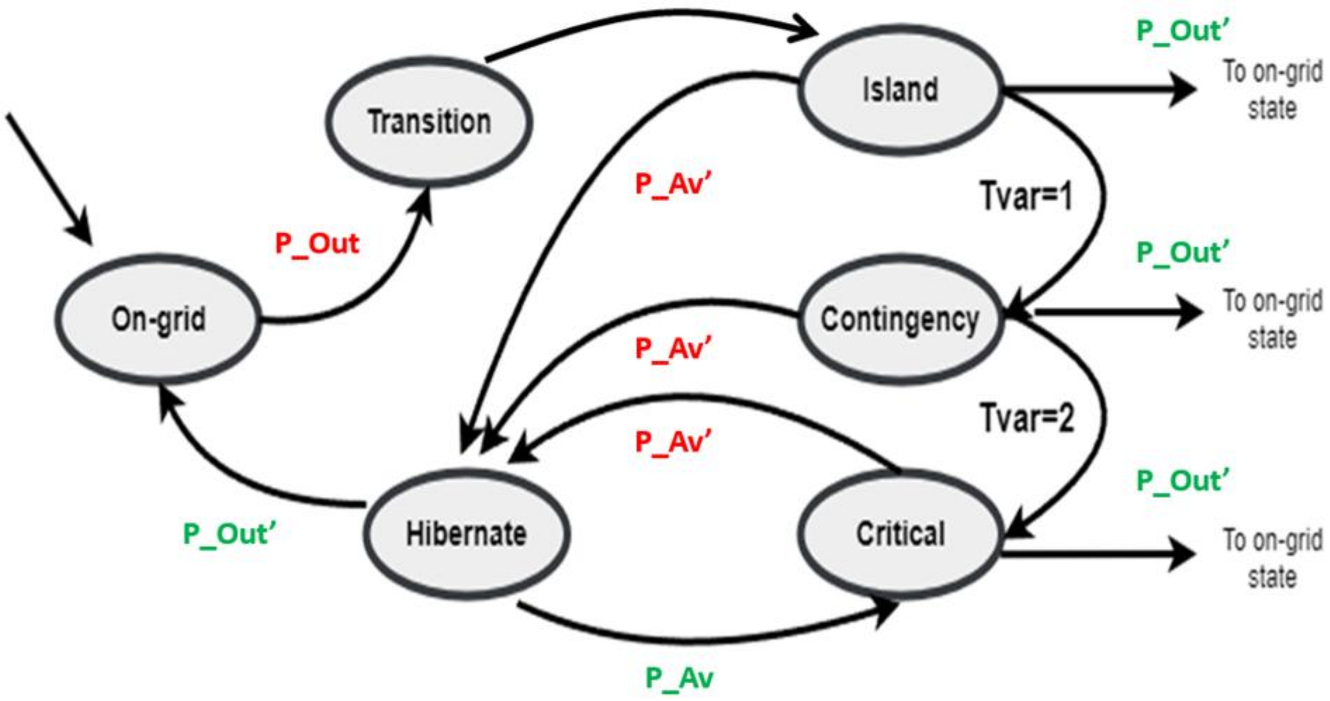
Resilience measures



Resilience curve



Microgrid operation



I. **On-Grid state** –Microgrid is supplied by the main grid.

II. **Transition from On-Grid to Island** – Transition from on-grid to islanded mode operation.

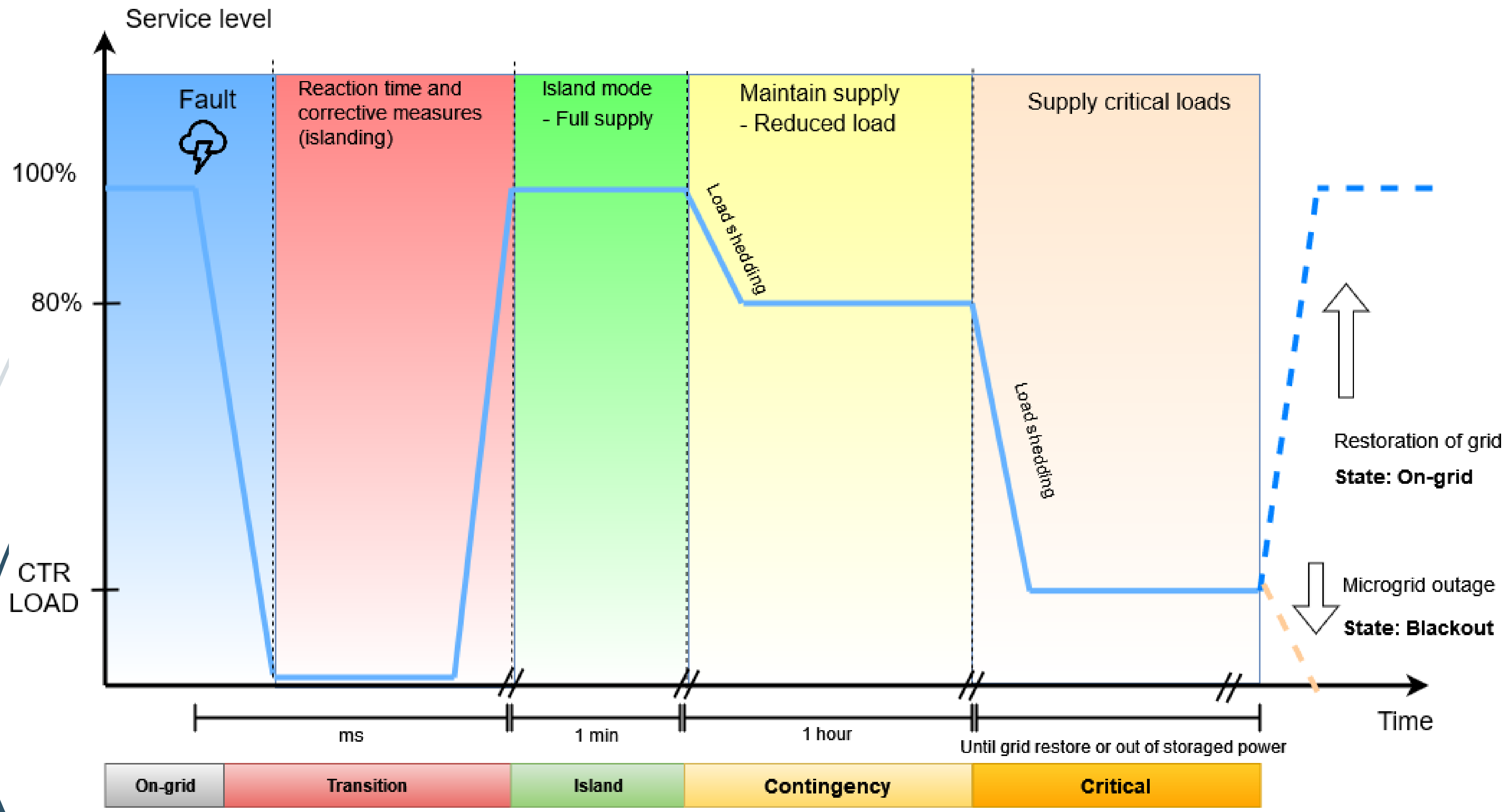
III. **Island state** –The microgrid is supplied by the PV system and batteries. All loads are supplied. Maintain full energy supply during the first minute.

IV. **Contingency state** – Loads and energy reserves are managed for up to one hour of operation. It will shed loads to increase the duration of the energy supply.

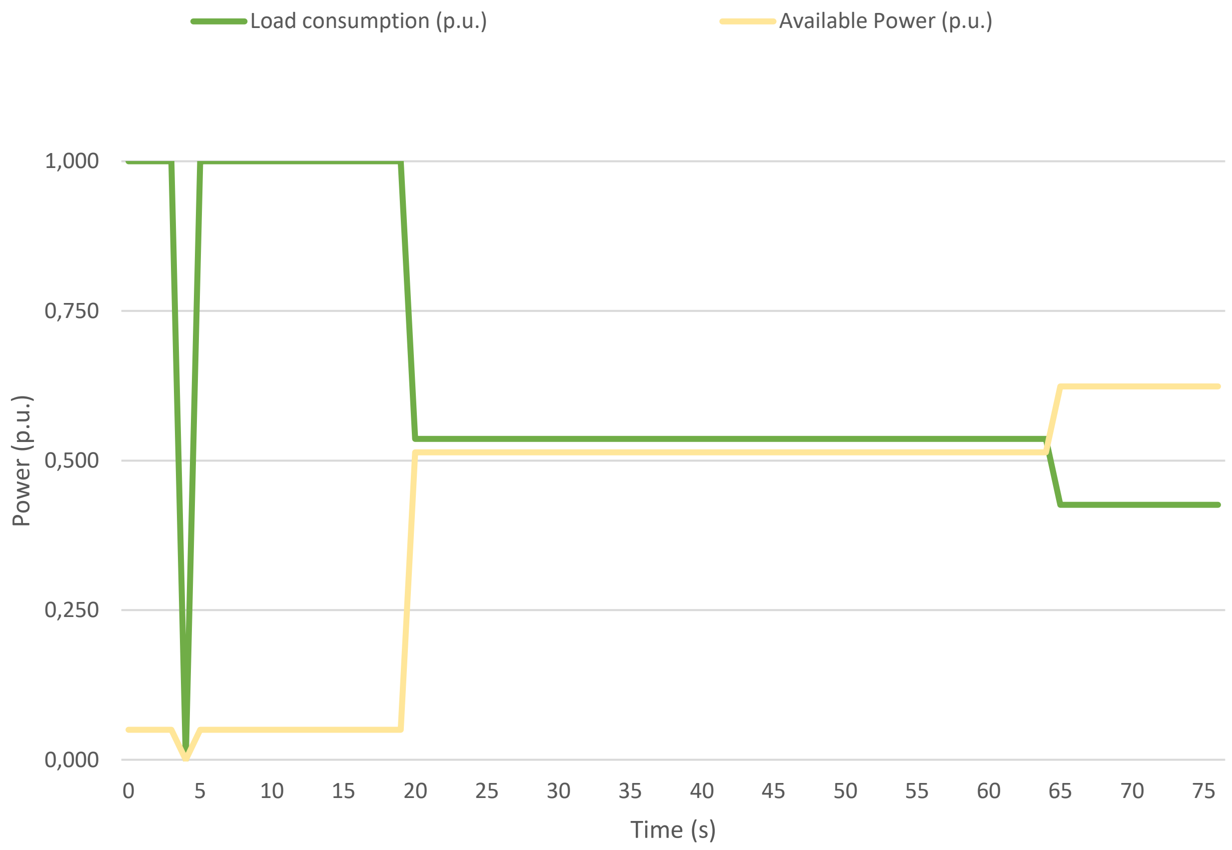
V. **Critical state** – Only the highest priority loads are supplied.

VI. **Hibernate state** – Only the controller and communications are powered. If enough energy is restored, the microgrid returns to the Critical state, else it will remain in this state until the power outage from the main grid is solved.

Microgrid operation



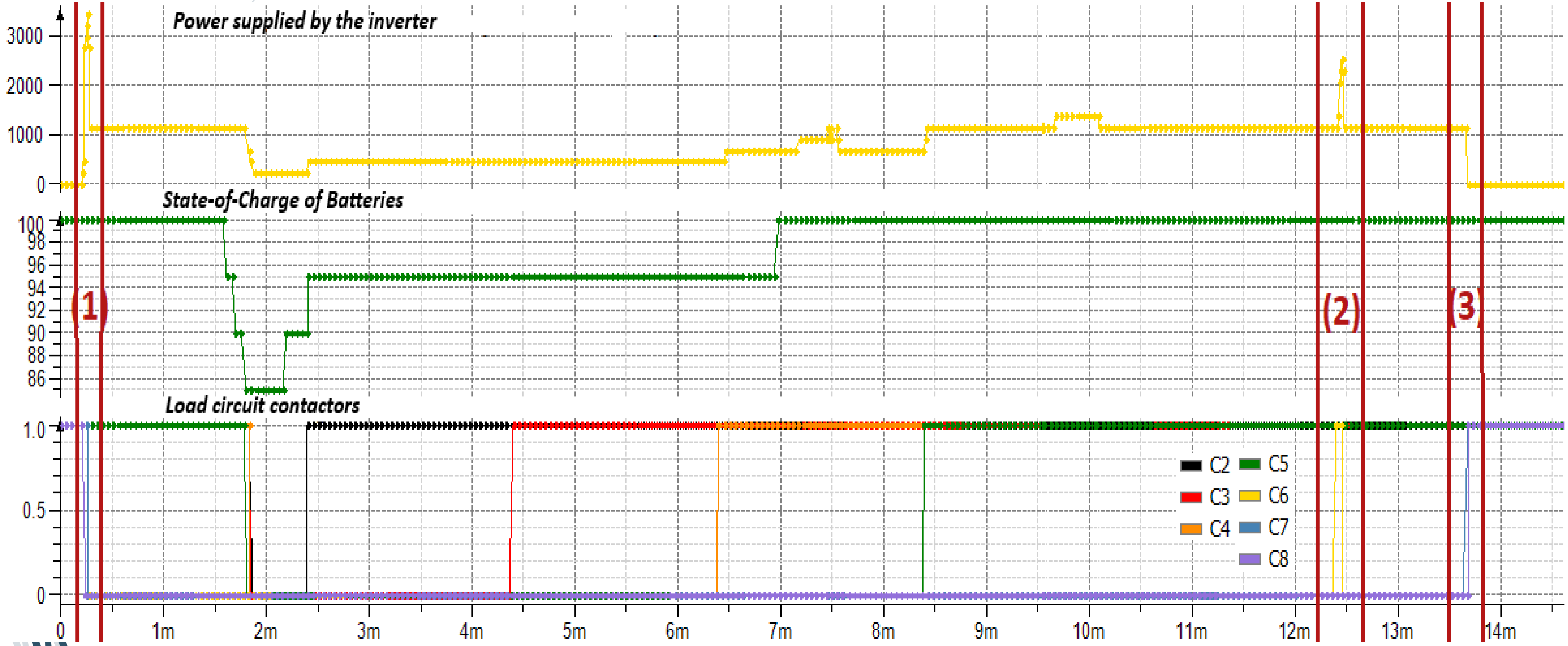
Microgrid operation – Increasing flexibility



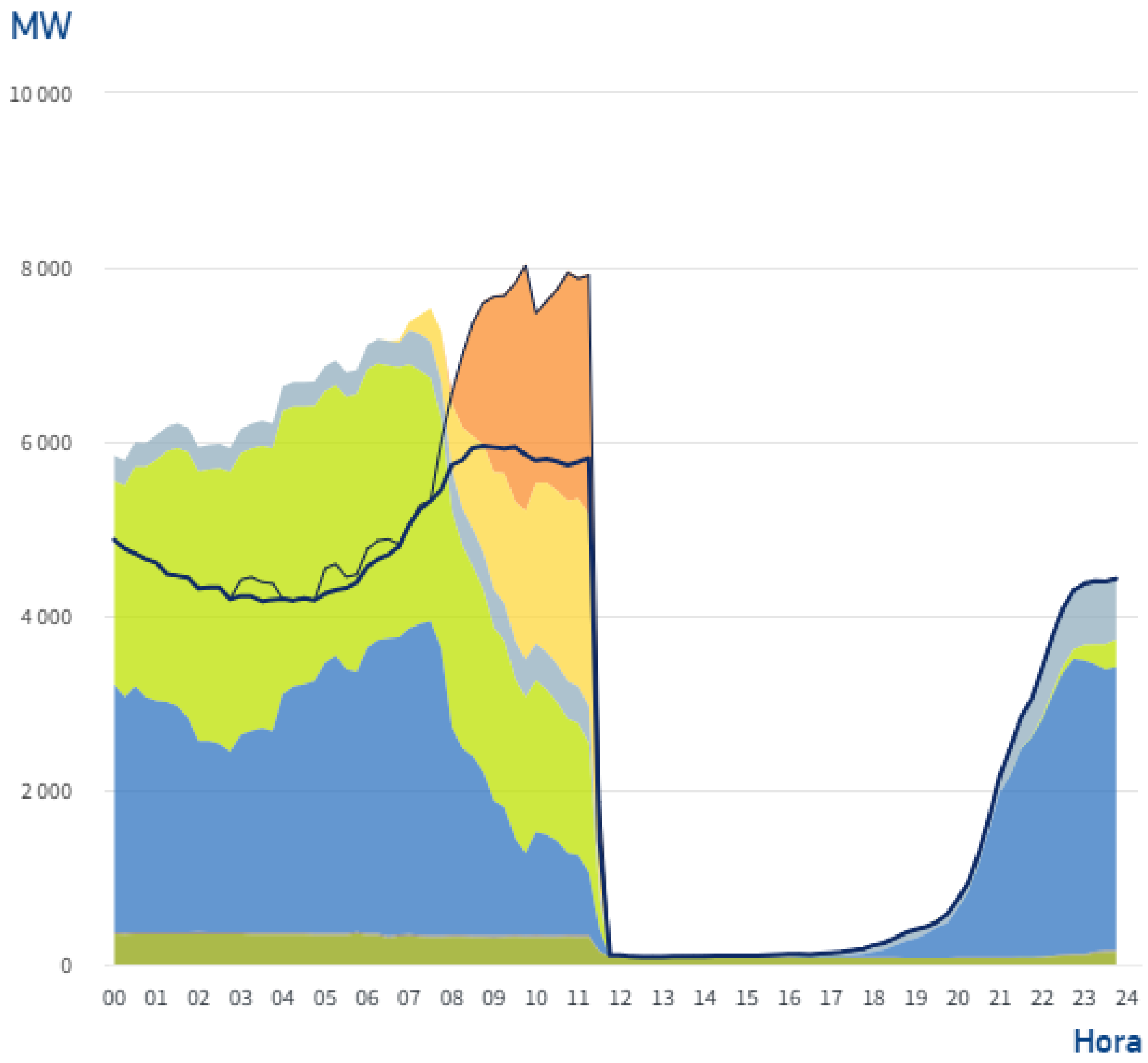
Microgrid operation - Transition

Microgrid operation - Stability

Microgrid operation – Test scenario



O Apagão Ibérico 2025



Conclusions

- O objectivo principal é o desenvolvimento duma solução que aumente a resiliência das microrredes.
- Foi desenvolvido um algoritmo que permite com sucesso aumentar a resiliência e a duração do fornecimento de cargas durante uma falha.
- O algoritmo introduz flexibilidade e permite prioritizar cargas críticas e adaptar a sua operação conforme a severidade da falha.
- O trabalho demonstrou que é possível aumentar a resiliência através duma gestão eficaz e inteligente dos recursos existentes sem necessidade de um grande investimento.

Published research

Articles:

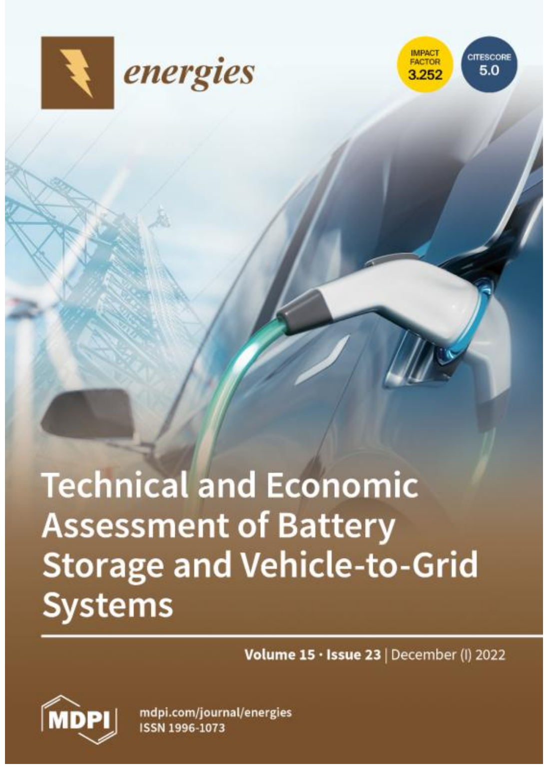
- **Alexandre F. M. Correia**, Miguel A. G. Neves, Ana. I. Casal dos Reis, António P. Coimbra, Tony R. O. de Almeida, Pedro S. Moura, and Aníbal T. de Almeida, "*Architecture and Operational Control for Resilient Microgrids—A University Case Study*", IEEE Access, March 2025 DOI: 10.1109/ACCESS.2025.3553350
- **Alexandre F. M. Correia**, Pedro S. Moura, Aníbal T. de Almeida, "*Technical and Economic Assessment of Battery Storage and Vehicle-to-Grid Systems in Building Microgrids*" Energies, 15(23), 8905, November 2022 DOI: 10.3390/en15238905
- **Alexandre F. M. Correia**, Luís M. Ferreira, A. Paulo Coimbra, Pedro S. Moura, Aníbal T. de Almeida, *"Smart Thermostats for a Campus Microgrid: Demand Control and Improving Air Quality"* , Energies, 15(4), 1359, February 2025 DOI: 10.3390/en15041359

Conference papers:

- **Alexandre F. M. Correia**, Miguel Cavaleiro, Miguel A. G. Neves, António P. Coimbra, Tony R. O. de Almeida, Pedro S. Moura and Aníbal T. de Almeida, *"Architecture and Operational Control for Resilient Microgrids"*, IEEE/IAS 60th Industrial and Commercial Power Systems Technical Conference (I&CPS), May 2024 DOI: 10.1109/ICPS60943.2024.10563523
- **Alexandre F. M. Correia**, José M. B. Lopes, António P. Coimbra, Pedro S. Moura and Aníbal T. de Almeida *"Architecture and Control Simulation for Improved System Resiliency of a Building Microgrid"*, IEEE/IAS 59th Industrial and Commercial Power Systems Technical Conference (I&CPS), May 2023 DOI: 10.1109/ICPS57144.2023.10142074
- Pedro S. Moura, **Alexandre F. M. Correia**, Joaquim Delgado, Paula Fonseca, Aníbal T. de Almeida "University Campus Microgrid for Supporting Sustainable Energy Systems Operation" IEEE/IAS 56th Industrial and Commercial Power Systems Technical Conference (I&CPS), June 2020, **DOI:** 10.1109/ICPS48389.2020.9176755

Projects and grants:

- **Research grant** 2023.02990.BD *"Optimização e gestão de microrredes para fornecer potência de alta qualidade em situações críticas ou de desastre",* Fundação para a Ciência e Tecnologia (FCT), Portugal 2023.
- **Research project** EXPL/EEI-EEE/1611/2021 *"RESImicrogrid - Optimization and Management of Microgrids to Deliver High Power Quality in Critical and Disaster Situations",* Fundação para a Ciência e Tecnologia (FCT), Portugal 2021.



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Obrigado pela atenção!

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